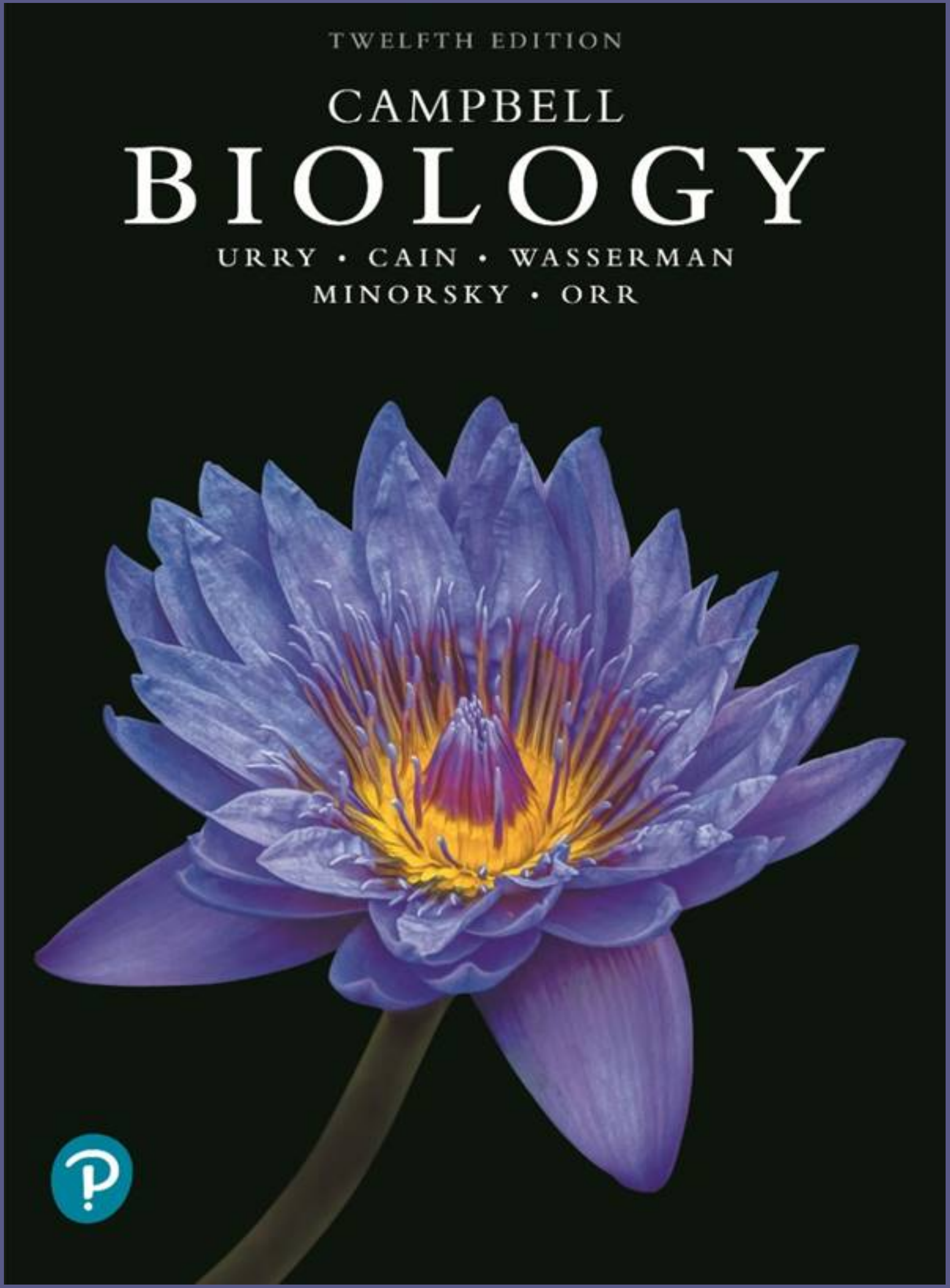


Chapter 22

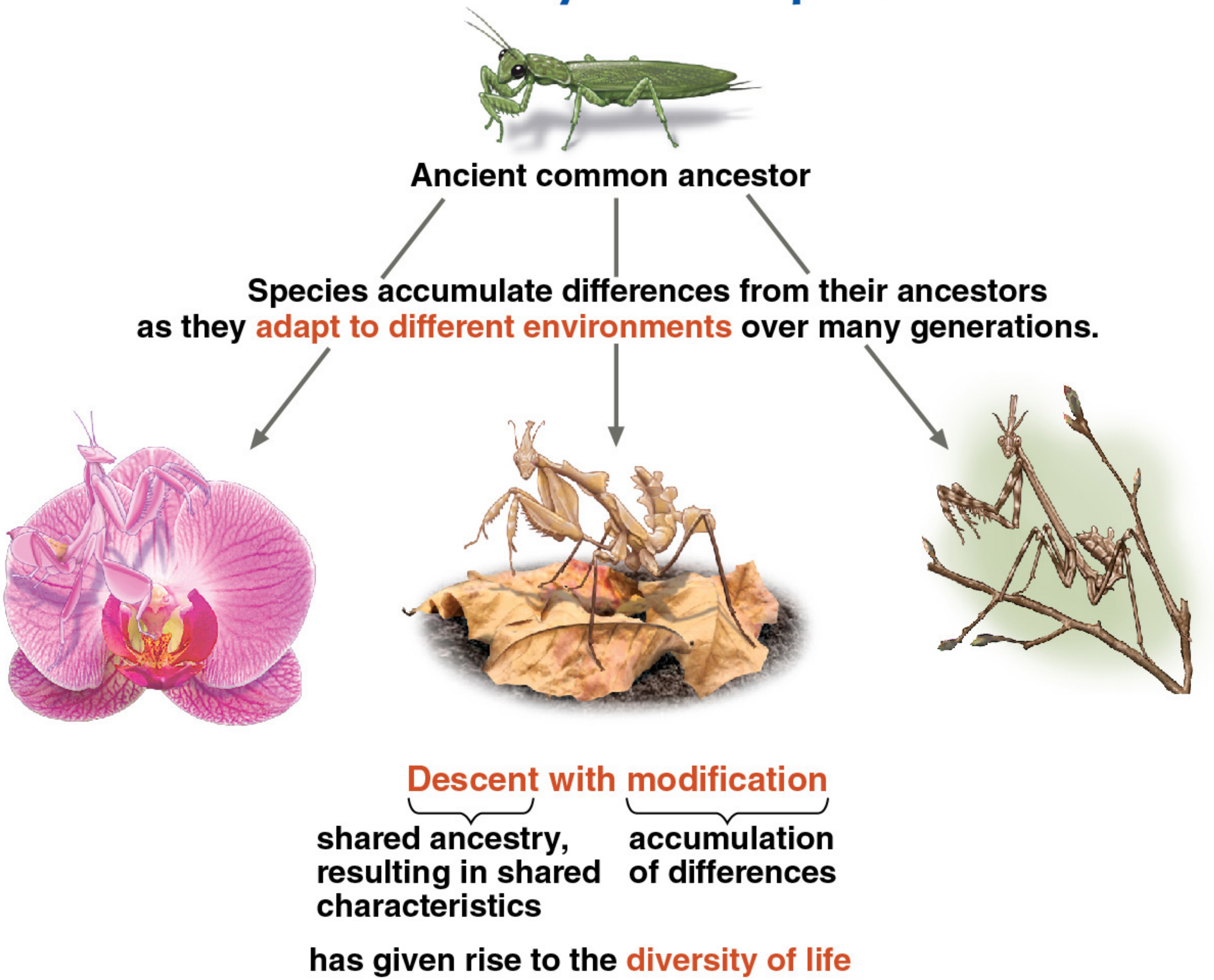
Descent with Modification: A Darwinian View of Life

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

Figure 22.1a

Figure 22.1b

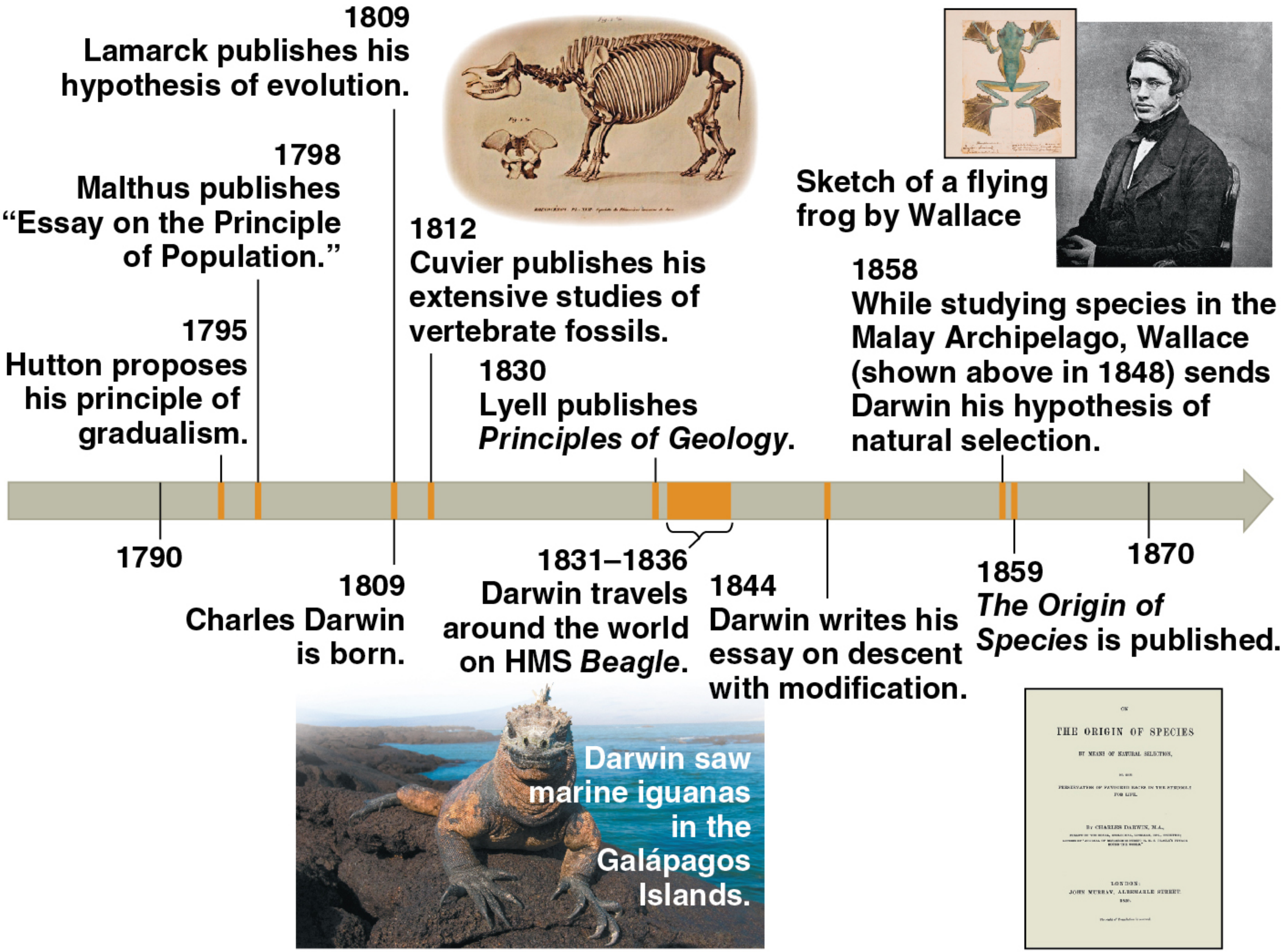
What causes the similarities and differences among Earth's many different species?



CONCEPT 22.1: The Darwinian revolution challenged traditional views of a young Earth inhabited by unchanging species

- Publication of *The Origin of Species* by Charles Darwin in 1859 started a scientific revolution—the era of evolutionary biology
- Darwin's ideas developed gradually, through the influence of other's works and his own travels

Figure 22.2


1809
Lamarck publishes his hypothesis of evolution.
1798
Malthus publishes “Essay on the Principle of Population.”
1795
Hutton proposes his principle of gradualism.
1812
Cuvier publishes his extensive studies of vertebrate fossils.
1830
Lyell publishes *Principles of Geology*.
Sketch of a flying frog by Wallace
1858
While studying species in the Malay Archipelago, Wallace (shown above in 1848) sends Darwin his hypothesis of natural selection.
1790
1809
Charles Darwin is born.
1831–1836
Darwin travels around the world on HMS *Beagle*.
1844
Darwin writes his essay on descent with modification.
1859
The Origin of Species is published.
1870
Darwin saw marine iguanas in the Galápagos Islands.
THE ORIGIN OF SPECIES
BY MEANS OF NATURAL SELECTION,
BY CHARLES DARWIN, M.A.,
LONDON:
JOHN MURRAY, ALBEMARLE STREET.

