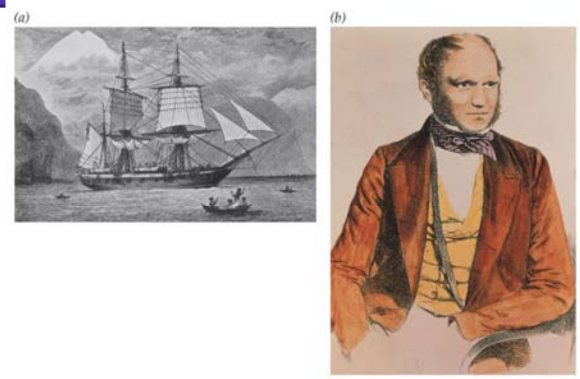
23

The Mechanisms of Evolution

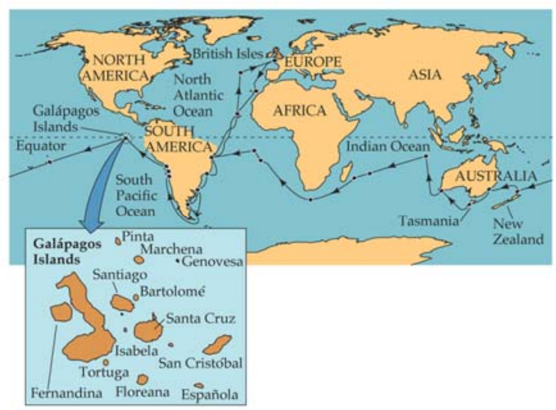
Figure 23.1 *Darwin and the Voyage of the* Beagle *(Part 1)*



The Mechanisms of Evolution

- Charles Darwin's Theory of Evolution
- Genetic Variation within Populations
- The Hardy–Weinberg Equilibrium
- Evolutionary Agents and Their Effects
- The Results of Natural Selection
- Assessing the Costs of Adaptations
- Maintaining Genetic Variation
- Constraints on Evolution
- Cultural Evolution
- Short-Term versus Long-Term Evolution

Figure 23.1 *Darwin and the Voyage of the* Beagle *(Part 2)*



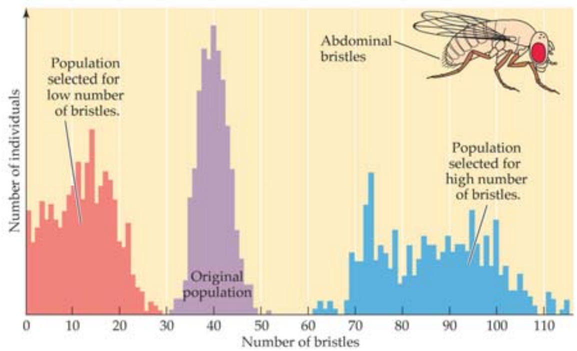
What I Will Emphasize in Lecture

- Galápagos!
- Genetic variation
  - Lots of it, most is hidden
  - How to describe?
    - Gene pool, Frequency, Hardy-Weinberg
  - Where does it come from?
    - Sex, Mutation, Migration, Selection can maintain it
- Genetic drift
  - Population bottleneck, founder effect
- Natural selection
- Sexual selection
- Cost of adaptation
- Constraints on adaptation

Genetic Variation

- Lots of it
- Much of it is hidden, not expressed
  - Alleles at same locus (dominance)
  - Alleles at different loci
  - Environment
- Artificial selection reveals genetic variation

Figure 23.5 *Artificial Selection Reveals Genetic Variation*



In-Text Art p. 464

Leaves of a white oak (*Quercus alba*)

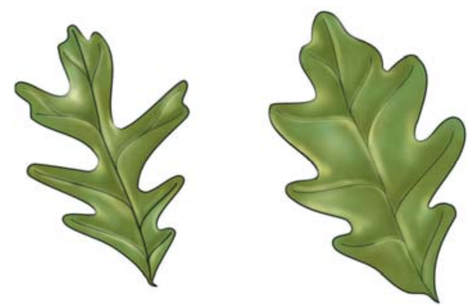


Figure 23. *Many Types of Pigeons Have Been Produced by Artificial Selection*

23 Genetic Variation within Populations

- Genes have different forms called **alleles**.
- A single individual has only some of the alleles found in the population to which it belongs.
- The sum of all the alleles in a population is the **gene pool**.
- The gene pool contains the variation (different alleles) that produces the differing phenotypes on which agents of evolution act.

