LSM1301
GENERAL BIOLOGY

Evolution

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Consultation via appointment

“Seen in the light of evolution, biology is, perhaps intellectually the most satisfying and inspiring science. Without that light it becomes a pile of sundry facts – some of them interesting or curious but making no meaningful picture as a whole”

Theodosius Dobzhansky,

Learning objectives

- To describe pre-Darwinian thinking on the natural world and the observations and logic by which Darwin and Wallace deduced the **theory of evolution through natural selection**
- To explain the process of natural selection and how **heritable variation** in traits results in **organisms becoming adapted** to their environments
- To explain how **evolution in populations** is related to a change in allele frequencies
- To describe different **mechanisms of evolutionary change** and types of evidence supporting evolution and descent from a **common ancestor**

Learning activities

- Pre-lecture
  - Watch videos on evolution Crash course (10min), Galapagos finches (10min), natural and sexual selection (8min) and e-tutorial on Evolutionary Change (8min)

    (LumiNUS > Multimedia > Pre-lecture video assignments > "Evolution:xxxxxxx")
  - Take down notes and refer to lecture slides.

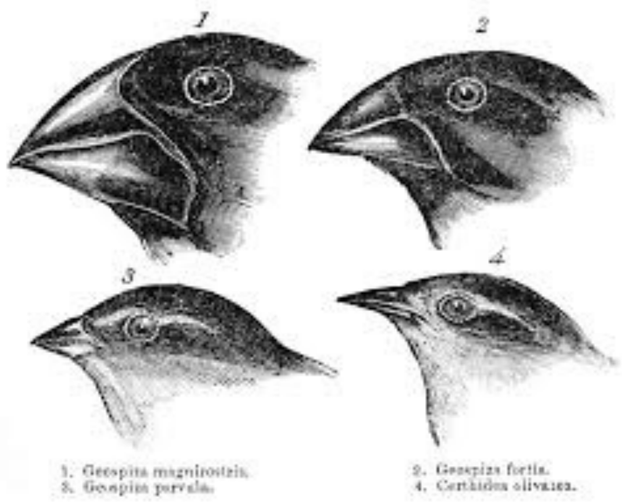
- During lecture
  - In class participation. Log in with NUS Poll Everywhere account.

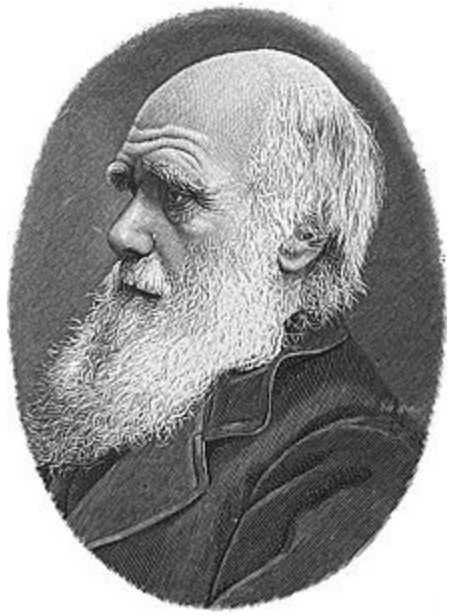
- Post-lecture
  - Take ungraded quiz to revise lecture material

    (LumiNUS > Quiz > "Evolution")

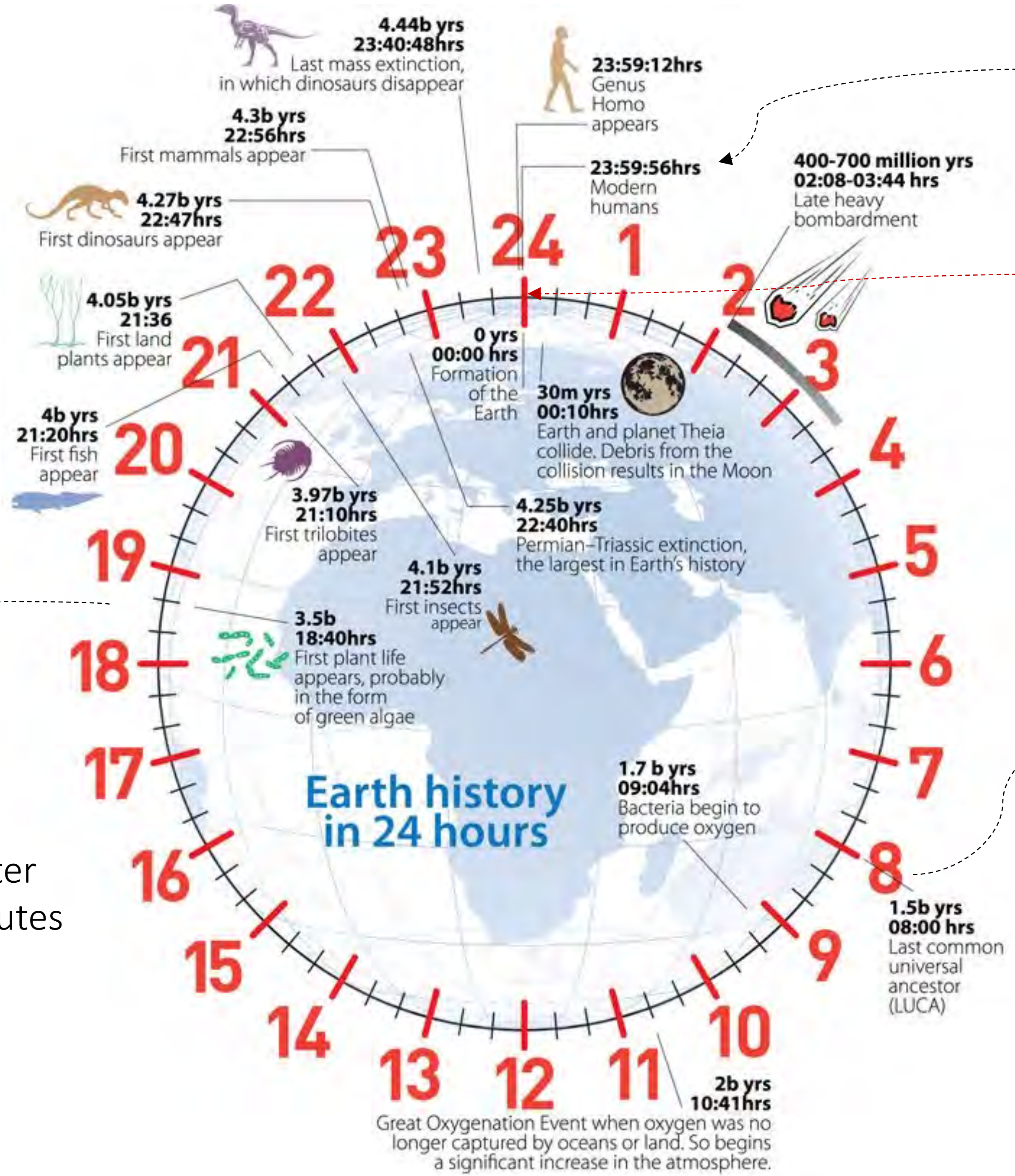
Outline

- Defining evolution
- History of evolutionary thought
  - ➢ Influential thinkers; Charles Darwin; Alfred Russel Wallace
  - ➢ Theory of natural selection and principles of inheritance
- Forces of evolutionary change
  - ➢ Mechanisms of selection (e.g. natural, artificial, sexual)
  - ➢ Mutation, genetic drift, gene flow
- Evidence for evolution
  - ➢ Fossils and comparative anatomy
  - ➢ DNA and biochemistry
- Evolution and us





Modern humans in the last four seconds.



Last common universal ancestor

First plant life after 18 hours 40 minutes

Defining evolution

- Process by which **extant** organisms have **descended** from ancient organisms **over time**

- Common textbook definitions:
  - "Descent with modification"
  - "Change in allele frequencies within a population from one generation to the next"
  - "Gradual change in inherited traits in a population over time that makes organisms more suited to the environment"

Defining evolution

Why evolve?

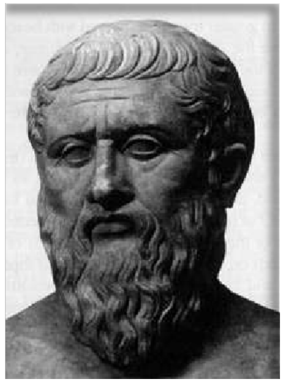
- The Earth is a dynamic, always changing environment
- Individuals with the right characteristics that make them **suited to their environment** will **survive to reproduce** and **pass on their genes**
- Theory of Natural Selection helps us understand how **populations** of organisms gradually **change** and become **adapted** to their environments

History of evolutionary thought

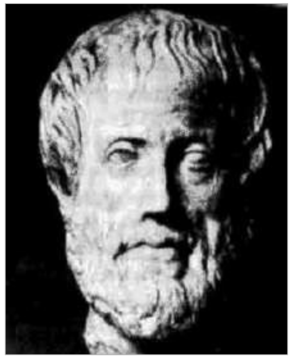
Early explanations for life's diversity:

- All organisms were created simultaneously
- Each organism has an ideal form: fixed and unchanging since its creation
- Life forms do not change through time from generation to generation
- Can be arranged on a "scale of perfection"

- Ideas persisted until 1700-1800s



Plato
(427-347 B.C.)



Aristotle
(384-322 B.C.)

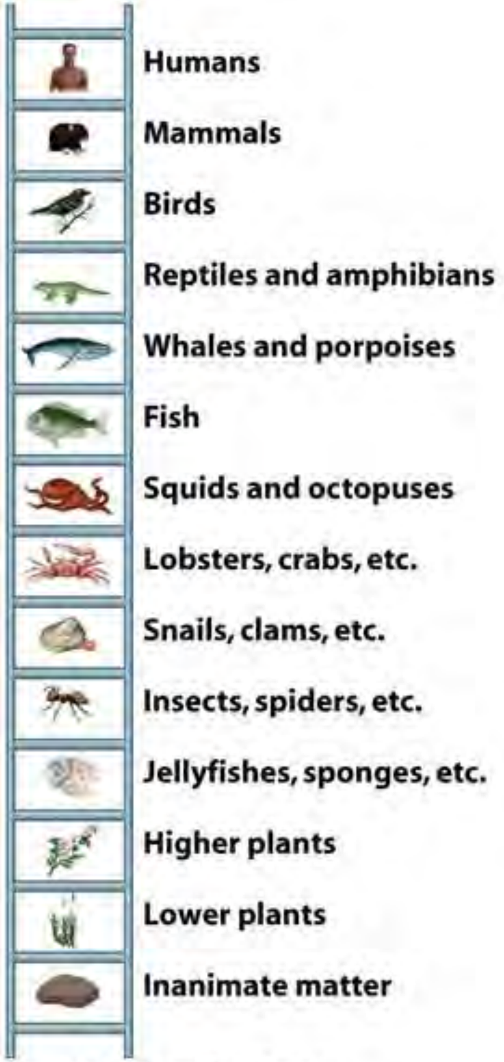
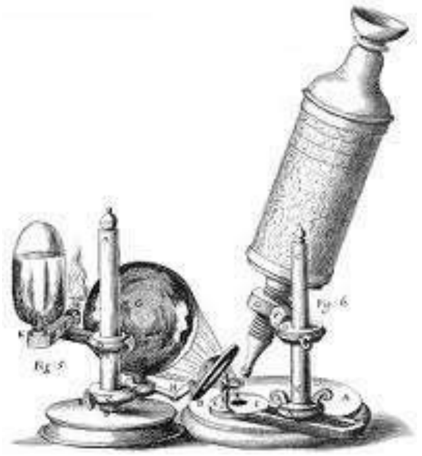


Figure 14-2 Biology: Life on Earth, 8/e
© 2008 Pearson Prentice Hall, Inc.

History of evolutionary thought

Progress in science and technology after the Middle Ages

- Disproved “spontaneous generation”
- Cell theory and germ theory – invention of microscope
- Study of natural geological processes



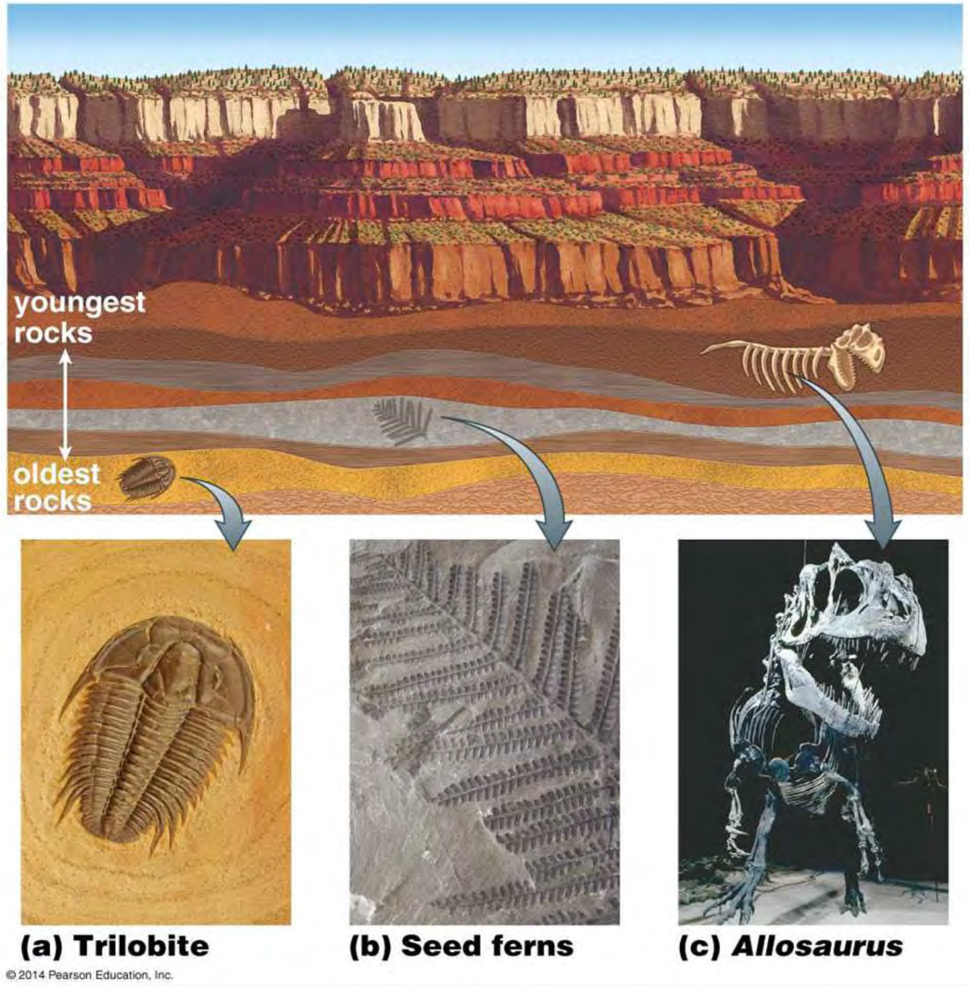
Exploration and colonization widened horizons

- Europeans “discover” new continents
- Encounter and collect strange animals and plants
- Increased interest in natural world

History of evolutionary thought

Advances in the study of fossils

- ➢ Different layers of rock have different fossil organisms
- ➢ The deeper the layer, the more dissimilar the fossils were to modern organisms



Extinct 230mya　Extinct 150mya　Extinct 65mya

- In the 1700-1800's, scientists started questioning: Can species change?

