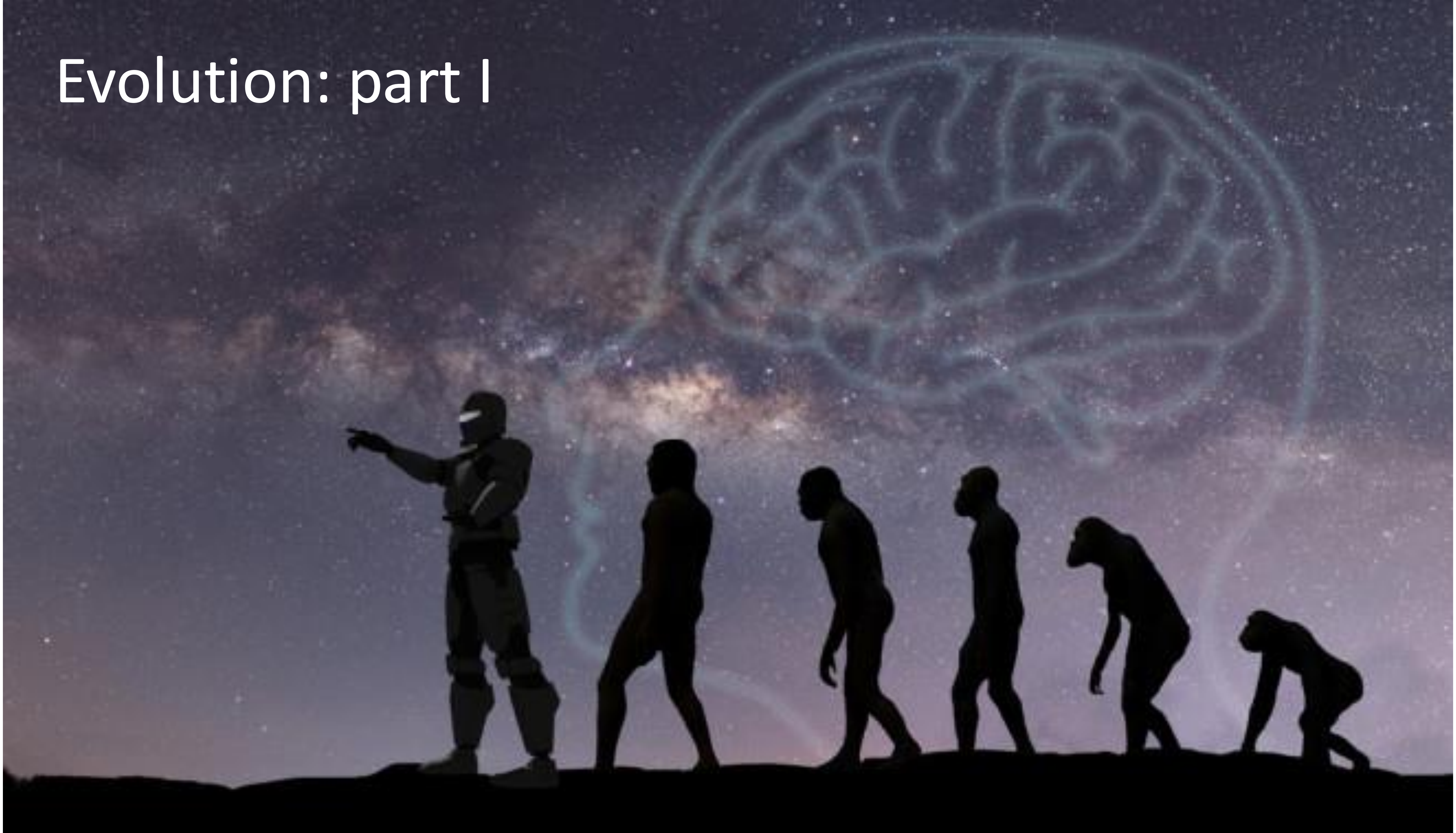
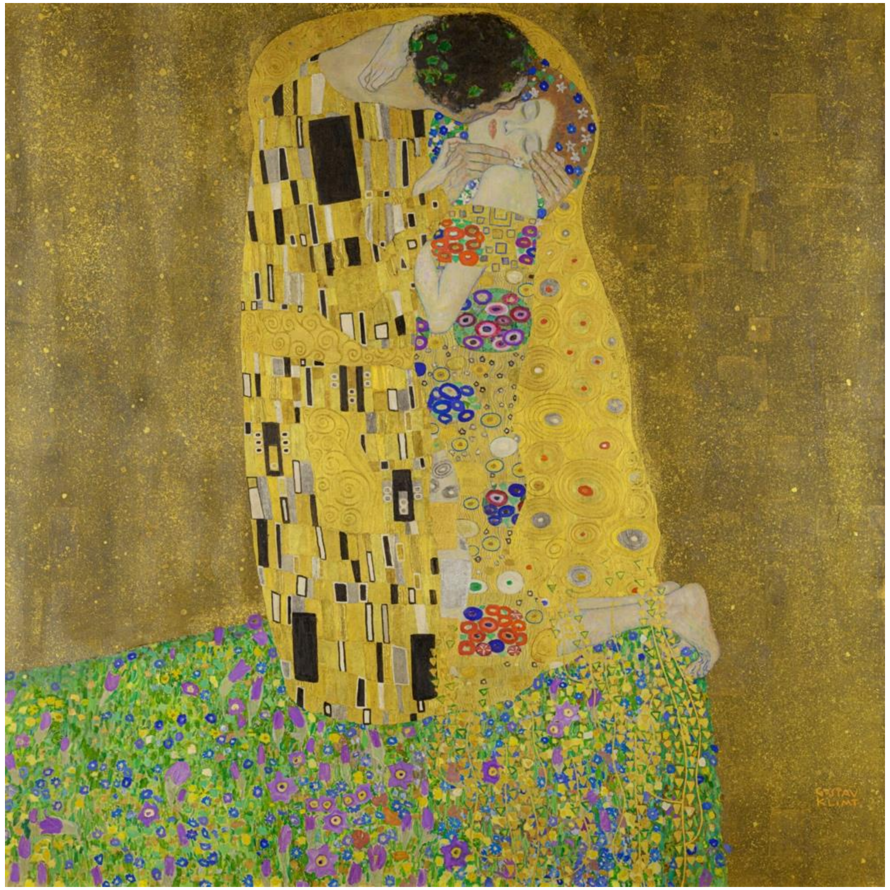
Evolution: part I



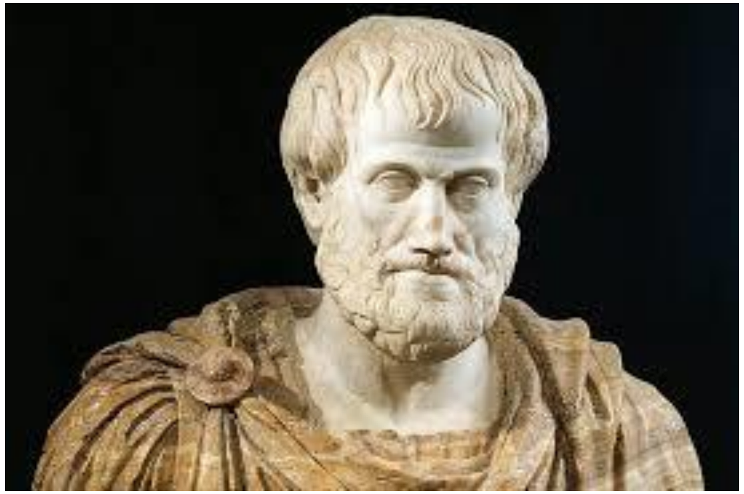
Why should we love evolution

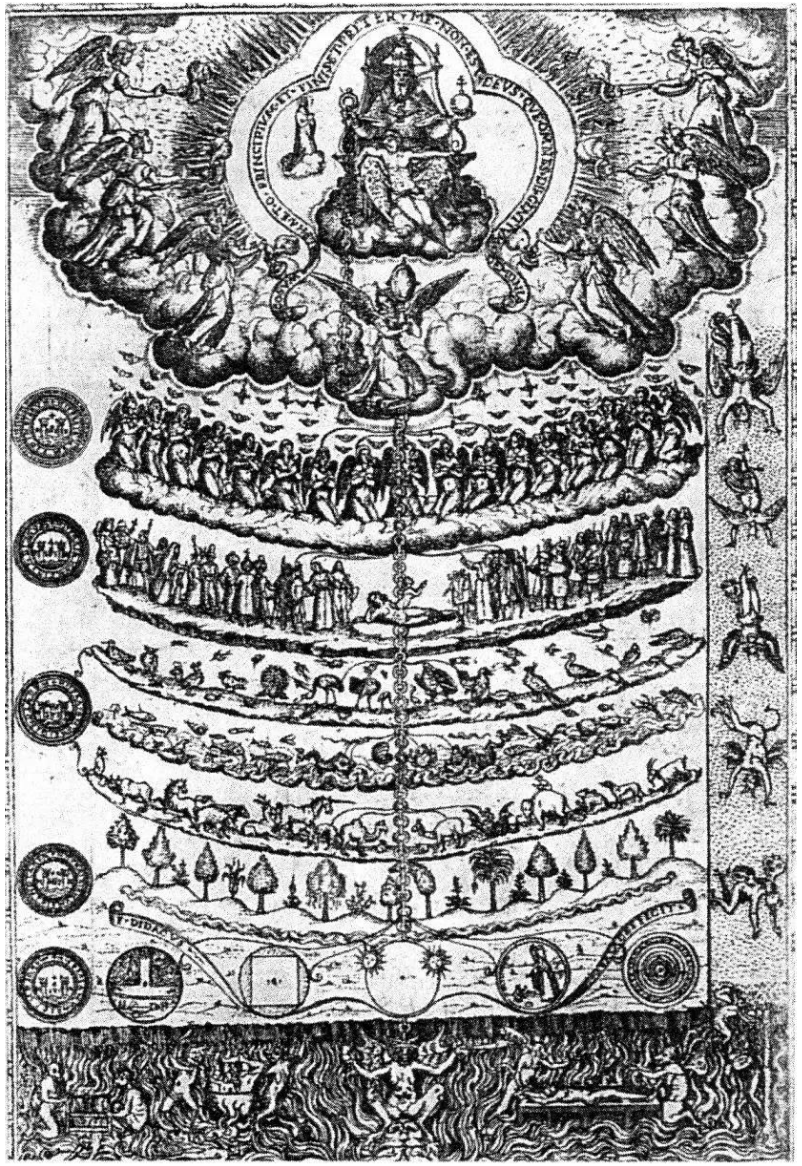


- **Understanding Ecosystem Resilience**: Evolution explains how species adapt to environmental stressors like pollution or climate change, helping engineers predict and manage ecosystem responses to human activities.
- **Designing Sustainable Solutions**: Knowledge of evolutionary processes guides the use of organisms (e.g. microbes) in biotechnologies such as wastewater treatment or bioremediation, ensuring these systems remain effective over time.
- **Preventing Unintended Impacts**: Evolutionary insight helps anticipate how species might evolve in response to human interventions (e.g., resistance to toxins or invasive species control), allowing engineers to design more responsible, long-term environmental strategies.

Scala Naturae and Classification of Species

- The Old Testament holds that species were individually designed by God and therefore perfect
- The Greek philosopher Aristotle (384 – 322 BC) viewed species as fixed and arranged them on a *scala naturae*





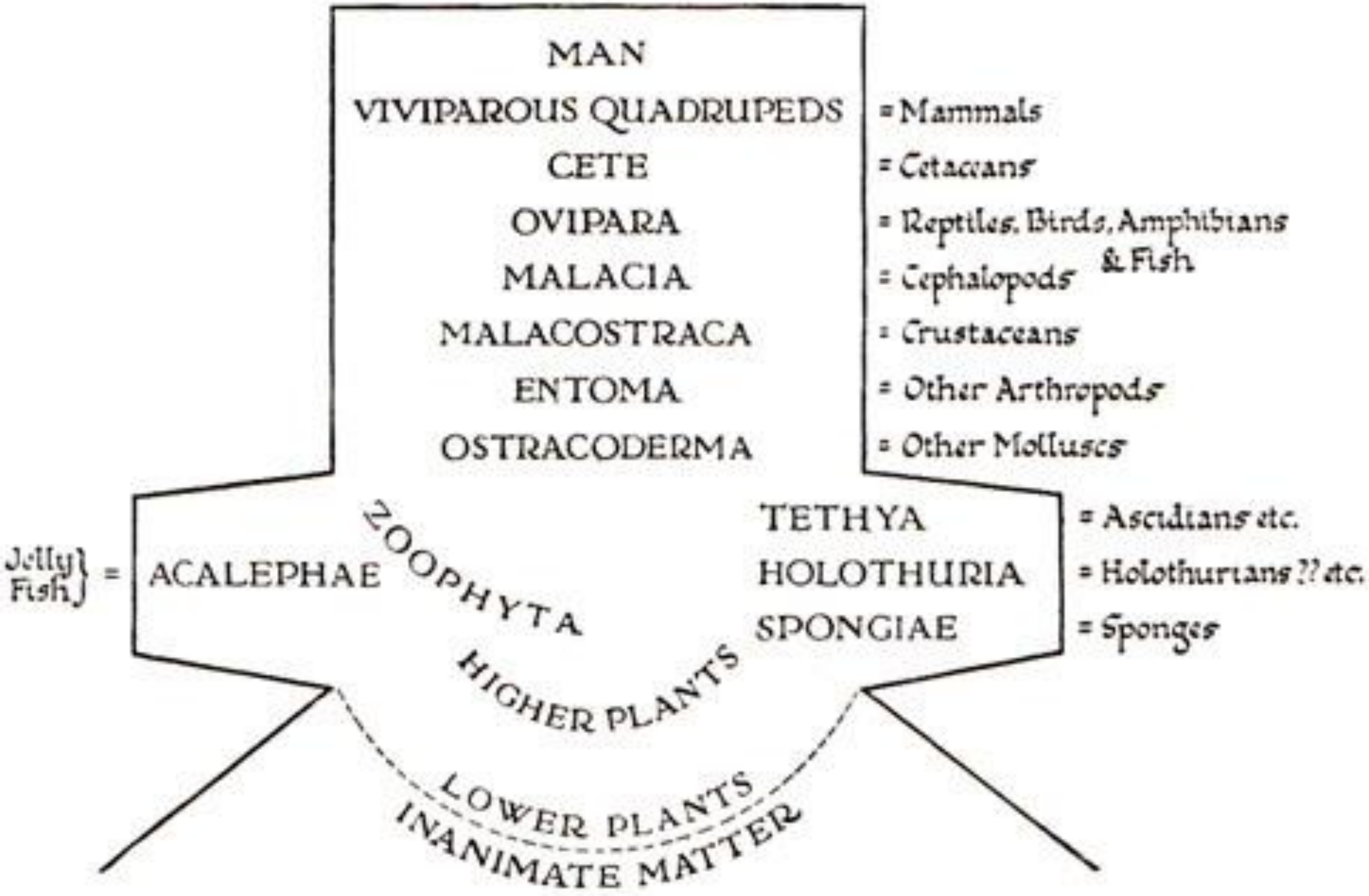
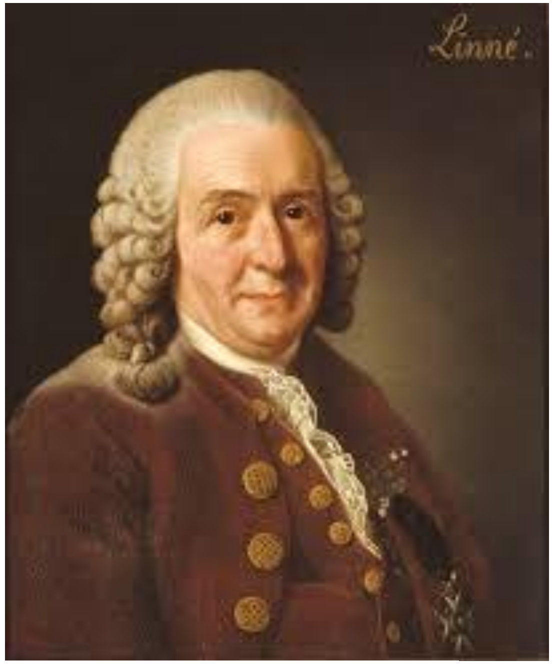
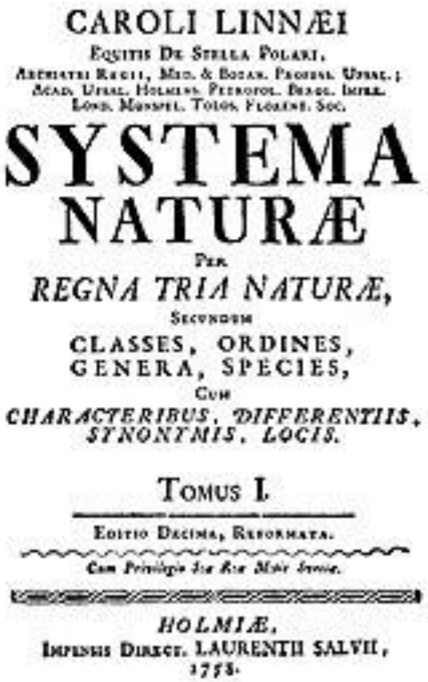