Endless Forms Most Beautiful

- Shared characteristics among different species illustrate the unity of life
  - For example, insect species in the order Mantodea (mantises) all have bulging eyes, and a flexible “neck”
- Different species also have differing characteristics
  - For example, mantis species differ in size, shape, and color

- Mantises illustrate three key observations about life:
  - Organisms are adapted for life in their biotic and abiotic environments
  - The many shared characteristics (unity) of life
  - The diversity of life

- **Evolution** refers to the process by which species accumulate differences from their ancestors as they adapt to different environments over time
- This definition is summarized by Darwin’s phrase *descent with modification*

- Evolution can be viewed as both a pattern and a process
  - Pattern is revealed by scientific data showing that life has evolved over time
  - Process consists of the mechanisms that cause the pattern of change

Scala Naturae and Classification of Species

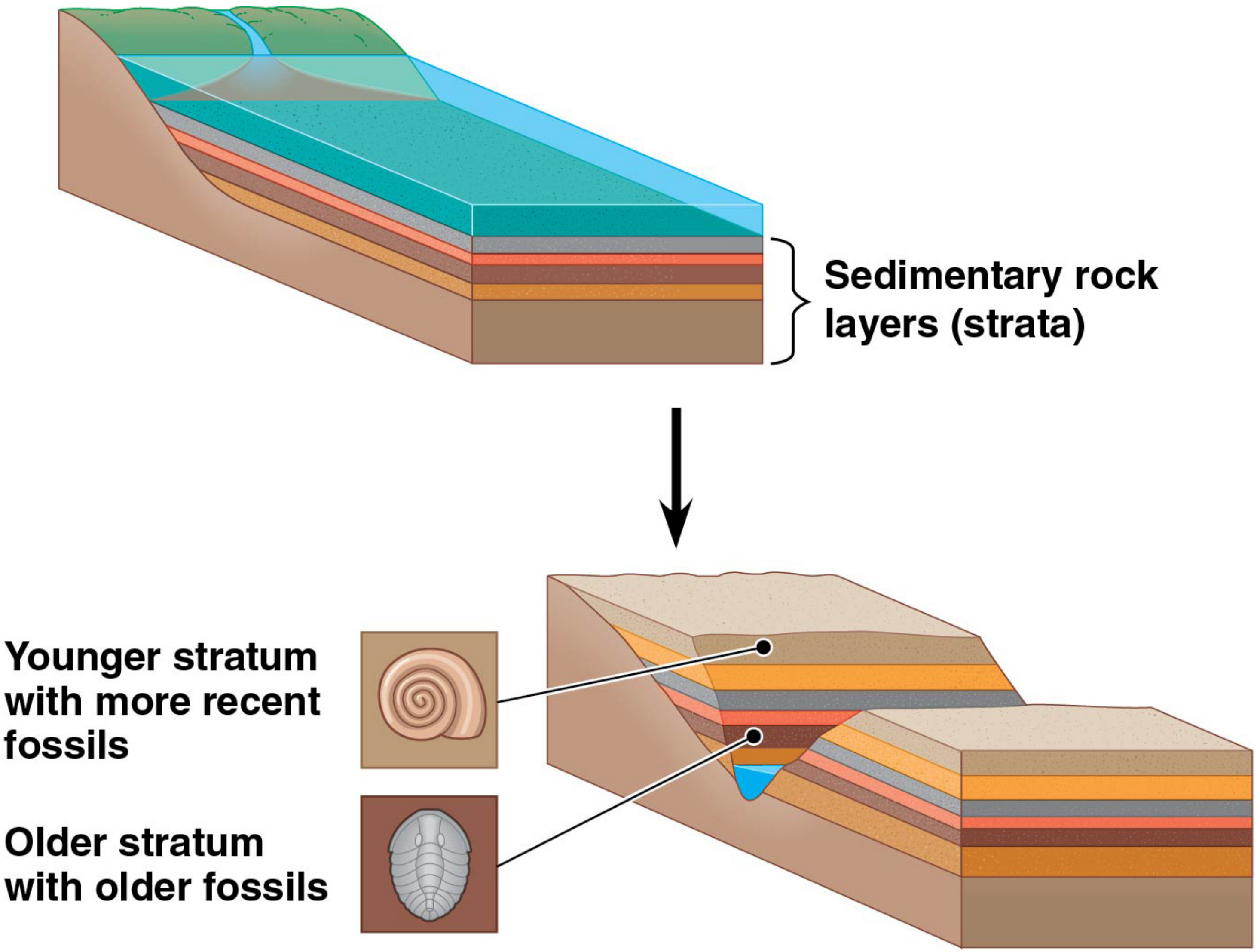
- Greek philosopher Aristotle (384–322 BCE) believed that species were fixed (unchanging)
- He arranged species on a scale of increasing complexity called the *scala naturae*
- In the 1700s, scientists interpreted adaptations as evidence of design by a Creator

- Carolus Linnaeus (1707–1778) developed a nested classification system grouping similar species into increasingly inclusive categories
- He also developed the binomial format for naming species (for example, humans are *Homo sapiens*)
- Both of these systems are still in use today

Ideas About Change over Time

- Darwin drew from the study of **fossils**, remains or traces of organisms from the past
- Many fossils are found in sedimentary rock, which appears in layers called **strata**

Figure 22.3



Sedimentary rock layers (strata)
Younger stratum with more recent fossils
Older stratum with older fossils

Video: Grand Canyon

- **Paleontology**, the study of fossils, was developed in large part by Georges Cuvier (1769–1832)
- Cuvier observed that older strata contain fossils less similar to current organisms than more recent strata
- He also observed that, from layer to layer, new species appear while others disappear

- Cuvier speculated that boundaries between strata represent sudden catastrophic events
- Darwin was also influenced by scientists proposing that slow, continuous processes caused change on Earth

- James Hutton (1726–1797) proposed that Earth's geologic features were formed gradually
  - For example, valleys being formed by rivers
- Charles Lyell (1797–1875) proposed that the same geologic processes operate today as in the past, at the same rate

- Darwin reasoned that the Earth must be older than the widely accepted age of a few thousand years
- If true, gradual processes could also account for substantial biological change

Lamarck's Hypothesis of Evolution

- Jean-Baptiste de Lamarck (1744–1829) proposed two principles to explain evolutionary change
  - Use and disuse: body parts used extensively become larger and stronger, unused parts deteriorate
  - Inheritance of acquired characteristics: modifications acquired in one's lifetime can be passed to offspring
- This mechanism is not supported by experimental evidence

Figure 22.4

CONCEPT 22.2: Descent with modification by natural selection explains the adaptations of organisms and the unity and diversity of life

- By the early 19th century, it was still generally thought that species were created, and remained unchanged
- However, doubts were beginning to gather

Darwin's Research

- Charles Darwin (1809–1882) had a consuming interest in nature throughout his life
- He studied medicine (unsuccessfully) and then switched to theology at Cambridge University
- After graduation, he took a position as naturalist on a five-year, worldwide voyage on the HMS *Beagle*

The Voyage of the Beagle

- During his travels on the *Beagle*, Darwin collected specimens of South American plants and animals
- He noted that fossils resembled living species from the area in which they were found, and living species resembled other species from areas nearby

- During an earthquake in Chile, Darwin observed the uplift of rocks by several meters
- He inferred that rocks containing fossils of ocean organisms in the Andean Mountains must have been raised there by many similar earthquakes

- On the Galápagos Islands, Darwin collected many similar, but different species of birds, some unique to individual islands, others found on multiple islands
- Animals unique to the islands resembled species on the nearby mainland of South America
- Darwin hypothesized that species from the mainland colonized and then diversified on the islands

Figure 22.5


Darwin in 1840, after his return from the voyage
HMS *Beagle* in port
The Galápagos Islands
Pinta
Marchena
Genovesa
PACIFIC OCEAN
Equator
Santiago
Fernandina
Isabela
Santa Cruz
Santa Fe
San Cristobal
Floreana
Española
0 20 40
Kilometers
NORTH AMERICA
ATLANTIC OCEAN
Great Britain
EUROPE
AFRICA
SOUTH AMERICA
Equator
Chile
Andes Mtns.
Brazil
PACIFIC OCEAN
Argentina
Cape Horn
Cape of Good Hope
Malay Archipelago
AUSTRALIA
PACIFIC OCEAN
Tasmania
New Zealand

Video: Galápagos Islands Overview

Video: Galápagos Marine Iguana

Video: Galápagos Sea Lion

Video: Galápagos Tortoise

Darwin's Focus on Adaptation

- Darwin observed many examples of adaptations during the voyage of the *Beagle*
- **Adaptations** are inherited characteristics that enhance an organism's survival and reproduction in specific environments

- Darwin perceived that new species could arise from ancestral forms through gradual accumulation of adaptations
- This process formed the diverse group of Galápagos finches

Figure 22.6

(a) Cactus-eater

(b) Insect-eater

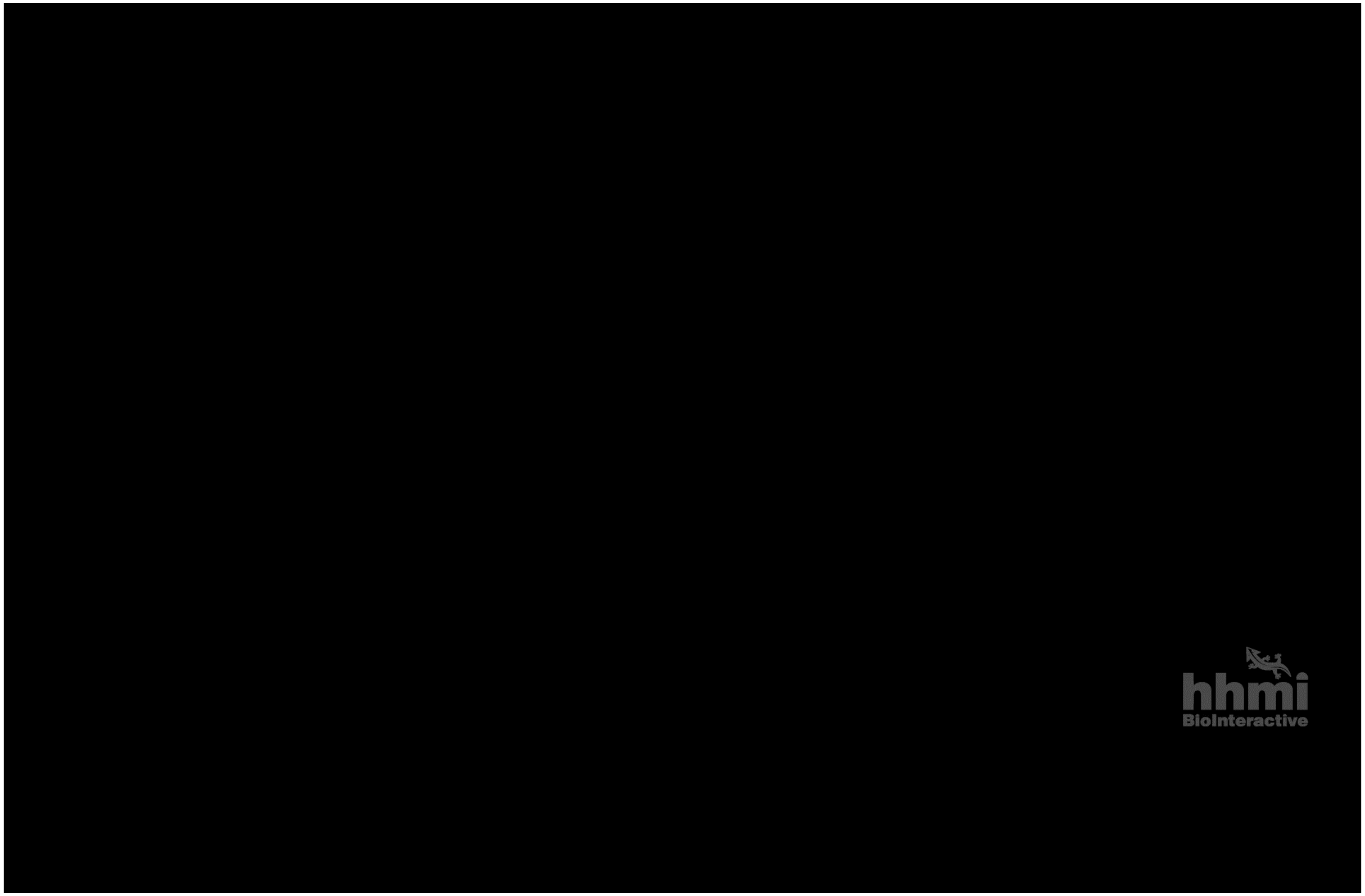
(c) Seed-eater

- Darwin proposed natural selection as an explanation for adaptation
- **Natural selection** is a process in which individuals with certain inherited traits tend to survive and reproduce at higher rates because of those traits

- Darwin wrote down his ideas in 1844, but did not publish out of concern they would cause an uproar
- He continued to compile supporting evidence
- In June 1858, Alfred Russel Wallace (1823–1913) sent Darwin a manuscript describing a nearly identical hypothesis of natural selection

- Papers by both Wallace and Darwin were presented to the Linnean Society of London on July 1, 1858
- Darwin quickly finished *The Origin of Species* and published it the next year
- Within a decade, most scientists were convinced that life's diversity is the product of evolution

