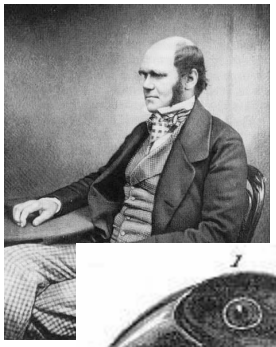
NATIONAL
MATH + SCIENCE
INITIATIVE

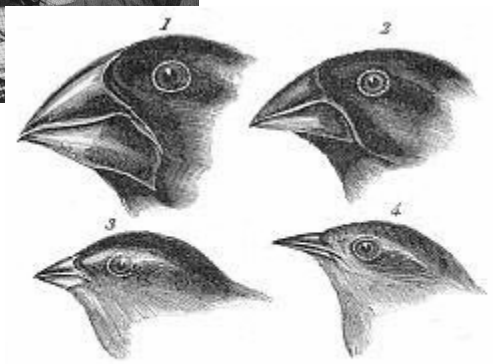
Evolution

Chapter 22: Evolution by Natural Selection



Charles Darwin (1809-1882)

- **British naturalist**
  - **Proposed the idea of evolution by natural selection**
  - **Collected clear evidence to support his ideas**
- **Voyage of the HMS Beagle (1831-1836)**
  - **Travels around the world**
  - **Makes many observations of natural world**
    - **Main mission of the *Beagle* was to chart South American coastline.**
- **Galapagos**
  - **Of relatively recent volcanic origin most of animal species on the Galápagos live nowhere else in world, but they resemble species living on South American mainland.**