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Figure 23.4 *Many Vegetables from One Species*

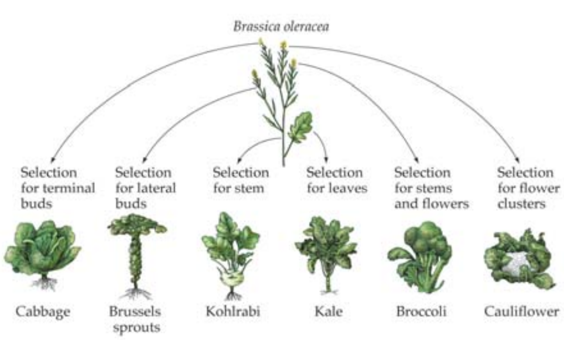
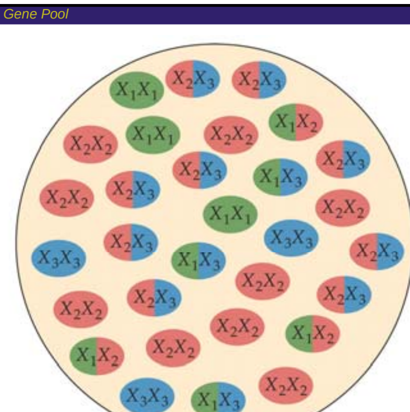


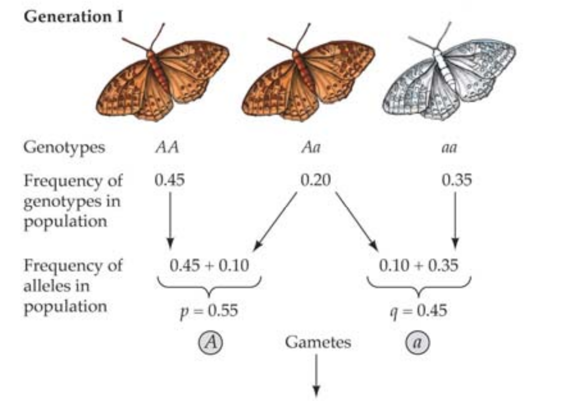
Figure 23.3 *A Gene Pool*



Genetic Variation within Populations

- Allele frequencies can be calculated using mathematics with the following variables:
  - N_{AA} = the number of individuals that are homozygous for the *A* allele (*AA*)
  - N_{Aa} = the number of individuals that are heterozygous (*Aa*)
  - N_{aa} = the number of individuals that are homozygous for the *a* allele (*aa*)
  - Note that $N_{AA} + N_{Aa} + N_{aa} = N$, the total number of individuals in a population.

Figure 23.7 *Calculating Hardy–Weinberg Genotype Frequencies (Part 1)*



Genetic Variation within Populations

- The total number of alleles in a population is 2N because each individual is diploid (in this case, either *AA*, *Aa*, or *aa*).
- *p* = the frequency of allele *A*.
- *q* = the frequency of allele *a*.
- For each population, *p* + *q* = 1.

Figure 23.7 *Calculating Hardy–Weinberg Genotype Frequencies (Part 2)*

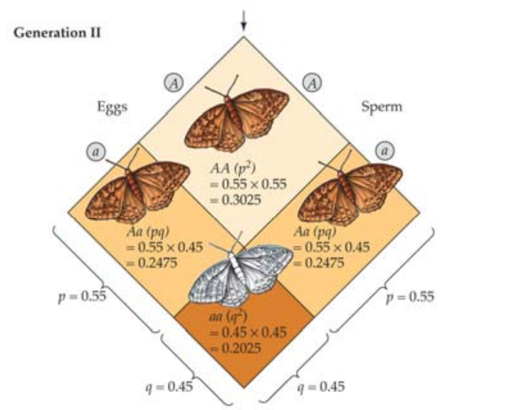


Figure 23.6 *Calculating Allele Frequencies*

In any population:

$$\text{Frequency of allele } A = p = \frac{2N_{AA} + N_{Aa}}{2N} \qquad \text{Frequency of allele } a = q = \frac{2N_{aa} + N_{Aa}}{2N}$$

where *N* is the total number of individuals in the population.