FIG. 18. The *Scala Naturae* or 'Ladder of Life' according to the descriptions of Aristotle.

Carolus Linnaeus (Sweden, 1707-1778)

- Carolus Linnaeus interpreted organismal adaptations as evidence that the Creator had designed each species for a specific purpose
- Linnaeus was the founder of taxonomy, the branch of biology concerned with classifying organisms
- He developed the binomial format for naming species (for example, *Homo sapiens*)




CAROLI LINNÆI

EQUITIS DE STELLA POLARI,

[illegible]

SYSTEMA NATURÆ

PER

REGNA TRIA NATURÆ,

SECUNDUM

CLASSES, ORDINES, GENERA, SPECIES,

CUM

CHARACTERIBUS, DIFFERENTIIS, SYNONYMIS, LOCIS.

TOMUS I.

EDITIO DECIMA, REFORMATA.

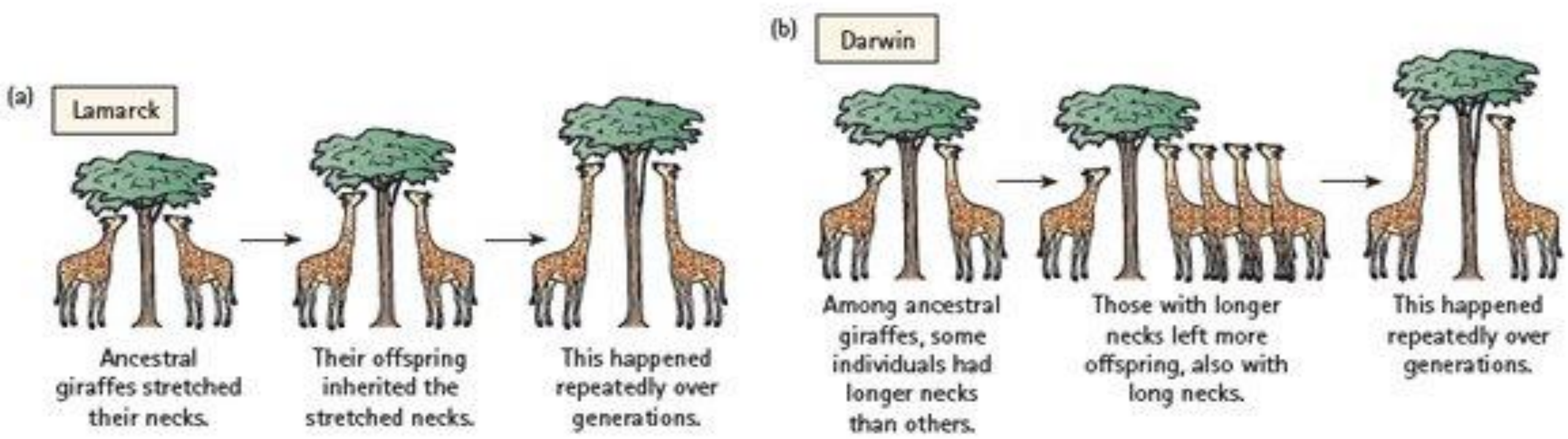
HOLMIÆ,

IMPENSIS DIRECT. LAURENTII SALVII,

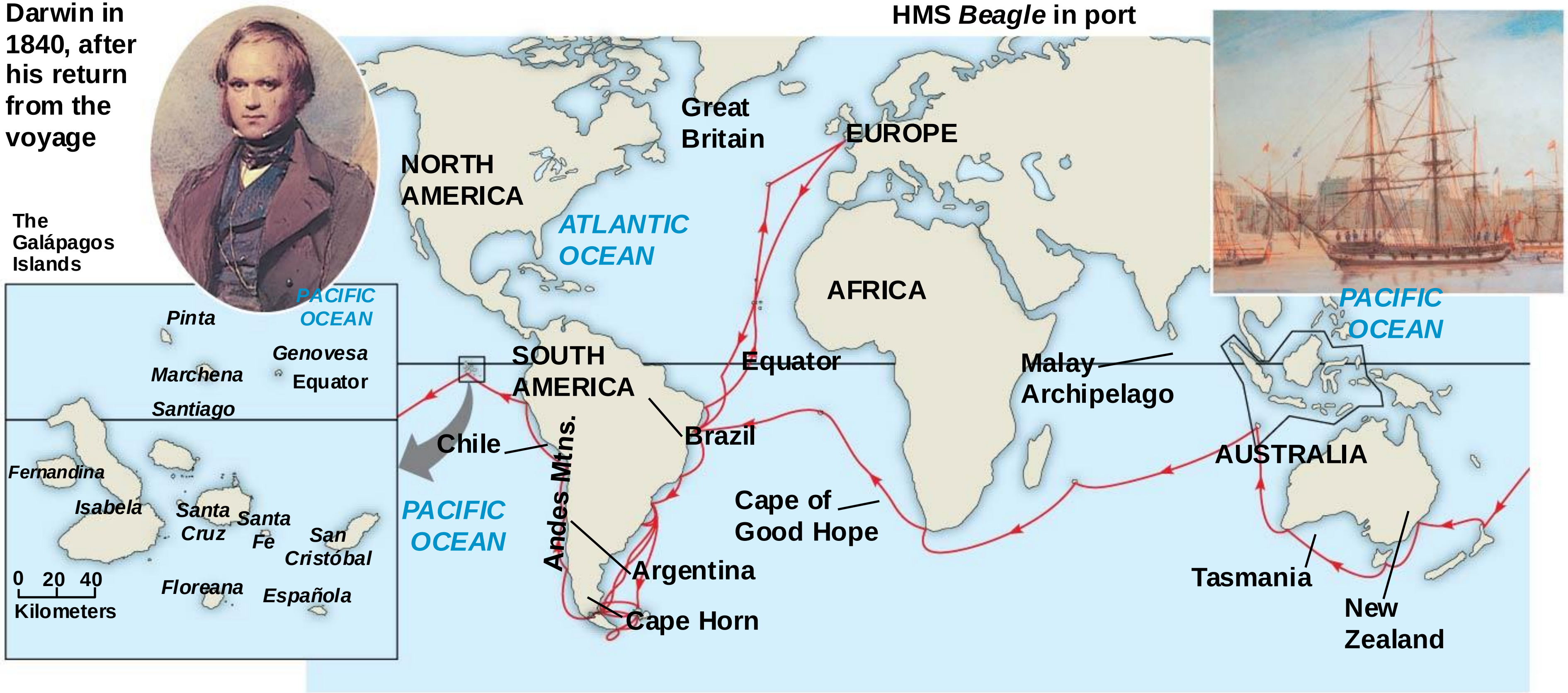
1758.

Lamarck’s Hypothesis of Evolution

- French biologist Jean-Baptiste de Lamarck (1744-1829) hypothesized that species evolve through use and disuse of body parts and the inheritance of acquired characteristics
- The mechanisms he proposed are unsupported by current evidence



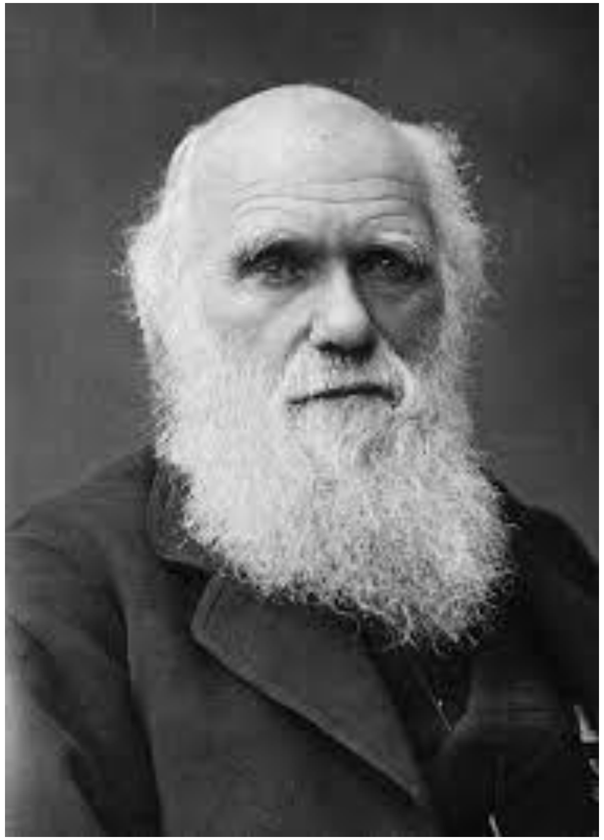
Darwin: the voyage of HMS Beagle (December 1831-October 1836)



Amara, Bon.
Harpalus, Lat.
Clair.
Pay.
Fab.
molossus, Zieg.
meridianus, Lin.
consularis, Duft.
familiaris

Charles Darwin and *The origin of species*

- A new era of biology began in 1859 when Charles Darwin published *The Origin of Species*
- *The Origin of Species* focused biologists' attention on the great diversity of organisms
- Darwin noted that current species are descendants of ancestral species
- **Evolution** can be defined by Darwin's phrase *descent with modification*

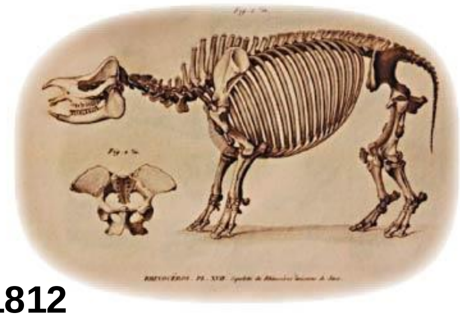


The intellectual context of Darwin's ideas

1795
Hutton proposes his principle of gradualism.

1798
Malthus publishes "Essay on the Principle of Population."

1809
Lamarck publishes his hypothesis of evolution.



1809
Charles Darwin is born.

1812
Cuvier publishes his extensive studies of vertebrate fossils.

1830
Lyell publishes *Principles of Geology.*

1831–1836
Darwin travels around the world on HMS *Beagle*.

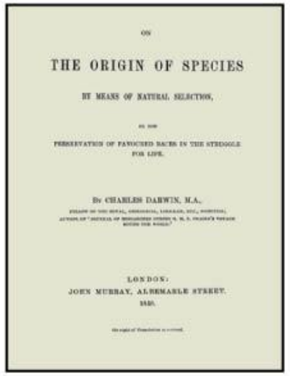
Darwin saw marine iguanas in the Galápagos Islands.

1844
Darwin writes his essay on descent with modification.

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.

1859
The Origin of Species is published.


ON
THE ORIGIN OF SPECIES
BY MEANS OF NATURAL SELECTION,
OR THE
PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.
BY CHARLES DARWIN, M.A.,
LONDON:
JOHN MURRAY, ALBEMARLE STREET.

