PRINCIPLES OF EVOLUTION

Unit 10

Learning Objectives

- Understand how evolution can be observed in various populations
- Describe Charles Darwin's impact on evolution and the study of biology
- Identify the individuals who influenced Darwin
- Describe Darwin's most important observations
- Explain the four ways evolutionary change can take place
- Identify the difference between evolution and natural selection
- Understand and explain the five different lines of evidence for the occurrence of evolution
- Describe ways evolution can be observed today

Evolution vs. Natural Selection

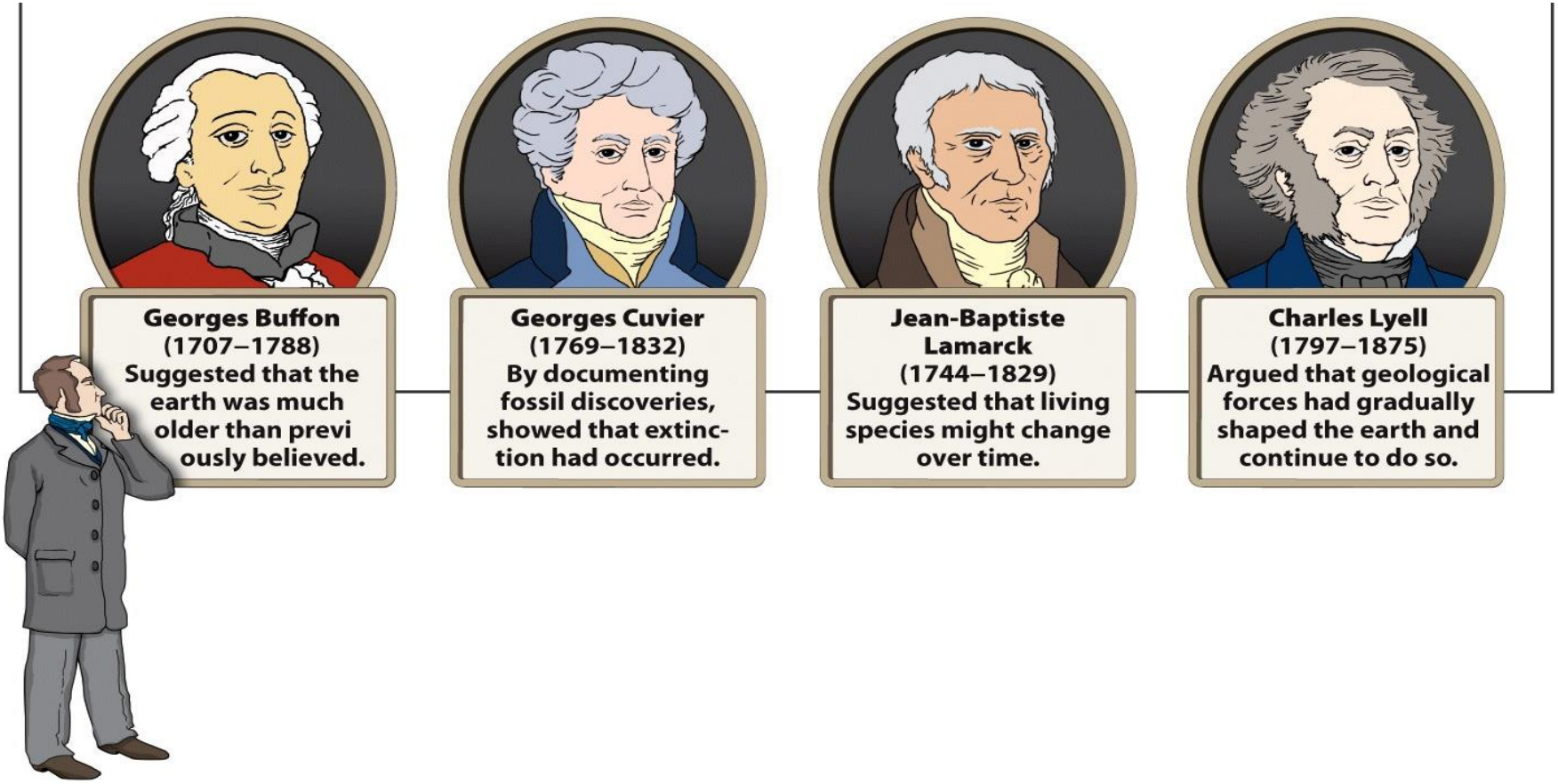
- **Evolution**
  - a genetic change in the population (group of organisms of the same species living in the same geographic region).

- **Natural selection**
  - the consequence of certain individual organisms in a population being born with characteristics that enable them to survive better and reproduce more than the offspring of other individuals in the population

History of Evolutionary Theory

- Many proposals as to how life began on Earth
  - Buffon
  - Cuvier
  - Hutton
  - Lyell
  - Lamarck

Darwin's Influences



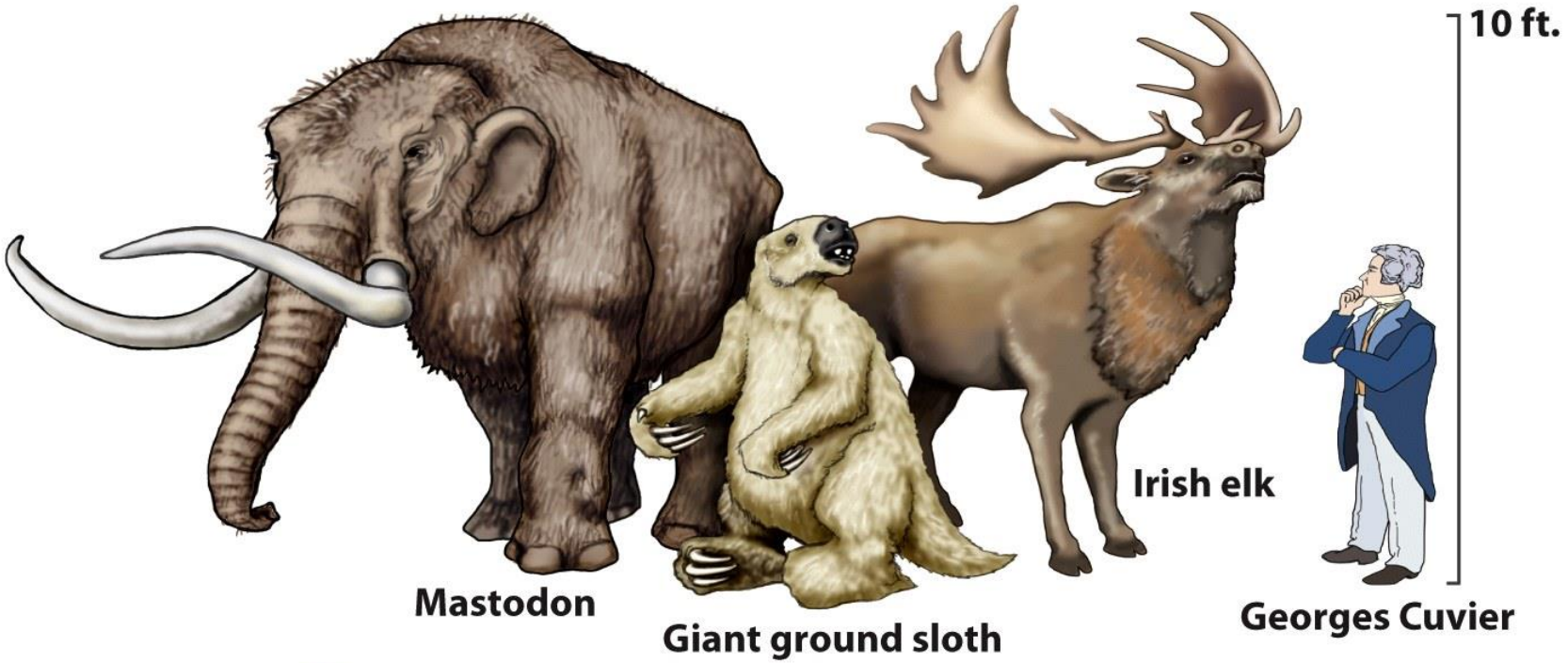
Georges-Louis Leclerc, Comte de Buffon

- challenged then-popular belief that the Earth was only 6,000 years old
- also suggested that the fact that animals retain parts that serve no known purpose to them is evidence that animals have evolved

Georges Cuvier

- questioned accepted view of the history of Earth as well as the relatedness of fossil organisms to living species
- extensive field collection and meticulous study of fossil specimens
- amassed evidence that would establish extinction as a biological reality
- paved the way for future paleontologists

Georges Cuvier



Fossils of organisms no longer found on earth means that extinction occurs!

Jean-Baptiste Lamarck

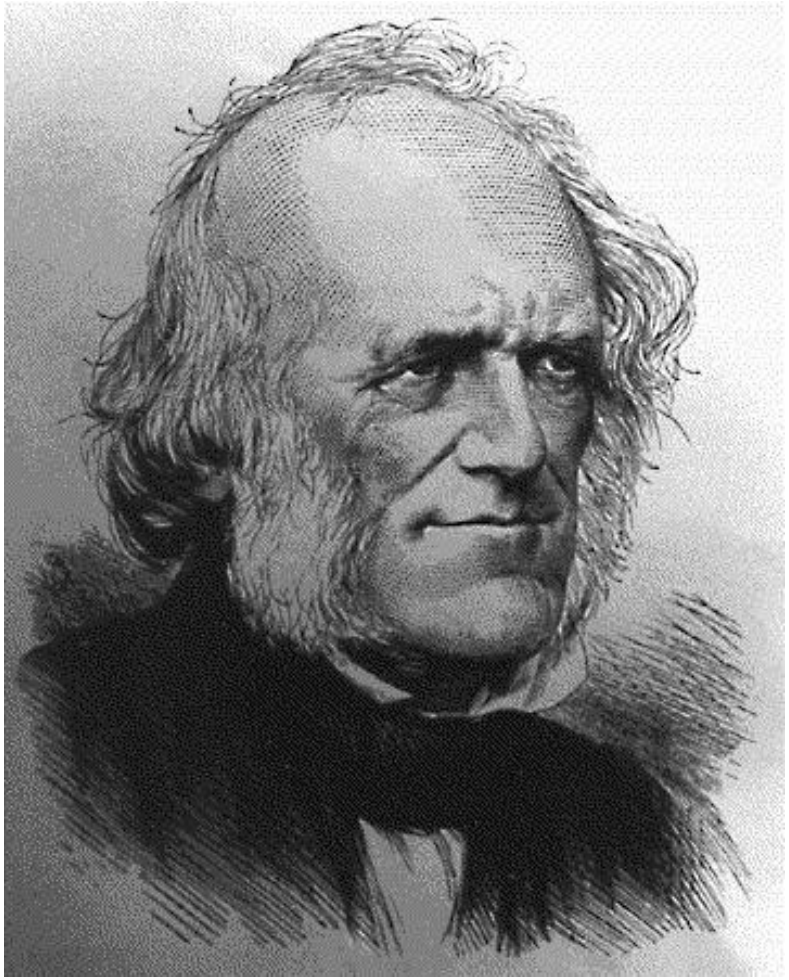
- species might change – through use and disuse – over time

James Hutton

- "Principle of Uniformitarianism“ (1785)
- current geological processes s/a volcanic activity and erosion were at work in the past, present & and future
- "the present is the key to the past"

Charles Lyell

- Geologist
- 1830 book *Principles of Geology*
  - Geological forces had shaped the earth and were continuing to do so.
- Gradual but constant change



The Modern Synthesis of Evolutionary Theory

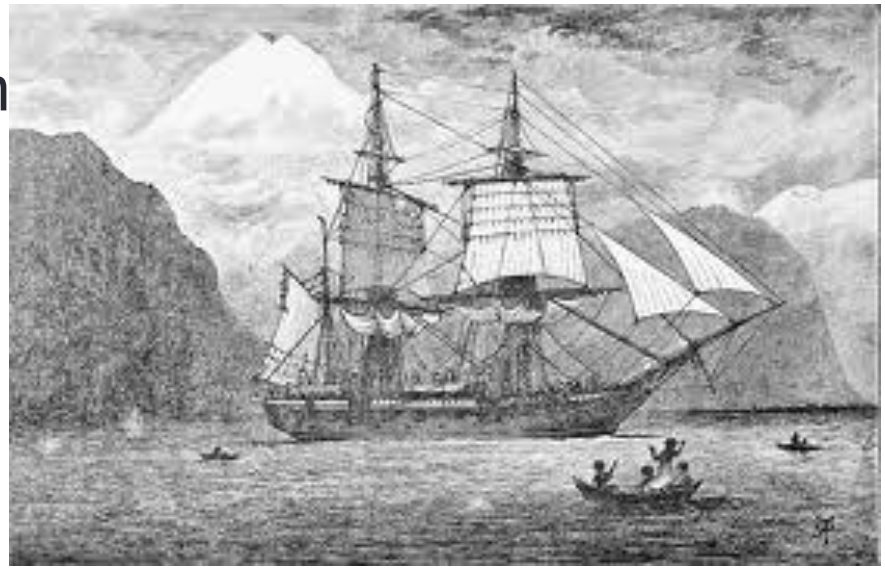
- 1930s and 1940s: scientists in a variety of related fields assembled a new picture of
  - biological change
  - mutation
  - variation
- merged genetics with Charles Darwin's vision of natural selection
- drew upon many fields
  - population geneticists
  - paleontologists
  - ornithologists
  - mathematical geneticists
  - naturalists

Take-Home Message

- People used to think that the earth was 6,000 years old and that species were unchanging.
- In the 18th and 19th centuries, scientists began to change their beliefs.
- These changes helped shape Darwin's thinking.

Darwin's Journey to an Idea

- A job on a 'round-the-world survey ship allowed Darwin to indulge and advance his love of nature.



Darwin's Journey to an Idea

- Age 16, University of Edinburgh, medical studies
- Studied theology at Cambridge University
- His real love: study of nature

