

## **SCIENTIFIC BASIS OF BIOLOGY**

**Scientific Method:** make observations about natural world, develop explanations, test by collecting more information (curiosity + skepticism)

**Hypothesis:** tentative explanation; testable and falsifiable

- idea formed by examining existing literature, observations

**Null Hypothesis:** that there is no significant difference b/w specified populations and/or that particular factor has no effect

**Logical Prediction:** based on theory; if certain factors exist, a certain outcome can be expected ("if"..."then"...) ← inductive

**Chronological Prediction:** foretelling the future; based on time/order of past events??

Everything is same in controlled/treated models except **experimental variable**, to which any observed differences are attributed

**Scientific Theory:** well-substantiated explanation of an aspect of natural world, confirmed by every conceivable test

- based on broad range observations, multiple hypotheses
- usually explain phenomena more general than hypothesis
  - o hypotheses often combined into theory

**Fact:** when there is no doubt of theory; rare in science

**Laws:** must be universal; applies to planets/universe (e.g. gravity), not in biology

- a few in subcellular biochemical events (e.g. Mendel's Law of Inheritance)

**Observational Sciences:** (vs **experimental**) astronomy, ecology, evolutionary biology (cannot establish fully controlled experiments) → field experiments

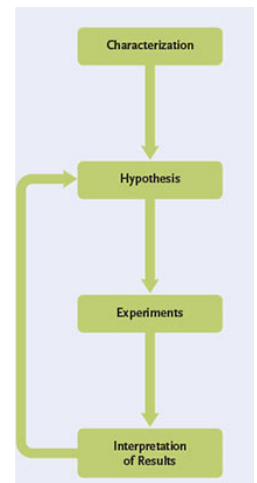
### **Scientific Method:**

1. Question that needs to be answered
2. Gather information already known
- 3.
4. Interpret results of test
5. Retest
6. Publish results

Other experimental components: controls, control of variables, repeat the test

**Replication:** repeating entire experiment (different than increasing # measurements)

- more measurements reduces **sampling error**
- numbers similar in lab experiment replicates; outcomes same in field



Distribution of scientific facts:

1. Journal selection
2. Manuscript preparation
3. Peer review
4. Revision
5. Publication

\* include background for hypothesis, experimental design, alternate interpretations, conclusions/implications

**Primary Literature:** authors directly involved in work

**Secondary Literature:** peer-reviewed articles written by experts; summarize scientific topics as review articles

**Tertiary Literature:** general summary written by the scientists (e.g. textbook)

Industrial Melanism (natural selection)

*Observation 1:* Original collections all white peppered moths; by 1900, traps collected 90% black

*Question 1:* Why did moth morphology shift light → dark?

*Hypothesis 1:* Fitness decreased when moths more visible against trees

*Null Hypothesis 1:* Fitness remains same, unaffected by background

*Hypothesis 2:* Bark colour of trees changed

*Null Hypothesis 2:* Bark colour of trees unchanged

*Experiment 1:* Artificially rear light/dark morphs, place on tree and observe survival

*Experiment 2:* Locate light/dark coloured trees

*Result 1:* Birds selected most visible moths

*Result 2:* Dark trees showed same distribution as coal-based industry

*Questions:*

- a) Do moths “rest” on backgrounds that match their colouration?
- b) What impact would the clean air act (reduced pollutant emissions) have on moth population morphs?
- c) What happens to other moths with light/dark colour morphs?

| Physical Science  | Natural (Descriptive) Science   |
|---|---|
| <ul style="list-style-type: none"> <li>• inanimate objects</li> <li>• physical/chemical laws</li> <li>• universal</li> <li>• based on empirical observations</li> <li>• preferred method = experimentation</li> <li>• single theory</li> <li>• single falsification → abandon theory</li> </ul> | <ul style="list-style-type: none"> <li>• animate objects</li> <li>• more than physical/chemical laws (genetics)</li> <li>• not universal</li> <li>• based on historical narratives</li> <li>• preferred method = induction</li> <li>• multiple theories</li> <li>• single falsification, not necessary to abandon theory</li> </ul> |

**Narratives:** scientists before revolution wrote ‘stories’ explaining observations of natural world; changed to experiments in scientific revolution

- inductive reasoning; looked down upon by deductive physicalists
- used for “why” questions, ultimate causes

**Deduction:** general → specific

- e.g. all insects have wings and this animal is an insect, therefore it has wings
- used in physical sciences

**Induction:** specific → general

- e.g. this animal is an insects and it has wings therefore all insects have wings
- after many observations, but can never see every example in natural science

**Physicalists** felt that all living things except humans were machines, could be reduced into various parts

**Vitalists** believed in vital essence of life (physical/chemical laws still apply)

- can’t rule out every possibility due to variability; one theory does not vito another
- divide continued until genetics discovered as ‘vital life force’

**Organacists’ (Holistic) View:** 1930s – life ruled by laws of physics/chemistry but, through the genetic program, the whole is more than the sum of its parts = **emergence**, (“swarm behavior”)

- genetic program replaced vital force

\*giraffes feed at shoulder height, couldn’t have been selective pressure for long necks → actually weapon for sexual competition (males)

- however, during drought only high vegetation might be available
- 2 explanations! (differs from physical science)

Parts of scientific theory: pattern + mechanism/process

Questions: What? How (proximate cause)? Why (ultimate cause)?

**Proximate Cause:** something happens, very next thing is result; *how*

- hit knee with hammer, causes muscle contraction
- e.g. DDT kills pests

**Ultimate Cause:** neurotransmission, even gene sequences; *why*

- DDT ultimate cause of turning on detoxifying genes → resistant mosquitos

| <b>Proximate Causes<br/>(physical science-like biology)</b>  | <b>Ultimate Causes<br/>(natural science-like biology)</b>  |
|--|--|
| <ul style="list-style-type: none"><li>• Phenotype: morphology/behavior</li><li>• Mechanical (predictable)</li><li>• Here + now</li><li>• Genes in action</li><li>• Experiments</li></ul> | <ul style="list-style-type: none"><li>• Genotype: genes/history</li><li>• Variable (probabilistic)</li><li>• Evolutionary past</li><li>• Changes in genetic programs</li><li>• Historical narratives</li></ul> |

\*biology involves both proximate + ultimate causes

**Ernst Mayr (1997):** both physicalism/vitalism apply in biology in differing degreed depending on type of questions being asked

- “What” questions → hypotheses/theories
- “How” and “Why” questions used as test
  - “how” = proximate causes; addresses mechanisms, observed through morphological/behavioural phenotype
  - “why” = fundamental underlying causes; troubled physicalists, brought back into biology by Darwin

## PREDARWINIAN BIOLOGY

1802: Treviranus created first recorded definition of biology; young science!