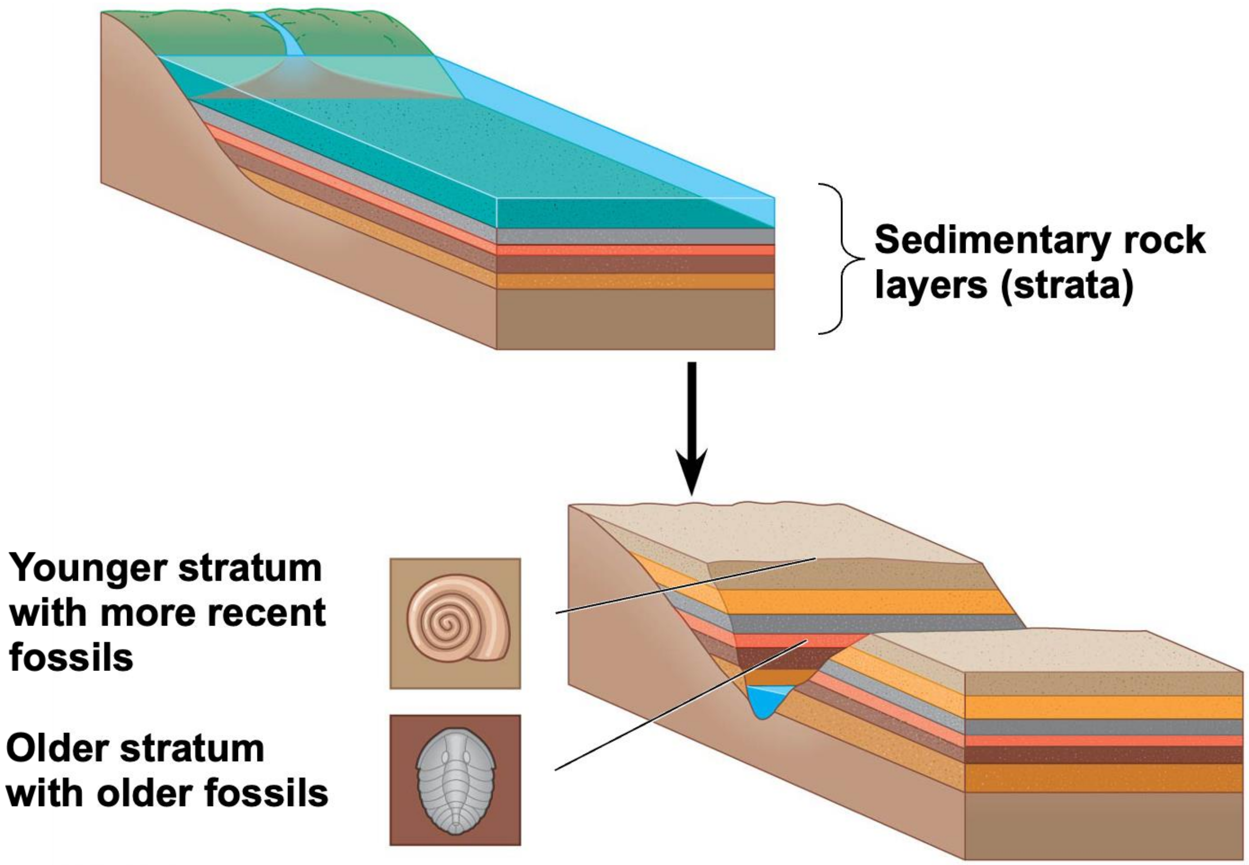
1790

1870

Fossils and darwinism

- The study of **fossils** helped to lay the groundwork for Darwin's ideas
- Fossils are remains or traces of organisms from the past, usually found in sedimentary rock, which appears in layers called **strata**

Formation of sedimentary strata with fossils



Three examples of beak variation in Galápagos finches

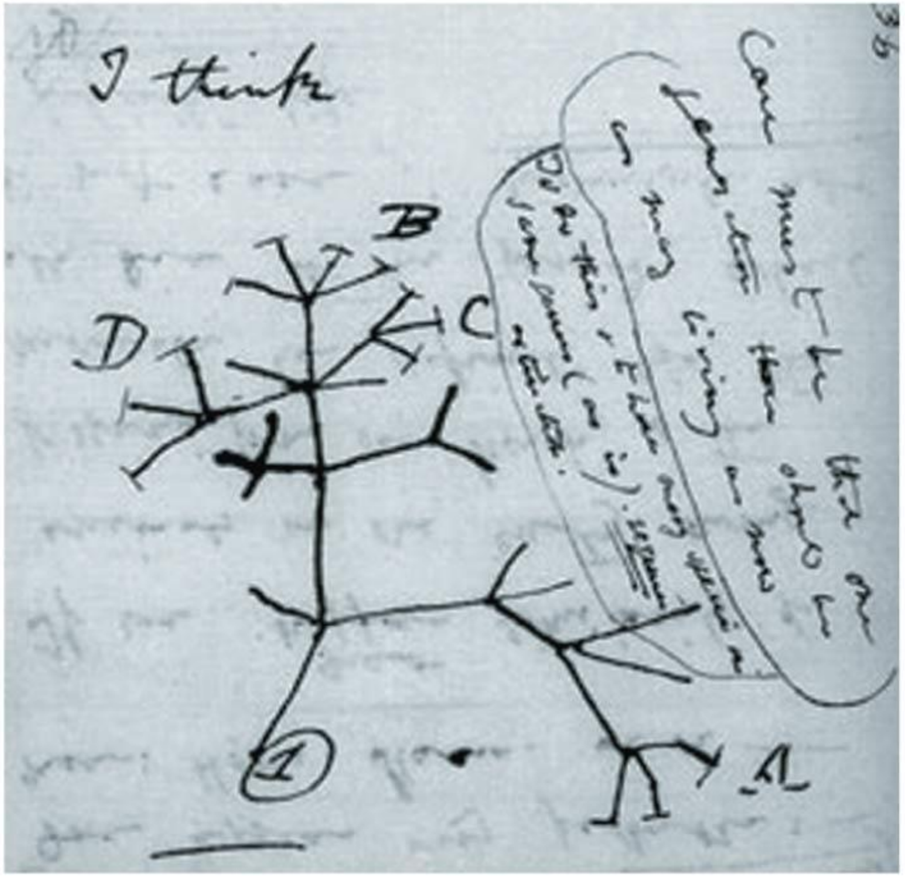
(a) Cactus-eater

(b) Insect-eater

(c) Seed-eater

Ideas from *The Origin of Species*

- Darwin explained three broad observations:
  - The unity of life
  - The diversity of life
  - The ways organisms are suited to life in their environments

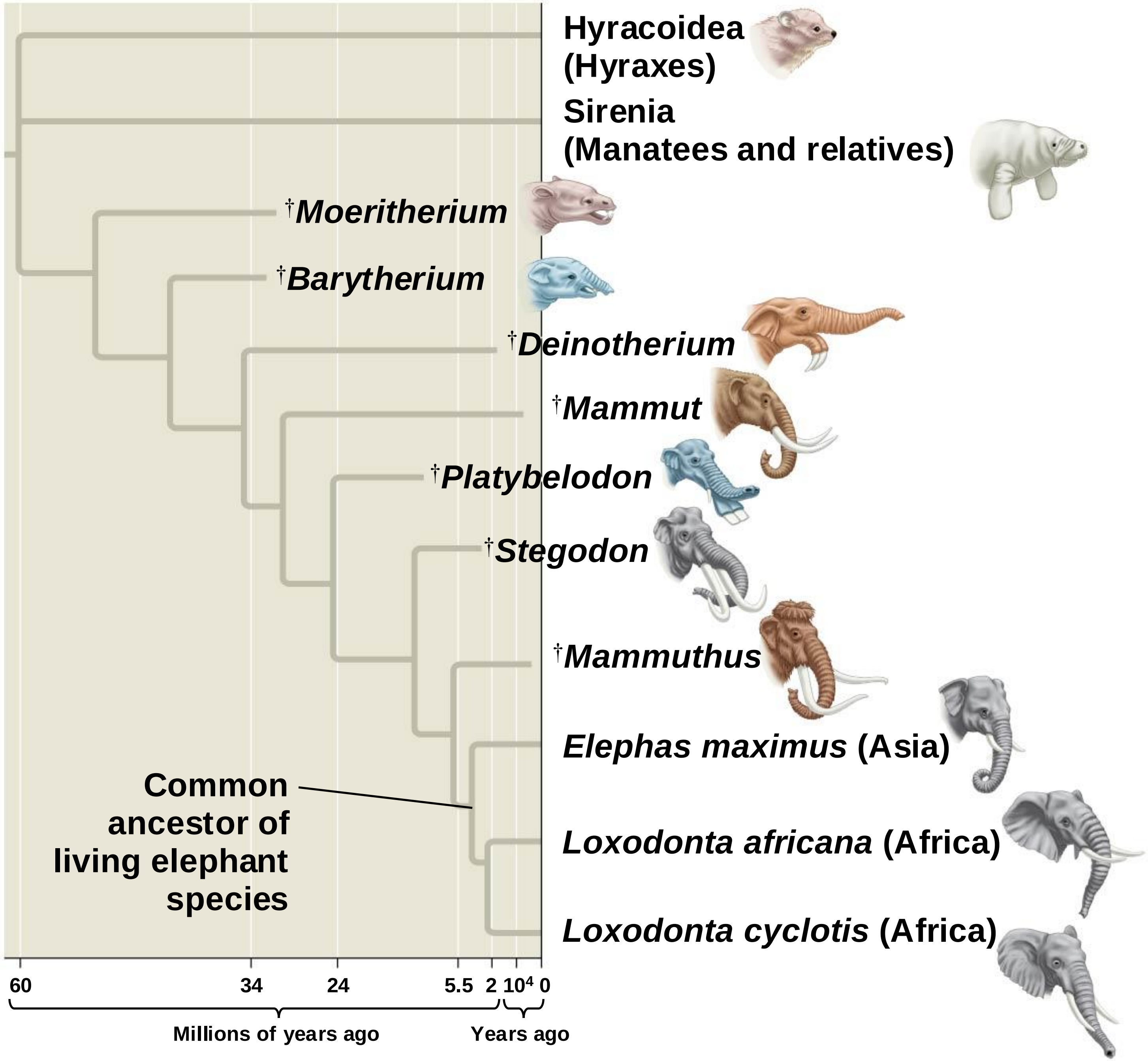


“I think. . . .” In this 1837 sketch, Darwin envisioned the branching pattern of evolution.

Descent with Modification or “evolution”

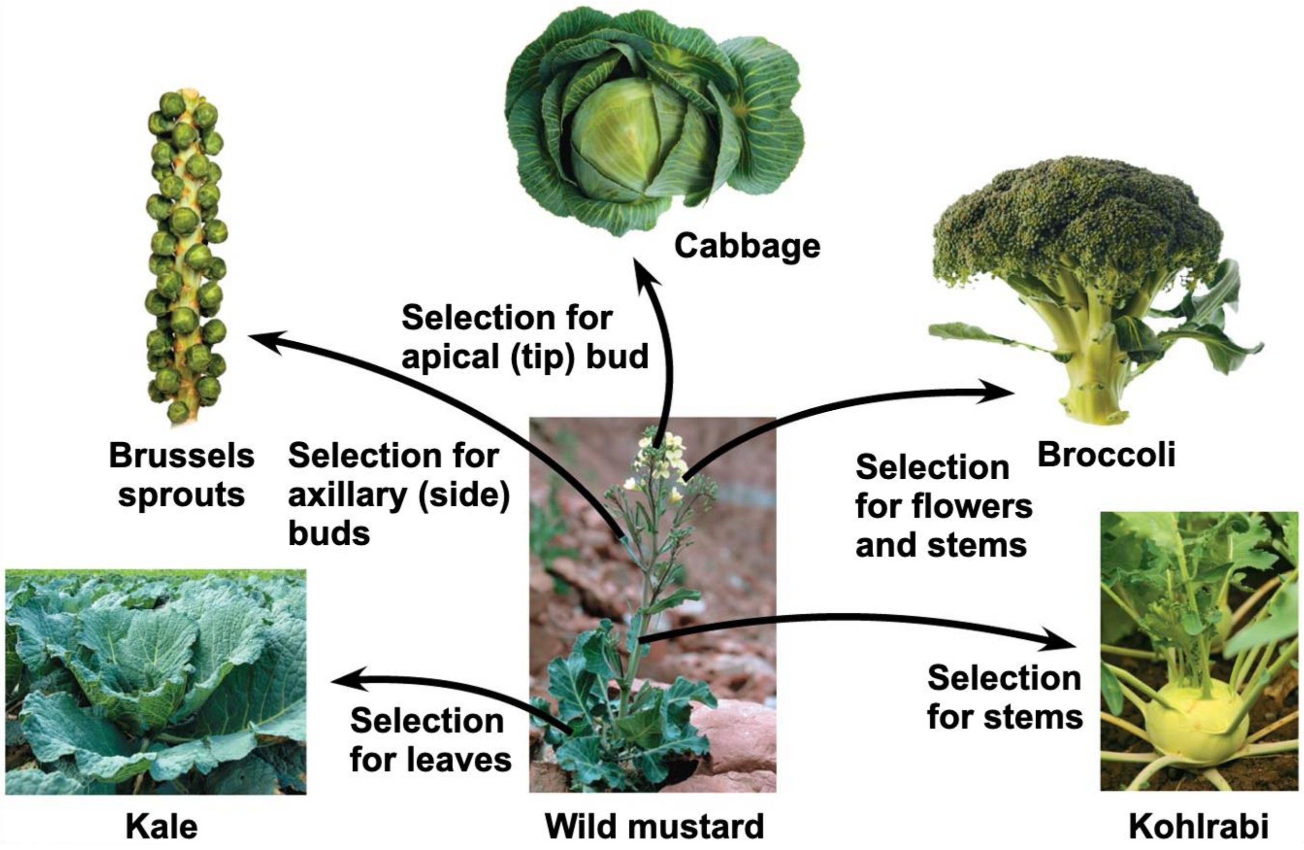
- Darwin never used the word *evolution* in the first edition of *The Origin of Species*
- The phrase ***descent with modification*** summarized Darwin’s perception of the unity of life
- The phrase refers to the view that all organisms are related through descent from an ancestor that lived in the remote past
- In the Darwinian view, the history of life is like a tree with branches representing life’s diversity
- Darwin reasoned that large morphological gaps between related groups could be explained by this branching process and past extinction events

Descent with modification



Artificial Selection, Natural Selection, and Adaptation

- Darwin noted that humans have modified other species by selecting and breeding individuals with desired traits, a process called **artificial selection**



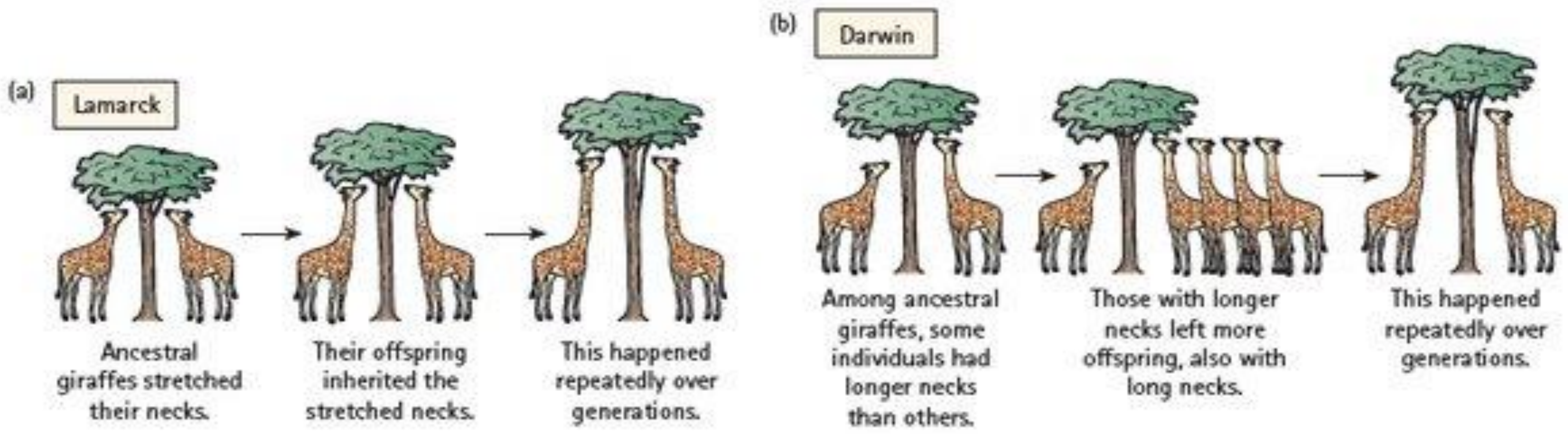
Darwin drew two inferences from two observations:

- **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

- **Inference #1**: Individuals whose inherited traits give them a higher probability of surviving and reproducing in a given environment tend to leave more offspring than other individuals
- **Inference #2**: This unequal ability of individuals to survive and reproduce will lead to the accumulation of favorable traits in the population over generations