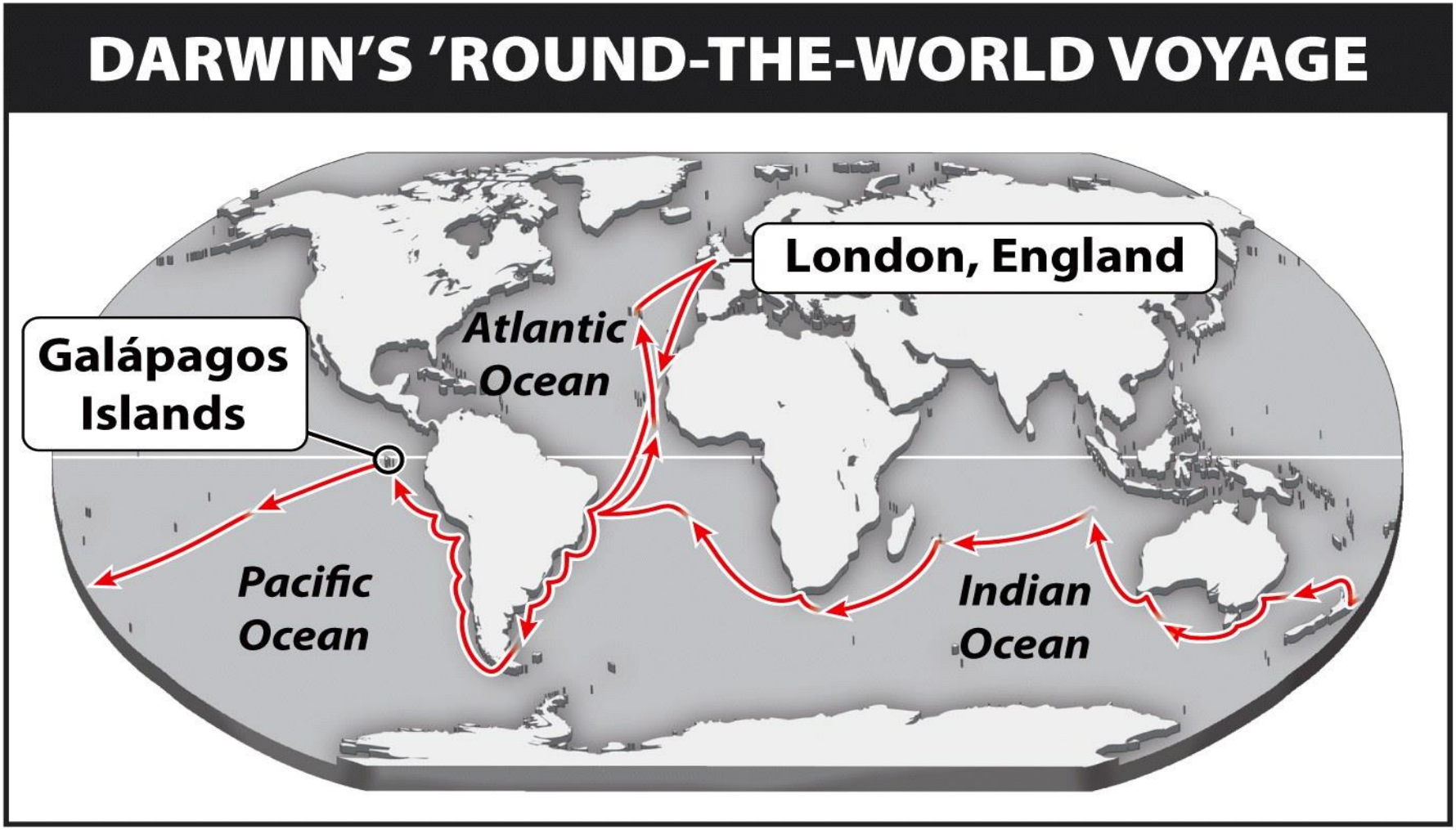


Figure 8-5 part 1
What Is Life? A Guide to Biology

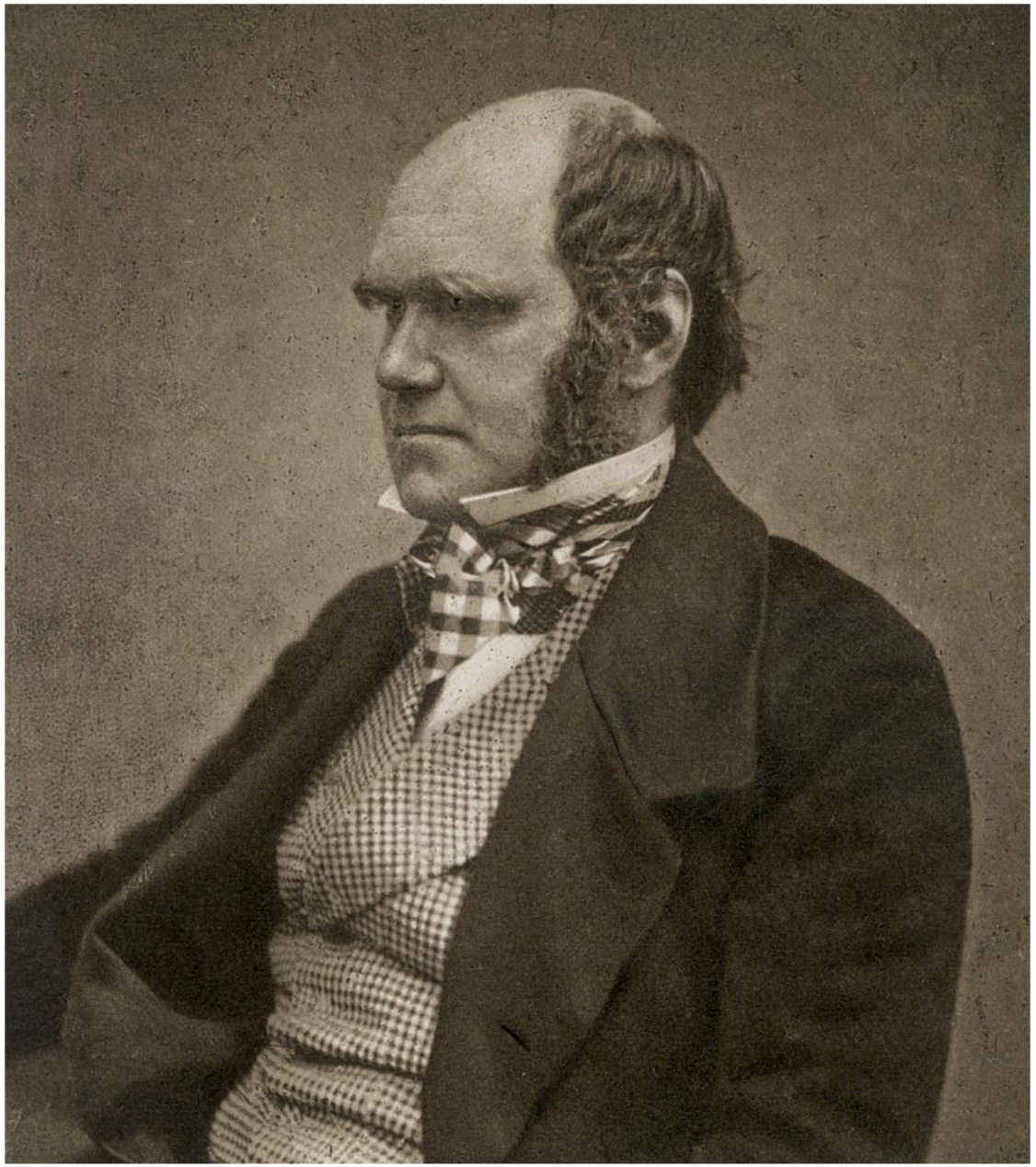
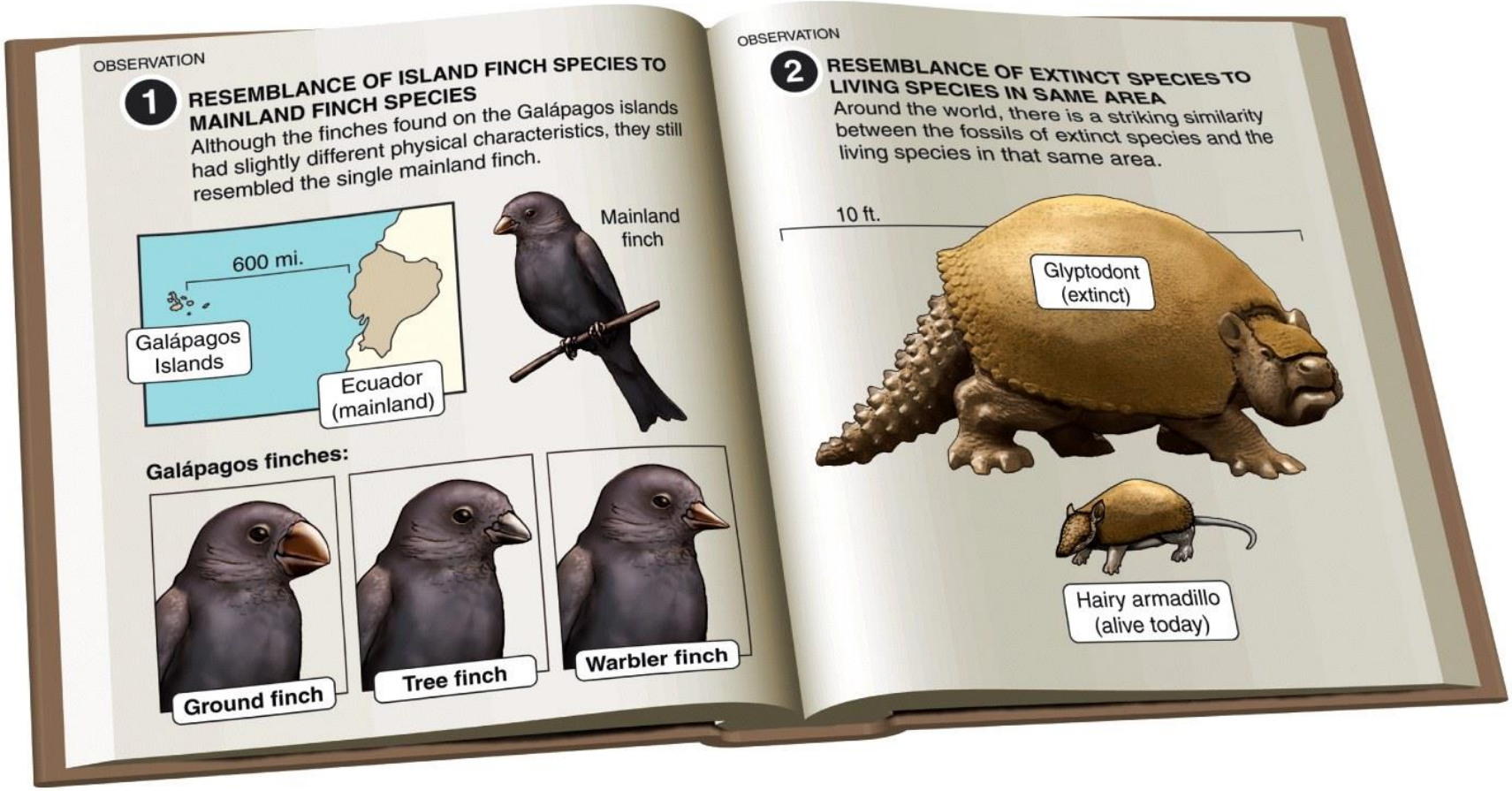


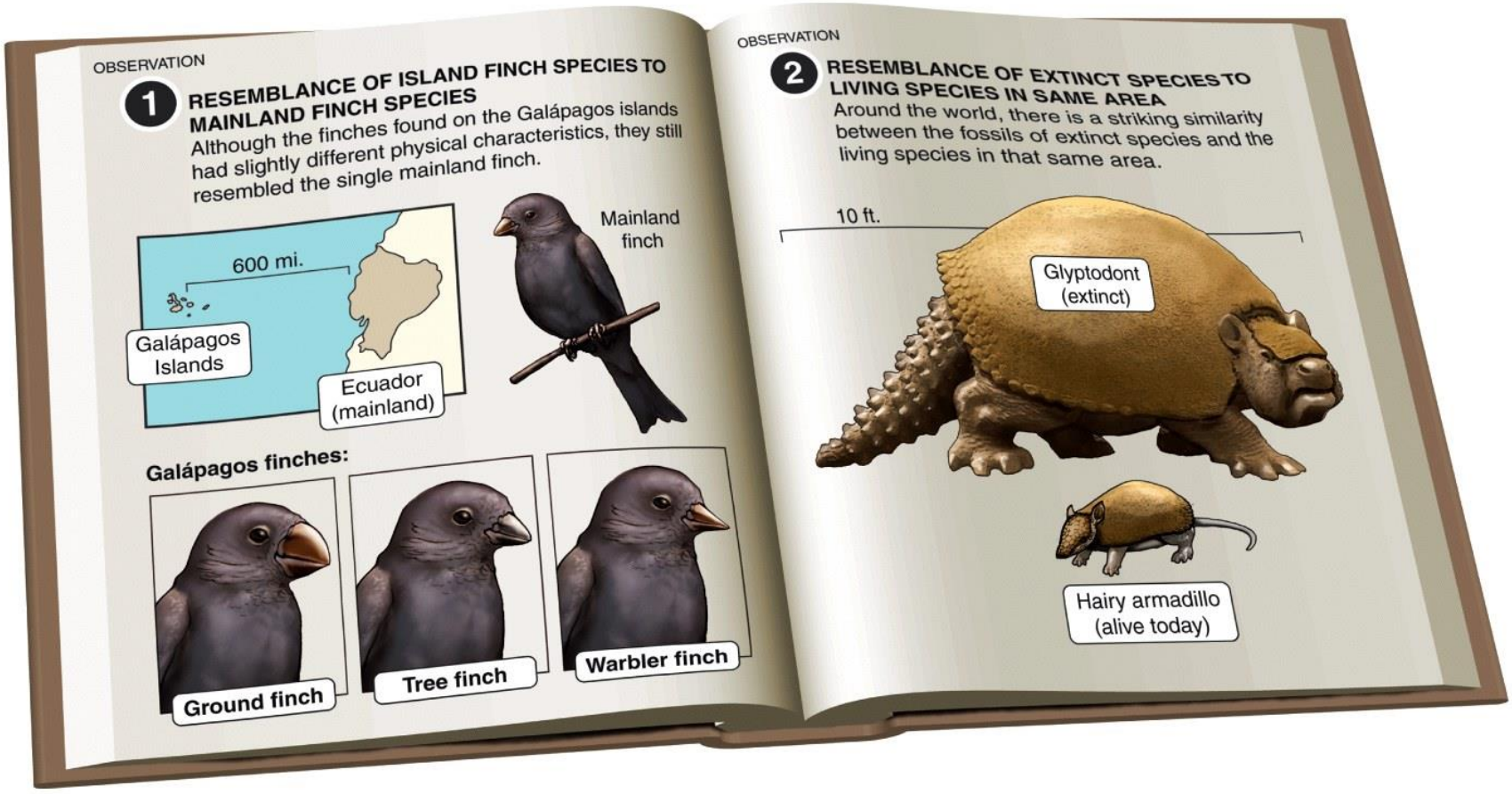
Figure 8-6
What Is Life? A Guide to Biology

DARWIN'S 'ROUND-THE-WORLD VOYAGE

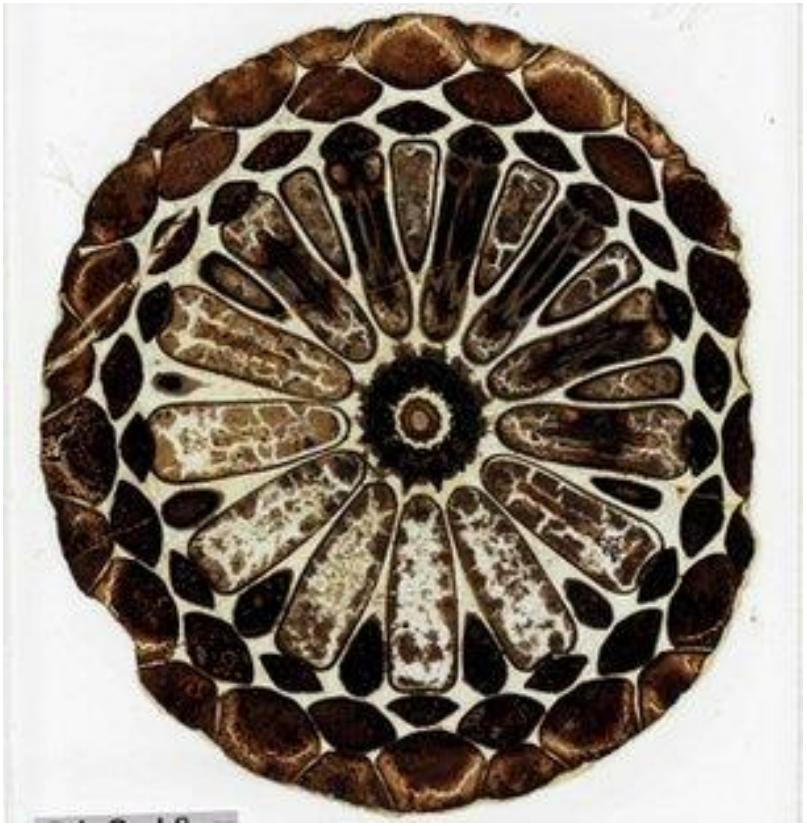
Two important and unexpected patterns



Two important and unexpected patterns



Darwin's Fossils



The slides were made by slicing and polishing the fossils into translucent sheets and then placing them between two glass plates so they could be studied under a microscope.

Darwin's Fossils

Charles Darwin collected fossil specimens from the Falklands, and later wrote:

"*The concurrence of these several organic forms in this remote part of the southern ocean..... is an interesting circumstance*".

This particular photograph shows brachiopods shells in the Fox Bay Formation, collected by Darwin during his *Beagle* voyage.

Darwin’s Fossils

These images were made available by the Royal Holloway, University of London on Jan. 17, 2012 . and were collected by Charles Darwin during the course of his famous "Voyage of the Beagle." (University of London, Kevin D'Souza Ho,AP Photo/Royal Holloway)

Thomas Malthus

- Economist
- *Essay on the Principle of Population*
- Darwin realized that favorable variations are preserved

The Book that Would “Rock the World”

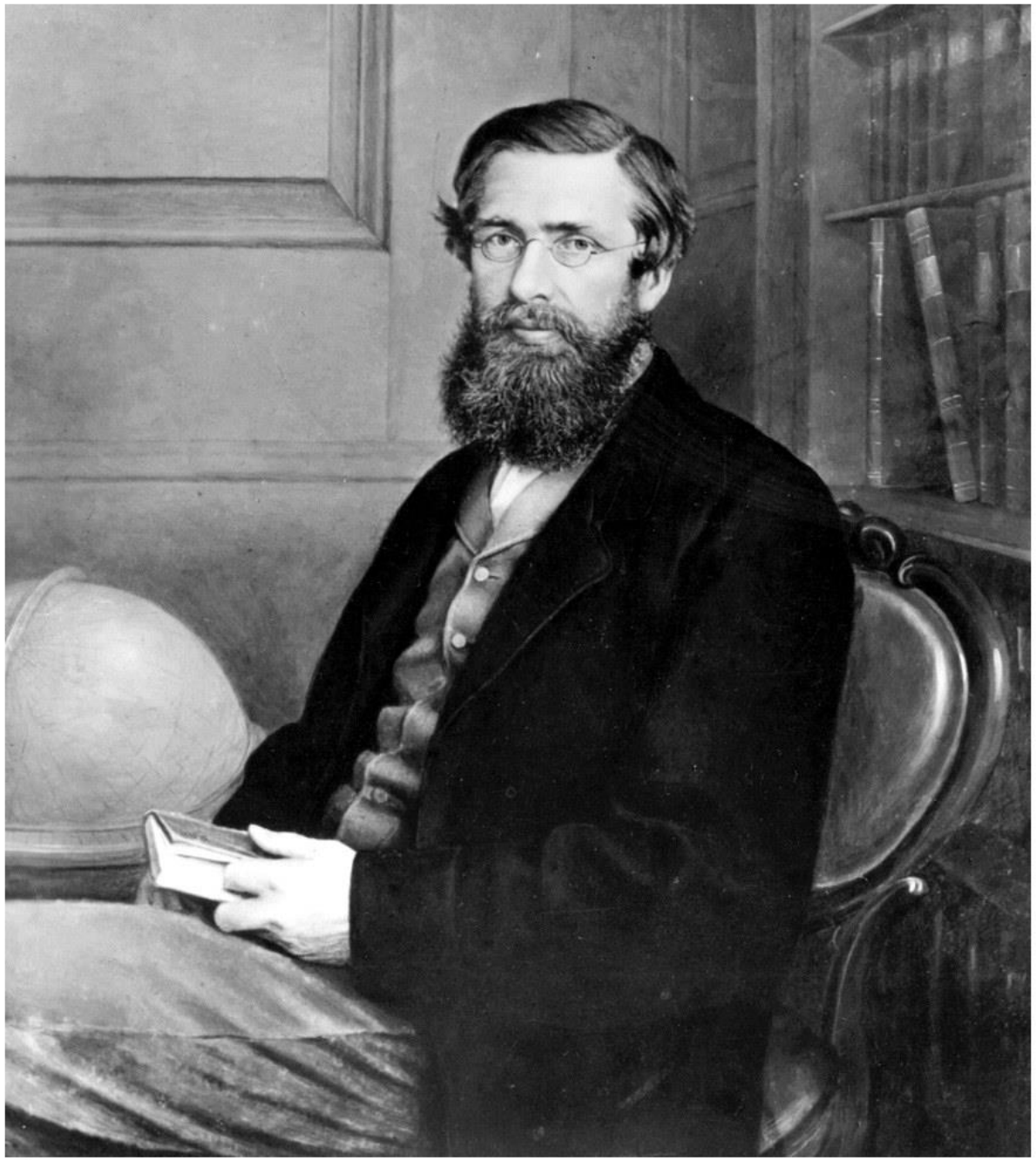
- 1842 first draft
- 14 years in a drawer

Take-Home Message

- After initially training in medicine and theology, Charles Darwin studied the natural world on a ‘round-the-world voyage.
- Darwin noted unexpected patterns among fossils he found and living organisms he observed while on the voyage of the *Beagle.*

Take-Home Message

- Fossils resembled but were not identical to the living organisms in the same area.
- Finch species on the Galapagos Islands differed in small but significant ways.
- These observations helped him to develop his theory of how species might change over time.



WORLDVIEW BEFORE & AFTER DARWIN

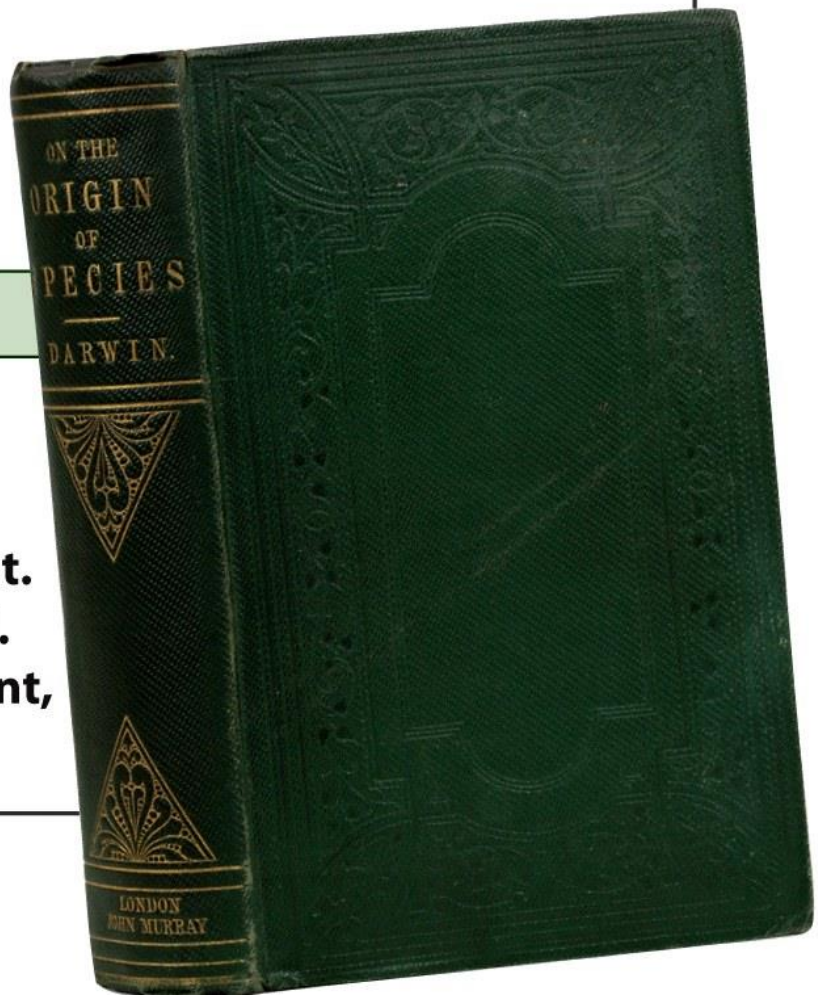
BEFORE:

- Organisms were all put on earth by a creator at the same time.
- Organisms are fixed:
  no additions, no subtractions.
- Earth is about 6,000 years old.
- Earth is mostly unchanging.