For population 1 (mostly homozygotes):

$N_{AA} = 90$, $N_{Aa} = 40$, and $N_{aa} = 70$

so

$$p = \frac{180 + 40}{400} = 0.55$$

$$q = \frac{140 + 40}{400} = 0.45$$

For population 2 (mostly heterozygotes):

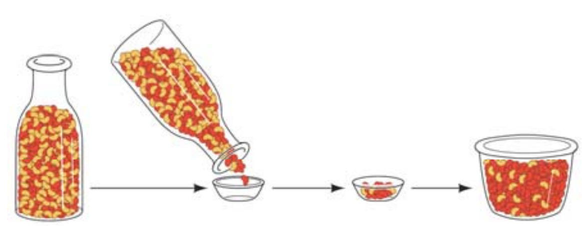
$N_{AA} = 45$, $N_{Aa} = 130$, and $N_{aa} = 25$

so

$$p = \frac{90 + 130}{400} = 0.55$$

$$q = \frac{50 + 130}{400} = 0.45$$

Figure 23.8 *A Population Bottleneck*



23 The Hardy–Weinberg Equilibrium

- A population of sexually reproducing organisms in which allele and genotype frequencies do not change from generation to generation is said to be at **Hardy–Weinberg equilibrium**.
- Five assumptions must be made in order to meet Hardy–Weinberg equilibrium.
  - Mating is random.
  - Population size is very large.
  - There is no migration between populations.
  - There is no mutation.
  - Natural selection does not affect the alleles under consideration.

Figure 23.9 *A Species with Low Genetic Variation*

Tympanuchus cupido (male)

23 Evolutionary Agents and Their Effects

- **Genetic drift** is the random loss of individuals and the alleles they possess.
- In very small populations, genetic drift may be strong enough to influence the direction of change of allele frequencies even when other evolutionary agents are pushing the frequencies in a different direction.
- Organisms that normally have large populations may pass through occasional periods when only a small number of individuals survive (a **population bottleneck**).

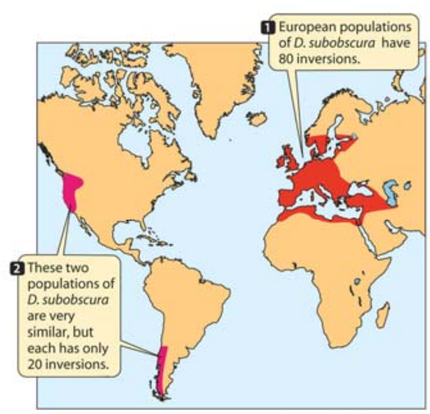
23 Evolutionary Agents and Their Effects

- When a few pioneering individuals colonize a new region, the resulting population will not have all the alleles found among members of the source population.
- The resulting pattern of genetic variation is called a **founder effect**.

23 Evolutionary Agents and Their Effects

- During a population bottleneck, genetic variation can be reduced by genetic drift.
- Populations in nature pass through bottlenecks for numerous reasons; for example, predation and habitat destruction may reduce the population to a very small size, resulting in low genetic variation.

Figure 23.10 *A Founder Effect*



23 Evolutionary Agents and Their Effects

- For adaptation to occur, individuals that differ in heritable traits must survive and reproduce with different degrees of success.
- When some individuals contribute more offspring to the next generation than others, allele frequencies in the population change in a way that adapts individuals to the environments that influenced their success.
- This process is known as **natural selection**.

23 Evolutionary Agents and Their Effects

- The reproductive contribution of a phenotype to subsequent generations relative to the contributions of other phenotypes is called its **fitness**.
- The fitness of a phenotype is determined by the average rates of survival and reproduction of individuals with that phenotype.

23 The Results of Natural Selection

- Most characters are influenced by alleles at more than one locus and are more likely to show quantitative rather then qualitative variation.
- For example, the size of individuals in a population is influenced by genes at many loci, and distribution of sizes is likely to be a bell-shaped curve.
- Natural selection can act on characters with quantitative variation in three ways:
  - Stabilizing selection
  - Directional selection
  - Disruptive selection

23 The Results of Natural Selection

- **Stabilizing selection** preserves the characteristics of a population by favoring average individuals.
- Stabilizing selection occurs when the extremes of a population contribute relatively fewer offspring than the average members to the next generation.
- Stabilizing selection operates on human birth weight. Babies that are born lighter or heavier than the population mean die at higher rates than babies whose weights are close to the mean.