Influential thinkers

Georges Cuvier

- Father of palaeontology
- "Principle of Superposition" of geologic layers:
  - New rocks form above old ones
- Accepted that fossils are extinct species
- "Catatrophism" to explain changes in fossils the different layers:
  - Extinct species were created at same time as existing species but had died in catastrophic events

Georges Cuvier (1769-1832)

Influential thinkers

James Hutton & Charles Lyell

- Theory of “Uniformitarianism”:
  - Geological processes occur at the slow and steady rate observed in the present day
- Long periods of time has produced extreme geological change
  - Example: River erosion forming the Grand Canyon

- Implies that the earth is much, much older than 6,000 years

James Hutton (1726–1797)

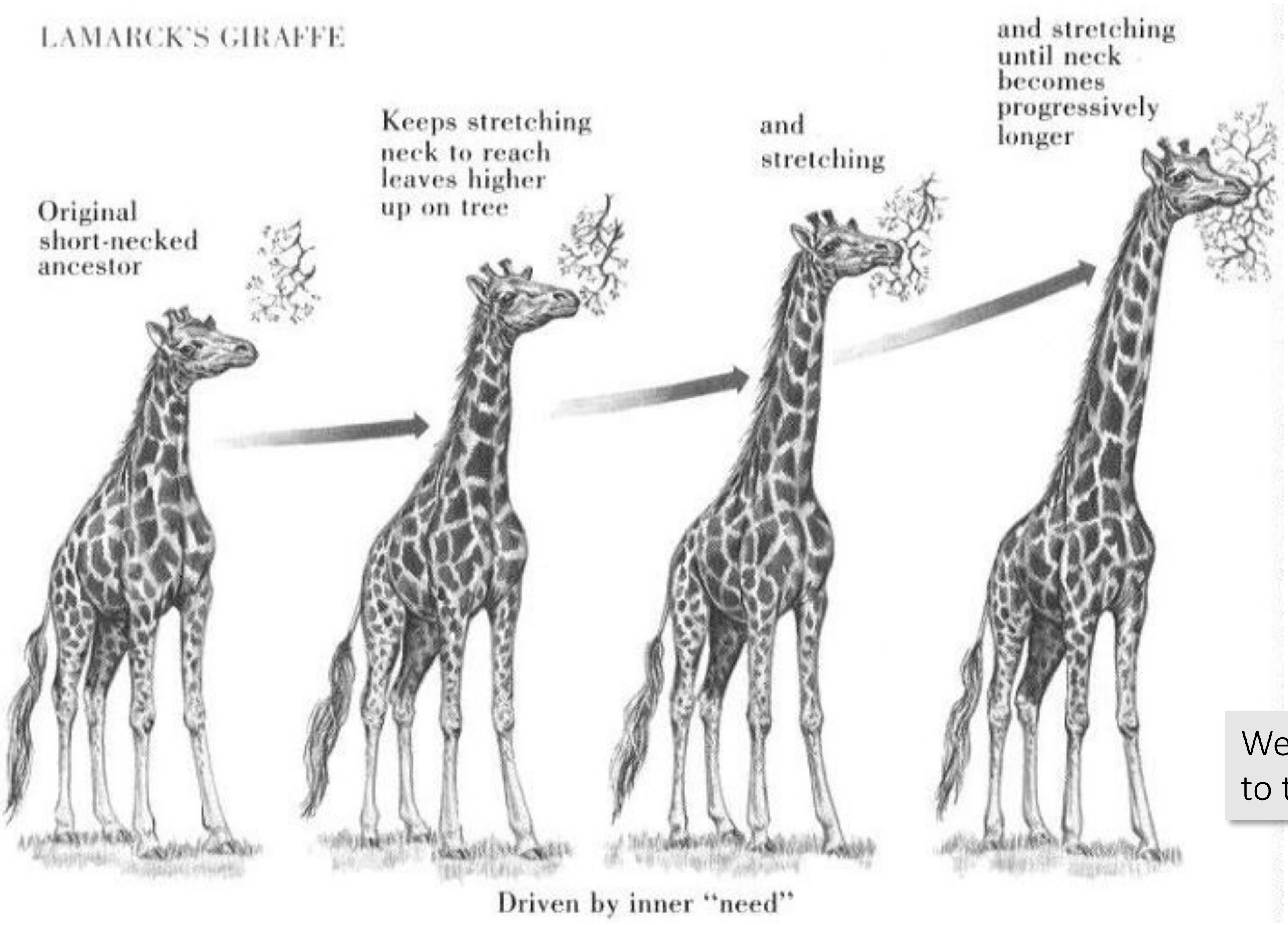
Sir Charles Lyell (1797–1875)

Influential thinkers

Jean-Baptiste de Lamarck

- First to propose a scientifically testable mechanism for species transformation
- Inheritance of acquired characteristics
  - Individuals can improve their abilities by using a part of their body repeatedly
  - Parts are changed by use or disuse
  - Modifications are inherited by offspring
- Environment influences the acquisition or loss of traits (*within* a lifetime)

Jean Baptiste Lamarck (1744–1829)



Jean Baptiste Lamarck (1744–1829)

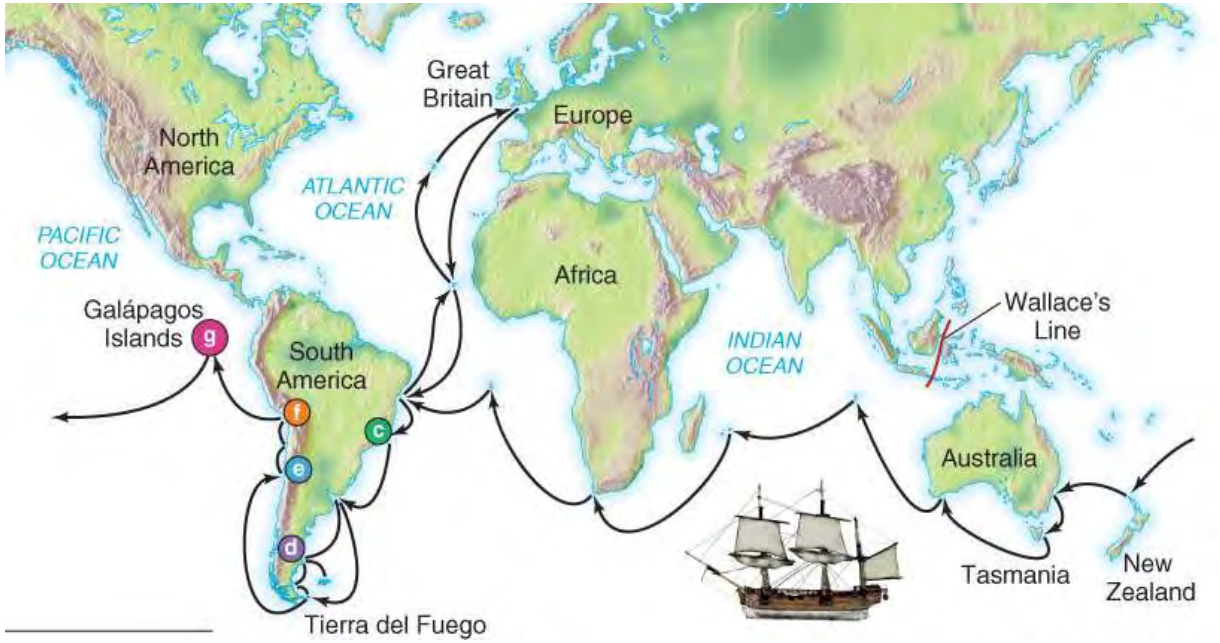
We'll return to this later…

Savage (1969) *Evolution*

Charles Darwin

- Naturalist, geologist and biologist who joined the HMS Beagle's voyage around the world (1831-1836)
- Collected thousands of specimens of living and fossil organisms

Charles Darwin (1808-1882)



Charles Darwin

Collected thousands of specimens of living and fossil organisms.

Observations on the trip formed basis for explaining how species change through ‘descent with modification’:

- Fossils of extinct animals were likely related to living organisms
- Unrelated organisms shared similar features when they inhabit similar habitats on different continents
- Related organisms inhabiting different habitats on islands had features suited to those different environments

Glyptodont

Armadillo

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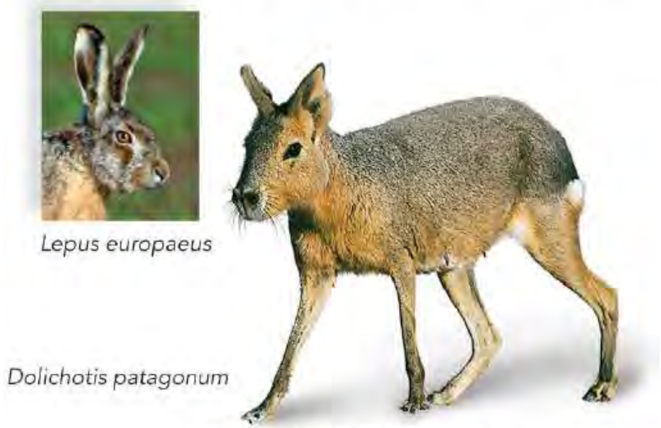
Rabbit in Europe



Cavy in South America

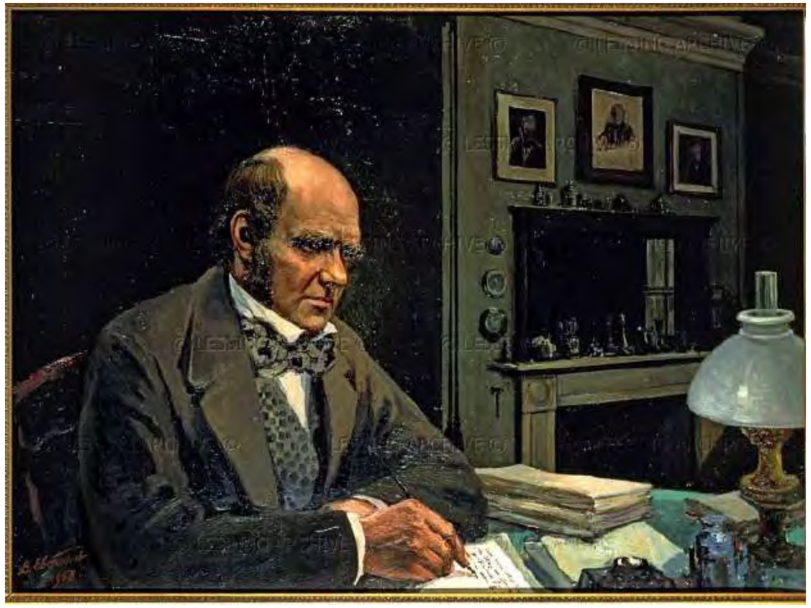
(Left): © WILDLIFE/Peter Arnold/Photolibrary; (Right): © Juan & Carmecita Munoz/Photo Researchers, Inc.

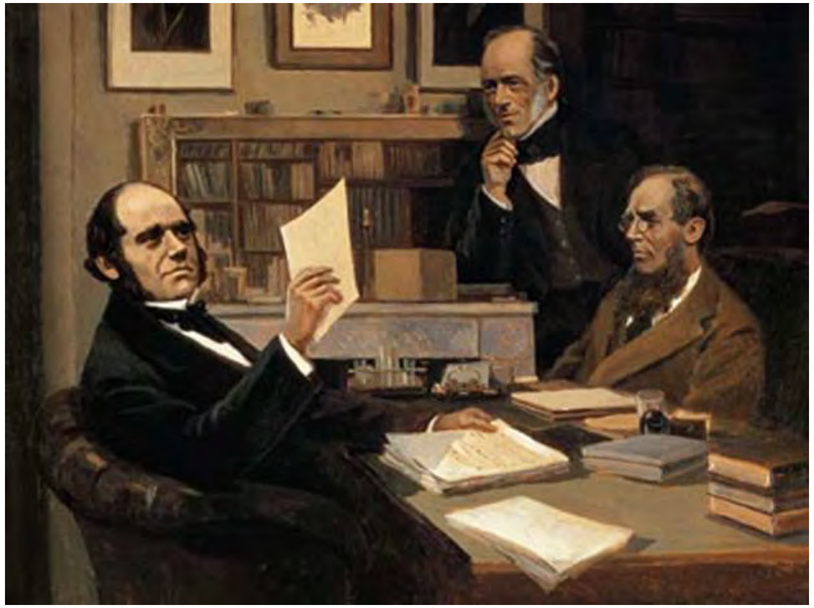
Galapagos island finches

Charles Darwin

Returned to England and read Thomas Malthus' *Essay on the Principle of Populations*

- Populations have the potential to increase quickly but are limited by food supply, disease, etc.
- More children are born in a generation than survive to become adults
- Environmental challenges and competition mean that the individuals who cannot obtain essential resources will die



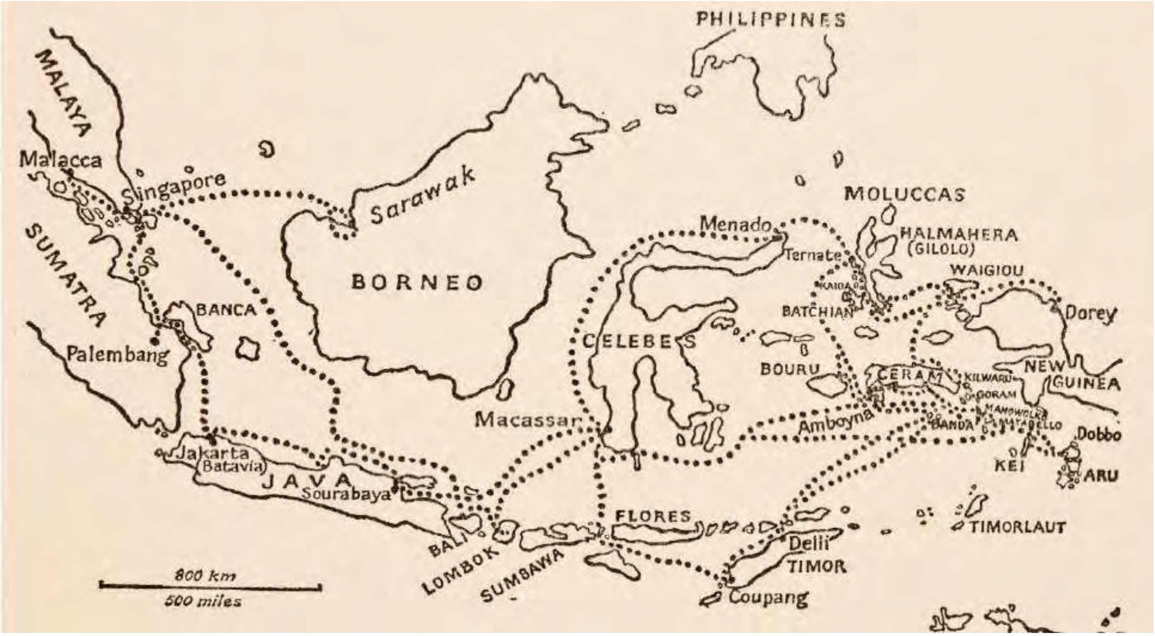


Carefully gathered evidence and formulated his theory for over 10 years without publishing

Alfred Russel Wallace

- Professional collector of animal specimens who travelled in South America (1848-1852) and Southeast Asia (1854-1862)
- Independently proposed the same mechanism for species change as Darwin

Alfred R. Wallace (1823-1913)



Alfred Russel Wallace

Wallace collected extensively in Singapore in mid 1800s

"In about 2 months, I obtained no less than 700 species of beetles, with 130 distinct kinds of the elegant Longicorns (Cerambycidae) so much esteemed by collectors. Almost all these were collected in one patch of jungle, not more than a square mile in extent, and in all my subsequent travels in the East. I rarely ever met with so productive a spot"

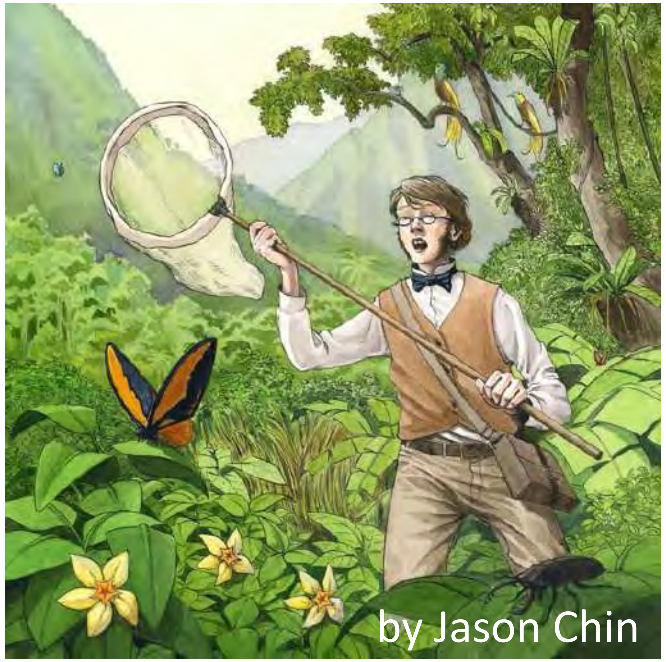
Catharsius molossus
Collected Sept-Oct 1854
1.283° N | 103.83° E

Alfred Russel Wallace

Wallace collected multiple individuals of the same species in tropical jungles

- Noticed small differences between individuals in his collections
- “The existence of wild animals is a struggle for existence”: those which are weak, old, diseased do not survive

- Hypothesized that the slight **variations** between individuals may have an effect on **survival**



Theory of Natural Selection

to explain how species evolve

Observations

- Individuals are different from each other — VARIATION
- Traits are passed from parents to offspring — HERITABLE
- More offspring are born than survive to reproduce — FITNESS
- There is competition for limited resources in nature — SELECTION

Inferences

- The **inherited characteristics** of some individuals will make them **more successful at survival and reproduction**
- Over many generations, this will lead to the **accumulation of favourable traits** in a population

Evolution by natural selection

Giraffe evolution under natural selection

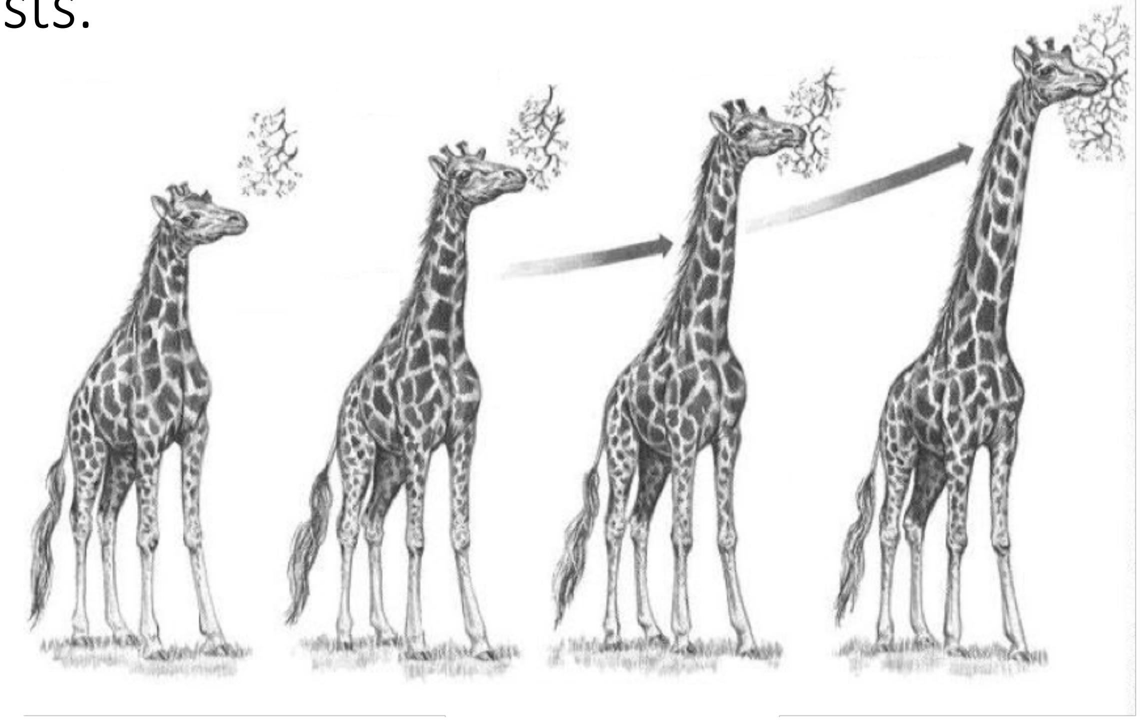
1. Most giraffes have **average neck length** and must compete for limited food resources

2. Some giraffes with average neck length **die due to lack of food**

3. Occasional **mutant** giraffes with **long necks** will have access to exclusive food resources and thus have a **higher survival rate** and be overrepresented in the next generation

Evolution by natural selection

This process continues until the benefits of a longer neck are outweighed by the costs.