First published in 1859

AFTER:

- Organisms change over time.
- Some organisms have gone extinct.
- Earth is more than 6,000 years old.
- The geology of earth is not constant,
  but always changing.



Take-Home Message

- After putting off publishing his thoughts on natural selection for more than 15 years, Darwin did so only after Alfred Russel Wallace independently came up with the same idea.

- They published a joint presentation on their ideas in 1858 and Darwin published a much more detailed treatment in *The Origin of Species* in 1859, sparking wide debate and discussion of natural selection.

Which idea did not support the observations Darwin made during his trip on the HMS Beagle?

1. The earth is shaped by gradual forces. (Lyell)
2. Species are fixed and unchanging. (Aristotle)
3. The earth is older than 6,000 years. (Buffon)
4. Populations could grow beyond the ability of the environment to support them. (Malthus)

Four mechanisms can give rise to evolution.

- Evolution occurs when the *allele frequencies* in a population change.
  1. Mutation
  2. Genetic drift
  3. Migration
  4. Natural selection

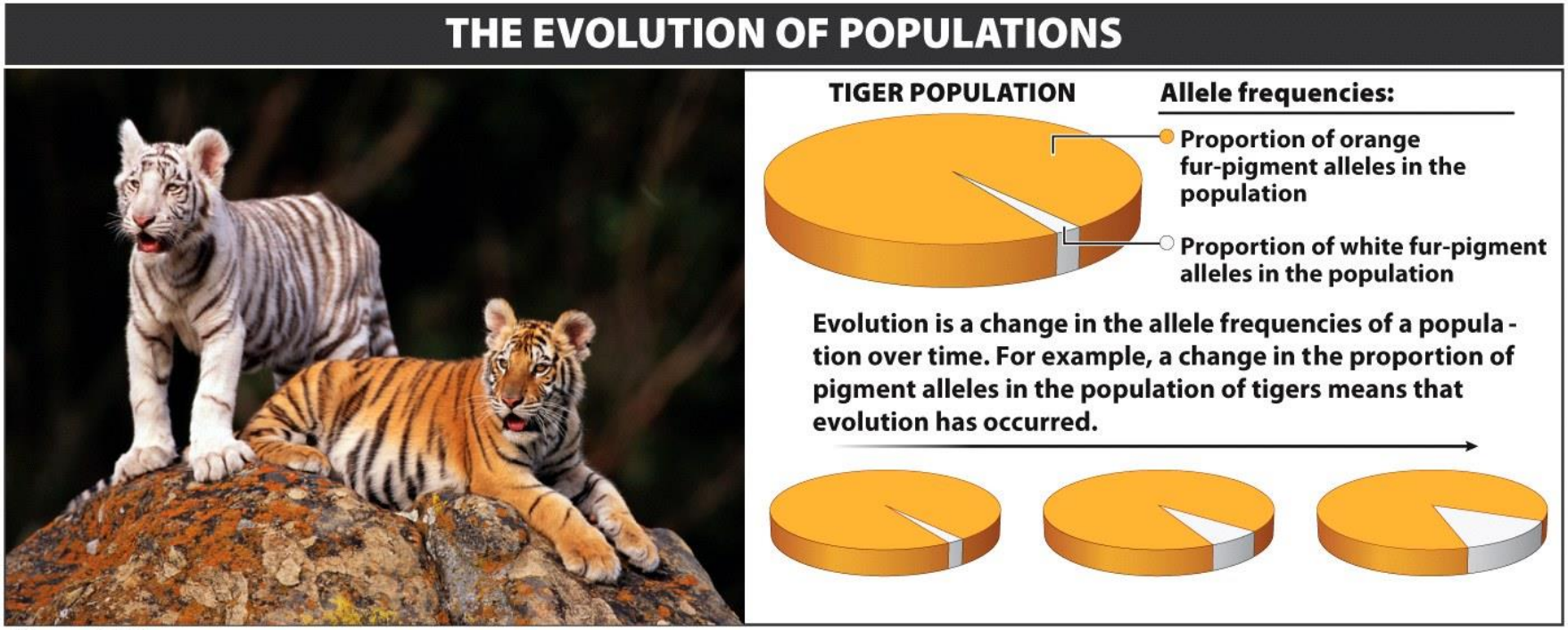


Figure 8-10

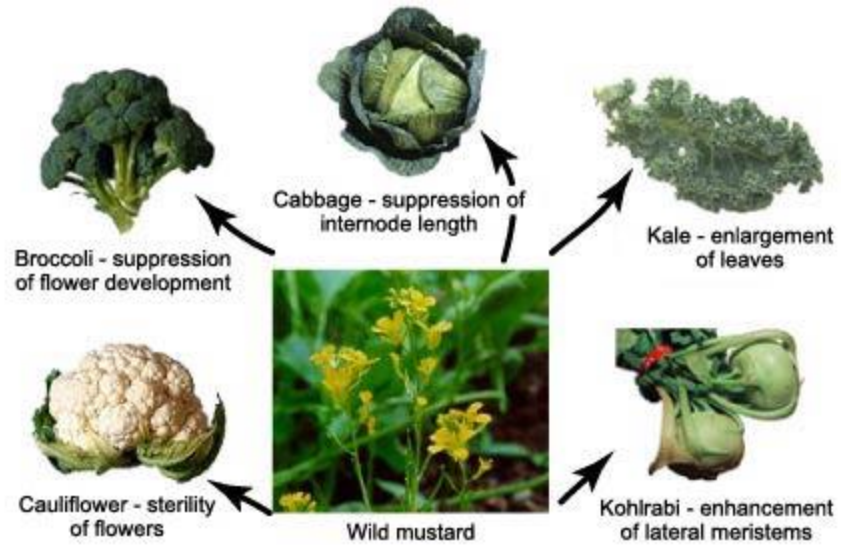
What Is Life? A Guide to Biology

Witnessing Evolution

- Alter the population
  - Increase the white phenotype through breeding.
- As the generations go by…
  - Higher proportion of white tigers
- Evolution = change on allele frequencies of the population

Artificial Selection

- A process in which humans consciously select for or against particular features in organisms.
- As shown below, farmers have cultivated numerous popular crops from the wild mustard, by artificially selecting for certain attributes.



Individuals do NOT evolve.

- Populations evolve
- Allele frequencies
- It is helpful to think of each allele as having some “market share” of all of the alleles.

Which example below is an example of allelic frequency?

1. The skin of a population of Caucasian students gets darker during the summer and lighter during the winter.
2. 1 in 2,500 Caucasians are affected by an inherited disorder called cystic fibrosis.
3. African Americans made up 12.3% of the U.S. population in the year 2000.
4. 2 and 3.
5. All of the above.

Natural Selection

- An efficient mechanism of evolution…
- …and a powerful force in adapting populations to their environment.
- Evolution and natural selection, however, are not the same thing.

Agents of Evolutionary Change

1. Mutation
2. Genetic drift
3. Migration
4. Natural selection

Evolution is genetic change in a population.

Take-Home Message

- Evolution is a change in allele frequencies within a population.

- It can occur by four different mechanisms: mutation, genetic drift, migration, and natural selection.

Mutation

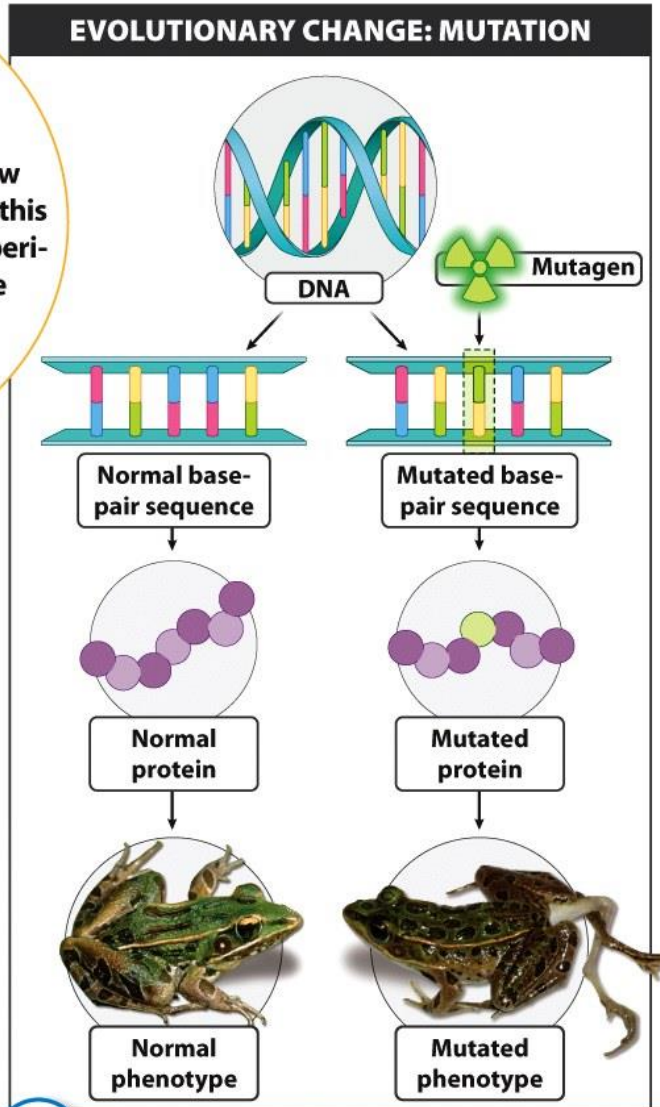
- An alteration of the ***base-pair sequence*** of an individual's ***DNA***

- When this alteration occurs in a ***gene***, the change in the DNA sequence may change the ***allele***.

MECHANISMS OF EVOLUTION

MUTATION

A mutation can create a new allele in an individual. When this happens, the population experiences a change in its allele frequencies and, consequently, experiences evolution.



Despite mutation's vital role in the generation of variation, mutations almost always cause early death or lower the reproductive success of an organism.

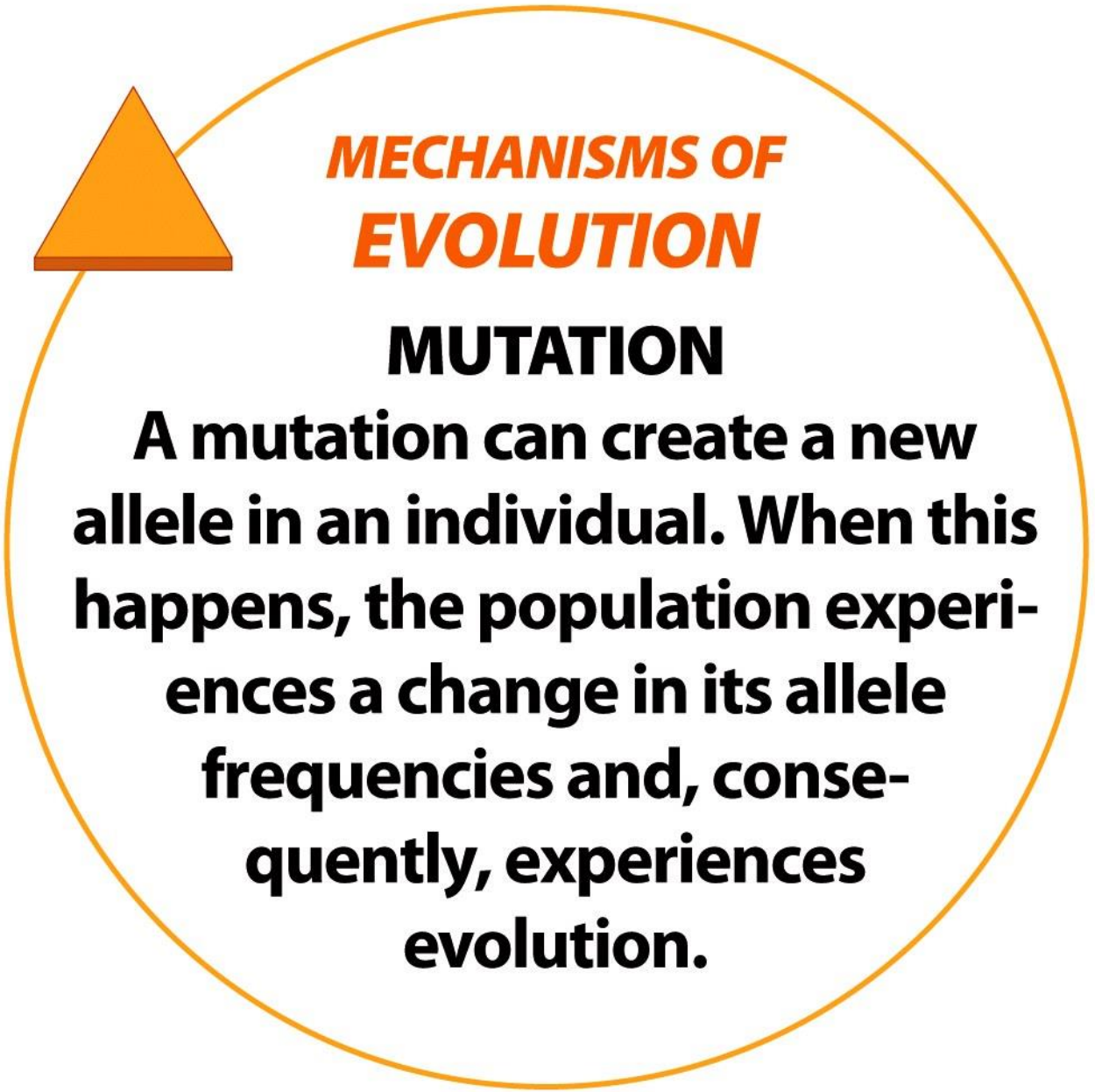


Figure 8-11 part 1
What Is Life? A Guide to Biology

What causes mutations?

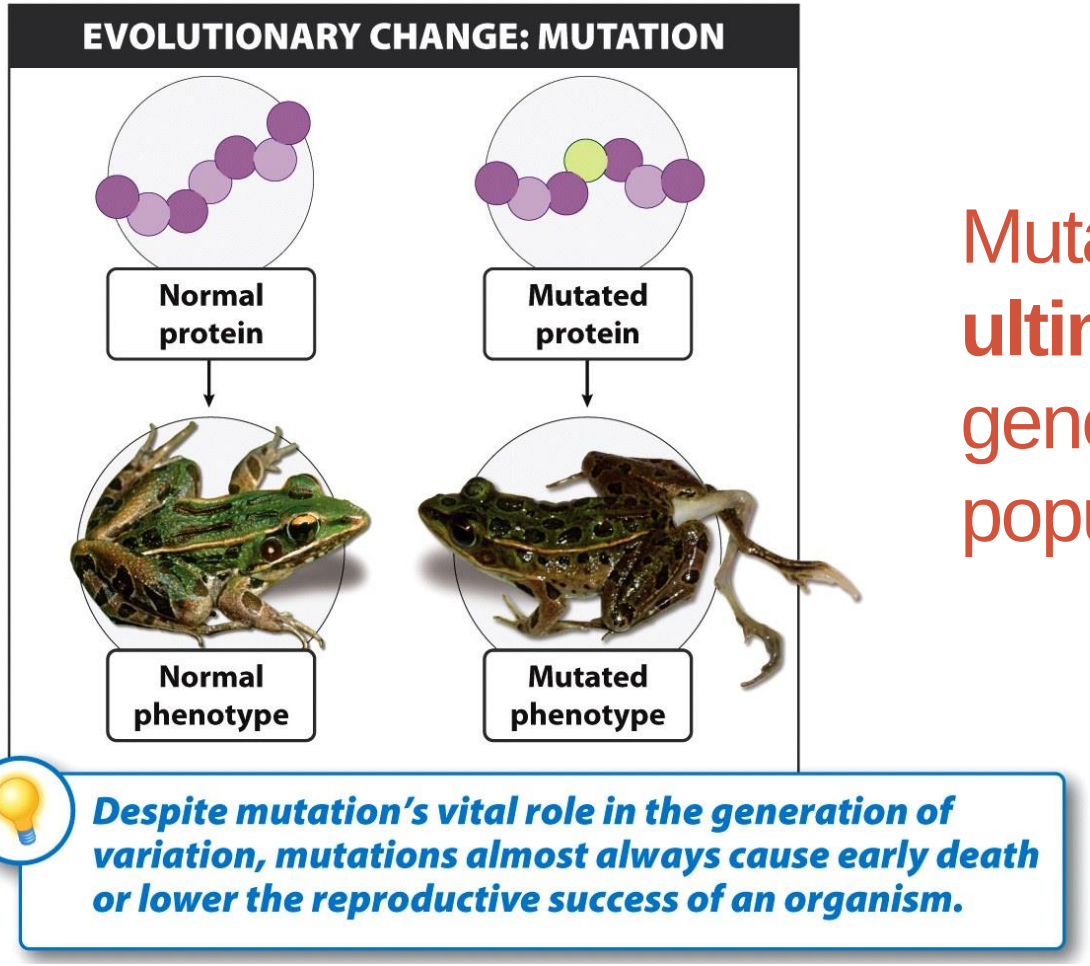
- The process of cells dividing can go awry.
- Environmental phenomena
  - mutagens
- Mutations are random
  - Beneficial?
  - Detrimental?

Tanning beds bombard the body with ultraviolet radiation.

Can they cause mutations?

Mobile phones release radiation.

Can they cause brain tumors?



Mutation is the **ultimate source** of genetic variation in a population.

Take-Home Message

- Mutation is an alteration of the base-pair sequence in an individual's DNA.
- This constitutes evolution if it changes an allele the individual carries.

Take-Home Message

- Mutations can be caused by high-energy sources or chemicals in the environment and also can appear spontaneously.

- Mutation is the only way that new alleles can be created within a population, and so generates the variation on which natural selection can act.

Genetic Drift

- A random change in allele frequencies in a population.