**Biology:** subject matter is the various forms/manifestations of life, the conditions/laws controlling their existence, and the causes by which this is effected; AKA “science of life”

- people don't generally call themselves “biologists”
  - o molecular bio, biochem, genetics, cell bio, physiology, developmental bio, morphology, evolution/systemic bio, ecology, behavioural bio, nutrition, disease mechanisms, pharmacology, genomics, proteomics
- scientific revolution of renaissance = physical sciences (physics, mechanics, math, astronomy)
- used to be “naturalists”, “natural sciences”

## Douglas Adams' Four Ages of Sand (silica/glass) 1951-2001

1. Telescope 1608
  - Astronomy, physics, equations, planetary motions → geometry, calculus, algebra
2. Microscope 1678
  - See things smaller than w/ human eye → discover smaller organisms
  - Cellular components, tissues (histology)
3. Computer chip 1961
  - Silica transistor; charged score = 1, discharged= 0 → binary code, programming
  - Calculators, searching for/archiving information
  - Computational analysis, mathematical models of biological systems
4. Fiber optics 1980s
  - Connectivity, sharing of resources → scientific collaboration/networking
  - Lightning-speed transmission of data

Major events:

1. Predarwinian and the natural sciences (400 BCE – late 1800s)
  - a. Green and Roman ages (400 BCE – 450 CE)
  - b. Medieval Ages (450 – 16<sup>th</sup> century)
  - c. Renaissance and the scientific reolution (16<sup>th</sup>-18<sup>th</sup> century)
2. Darwin and evolutionary thought (late 1800s – mid 1900s)
3. Modern theory of evolution and more (mid 1900s – present)

## 400 BCE – 450 CE:

- Greek philosophers believed that world had existed forever, unchanged
  - o Hippocrates (460-370 BCE) – medicine
  - o Aristotle (382-322 BCE) – zoology
  - o Theophrastus (371-287 BCE) – botanist
- all produced works that were lists/catalogues, didn't address actual biology of organisms
  - o believed Plato's idea of **essentialism** (organisms discrete, unchanged; differences due to internal "essence")
  - o essence passed on during reproduction
  - o **Special Creation:** all species created independently by God; perfect, unchanging; relatively recent creation
- Greeks/Romans first to travel, created commerce zone, people started identifying plants/minerals/animals (cataloging, understanding)
  - o different from where they came from
  - o put in infrastructure, shipping, roads
  - o culture → wealth → knowledge → recorded/coded
  - o communication, understanding, movement

### **Hippocrates:** (460-370 BCE) "Father of medicine"

- Hippocratic oath taken by doctors
- w/ others, assembled (written) every practice in human bio/medicine known in Roman world
- no longer by word of mouth, now one location
- **Hippocratic Corpus** = written record of human biology

### **Aristotle:** (384-322 BCE) Greek philosopher, student of Plato

- believed both inanimate objects and living organisms had fixed characteristics; tried to organize complexity visible in living world
- primarily studied animals
- created ladderlike/hierarchical classification (minerals → plants → animals → humans → gods)
  - o **Scala Naturae** = *Great Chain of Being*; still essentialism
  - o "the gods did it"; after beginning organization, starting think about *why* everything is there
  - o viviparous quadrupeds = mammals
  - o sea-born vs land-born, eggs/shell birth, etc.
  - o ranked based on perceived importance (e.g. high plants have flowers/fruits)

**Theophrastus:** “Ancient Father of Taxonomy” (modern is different)

- worked exclusively in botany, student of Aristotle
- plants important for medicine, catalog healing properties (most recognized work of Theophrastus); also food, fibre (cotton, wood)

*Changes in Scala Naturae:*

Greek/Roman Ages: multiple gods

Medieval Ages: 1 gods → arc angels → people in heaven → mankind → birds → on ground → in ground → SATAN

- really no advancement at all

**Medieval Ages (450-16<sup>th</sup> century)** ← only W culture (Europe area)

- Germanic **Goths** attacked → fall of Rome
    - o Rome had expanded, couldn't protect perimeter
  - end of commerce/knowledge sharing/transportation
  - Europe's function crashed, small communities or self-supporting
  - Lasted 1500 years (plague!)
  - Europe's **Dark Ages**; great scientific works hidden away
  - Scholarship surge in 800-900s = law, arts, architecture
1. 400-700 Early Middle Ages (Dark Ages)
    - recovering from abandonment of Rome/civilization from Europe
    - mostly ruins, still pockets of culture; small communities trying to survive
    - cities/roads beginning to be rebuilt
  2. 1000-1300 High middle ages
    - Big cathedrals
    - Europe and West builds up resources/revenue/knowledge, rebuilds culture
  3. 1300-1500 Late middle ages
    - Black Plague 1347-1351 (killed ½- 2/3 of population)

**11<sup>th</sup>/12<sup>th</sup> centuries:** Europe contacts Muslim world in crusades → influences medicine/religion

**1347-1351:** Black plague kills <50% of population, climatic change causes food issues, economic setback

- open revolt across Europe (Protestantism, against Roman Catholic church)

14th Century: Aristotle's classification merged w/ biblical creationism in Christian/Islamic worlds

**Natural Theology:** belief that knowledge of God may be acquired through study of natural phenomena; dominated biology at time

- Europeans thought all organisms created by a god, new kinds couldn't arise

- sought to name/catalogue all God's creations, identify position in Scala Naturae
- work of **Carolus Linnaeus**

Byzantium and Islamic World: Constantinople becoming 2<sup>nd</sup> Rome

- Arabic translations of work from Greeks/Romans → golden era of Muslim world
  - o Christian Europe meanwhile in Dark Ages

**Al-Jahiz (781-869)**: "Book of Animals"

- animal struggle for existence (resources, predators, reprod)
- environmental factors influence development of new characteristics → new species
- surviving organisms pass on successful characters
- basically natural selection!!

**al-Dinwari (826-896)**: botany, catalogued plants (took Theo's book farther); provided prescriptions (how to use plants medically)

**Avicenna (980-1037)**: philosopher; adds to Hippocrates' work, adds medical knowledge of Islamic/Indian world

- summarized Greek/Indian/Muslim medicine (used until 17<sup>th</sup> cent)

**Alhazen (965-1040)**:

- set of rules about making observations of scientific world (ensures valid/repeatable)
  - **scientific method** that we still use today
1. Observation
  2. Statement of problem
  3. Hypothesis
  4. Experimentation
  5. Analysis of results
  6. Interpretation of data, conclusion
  7. Publication

**Ibn al-Baitar (1197-1248)**: expands on pharmaceutical list further; his list gets translated to Latin, brought to W world (starting to blossom again); used until 19<sup>th</sup> century

**1453**: Ottoman Empire attacked → Constantinople fell

- W culture invaded Islamic world (Church wanted to free holy sites of Christianity, remove Islam)
- collected works of ancient Greece, Roman Empire, Muslim world available to Europe
- "14 hundred 92, Columbus sailed the ocean blue"
- still Scala Naturae, essentialism, fixed date...