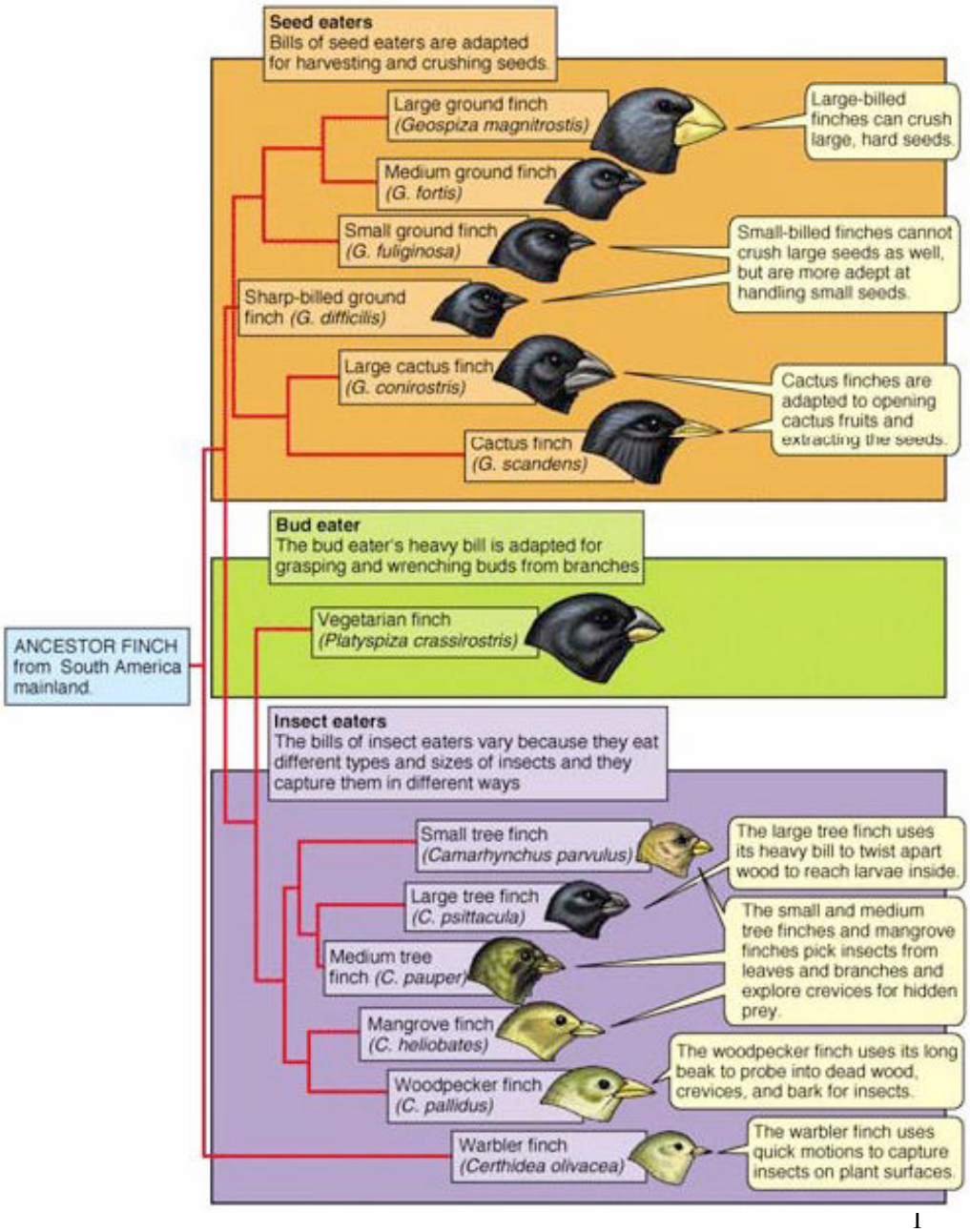


1. Geospiza magnirostris
2. Geospiza fortis
3. Geospiza parvula
4. Certhidea olivacea

Finches from Galapagos Archipelago

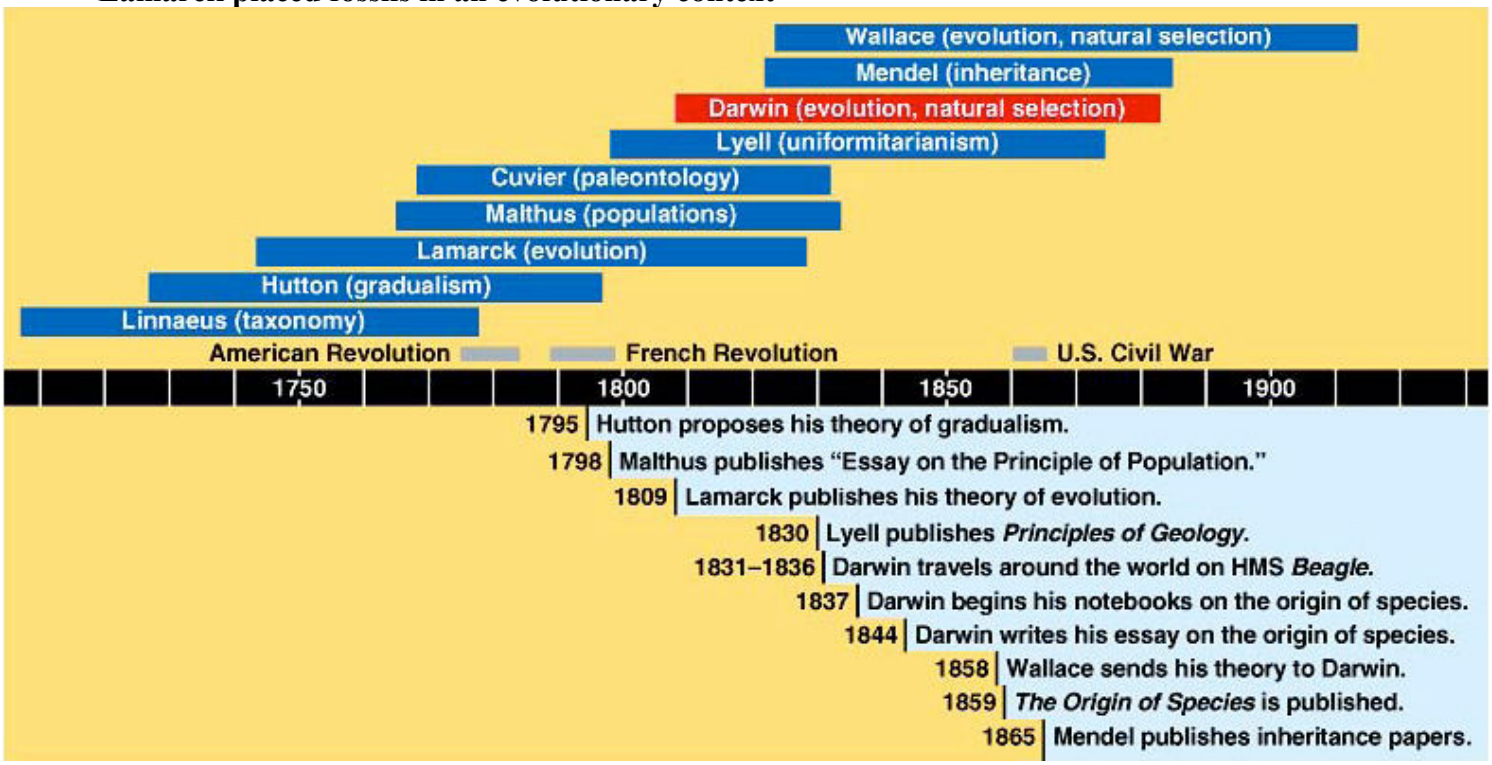
Darwin's Finches

- **13 species of finches on Galápagos**
- **Puzzling finding**
  - **Only 1 species of this bird on mainland of South America, 600 miles to east**
  - **All presumably originated from mainland**
- **Differences in beaks**
  - **Associated with eating different foods.**
  - **Adaptations to foods available on islands.**
- **Darwin's conclusions**
  - **When original South American finches reached islands, adapted to available food in different environments.**
- **Finches with beak differences that allowed them to…**
  - **successfully feed**
  - **successfully compete**
  - **successfully reproduce**
    - **pass successful traits onto their offspring**



In Historical Context

- **Western culture resisted evolutionary views of life**
- **Theories of geologic gradualism helped clear path for evolutionary biologists**
- **Lamarck placed fossils in an evolutionary context**



What did Darwin say?

- **Variation**
  - **Every population of organisms includes differences between individuals.**
- **Where does variation come from?**
  - **Mutations are a source of new alleles.**
  - **Changes in nucleotide sequence of DNA.**
  - **Mutations of genes are rare & random.**
    - **shot in the dark**
    - **may be damaging = sickle cell disease**
    - **may be "silent"**
      - **introns**
      - **redundancy of codons**
  - **Only mutations in gametes are passed on.**
- **Effect: More or less fit?**
  - **Mutations that alter protein structure enough to impact its function.**
    - **More likely to be harmful than beneficial.**
    - **Our genome is product of thousands of generations of selection.**
  - **Fuel for evolution**
    - **Mutant allele may enable an organism to fit its environment better & increase reproductive success.**
    - **Especially likely if environment is changing.**

What did Darwin say?

- **Over-production**
  - **Organisms reproduce more than the environment can support**
  - **Some offspring survive & some offspring don't survive**
- **Competition**
  - **for food, for mates, for nesting spots, to escape predators**

Natural selection

- **Put together variation and competition and you get natural selection**
  - **Survival of the fittest**
  - **fittest are the ones that survive to reproduce**
- **Who is the fittest?**
  - **Traits fit the environment.**
  - **The environment can change.**
  - **Therefore who is "fit" changes.**
- **Peppered Moth (Why did the population change?)**
  - **early 1800s = pre-industrial England**
    - **low pollution**
    - **lichen growing on trees = light colored bark**
  - **late 1800s = industrial England**
    - **factories = soot coated trees**
    - **killed lichen = dark colored bark**
  - **mid 1900s = pollution controls**
    - **clean air laws**
    - **return of lichen = light colored bark**
  - **Industrial melanism**

Year	% dark	% light
1848	5	95
1895	98	2
1995	19	81

Support for Darwin's ideas

- **Fossil Record: change over time**
- **Biogeography: related organisms in similar range**
- **Comparative Anatomy**
- **Comparative Embryology**
- **Molecular Biology: measure of common ancestry**
- **Artificial Selection: induced evolution**

Fossil Record

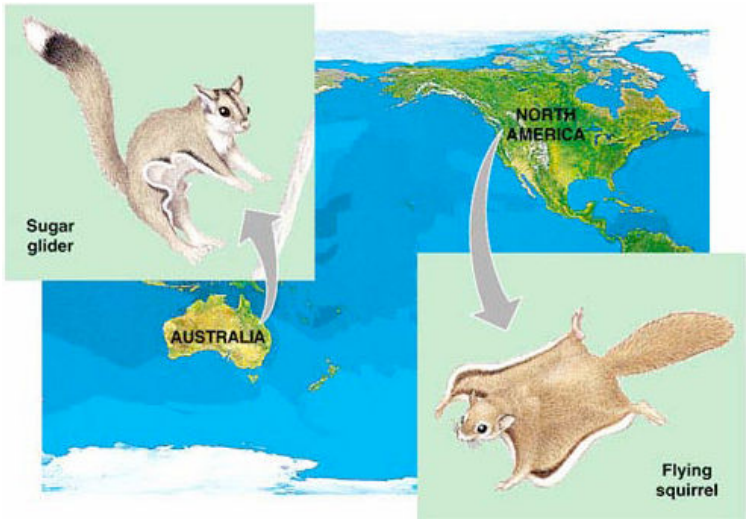
- **Layers of sedimentary rock contain fossils**
- **New layers cover older ones, creating a record over time**
- **Fossils within layers show that a succession of organisms have populated Earth throughout a long period of time.**

Acquired Traits

- **By comparing current invertebrate species with fossil forms, Lamarck could see what appeared to be several lines of descent**
  - **chronological series of older to younger fossils leading to a modern species**
  - **proposed a mechanism to explain how specific adaptations evolve**
    - **adaptation to the environment**
    - **use & disuse causes modifications**
    - **Acquired Characteristics are inherited**
    - **evolution is influenced by need to survive**

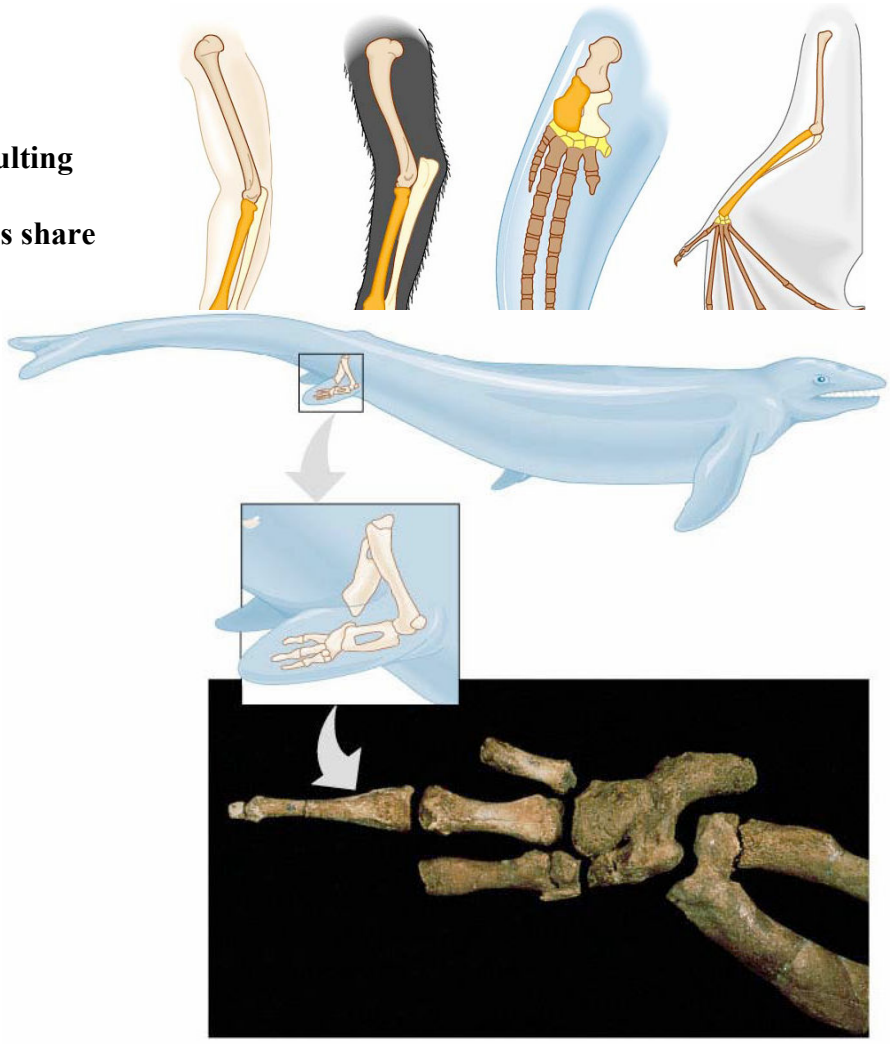
Biogeography

- **Geographical distribution of species**
  - **Species living in the same region tend to be more closely related to each other**
  - **Species which look similar but are from different parts of the world are often not closely related**
- **Convergent Evolution**
  - **Evolving similar solutions to similar "problems"**
- **Analogous structures**
  - **Convergent evolution of structures**
    - **similar functions**
    - **similar external form**
    - **different internal structure & development**
    - **different origin**
    - **no evolutionary relationship**
  - **Dolphins: aquatic mammal**
  - **Fish: aquatic vertebrate**
    - **have adapted to life in the sea**
    - **not closely related**