MECHANISMS OF EVOLUTION

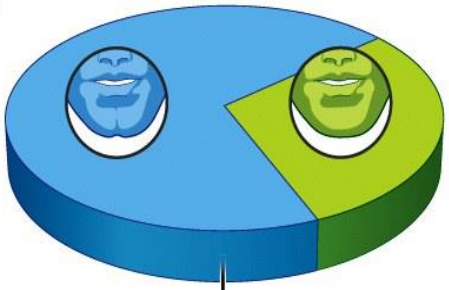
GENETIC DRIFT

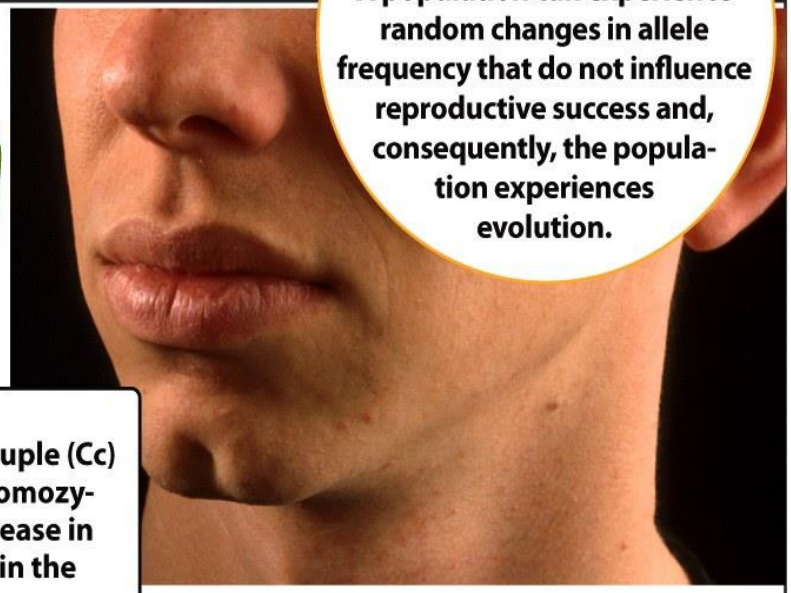
A population can experience random changes in allele frequency that do not influence reproductive success and, consequently, the population experiences evolution.

GENETIC DRIFT

POPULATION BEFORE GENETIC DRIFT

Allele frequencies:
- cleft chin (dominant)
- smooth chin (recessive)





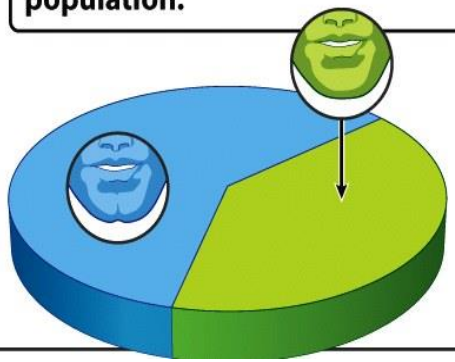
Neither allele is related to reproductive success. Inheritance is based solely on chance.

REPRODUCTION

In this example, a heterozygous couple (Cc) could have two children that are homozygous recessive (cc), causing an increase in the proportion of recessive alleles in the population.

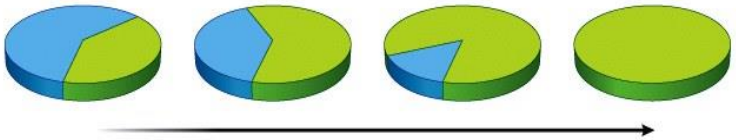
POPULATION AFTER GENETIC DRIFT

There are now more recessive alleles in the population than before.



FIXATION

Genetic drift leads to fixation when an allele's frequency becomes 100% in a population. If this occurs, there is no longer genetic variation for the gene.



The important factor that distinguishes genetic drift from natural selection:

- The change in allele frequencies is not related to the alleles' influence on reproductive success.

The impact of genetic drift is much greater in small populations than in large populations.

Fixation

- Genetic drift can lead to **fixation** for one allele for a gene in a population.
- If this happens, there is no more variability in the population for this gene.
- **Genetic drift reduces the genetic variation in a population.**

Two special cases of genetic drift, the **founder effect** and **population bottlenecks**, are important in the evolution of populations.

Founder Effect

- A small number of individuals may leave a population and become the founding members of a new, isolated population.

- The founders may have different allele frequencies than the original “source” population, particularly if they are a small sample.

Why are Amish people more likely to have extra fingers and toes?

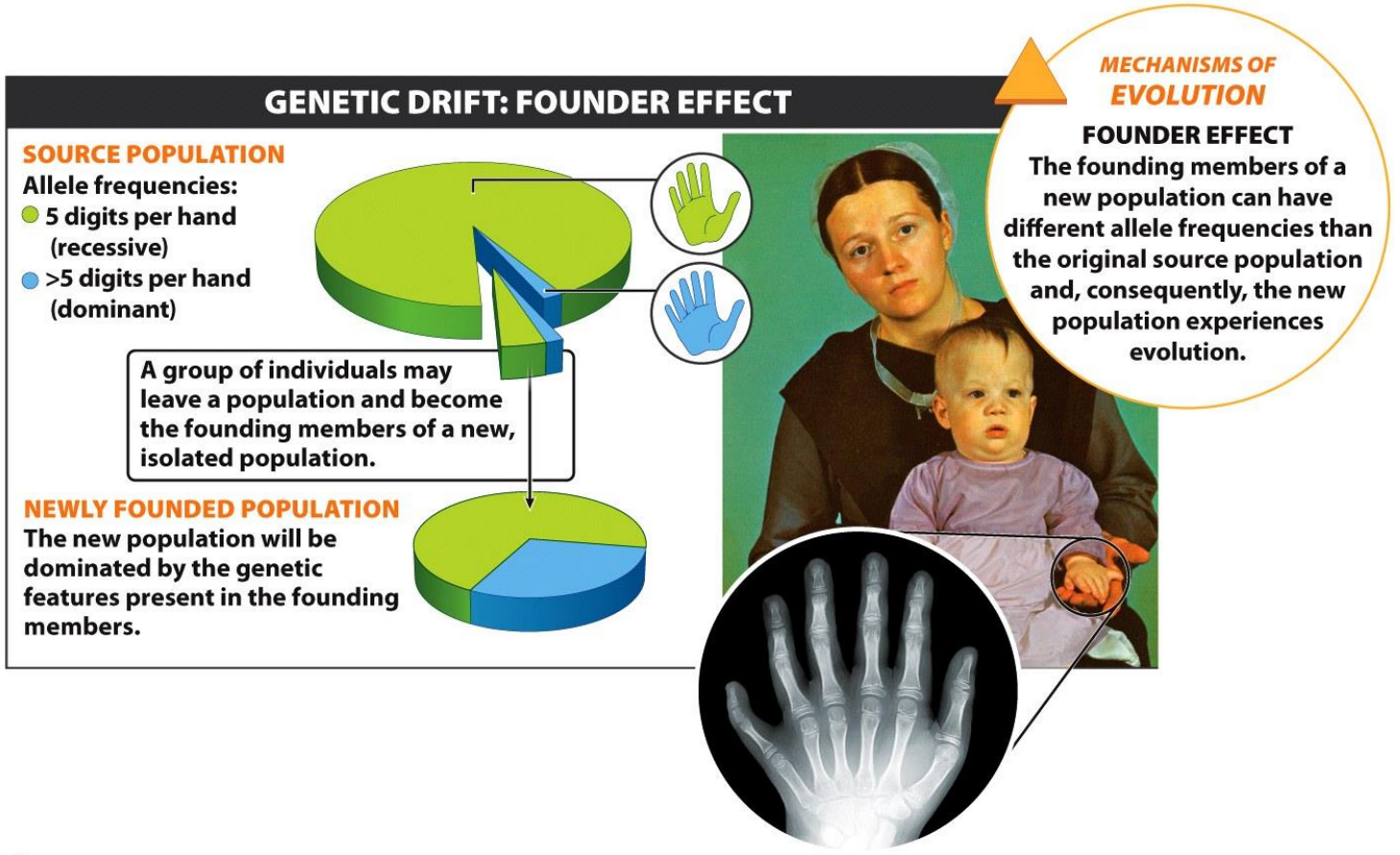


Figure 8-13
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Population Bottlenecks

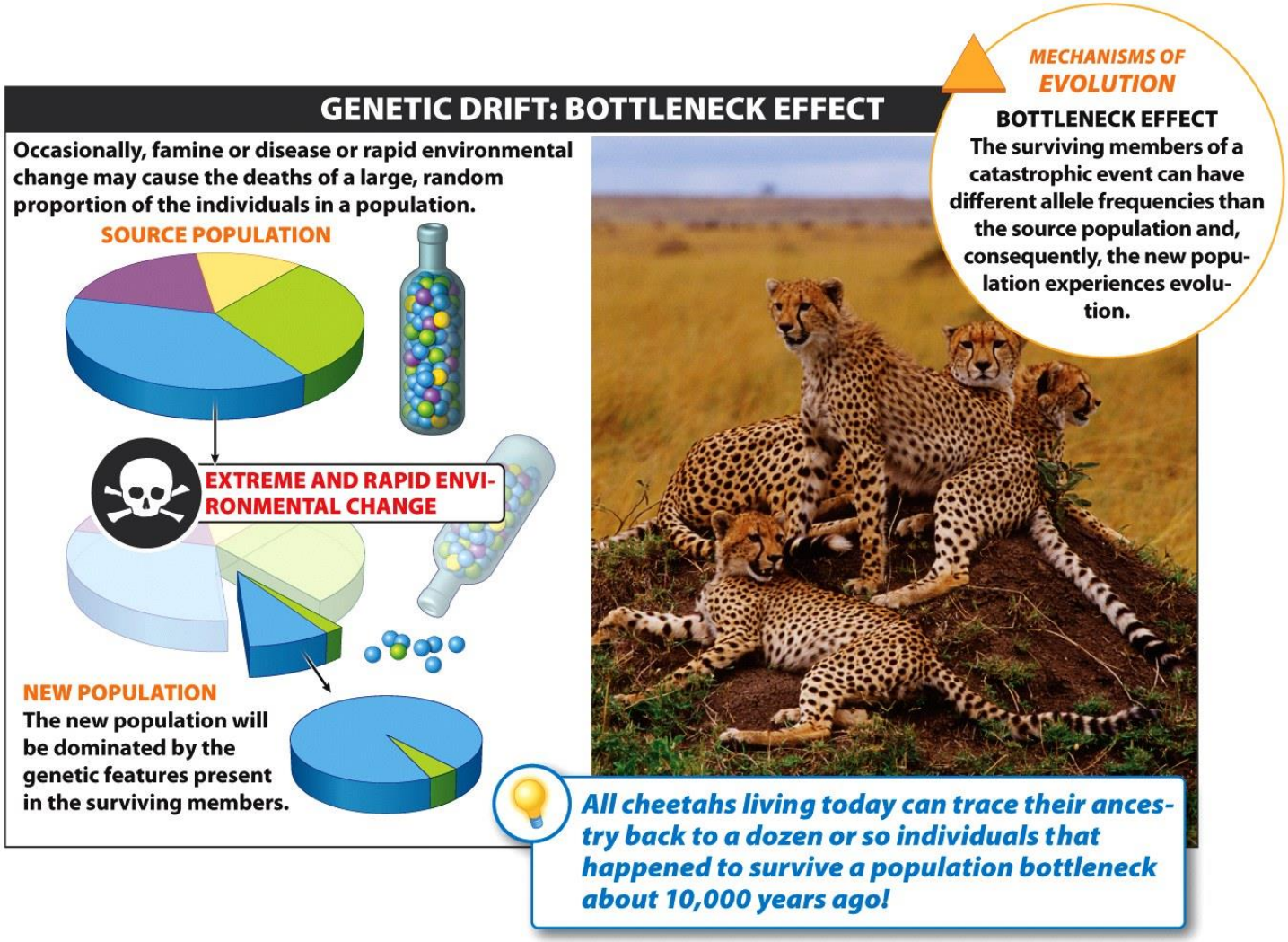

Figure 8-14
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Take-Home Message

- Genetic drift is a random change in allele frequencies within a population, unrelated to the alleles' influence on reproductive success.

- Genetic drift is a significant agent of evolutionary change primarily in small populations.

Migration

- Whether into or out of a population, migration may change allele frequencies.

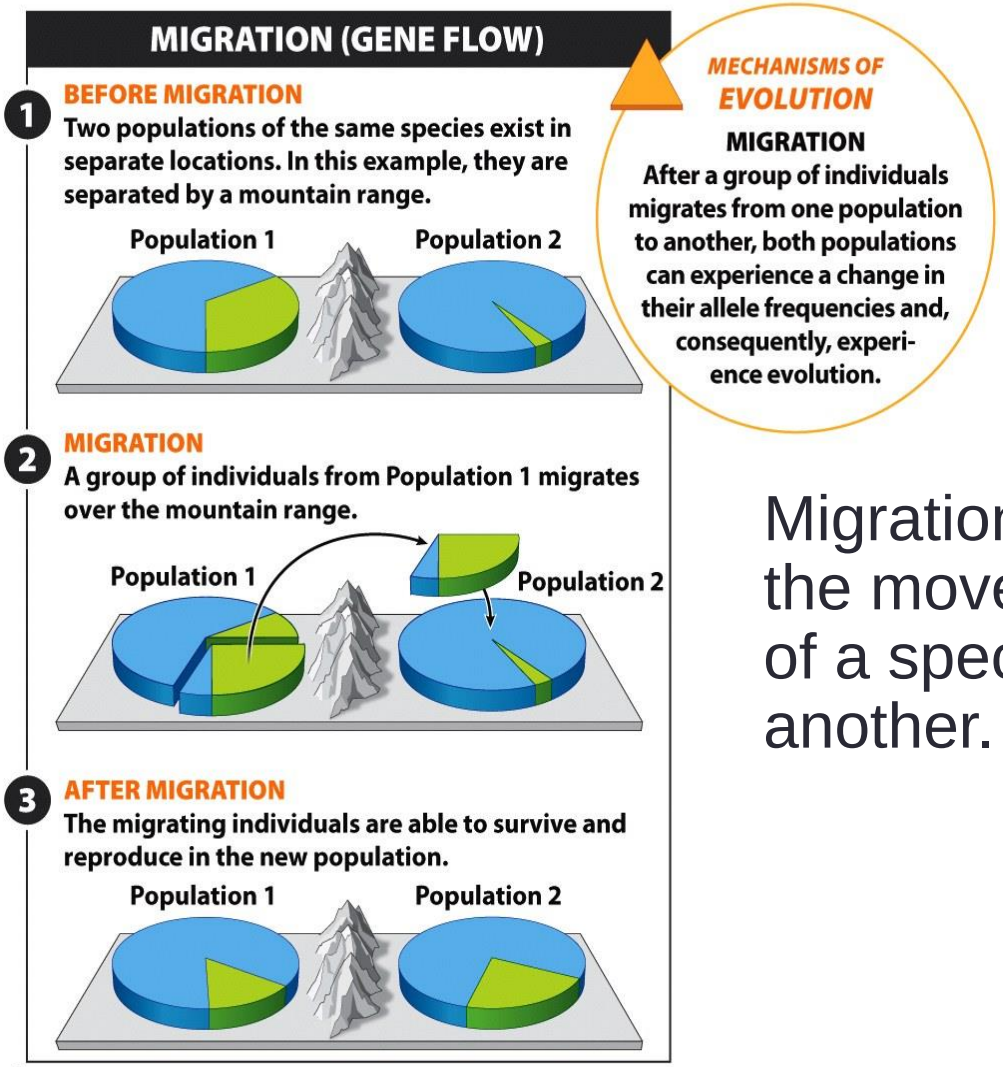

Figure 8-15
What Is Life? A Guide to Biology

Migration, also called **gene flow**, is the movement of some individuals of a species from one population to another.

Take-Home Message

- Migration, or gene flow, leads to a change in allele frequencies in a population as individuals move into or out of the population.

Natural Selection

- When three simple conditions are satisfied, evolution by natural selection occurs.

1. There must be variation for the particular trait within a population.

2. That variation must be inheritable.

3. Individuals with one version of the trait must produce more offspring than those with a different version of the trait.

Condition 1: Variation for a Trait

- Variation is all around us.
- Variation is the raw material on which evolution feeds.

Condition 2: Heritability

We call the transmission of traits from parents to their children through genetic information **inheritance** or **heritability**.

Condition 3: Differential Reproductive Success

1. There are more organisms born than can survive.
2. Organisms are continually struggling for existence.
3. Some organisms are more likely to win this struggle and survive and reproduce.

Differential Reproductive Success

From all the variation existing in a population, individuals with traits most suited to reproduction in their environment generally leave more offspring than individuals with other traits.

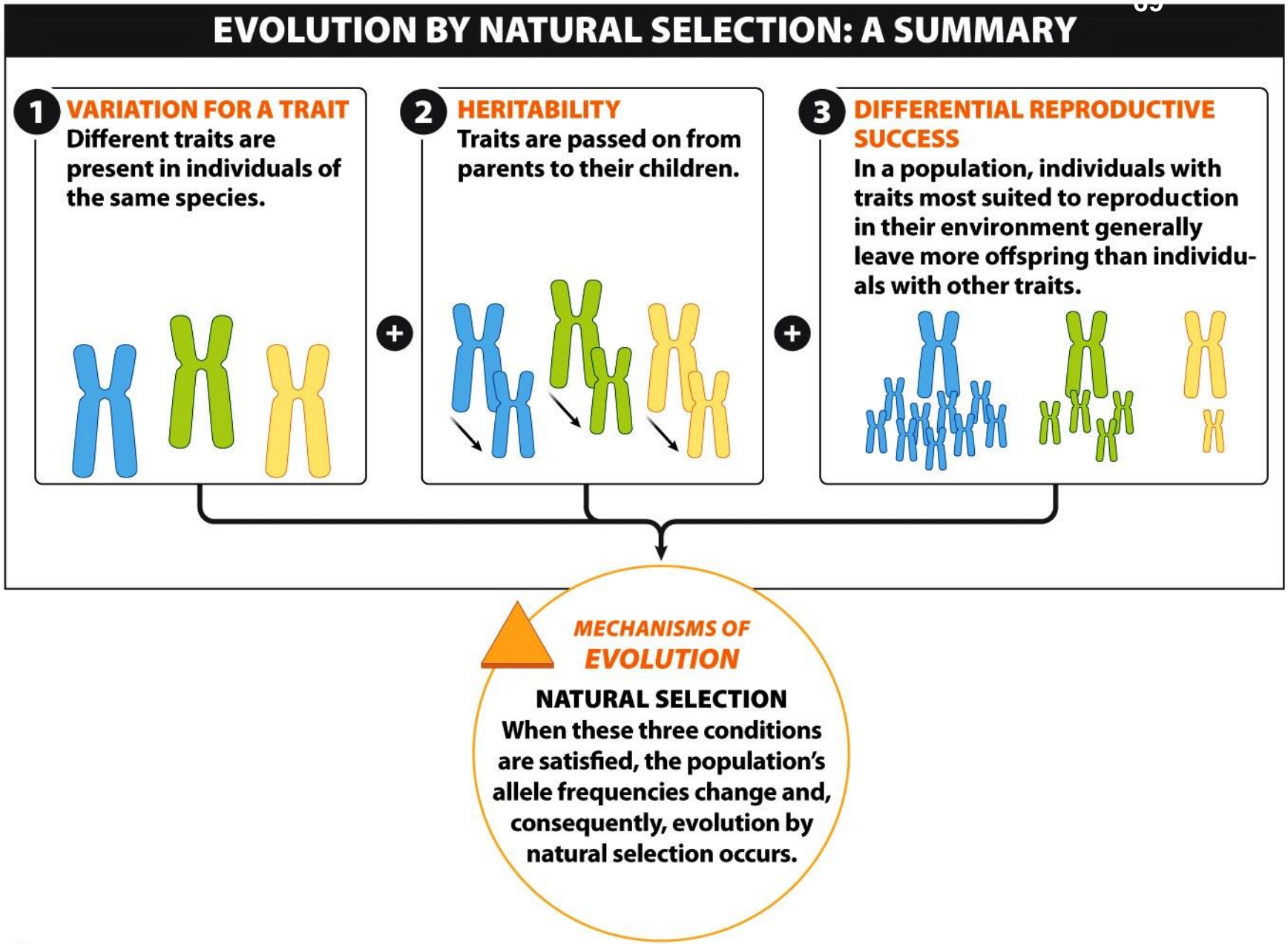

Figure 8-19
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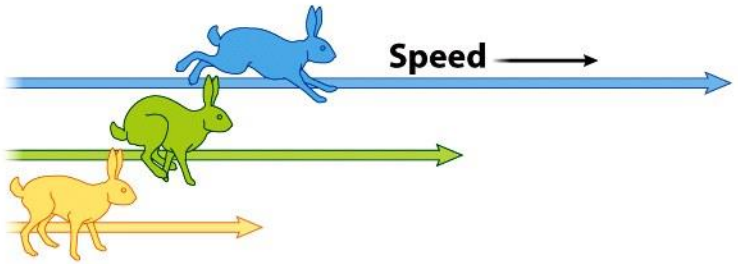
Most agricultural pests evolve resistance to pesticides.