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 a given environment
- If an environment changes over time, natural selection may result in adaptation to these new conditions and may give rise to new species



Camouflage as an example of evolutionary adaptation

Summary natural selection

- Note that individuals do not evolve; **populations evolve over time**
- Natural selection can only increase or decrease heritable traits that vary in a population
- Natural selection does not create new traits, but edits or selects for traits already present in the population
- Evolution by natural selection can occur rapidly in species with short generation times eg. Bacteria or viruses
- Adaptations vary with different environments
- The current, local environment determines which traits will be selected for or selected against in any specific population

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

- Two examples provide evidence for natural selection: natural selection in response to introduced species and the evolution of drug-resistant bacteria

Spatial sorting promotes rapid (mal)adaptation in the red-shouldered soapberry bug after hurricane-driven local extinctions

Mattheau S. Comerford, Tatum M. La, Scott Carroll & Scott P. Egan

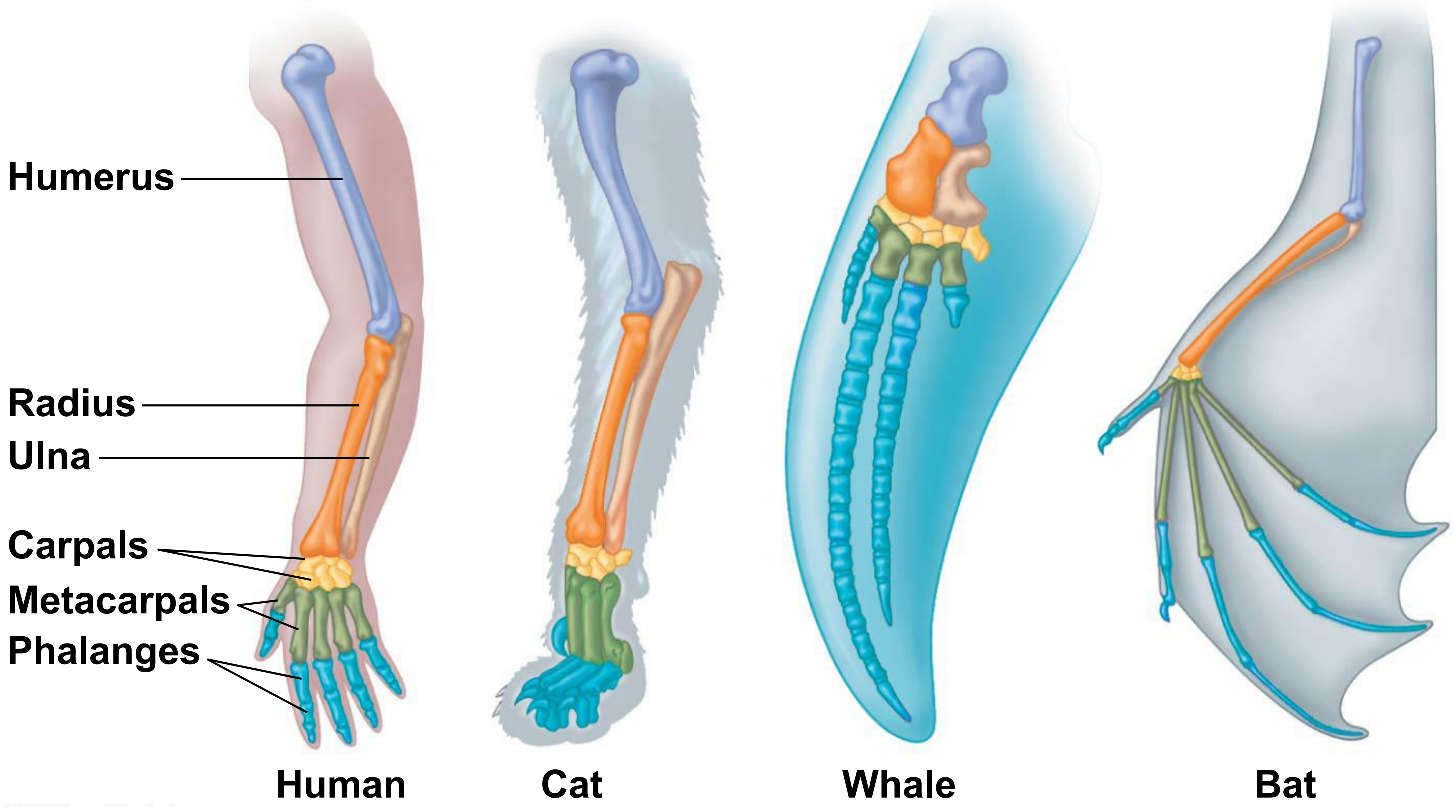
Nature Ecology & Evolution **7**, 1856–1868 (2023) | Cite this article

The Evolution of Drug-Resistant Bacteria

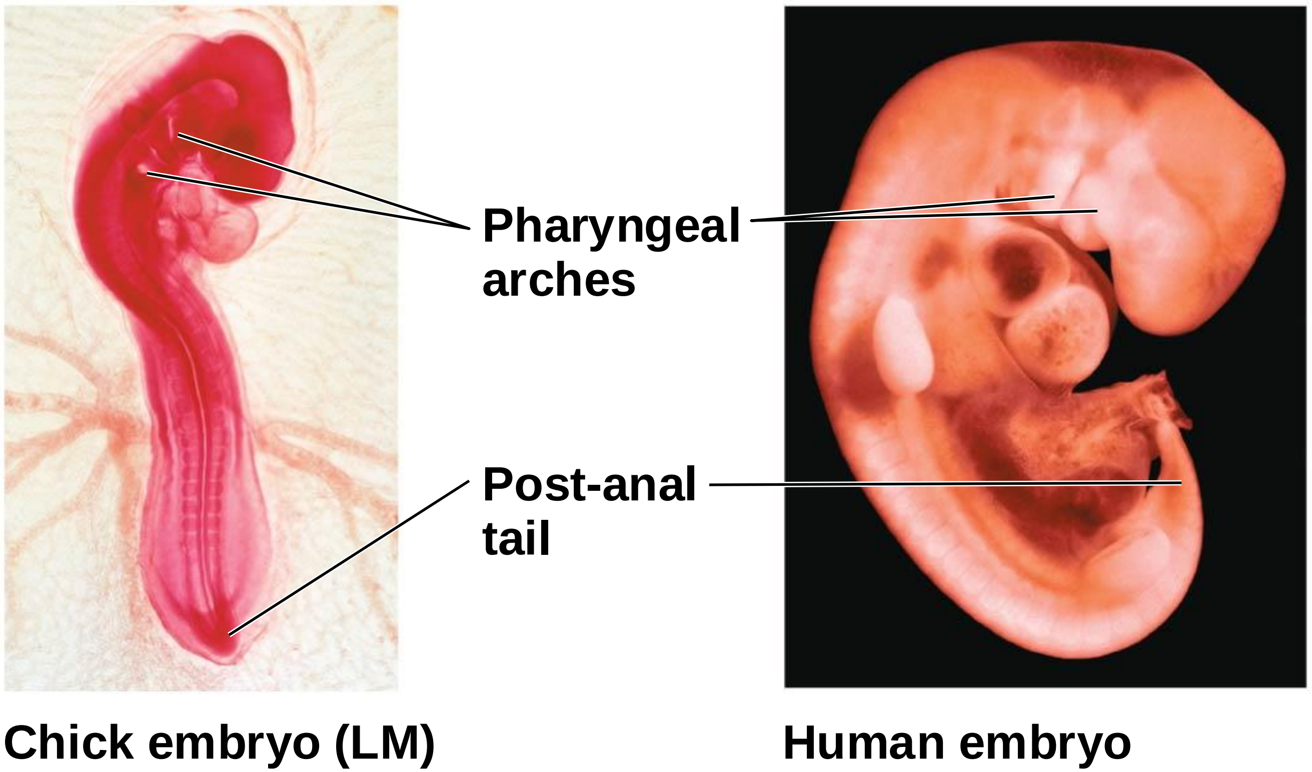
- The bacterium *Staphylococcus aureus* is commonly found on people
- One strain, methicillin-resistant *S. aureus* (MRSA), is a dangerous pathogen
- Resistance to penicillin evolved in *S. aureus* by 1945, two years after it was first widely used
- Resistance to methicillin evolved in *S. aureus* by 1961, two years after it was first widely used

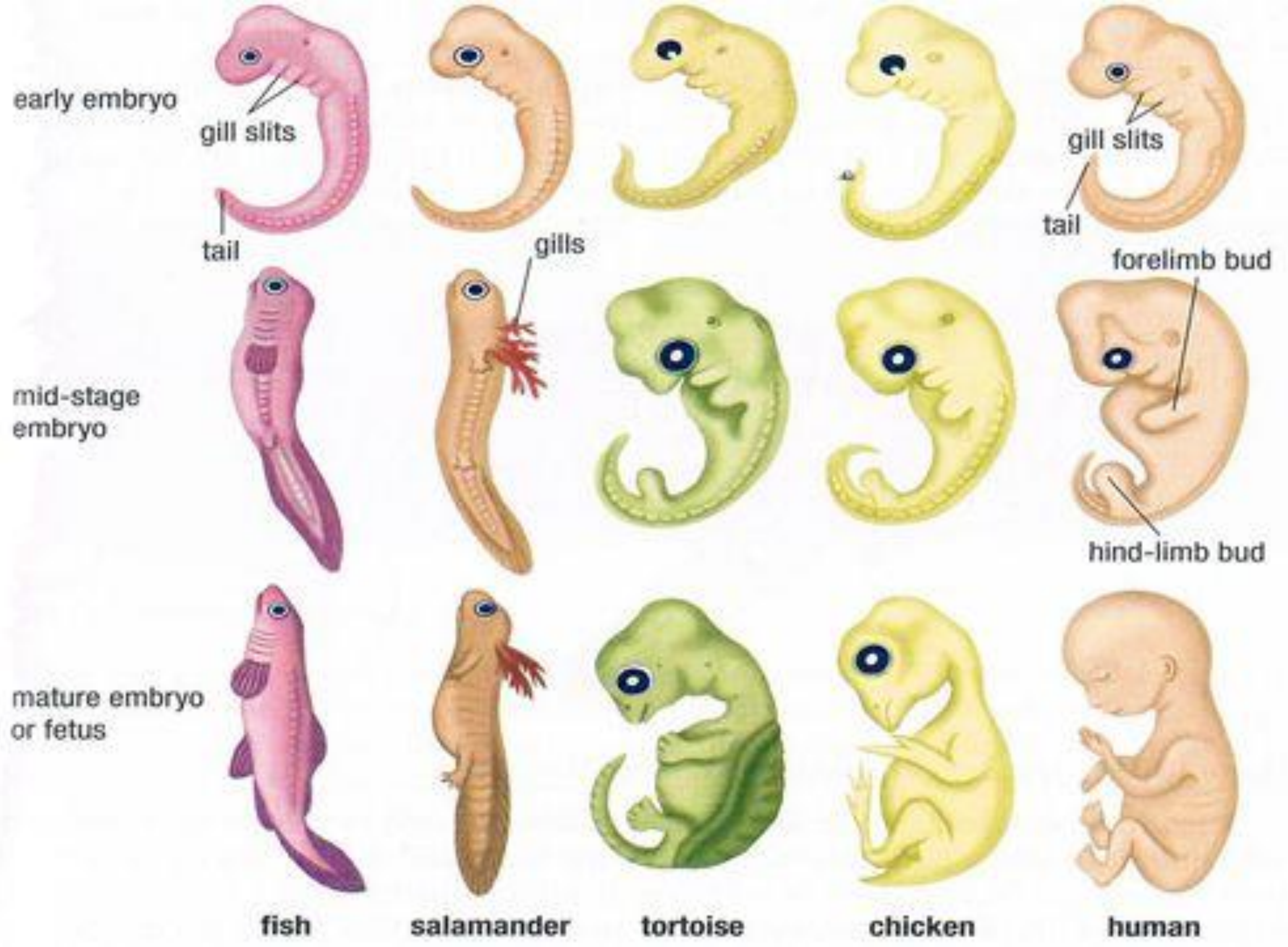
Homology

- **Homology** is similarity resulting from common ancestry
- **Homologous structures** are anatomical resemblances that represent variations on a structural theme present in a common ancestor



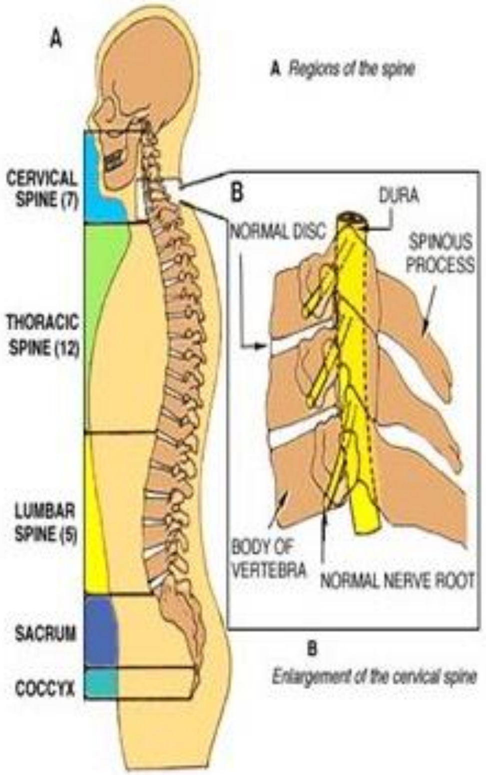
- Comparative embryology reveals anatomical homologies not visible in adult organisms
  - For example, all vertebrate embryos have a post-anal tail and pharyngeal arches

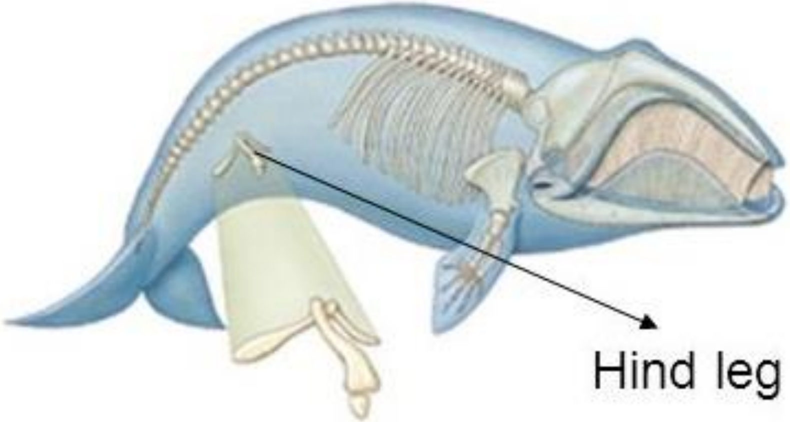



early embryo
gill slits
tail
gill slits
tail
gills
forelimb bud
mid-stage embryo
hind-limb bud
mature embryo or fetus
fish
salamander
tortoise
chicken
human