Comparative Anatomy

- **Homology**
  - **Similarities in characteristics resulting from common ancestry.**
- **Forelimbs of human, cats, whales, & bats share same skeletal structures**
  - **similar structure**
  - **similar embryological development**
  - **different functions**
  - **evidence of common ancestor**
    - **branched off from common 4-limbed ancestor**

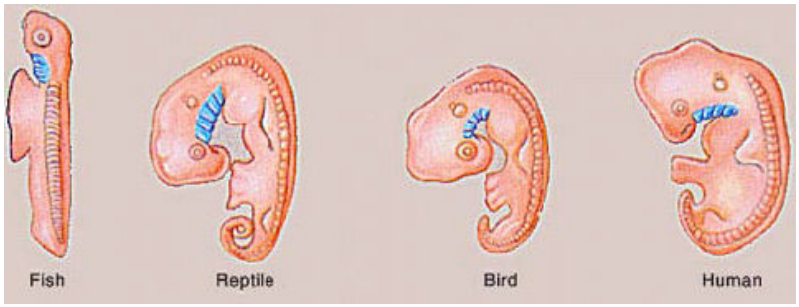


Vestigial Organs

- **Modern animals may have structures that serve little or no function**
  - **Remnants of structures that were functional in ancestral species**
  - **Evidence of change over time**
    - **Some snakes & whales show remains of the pelvis & leg bones of walking ancestors**
    - **Eyes on blind cave fish**
    - **Human tail bone**
    - **Hind leg bones on whale fossils. Why?**

Comparative Embryology

- **Similar embryological development in closely related species**
  - **All vertebrate embryos have a gill pouch at one stage of development**
    - **Fish, frog, snake, birds, human, etc.**



Molecular Biology

- **Comparing DNA & protein structure**
  - **universal genetic code!**
    - **DNA & RNA**
  - **cytochrome C (respiration)**
    - **protein structure**
  - **hemoglobin (gas exchange)**
    - **protein structure**
- **Evolutionary relationships among species are documented in their DNA & proteins. Closely related species have sequences that are more similar than distantly related species.**

Table 22.1 Molecular Data and the Evolutionary Relationships of Vertebrates

Species	Number of Amino Acids That Differ from a Human Hemoglobin Polypeptide (Total Chain Length = 146 Amino Acids)
Human	0
Rhesus monkey	8
Mouse	27
Chicken	45
Frog	67
Lamprey	125

Artificial Selection

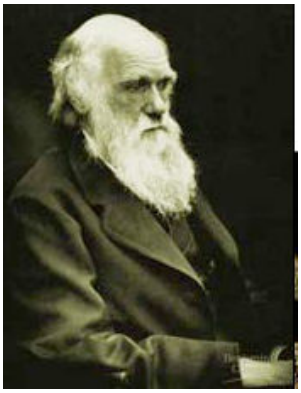
- **Artificial breeding can use differences between individuals to create vastly different "breeds" or "varieties".**

Natural selection in action

- **Insecticide & drug resistance**
  - **Insecticide didn't kill all individuals**
  - **Resistant survivors reproduce**
  - **Resistance is inherited**
  - **Insecticide becomes less & less effective**

Theory of Evolution

- **Evolution**
  - **Principle of evolution**
  - **Evolution is a fact**
  - **Observable & testable**
- **Natural selection**
  - **Widely accepted mechanism**
  - **Predictions have withstood thorough, continual testing by experiments & observations.**



Unity & Diversity

- **Only evolution explains both the unity & diversity of life.**
- **By attributing the diversity of life to natural causes rather than to supernatural creation, Darwin gave biology a strong, scientific, testable foundation.**

Chapter 23: Evolution of Populations

Populations Evolve

- **Natural selection acts on individuals**
  - **Differential survival**
    - **"survival of the fittest"**
  - **Differential reproductive success**
    - **bear more offspring**
- **Populations evolve**
  - **Populations of organisms change over time.**
  - **Traits which offer greater fitness become more frequent in the population.**
- **Individuals DON'T Evolve!!!!!**

Variation

- **Natural selection requires a source of variation within the population.**
  - **There have to be differences**
  - **Some individuals must be more fit than others.**

Mutation

- **Mutation creates variation.**
  - **New mutations are constantly appearing.**
- **Mutation changes DNA sequence.**
  - **Changes amino acid sequence?**
  - **Changes protein**
    - **Change structure?**
    - **Change function?**
  - **Changes in protein may change phenotype & fitness.**

Sex

- **Sex spreads variation.**
  - **One ancestor can have lots of descendants.**
  - **Sex causes recombination.**
  - **Offspring have new combinations of traits = new phenotypes.**
- **Sexual reproduction recombines alleles into new arrangements in every offspring.**

Changes in populations

- **Evolution of populations is really measuring changes in allele frequency**
- **All the genes & alleles in a population = gene pool**
  - **Factors that alter allele frequencies in a population**
- **Natural Selection**
  - **Genetic drift**
    - **Founder effect**
    - **Bottleneck effect**
  - **Gene flow**

Natural selection

- **Natural selection adapts a population to its environment.**
  - **A changing environment.**
    - **Climate change**
    - **Food source availability**
    - **New predators or diseases**
  - **Combinations of alleles that provide "fitness" increase in the population.**

Genetic Drift

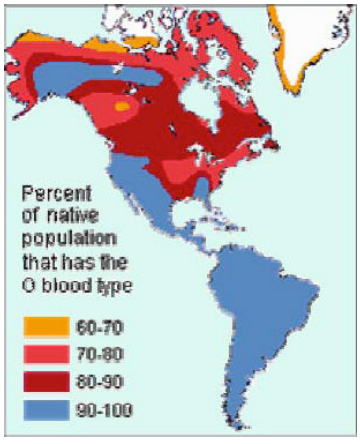
- **Changes in gene frequencies from 1 generation to another because of chance events**
  - **Examples:**
    - **1 family has a lot of children & grandchildren**
      - **Therefore has a greater impact on the genes in the population than other families**
    - **A small group splinters off & starts a new colony = founder effect**
    - **Famine reduces population to small number & then population recovers & expands = bottleneck**

Founder Effect

- **When a new population is started by only a few individuals**
  - **Some rare alleles may be at high frequency; others may be missing**
  - **Skew the gene pool of the new population**
    - **Human populations that started from small group of colonists**
    - **Example: white people!**

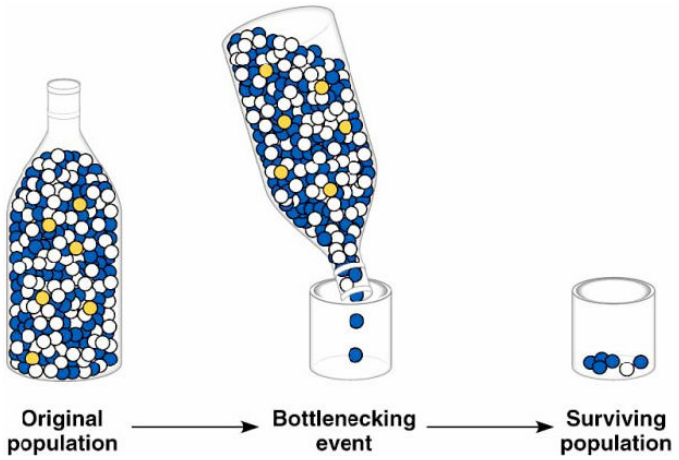
Distribution of Blood Types

- **South & Central American Indians were nearly 100% type O for the ABO blood system. Since nothing in nature seems to strongly select for or against this trait, it is likely that most of these people are descendants of a small band of closely related "founders" who also shared this blood type.**