Figure 23.12 *Natural Selection Can Operate on Quantitative Variation in Several Ways (Part 1)*

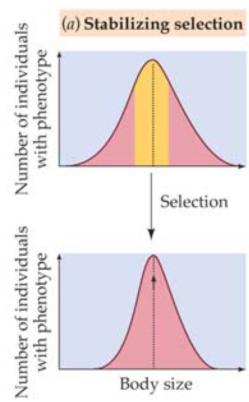
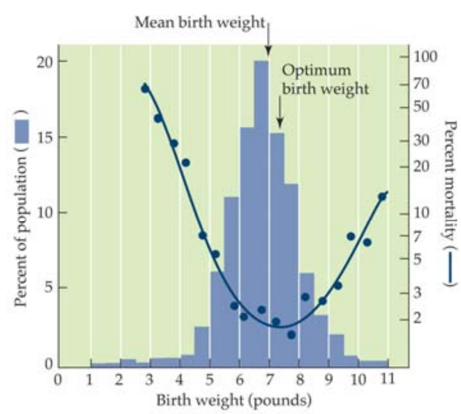


Figure 23.13 *Human Birth Weight Is Influenced by Stabilizing Selection*



23 The Results of Natural Selection

- **Directional selection** changes the characteristics of a population by favoring individuals that vary in one direction from the mean of the population.
- Directional selection occurs when one extreme of a population contributes more offspring to the next generation.
- Directional selection produced resistance to tetrodotoxin (TTX) in garter snakes.

23 The Results of Natural Selection

- Disruptive selection changes the characteristics of a population by favoring individuals that vary in both directions from the mean of the population.
- Disruptive selection occurs when individuals at both extremes of a population are simultaneously favored.
- The bill sizes of black-bellied seedcrackers provide an example of disruptive selection.

Figure 23.12 *Natural Selection Can Operate on Quantitative Variation in Several Ways (Part 2)*

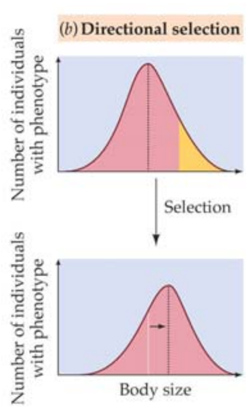


Figure 23.12 *Natural Selection Can Operate on Quantitative Variation in Several Ways (Part 3)*

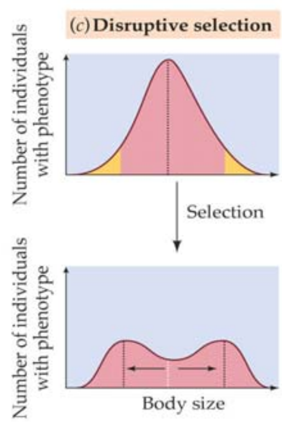


Figure 23.14 *Resistance to TTX Is Associated with the Presence of Newts*

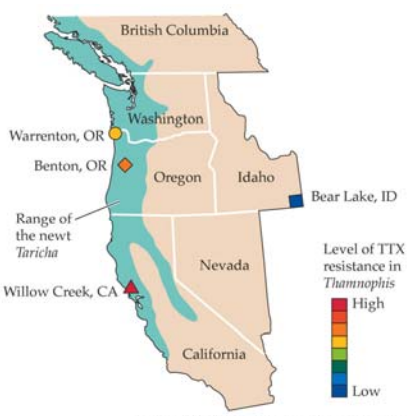
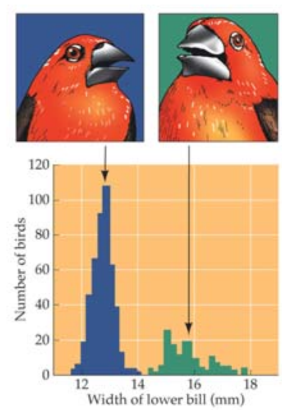


Figure 23.15 *Disruptive Selection Results in a Bimodal Distribution*



23 The Results of Natural Selection

- **Sexual selection** was Darwin's explanation for the evolution of apparently useless but conspicuous traits in males of many species, such as bright colors, long tails, horns, antlers, and elaborate courtship displays.
- He hypothesized that these traits either improved the ability of their bearers to compete for access to members of the other sex (**intrasexual selection**) or made them more attractive to the other sex (**intersexual** selection).
- Sexual selection may result in **sexually dimorphic** species.