How did this happen?

NATURAL SELECTION IN NATURE

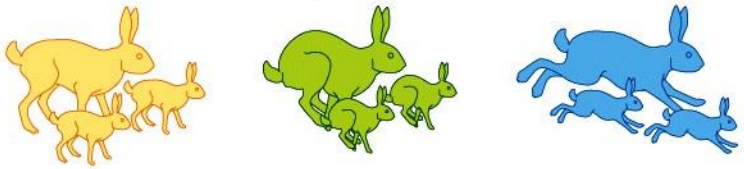
1 VARIATION FOR A TRAIT

Running speed in rabbits can vary from one individual to the next.



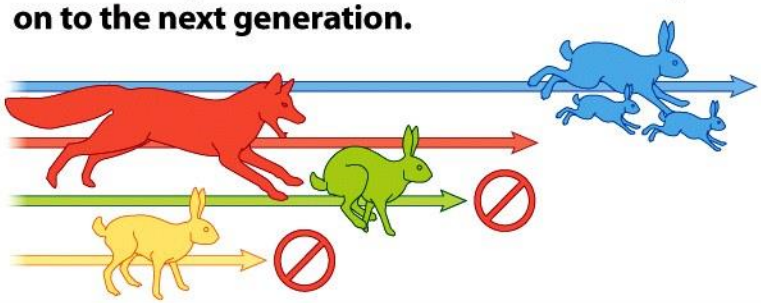
2 HERITABILITY

The trait of running speed is passed on from parents to their offspring.



3 DIFFERENTIAL REPRODUCTIVE SUCCESS

In a population, rabbits with slower running speeds are eaten by the fox and their traits are not passed on to the next generation.



Which trait in rabbits (listed below) has evolved due to interactions with predators?

1. Speed
2. Coat color
3. Eye color
4. 1 and 2
5. All of the above

Take-Home Message

- Natural selection is a mechanism of evolution that occurs when there is heritable variation for a trait, and individuals with one version of the trait have greater reproductive success than individuals with a different version of the trait.
- It can also be thought of as the elimination of alleles from a population that reduce the reproductive rate of individuals carrying them relative to the reproductive rate of individuals who do not carry the alleles.

Through natural selection, populations of organisms can become adapted to their environment.

- Traits causing individuals to have more offspring

“Survival of the Fittest”

- **Reproductive success**
- **Fitness**
  - a measure of the relative amount of reproduction of an individual with a particular phenotype, as compared with the reproductive output of individuals with alternative phenotypes

Fruit Fly Example

- One fly carries the genes for a version of a trait that allows it to survive a long time without food.
- The other fly has the genes for a different version of the trait that allows it to survive only a short while without food.
- Which fly has the greater fitness?

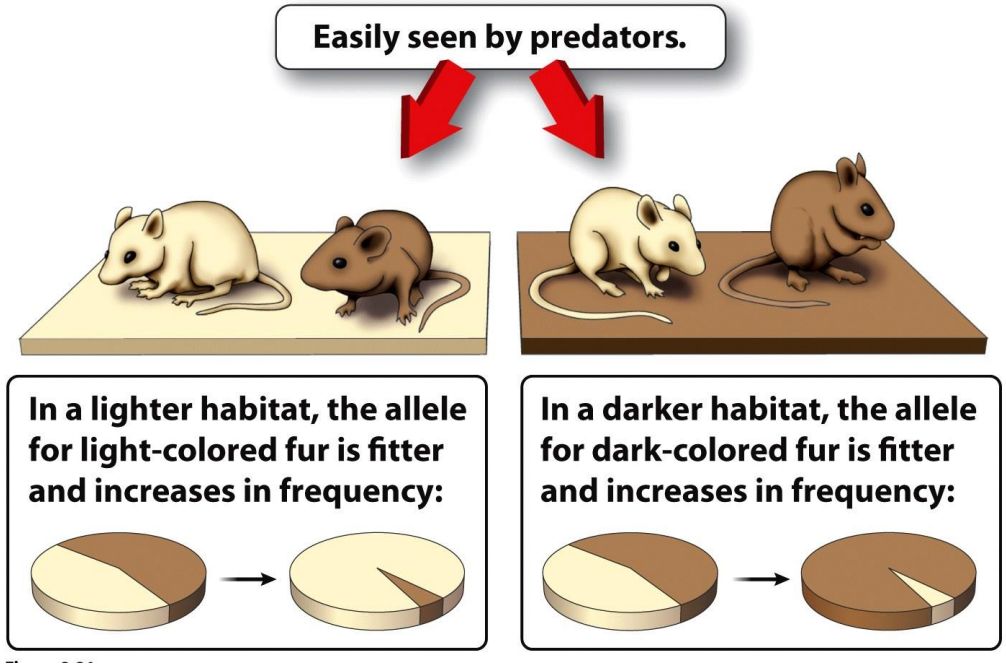
The *alleles* carried by an individual with high fitness will increase their market share in a population over time and the population will evolve.

There are three important elements to an organism's fitness:

1. An individual's fitness is measured relative to other genotypes or phenotypes in the population.

There are three important elements to an organism's fitness:

2. Fitness depends on the specific environment in which the organism lives.



There are three important elements to an organism's fitness:

3. Fitness depends on an organism's reproductive success compared to other organisms in the population.

"Survival of the fittest" is a misnomer.

Take-Home Message

- Fitness is a measure of the relative amount of reproduction of an individual with a particular phenotype, as compared with the reproductive output of individuals with alternative phenotypes.

- An individual's fitness can vary, depending on the environment in which the individual lives.

Through natural selection, populations of organisms can become adapted to their environment.

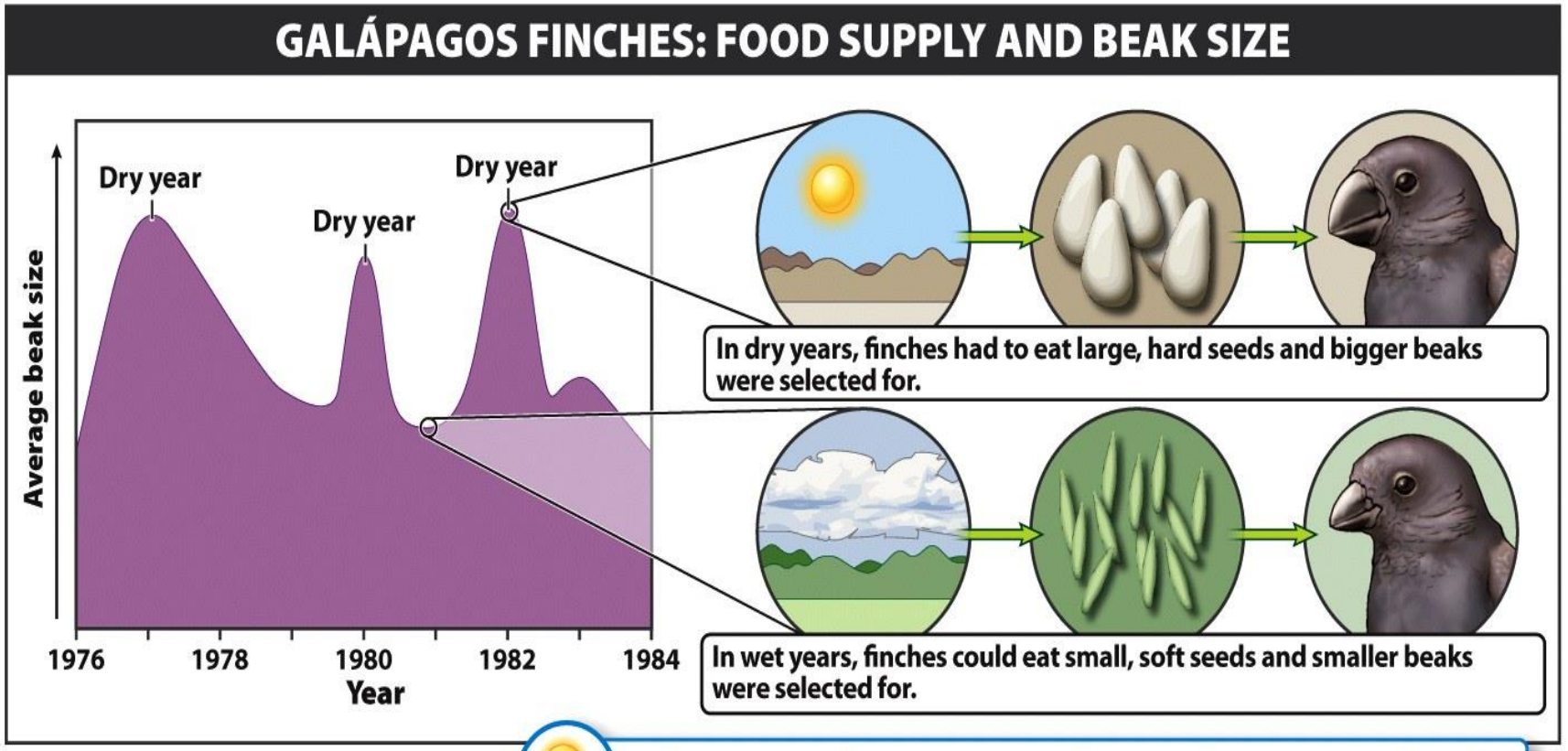
- Organisms in a population can become better matched to their environment through natural selection.

Take-Home Message

- Adaptation—the process by which organisms become better matched to their environment and the specific features that make an organism more fit—occurs as a result of natural selection.

Through natural selection, populations of organisms can become adapted to their environment.

- Natural selection does not lead to perfect organisms.



Adaptation does not march toward an optimal end-point. Average beak size within a population continues to fluctuate according to food supply.

- Evolution in general, and natural selection specifically, do not guide organisms toward “better-ness” or perfection.

- If the environment changes, the alleles causing the traits favored by natural selection may change, too.

Why doesn’t natural selection lead to the production of perfect organisms?

Factors that prevent populations from progressing inevitably toward perfection

1. Environments change quickly.

2. Variation is needed as the raw material of selection.

3. There may be multiple different alleles for a trait, each causing an individual to have the same fitness.

Take-Home Message

Natural selection does not lead to organisms perfectly adapted to their environment because:

1. Environments can change more quickly than natural selection can adapt organisms to them.
2. All possible alleles are not produced by mutation.
3. There is not always a single optimum adaptation for an environment.

Through natural selection, populations of organisms can become adapted to their environment.

- Artificial selection is just a special case of natural selection.

Take-Home Message

- Animal breeders and farmers utilize natural selection when they modify their animals and crops because the three conditions for natural selection are satisfied.
- Because the differential reproductive success is determined by humans and not nature, this type of natural selection is also called artificial selection.

Through natural selection, populations of organisms can become adapted to their environment.

- Natural selection can change the traits seen in a population in several ways.

TRAIT CATEGORIZATION

SPECIFIC CATEGORY

Some traits, such as chin shape, can be easily placed into one category or the other.

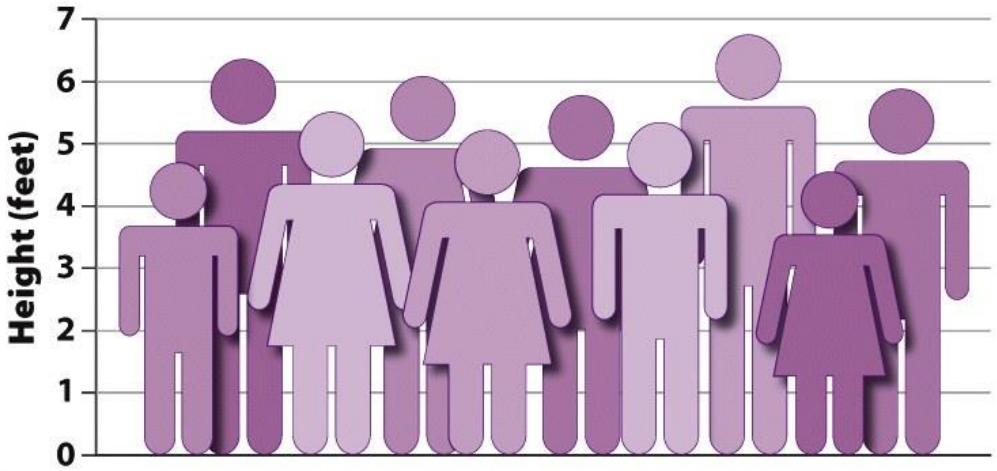
Cleft chin

Smooth chin

or

CONTINUOUS RANGE

Other traits, such as height, may fall into a wide range of values.



Whether a given trait is influenced by one gene or a complex interaction of many genes and the environment, it can be subject to natural selection and be changed in any of several ways.

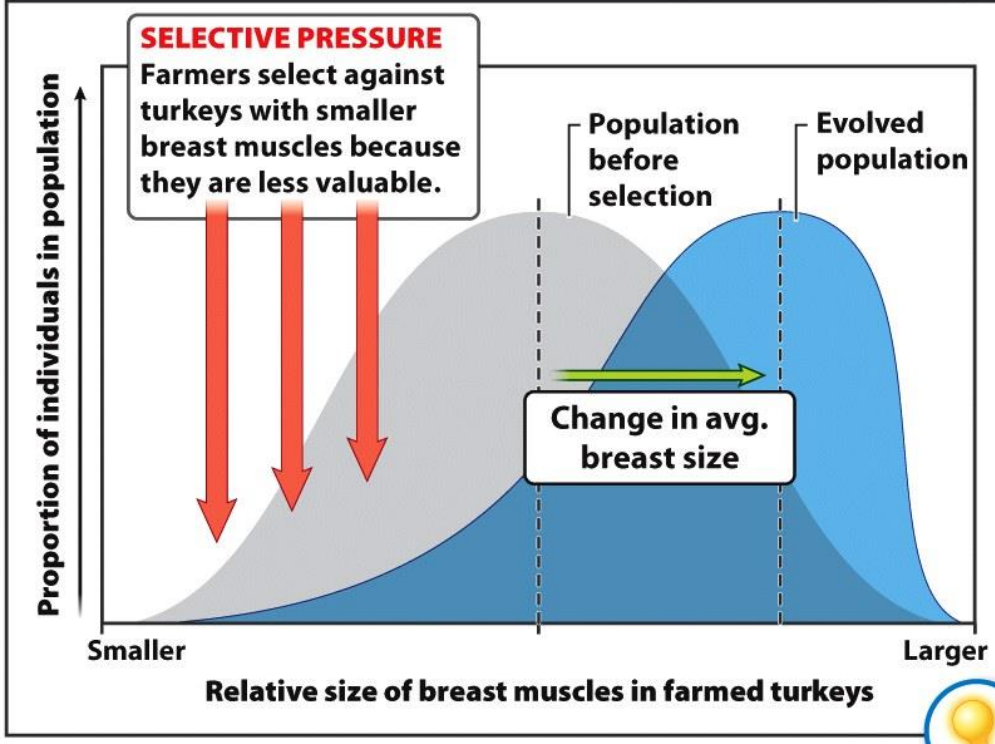
Directional Selection

Individuals with one extreme from the range of variation in the population have higher fitness.

Turkeys on poultry farms have such large breast muscles that they can't get close enough to each other to mate.

How can such a trait evolve?

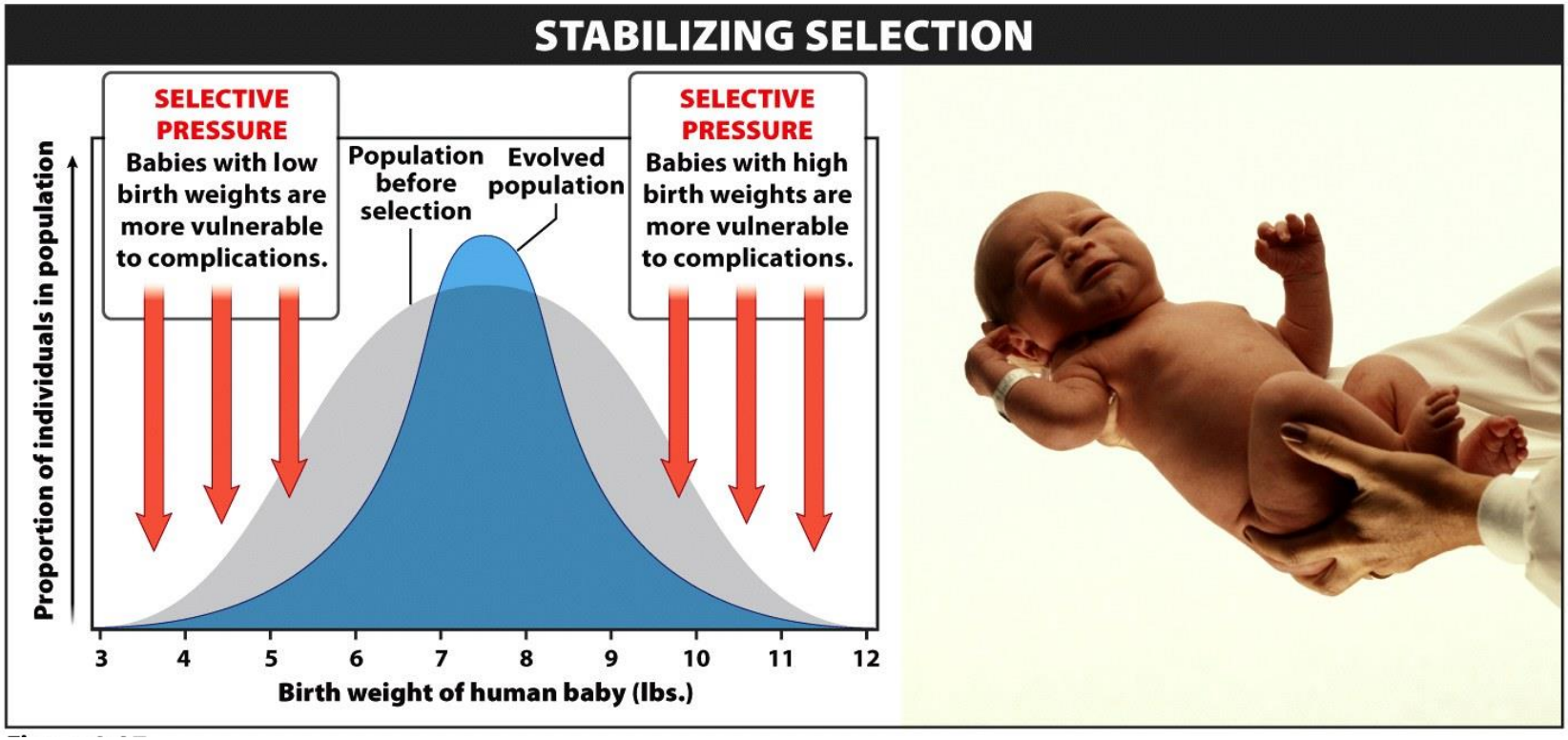
DIRECTIONAL SELECTION



Turkeys on poultry farms can no longer mate naturally! Their breast muscles have become so large that artificial insemination is required.