Vestigial structures

- **Vestigial structures** are remnants of features that served a function in the organism's ancestors eg. Appendix in humans (digestion of cellulose), wings in flightless birds…
- Examples of homologies at the molecular level are genes shared among organisms inherited from a common ancestor eg. Hemoglobin proteins

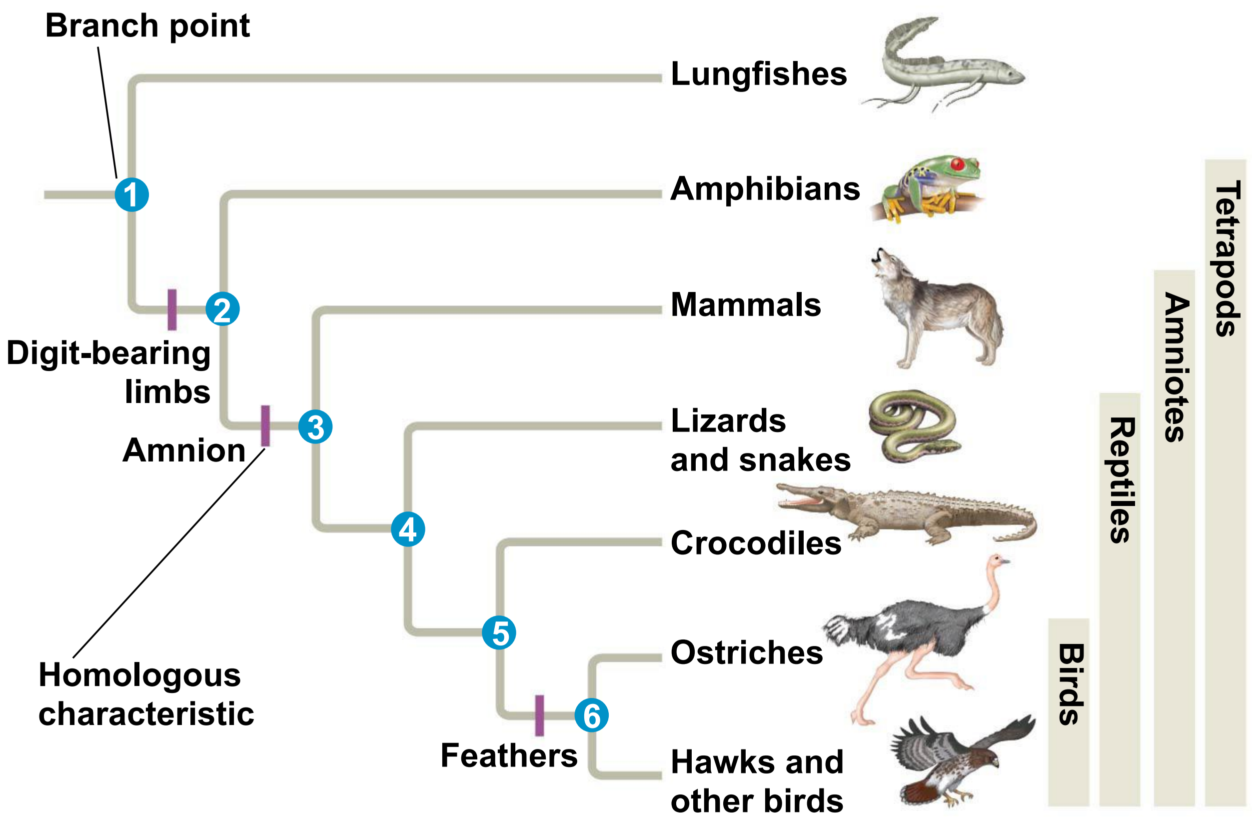




Hind leg in whales

Homologies and evolutionary trees

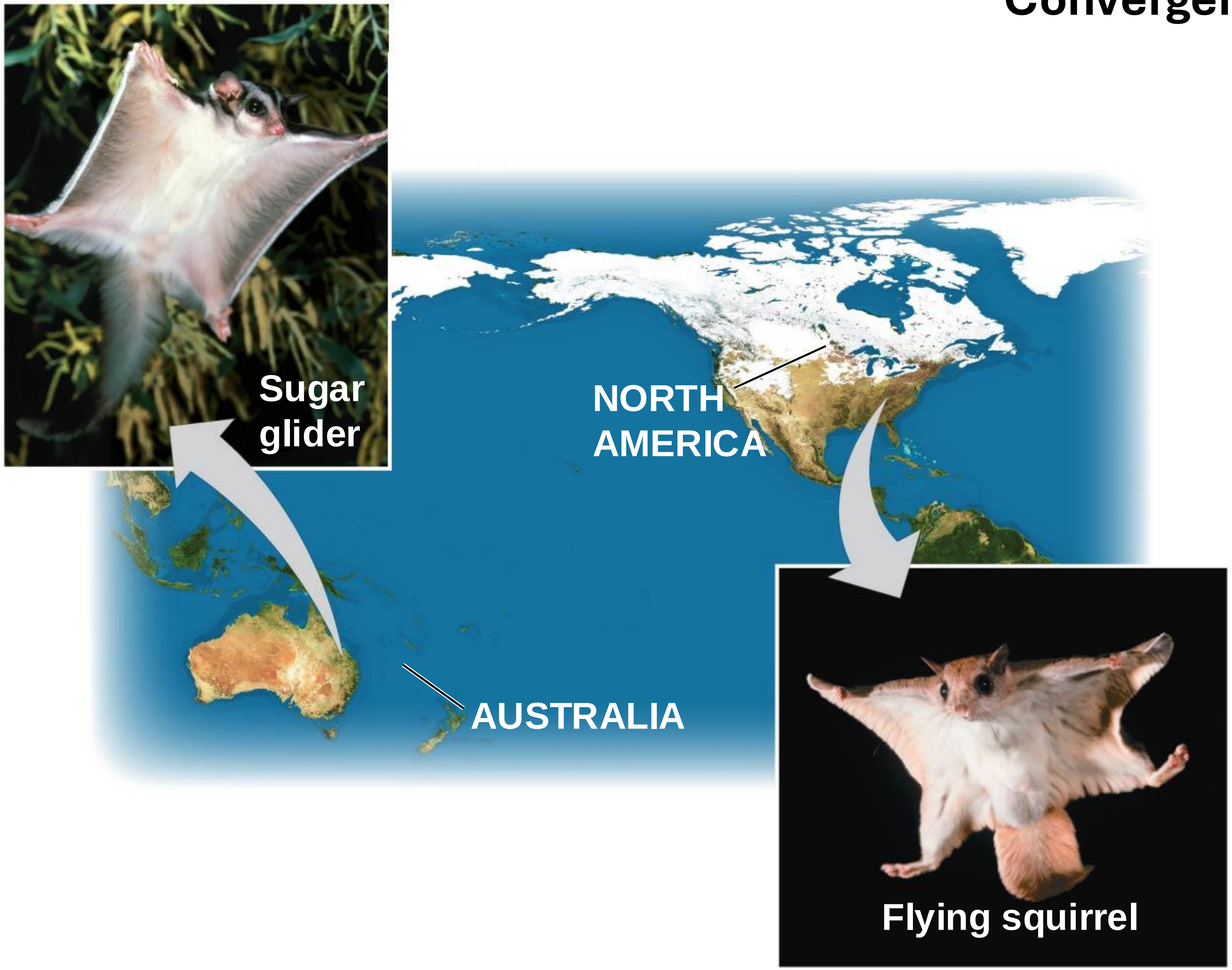
- **Evolutionary trees** are diagrams that reflect hypotheses about the relationships among different groups
- Homologies form nested patterns in evolutionary trees
- Evolutionary trees can be made using different types of data, for example, anatomical and DNA sequence data



A Different Cause of Resemblance: ***Convergent Evolution***

- **Convergent evolution** is the evolution of similar, or **analogous**, features in distantly related groups
- Analogous traits arise when groups independently adapt to similar environments in similar ways
- Convergent evolution does not provide information about ancestry
- **Examples: wings in birds, bats and insects, echolocation in dolphins and whales vs. bats, body shape in aquatic animals (dolphins, sharks, ictyosaures), bioluminescence.**

Convergent evolution

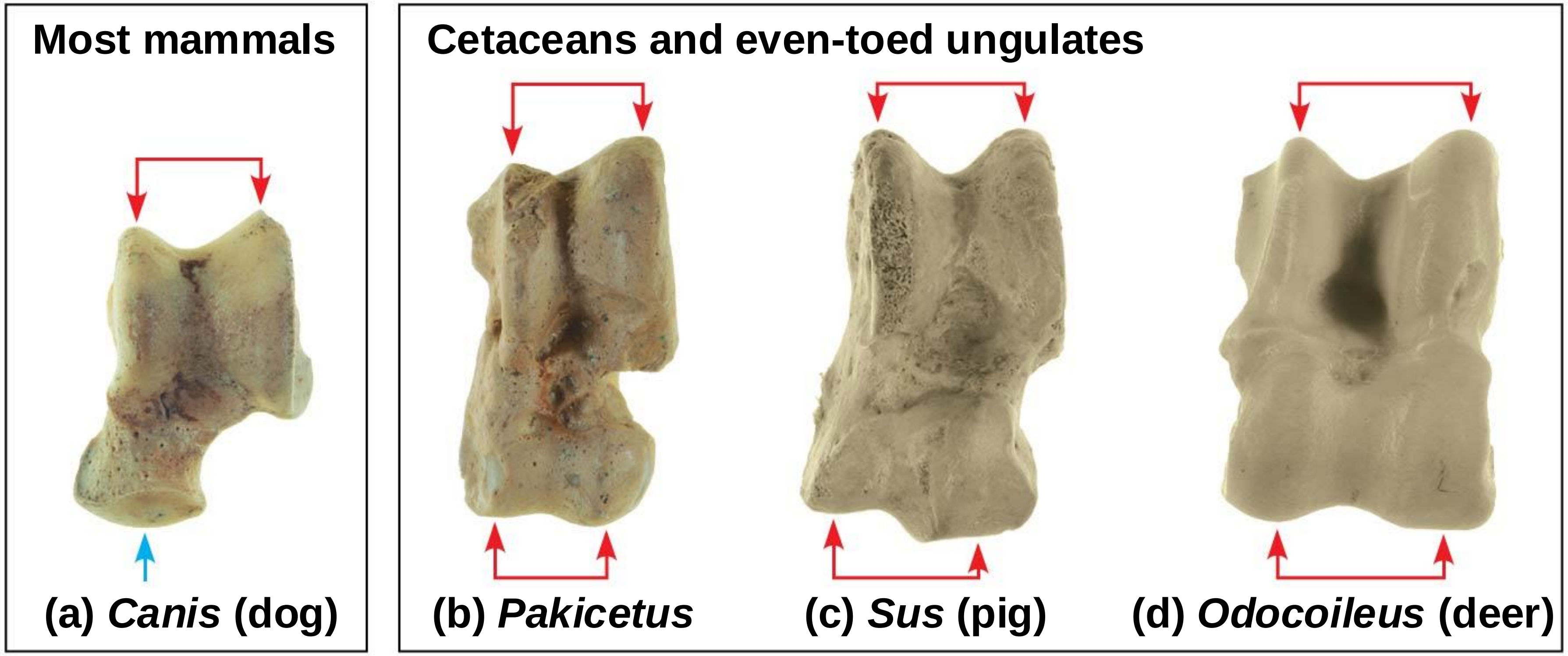


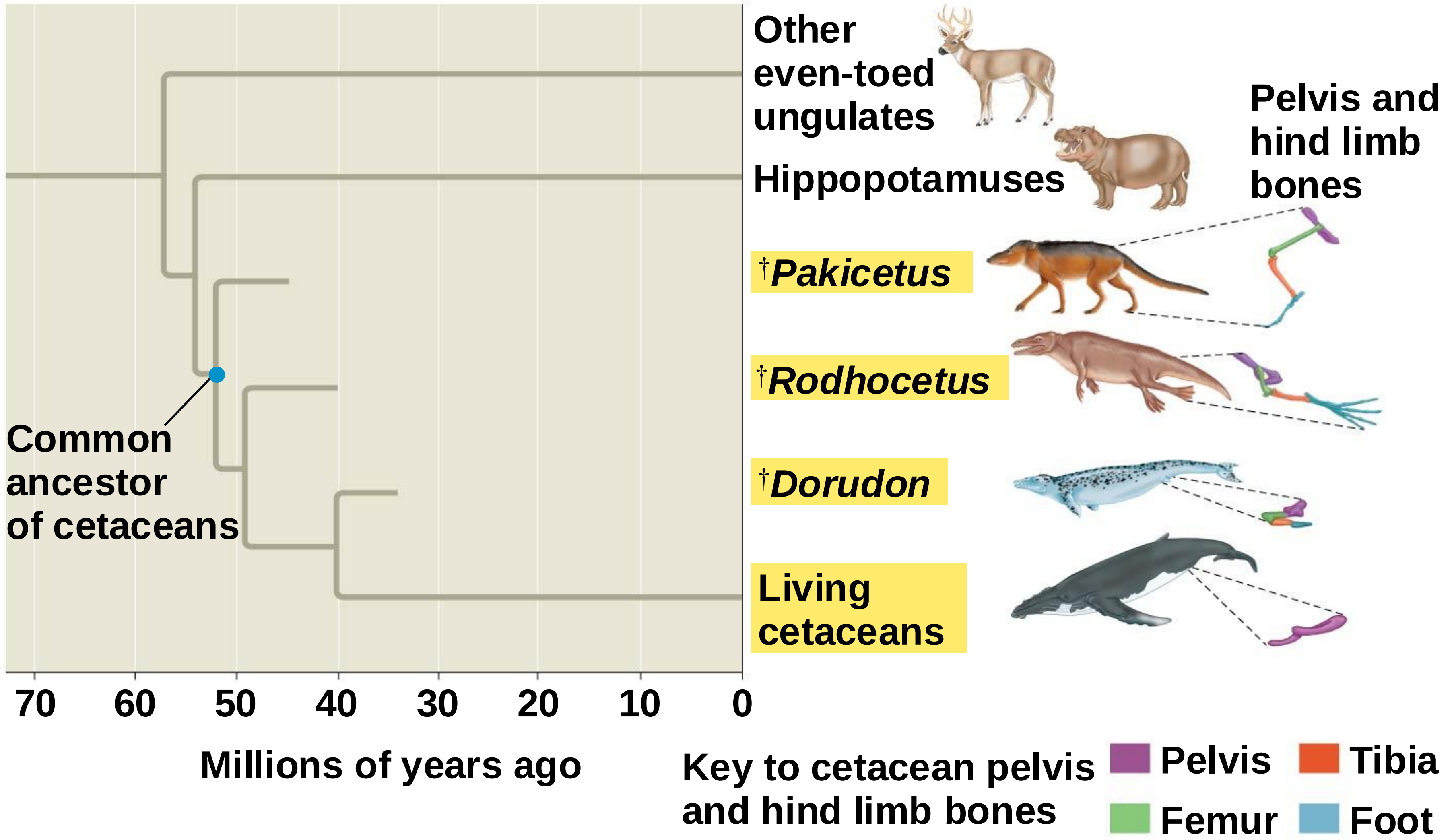
The Fossil Record

- The fossil record provides evidence of the extinction of species, the origin of new groups, and changes within groups over time