Video: The Origin of Species: The Making of a Theory



Ideas from *The Origin of Species*

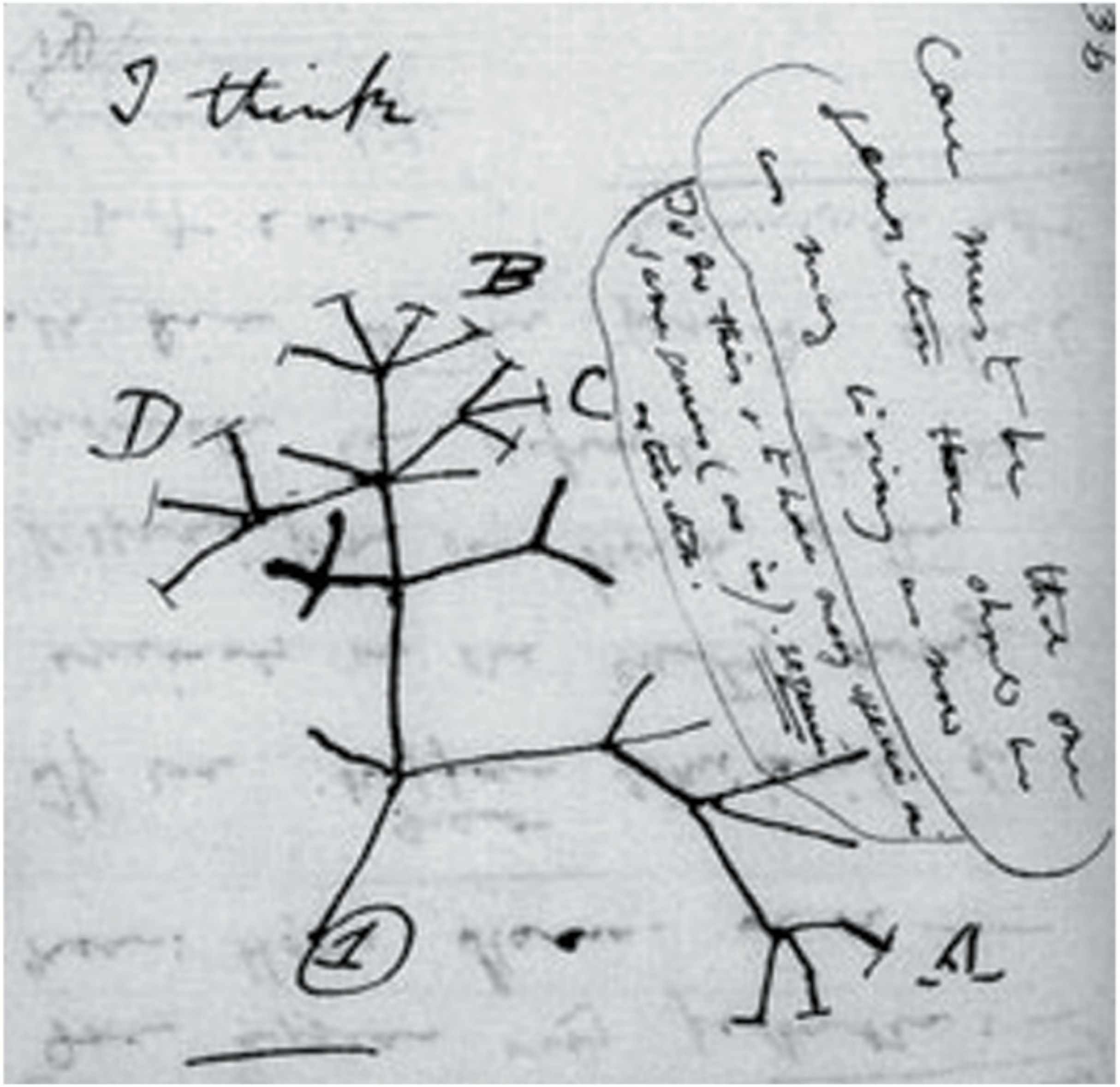
- Descent with modification by natural selection explains three broad observations:
  - The unity of life
  - The diversity of life
  - The ways organisms are suited to life in their environments

Descent with Modification

- Darwin used *descent with modification* to describe his view of life
- By this view, all organisms are related by descent from a common ancestor that lived in the past
- Related organisms living in different habitats gradually accumulated diverse modifications to fit them to specific ways of life

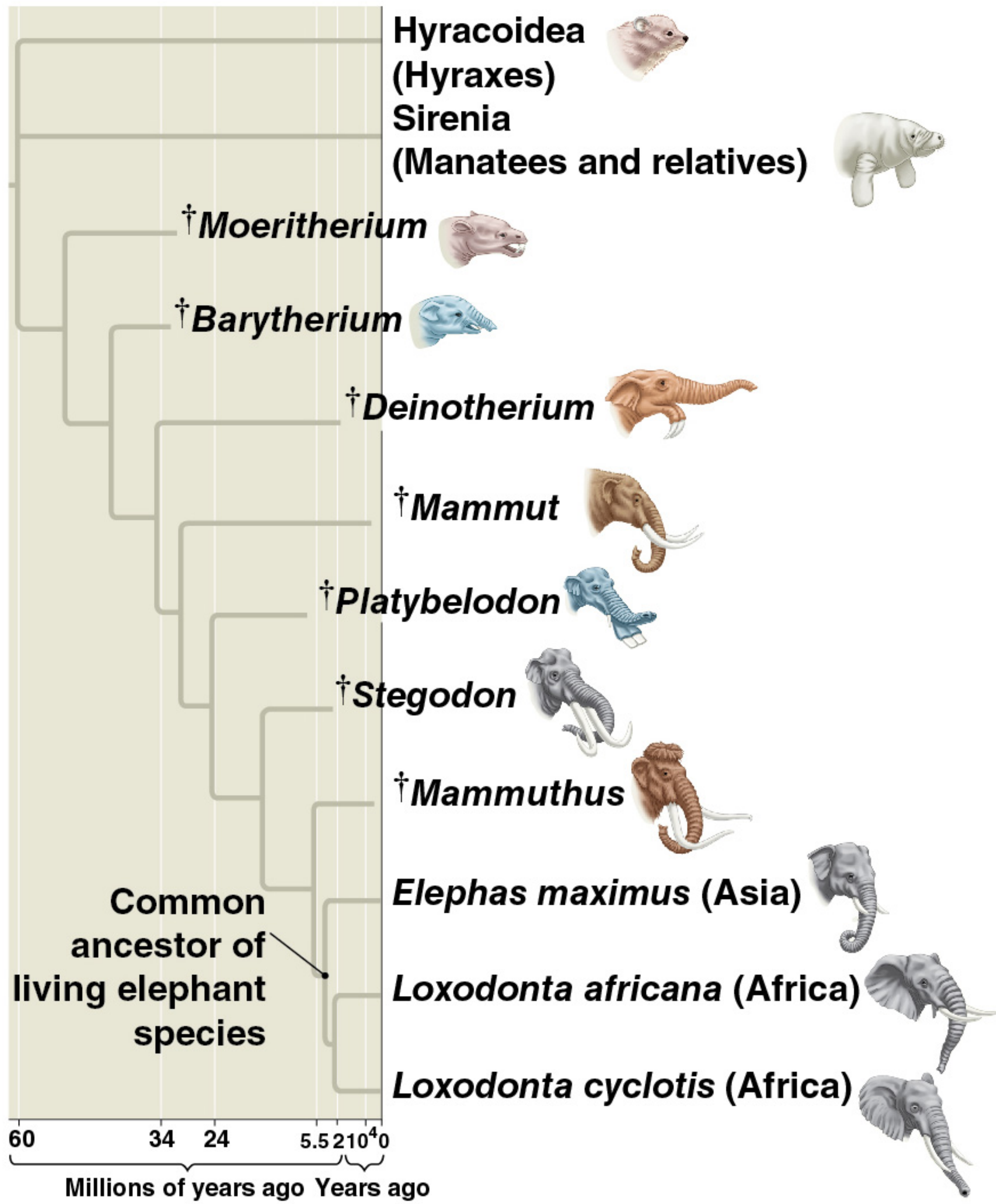
- Darwin viewed the history of life as a tree, with multiple branchings from a common trunk
  - Labeled branches represent groups of organisms living in the present day
  - Unlabeled branches represent extinct groups
  - A fork represents the most recent common ancestor of all lines of evolution branching from that point

Figure 22.7



- Large morphological gaps between related groups are explained by branching and extinction events
  - For example, living elephant species are similar because they split from a recent common ancestor
  - The extinction of seven older species helps explain the dissimilarity between elephants and their nearest living relatives, hyraxes and manatees

Figure 22.8

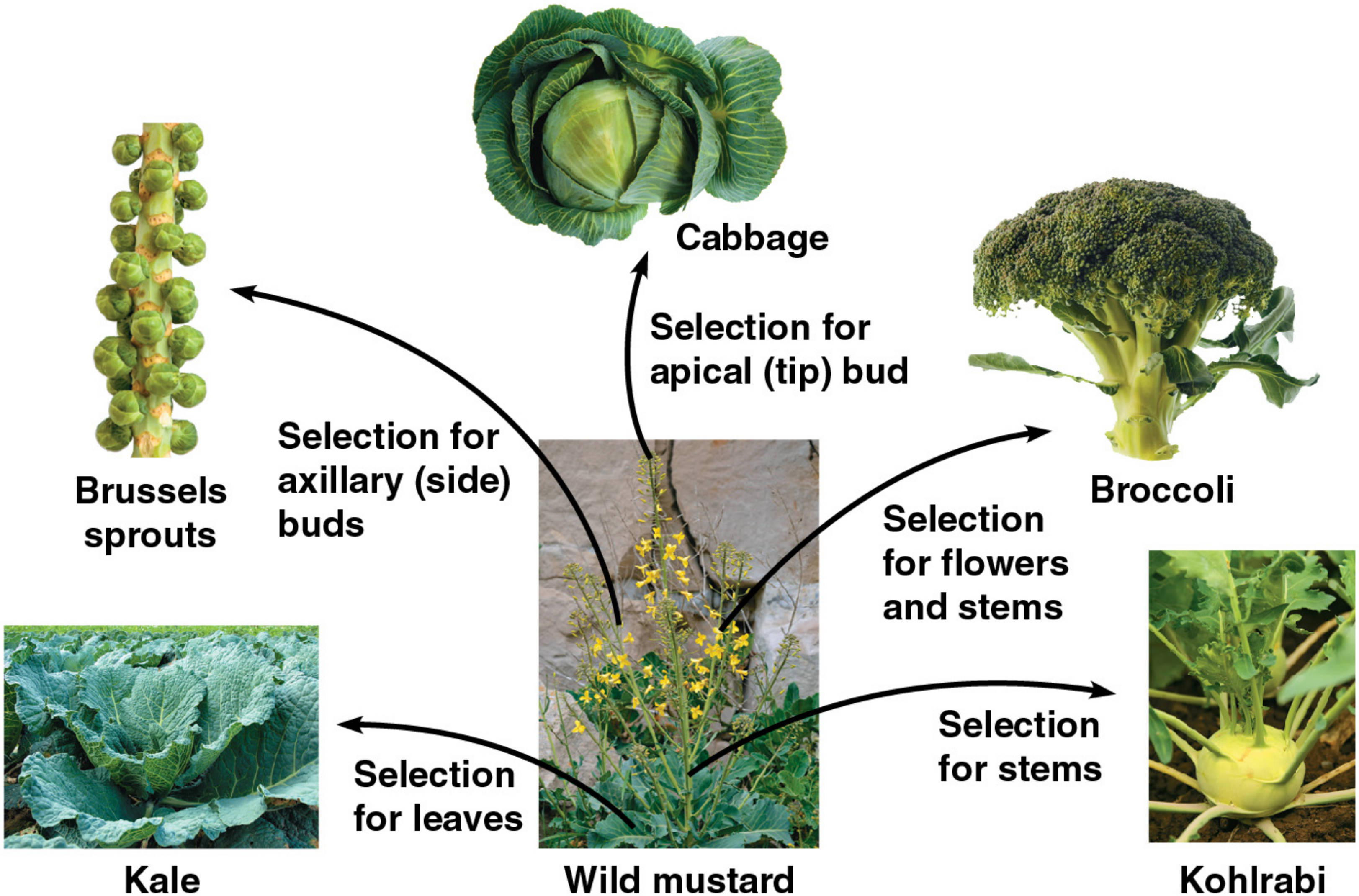


Hyracoidea (Hyraxes)
Sirenia (Manatees and relatives)
†Moeritherium
†Barytherium
†Deinotherium
†Mammut
†Platybelodon
†Stegodon
†Mammuthus
Elephas maximus (Asia)
Loxodonta africana (Africa)
Loxodonta cyclotis (Africa)
Common ancestor of living elephant species
60
34
24
5.5
2
1
0
10⁴
0
Millions of years ago
Years ago

Artificial Selection, Natural Selection, and Adaptation

- Humans modify species through **artificial selection**, breeding only individuals with desired traits
- Crops, livestock animals, and pets often bear little resemblance to their wild ancestors

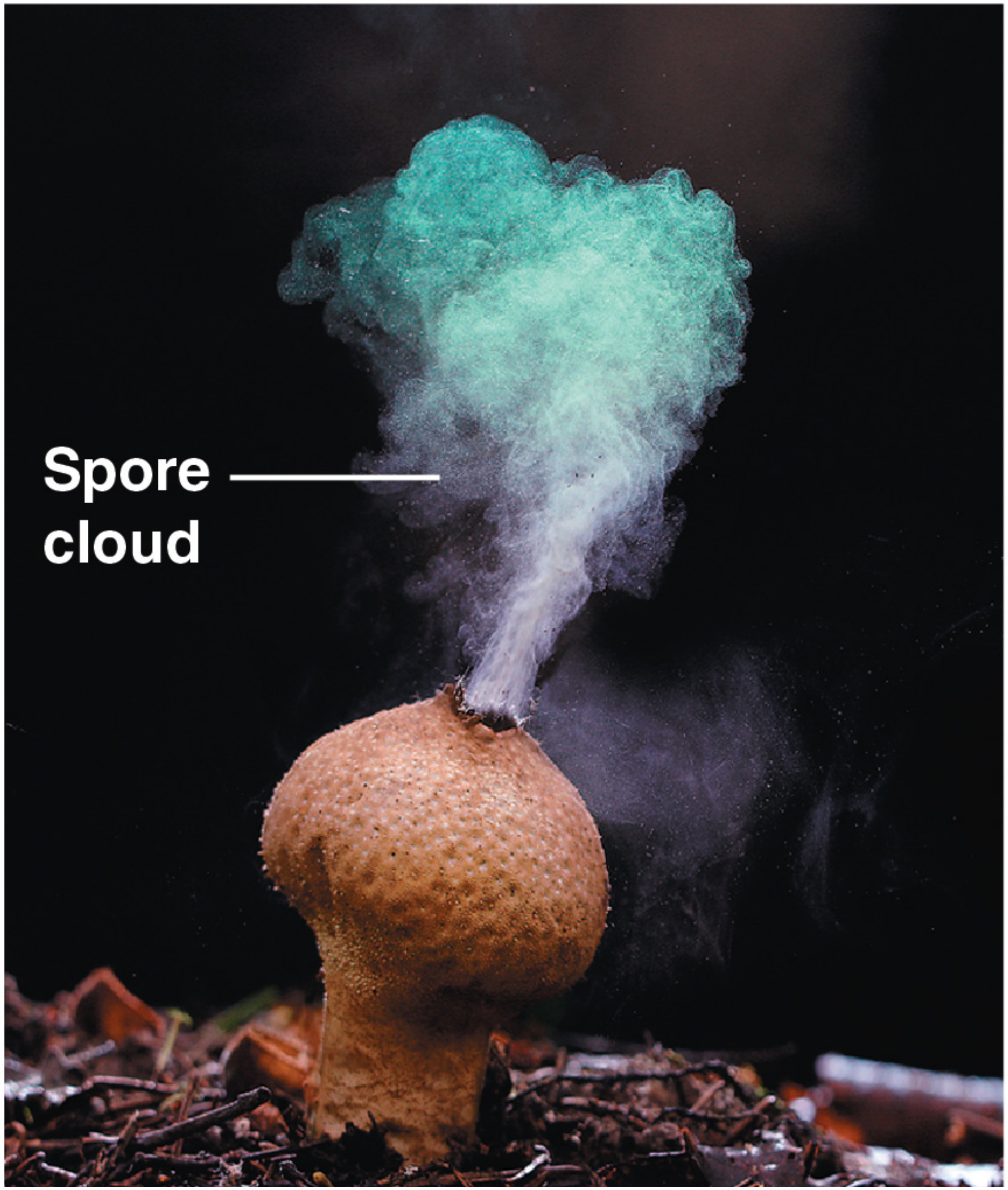
Figure 22.9


Cabbage
Selection for
apical (tip) bud
Brussels
sprouts
Selection for
axillary (side)
buds
Broccoli
Selection
for flowers
and stems
Kale
Selection
for leaves
Wild mustard
Selection
for stems
Kohlrabi