Trait /adaptation

1. Natural variation
2. Heritable
3. Differential fitness

So outcome looks similar to Lamarckian evolution, but mechanism is very different: natural selection

Principles of inheritance

Darwin and Wallace never knew what was the source of variation among individuals and how traits are passed down from parents to offspring

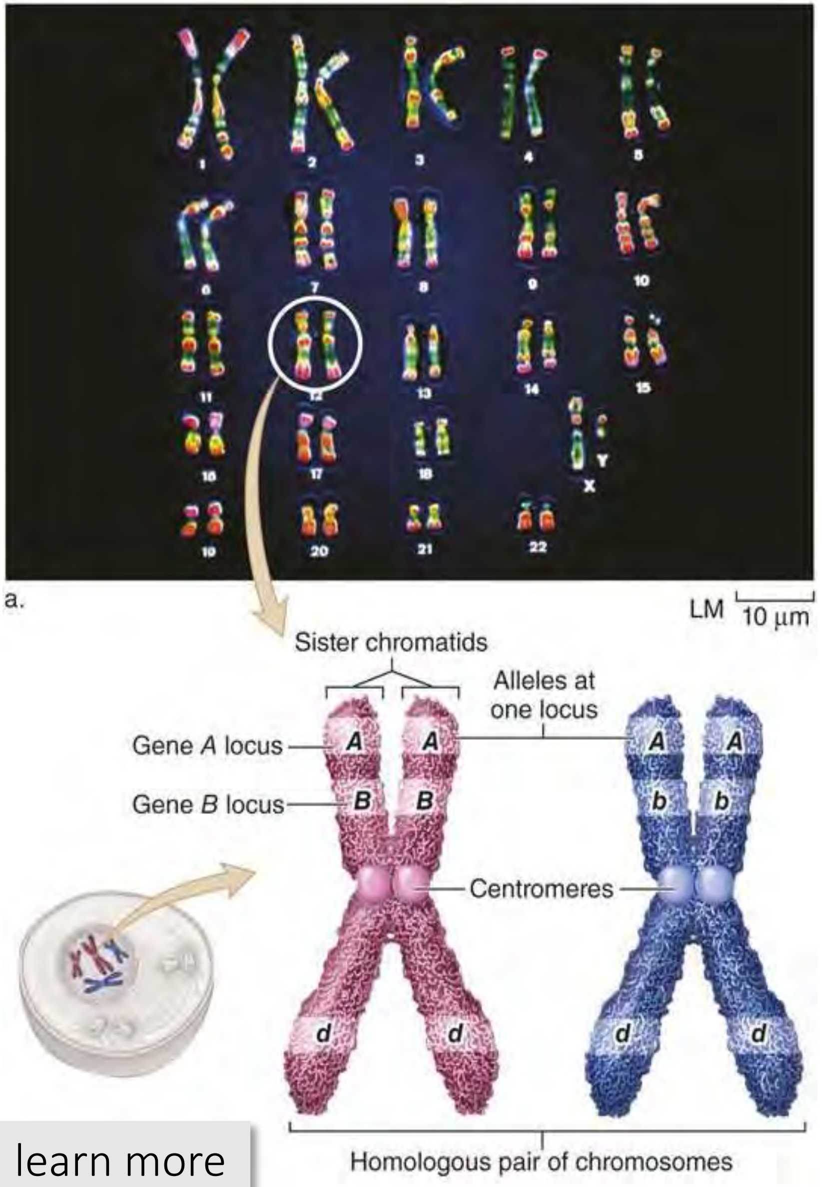
- Modern genetics can explain why individuals of the same species look different
- Physical traits have their basis in DNA, which is inherited

Principles of inheritance

DNA and Heredity

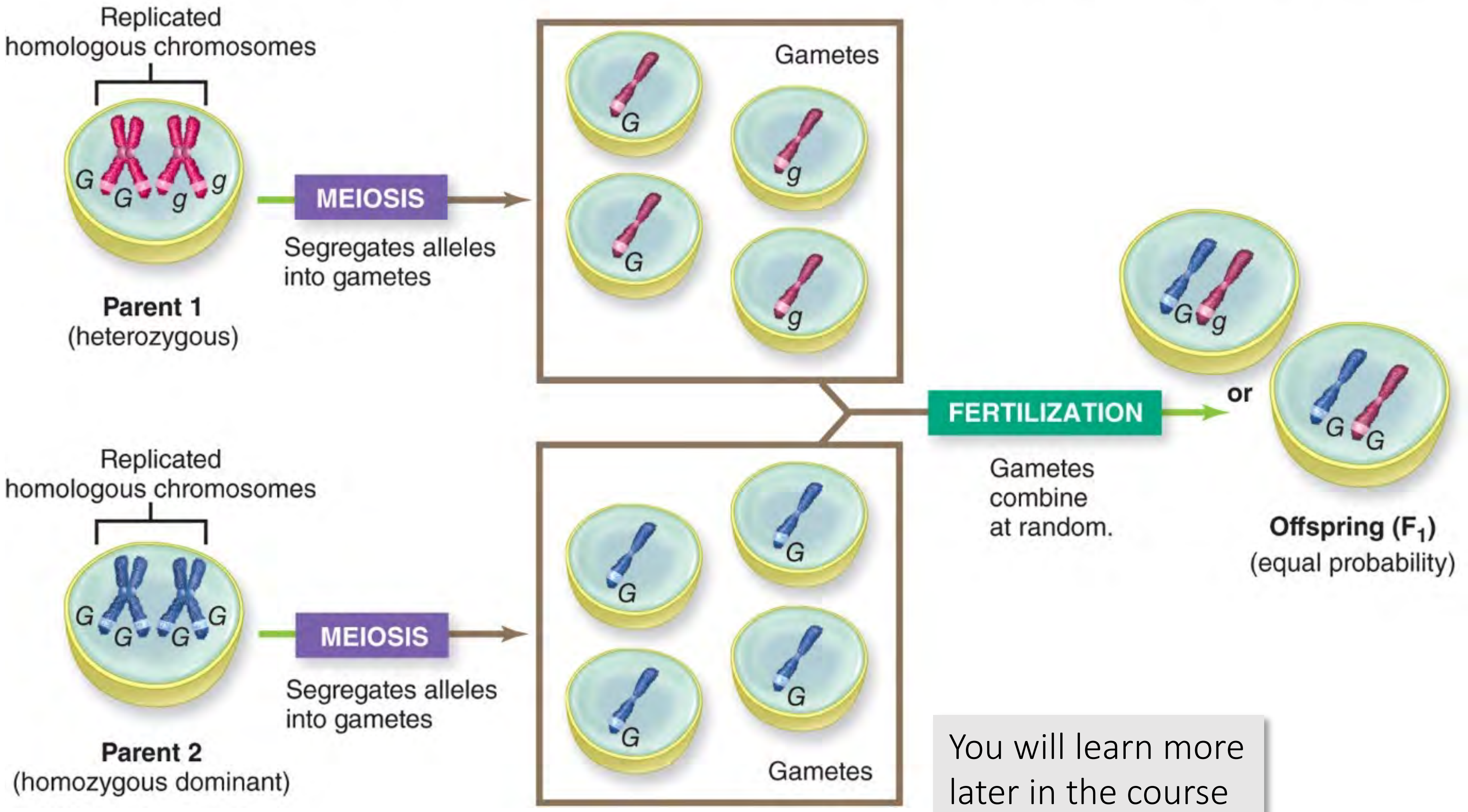
- DNA is tightly wound into chromosomes
- Diploid organisms have two sets of chromosomes inherited from their parents
- Members of a homologous pair of chromosomes have the same genes in the same sequence

Individuals may have different versions of those genes called **alleles**



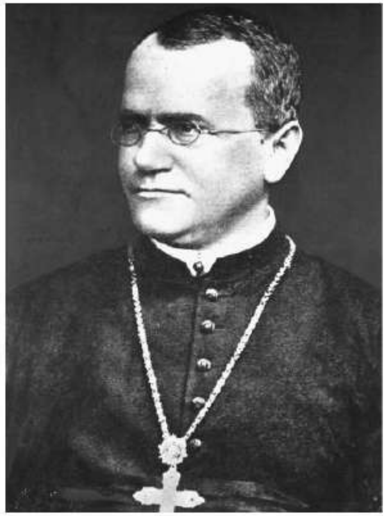
You will learn more later in the course

Principles of inheritance



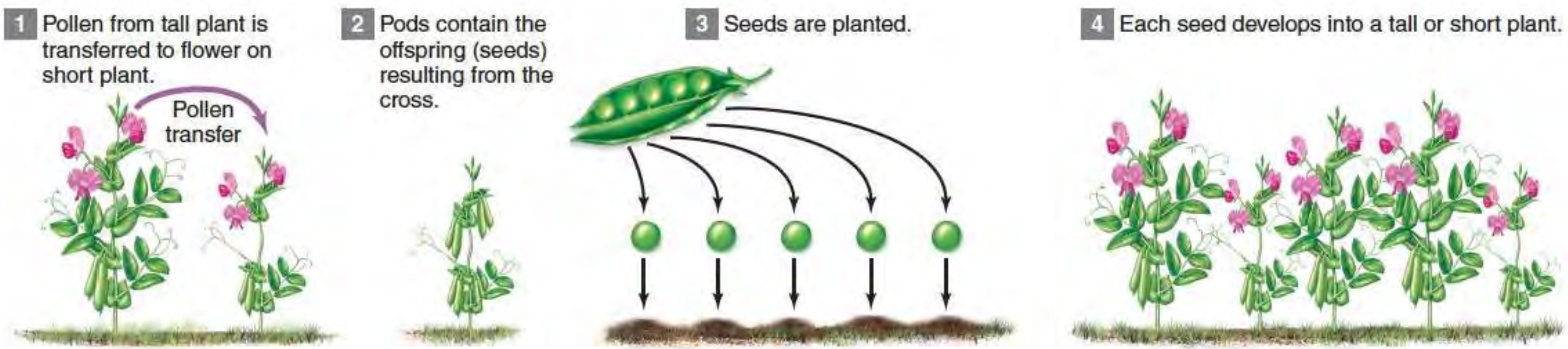
You will learn more later in the course

Principles of inheritance



Gregor Mendel

- Father of modern genetics, first to understand mechanisms of heredity
- Hand-pollinated pea plants to control their breeding and found that sometimes one trait could mask another
- Referred to these traits as “dominant” and “recessive”

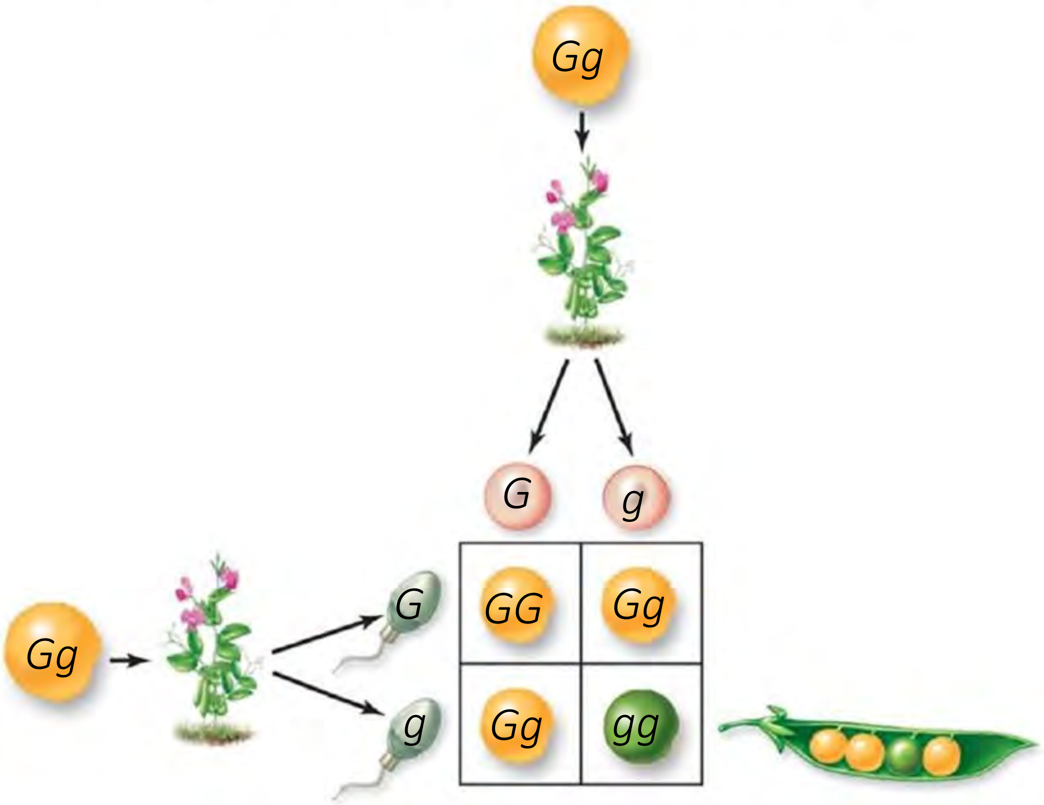


Principles of inheritance

Mendel studied traits that were encoded by genes with two alleles

- An individual's **genotype** (the combination of alleles) determines the **phenotype** (observable characteristic)
- Knowing the parents genotype, we know the probability of the offspring's phenotype

Genotype	Phenotype
Homozygous dominant (*GG*)	Yellow
Heterozygous (*Gg*)	Yellow
Homozygous recessive (*gg*)	Green



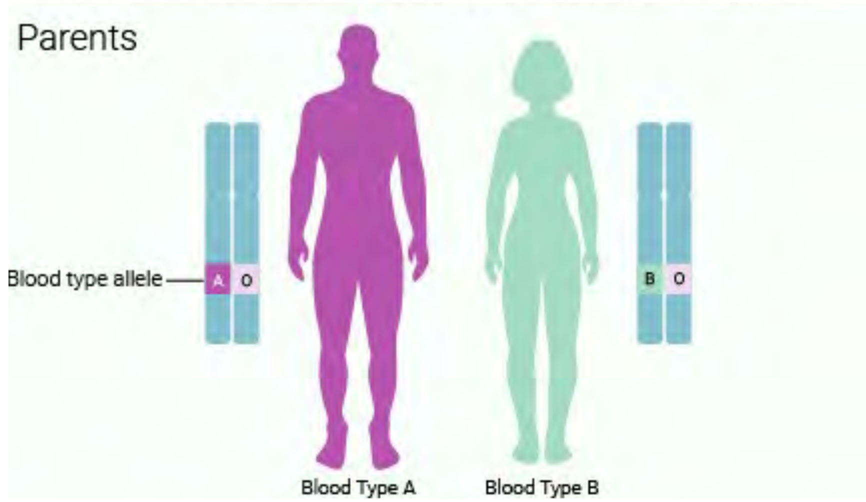
Genotypes and phenotypes – Blood groups

Blood group is identified by antibodies and antigens in the blood

Alleles

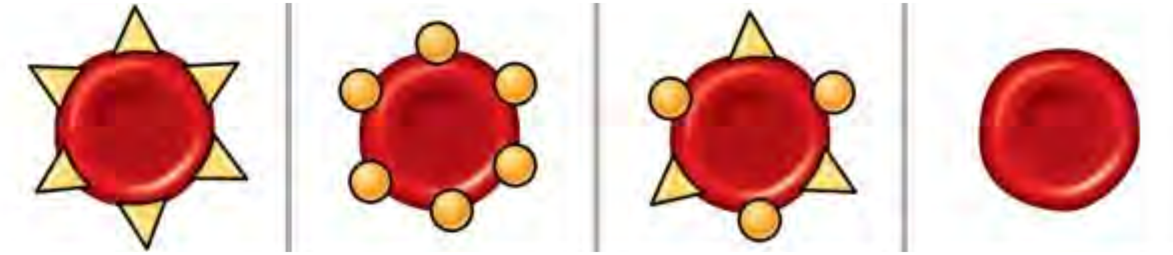
A  Dominant
B Dominant
O none Recessive

$\Big\}$ Co-dominant



Genotypes: AA AO BB BO AB OO

Genetic identity of a trait



Phenotypes: A B AB O

Physical expression or characteristic of the trait

6 different genotypes

4 possible phenotypes

Population genetics

Evolution is sometimes defined as a "change in **allele frequencies** within a population from one generation to the next"