23 The Results of Natural Selection

- In widowbirds, males with longer tails attract significantly more females than do males with shorter tails.
- Females may prefer males with longer tails because the ability to grow and maintain such a structure may indicate that the male is vigorous and healthy.

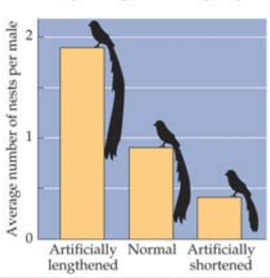
Figure 23.16 *The Longer the Tail, the Better the Male*

EXPERIMENT

Hypothesis: Sexual selection favors the evolution of long tails in African long-tailed widowbirds.

METHOD Capture males and artificially lengthen or shorten their tails by cutting feathers or gluing on feathers.

RESULTS



Conclusion: Sexual selection in widowbirds favors long tails.

23 The Results of Natural Selection

- The hypothesis that having well-developed ornamental traits signals vigor and health has been tested experimentally.
- Zebra finch bills are bright red because of carotenoids in their diet.
- Carotenoids are antioxidants and part of the immune system. Males in good health will have brighter bills because they need to allocate fewer carotenoids to immune function.
- Zebra finch males were fed diets with and without carotenoids. The diet with carotenoids enhanced immune function.

Figure 23.17 *Bright Bills Signal Good Health (Part 1)*

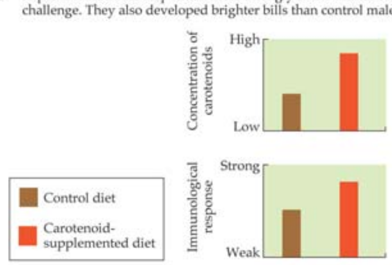
(*a*)

EXPERIMENT

Hypothesis: Having a bright red bill signals good health in a male zebra finch.

METHOD Provide carotenoids in drinking water for experimental, but not for control males. Challenge all males immunologically and measure response.

RESULTS Experimental males responded more strongly to the immunological challenge. They also developed brighter bills than control males.



Conclusion: Bill color is a clue to the health of a male zebra finch.

Figure 23.17 *Bright Bills Signal Good Health (Part 2)*

(*b*)

Taeniopygia guttata

Assessing the Costs of Adaptations

- In plants, plasmids can be used to transfer specific alleles to experimental individuals.
- Plasmid transfer techniques have been used to measure the cost associated with the resistance to an herbicide conferred by a single allele in *Arabidopsis thaliana*.
- Plants with the resistance allele produce 34 percent fewer seeds than nonresistant plants, indicating a high cost for resistance to the herbicide.

Assessing the Costs of Adaptations

- In **polygynous** species, such as deer, lions, and baboons, one male controls reproductive access to many females.
- Polygynous species tend to be sexually dimorphic, with males that are generally much larger than females and that generally bear weapons.
- There are costs to the males for this sexual dimorphism, including higher parasite loads and higher mortality rates.