**Sir Francis Bacon:** (1561-1626) ~1600, established **inductive reasoning**

- observation, experimentation, finding evidence to support theory
- other scientists (Copernicus, Galileo, Descartes, Sir Isaac Newton) proposed theories describing physical/mechanistic events
  - o formed biogeography, comparative morphology, geology
  - o awareness of change

**Renaissance (16<sup>th</sup>-18<sup>th</sup> century):** scientific revolution, start of modern sciences

- commerce returns, big cities reconnected (London, paris, etc.)
- beginning of modern age, but all about inanimate objects
  - o gravity, planets, gases, geometry/calculus
  - o mathematics, astronomy, physics, inorganic chemistry
  - o still essentialism for animate world
- only biological innovations: Linnaeus' hierarchical system of nested taxonomic groups and binomial nomenclature
  - o needed when European super powers explored world
- biology doesn't advance (church would get mad)
- most of physical science deemed as "instructions", essentialism/creationism still worked

Loads of important people:

- **Copernicus:** Earth not the centre of the universe
  - o afraid of getting in trouble with church (church funded research)
  - o told people, wrote a book, allowed publication on death bed
- **Kepler:** planetary motion
- **Newton:** laws of motion, gravity, thermal conduction
- **Galileo:** further proof of Earth revolving around sun
  - o annoying; kept publishing and publishing → excommunicated (reversed 1992)
- **Boyle:** behavior of gases
- **Pascal:** origins of calculus
- **Descartes:** geometry

Most important innovations:

- a) **Antonie van Leeuwenhoek:** first microscope
  - didn't release instructions on how to make microscope; had sole power, couldn't recreate for long time after he died
  - look through glass bead, move screws...
  - more organisms than we thought!

- b) **Andrea Vesalius:** Father of Anatomy
  - systematic dissections of human cadavers, creepy but accurate drawings
- c) **William Harvey:** Father of Physiology
  - how the living body works (blood flow, heart, pulmonary/systemic circuits...)
- d) **Linnaeus:** *Systema naturae* book (1735)

15<sup>th</sup>-17<sup>th</sup> Century: global explorations made it difficult to follow *Scala Naturae*

**Biogeography:** study of geographic plant/animal distributions

- similar species in different locations, different distributions, countless species

**Comparative Morphology:** comparison of anatomical structures of organisms

- e.g. flippers/legs/wings all have similar location, development, composition

**Homologous:** characters inherited from common ancestor

**Analogous:** different evolutionary origins, but superficially similar due to natural selection

**George-Louis Leclerc de Buffon:** (1707-1788) proposed that some animals had changed since creation

- puzzled by functionless body parts
- **Vestigial Structure:** anatomical feature of living organisms that no longer retains its function; must have functioned in ancestral organisms
- embarked on project to create 3-volume encyclopedia of world (inanimate, plants, animals)
  - o didn't get to plants, but wrote *Histoire Naturelle* on animals
- noticed similar basic appearance of animals during travels, but modifications depending on environment
  - o single "essence" of elephant by physical expression changes based on environment in arctic/Africa
  - o essence built from components available in environment

Also theorized that earth started as molten mass that cooled

- living forms w/ unique essences first formed at poles (cooler)
- moved toward equator during cooling, essence expressed as modified morphologies

\*still essentialism, but allows for modification/changing diversity; also proposes age of Earth as 70,000 (not 6000)

Geology:

**Georges Cuvier:** (1769-1832) French zoologist; realized that fossil layers represented organisms of different times

- abrupt changes = dramatic ancient environmental shifts
- **Catastrophism:** theory that Earth has been affected by sudden, violent, and sometimes worldwide events
  - o each layer = remains of organisms that died in catastrophe
  - o recolonized by different species after → repeat
  - o e.g. asteroid → extinction of dinosaurs 66 mya
  - o student linked to biblical flood of Noah
- coined term “extinction”, linked anatomy of extinct species w/ living → start of **comparative anatomy**

### Changing View of Earth

**Bishop James Ussher** (1581-1656): calculated age of Earth based on Bible;

- Creation = 4004 BCE (~5600 yo)

**Special Creation** (essentialism):

Pattern = species don't change due to special essence

Process = divine, by designer of some sort

**Dr. John Lightfoot** (1602-1675): more precise time= Oct. 23<sup>rd</sup>, 4004 BCE, 9am

**James Hutton:** (1726-1797) Scottish geologist; argued that slow/continuous physical processes produced Earth's geology

- water movement erodes land, deposits sediments → canyons/topsoil
- **Gradualism:** view that Earth and its living systems changed slowly over history (contrasts w/ **catastrophism**)

**Charles Lyell:** (1797-1875) English geologist; extended Hutton's ideas by arguing that geologic processes that sculpted Earth are still observed today (volcanic eruptions, earthquakes, erosion, glacial movement) = **uniformitarianism**

- Earth must be millions of years old, sedimentary rock formation is slow
- undermined notions of unchanging Earth
- noticed that mineral composition/fossils change over time and always in same sequence
- founded field of geological stratigraphy, created geological time scale
- erosion/sedimentation etc. now known as “Rock Cycle”; plate tectonics not proposed until 1920s (continental slabs submerge back into Earth's core)

## **SPECIES**

**Species:** population of organisms capable of interbreeding and producing fertile offspring; definition varies

- biodiversity is discrete, not a continuum
- definition doesn't work for organisms that reproduce asexually or hybridize
- evolution is dynamic process, doesn't accommodate rigid definitions
- **Hybridization:** 2 species interbreed and produce fertile offspring

**Taxonomy:** science of the classification of organisms into an ordered system that indicates natural relationships (identifies/names/classifies species)

- set of rules determining **classification**
- allows observance of changes in world
- classification mechanisms are innate in organisms (e.g. plants recognize own pollen for fertilization)
- humans record classification systems and pass on in spoken/written word

**Systematics:** study/classification of organisms via reconstruction of evolutionary histories/relationships

**Folk Taxonomies:** classification/rules passed by spoken word

- e.g. tomato is vegetable
- native cultures use classification schemes to distinguish different plants as foods/medications
- varies based on culture (North Americans have many different names for cars, Eskimos have 30 names for snow)
  - o some commonalities: <4 levels classifying living world, highest separates plants/animals
- individuals assigned as keepers of collective wisdom; info transferred to apprentice
- studied by cognitive scientists/anthropologists
- max ~500 unique elements/species

**Artificial Taxonomies:**

- first used by Plato and students (Aristotle/Theophrastus) ← huge deal!
- based on folk taxonomies, Aristotle recorded animals, Theophrastus plants
- shift when things were written down, ordered
- not based on evolution, not necessarily biologically correct
- Greek/Romans travelled, texts passed on, translated into Latin/Arabic
- lists grew longer, based on detailed descriptions

**Mechanical Taxonomies:** based on physical characteristics of organisms, descriptive commonalities

- lists were ~2000 y.o., too long; Europeans explored Americas/Indochina
  - o Latin = universal language of scholars
- end of ancient taxonomies
- “mechanical” because groups weren’t really based on biology/relatedness
  - o series of nested boxes, arbitrary criteria; evolution not discovered
  - o e.g. all long, tubular, legless animals placed in single phylum (now many very different worm-like phyla)
  - o parts of system still considered correct, many names still same

**Carolus Linnaeus:** (1707-1778) Swedish naturalist, first modern practitioner of taxonomy; mechanical taxonomy

- developed system for naming/classifying organisms still used = **Systema Naturae** (title of book)
- holds much info in organisms’ names → **binomial nomenclature**
- sent students around world to gather specimens

Main contributions:

1. Binomial nomenclature
  2. Hierarchy (nested): each category has set of predictable features
    - a. Positioning indicates characteristics based on higher groupings (not just name)
    - b. Predictability, defining characteristics
- better divisions of plants, he’s actually a botanist
  - phylum and family were added later

**Binomen** = name w/ 2 parts

**Binomial Nomenclature:** 2-part Latinized scientific name; 1<sup>st</sup> = genus, 2<sup>nd</sup> = species

**Genus:** Linnaean taxonomic category consisting of a group of species w/ similar characteristics; below family, above species ← **generic name** = Latin noun

**Specific Epithet:** species name = adjective (*Brantor canadensis* = Canadian goose)

- generic name capitalized, species never capitalized, all italics (underline by hand) because different language
- species names must be preceded by generic (same names for species in different genera)
- subsequent mentions of organism can use first letter of genus only (e.g. *U. maritimus*)
- naming of species follows publication of description in scientific journal; international commissions settle disputes
- named based on organism/habitat, biologist, humorously...