- Population is a group of individuals of the same species living in the same area with potential to interbreed

Selection acts on the phenotype, but has a corresponding effect on genotype

- Evolution detectable by examining a population's gene pool (the entire collection of genes and alleles) over time

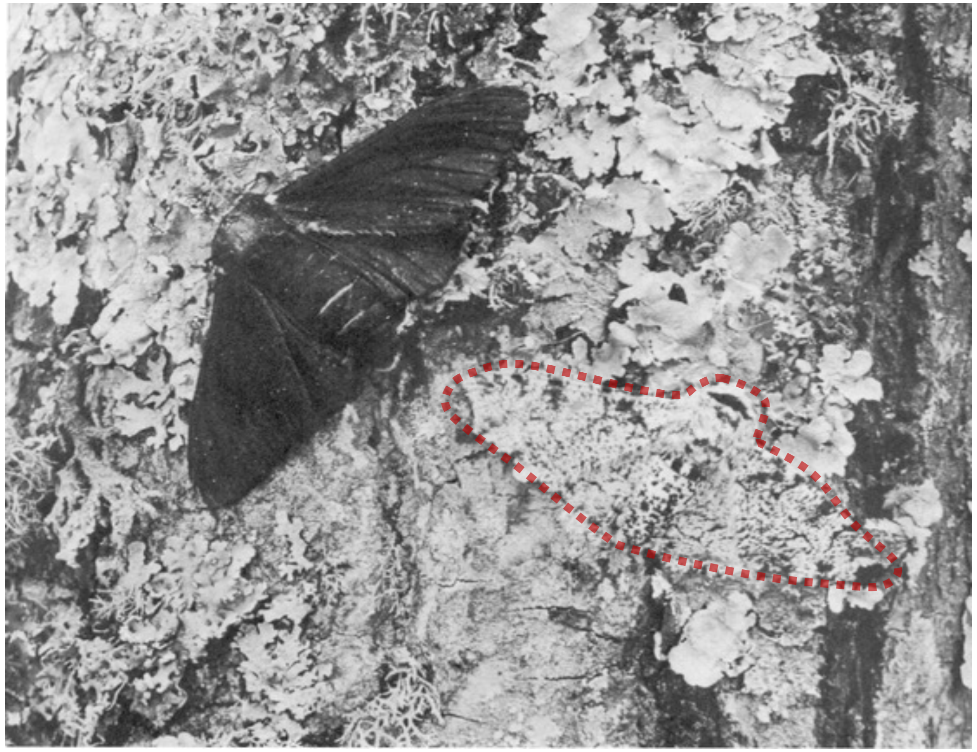
Evolution occurs at the population level

Allele frequencies

$$\frac{\text{\# of copies of an allele}}{\text{Total \# of alleles for the same gene in the population}}$$

Evolution by natural selection

Case study: Peppered moths

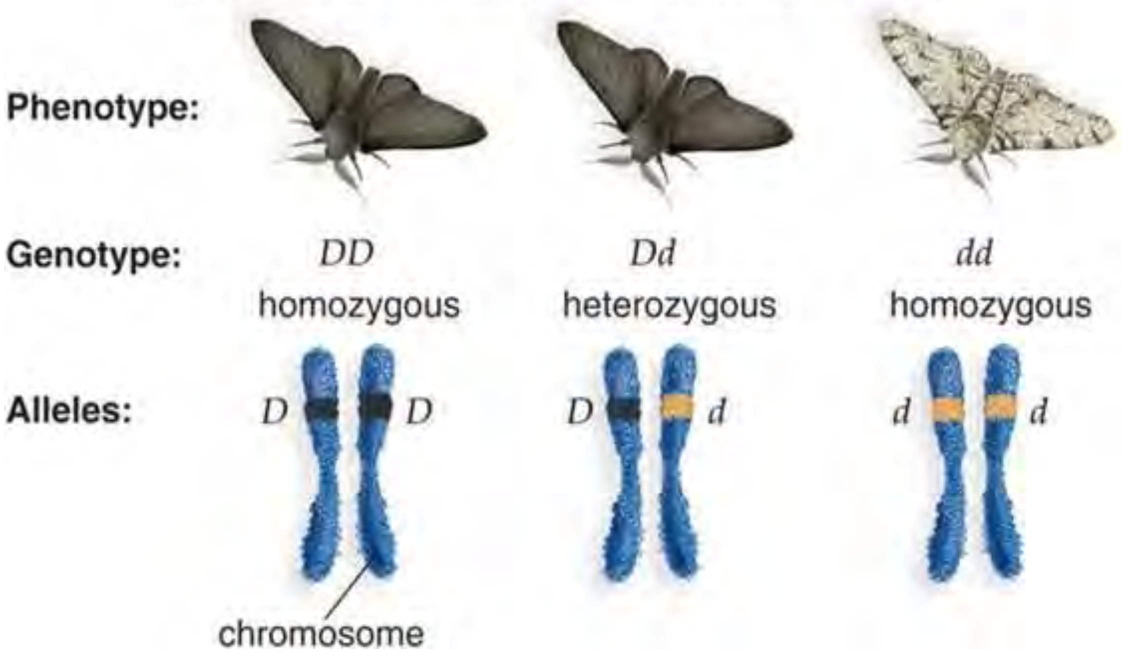


Along coastal regions away from urban areas

In and around industrial towns and cities

Evolution by natural selection

Case study: Peppered moths



"Black" form

DD or *Dd*

"Peppered" form

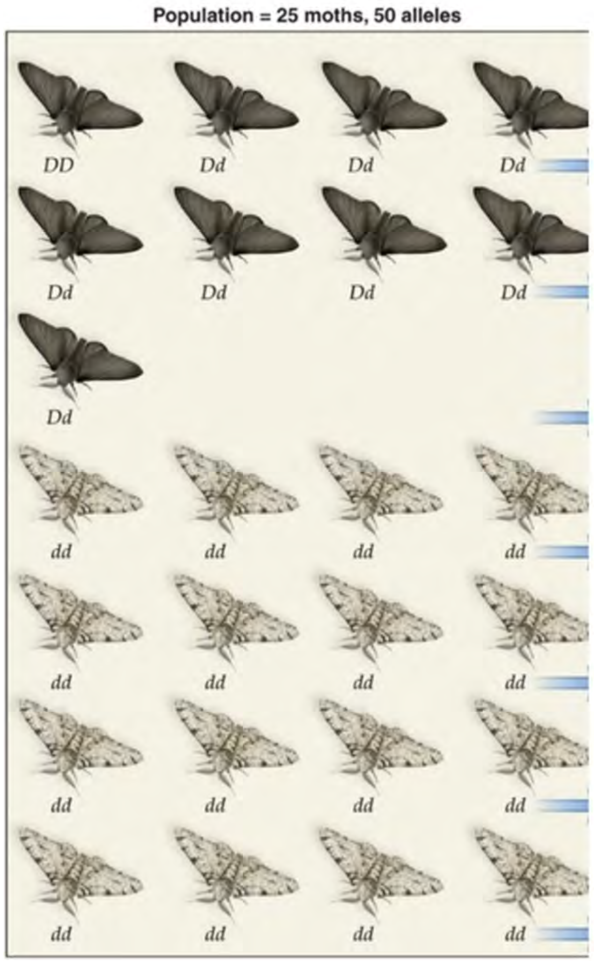
dd

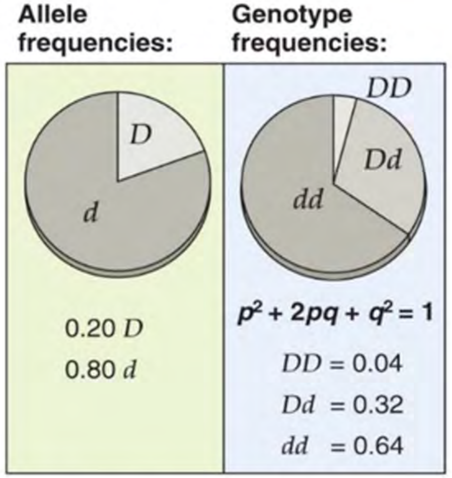
Allele frequencies

$$\frac{\text{\# of copies of an allele}}{\text{Total \# of alleles for the same gene in the population}}$$

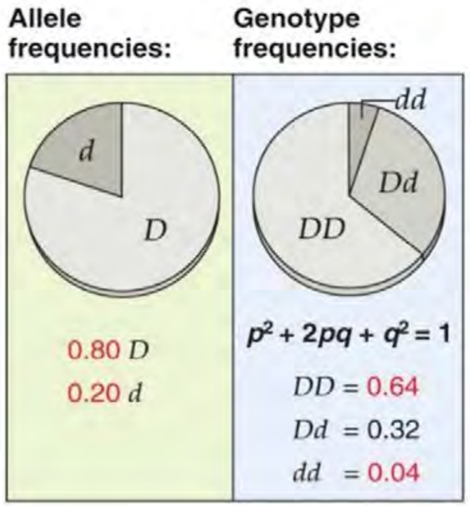
Evolution by natural selection

Case study: Peppered moths





In a population
BEFORE
industrialization



In a population
AFTER
industrialization

E-tutorial

Forces of evolutionary change

Natural Selection

- Key process behind evolution
- Explains how some traits (thus alleles) become more frequent/infrequent in a population over time
- Environmental factors determine which traits are selected for/selected against
  - Examples:
    - Features of the habitat
    - Presence of predators
    - Competition for limited resources

Variation

Inheritance

Selective pressure

Time

Forces of evolutionary change

<u>Natural Selection</u> results in **adaptations**

- Traits that enable an organism to **survive and reproduce better**
- A structure, function, or behaviour
- Is genetically encoded, passed from parents to offspring

Many traits in extant organisms are products of past selection

But not every trait is an adaptation or will always be one e.g. **neutral** traits or **maladaptive** traits

Case study: Adaptation in anoles

Twig anole

- Short legs
- Slender body
- Agile movement on thin branches
- Brown/green body

Trunk ground anole

- Long legs
- Stocky body
- Sprints across bottom of tree trunks
- Brown body

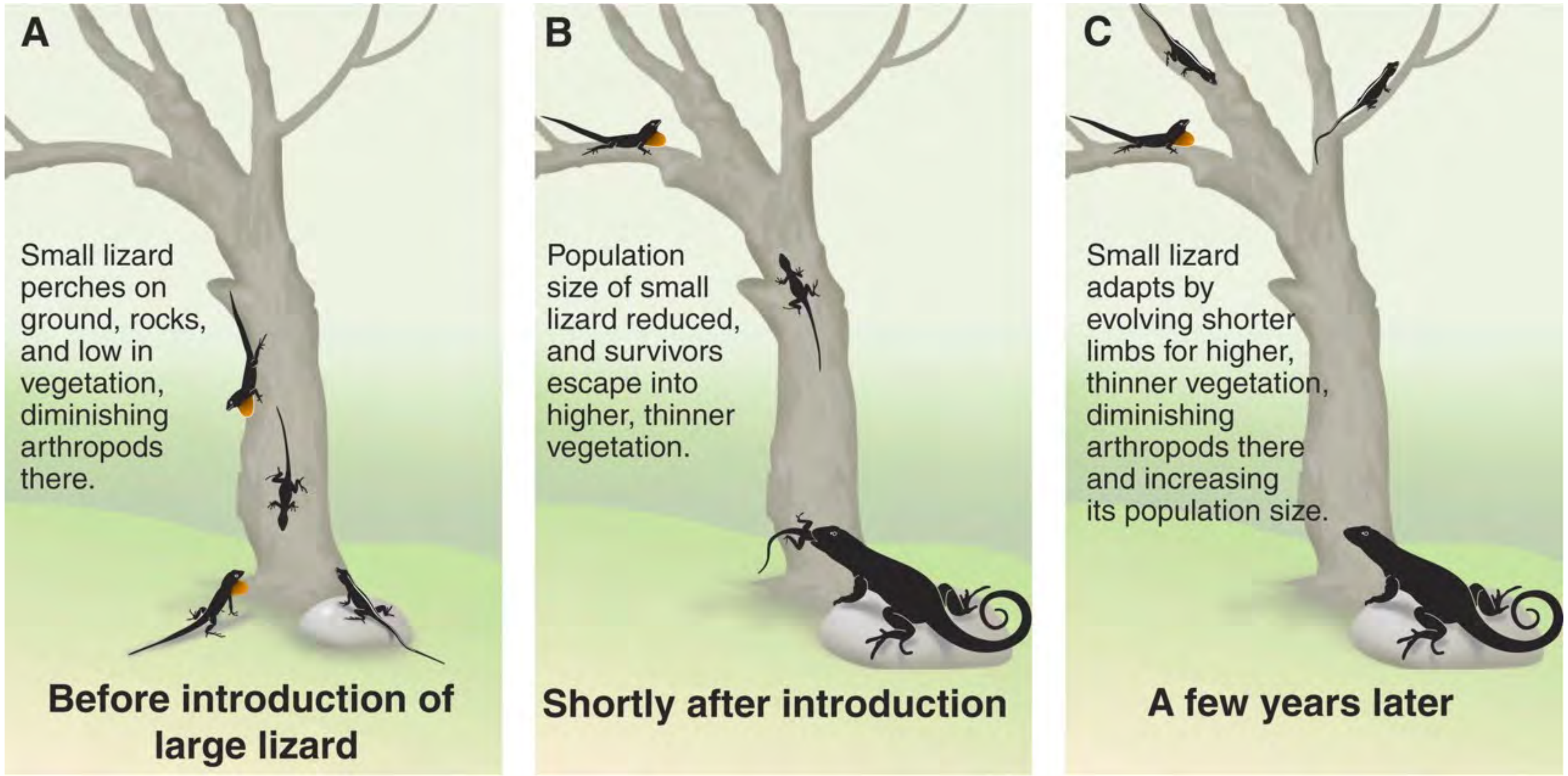
Case study: Adaptation in anoles

Green canopy anole

- Enlarged toe pads
- Stable, vertical movement amidst canopy
- Green body

Why bother going up to the canopy?