- Darwin drew two inferences from two observations
  - **Observation #1**: Members of a population often vary in their inherited traits
  - **Observation #2**: All species can produce more offspring than the environment can support, and many of these offspring fail to survive and reproduce

Figure 22.10

Figure 22.11



- **Inference #1**: Individuals with inherited traits that increase survival and reproduction in an environment tend to produce more offspring than other individuals
- **Inference #2**: The unequal ability of individuals to survive and reproduce will lead to the accumulation of favorable traits in the population over generations

- Thomas Malthus wrote about the capacity of human populations to increase faster than critical resources
- Darwin recognized this capacity in all species
- Only a fraction of offspring complete development and reproduce; the rest are starved, eaten, unmated, diseased, or intolerant of physical conditions

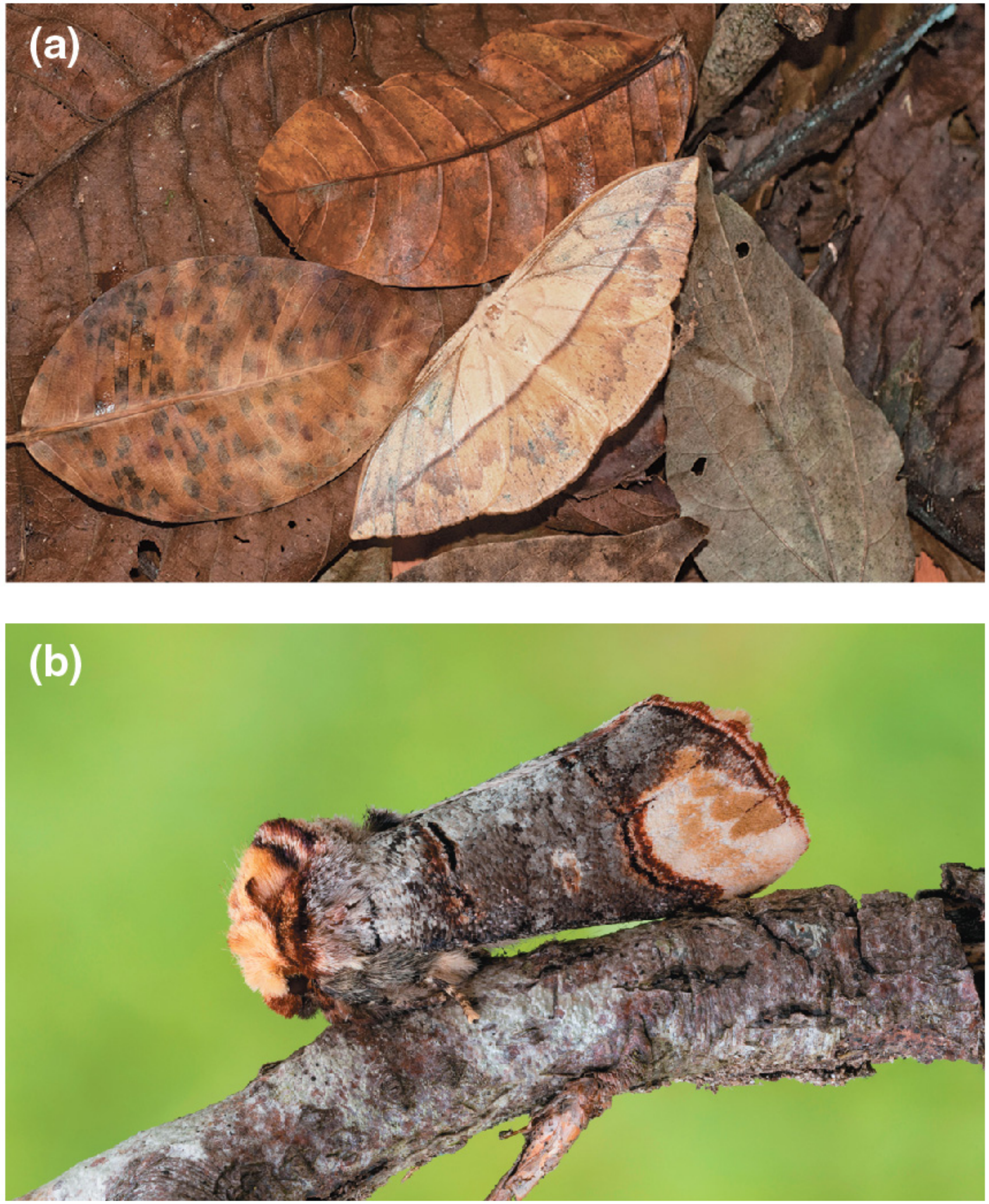
- If advantageous traits increase the number of offspring that survive and reproduce, then they will appear at higher frequency in the next generation
  - For example, offspring may inherit a trait that helps them escape predators or obtain food

- Over time, natural selection by predators, lack of food, or adverse conditions can increase the proportion of favorable traits in the population
- Even slight advantages gradually accumulate in the population, while less favorable variations diminish
- In this way, organisms become better suited for life in their environment

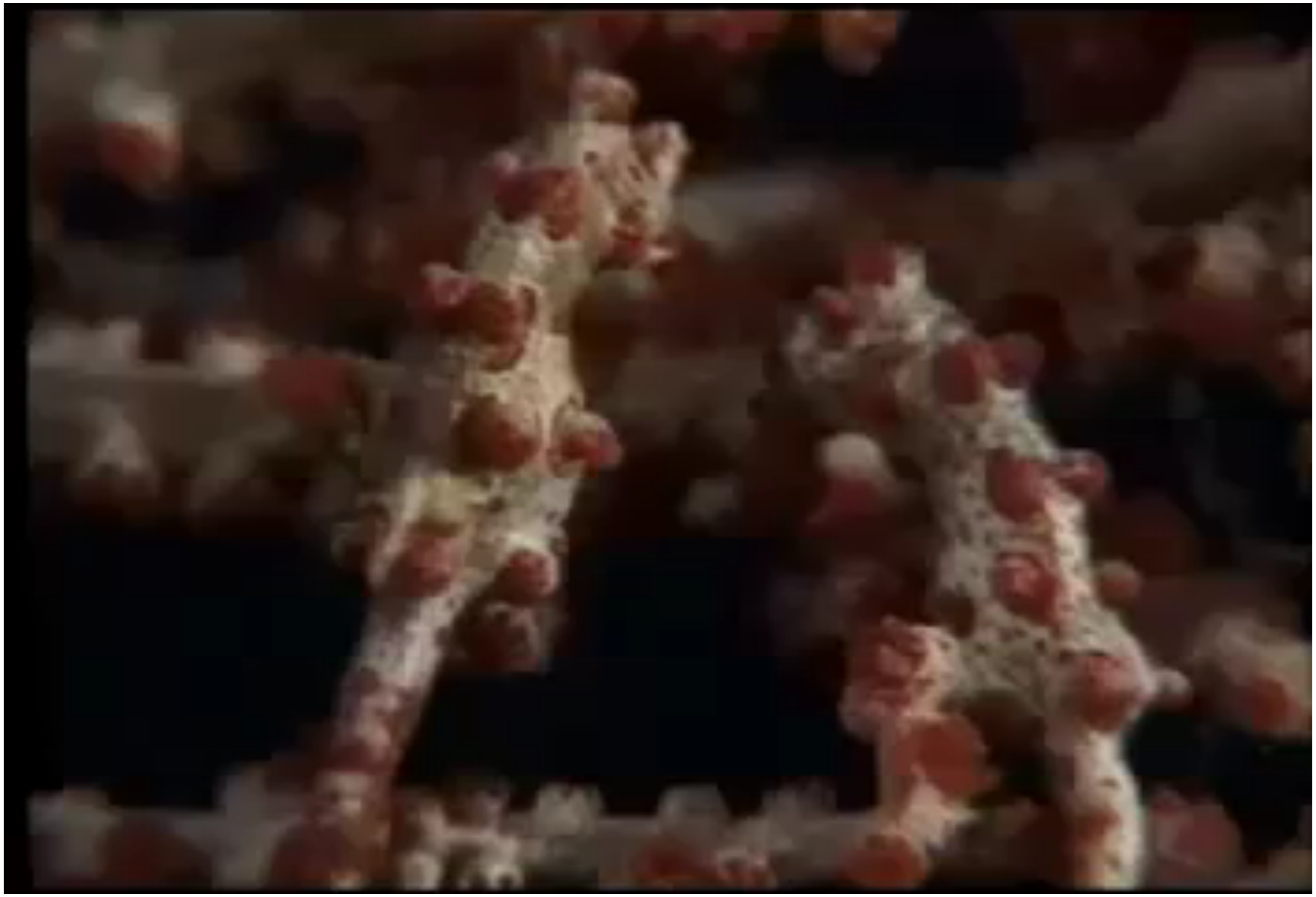
Key Features of Natural Selection

- Individuals with certain heritable traits survive and reproduce at a higher rate than other individuals
- Natural selection increases the frequency of adaptations that are favorable in an environment
- If the environment changes, natural selection may drive adaptation to new conditions, giving rise to new species

Figure 22.12



Video: Sea Horses



- Individuals do not evolve; it is the population that evolves over time
- Natural selection can only increase or decrease heritable traits that are variable in a population
- The environment varies from place to place and over time; favorable traits vary with the environment

CONCEPT 22.3: Evolution is supported by an overwhelming amount of scientific evidence

- New discoveries continue to fill the gaps identified by Darwin in *The Origin of Species*
- Four types of data document the pattern of evolution
  - Direct observations
  - Homology
  - The fossil record
  - Biogeography

Direct Observations of Evolutionary Change

- Biologists have documented evolutionary change in thousands of scientific studies
- Two examples include natural selection in response to introduced species and the evolution of drug-resistant bacteria

Natural Selection in Response to Introduced Species

- Herbivores often have adaptations to help feed efficiently on their primary food source
  - For example, soapberry bugs use a long “beak” to feed on seeds embedded within the fruits of various plants

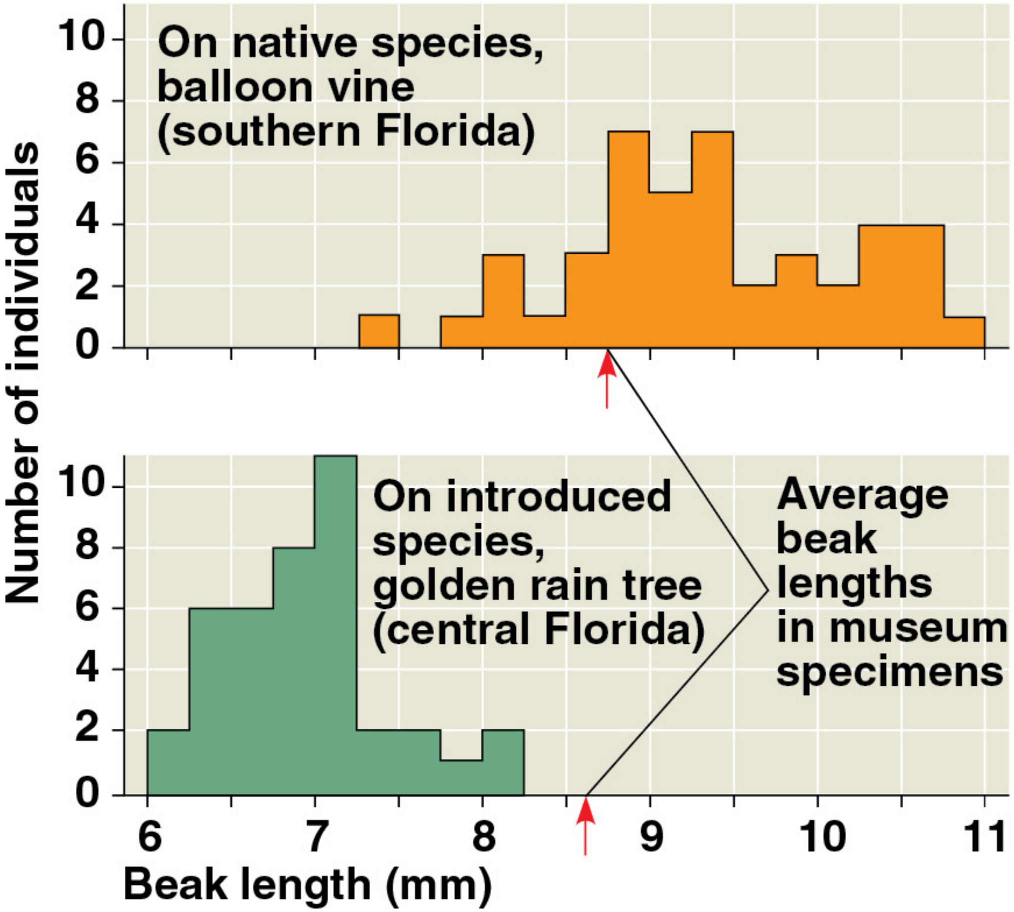
- Feeding is most effective when beak length is closely matched to seed depth within the fruit
  - In southern Florida, soapberry bugs feed on native balloon vines with large fruit; they have long beaks
  - In central Florida, they feed on introduced golden rain trees with smaller fruit; they have shorter beaks