**Classification:** arrangement of organisms into hierarchical groups reflecting their relatedness

**Taxonomic Hierarchy:** classification system based on arranging organisms into ever more inclusive categories

1. **Domain:** group of organisms w/ characteristics that set it apart as major branch of evolutionary tree
2. Kingdom
3. Phylum (*added by Cuvier*)
4. Class (6 for Animalia)
5. Order
6. Family
7. Genus
8. Species
9. (Subspecies)

**King Peter Came Over**  
**From Germany for Sex**

**Taxon:** (*pl. taxa*) group of organisms included within a category in Linnean taxonomic hierarchy – e.g. “woodpeckers are a taxon (Picidae) at the family level”

**Autapomorphy:** distinctive characteristic that defines (is unique to) a group

- Kingdom Animalia: multicellular, heterotrophic, eukaryotic, “ingestive”
- Fungi: secrete enzymes to digest food (absorptive)
- Protista/Protozoa: unicellular
- Bacteria: prokaryotic
- Plants: autotrophic

**Natural/Classical/Traditional Taxonomy:** organisms in taxon have same common ancestor; ordering of taxa reflects evolutionary relationships

- after publication of Darwin’s works

**Cladistic (Phylogenetic) Taxonomy:** systematic approach that ignores morphological divergence; phylogenetic hypotheses/classifications reflect only evolutionary branching

- uses shared derived characters to infer phylogenetic relationships
- emerged due to lack of clarity in classification based on branching evolution and morphological divergence (distinct phenomena)

**Clade:** monophyletic group of organisms sharing homologous features derived from common ancestor

**Cladograms:** phylogenetic trees that illustrate hypothesized evolutionary branchings

**Monophyletic:** descended from common evolutionary ancestor/group

**Phylogenesis:** evolutionary development/diversification of species

## **BIOLOGICAL EVOLUTION**

**George-Louis Leclerc, Comte de Buffon:** naturalists that goes all over, observes

- notices many animals with similar appearances (cats)
- if everything arrived at once, why so many variations of an organism
- explanation: when organisms arrived, there was only 1, planted on Earth in one location (Garden of Eden)
  - o cats start to disperse (move out of garden)
  - o different nutrients/components of environments; consumption modifies essence/morphology
  - o essences are not fixed; changeable, altered by environment
  - o geography affects appearance of organism, organisms change over time

**Georges Cuvier:** (France) finding bones/fossils

- people used to think they were dragons/demons/devils
- Cuvier starts assembling them (first person), finds full organisms, similar to current animals (**comparative biology**)
- **Extinction:** concludes that relatives of current organisms have disappeared over time due to sudden catastrophe (**catastrophic theory**)
- Student linked to bible (Noah); bones are all from animals that didn't make it to ark

\*Cuvier didn't distinguish between fossils in all the layers of rock → **Lyell**

19<sup>th</sup> century: still naturalists (not "biologists"), *Scala Naturae* questioned, term **extinction** coined, Lyell's uniformitarian against Cuvier's catastrophism

- Lamarck first to hypothesize mechanism
- Darwin corrected it: variation within population, not individuals

**Erasmus Darwin:** doctor, Charles' grandfather;

- Translated Linnaeus System Naturae into English
- publishes *Zoonomia (laws of organic life)*; mostly medical, but speculates on relationships of visible organisms in living world
- near end of career, published *Temple of Nature* poem
  - o life first appeared in oceans as microscopic ("unseen by spherical class"), increased complexity, moved to land
  - o once vegetation springs up on land, animals evolved from fin to feet/wing

**Jean Baptiste de Lamarck:** (1744-1829) metaphysical “perfecting principle” caused organisms to become better suited to their environments

- simple → complex organisms; essence changes w/ environment
- microscopic organisms @ bottom replaced by spontaneous **infusoria** generation (from abiotic)
- “**transmutation (change) of species**”
- section through time = organisms at all stages (linear – one starts out, then another, then another...)
- no one else at time was trying to explain how things were actually changing
- How does change move between generations? How is it passed on?
  - o acquired inheritance (wrong!)
  - o physical stretching of parent giraffe neck passed on to baby
- didn't know that gamete precursors (dormant germ cells) are already present in animalia at birth (set aside in embryo); protects DNA from damage
- he was talking about changes in somatic cells (not passed on)
- sperm/egg mechanisms undiscovered

2 mechanisms of evolution:

1. Principle of Use and Disuse: body parts grow/shrink in proportion to use
2. Inheritance of Acquired Characteristics: changes acquired during lifetime passed to offspring
  - herons descended from short-legged ancestors that gradually stretched legs (to stay dry while feeding) over many generations

Incorrect, but 4 important proposals fostered discussion:

- 1) Species change through time
- 2) Changes passed b/w generations
- 3) Organisms change in response to their environments
- 4) Existence of specific mechanisms causing evolutionary change

Essentialist explanation:

1. **Transmutation** (not Lamark!!!) → rapid change in essence
  - sudden/dramatic change in essence between 2 generations → new organism
2. **Essential Transformation** (slow change)
  - a) **Finalism:** natural inherent quality of essence causes it to automatically change by itself
  - b) **Environmental** (this is Lamark)

Lamarck's transmutation is example of environmental transformation of the essence

**Charles Darwin:** (1809-1882) documented variation, described mechanisms of selection.

- sailed as naturalist on HMS *Beagle* (1831-1836), brought home thousands of specimens/fossils (very rich, could ship back to England)
- read Charles Lyell's *Principles of Geology*, applied gradualism/uniformitarianism to living world
  - o Lyell got Darwin job on *Beagle* (originally cabin-boy)

Argentina: fossils resembled living organisms

- linked living armadillo to extinct glyptodont (fossilized) → descendant

Galapagos Islands:

- species on different islands varied slightly, resembled those on South American mainland
- must be descended, appearance changes after isolation on island
- species carried to Galapagos by wind/ocean currents

Darwin collected finches w/ different bill shapes from different islands

- incorrectly assumed to be same species, actually different

### Theory of Natural Selection

\*\*\*\**Darwin did NOT come up with the theory of evolution, just natural selection*\*\*\*\*

**Artificial Selection:** selective breeding of plants/animals to ensure the increased frequency of certain desirable traits in successive generations

- already common though mechanism not understood (e.g. faster horses)

**Natural Selection:** evolutionary process by which alleles that increase likelihood of survival/reproduction become more common in subsequent generations

- principle by which each slight variation of a trait, if useful, is preserved

Thomas Malthus: English clergyman/economist, observed that England's population growing faster than agricultural capacity; wrote *Essay on Principles of Population*

- Darwin read book, applied to nature
- most species produce more offspring than parents, but population doesn't explode → some die w/out reproducing

Observations:

1.