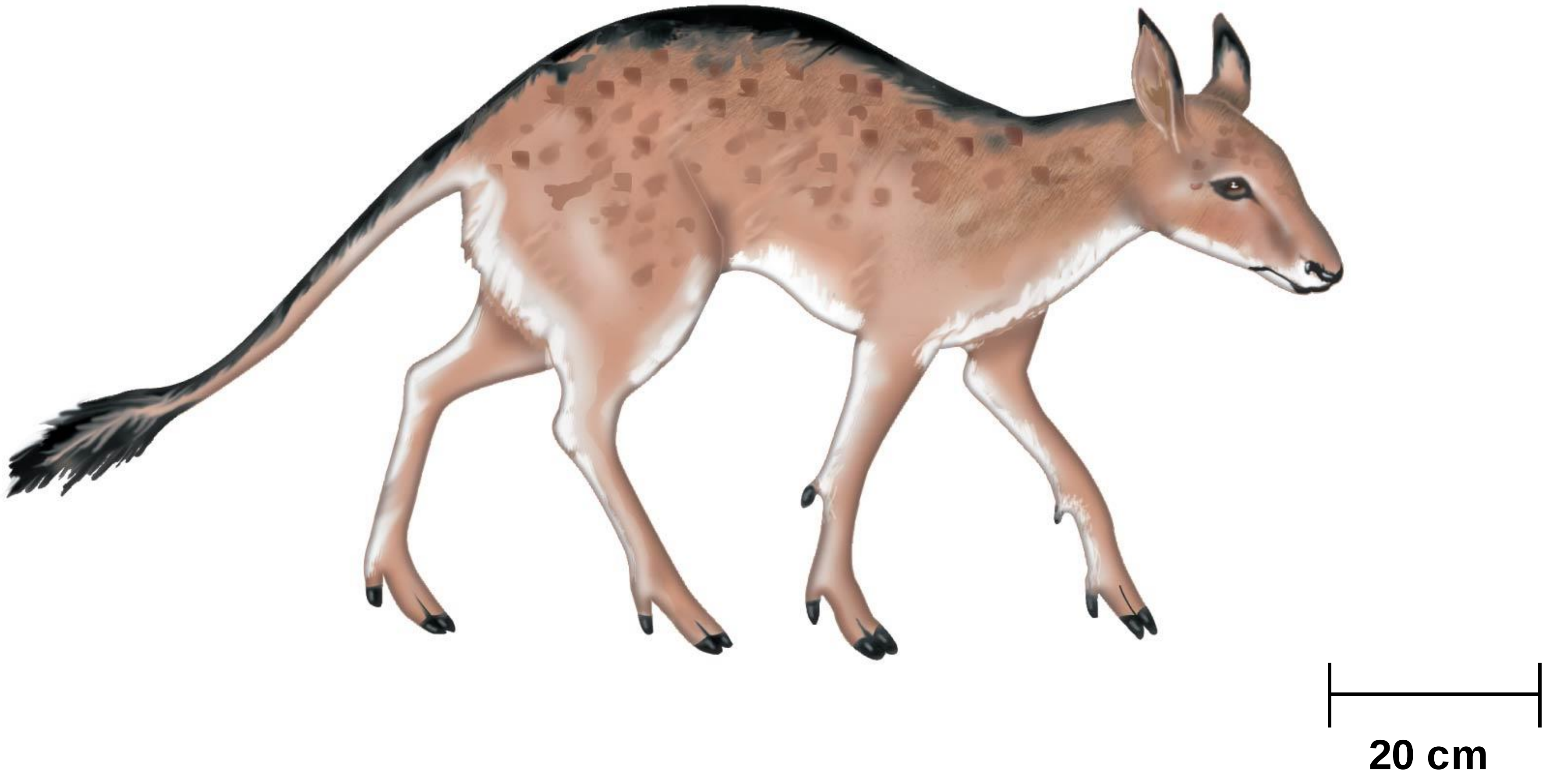
  - **Fossils can document important transitions**
    - For example, the transition from land to sea in the ancestors of cetaceans

Astragalus (ankle bone)



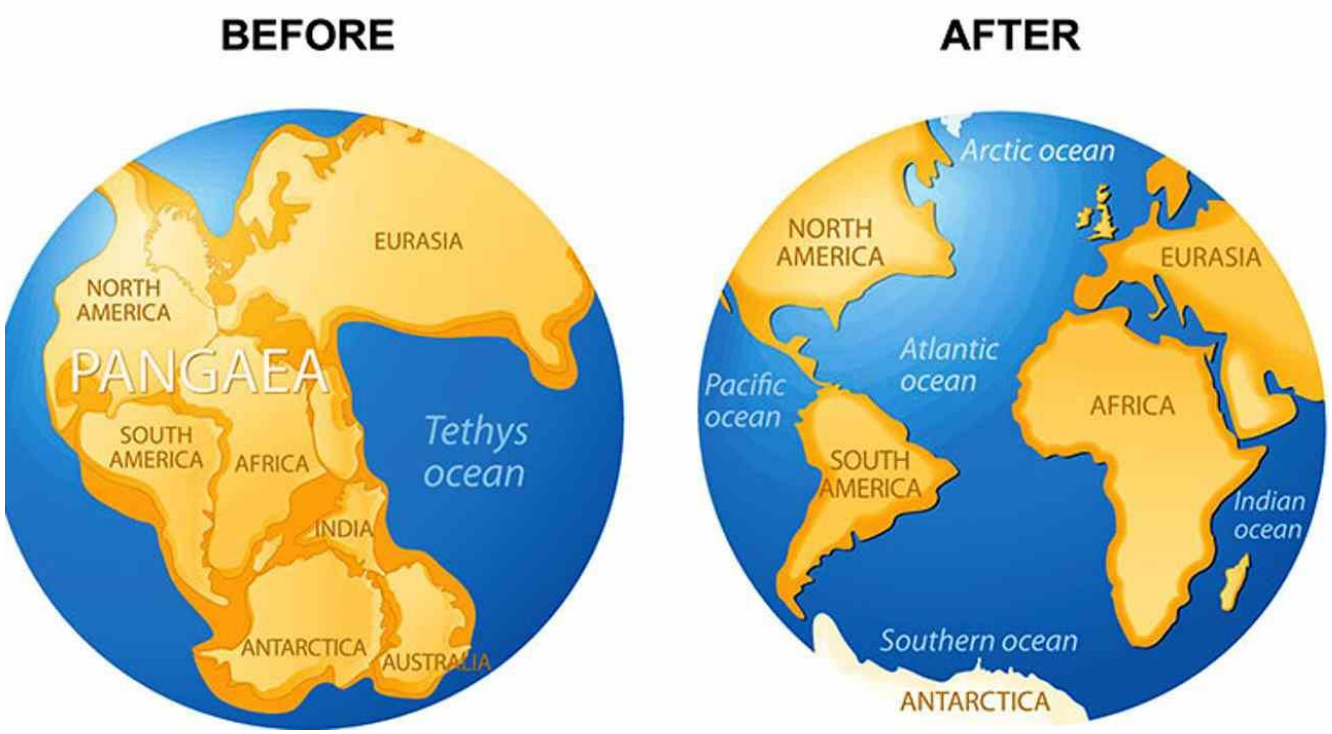

Other even-toed ungulates
Hippopotamuses
†Pakicetus
†Rodhocetus
†Dorudon
Living cetaceans
Pelvis and hind limb bones
Common ancestor of cetaceans
70
60
50
40
30
20
10
0
Millions of years ago
Key to cetacean pelvis and hind limb bones
Pelvis
Tibia
Femur
Foot

- Fossil evidence shows that living cetaceans and their close relatives, the even-toed ungulates, are more different from each other today than were early cetaceans and even-toed ungulates



Biogeography

- **Biogeography**, the scientific study of the geographic distribution of species, provides evidence of evolution
- Earth's continents were formerly united in a single large continent called **Pangaea**, but have since separated by continental drift
- An understanding of continent movement and modern distribution of species allows us to predict when and where different groups evolved



Endemic species

- **Endemic** species are species that are not found anywhere else in the world
- Islands have many endemic species that are often closely related to species on the nearest mainland or island
- Darwin suggested that species from the mainland colonized islands and gave rise to new species as they adapted to new environments

What is a species?

Species and speciation

- **Speciation**, the process by which one species splits into two or more species, is at the focal point of evolutionary theory
- **Microevolution** consists of changes in allele frequency in a population over time
- **Macroevolution** refers to broad patterns of evolutionary change above the species level
- Speciation forms a conceptual bridge between microevolution and macroevolution

Animation: Macroevolution

The Biological Species Concept

- *Species* is a Latin word meaning "kind" or "appearance"
- Biologists compare morphology, physiology, biochemistry, and DNA sequences when grouping organisms
- The **biological species concept** states that a **species** is a group of populations whose members have the potential to interbreed in nature and produce viable, fertile offspring; they do not breed successfully with members of other such groups
- Gene flow between populations holds a species together genetically

The biological species concept is based on the potential to interbreed, not on physical similarity

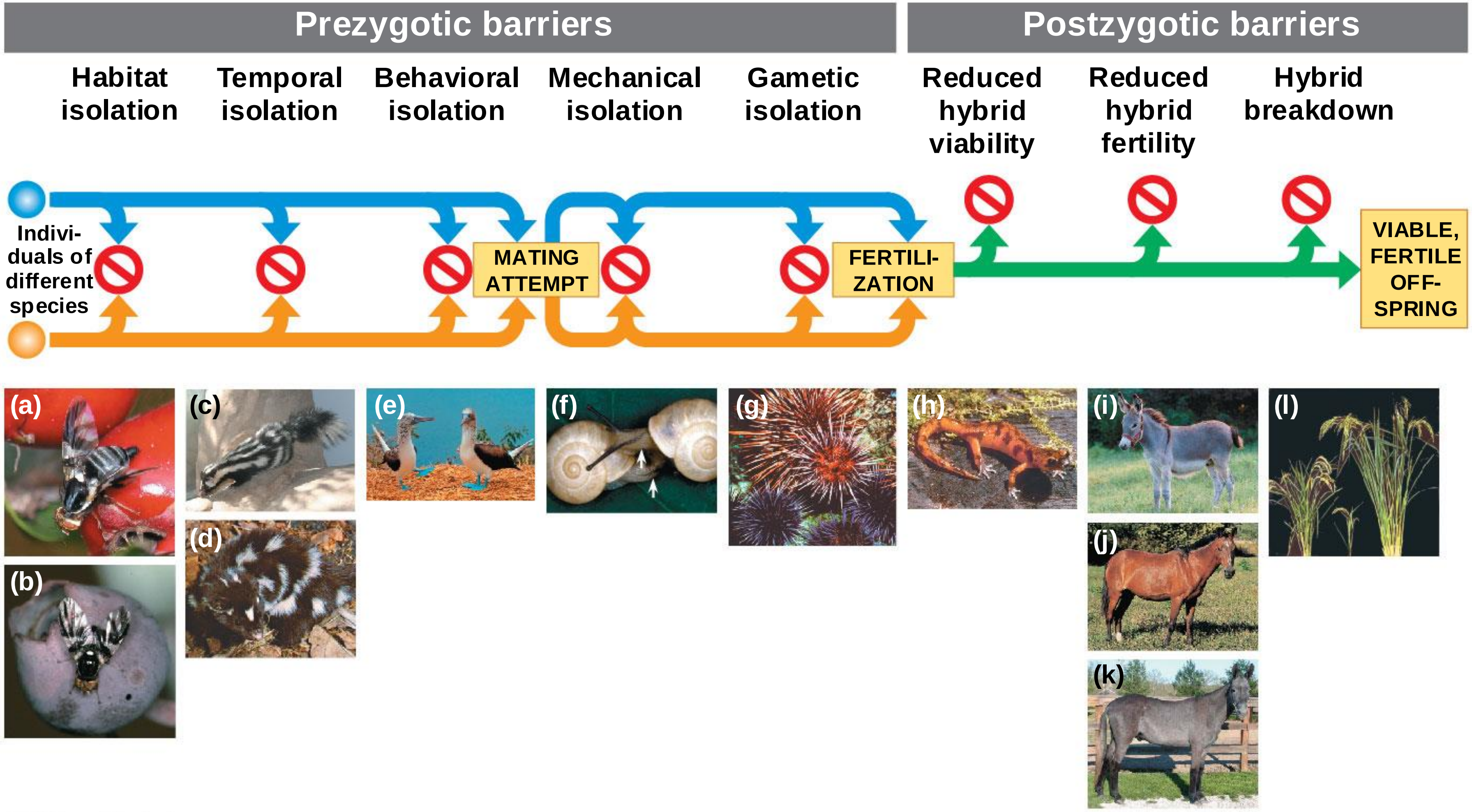
(a) Similarity between different species

(b) Diversity within a species

Reproductive Isolation

- **Reproductive isolation** is the existence of biological factors (barriers) that impede two species from producing viable, fertile offspring
- **Hybrids** are the offspring that result from mating between different species
- Reproductive isolation can be classified by whether factors act before or after fertilization