Figure 22.13

Field Study

Soapberry bug with beak inserted in balloon vine fruit

Results



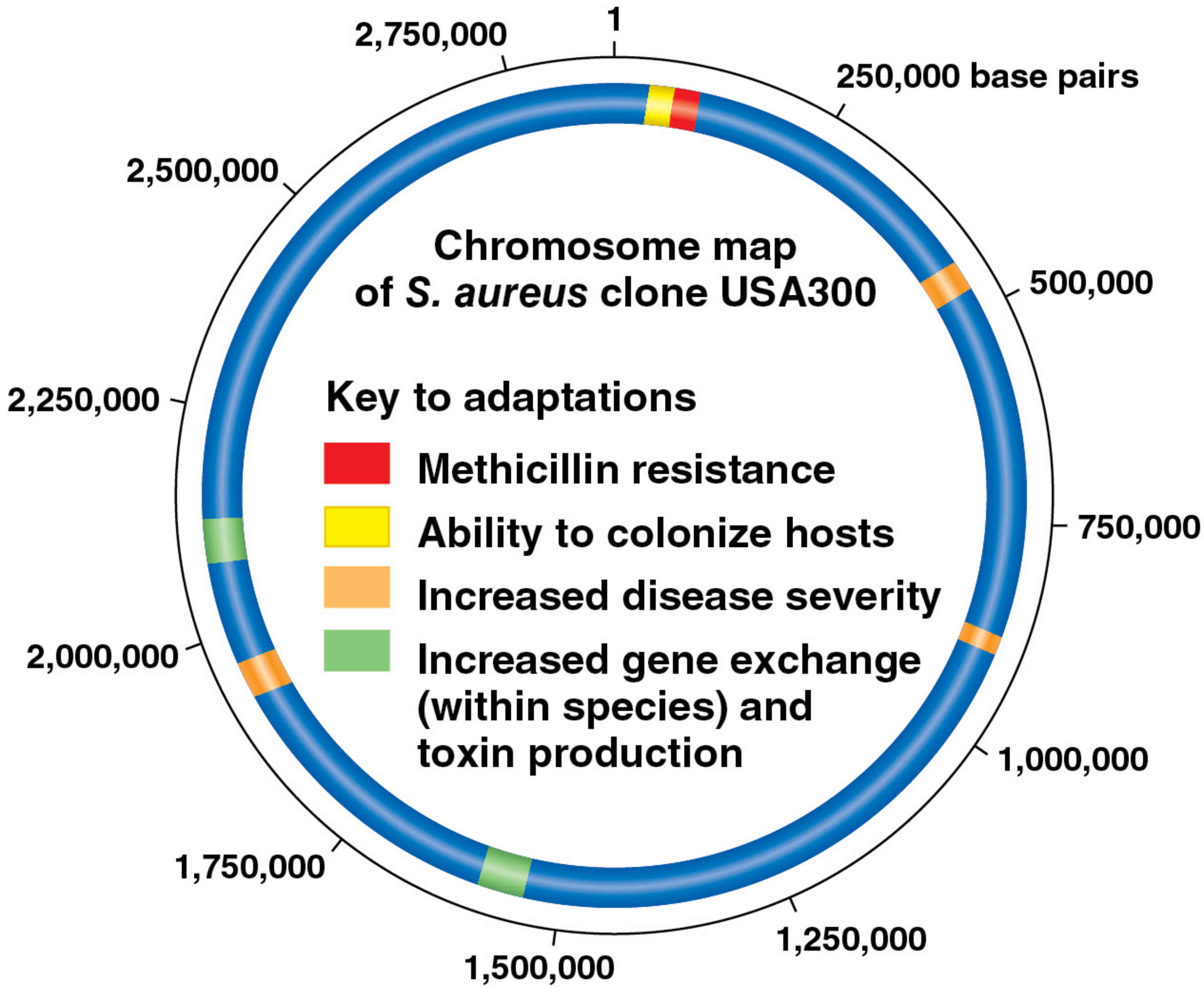
Data from S. P. Carroll and C. Boyd, Host race radiation in the soapberry bug: natural history with the history, *Evolution* 46:1052–1069 (1992).

- Correlation between fruit size and beak size has also been found in Louisiana, Oklahoma, and Australia
- In all cases, longer beaks evolved when bugs fed on the larger fruit of introduced plants
- In Florida, evolution in beak size occurred in less than 35 years

The Evolution of Drug-Resistant Bacteria

- The bacterium *Staphylococcus aureus* occurs on the skin or nasal passages of about one in three people
- Certain strains, called methicillin-resistant *S. aureus* (MRSA), are pathogens that can cause potentially fatal infections
  - For example, clone USA300 can cause “flesh-eating disease”

Figure 22.14



1
250,000 base pairs
500,000
750,000
1,000,000
1,250,000
1,500,000
1,750,000
2,000,000
2,250,000
2,500,000
2,750,000
Chromosome map
of *S. aureus* clone USA300
Key to adaptations
Methicillin resistance
Ability to colonize hosts
Increased disease severity
Increased gene exchange
(within species) and
toxin production

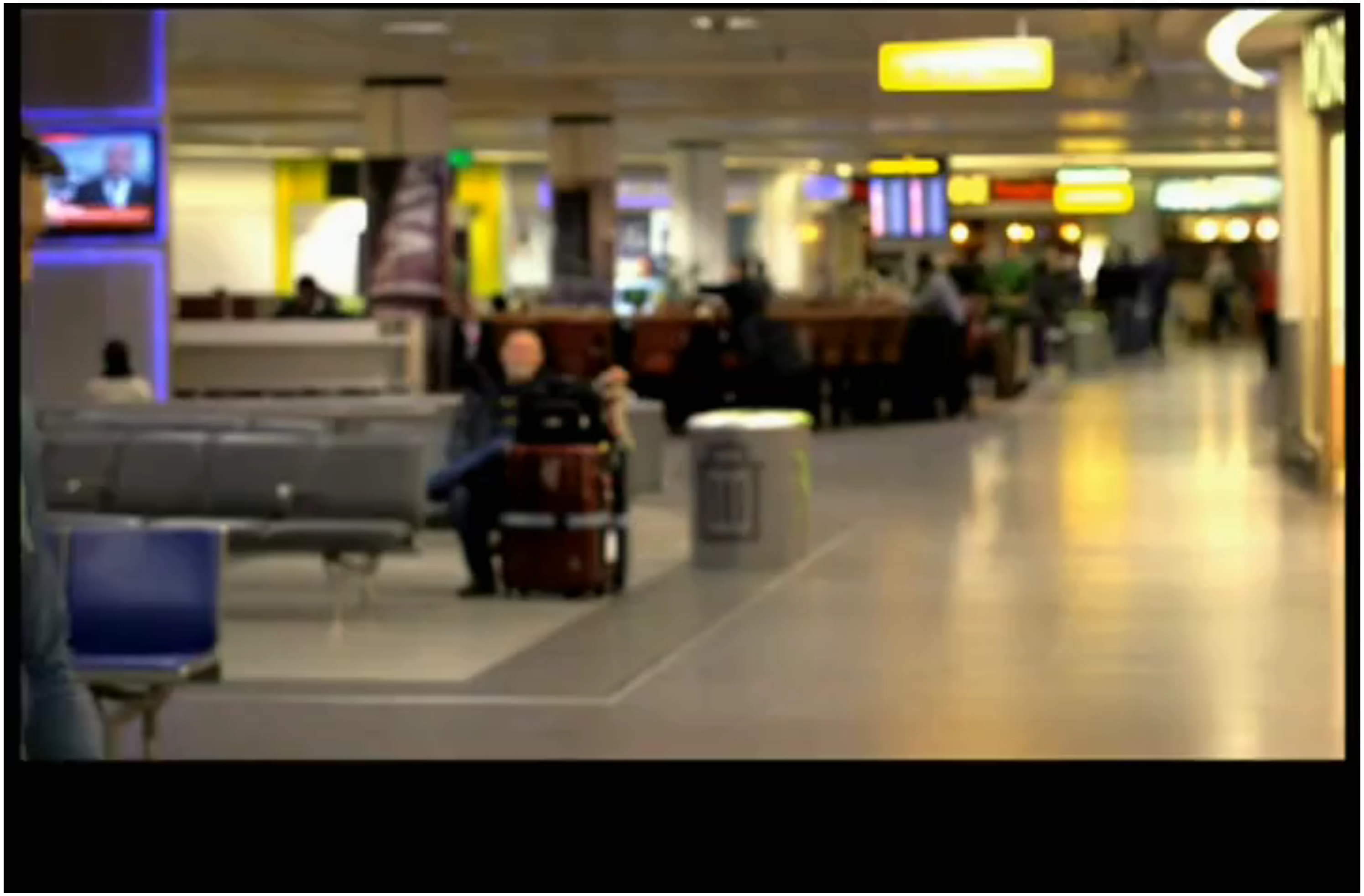
- In 1943 penicillin became the first widely used antibiotic to treat bacterial infections
- Penicillin resistance evolved in *S. aureus* by 1945
- A new antibiotic, methicillin, was introduced in 1959
- Methicillin resistance evolved in *S. aureus* by 1961

- Methicillin works by inhibiting an enzyme used by bacteria to produce cell walls
- MRSA bacteria are able to use a different enzyme that is not affected by methicillin
- Resistance increases in the presence of methicillin because MRSA strains are more likely to survive and reproduce than nonresistant strains

- Multidrug-resistant strains have evolved through the exchange of resistance genes between individuals
- Resistance is now spreading faster than new antibiotics are being discovered
- A new antibiotic, “teixobactin,” discovered in 2015, shows promise for treating resistant pathogens

- Natural selection does not create new traits; it selects for traits already present in the population
- Evolution by natural selection can occur rapidly in species with short generation times
- Natural selection favors traits that are advantageous in the current, local environment

Video: A Future Without Antibiotics?



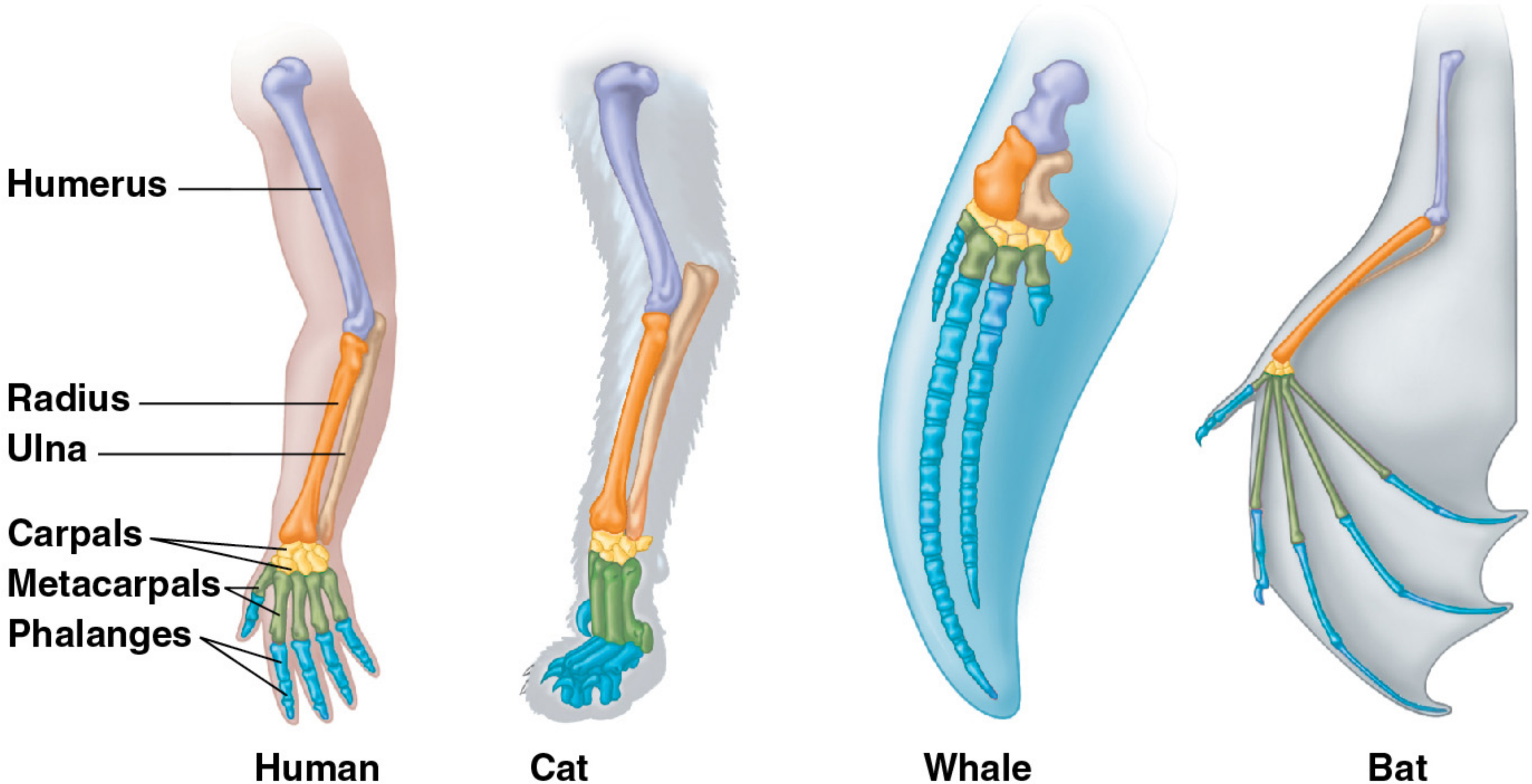
Homology

- **Homology**, similarity resulting from common ancestry, is another type of evidence for evolution
- Related species can have characteristics that have an underlying similarity yet function differently