Figure 23.18 *Producing and Maintaining Resistance Is Costly (Part 1)*

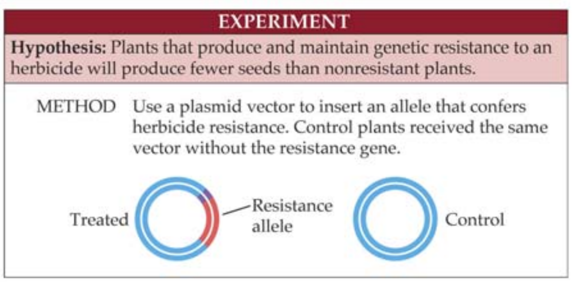


Figure 23.19 *Sexually Selected Traits Impose Costs*

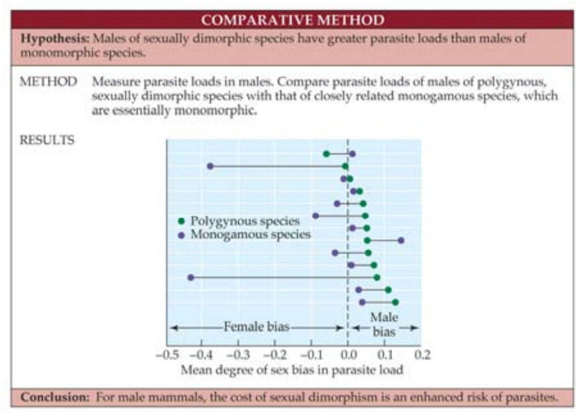
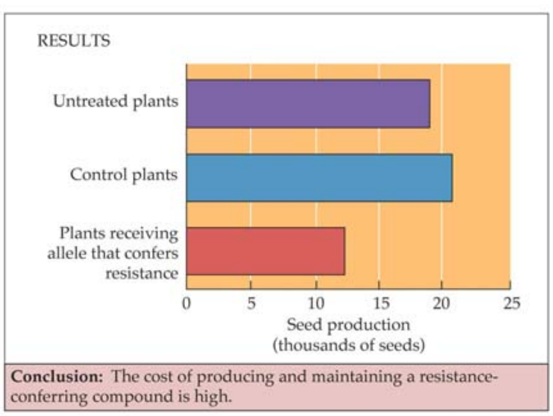


Figure 23.18 *Producing and Maintaining Resistance Is Costly (Part 2)*



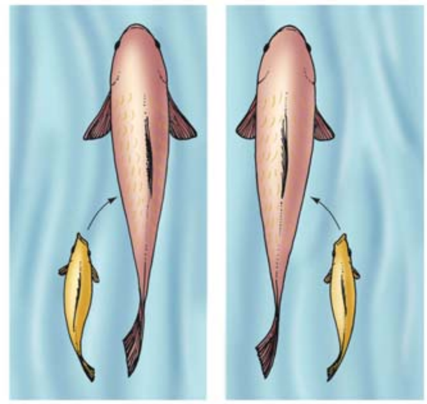
Maintaining Genetic Variation

- Genetic drift, stabilizing selection, and directional selection all tend to reduce genetic variation within an animal population.
- However, most species have considerable genetic variation.

23 Maintaining Genetic Variation

- When organisms reproduce sexually, existing genetic variation is amplified.
- Random assortment of chromosomes during meiosis, crossing over, and the cellular component of each gamete contribute to the diversity of offspring.
- Sexual recombination does not alter the frequency of alleles; rather, it generates new combinations of alleles on which natural selection can act.
- It expands variation in a trait influenced by alleles at many loci by creating new genotypes.

Figure 23.20 *A Stable Polymorphism*



23 Maintaining Genetic Variation

- An allele that does not affect the fitness of an organism is called a **neutral allele**.
- Neutral alleles tend to accumulate in a population of organisms over time, resulting in genetic variation.
- Most variation in neutral alleles cannot be observed without the aid of molecular biology techniques.

23 Constraints on Evolution

- Thus far, it has been implied that sufficient genetic variation always exists for the evolution of favored traits; this is not always true.
- Evolution is limited by a serious constraint: Evolutionary changes must be based on modifications of previously existing traits.
- For example, skates and rays evolved from sharks with somewhat flattened bodies. They lie on their bellies on the sea bottom.
- Plaice and flounder descended from laterally flattened fish, and therefore lie on their sides.

23 Maintaining Genetic Variation

- A **polymorphism** is the coexistence of two or more alleles at a locus at frequencies greater than mutations can produce.
- A polymorphism may be maintained when the fitness of a genotype (or phenotype) varies with its frequency relative to that of other genotypes (or phenotypes).
- This process is know as **frequency-dependent selection**.
- Fish with right- and left-mouthed individuals in Lake Tanganyika are an example of frequency-dependent selection in action.

23 Cultural Evolution

- Cultural evolution is a means of acquiring new traits by learning them from other individuals.
- Cultural evolution is most highly developed in humans, but is seen in other animals including birds and apes.
- The only requirement for traits to evolve via cultural evolution is that individuals have the ability to learn them.
- Birds will copy the songs of other individuals, resulting in the evolution of song "dialects."
- Apes use a number of learned behaviors, including specialized feeding techniques and alternative forms of social signals.

Figure 23.23 *Orangutans Have Culturally Transmitted Behaviors*

Pongo pygmaeus

LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 23.23 Orangutans Have Culturally Transmitted Behaviors