Bottleneck Effect

- When larger population is drastically reduced by a disaster.
  - Loss of Variation
    - By chance, some alleles may be overrepresented & others under-represented among survivors.
    - Some alleles may be eliminated altogether.
    - Narrows the gene pool.
- Cheetahs
  - All cheetahs share a small number of alleles
    - less than 1% diversity
    - as if all cheetahs are identical twins
  - 2 bottlenecks
    - 10,000 years ago
      - Ice Age
    - last 100 years
      - poaching & loss of habitat



- Conservation Issues
  - Bottlenecking is an important concept in conservation biology of endangered species.
    - Populations that have suffered bottleneck incidents have lost at least some alleles from the gene pool.
    - This reduces individual variation & adaptability.
    - At risk populations.

Gene Flow

- Have a population spread over a large geographic area
- Individuals can move from one area to another
- Sub-populations may have different allele frequencies
- Migrations cause mixing across regions = gene flow
  - New alleles are moving into gene pool
  - Reduce differences between populations
- World Wide Travel
  - Gene flow in human populations is increasing today
  - transferring alleles between populations

Gene Flow & Human Evolution

- Are we moving towards a blended world?

Chapter 23: Population Genetics

Essential Questions

- **How can we measure evolutionary change in a population?**
- **What produces the variation that makes evolution possible?**
- **What are the primary mechanisms of adaptive evolution?**

Population genetics provides a foundation for studying evolution.

Smallest unit of evolution

- **Individuals are selected.**
- **Populations evolve.**

Modern Synthesis

- **Evolution since Darwin**
- **Comprehensive theory of evolution took form in early 1940s.**
- **Integration of natural selection & Mendelian inheritance (genetics).**
    - **aka Neo-Darwinism**
    - **R.A. Fisher**
    - **J.B.S. Haldane**
    - **Theodosius Dobzhansky**
    - **Ernst Mayr**
    - **Sewall Wright**
    - **George Gaylord Simpson**
    - **Ledyard Stebbins**

Populations & Gene pools

- **Concepts**
    - **A population is a localized group of interbreeding individuals**
    - **Gene pool is collection of alleles in the population**
        - **Remember difference between alleles & genes!**
- **Allele frequency is frequency of allele in a population**
    - **How many A vs. a in whole population**

Evolution of Populations

- **Evolution implies a change in allele frequencies in a population**
    - **Hypothetical: what would it be like if allele frequencies didn't change?**
    - **Non-evolving population**
        - **Very large population size (no genetic drift)**
        - **No migration (in or out)**
        - **No mutation**
        - **Random mating (no competition)**
        - **No natural selection**

Hardy-Weinberg Equilibrium

- **Hypothetical, non-evolving population**
    - **Preserves allele frequencies**
- **Serves as a Model**
    - **Natural populations rarely in H-W equilibrium**
    - **Useful model to measure if forces are acting on a population.**

Hardy-Weinberg theorem

- **Alleles**
  - **frequency of dominant allele = p**
  - **frequency of recessive allele = q**
    - **frequencies must add to 100%, so:**

$$p + q = 1$$

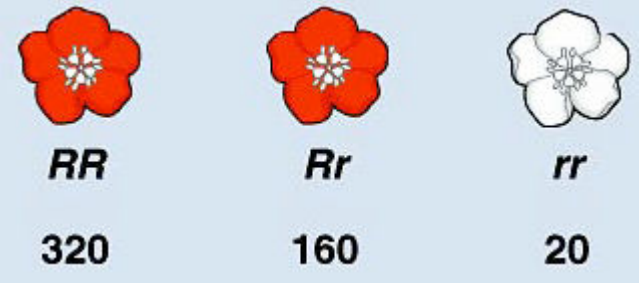
- **Individuals**
  - **frequency of homozygous dominant = p^2**
  - **frequency of homozygous recessive = q^2**
  - **frequency of heterozygotes = 2pq**
    - **frequencies must add to 100%, so:**

$$p^2 + 2pq + q^2 = 1$$

Calculating Frequency of Alleles

- **Example:**

  A wildflower population with 2 flower colors.
  - **Allele for red flower color (R) is completely dominant to the allele for white flowers (r).**



- **Population of 500 plants**
  - **What is the allele frequency?**
  - **What % of gene pool is red allele vs. white allele?**
  - **Remember diploid = 1000 alleles**

	R		**r**
RR:	**320 x 2 = 640**	**rr:**	**20 x 2 = 40**
Rr:	**160 x 1 =160**	**Rr:**	**160 x 1 =160**
R =	**800/1000 = 80%**	**r =**	**200/1000 = 20%**
p =	**0.8**	**q =**	**0.2**

Application of HW theorem

- **What is the frequency of an allele in the population**
  - **Example:**
    What % of the human population carries allele for PKU (phenylketonuria)?
  - **~ 1 in 10,000 babies born in the US is born with PKU, which results in mental retardation & other problems if untreated.**
  - **Disease is caused by a recessive allele.**
- **PKU**
  - **frequency of homozygous recessive individuals**
    (q^2) = 1 in 10,000 or 0.0001
  - **frequency of recessive allele**
    (q): $\sqrt{q^2} \rightarrow \sqrt{0.0001} = 0.01$
  - **frequency of dominant allele**
    (p): $p = 1 - q \rightarrow 1 - 0.01 = 0.99$
  - **frequency of carriers, heterozygotes**
    (2pq*):* 2 x (0.99 x 0.01) = 0.0198 or ~2%
- **~2% of the US population carries the PKU allele**

Implications of HW theorem

- **In H-W population, all alleles remain at the same frequencies.**
- **If allele frequencies change, then population is not in equilibrium & evolution is occurring.**
- **Population biologists measure & study.**
    - **Sampling of individuals & genetic testing.**
    - **Measure from year to year.**

Using H-W Theorem

- **Microevolution**
    - **generation to generation change in a population's allele frequencies.**
- **Measuring changes in population from generation to generation.**

Mutation & sexual recombination produce the variation that makes evolution possible.

Mutation

- **Mutation creates variation.**
    - **New genes & new alleles originate only by mutation**
    - **Only mutations to sex cells can be passed on**
- **Mutation changes DNA sequence.**
    - **Changes amino acid sequence**
    - **Changes protein**
        - **Change structure? Change function?**
    - **Changes in protein may change phenotype & therefore change fitness.**
        - **Most mutations are deleterious**

Types of Mutations

- **Point mutations**
    - **sickle cell anemia**
- **Duplications**
    - **hemoglobin chains, fetal hemoglobin**
    - **olfactory receptors**
    - **immunoglobulins**
    - **tRNAs & rRNAs**
- **Rearrangements**
    - **Translocations**