Reproductive barriers



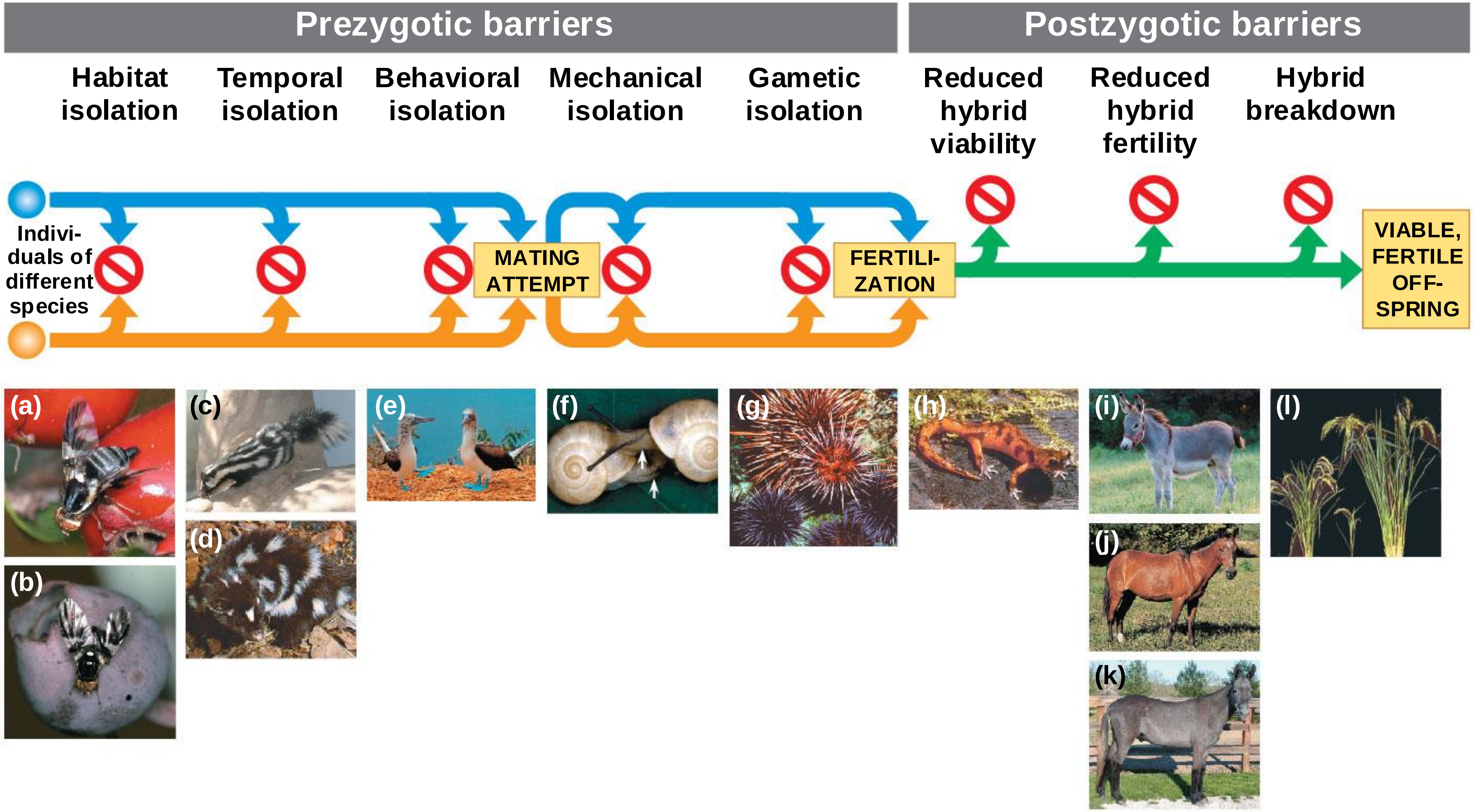
- **Prezygotic barriers** block fertilization from occurring by
  - Impeding different species from attempting to mate
  - Preventing the successful completion of mating
  - Hindering fertilization if mating is successful

- **Habitat isolation**: Two species encounter each other rarely, or not at all, because they occupy different habitats, even though not isolated by physical barriers

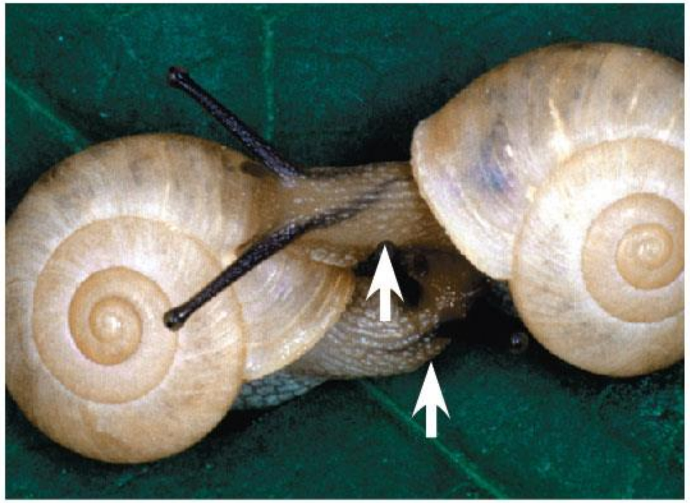
- **Temporal isolation**: Species that breed at different times of the day, different seasons, or different years cannot mix their gametes

- **Behavioral isolation**: Courtship rituals and other behaviors unique to a species are effective barriers to mating

Video: Albatross Courtship Ritual

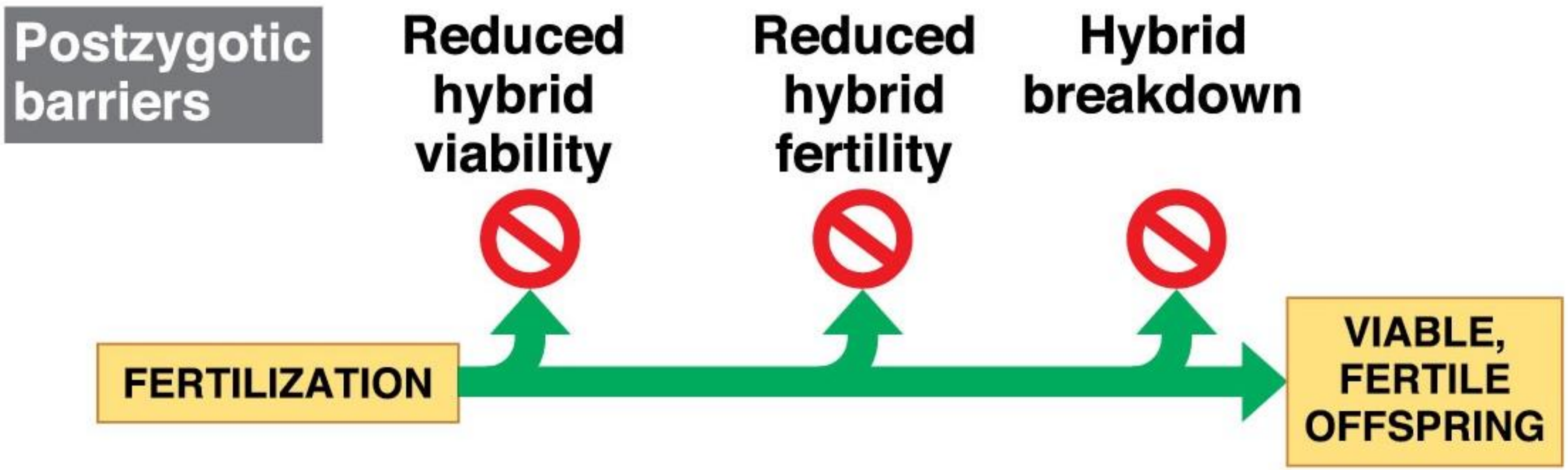

Prezygotic barriers
Postzygotic barriers
Habitat isolation
Temporal isolation
Behavioral isolation
Mechanical isolation
Gametic isolation
Reduced hybrid viability
Reduced hybrid fertility
Hybrid breakdown
Individuals of different species
MATING ATTEMPT
FERTILIZATION
VIABLE, FERTILE OFFSPRING
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)

- **Mechanical isolation**: Morphological differences can prevent successful completion of mating



- **Gametic Isolation:** Sperm of one species may not be able to fertilize eggs of another species

- **Postzygotic barriers** prevent the hybrid zygote from developing into a viable, fertile adult by
  - Reduced hybrid viability
  - Reduced hybrid fertility
  - Hybrid breakdown



- **Reduced hybrid viability:** Genes of the different parent species may interact and impair the hybrid's development or survival in its environment

- **Reduced hybrid fertility:** Even if hybrids are vigorous, they may be sterile

Donkeys (Equus africanus asinus)

Horse (Equus ferus caballus)

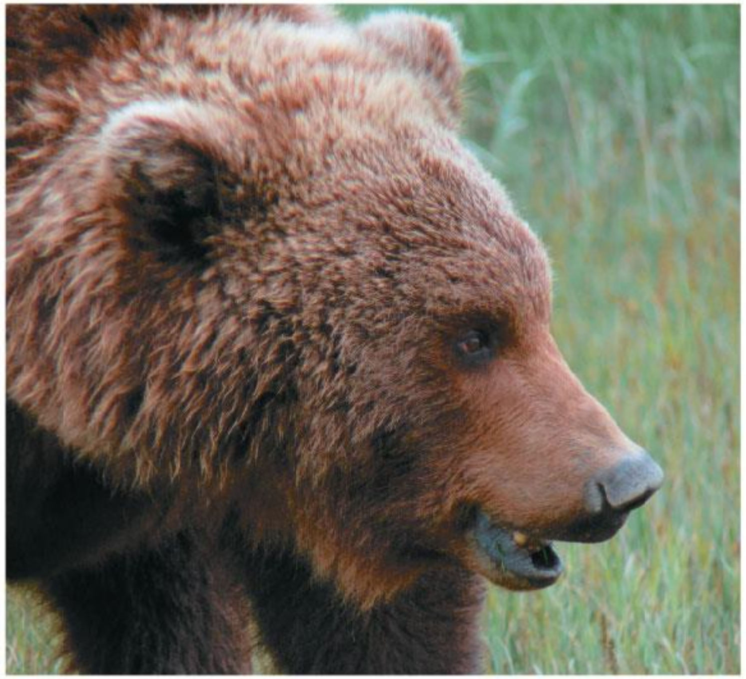
Mules (Equus mulus)

Sterile

- **Hybrid breakdown**: Some first-generation hybrids are fertile, but when they mate with each other or with either parent species, offspring of the next generation are feeble or sterile

Limitations of the Biological Species Concept

- The biological species concept cannot be applied to fossils or asexual organisms (including all prokaryotes)
- The biological species concept emphasizes absence of gene flow
- However, gene flow can occur between morphologically and ecologically distinct species
  - For example, grizzly bears and polar bears can mate to produce “grolar bears”



Grizzly bear (*U. arctos*)

Polar bear (*U. maritimus*)

Hybrid “grolar bear”

Other Definitions of Species

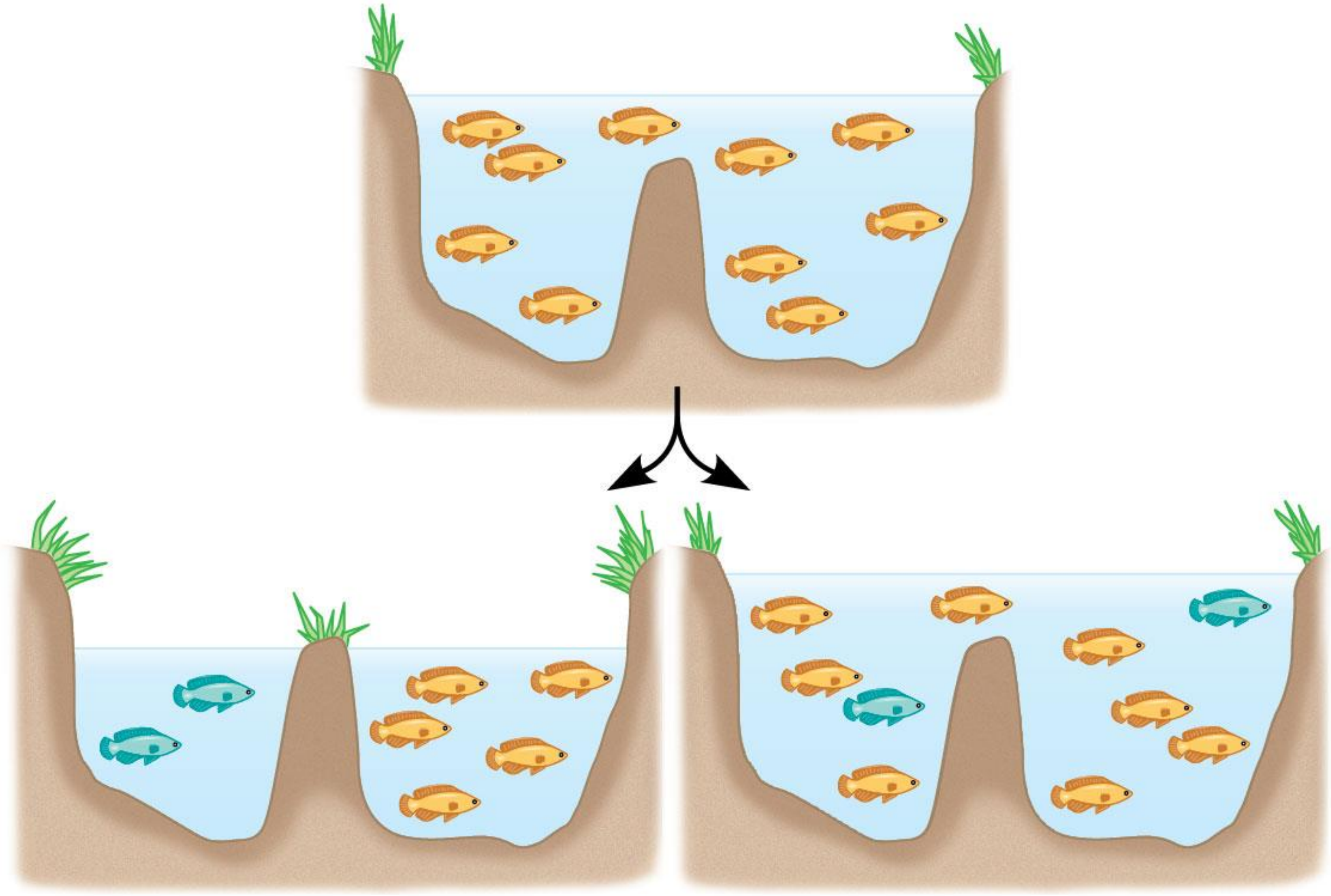
- Other species concepts emphasize the unity within a species rather than the separateness of different species
- The **morphological species concept** defines a species by structural features
    - It applies to sexual and asexual species but relies on subjective criteria

- The **ecological species concept** defines a species in terms of its ecological niche
  - It applies to sexual and asexual species and emphasizes the role of disruptive selection
- Many species definitions have been proposed; the usefulness of each depends on the situation and the research questions being asked

Speciation

Speciation can take place with or without geographic separation.

- Speciation can occur in two ways:
  - Allopatric speciation
  - Sympatric speciation



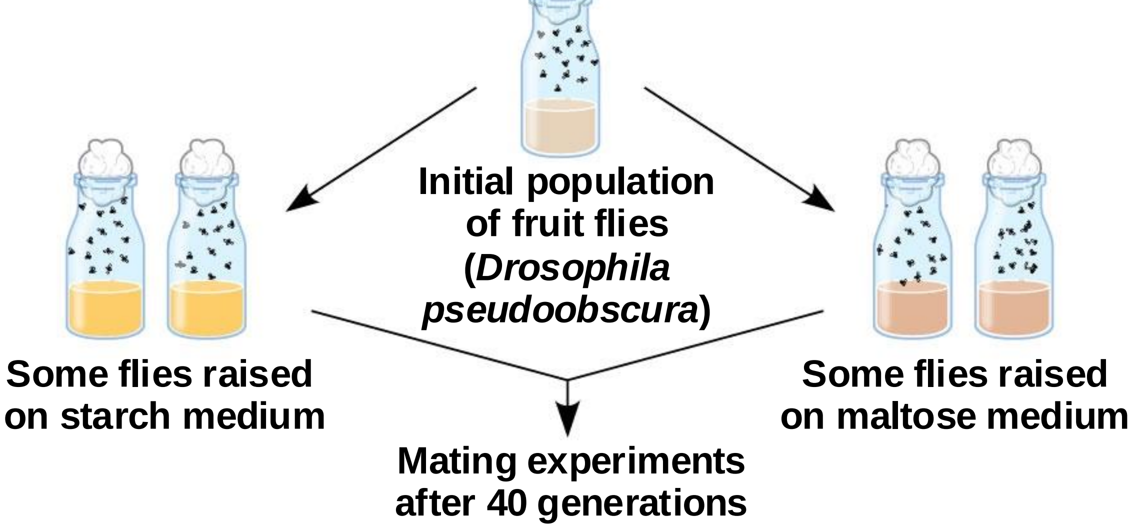
(a) Allopatric speciation (b) Sympatric speciation

Allopatric Speciation

- In **allopatric speciation**, gene flow is interrupted or reduced when a population is divided into geographically isolated subpopulations
  - For example, the flightless cormorant of the Galápagos likely originated from a flying species on the mainland

Can divergence of allopatric populations lead to reproductive isolation?