- a) Most organisms produce >1-2 offspring
- b) Population sizes don't increase indefinitely
- c) Food/resources are usually limited

2.

- d) Individuals within a population vary in many characteristics (size, form, colour, behavior, etc.)

**Fig. 17.8**

- e) Many of these variations are passed from parent → offspring
- f) Some inherited variations favour the survival/reproduction of certain individuals, become more common in next generation
- g) If next generation subject to same selection process, favourable traits become even more common

**Adaptive Traits:** genetically based characteristic, preserved by natural selection, that increases an organism's likelihood of survival or its reproductive output

**Disruptive (Diversifying) Selection:** extreme values for a trait favored over intermediates; population divided into 2 distinct groups

- e.g. during drought, long-billed cactus finches feed on pulp of cactus fruits, deep-billed strip bark from trees to locate insects
  - o intermediate bills favoured during nondrought (insects/small seeds)

**Evolutionary Divergence:** process whereby natural selection causes populations to become more different over time (→ new species)

**Alfred Russel Wallace:** same time as Darwin, studied Amazonian rain forest and East Indies

- they both didn't focus on individual changing (like Lamarck), focused on variability of traits in population; ranges of characteristics

**1858:** Wallace wrote Darwin re ideas of how populations change over time

- Darwin had been reluctant to publish (wife important member of church, rich)
- Wallace sends communication to Darwin asking for comments, mirrored Darwin's research
- Darwin shows to Lyell, says he waited too long
- Wallace/Darwin published papers together (but most complete data comes from Darwin)

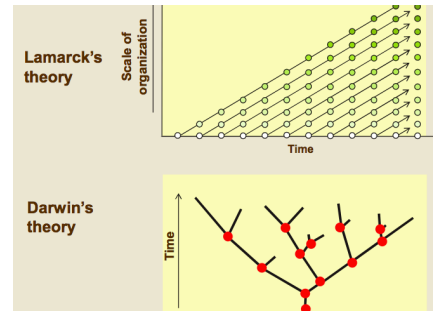
**1859:** Darwin published *On the Origin of Species by Means of Natural Selection*

- all organisms arose through **descent with modification** (evolutionary alteration/diversification of ancestral species)
- 5 theories to explain changing biodiversity, natural selection was most important
- narrative/story (no equations)

**Natural Taxonomy:** organisms should be sorted based on branching pattern, ancestry

**Phylogenesis:** evolutionary development/diversification

- analogy = “tree of life”, different than Lamarck’s linear model
  - o branches that end = extinct; uppermost twigs = living species



**Darwin's 5 Theories:** (according to Mayr)

1. No constancy of species
2. Common ancestry
  - today we can map down to lowest universal common ancestor of life (*luca*)
3. Gradual changes
4. Multiplication of species
  - new species, increasing diversity over time
5. Natural selection
  - better fitness → pass on traits

\*first 2 receive universal acceptance on publication, other 3 not initially accepted

- No idea what underlying mechanism of change, difference is
- What defines new species? What creates traits? What are we selecting for?
- Answer (unknown): genetics, genes, heritability
- Denoted “modern theory of evolution” after genetics discovered, all of Darwin’s theories accepted

No constancy of species:

- Fossils (Cuvier’s comparative anatomy)
  - o Rare (most dead organisms don’t fossilized → decomposition)
  - o Very unusual (special circumstances), hard to find
  - o Record critiqued as poor, has gaps
    - Where are fossils of jellyfish, sponges, worms...?
    - Only recently found collection of soft-bodied invertebrate fossils
  - o Continental drift
  - o Plate tectonics tells us where we have best probability of finding fossils
  - o Gap: 1 type of organism, then another → don’t see transition?
    - Transitional fossils
    - Evolution of horse
      - run faster, feed on grass (abundant)
        - o open to predation, had to be agile → single digit

- teeth (robust, stronger enamel) for plant abrasiveness
- Extinction (disappeared in branching pattern)
- Transitional forms – fill in gaps
  - Horse (see above)
  - Archaeopteryx: looks like bird, but also looks like reptile
    - Feathers not unique to birds
  - Land → sea (whales)
  - Uncommon/unheard of back then (modern discoveries)

Common ancestry evidence:

- comparative anatomy (Cuvier's work)
  - Homology – divergent evolution
    - Structure has same underlying structure but highly modified to serve specific function
    - E.g. arm structure started with first land animals (amphibians)
- comparative embryology
  - in animals: 8-cell embryo divides into 2 sets of four (4 top, 4 underneath)
    - 1 group: 4 sit on top
    - other: shift, bottoms sit in grooves of cells below
      - entire branching lineage!
- vestigial structures
  - goosebumps, nictitating membrane (eye – ancestors needed to protect eyes; aquatic organisms), NOT appendix (immunity, allergy, gut flora...)
- biogeography
- molecules
  - compare like anatomy
  - protein chain undergoes change in sequence in group, probably share common ancestor

How Darwin's theory for biological diversity and adaptive traits differed:

- 1) Purely physical (not spiritual) explanations
- 2) Recognized that evolutionary change occurs in groups of organisms (not individuals); some members survive/reproduce better
- 3) Multistage: variations arise, natural selection eliminates unsuccessful variations, next generations inherits successful
- 4) Like Lamarck, understood evolution occurs because some organisms function better in a particular environment

\*lacked explanation of how variants arose, mechanisms of heredity

1871: published *The Descent of Man, and Selection in Relation to Sex*

- suggested humans/apes shared common ancestry
- previous book didn't involve human evolution

**Louis Pasteur:** (1822-1895)

- life from life, not spontaneous generation as source of new life
- germ theory
  - o minimal germ = basis of all life

**Cell Theory:** Schleiden (plants)/Schwann (animals – Schwann cells!), 1860

- basic unit of all organisms is the cell
- individual cells have all the characteristics of life
- all cells come from the division of other cells
- fundamental “germ” that Pasteur was talking about

**Gregor Mendel:** (1822-1884)

- rediscovered 1900 (wasn't accessible to Darwin)
- Law of Segregation of Characters
- Law of Independent Assortment

## **GEOLOGY**

**Rock Cycle:** Lyell knew there were 2 types of rock, mixed slightly via rock cycle

1. Existed on formation (molten, first mantle)
2. Built by sedimentation, sit on top of original rock
  - organisms get trapped in layers
  - these rocks important to Lyell