Sexual Recombination

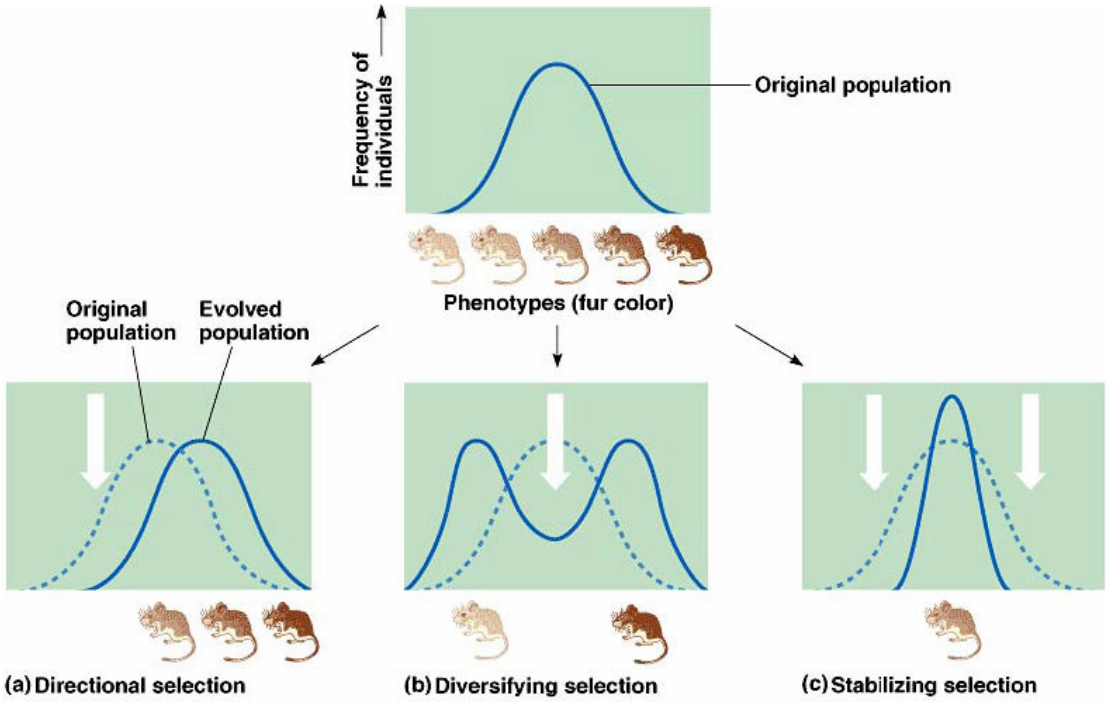
- **Sex spreads variation**
    - **Sex causes recombination**
        - **segregation & independent assortment**
    - **Offspring have new combinations of traits = new phenotypes**
- **Sexual reproduction recombines alleles into new arrangements in every offspring.**

Selection & Variation

- **Natural selection requires a source of variation within the population.**
    - **There have to be differences.**
    - **Some individuals are more fit than others.**
- **Genetic variation is the substrate for natural selection.**

Types of Selection

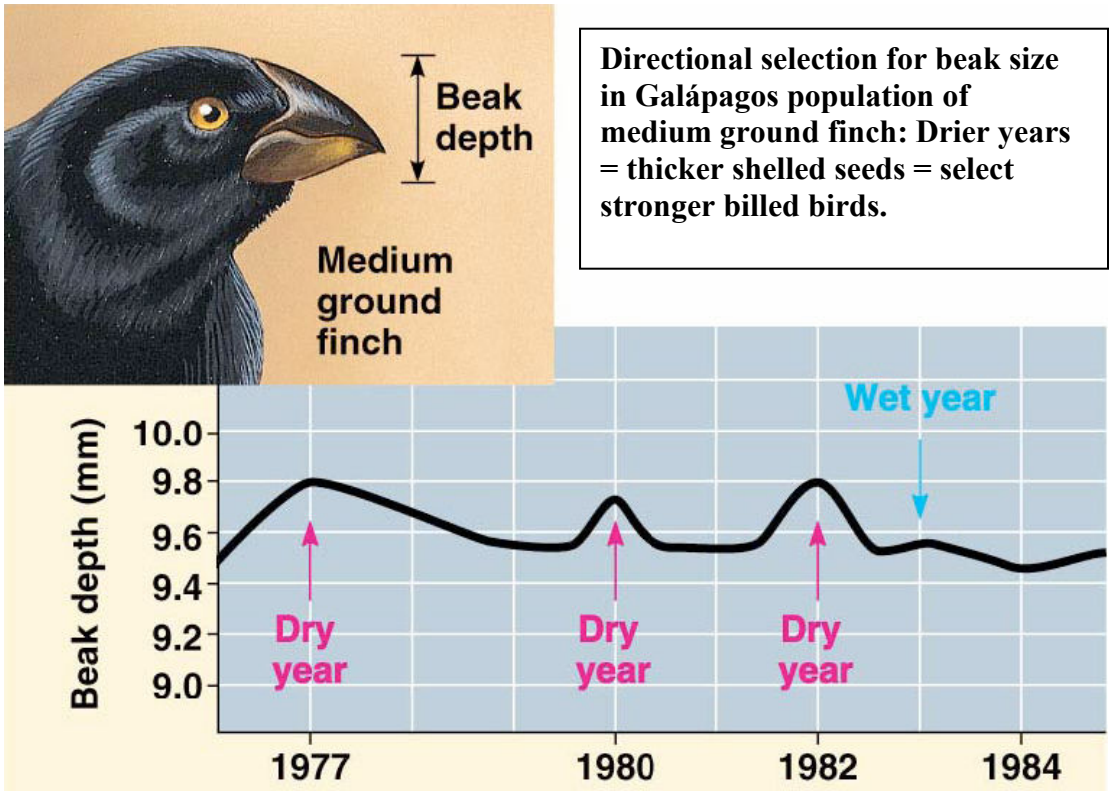
- **The effect of selection depending on what is "fit"**



Directional Selection

- **Environment favors one extreme.**

Directional selection for beak size in Galápagos population of medium ground finch: Drier years = thicker shelled seeds = select stronger billed birds.

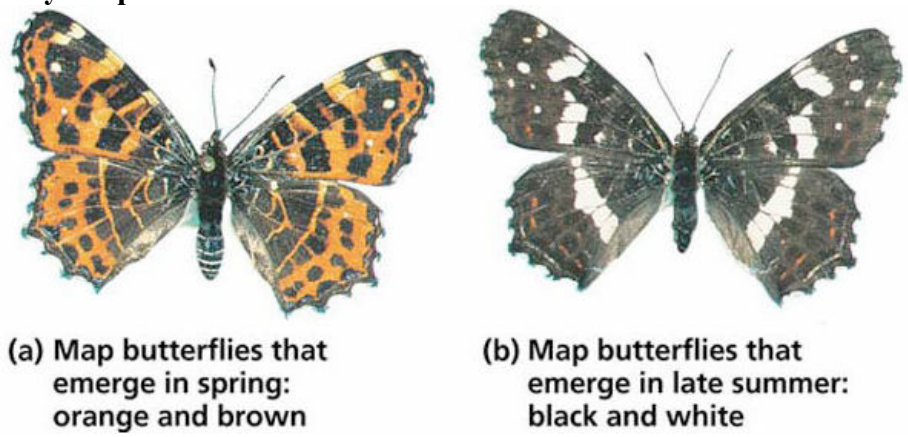


Directional selection for beak size in Galápagos population of medium ground finch: Drier years = thicker shelled seeds = select stronger billed birds.

Variation

- **Discrete vs. Quantitative Characters**
  - **red vs. white flower color = discrete**
  - **Human height = quantitative**
- **Polymorphic**
  - **Morphs**
    - **Distinct types in a population**
- **Geographic variation**
  - **Clines**