Anatomical and Molecular Homologies

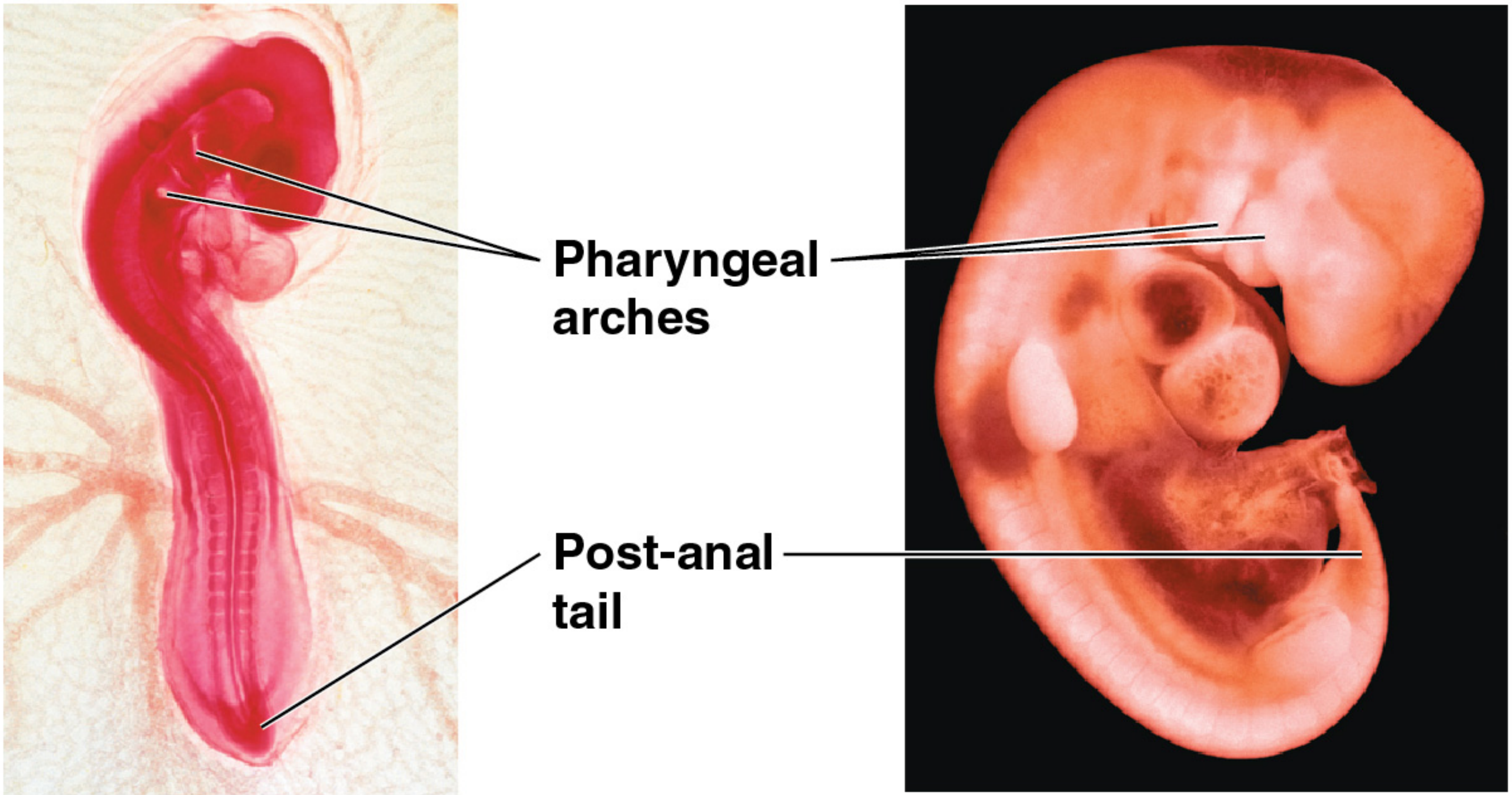
- **Homologous structures** are anatomical resemblances that represent variations on a structural theme present in a common ancestor
  - For example, the forelimbs of all mammals have the same arrangement of bones, but different functions

Figure 22.15


Humerus
Radius
Ulna
Carpals
Metacarpals
Phalanges
Human
Cat
Whale
Bat

- Comparative embryology reveals anatomical homologies not visible in adult organisms
  - For example, all vertebrate embryos have a post-anal tail and pharyngeal arches
  - The arches develop into structures with very different functions in adults from different vertebrate groups

Figure 22.16



Chick embryo (LM)

Human embryo

- **Vestigial structures** are remnants of features that served a function in the organism's ancestors
  - For example, snakes arose from ancestors with legs; the skeletons of some snakes retain vestiges of pelvis and leg bones

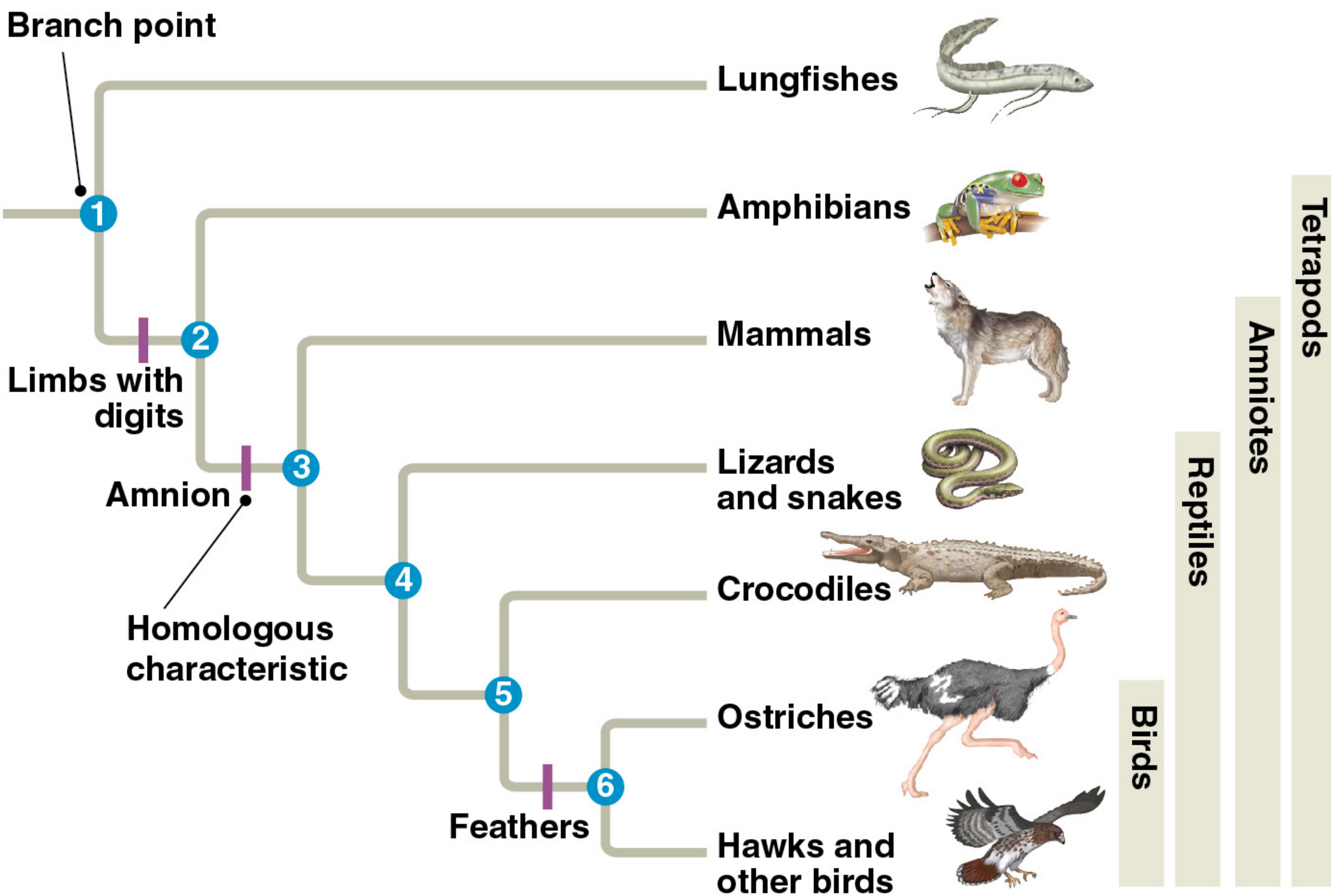
- Molecular homologies include the genetic code shared by all life and specific genes that are shared between vastly different organisms
- In some species, homologous genes may acquire new functions, or lose function entirely
- Similarities in such genes are evidence of inheritance from a common ancestor

Homologies and "Tree Thinking"

- Characteristics shared by many species date to a deep ancestral past; homologies that evolved more recently are shared only within smaller groups
  - For example, tetrapods, like all vertebrates, have a backbone
  - Unlike other vertebrates, all tetrapods also have limbs with digits

- **Evolutionary trees** are diagrams that reflect hypotheses about the relationships among groups
- Homologies form nested patterns on the tree
- Relatedness is determined by the recent common ancestor, not the proximity of groups on the tree
- Evolutionary trees show relative timing of events, not actual dates

Figure 22.17



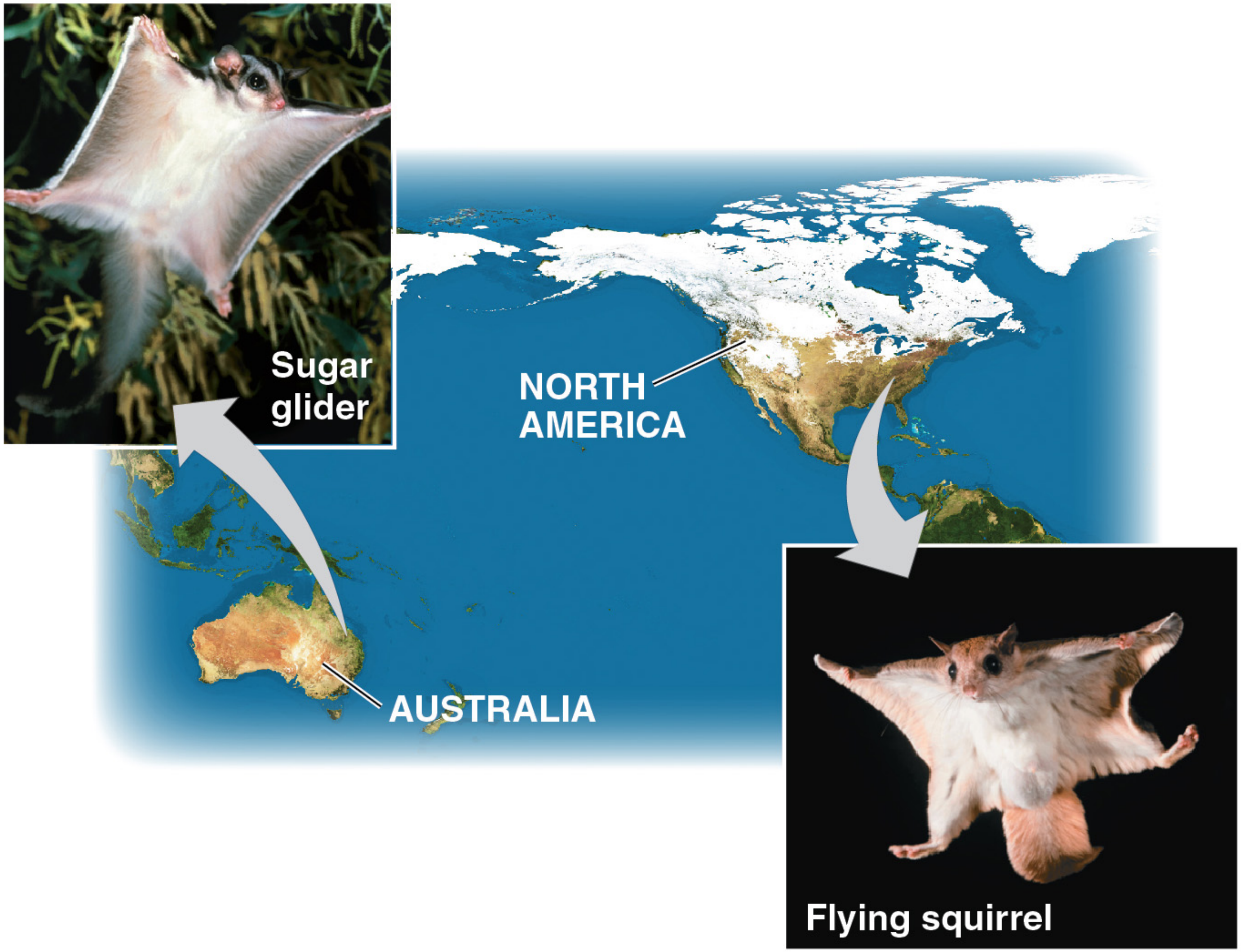
Branch point
1
2
3
4
5
6
Limbs with digits
Amnion
Homologous characteristic
Feathers
Lungfishes
Amphibians
Mammals
Lizards and snakes
Crocodiles
Ostriches
Hawks and other birds
Birds
Reptiles
Amniotes
Tetrapods

- Evolutionary trees are made using many different data sets, including both anatomical and DNA sequence data
- Well-supported trees can be used to make predictions about organisms

A Different Cause of Resemblance: Convergent Evolution

- **Convergent evolution** is the evolution of similar, or **analogous**, features in distantly related groups
- Analogous traits arise not through common ancestry, but through independent adaptation to similar environments
  - For example, the sugar glider is an Australian marsupial that superficially resembles the flying squirrel, a North American eutherian