Stabilizing Selection

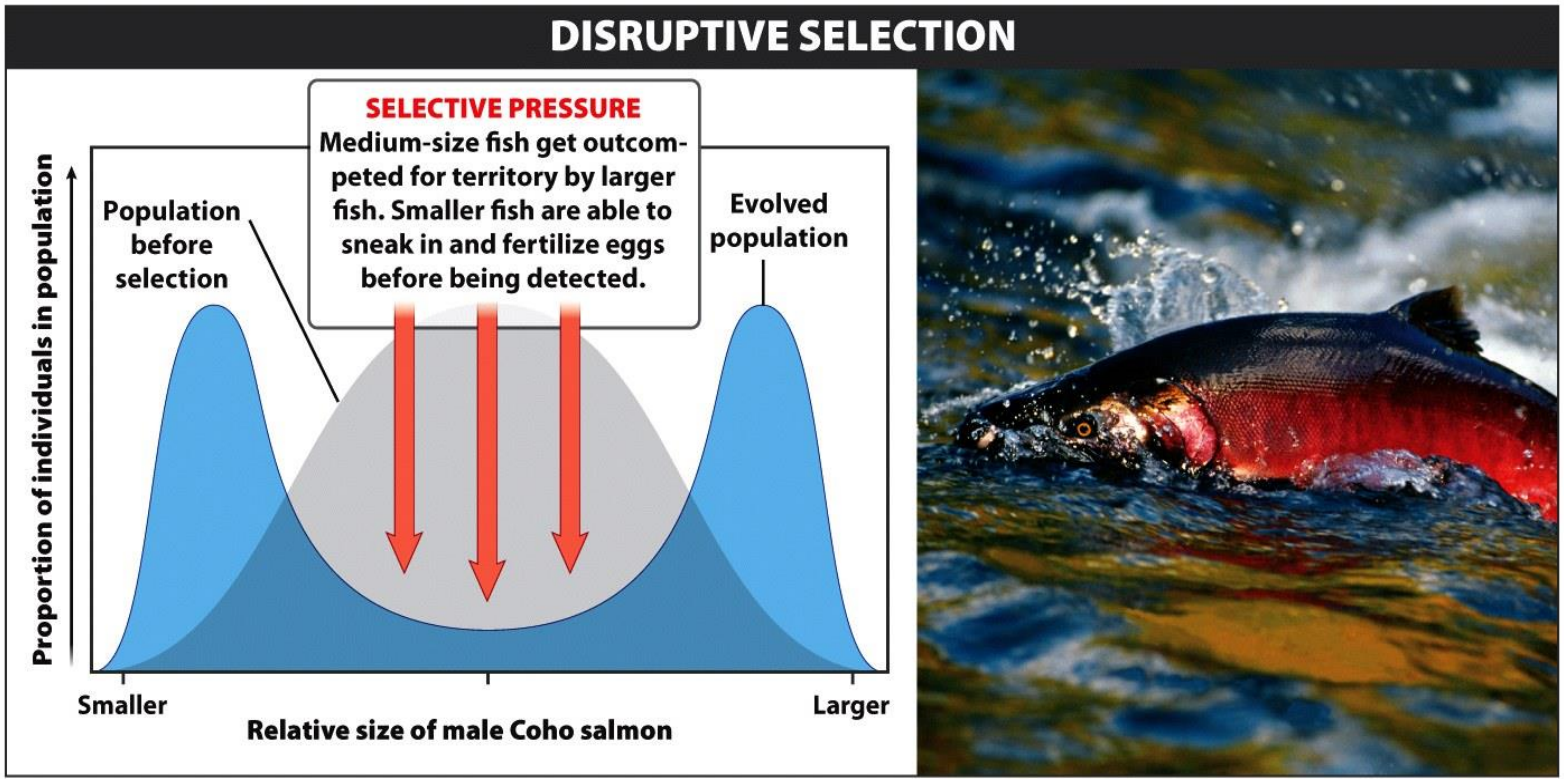
Individuals with intermediate phenotypes are most fit.



How is medical technology undoing the work of natural selection in optimizing the number of babies with normal birth weights?

Disruptive Selection

Individuals with extreme phenotypes experience the highest fitness, and those with intermediate phenotypes have the lowest.



Most mammals do not drink milk after they are weaned because they lose the ability to digest lactose. This is true for about 60% of people. But most people of northern European descent can drink milk (areas where dairy farming is historically prevalent). What type of evolution would this exemplify?

1. Directed selection
2. Stabilizing selection
3. Disruptive selection

Take-Home Message

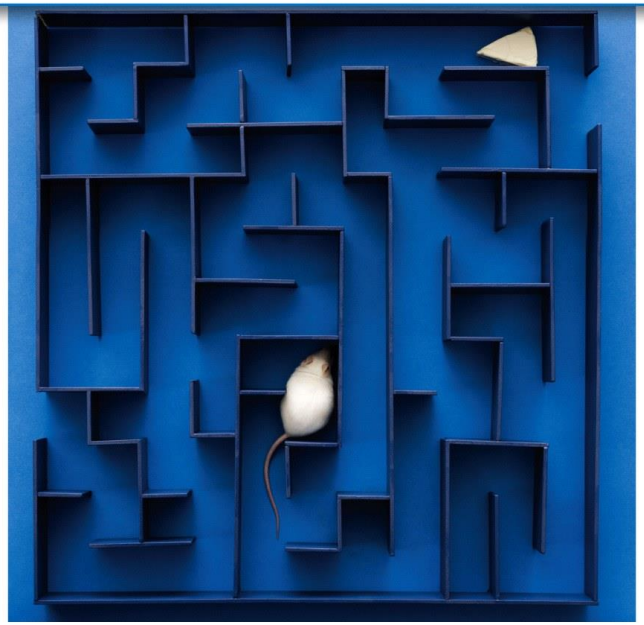
- Natural selection can change populations in several ways:

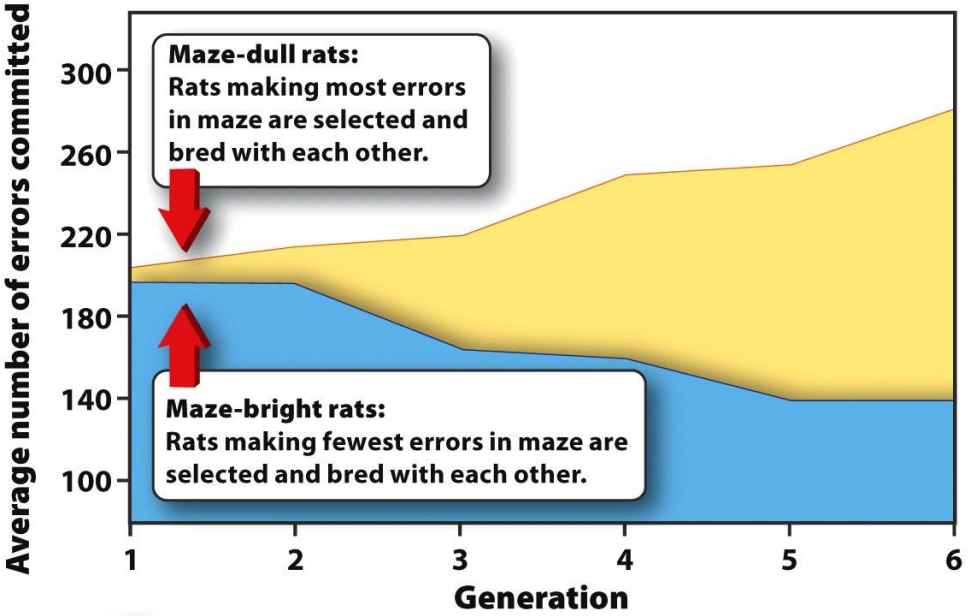
1. directional selection, in which the average value for the trait increases or decreases
2. stabilizing selection, in which the average value of a trait remains the same while extreme versions of the trait are selected against
3. disruptive selection, in which individuals with extreme phenotypes have the highest fitness

Through natural selection, populations of organisms can become adapted to their environment.

- Natural selection can cause the evolution of complex traits and behaviors.

Can natural selection improve complex traits such as maze-running ability in rats?

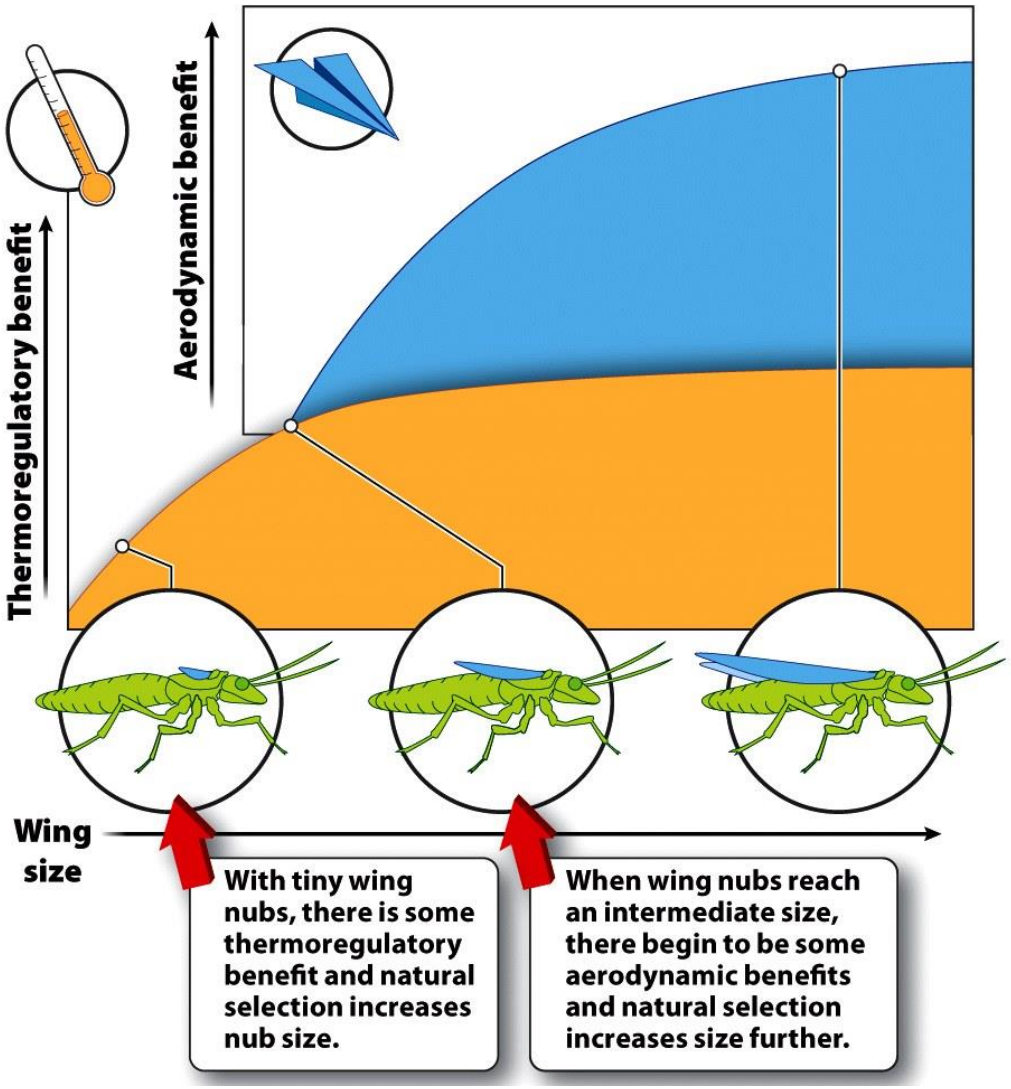




After 6 generations of selection, the maze-bright rats made only half as many errors as the maze-dull rats.

How can a wing evolve if 1% of a wing doesn't help an organism fly or glide at all?

How could natural selection produce an insect wing, when the primitive wing nub had no aerodynamic benefits?



Often, structures appear because they serve some other purpose.

Functional Shifts

Take-Home Message

- Natural selection can change allele frequencies for genes involving complex physiological processes and behaviors.
- This sometimes involves a trait that has been selected for one function being modified at a later time to serve a completely different function.

It is indeed remarkable that this theory [evolution] has been progressively accepted by researchers, following a series of discoveries in various fields of knowledge.

The convergence, neither sought nor fabricated, of the results of work that was conducted independently is in itself a significant argument in favor of this theory.

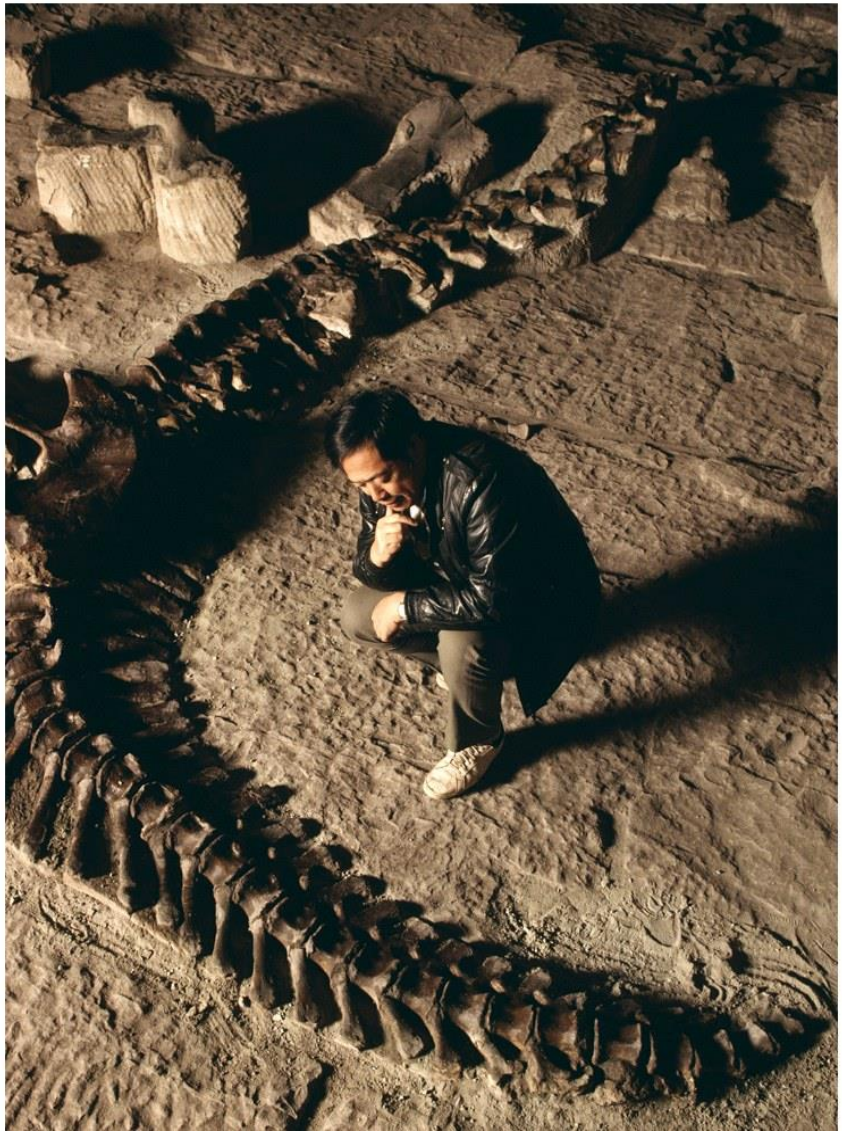
—Pope John Paul II, 1996

Five primary lines of evidence:

1. The fossil record
2. Biogeography
3. Comparative anatomy and embryology
4. Molecular biology
5. Laboratory and field experiments

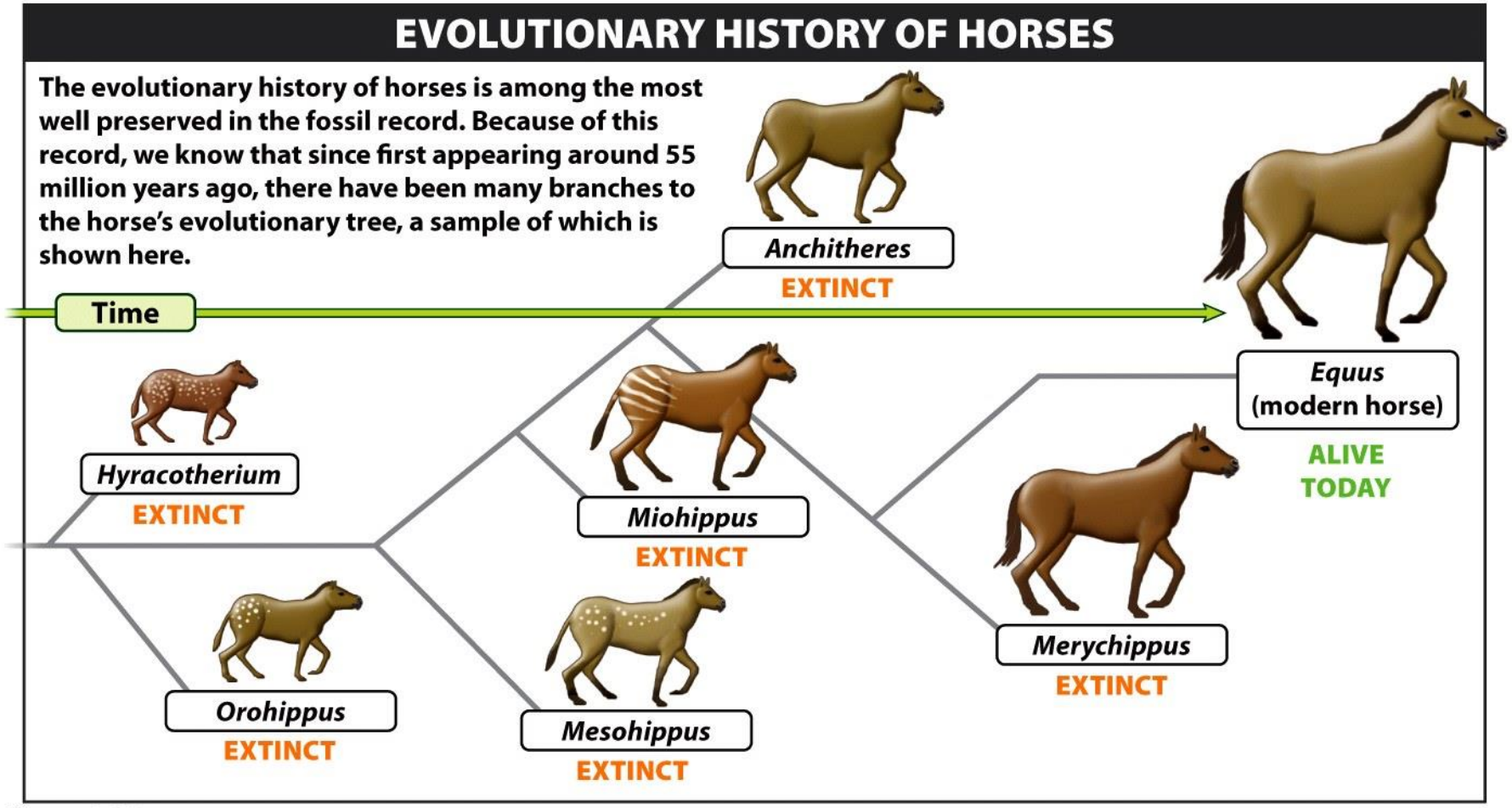
The evidence for the occurrence of evolution is overwhelming.