Polymorphic

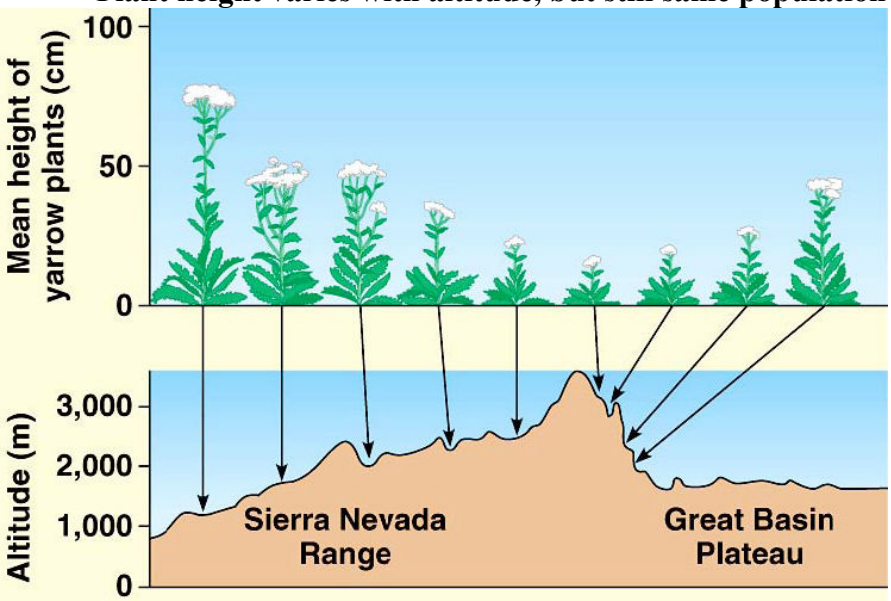


(a) Map butterflies that emerge in spring: orange and brown

(b) Map butterflies that emerge in late summer: black and white

Clines

- **Plant height varies with altitude, but still same population**

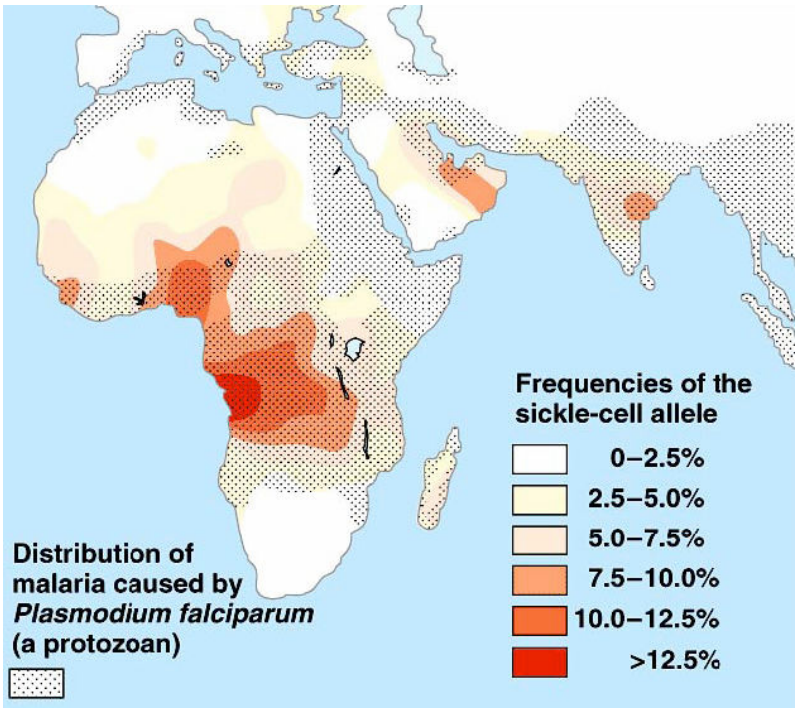


Preserving Variation

- **Diploidy**
  - **Genetic variation— even lethal alleles— are hidden in heterozygotes**
- **Balancing Selection**
  - **Balanced polymorphism**
    - **Maintaining 2 or more phenotypes through selection**
    - **Heterozygote advantage**
    - **Frequency-dependent selection**

Heterozygote Advantage

- **Heterozygotes have a greater fitness**
  - **Maintain both alleles in population**
  - **Sickle cell anemia**
- **Heterozygotes are protected severest effects of malaria & do not develop sickle cell disease.**



Frequency-dependent Selection

- **Fitness of any morph decrease if it becomes too common.**
- **Selection against more abundant phenotype.**
- **Consider action of both predators & parasites.**

Sexual Selection

- **Natural selection for mating success.**
  - **Competition amongst males for females.**
    - **Ritual displays & battles between males.**
  - **Female choice**
    - **Courtship displays to attract females.**

Female choice rules animal kingdom!

(Sexual dimorphism)

Males may go to extremes.

Limitations of Natural Selection

- **Natural selection cannot fashion perfect organisms.**
  - **Evolution is limited by genetic constraints.**
    - **legacy of ancestral genes**
    - **existing variations may not be ideal**
  - **Adaptations are often compromises.**
    - **Adaptation for one situation may be limitation for another.**
  - **Chance & natural selection interact.**
    - **The founders may not be the fittest**

Chapter 24: The Origin of Species

Essential Questions

- **How and why do new species originate?**
- **What is a species?**
- **Biological species concept**
  - **Defined by Ernst Mayr**
  - **Population whose members can interbreed & produce viable, fertile offspring.**
  - **Reproductively compatible**

Eastern Meadowlark Western Meadowlark

Biological Species Concept

- **Similar body & colorations, but are distinct biological species because their songs & other behaviors are different enough to prevent interbreeding.**

Diversity & Taxonomy

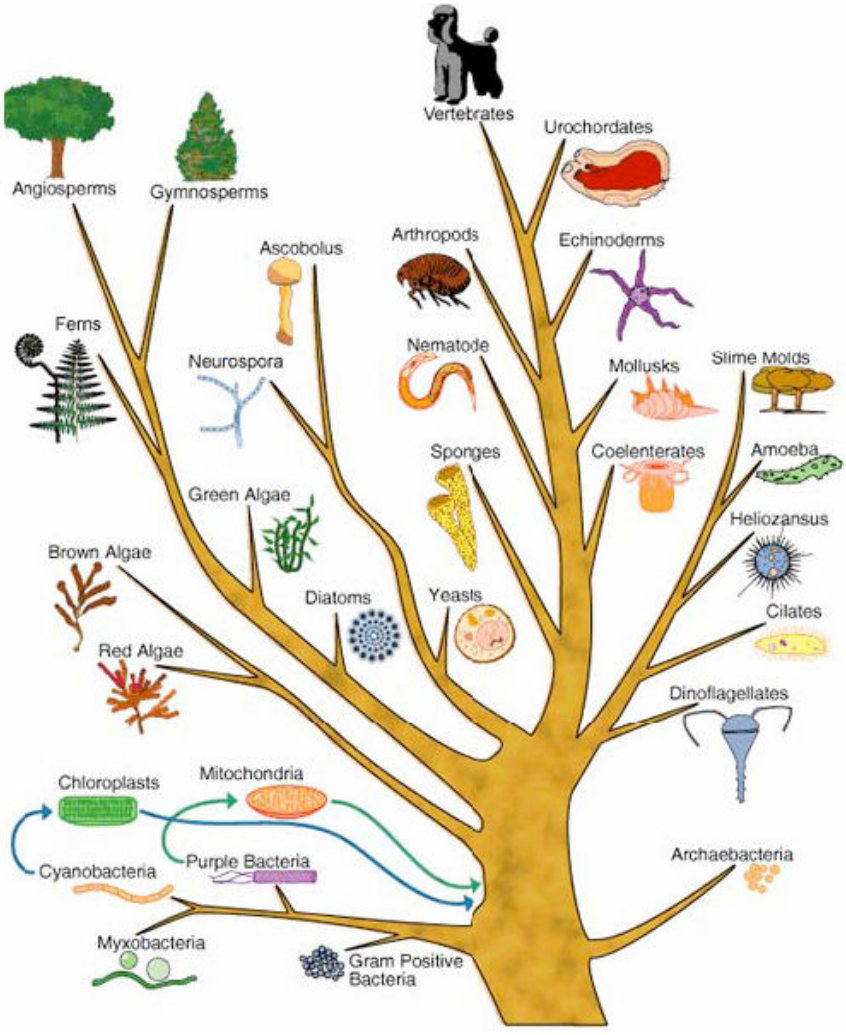
- **The Tree of Life**
  - **Species are the smallest unit at the ends of branches.**
  - **Basic unit for organizing & categorizing living things.**
  - **Smallest unit by which we measure diversity.**

Reproductive Isolation

- **Species concept hinges on reproductive isolation.**
- **Biological barriers that impede members from producing viable offspring.**
- **Before vs. after fertilization**
- **Pre-zygotic barriers (before the zygote).**
- **Post-zygotic barriers (after the zygote).**

Prezygotic Barriers

- **Impede mating or hinder fertilization if mating occurs.**
- **Habitat isolation**
- **Temporal isolation**
- **Behavioral isolation**
- **Mechanical isolation**
- **Gametic isolation**



Habitat Isolation

- **Two species may occupy different habitats within same area so may encounter each other rarely.**
- **2 species of garter snake, *Thamnophis*, occur in same area, but one lives in water & the other is terrestrial.**

Temporal Isolation

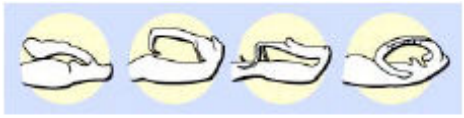
- **Species that breed during different times of day, different seasons, or different years cannot mix gametes.**
- **Eastern spotted skunk (L) & western spotted skunk (R) overlap in range but eastern mates in late winter & western mates in late summer.**