Case study: Adaptation in anoles



Stuart *et al.* 2014 Science 346: 463-466

Rapid evolution of native *Anolis* species following invasion by a large predator within 15 years (~ 20 generations)

Forces of evolutionary change

<u>Sexual selection</u>

- A type of selection that acts on traits to increase **reproductive success**
- Competition within the same species: opportunities to reproduce are limited
- Can produce features or behaviours that are harmful to individual's survival
- Sexual reproduction is a way to pass on genes and also **increase genetic diversity**

Evolutionary "fitness" is determined by an individual's contribution to the next generation's gene pool

Forces of evolutionary change

Examples of <u>**sexual selection**</u>

- **Intrasexual** via restricting access of rivals to mating (e.g. male-male competition)
    - Selects for larger size, aggressiveness, structures for physical combat like antlers or horns

Often leads to difference in appearance between the sexes

Male Female

Stag beetles defending territory

Forces of evolutionary change

Examples of <u>sexual selection</u>

Great argus pheasant

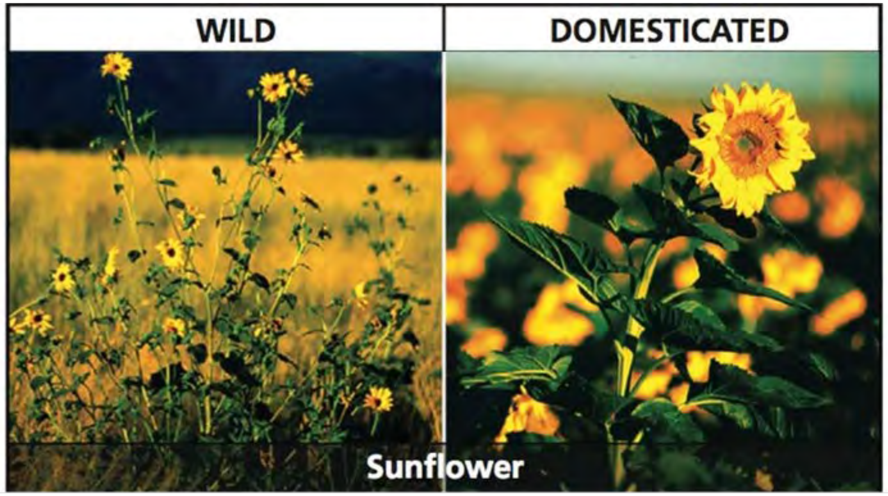
- Intrasexual via restricting access of rivals to mating (e.g. male-male competition)
  - Selects for larger size, aggressiveness, structures for physical combat like antlers or horns
- **Intersexual** via non-random mating with attractive mates (e.g. female choice)
  - Selects for bright/elaborate colours or body structures, display behaviour

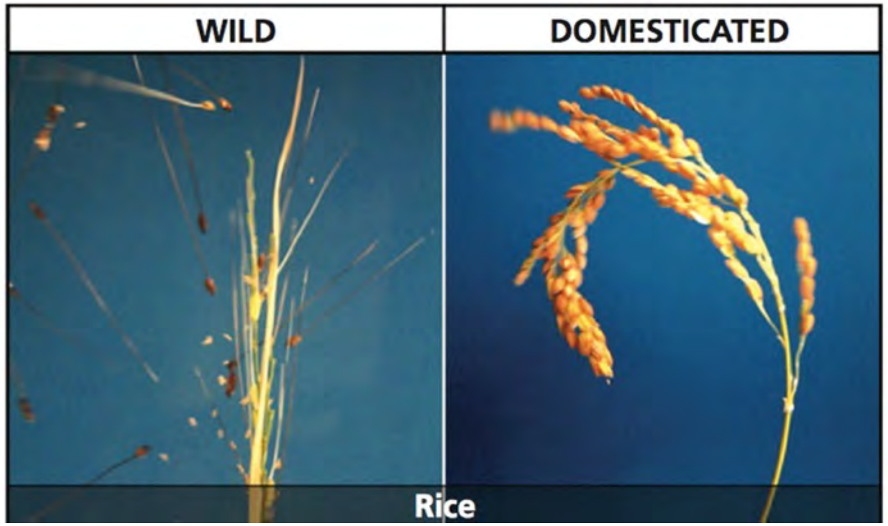
Often leads to difference in appearance between the sexes

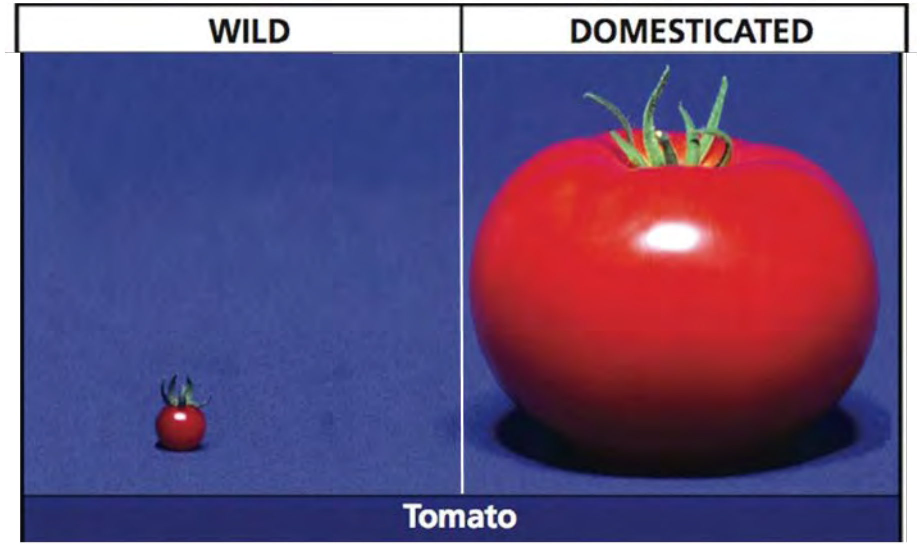
Forces of evolutionary change

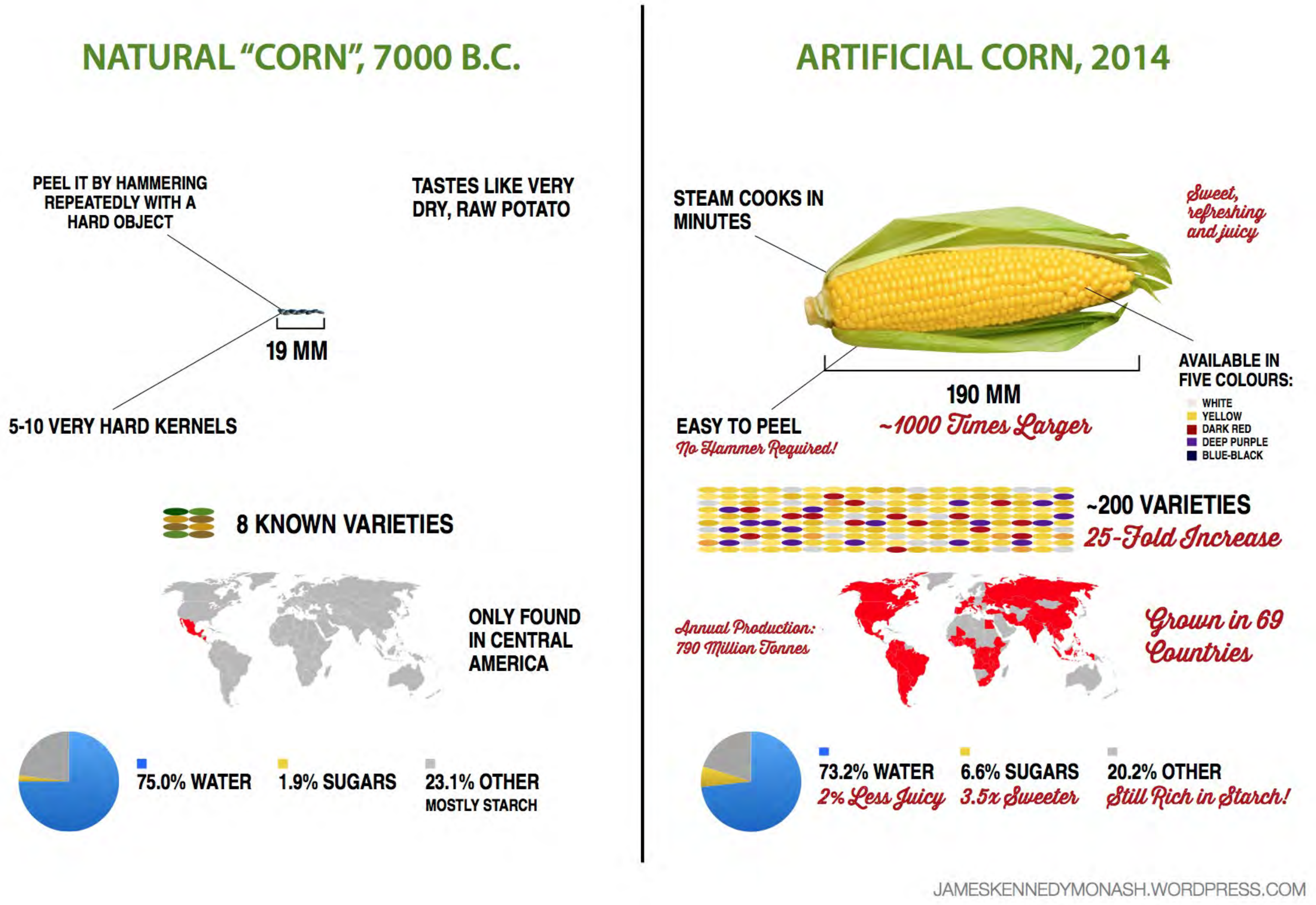
Artificial selection

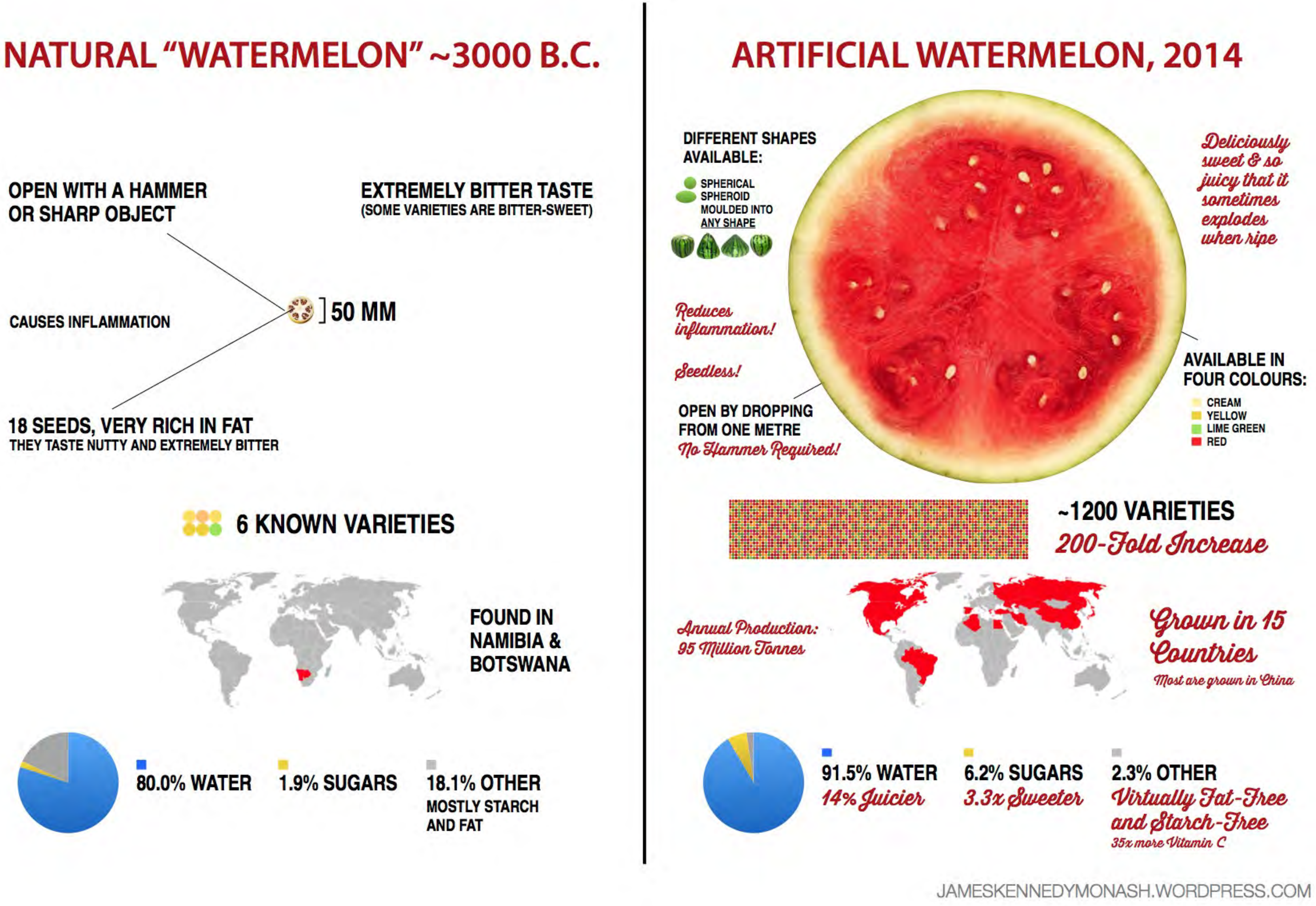
- Dramatic differences between **domesticated** crops and their closest **wild** relatives








NATURAL "CORN", 7000 B.C.
PEEL IT BY HAMMERING REPEATEDLY WITH A HARD OBJECT
TASTES LIKE VERY DRY, RAW POTATO
19 MM
5-10 VERY HARD KERNELS
8 KNOWN VARIETIES
ONLY FOUND IN CENTRAL AMERICA
75.0% WATER
1.9% SUGARS
23.1% OTHER
MOSTLY STARCH
ARTIFICIAL CORN, 2014
STEAM COOKS IN MINUTES
Sweet, refreshing and juicy
190 MM
~1000 Times Larger
EASY TO PEEL
No Hammer Required!
AVAILABLE IN FIVE COLOURS:
WHITE
YELLOW
DARK RED
DEEP PURPLE
BLUE-BLACK
~200 VARIETIES
25-Fold Increase
Annual Production: 790 Million Tonnes
Grown in 69 Countries
73.2% WATER
2% Less Juicy
6.6% SUGARS
3.5x Sweeter
20.2% OTHER
Still Rich in Starch!
JAMESKENNEDYMONASH.WORDPRESS.COM



NATURAL "WATERMELON" ~3000 B.C.
OPEN WITH A HAMMER OR SHARP OBJECT
EXTREMELY BITTER TASTE
(SOME VARIETIES ARE BITTER-SWEET)
CAUSES INFLAMMATION
50 MM
18 SEEDS, VERY RICH IN FAT
THEY TASTE NUTTY AND EXTREMELY BITTER
6 KNOWN VARIETIES
FOUND IN NAMIBIA & BOTSWANA
80.0% WATER
1.9% SUGARS
18.1% OTHER
MOSTLY STARCH AND FAT
ARTIFICIAL WATERMELON, 2014
DIFFERENT SHAPES AVAILABLE:
SPHERICAL
SPHEROID
MOULDED INTO ANY SHAPE
Deliciously sweet & so juicy that it sometimes explodes when ripe
Reduces inflammation!
Seedless!
OPEN BY DROPPING FROM ONE METRE
No Hammer Required!
AVAILABLE IN FOUR COLOURS:
CREAM
YELLOW
LIME GREEN
RED
~1200 VARIETIES
200-Fold Increase
Annual Production: 95 Million Tonnes
Grown in 15 Countries
Most are grown in China
91.5% WATER
14% Juicier
6.2% SUGARS
3.3x Sweeter
2.3% OTHER
Virtually Fat-Free and Starch-Free
35x more Vitamin C
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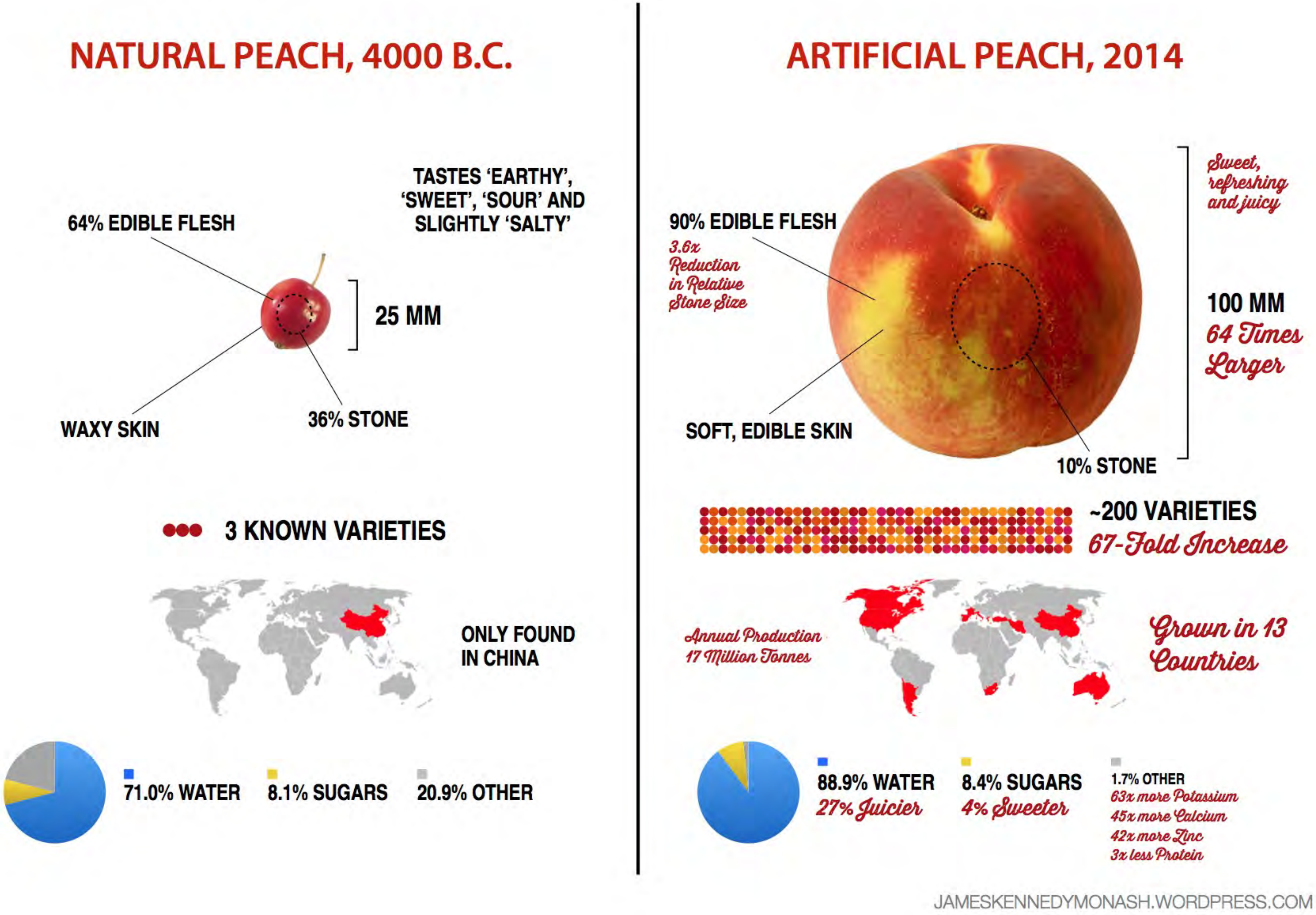
NATURAL PEACH, 4000 B.C.
TASTES 'EARTHY', 'SWEET', 'SOUR' AND SLIGHTLY 'SALTY'
64% EDIBLE FLESH
25 MM
WAXY SKIN
36% STONE
3 KNOWN VARIETIES
ONLY FOUND IN CHINA
71.0% WATER
8.1% SUGARS
20.9% OTHER
ARTIFICIAL PEACH, 2014
Sweet, refreshing and juicy
90% EDIBLE FLESH
3.6x Reduction in Relative Stone Size
100 MM
64 Times Larger
SOFT, EDIBLE SKIN
10% STONE
~200 VARIETIES
67-Fold Increase
Annual Production 17 Million Tonnes
Grown in 13 Countries
88.9% WATER
27% Juicier
8.4% SUGARS
4% Sweeter
1.7% OTHER
63x more Potassium
45x more Calcium
42x more Zinc
3x less Protein
JAMESKENNEDYMONASH.WORDPRESS.COM