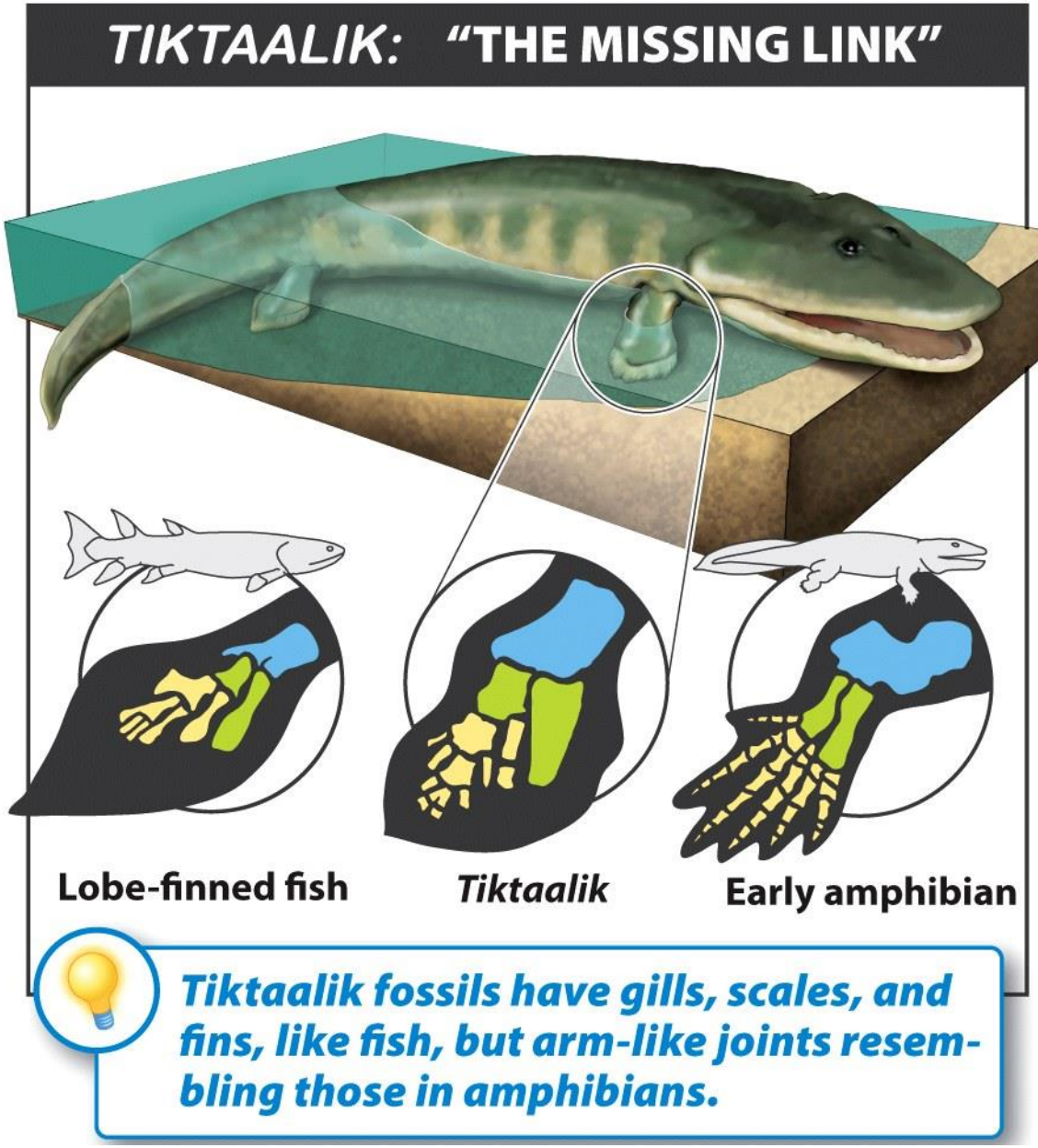
- The fossil record documents the process of natural selection.



Radiometric Dating

- Radiometric Dating
- What Can Fossil Teeth Tell Us?


EVOLUTIONARY HISTORY OF HORSES
The evolutionary history of horses is among the most well preserved in the fossil record. Because of this record, we know that since first appearing around 55 million years ago, there have been many branches to the horse's evolutionary tree, a sample of which is shown here.
Time
Anchitheres
EXTINCT
Equus
(modern horse)
ALIVE
TODAY
Hyracotherium
EXTINCT
Miohippus
EXTINCT
Merychippus
EXTINCT
Orohippus
EXTINCT
Mesohippus
EXTINCT


TIKTAALIK: "THE MISSING LINK"
Lobe-finned fish
Tiktaalik
Early amphibian
Tiktaalik fossils have gills, scales, and fins, like fish, but arm-like joints resembling those in amphibians.

Take-Home Message

- Radiometric dating confirms that the earth is very old and makes it possible to determine the age of fossils.

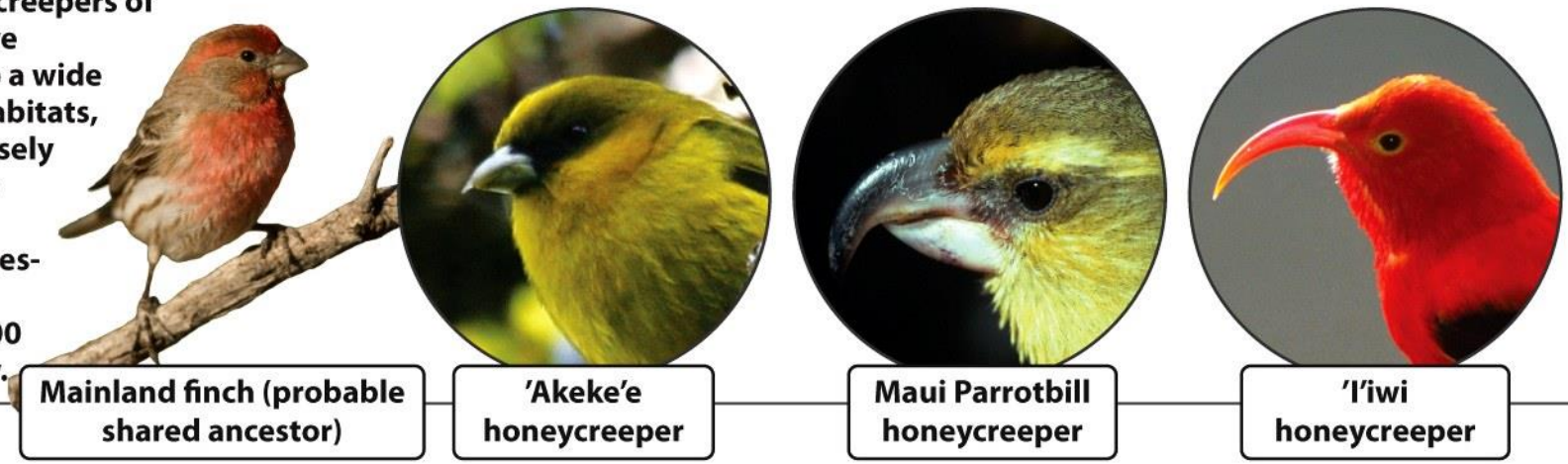
- Analysis of fossil remains enables biologists to reconstruct what organisms looked like long ago, learn how organisms were related to each other, and understand how groups of organisms evolved over time.

The evidence for the occurrence of evolution is overwhelming.

- Geographic patterns of species' distributions reflect their evolutionary histories.

BIOGEOGRAPHY: HAWAIIAN HONEYCREEPERS

The honeycreepers of Hawaii have adapted to a wide range of habitats, yet still closely resemble a finch-like shared ancestor found nearly 2,000 miles away.



Mainland finch (probable shared ancestor)

'Akeke'e honeycreeper

Maui Parrotbill honeycreeper

'I'iwi honeycreeper

History Matters

- Who arrived first?
- Are numerous different habitats available?

BIOGEOGRAPHY: AUSTRALIAN MARSUPIALS AND THEIR PLACENTAL COUNTERPARTS

AUSTRALIAN MARSUPIALS

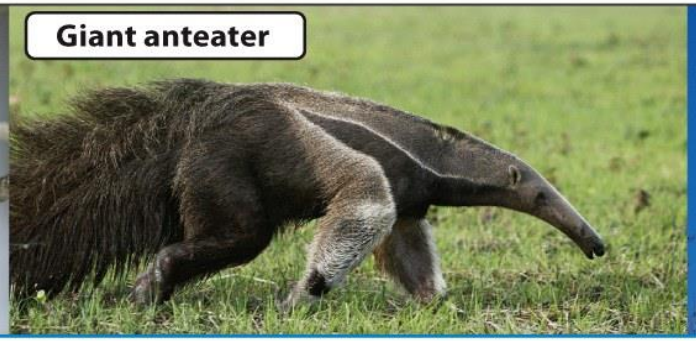

Sugar glider


Numbat


Tasmanian wolf

PLACENTAL COUNTERPARTS


Gray squirrel


Giant anteater


Gray wolf

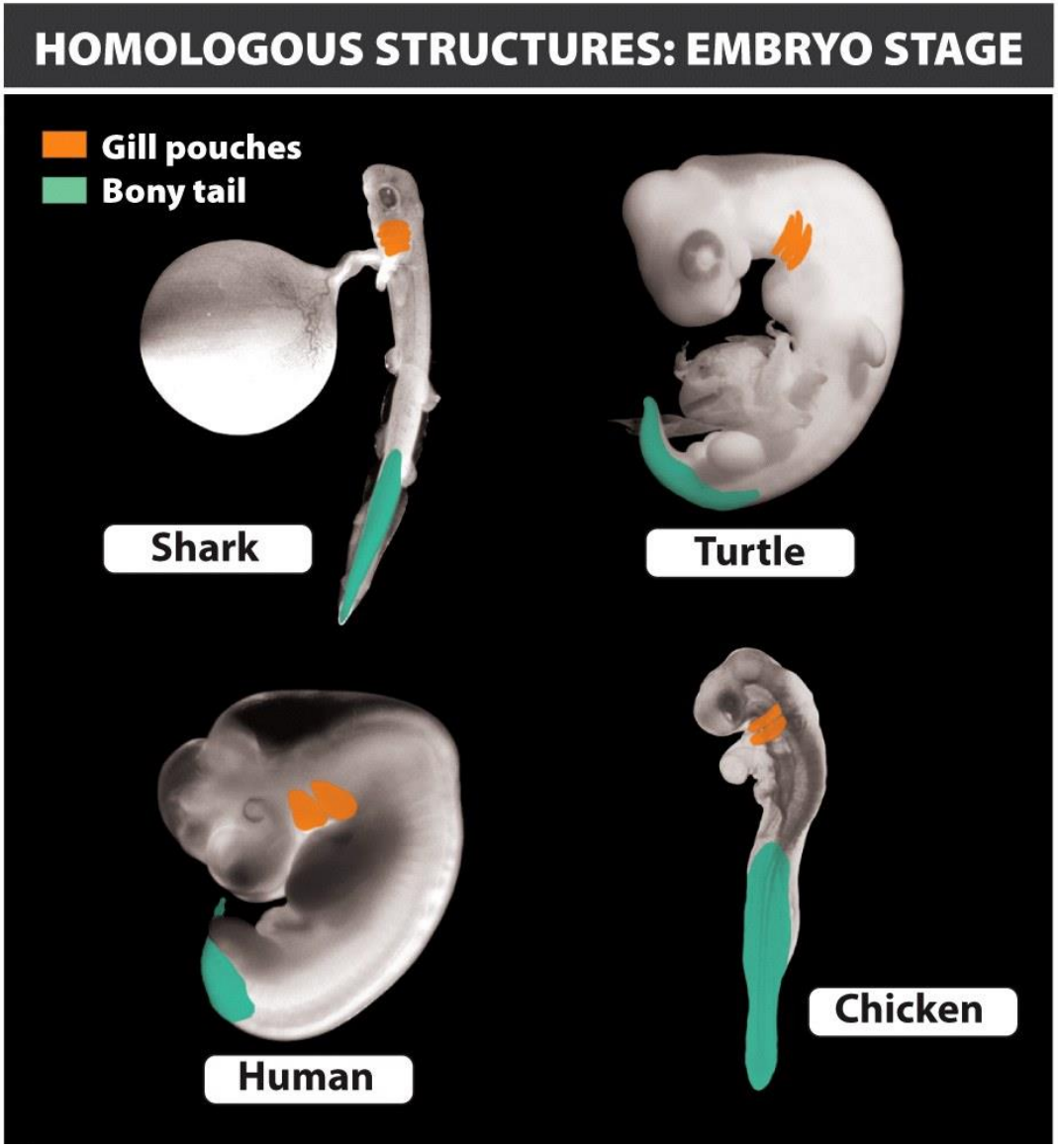
Though less related to each other than you are to a shrew, these marsupials and their placental counterparts have come to resemble each other as natural selection has adapted them to similar habitats.

Take-Home Message

- Studying where populations of species live can help us to understand evolutionary histories of populations.

The evidence for the occurrence of evolution is overwhelming

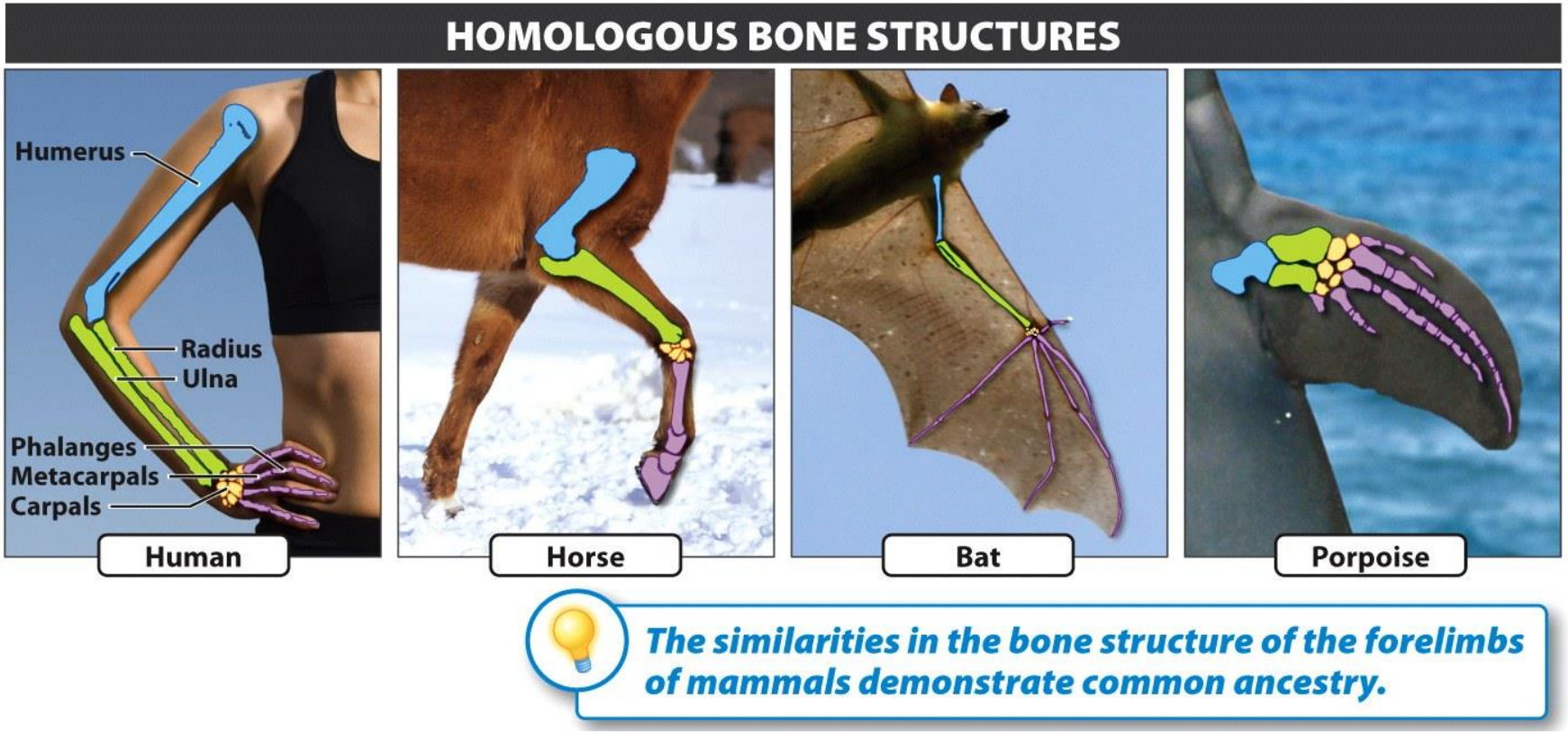
Comparative anatomy and embryology reveal common evolutionary origins.


HOMOLOGOUS STRUCTURES: EMBRYO STAGE
Gill pouches
Bony tail
Shark
Turtle
Human
Chicken

Chick embryos and human embryos both have gills because…

1. They both need to breathe through the gills (while in the egg and placenta respectively) during development.
2. They both spend some time in the water where gills are useful.
3. They both share a common ancestor who had gills.
4. 1 and 3.