Experiment



Results

Number of matings in experimental group

		Female: Starch	Female: Maltose
Male	Starch	22	9
Male	Maltose	8	20

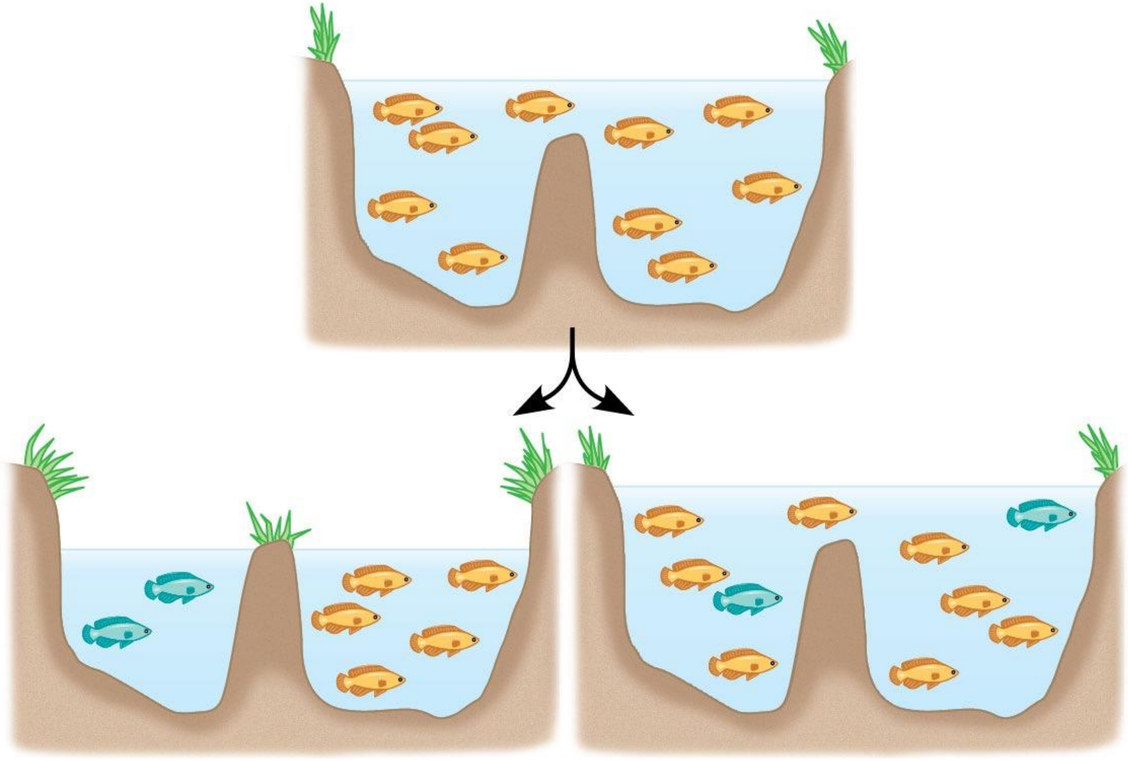
Number of matings in control group

		Female: Starch population 1	Female: Starch population 2
Male	Starch population 1	18	15
Male	Starch population 2	12	15

Data from D. M. B. Dodd, Reproductive isolation as a consequence of adaptive divergence in *Drosophila pseudoobscura*, *Evolution* 43:1308–1311 (1989).

Sympatric Speciation

- In **sympatric speciation**, speciation occurs in populations that live in the same geographic area
- Sympatric speciation can occur if gene flow is reduced by factors including
  - Polyploidy
  - Sexual selection
  - Habitat differentiation

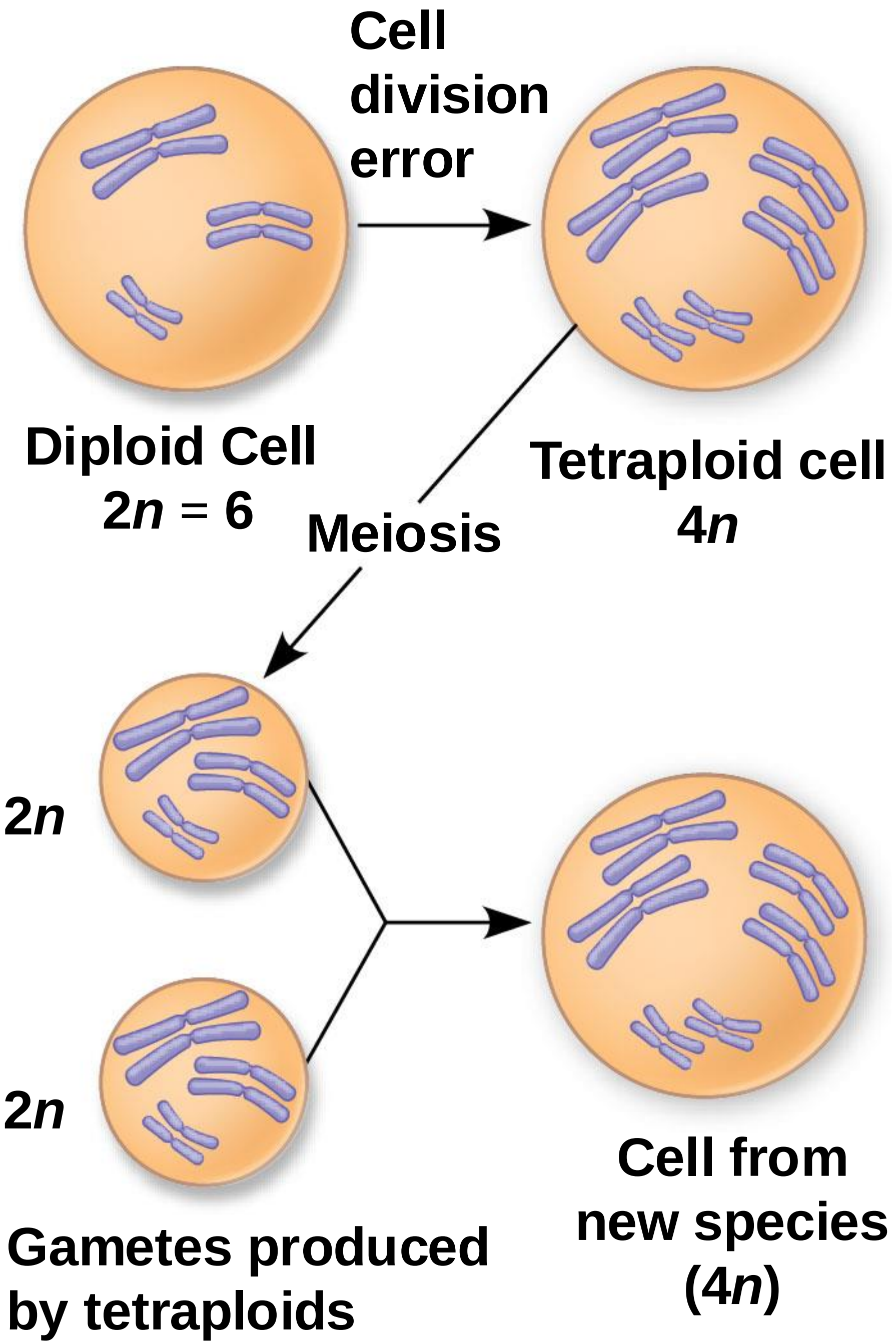


(a) Allopatric speciation (b) Sympatric speciation

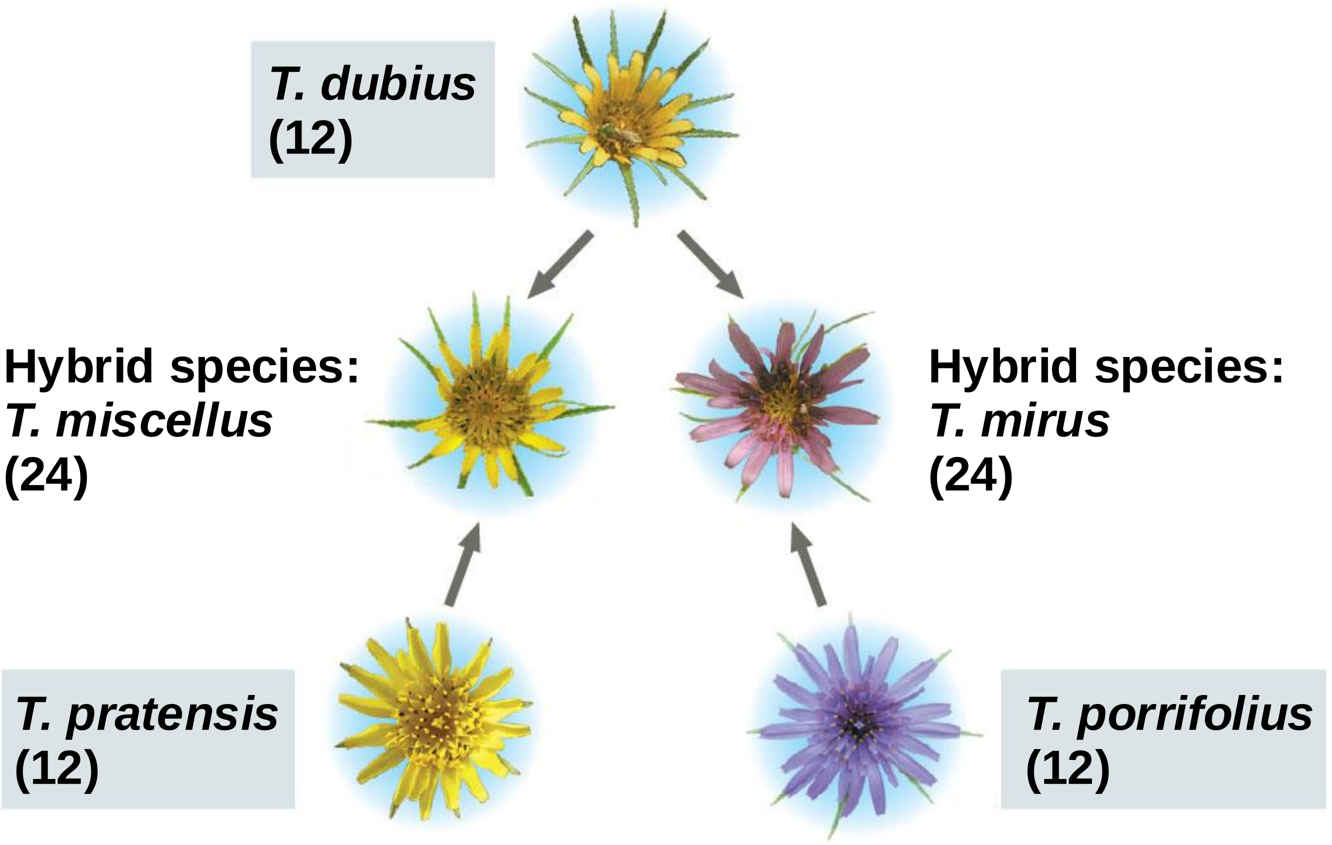
Polyploidy

- **Polyploidy** is the presence of extra sets of chromosomes due to accidents during cell division
- Polyploidy is much more common in plants than in animals
- Polyploidy can produce new biological species in sympatry within a single generation
- An **autopolyploid** is an individual with more than two chromosome sets derived from a single species
- The offspring resulting from mating between polyploids and diploids have reduced fertility

Sympatric speciation by autopolyploidy



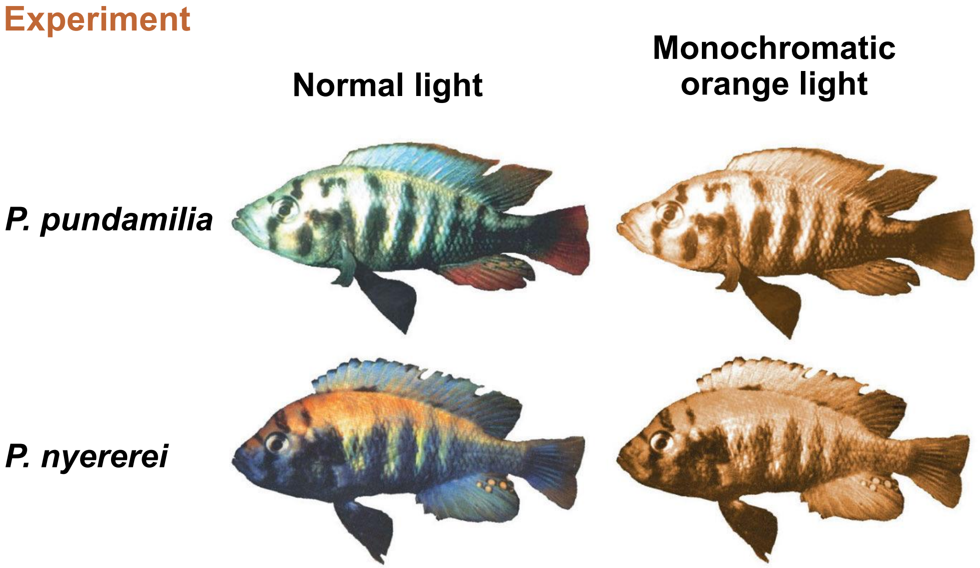
- At least five new plant species have originated by polyploid speciation since 1850
  - For example, in the genus *Tragopogon*, two allopolyploid species have evolved from three diploid parent species



- Many important crops (oats, cotton, potatoes, tobacco, and wheat) are polyploids
- Plant geneticists can produce new polyploid agricultural species using chemicals to induce errors in cell division

Sexual Selection

- Sexual selection can drive sympatric speciation
- Sexual selection for mates of different colors has likely contributed to speciation in cichlid fish in Lake Victoria



Data from O. Seehausen and J. J. M. van Alphen, The effect of male coloration on female mate choice in closely related Lake Victoria cichlids (*Haplochromis nyererei* complex), *Behavioral Ecology and Sociobiology* 42:1–8 (1998).

Habitat Differentiation

- Sympatric speciation can also result from the appearance of new ecological niches
  - For example, populations of the North American maggot fly (*Rhagoletis pomonella*) can live on native hawthorn trees, as well as more recently introduced apple trees
  - Flies that use different host species experience both habitat and temporal isolation

(a) *Gryllus pennsylvanicus* prefers sandy soil.

(b) *Gryllus firmus* prefers loamy soil.