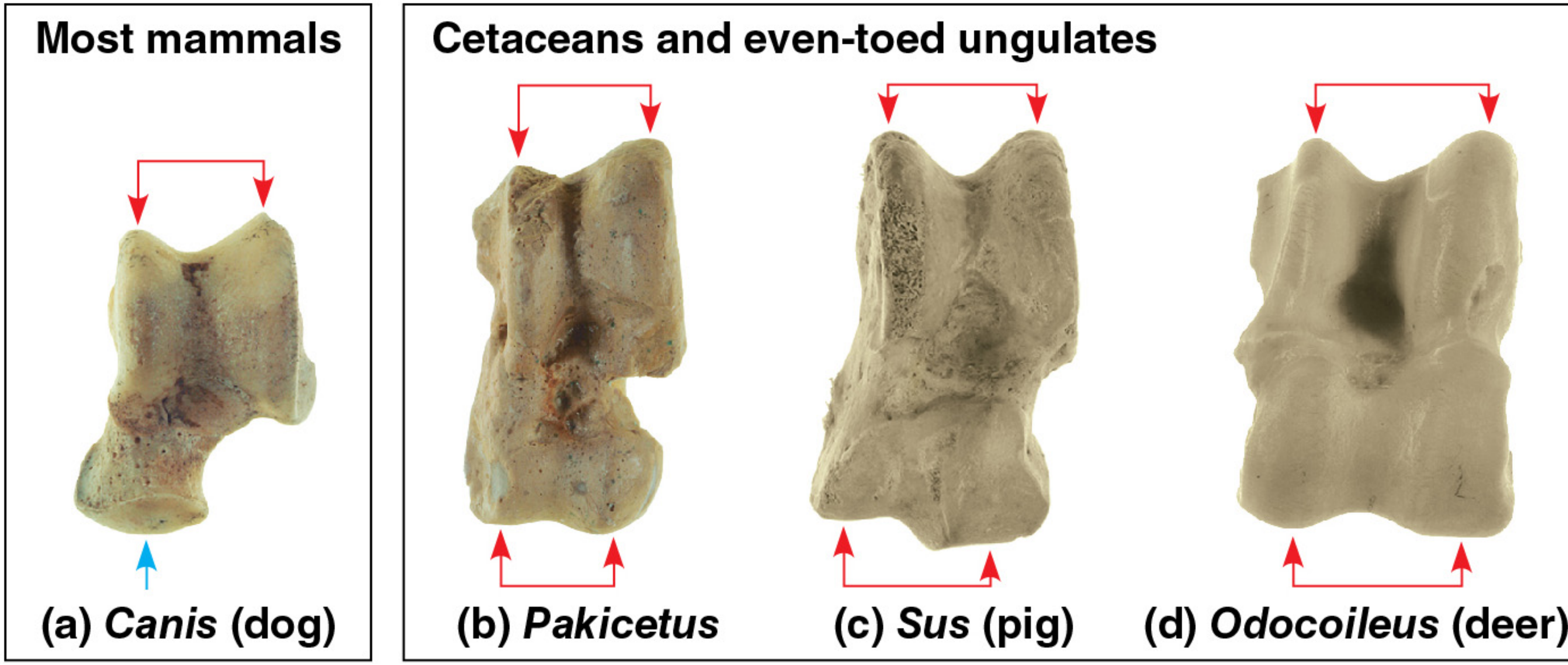
Figure 22.18



The Fossil Record

- The fossil record provides evidence of the extinction of species, the origin of new groups, and changes within groups over time
  - For example, the fossil record supported the DNA-based hypothesis that cetaceans are close relatives of even-toed ungulates

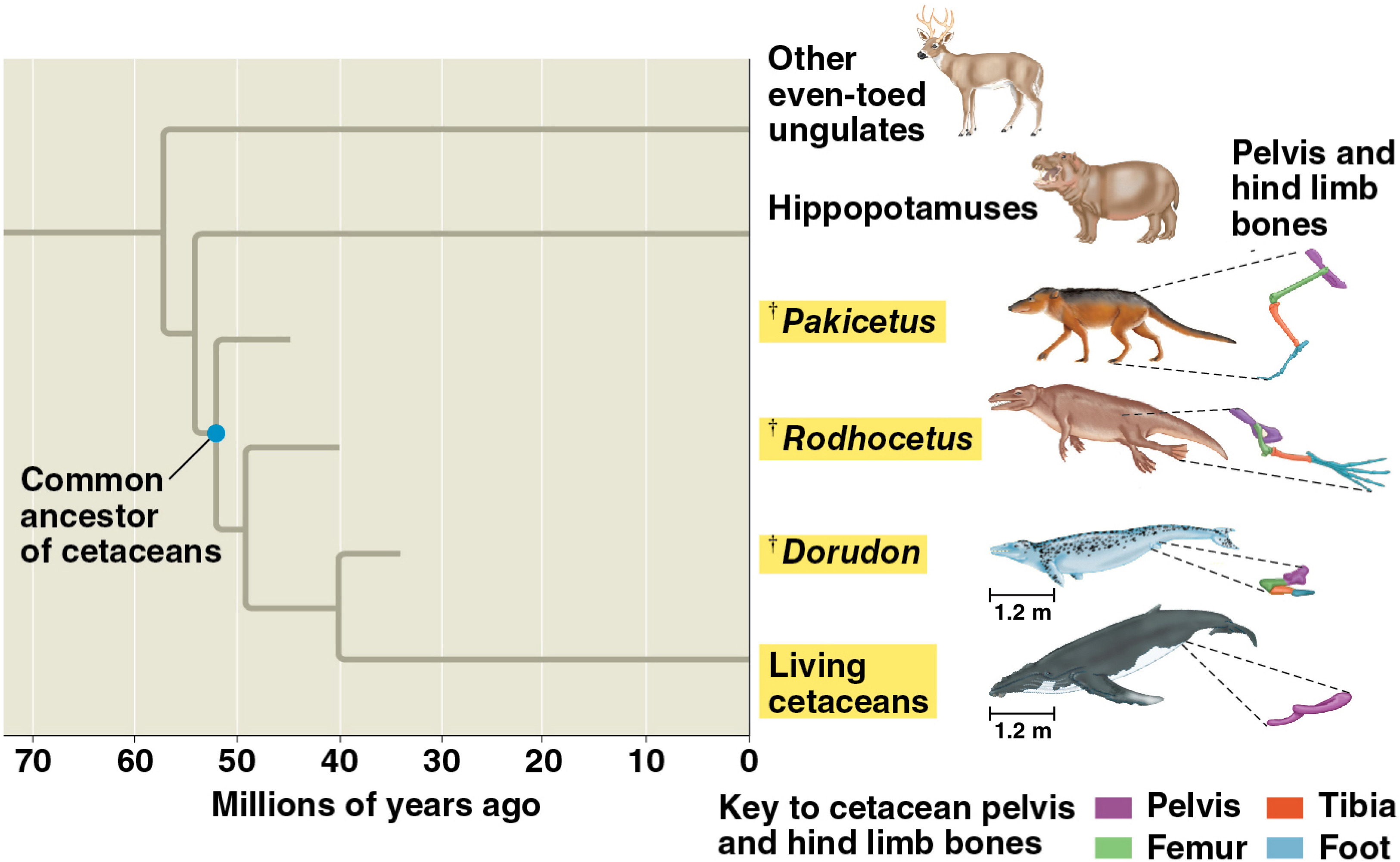
Figure 22.19



Most mammals
Cetaceans and even-toed ungulates
(a) *Canis* (dog)
(b) *Pakicetus*
(c) *Sus* (pig)
(d) *Odocoileus* (deer)

- Fossils can document important transitions, such as the transition from land to sea in the ancestors of cetaceans

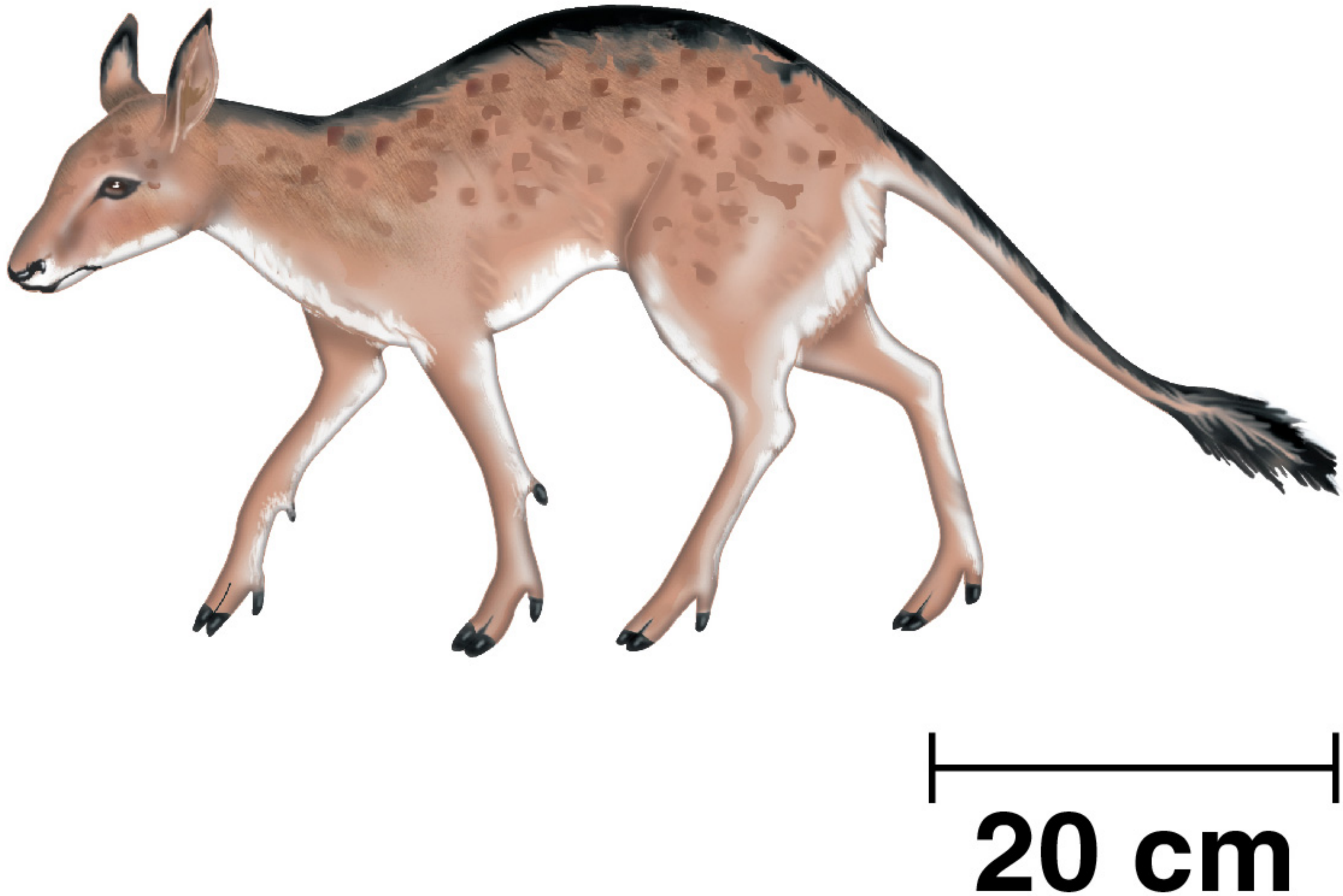
Figure 22.20



Other even-toed ungulates
Hippopotamuses
Pelvis and hind limb bones
† Pakicetus
† Rodhocetus
† Dorudon
Living cetaceans
1.2 m
1.2 m
Common ancestor of cetaceans
70
60
50
40
30
20
10
0
Millions of years ago
Key to cetacean pelvis and hind limb bones
Pelvis
Tibia
Femur
Foot

- Fossil evidence shows that living cetaceans and even-toed ungulates are more different from each other than were earlier members of these groups
  - For example, *Pakicetus*, an early cetacean, closely resembles *Diacodexis*, an early even-toed ungulate

Figure 22.21



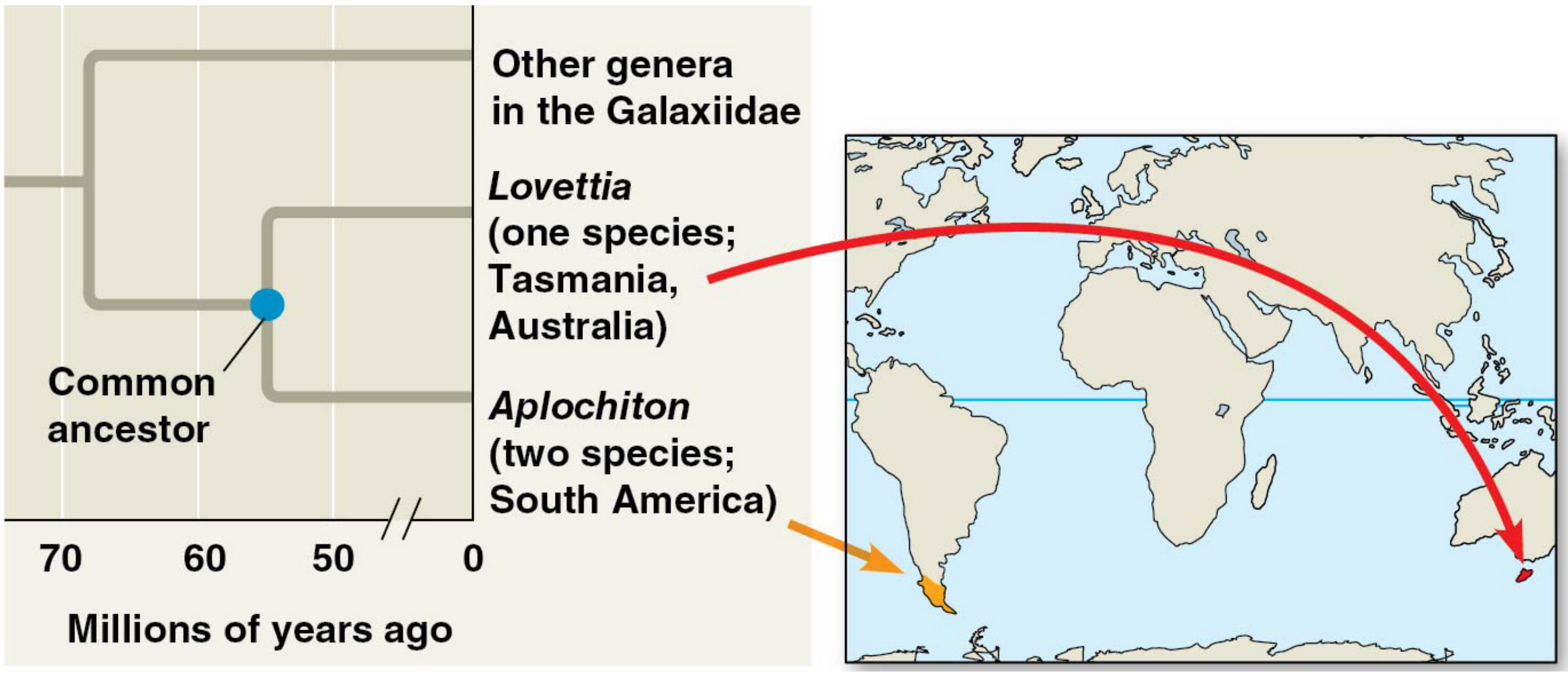
Biogeography

- Evidence from **biogeography**, the scientific study of the geographic distribution of species, provides support for evolution