**Plate Tectonics:** rigid lithospheric plates floating/moving on underlying magma core

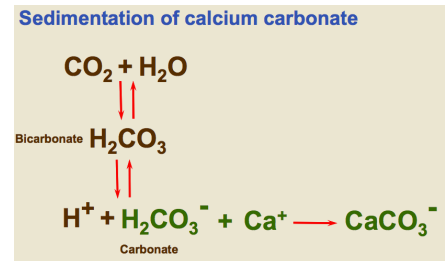
- Lyell didn't know about this, couldn't figure out why strata were missing in some places, sideways in others

**Carbon Cycle:** global circulation of C atoms (esp. via photosynthesis/respiration)

- Lyell knew there was a balance b/w CO<sub>2</sub> in air/water
- C moves independently in sea/land, linked by atmospheric CO<sub>2</sub>
- most in marine sediments and terrestrial rocks, but most *available* C in dissolved bicarbonate ions (HCO<sub>3</sub><sup>-</sup>)
  - o soil/atmosphere/plant biomass = available, but less
- CaCO<sub>3</sub> in shells (uses dissolved C)
- CO<sub>2</sub> diffuses from atmosphere → water (C sink)
  - o raises acidity when it dissolves in water (carbonate/bicarbonate)

In water:

1. Marine species photosynthesis
2. Carbonates precipitate from seawater, death/sedimentation of marine organisms → marine sediments
  - o precipitation when bicarbonate reacts w/ positive mineral ion (Ca/Mg/Zn)
3. Uplifted → terrestrial rocks
4. Weathering moves C into soil water
5. Leaching/runoff → ocean, sedimentation → marine sediments



Land:

1. Terrestrial species photosynthesis
2. Released into atmosphere (CO<sub>2</sub>) during respiration
3. Death of organisms, organic matter buried/compacted by sediments before fully decomposed (low O<sub>2</sub>) → fossil fuels (gas/petroleum/coal; millions of years)

\*seed oceans w/ iron to get rid of CO<sub>2</sub> in atmosphere

**Global Warming:** CO<sub>2</sub> (greenhouse gas) traps heat in atmosphere

- burning wood, fossil fuels; volcanic eruptions

**Watershed:** area of land from which precipitation drains into a single stream/river (topography)

- watershed drained by river may encompass many small watersheds drained by streams (which join together)
- nutrients exit ecosystem through single outlet; good for field experiments

**Hubbard Brook Experimental Forest:** Bormann/Likens measured precipitation and nutrient input into watersheds, uptake, and amount leaving via streamflow

- clear-cut some watersheds → determined that this reduced water absorption, nutrient conservation
- transpiration uses 40% of precipitation, maintains Ca/K/N
- deforestation → more flooding, decreased ecosystem fertility

**Continental Drift:** discovered in 1900s by Alfred Wegener, German meteorologist; continents haven't been in same place since formation of earth, gradually move across Earth's surface

- time when all locked together as Pangaea, when multicellular life started to arise, then continents pulled apart
- very recently accepted principle
- will eventually come back together

## **BIOLOGICAL EVOLUTION**

**Huxley:** (1887-1975) Synthetic/Modern Theory of Evolution

- population genetics and natural selection based on Mendelian genetics

**Microevolution:** small-scale genetic changes within populations, often in response to shifting environmental circumstances or chance events

- change in allele frequencies/heritable phenotypic variants over time in pop
- changes in chromosome structure/numbers due to mutation, recombination
- freqs change → evolution has occurred (micro is underlying mechanism)

**Population:** all individuals of a single species living together in same place/time

- to study microevolution, analyze variations and their heritability
- microevolution results from several processes (not just natural selection)
  - o may counteract each other

Mitochondrial DNA (mtDNA) studied because small, easily extracted/analyzed

- steady mutation rate, haploid

**Mendel:** mathematical probabilities → laws (universal)

- “if there is life with these properties...these ratios will result”
- works with 7 characters
  - o equaled # of chromosomes in pea
  - o managed to pick characters all on separate chromosomes

**Law of Segregation:** alleles of a given locus segregate into separate gametes

- different alleles for a trait don't blend, passed as discrete traits in predictable ratios
- paired traits separated during gamete formation

**Law of Independent Assortment:** alleles of one gene sort into gametes independently of alleles of another gene

**Phenotypic Variation:** differences in appearance/function between individual organisms of population; may be heritable

- causes: genetics, environments, interactions b/w genetics and environment
- *only genetically based variation → evolutionary change*
- phenotype (not genotype) determine success!!
  - o whole phenotype (not just one gene at a time)
- test by changing environmental variable and measuring effects on genetically similar subjects

**Quantitative Variation:** measured on a continuum, indiscrete (multiple loci traits)

- display in bar graph → bell-shaped curve
  - o *width* = variability among individuals (spread)
  - o mean = average value of character
- define by median/average value and amount of spread

**Qualitative Variation:** exist in 2+ discrete state, intermediates often absent

**Polymorphism:** existence of discrete variants of a character among individuals in a population (traits = *polymorphic*)

- snail shells polymorphic in colour, number of stripes
- human blood types = biochemical polymorphism
- described quantitatively via **frequency** (percentage)

Genetic bases of phenotypic variation tested using breeding experiments...

- Mendel inferred from his experiments
- Artificial selection
  - o breeding mice that exhibit increase running behavior/speed proved genetic basis

Crossed distance-runner mice with others that were also highly active, also interbred couch potatoes → genetic profiles completely changed in 10 generations

- passed traits to offspring
- distance and speed of running
- selection applies to behavior as well as appearance

\*can't use for breeding experiments for humans (genealogical pedigrees instead)

**Genetic Variation:** raw material molded by microevolution

- production of new alleles or rearrangement of existing alleles
  - o small-scale DNA mutations
  - o larger-scale changes in chromosome structure/number
  - o genetic recombination, independent assortment of nonhomologues

**Allele:** one version of a gene; occupies single **locus** on chromosome

### 3 Modes of Natural Selection

1. **Directional selection:** individuals near one end of phenotypic spectrum have the highest relative fitness
  - traits shifts away from mean, toward one extreme (mean changes)
  - variability constant in mathematically ideal scenario
    - if narrows, combo stabilizing + directional
  - very common, artificial selection
  - e.g. peppered moths, small Chihuahuas
2. **Stabilizing Selection:** intermediate phenotype = highest relative fitness
  - eliminates extremes, reduces genetic/phenotypic variation
  - median stays same
  - most common mode of natural selection
  - e.g. very small/very large newborns have lower fitness
  - multiple selective forces may act in opposite directions on trait

Gallmaking fly feeds on tall goldenrod plant

- fly larva hatches, bores into goldenrod stem, plant produces spherical gall, larva feeds on inside of gall
  - gall size is heritable trait of fly, also plant genotype
- a) Wasp parasitizes flies, lays eggs in fly larvae inside galls
    - hatched wasps feed on/kill fly larvae
    - adult wasps can't penetrate thick walls of large gall (favors them)
  - b) Birds feed on mature fly larvae, prefer large galls (small hard to manipulate)

2 factors ~equal frequency → stabilization

3. **Disruptive Selection:** extreme phenotypes have higher relative fitness than intermediate; promotes polymorphism
  - least common