Homologous Structures



A human forearm, horse's front leg, bat's wing, and porpoise's flipper have similar bone structure. What conclusions can we draw from the similarities in bone structure between these mammals?

1. Since each limb is used for different functions, these species must be unrelated evolutionarily.

2. Since each limb has a different shape, these species must be related evolutionarily.

3. Since each limb shares the same type of bone structure but performs different functions, these structures are the product of adaptive evolution.

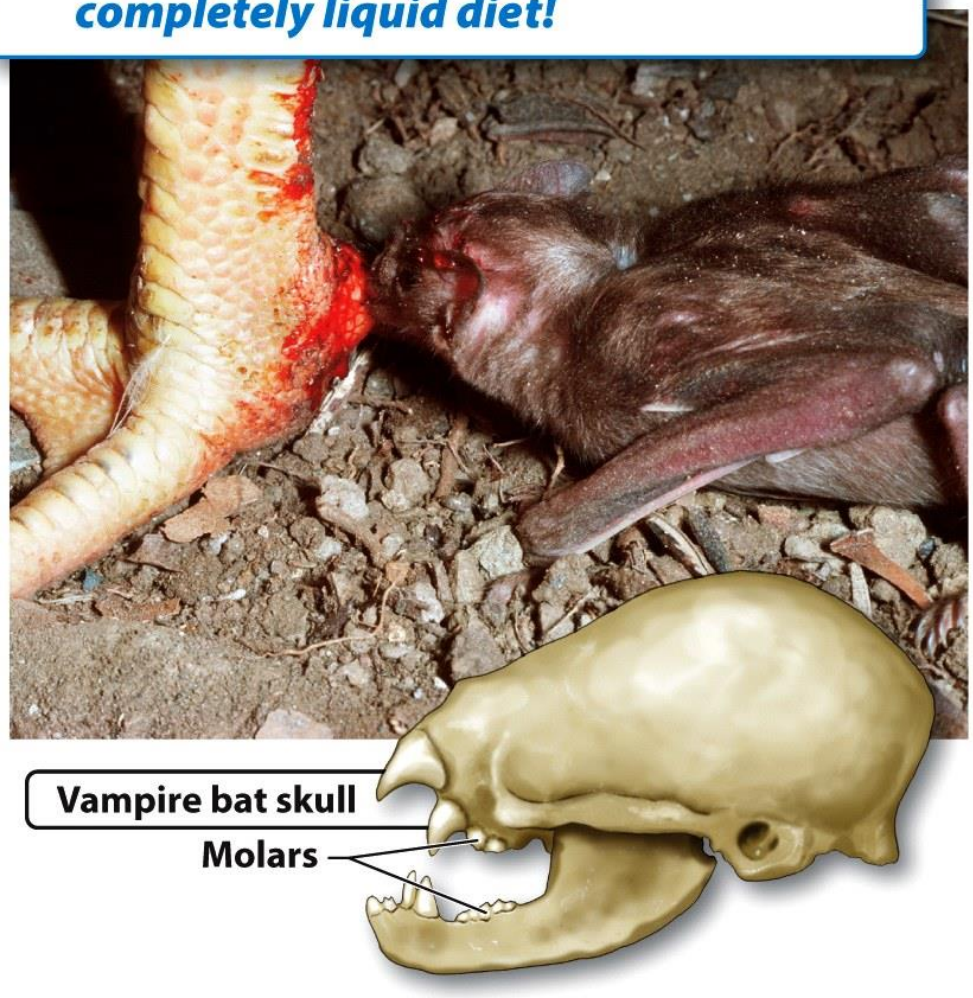
4. Since each limb shares the same type of bone structure but performs different functions, these species cannot possibly be related evolutionarily.

The human appendix serves no function.

Why are we all born with one?

Vestigial Structures

Molars continue to grow in vampire bats, even though they consume a completely liquid diet!



Convergent Evolution

Analogous structures all developed from different original structures.

Take-Home Message

- Similarities in how organisms look and develop shows their common evolutionary origins.

The evidence for the occurrence of evolution is overwhelming

- Molecular biology reveals that common genetic sequences link all life forms.

The genetic code provides our fourth line of evidence that evolution occurs.

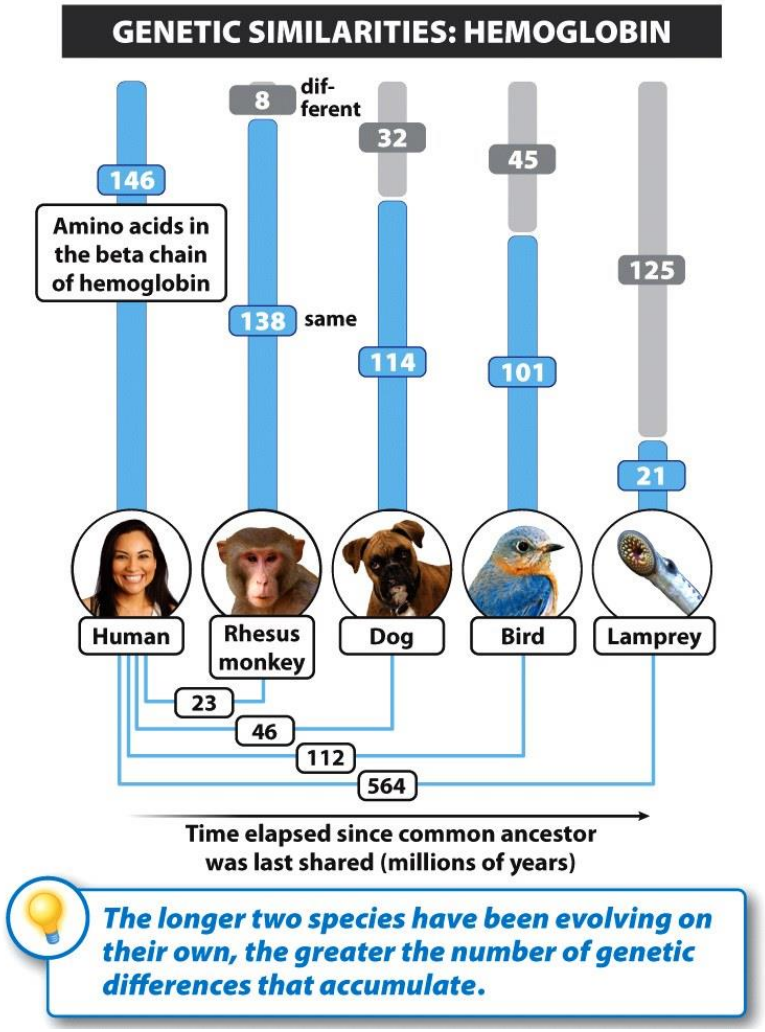
DNA Similarities and Differences

- Related vs. unrelated individuals
- The more distantly you and another individual are related, the more your DNA differs.

DNA Similarity between Two Species

- Compare their DNA sequences for individual genes.
- In Rhesus monkeys, 138 amino acids are the same as those found in human hemoglobin.

Recency of Common Ancestry



- Estimates of evolutionary relatedness made from:
  - Comparative Anatomy
  - Embryology
  - The Fossil Record
- "Molecular Clocks"

Take-Home Message

- All living organisms are share the same genetic code.

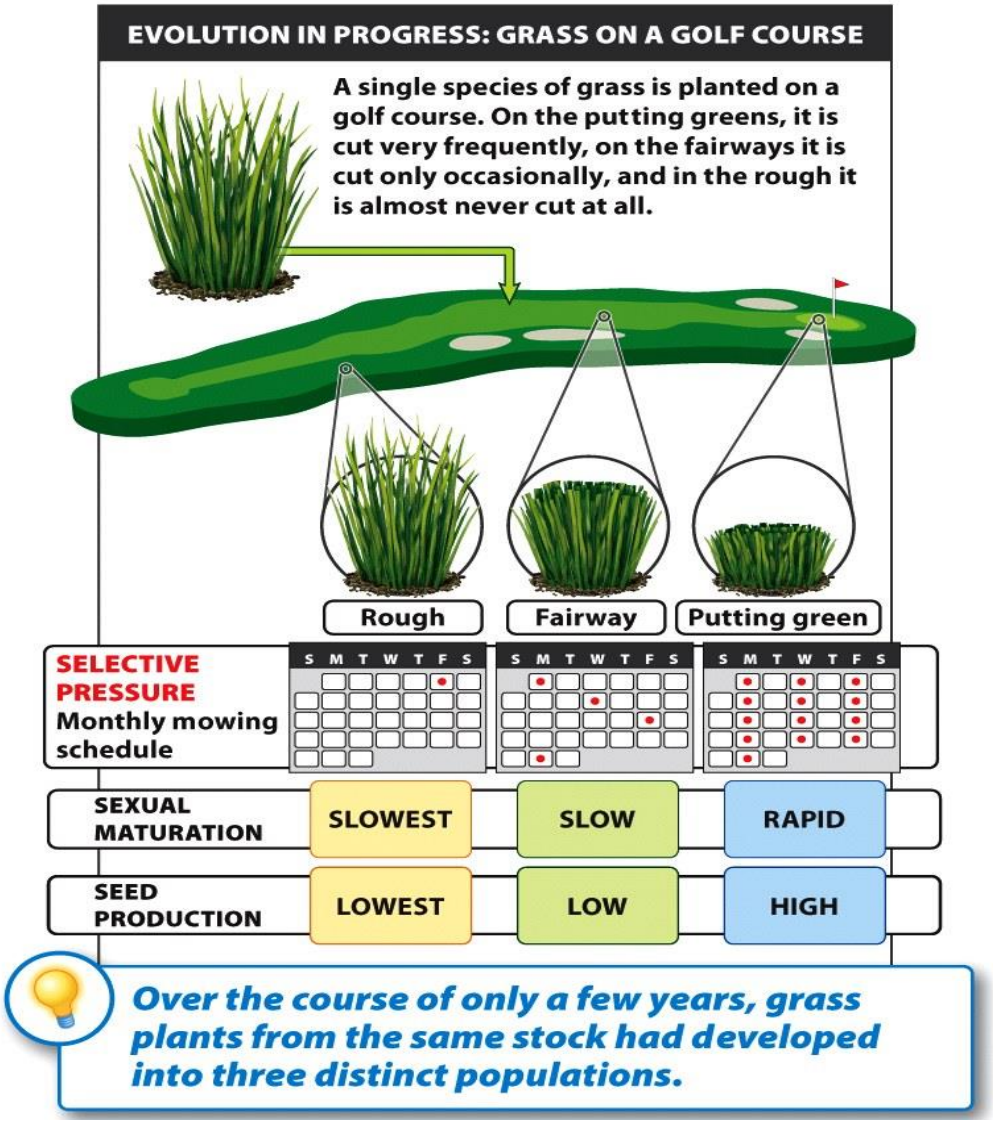
- The degree of similarity in the DNA of different species can reveal how closely related they are and the amount of time that has passed since they last shared a common ancestor.

The evidence for the occurrence of evolution is overwhelming

- Laboratory and field experiments enable us to watch evolution in progress.

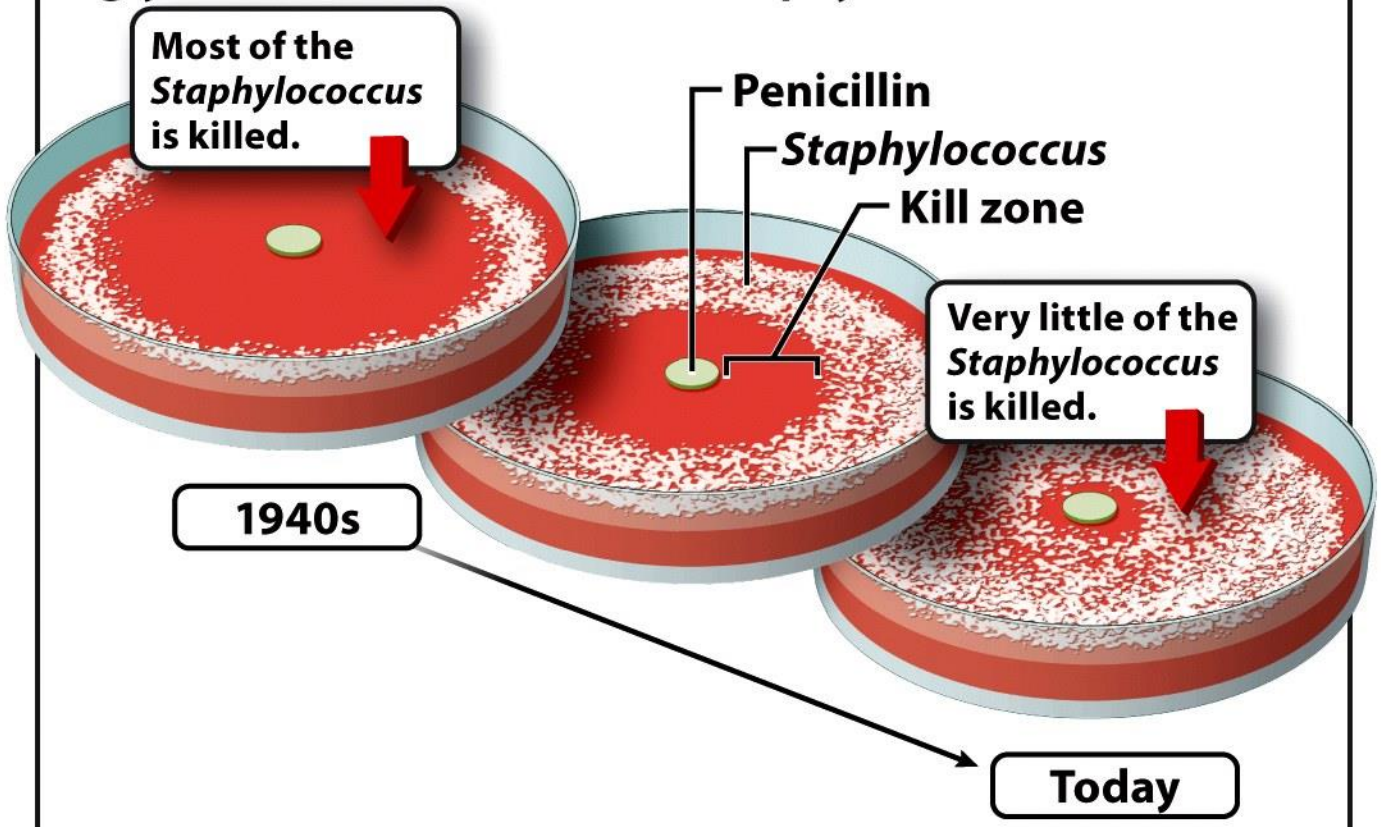
A fifth line of evidence for the occurrence of evolution comes from multi-generation experiments and observations.

Changes in the Frequency of the Various Alleles



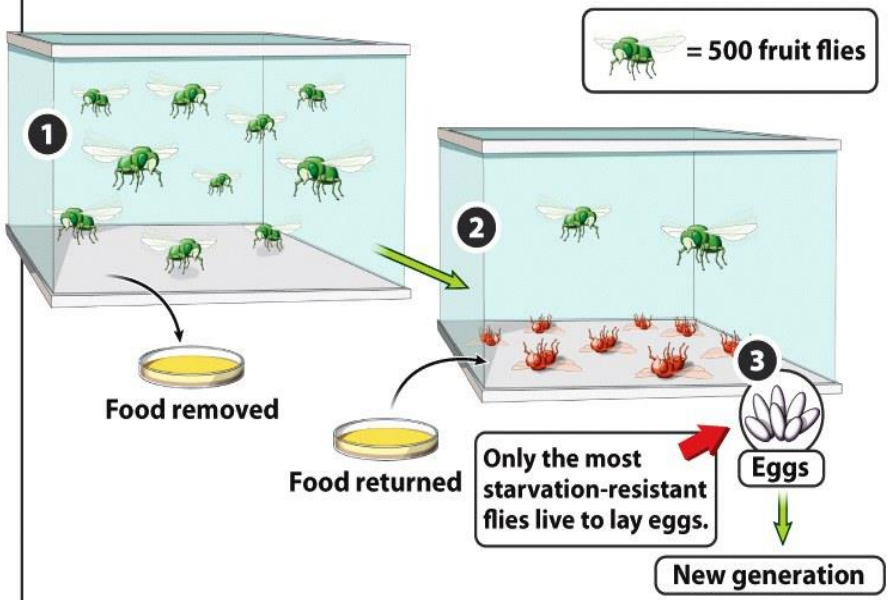
EVOLUTION OF ANTIBIOTIC RESISTANCE

When first used as medicine in the 1940s, penicillin was uniformly effective in killing the bacterium *Staphylococcus aureus*. Today, natural selection has led to an increase in antibiotic-resistant alleles, and humans are increasingly at risk from untreatable *Staphylococcus* infections.



Can fruit flies evolve so that they can resist starvation longer?

THE EXPERIMENT

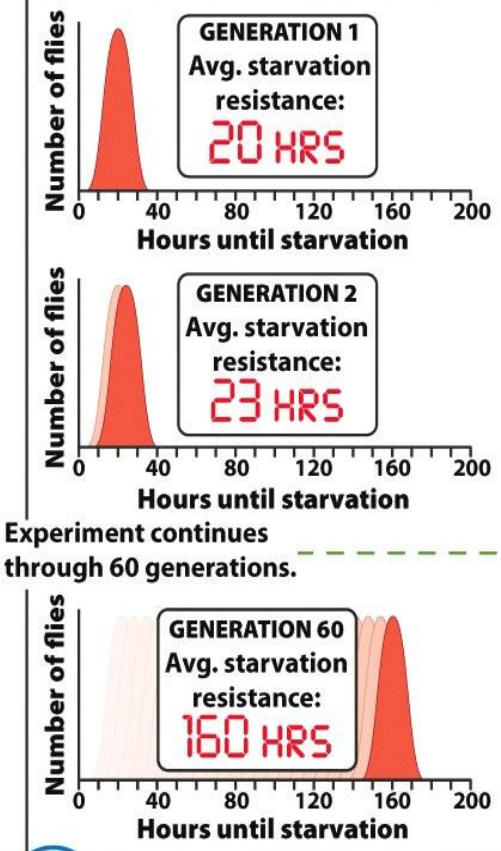


1 INITIAL SETUP
Start with a cage that contains a large number of fruit flies (5,000), and remove the food.

2 TESTING STARVATION RESISTANCE
Wait until 80% of the flies starve to death, then return the food to the cage. Record the average starvation-resistance time.

3 START NEW GENERATION
After the surviving flies eat a bit, collect the eggs those flies lay and transfer them to a new cage.

THE RESULTS



Over many generations of natural selection, the population changes! The flies now resist starvation much longer.

Take-Home Message

- Carefully designed lab experiments and observations of natural populations allow us to watch and measure evolution as it occurs.

What do you think? Understanding evolution can help scientists find strategies to combat antibiotic and pesticide resistance.

1. Strongly agree
2. Agree
3. Neutral
4. Disagree
5. Strongly disagree