- Species distributions are influenced by continental drift, the gradual movement of Earth's landmasses
  - For example, 250 million years ago, all landmasses formed a single large continent called **Pangea**
  - By 20 million years ago, they had drifted apart to form the continents near their present locations

- Understanding continental drift and modern species distribution helps predict when and where different groups evolved
  - For example, freshwater fish in the family Galaxiidae live in South America and Australia, separated by wide stretches of open ocean
  - All three species share an ancestor dating back to the time that these continents broke away from Pangea

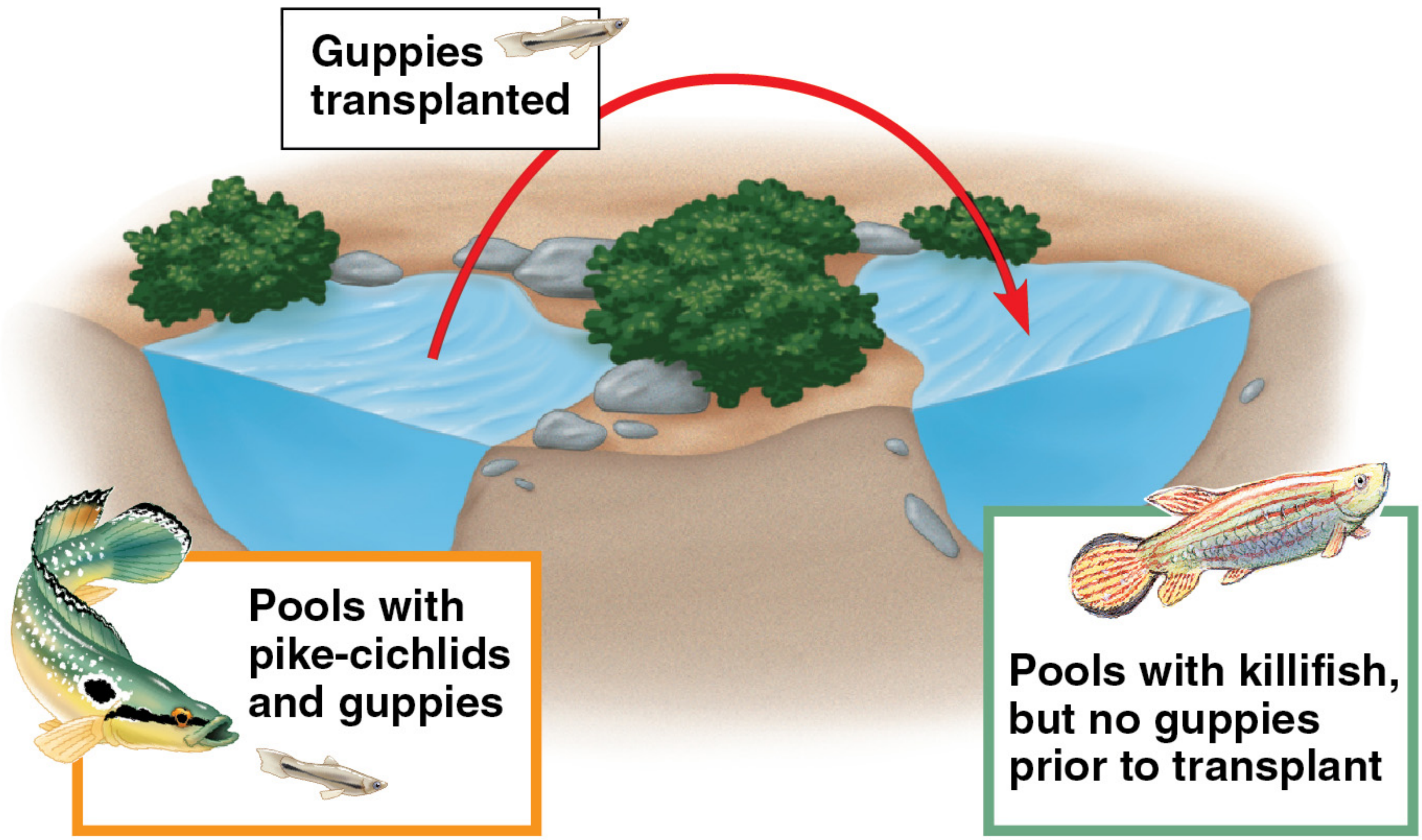
Figure 22.22

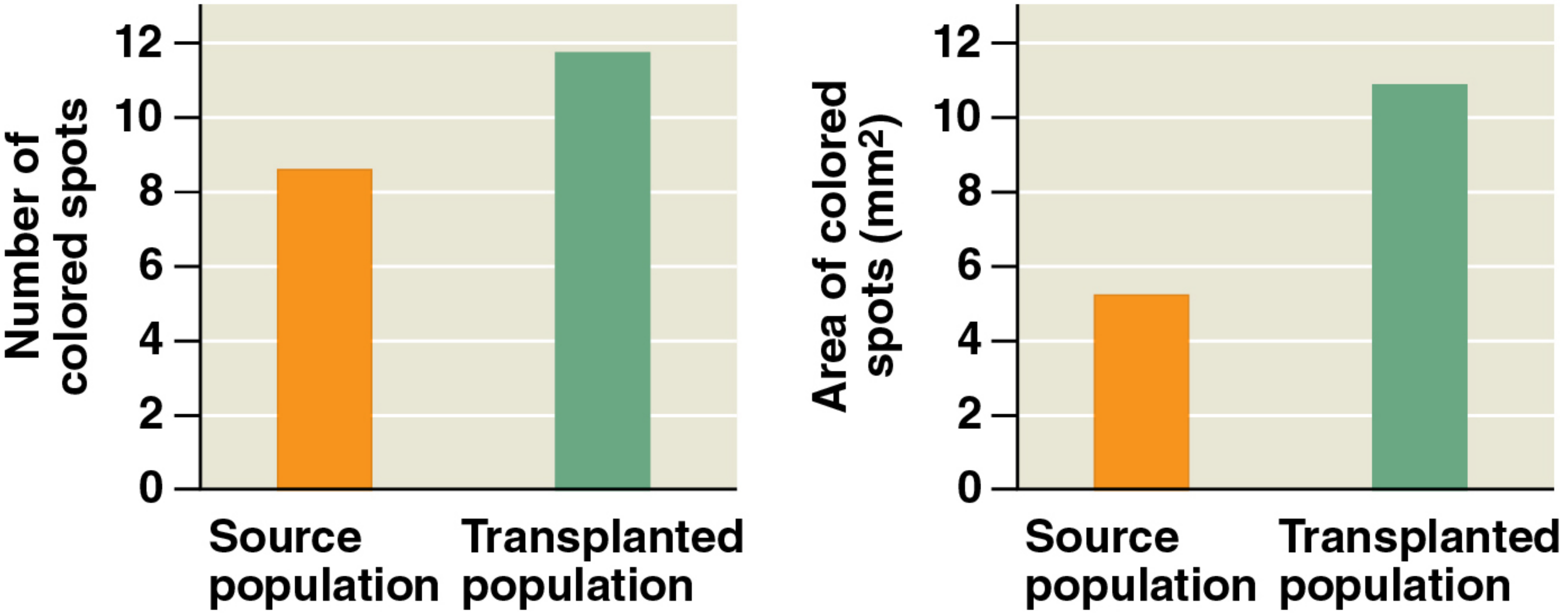

Other genera in the Galaxiidae
Lovettia (one species; Tasmania, Australia)
Aplochiton (two species; South America)
Common ancestor
70
60
50
0
Millions of years ago

What Is Theoretical About Darwin's View of Life?

- In science, a theory accounts for many observations and data, and attempts to explain and integrate a great variety of phenomena
- Darwin's theory of evolution by natural selection integrates diverse areas of biological study and stimulates many new research questions
- Ongoing research adds to our understanding of evolution

Figure 22.UN01a





Data from J. A. Endler, Natural selection on color patterns in *Poecilia reticulata, Evolution* 34:76–91 (1980).

Figure 22.UN02

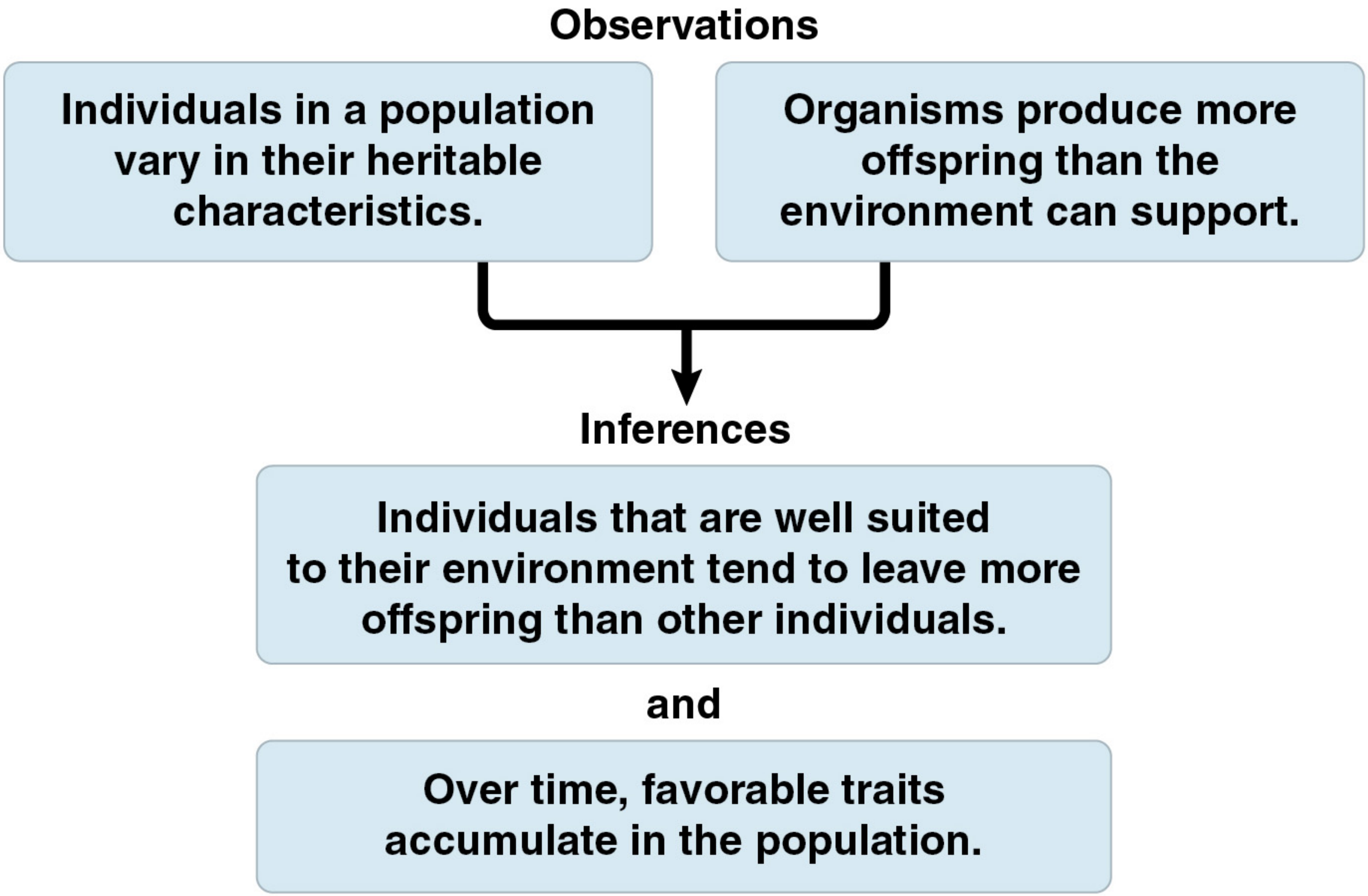


Figure 22.UN03

Month	0	8	12
Mosquitoes Resistant* to DDT	4%	45%	77%

*Mosquitoes were considered resistant if they were not killed within 1 hour of receiving a dose of 4% DDT.

Data from C. F. Curtis et al., Selection for and against insecticide resistance and possible methods of inhibiting the evolution of resistance in mosquitoes, *Ecological Entomology* 3:273–287 (1978).

Figure 22.UN04