Forces of evolutionary change

Artificial selection

- Intentional breeding of organisms by humans for desirable traits
- Breeding of highly related individuals can result in expression of harmful alleles

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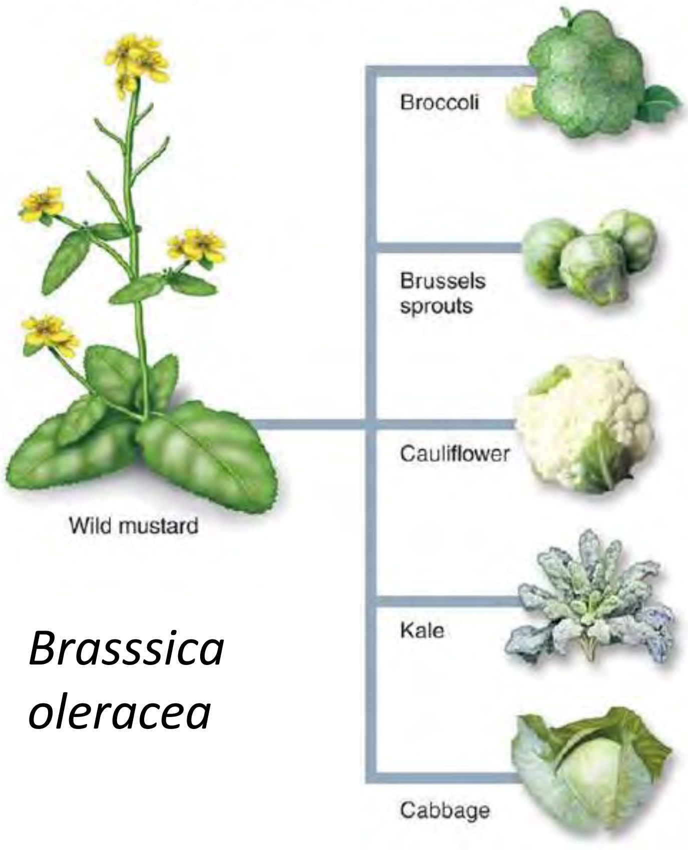
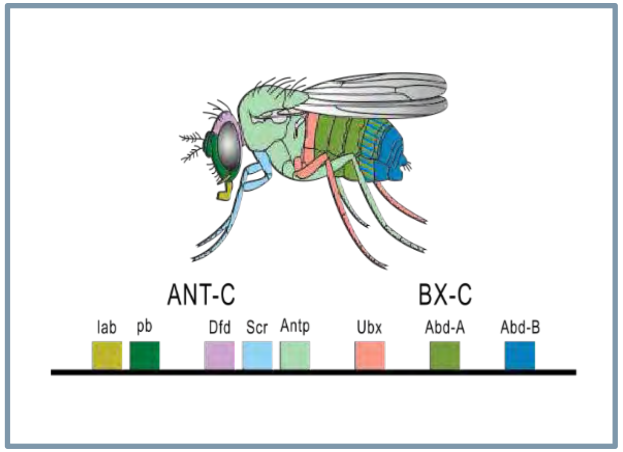


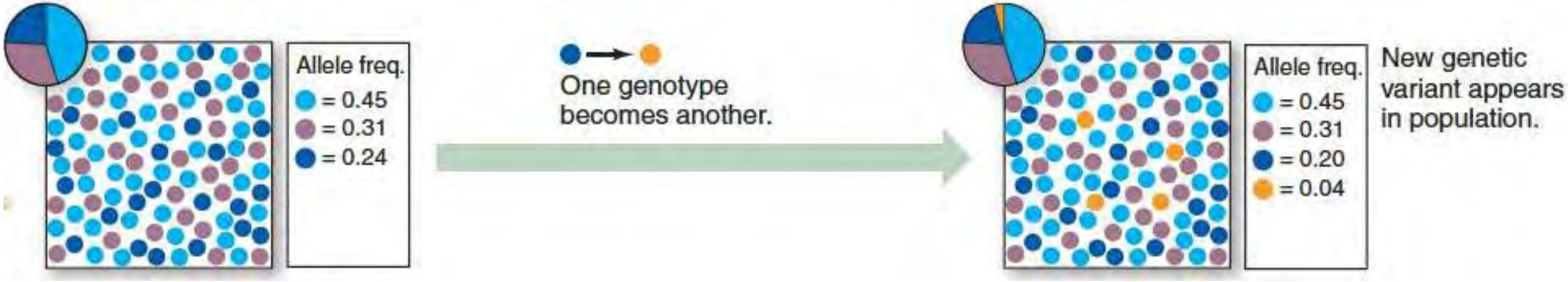
Brasssica oleracea

Forces of evolutionary change

Mutation

- Random change in DNA sequences can result in new traits
- A source of new alleles
- But not all mutations are beneficial or heritable





Forces of evolutionary change

Genetic drift

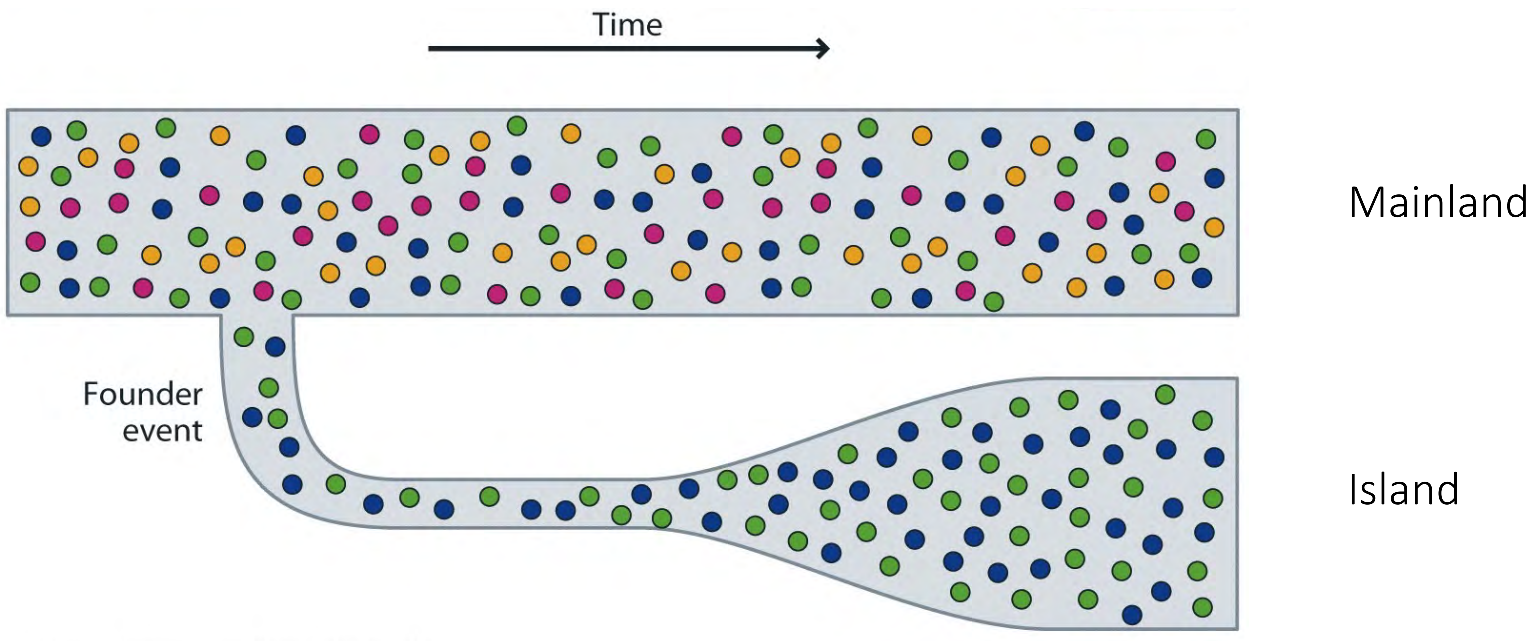
- Change in **allele frequencies** that occur purely by random chance

Forces of evolutionary change

Genetic drift

- Change in **allele frequencies** that occur purely by random chance

  Examples: Founder effect - a few individuals establish new populations

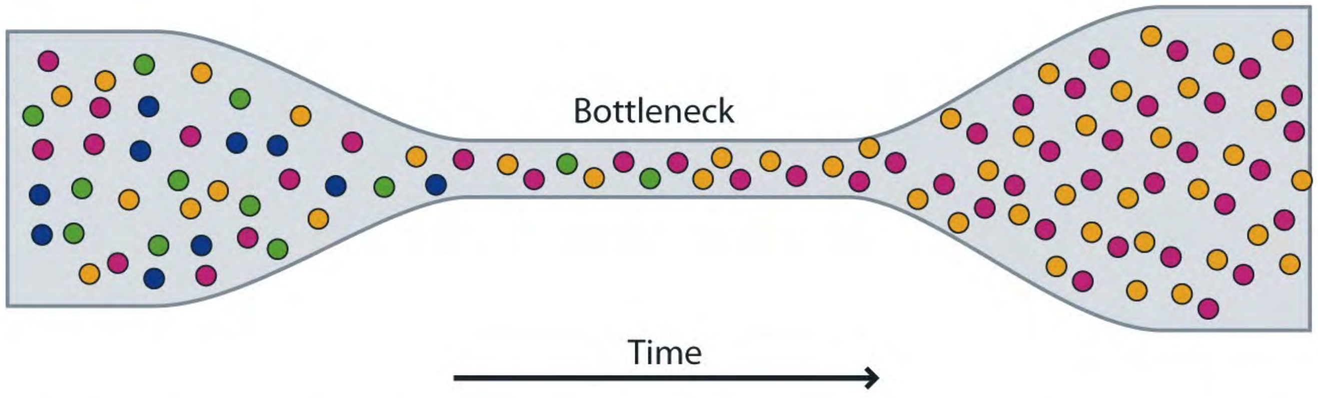


Forces of evolutionary change

Genetic drift

- Change in **allele frequencies** that occur purely by random chance

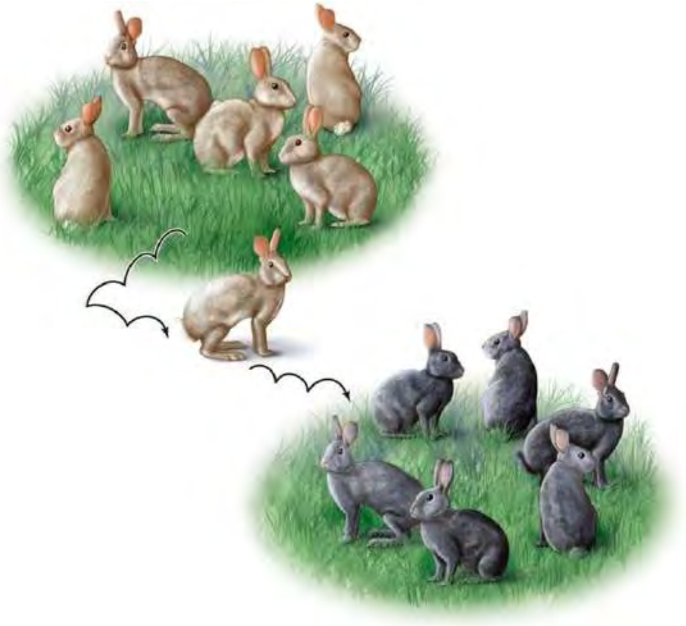
  Examples: Genetic bottleneck - drastic reduction in population size



Forces of evolutionary change

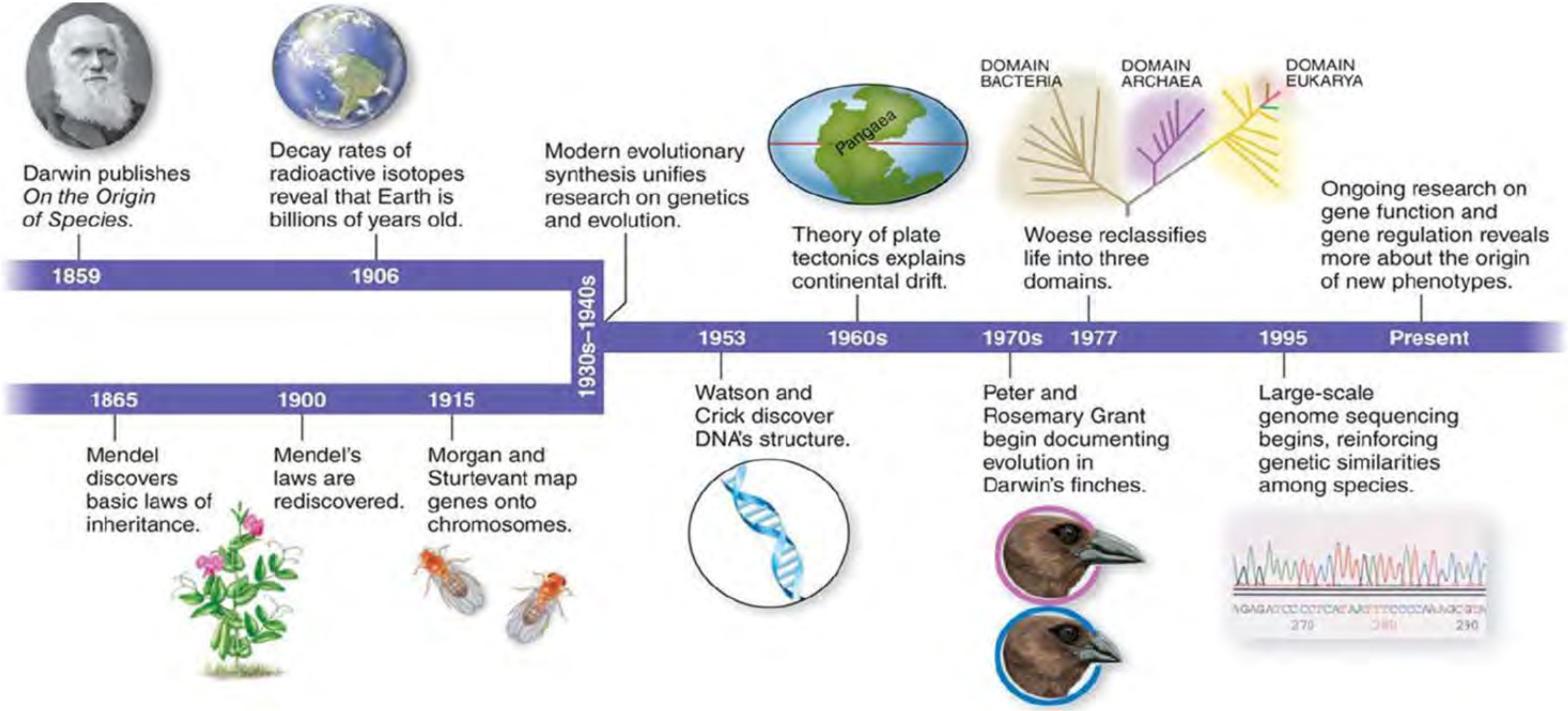
Gene flow

- Genetic exchange due to **immigration** and **emigration** of individuals between populations
- Can add or remove alleles from a population
  - May counteract genetic drift



Evidence for evolution

Modern evolutionary synthesis unifies the understanding of natural selection and genetics, using many lines of evidence and modern technologies