- results in two “separate” normal distributions
- e.g. Galapagos finches (beaks)
  - drought, plants only produced small/large seeds (different plant species)
  - sympatric speciation
  - rains returned, seeds returned, distribution returned
- could lead to cladogenesis, 2 new species
  - other drifts could potentially lead to anagenesis

### Population Genetics

Describe genetic structure, form hypothesis (mathematical models) to describe possible effects of evolution → test

**Gene Pools:** sum of all alleles at all gene loci in all individuals of population

- calculate **genotype frequencies** in a representative sample
- then **allele frequencies** and **relative abundances** of alleles
- $p$  = freq of one allele,  $q$  = freq of other

**Genotype Frequency:** percentage of individuals in population w/ particular genotype

**Allele Frequency:** abundance of one allele relative to other at the same gene locus in individuals of a population

- gene locus w/ 2 alleles → 3 genotype freqs but only 2 allele freqs!! ( $p/q$ )

Snapdragons

| Flower Colour Phenotype | Genotype  | Number of Individuals | Genotype Frequencies ★     | Total Number of $C^R$ Alleles ★ | Total Number of $C^W$ Alleles ★ |
|-------------------------|-----------|-----------------------|----------------------------|---------------------------------|---------------------------------|
| Red                     | $C^R C^R$ | 450                   | $450/1000 = 0.45$          | $2 \times 450 = 900$            | $0 \times 450 = 0$              |
| Pink                    | $C^R C^W$ | 500                   | $500/1000 = 0.50$          | $1 \times 500 = 500$            | $1 \times 500 = 500$            |
| White                   | $C^W C^W$ | 50                    | $50/1000 = 0.05$           | $0 \times 50 = 0$               | $2 \times 50 = 100$             |
|                         | Total     | 1000                  | $0.45 + 0.50 + 0.05 = 1.0$ | 1400                            | 600                             |

To calculate allele frequencies, use the total of  $1400 + 600 = 2000$  alleles in the sample:

$$p = \text{frequency of } C^R \text{ allele} = 1400/2000 = 0.7$$

$$q = \text{frequency of } C^W \text{ allele} = 600/2000 = 0.3$$

$$p + q = 0.7 + 0.3 = 1.0$$

### The Hardy-Weinberg Principle

Studies using observational data rather than experimental often can't have “control” treatment → **null models** predict what would be seen if the factor had no effect

Early 1900s: geneticists assumed natural selection replaced recessive alleles w/ dominant ones (didn't understand why they persisted)

**Hardy-Weinberg Principle:** mathematical model; specifies conditions under which a population of diploid organisms achieves **genetic equilibrium** (neither allele/genotype freqs changing in generations)

- dominant alleles need not replace recessive
- shuffling of genes in sexual reprod doesn't itself change frequencies
- describes how genotype freqs are established in sexually reprod organisms

Problem most traits not attributable to 1 or 2 simple alleles (dominant + recessive)

- range of variability that comes from multiple genes (i.e quantitative traits)

Genetic Equilibrium is possible if ALL of the following conditions are met:

1. No mutations are occurring (genes can't change forms)
2. Population closed to migration from other population (no gene flow)
3. Population is infinite in size (no genetic drift)
4. All genotypes in population survive/reproduce equally well (selection not acting on trait of interest)
5. Individuals of population mate randomly wrt trait of interest (no sexual selection)

\*unique because it explains what happens when *nothing* is happening (stasis, equilibrium)

If met, allele freqs of population for identified gene locus will never change; genotype freqs stop after 1 generation

Hardy-Weinberg = null model serving as reference point for evaluating when evolution may occur

- if allele freqs changing over time, evolution is occurring → which conditions not met?

### \*\*Using HW Principle\*\*

Use calculations to determine whether pop is near predicted genetic eq for a loci

- assume that each individual produces only 2 gametes, both contribute to production of offspring
  - o segregate to different gametes
  - o allele freqs in gametes = allele freqs in parent generation

Random mating:  $(p+q)$  sperm w/  $(p+q)$  eggs

$$\rightarrow (p+q)(p+q) = p^2 + 2pq + q^2 = (p+q) = 1$$

If population @ genetic equilibrium...

$p^2$  = freq of AA genotype,  $2pq$  = freq of Aa genotype,  $q^2$  = freq of aa genotype

- use gamete freqs to calculate predicted freqs in offspring
- if changes, starting population was not in equilibrium at gene locus
- examine offspring to see if #s match predictions

$p'$  and  $q'$  indicate offspring allele frequencies → DOES NOT CHANGE

- population now at genetic equilibrium for that locus
- neither freqs will change in next generations if pop meets HW conditions

## Evolutionary Agents

Processes that produce genetic variation/microevolution: mutation, gene flow, genetic drift, natural selection, nonrandom mating

| Agent             | Definition   | Effect on Genetic Variation  |
|-------------------|--|--|
| Mutation          | Heritable change in DNA  | Introduces new genetic variation into population; does not change allele frequencies quickly |
| Gene flow         | Change in allele frequencies as individuals join a population and reproduce        | May introduce genetic variation from another population                                      |
| Genetic drift     | Random changes in allele frequencies caused by chance events                       | Reduces genetic variation, especially in small populations; can eliminate rare alleles       |
| Natural selection | Differential survivorship or reproduction of individuals with different phenotypes | One allele replacing another or allelic variation being preserved                            |
| Nonrandom mating  | Choice of mates based on their their phenotypes and genotypes                      | Does not directly affect allele frequencies, but usually prevents genetic equilibrium        |

**Mutation:** spontaneous/heritable DNA change

- rare (1 gamete in < a million has a mutation at a particular locus)
- little/no immediate effect on allele freqs
- accumulate in biological lineages, creates new genetic variations
- major source of heritable variation!
- to be heritable, must mutate in germ line or meristem (plants)

**Deleterious Mutations:** alter individuals structure/function harmfully

- lethal dominant alleles will kill both homos/hets

**Neutral Mutations:** neither harmful nor helpful

- redundancy of genetic code (different nucleotides in 3<sup>rd</sup> spot = same amino acid)
- mutations at 3<sup>rd</sup> position persist longer in populations
- other mutations may change sequence but not influence fitness
  - o may become beneficial later if environment changes

**Advantageous Mutation:** confers benefit on individual; may be preserved by natural selection

- once mutation passes to next generation, other agents determine longterm fate

Eukaryotic variability – random segregation

$2^n$  combinations of maternal/paternal alleles in gametes where  $n = \#$  chromosomes

- random segregation in meiosis
- Fig 10.16 (old textbook)

**Point mutation:** single base altered; beneficial, neutral, deleterious

- mutations very rare ( $\sim 2$  in lifetime) due to redundancy of genetic code

**Chromosomal mutations:** inversions, translocation, deletion, duplication, polyploidy, genome duplication, crossing over

Crossing over during Prophase I:

- farther apart traits have higher recombination frequency
- this is source of variation in euks (not point mutations)
- genetic advantage of sex

Genome duplication: amplifying genome but NOT through meiosis; chromosomes don't separate during mitosis

- creates backup copy
- can try new things with one copy while backup performs vital functions
  - o not same as diploidy
- originally thought to be only in plants (wrong); happened twice between lancelets and jawed vertebrates  $\rightarrow$  explosion of vertebrate life
- resulted in diversification of vertebrates