Behavioral Isolation

- **Courtship rituals that attract mates & other unique behaviors to a species are effective reproductive barriers.**
- **Blue footed boobies mate only after a courtship display unique to their species.**

Mechanical Isolation

- **Morphological differences can prevent successful mating.**
- **Even in closely related species of plants, the flowers often have distinct appearances that attract different pollinators. These 2 species of monkey flower differ greatly in shape & color, therefore cross-pollination does not happen.**
- **For many insects, male & female sex organs of closely related species do not fit together, preventing sperm transfer.**
- **Lack of "fit" between sexual organs: hard to imagine for us, but a big issue for insects with different shaped genitals!**



Damsel fly penises

Gametic Isolation

- **Sperm of 1 species may not be able to fertilize eggs of another species.**
  - **Variety of mechanisms.**
    - **Chemical incompatibility.**
      - **Sperm cannot survive in female reproductive tract.**
    - **Biochemical barrier so sperm cannot penetrate egg.**
- **Sea urchins release sperm & eggs into surrounding waters where they fuse & form zygotes. Gametes of different species—red & purple —are unable to fuse.**

Postzygotic Barriers

- **Prevent hybrid zygote from developing into a viable, fertile adult.**
  - **Reduced hybrid viability**
  - **Reduced hybrid fertility**
  - **Hybrid breakdown**

zebroid

Reduced Hybrid Viability

- **Genes of different parent species may interact & impair the hybrid's development.**
- **Species of salamander genus, *Ensatina,* may interbreed, but most hybrids do not complete development & those that do are frail.**

Reduced Hybrid Fertility

- **Even if hybrids are vigorous they may be sterile**
- **Chromosomes of parents may differ in number or structure & meiosis in hybrids may fail to produce normal gametes**

Horses have 64 chromosomes

Mule are vigorous, but sterile

Donkeys have 62 chromosomes

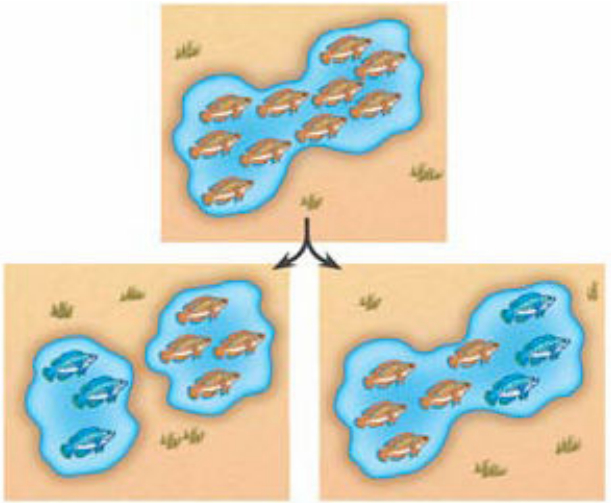
Mule have 63 chromosomes!

Habitat Breakdown

- **Hybrids may be fertile & viable in first generation, but when they mate offspring are feeble or sterile.**
- **Strains of cultivated rice have accumulated recessive alleles. Hybrids are vigorous but plants in next generation are small & sterile. They are on a path to separate species.**

Speciation

- **Species are created by a series of evolutionary processes.**
  - **Populations become isolated**
    - **reproductively isolated**
    - **geographically isolated**
  - **Isolated populations evolve independently.**
- **Isolation**
  - **Allopatric**
  - **Sympatric**

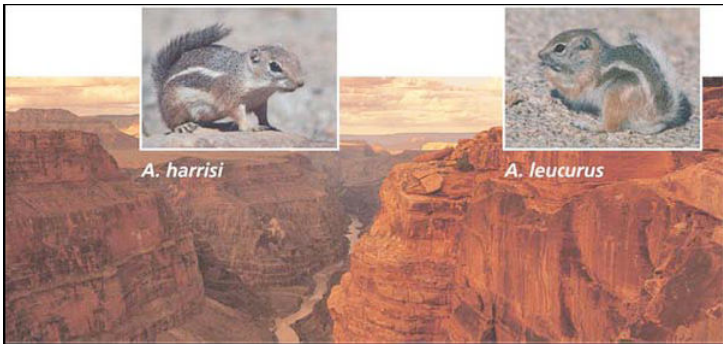


(a) **Allopatric speciation.** A population forms a new species while geographically isolated from its parent population.

(b) **Sympatric speciation.** A small population becomes a new species without geographic separation.

Allopatric Speciation

- **Allopatric = "other country"**
  - **geographic separation**
    - **migration**
    - **physical barrier**
- **Harris's antelope squirrel inhabits the canyon's south rim (L). Just a few miles away on the north rim (R) lives the closely related white–tailed antelope squirrel**



Sympatric Speciation

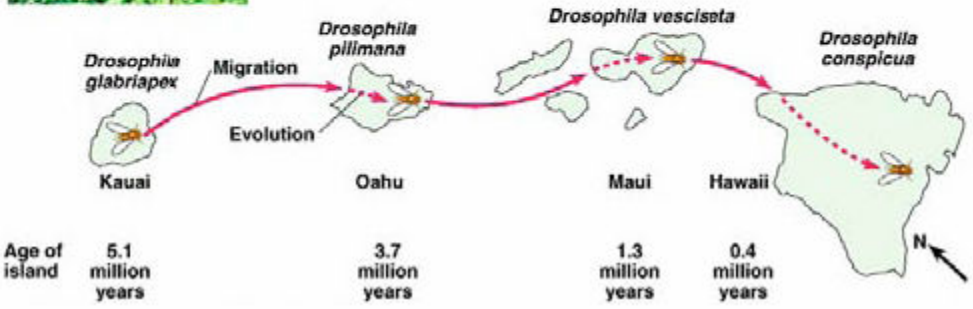
- **Sympatric = "same country"**
  - **Isolation even though members of population remain in contact**
  - **What causes this isolation?**
    - **Chromosomal changes**
      - **polyploidy**
        - **mostly in plants**
        - **oats, cotton, potatoes, tobacco, wheat**
    - **Non-random mating**

Adaptive Radiation

- **Evolution of many diversely adapted species when introduced to various new environmental challenges & opportunities.**

Adaptive Radiation

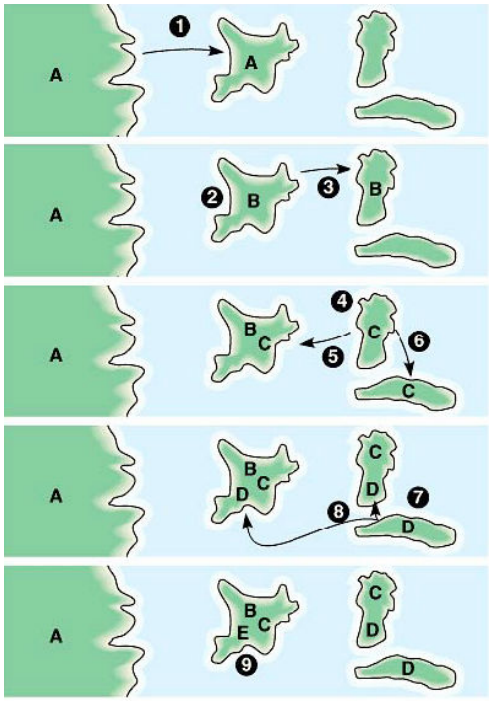
- **Many ecological niches open**
- **Evolution of many diversely-adapted species from a common ancestor to fill niches**
  - **Darwin's finches**
  - **Mammals**



Review

Speciation is a process.