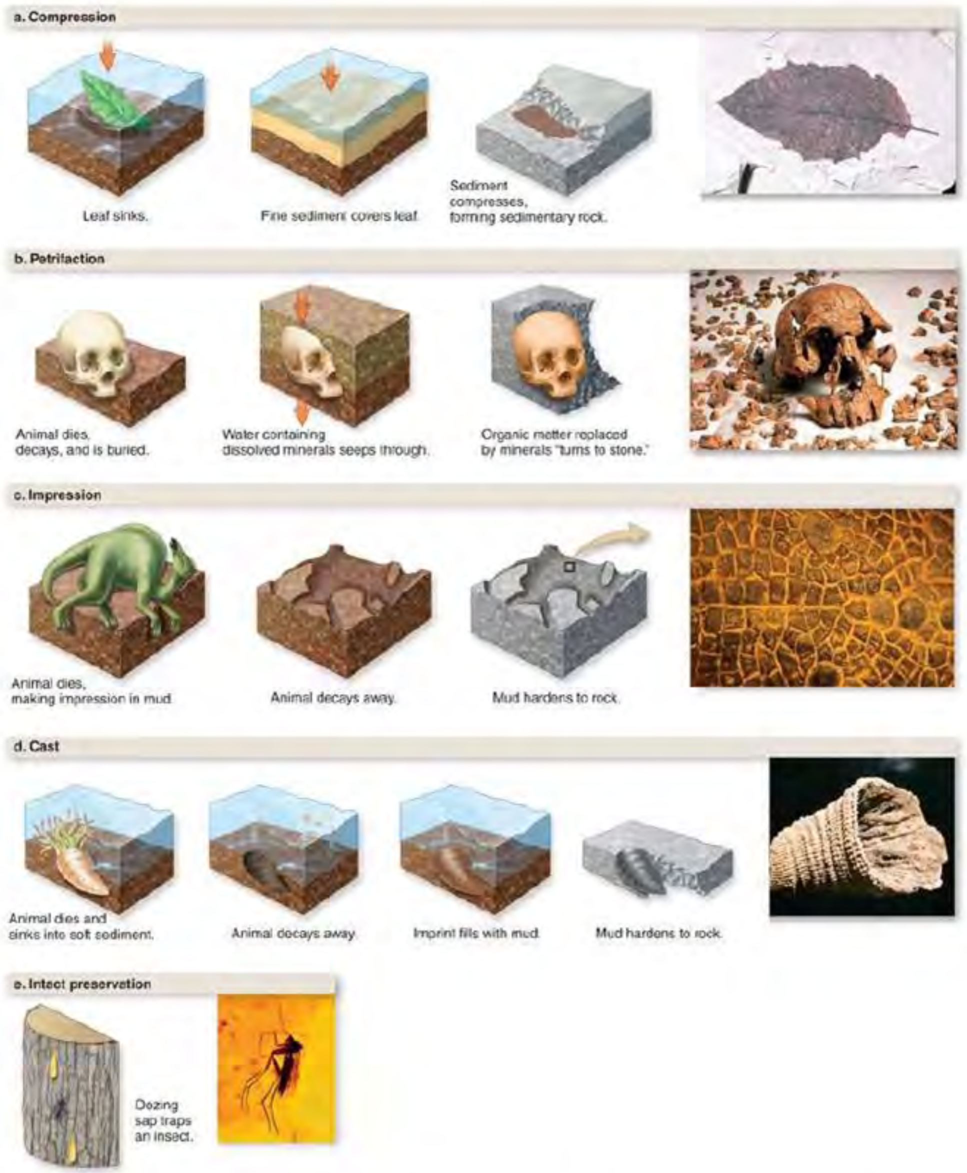
Evidence for evolution

Fossils

- Remains of ancient organisms show evidence of evolutionary change over time

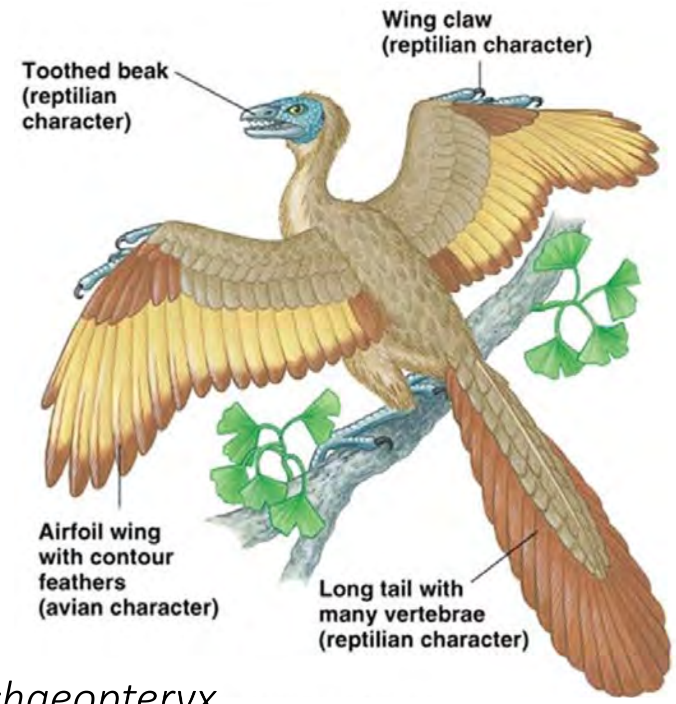
Fossil record

- Can be dated to recreate a timeline and reconstruct changes in body structures over millions of years
- Allows tests of hypotheses about relationships
  - Will always be incomplete



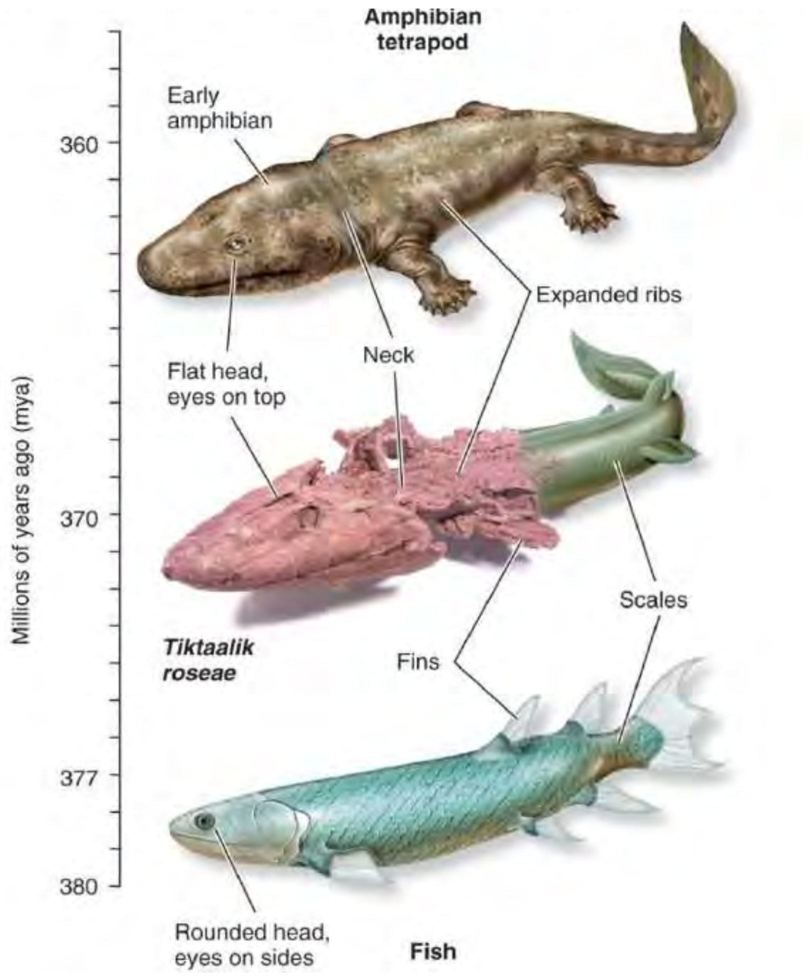
Evidence for evolution

- Transition fossils show features linking major group that exist today



Archaeopteryx

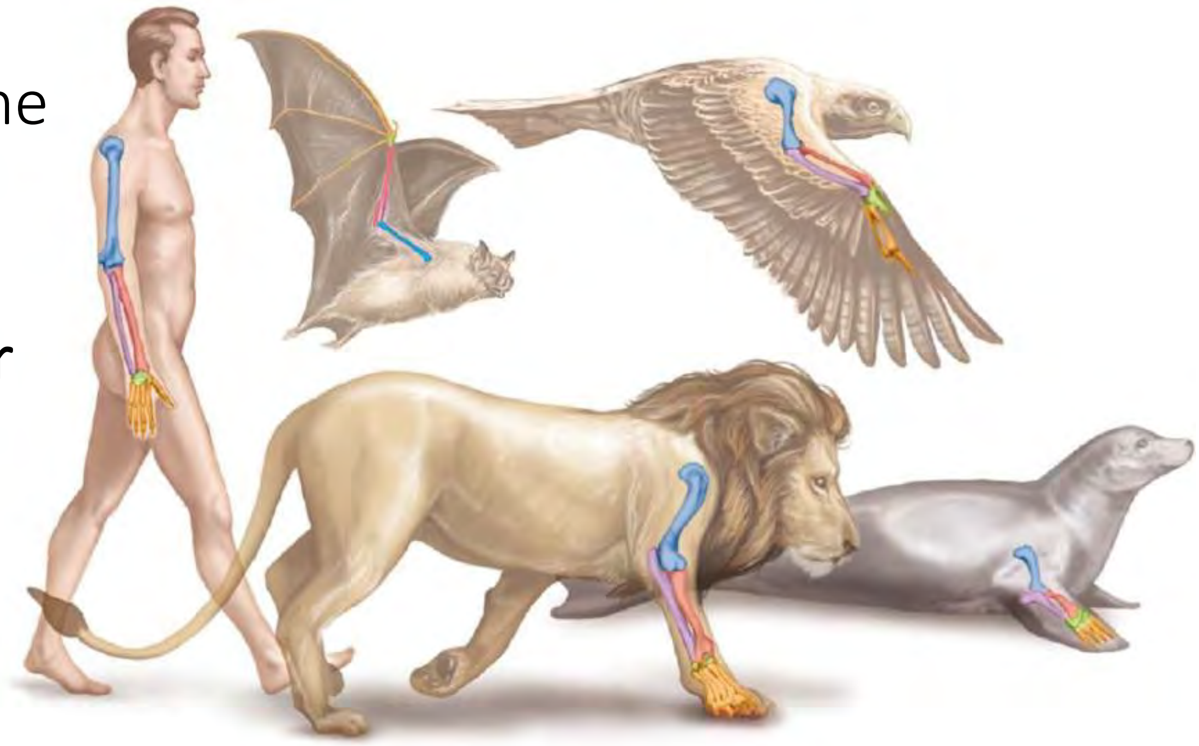
Tiktaalik



Evidence for evolution

Comparative anatomy

- Anatomical features can help determine the evolutionary relationship among organisms
- Similarities suggests **common ancestor** as well as descent with modification

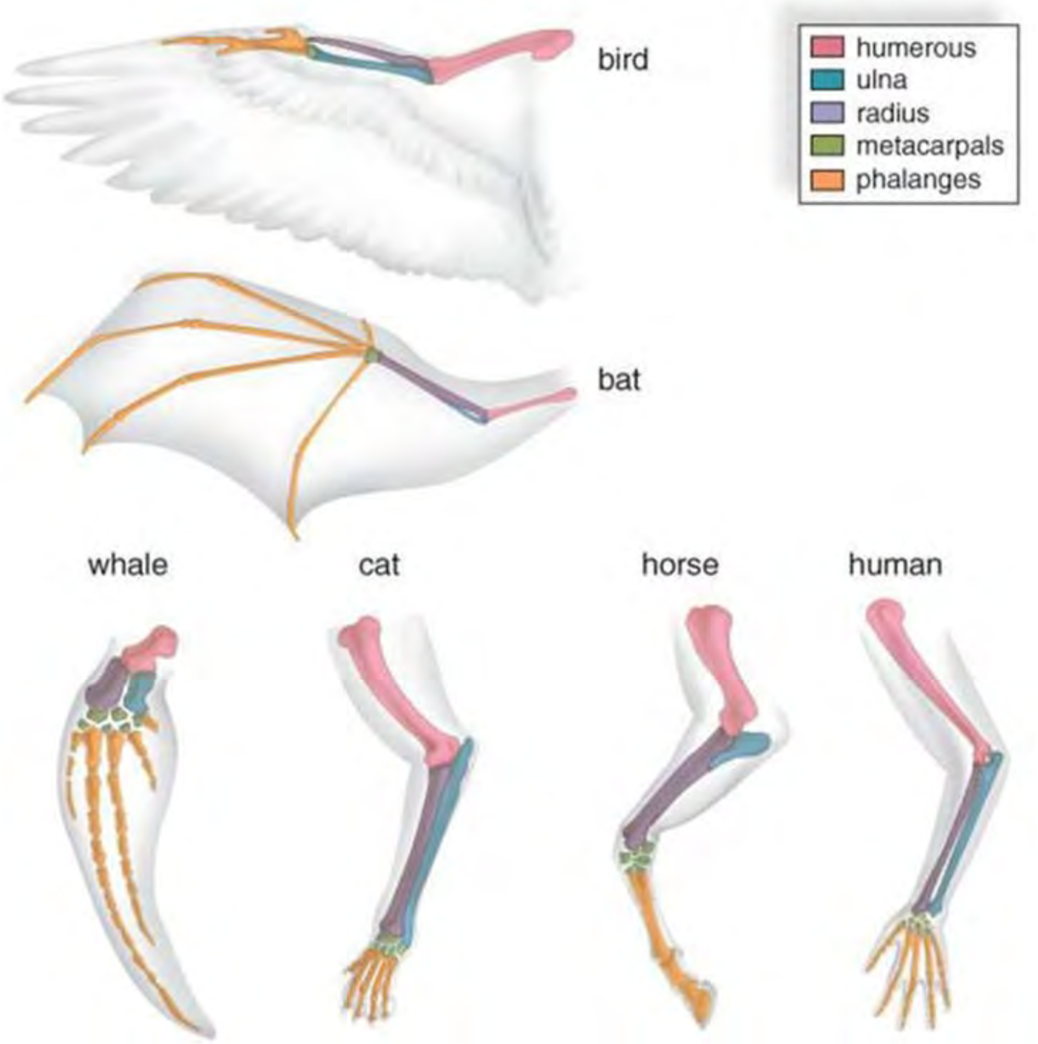


Evidence for evolution

Homologous structures

- Body parts with same genetic basis or form in a similar way during development
- Often same in position or configuration but modified by selection for different environments

Two structures are homologous if the similarities between them reflect **common ancestry**



Evidence for evolution

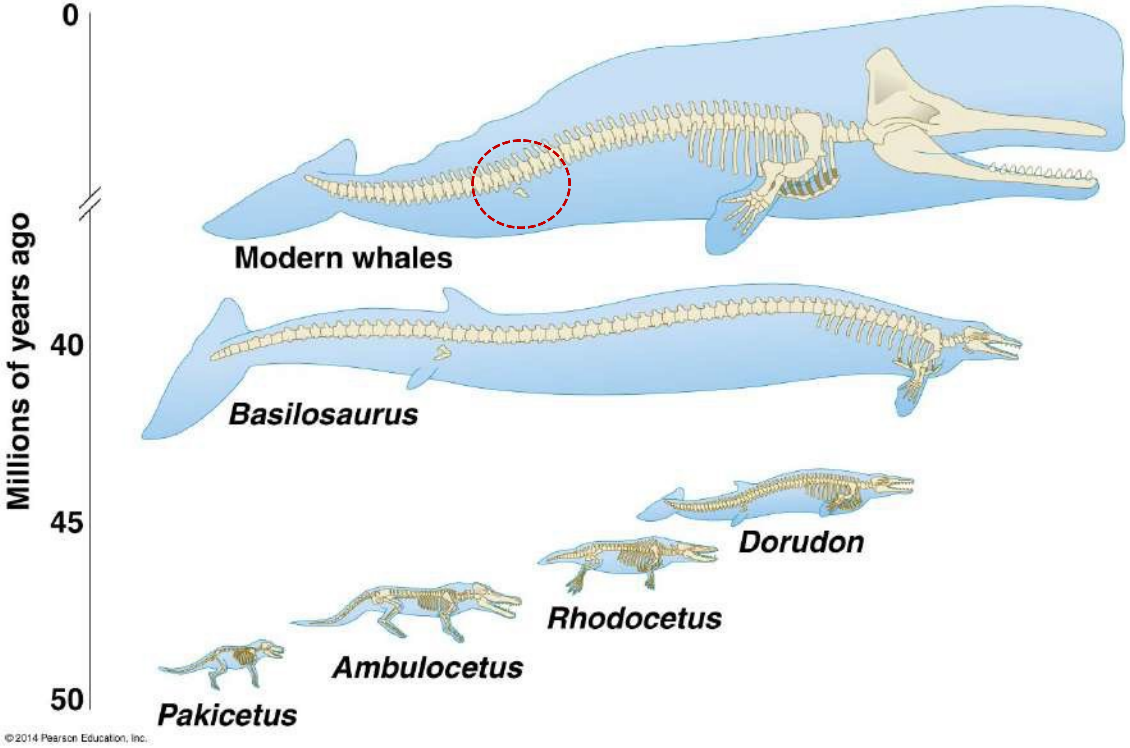
Case study: A glimpse into primate evolution

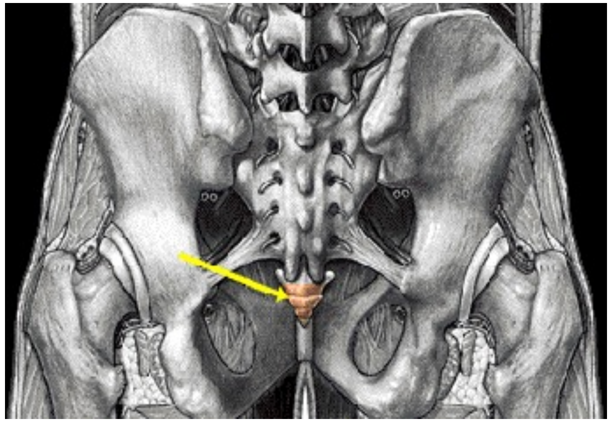
You will learn more during next week's laboratory practical

Evidence for evolution

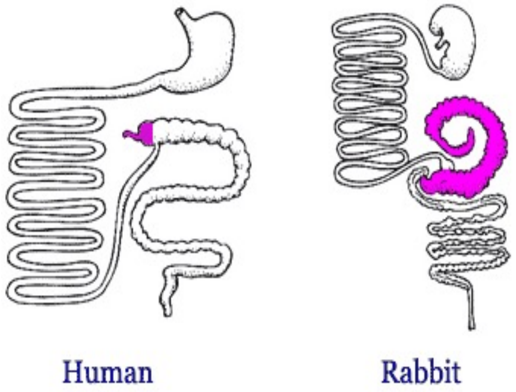
Vestigial structures

- Remnants of structures inherited from ancestors that have become non-functional





Coccyx or tailbone at the end of the spine



Appendix, an outgrowth of the large intestine

Evidence for evolution

Analogous structures

- Anatomical parts that are superficially similar but **do not derive** from a common ancestor
- Usually have similar function as an **adaptation** to similar environmental conditions

Product of **convergent evolution**

Evidence for evolution

DNA and biochemistry

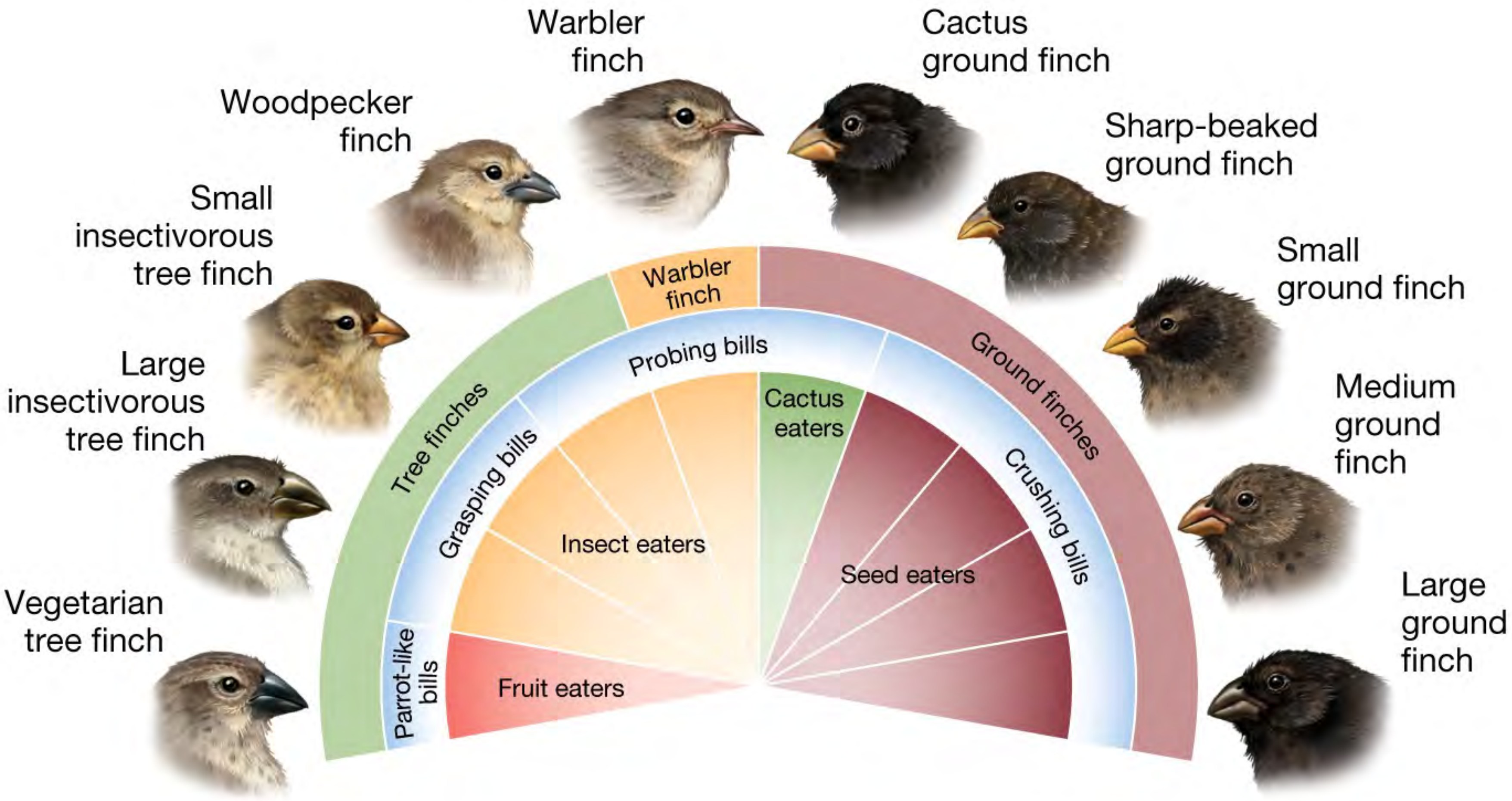
- Show **relatedness** among different organisms: the more closely-related species are, the more alike their DNA and proteins
- Presence of same protein, encoded by same gene and performing same function suggests **common ancestor**

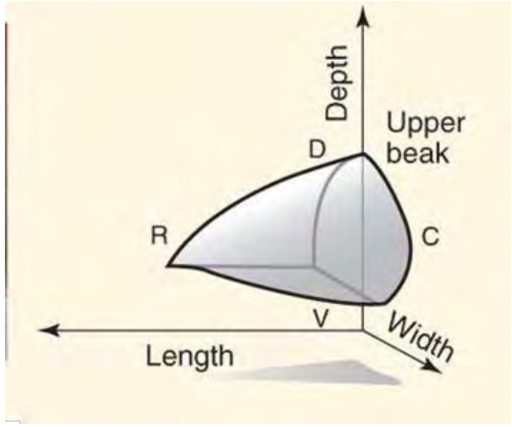
You will learn more later in the course

Cytochrome *c* Evolution

Organism	Number of amino acid differences from humans
Chimpanzee	0
Rhesus monkey	1
Rabbit	9
Cow	10
Pigeon	12
Bullfrog	18
Fruit fly	25
Yeast	40

Evidence for evolution





Evidence for evolution

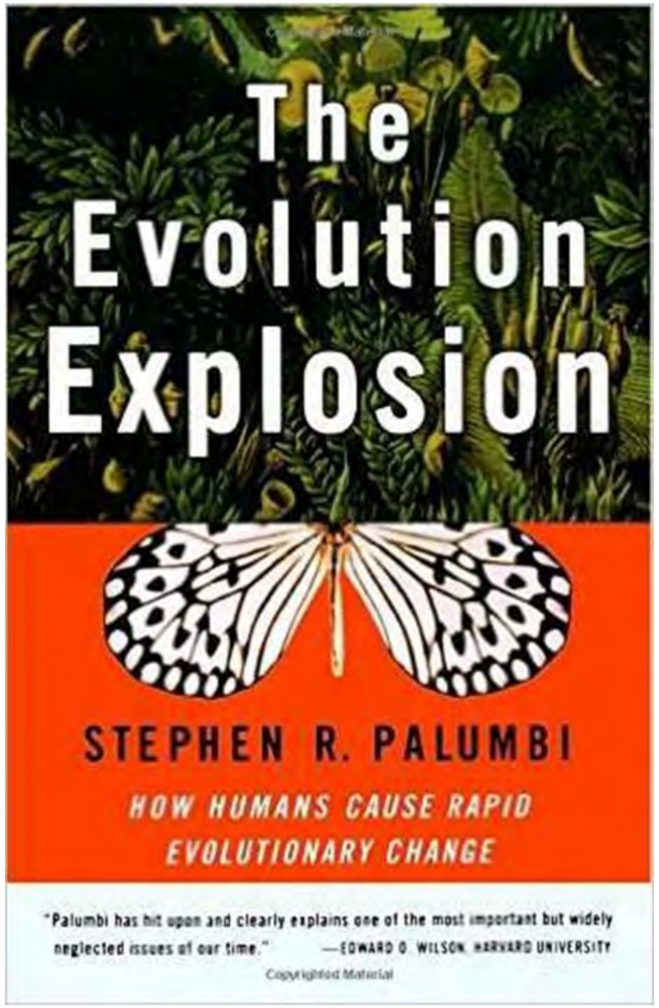
Long-term experimental studies

- *E. coli* long-term experiment
  - 12 populations tracked since 1988 (>50,000 generations)
  - One strain adapted to use citric acid as a carbon source in aerobic environment instead of just glucose

Evolution and Us

Understanding how human activities are affecting the evolution of other organisms

- Process of artificial selection can result in maladaptive traits
- Lack of genetic variation in crops means they may be unable to adapt to changing environments
- Endangered species with small populations and low genetic diversity are vulnerable to extinction
- Overuse of antibiotics and pesticides can drive the evolution of resistant weeds and pests



Evolution and Us

The imminent death of the Cavendish banana and why it affects us all

By Duncan Leatherdale
BBC News

24 January 2016 | England

Share

More than 100 billion bananas are consumed each year, making it the fourth most important crop after wheat, rice and corn

Buy a banana and it will almost certainly be descended from one plant grown at an English stately home. But now we face losing one of the world's most-loved fruits.

Cassava is genetically decaying, putting staple crop at risk

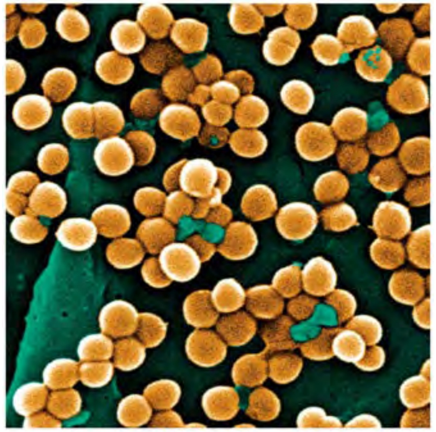
April 28, 2017 by Amanda Garris

A cassava farm in Nigeria, which is the world's largest producer of the crop. Credit: Cornell University

For breeders of cassava, a staple food for hundreds of millions in the tropics, producing improved varieties has been getting harder over time. A team at Cornell used genomic analysis of cassava varieties and wild relatives to make a diagnosis: Mutations have corroded the genome, producing many dysfunctional versions of genes and putting at risk a crop crucial to the survival of one-tenth of the world's population.

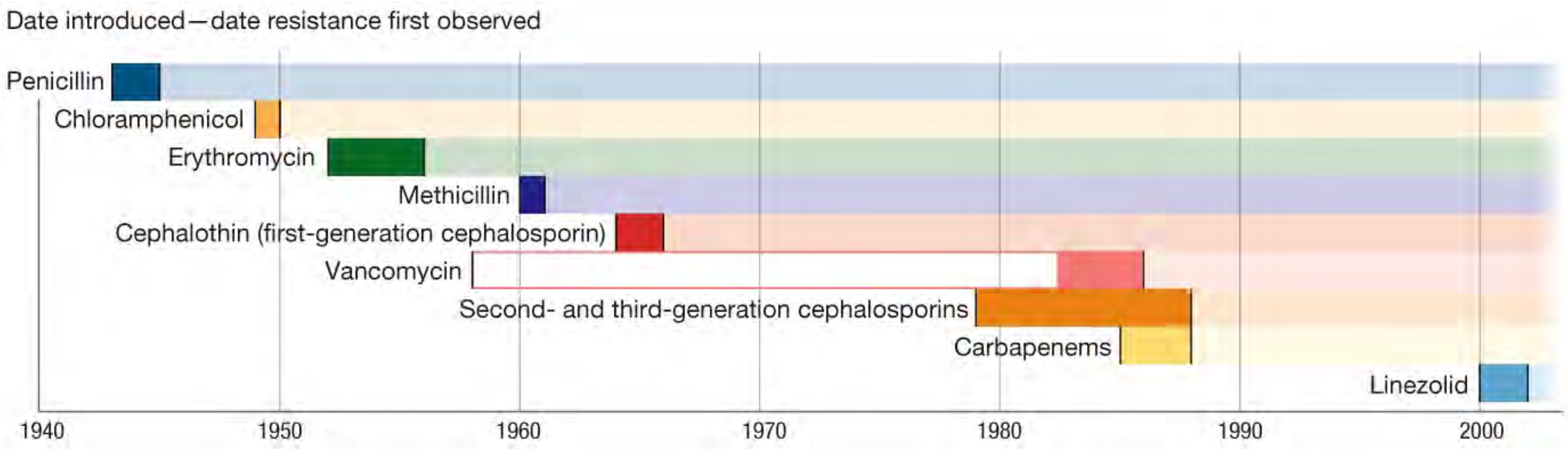
Evolution and Us

Bacteria have rapidly evolved resistance to clinical antibiotics



Methicillin-resistant *Staphylococcus aureus* (MRSA)

Vancomycin-resistant *Enterococcus faecalis*



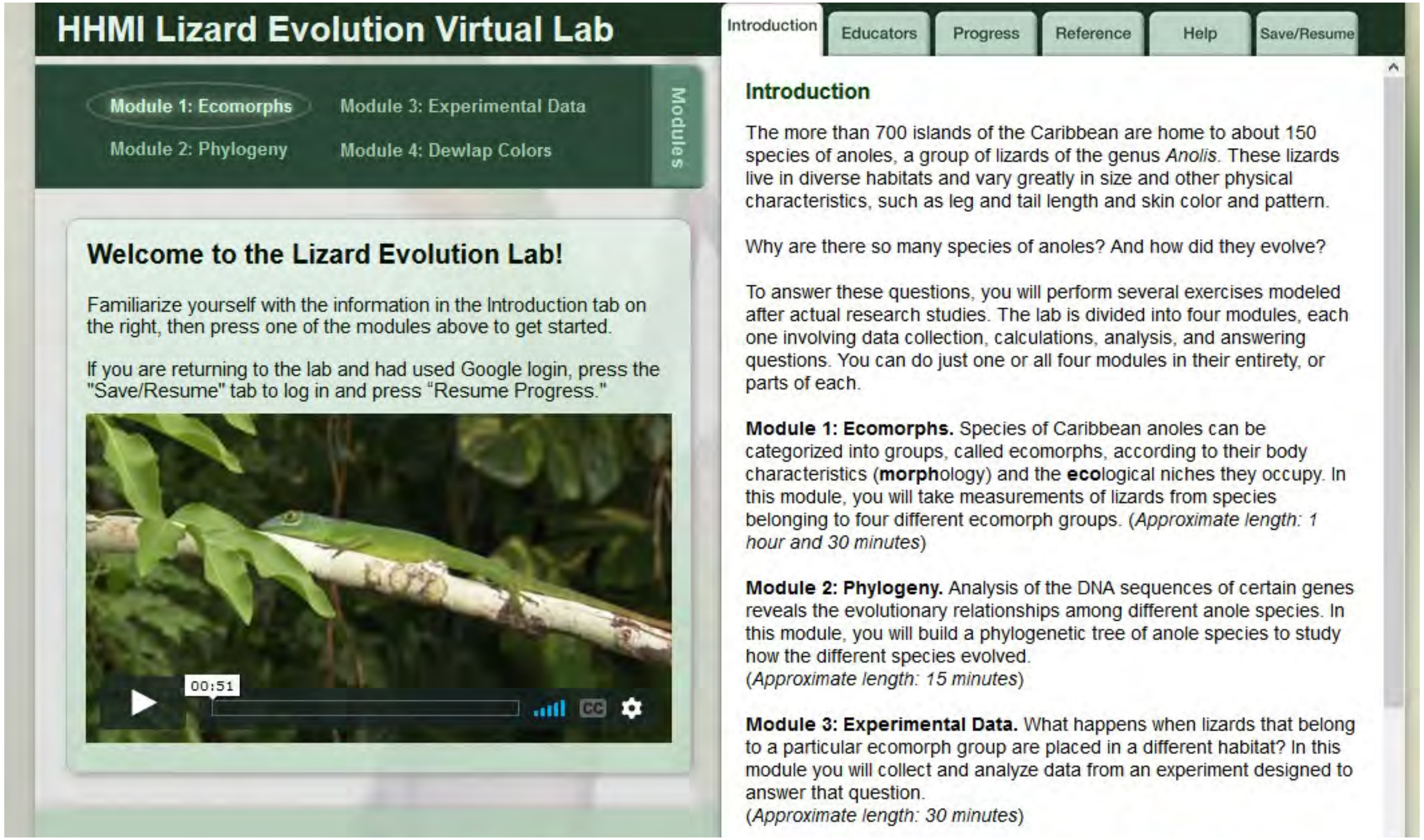
Summary

- Understanding evolutionary biology is crucial to understanding variation in the natural world.
- Helps explain many natural patterns observed & understand how they are linked.
- Evolution by natural selection is based on **heritable variation** that results in **differential fitness**.
- Take home questions:
  - How would you apply the knowledge from this topic?
  - What are the implications for next week's lecture on biodiversity?

Thursday: Online tutorial

No Zoom meeting.

Own time
Own target



- Deadline 26th Jan (2359h)
- Requires plagiarism check
  Submit first draft at least 48h before