- **Populations become isolated**
  - **Geographic isolation**
    - **different environmental conditions: food, predators, disease, habitat**
    - **different selection pressures**
    - **genetic drift**
  - **Reproductive isolation**
    - **different selection pressures: sexual selection**
- **Isolated populations evolve independently**



Current Debate

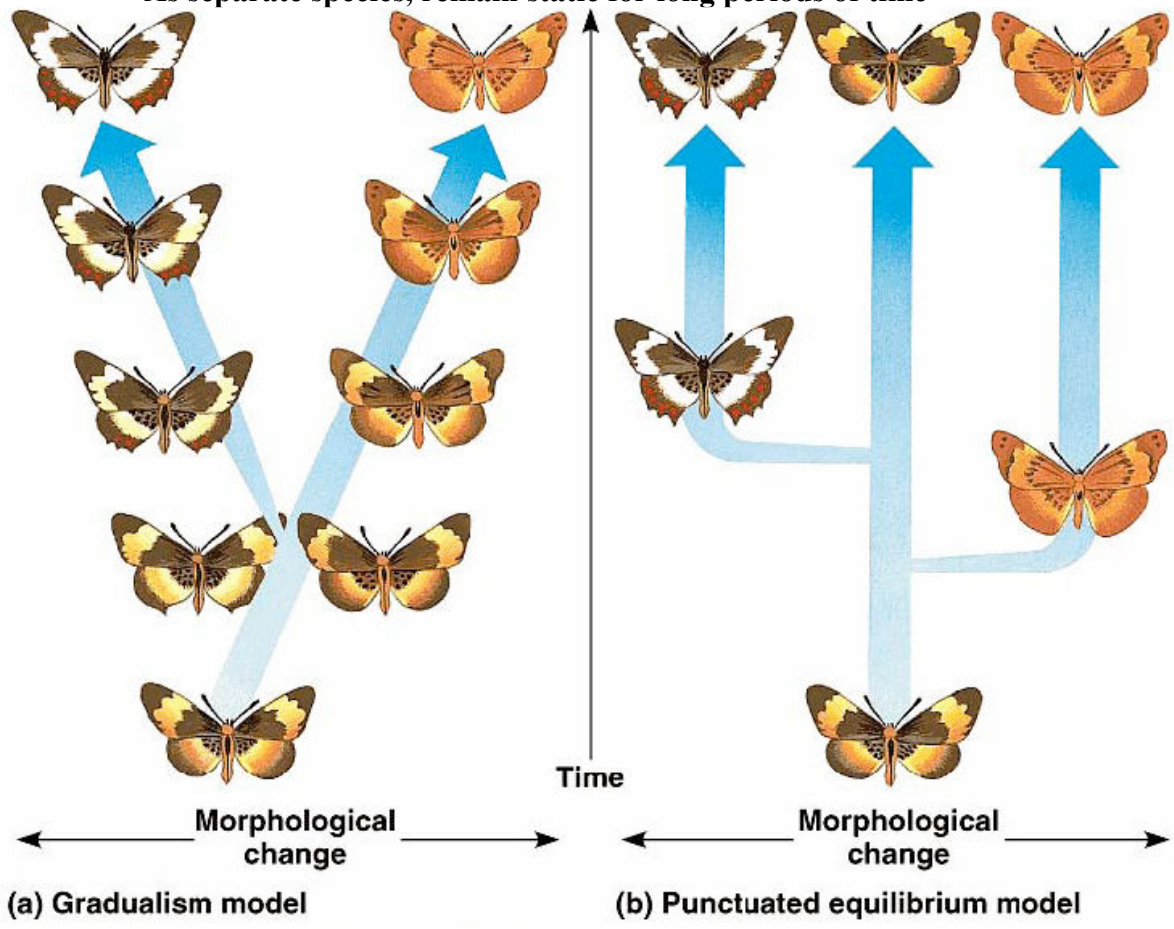
- **Does speciation happen gradually or rapidly perhaps in response to environmental change**
  - **Gradualism**
    - **Charles Darwin**
    - **Charles Lyell**
  - **Punctuated equilibrium**
    - **Stephen Jay Gould**
    - **Niles Eldredge**

Gradualism

- **Gradual divergence over long spans of time.**
  - **Assume that big changes occur as the accumulation of many small ones.**

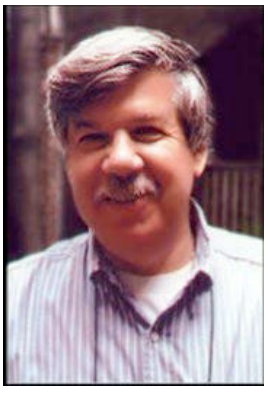
Punctuated Equilibrium

- **Rate of speciation is not constant**
  - **Species undergo most change when they 1st bud from parent population**
  - **As separate species, remain static for long periods of time**



Stephen Jay Gould (1941-2002)

- **Harvard paleontologist & evolutionary biologist**
  - **Punctuated equilibrium.**
  - **Prolific author.**
    - **Popularized evolutionary thought.**



Evolution is NOT Goal-Oriented

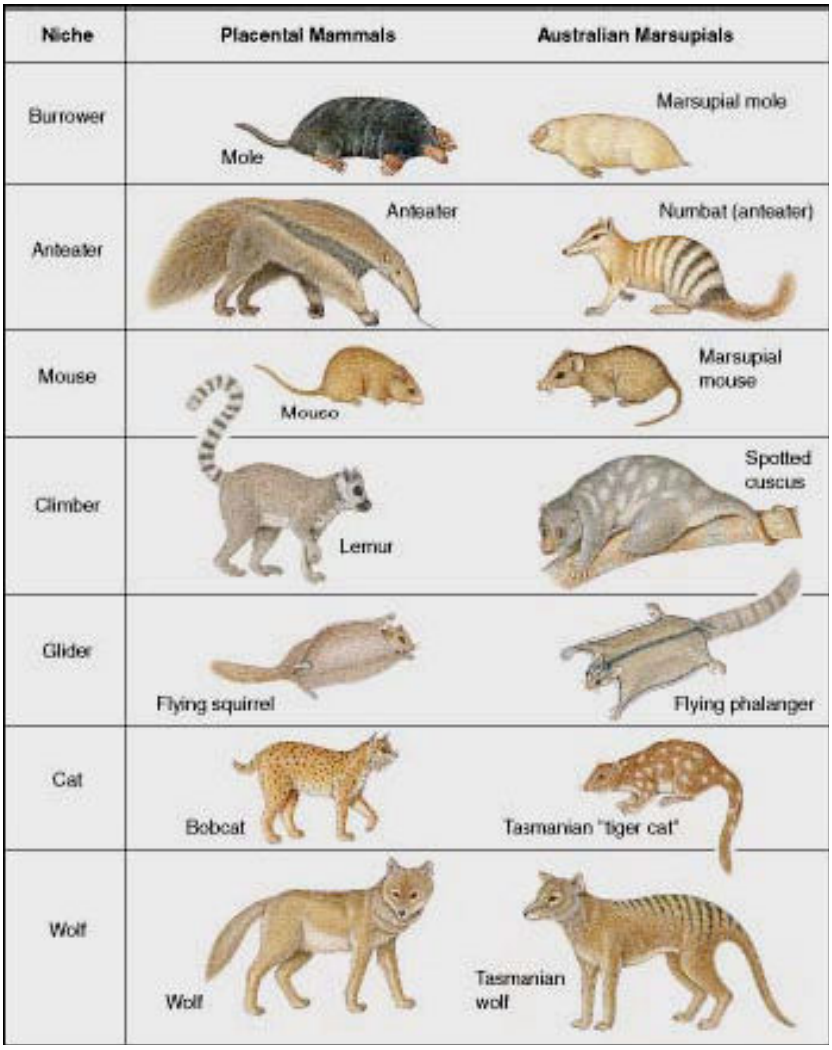
- **An evolutionary trend does not mean that evolution is goal oriented. The modern horse is the only surviving twig of an evolutionary bush with many divergent trends.**

Convergent Evolution

- **Flight evolved 3 separate times.**
- **Evolving similar solutions to similar "problems".**

Parallel Evolution

- **Parallel paths.**
- **Filling similar niches therefore exhibit similar adaptations.**
- **But are not closely related.**



Co-Evolution

- **Predator-prey relationships**
- **Parasite-host relationships**
- **Flowers & pollinators**

Darwin Awards

- **Named in honor of Charles Darwin, the father of evolution, the Darwin Awards commemorate those who improve our gene pool by removing themselves from it.**
- **The Darwin Awards salute the improvement of the human genome by honoring those who accidentally kill themselves in really stupid ways. Of necessity, this honor is generally bestowed posthumously.**

www.DarwinAwards.com