Polyploidy and Speciation

**Autopolyploid:**

$2^{\text{nd}}$  meiotic division doesn't occur

- self-fertilization  $\rightarrow$  tetraploid
- usually detrimental, but not always
- polyploidy = multiple of original chromosome complement
- new organism w/ different chromosome complement

Very early on, animals developed gametic isolation b/w species

- only successful meiosis products will maintain species

Plants aren't mobile, can't search out mates (produce spores, hope for external fertilization or self-)

- selfing in euks not same as asexual cloning (still creates some variation)
- allow polyploidy
- increasing chromosome # ramps up their functions
  - o larger seeds, more fruit, faster growth...
  - o almost all crops selected for traditionally are polyploid

**Allopolyploidy:** closely related plant species can interbreed

- gametic isolation only developed in flowering plants
- interspecific species
- in mitosis, homologues can't pair
- "allo" = other

Wheat: sympatric speciation

- einkorn + unknown wild wheat each had 2 sets of 7 chromosomes
- allopolyploidy had 28 chromosomes (14 from each species) = emmer wheat
- emmer wheat crossed again → 42 chromosomes AABBDD (hexaploid)
- allopolyploidy selected for in this case (often with plants)

**Gene Flow:** gene transfer b/w pops via movement of individuals or their gametes

- pollen, spores, fertilized eggs
- if immigrants reproduce, may introduce novel alleles to pop
- e.g. ocean currents carry marine invertebrate eggs/larvae

**Dispersal agents** (wind/animals) facilitate gene flow for plants

- blue jays carry acorns from nut-bearing trees to winter caches → oak gene flow

\*Evolutionary importance depends on genetic differentiation b/w pops

- if very different gene pools, small flow can increase variability and make pops more similar
- if already similar, lots of flow = little effect

**Genetic Drift:** random fluctuations in allele freqs as a result of chance events; usually reduces genetic variation in a population

- dramatic effects on small pops
- a) **Population Bottleneck:** evolutionary event that occurs when a stressful factor reduces population size greatly and eliminates some alleles from a population
  - e.g. elephant seals rebounded after overhunting, now have little genetic variation
- b) **Founder Effect:** opposite to bottleneck; population that was established by few colonizing individuals has only a fraction of the genetic diversity seen in pop from which it was derived
  - some alleles missing, rare alleles might have high freqs
  - e.g. Saguenay Lac St Jean region has high incidence of certain diseases (human population)

\*Small population sizes problematic for endangered species, conservation biology

- e.g. hypothesized that bottleneck resulted in high freq of deleterious alleles in cheetah population

Bison on prairies: huge population knocked down to almost nothing (750) by European colonists

- repopulation all from 750 individuals
- don't have same heartiness/disease resistance (anthrax)
- also elephant seals from few individuals when sealing halted, killer whales

**Gene Flow:** migration (individuals living/coming)

- hand-in-hand with bottleneck for conservation
- Rockies: bridges over highway/railway with vegetation on top to minimize allopatric separation
- prevent bottleneck effect, allows gene flow, minimizing isolation
- initiative to connect parks/reserves from Yellowstone to Yukon (Y2Y)

**Relative Fitness:** number of surviving offspring produced by an individual compared with numbers left by other in the population

- natural selection doesn't affect traits that appear in postreproductive life

**Nonrandom Mating:** selection of mate with particular phenotype

- next generation contains fewer hets than HW model predicts

**Inbreeding:** genetically related individuals mate w/ each other

**Self-Fertilization:** gametes produced by single parent (usually plants)

- inbreeding → less hets (more expression of recessive phenotypes)
- selfing: homos produce homos only, hets produce some homos
- does NOT change HW equilibrium; gene numbers same, just not mixed

Hemophilia in Europe's royals: no influx of new genetic material

- heterozygotes had high incidence of breeding out deleterious effects
- relatives share alleles, identical copies brought together more often than would occur by chance

**Sexual Selection:** not every individual has equal opportunity to mate (favourable attributes)

**Sexual Dimorphism:** distinct phenotypic differentiation b/w sexes of a species

- adornments signal that individual is sufficiently healthy to take E sources that would be used to keep alive to add these extra desirable attributes
- so successful in acquiring food, metabolism (function/survival + more!)
- e.g. bird song – so much energy that I can sing

Females produce limited # eggs (more complex animals produce fewer, spend more time developing them)

- start by protecting eggs
- then mammals that take years for 1
- putting “all eggs in one basket”, must find healthy mate
- males don’t expend energy on sperm, just trying to find females to spread it to

### Sexual Selection on Males

a) **Female Choice:** female evaluating male

- e.g. certain bird of paradise females prefer longer tail feathers
  - o when cut long tails and lengthened short ones, females chose only based on tail length
- another bird of paradise has mating dance

b) **Competition:** male choice

a. *Combat* – fight it out among themselves

- elephant seals, most will never mate; one male controls harem, won’t let any other male mate with them (could be 100 females)
- few individuals passing on genome
- sneaky fucker theory (few just have sex with everything)

b. *Sperm competition*

- generally no sexual selection prior to mating
- after mating, will sperm get to fertilize egg?
- Insects: sperm are stored and fertilization takes place later
  - o dragonflies, damselflies
  - o **Copulatory Wheel:** 2 insects flying in tandem; male grasped female, passed sperm into reprod tract, holds on to make sure sperm makes it to storage point
  - o another male may dislodge first, reach inside female and remove other sperm, place his sperm there instead
  - o if male can’t hold on long enough, female ejects sperm

c. *Infanticide:*

- lion pride: female + sisters + progeny + 1 male
- male mates with all mature females
- when male becoming less dominant, will be defeated by a rival male
- females going to belong to new male, young still contain genes of previous male
- new lion immediately kills all cubs
- mothers no longer nursing, can reproduce again

How does variation persist w/ stabilizing selection + genetic drift??

**Diploidy** reduces effectiveness of natural selection on harmful recessive alleles

- may have little/no effect on hets, dominant allele expressed/selected

**Balanced Polymorphism:** 2+ phenotypes maintained in ~stable proportions over many generations

- preserved by natural selection when...
  - a) Heterozygotes have higher relative fitness
  - b) Different alleles favoured in different environments
    - a. e.g. European garden snails predated on based on visibility; pops spread over different habitats, have different shell colours
  - c) Rarity of a phenotype provides an advantage

**Heterozygote Advantage:** individuals heterozygous at a particular locus have higher relative fitness than either homozygote

- “hybrid vigour”
- may respond more effectively to environmental variation

*HbS* (sickle cell) allele differs from normal hemoglobin from *HbA* allele by 1 amino acid

- homo *HbS*: faulty hemoglobin forms long, fibrous change when low O<sub>2</sub> → sickle shape
  - o usually die before reproducing
- in tropical Africa, hets = 25% of population (preserved by nat selection)
  - o sickle cell disease common where malaria is prevalent
  - o in malaria, parasites infect red blood cells
  - o when hets contract malaria, infected RBCs assume sickle shape
    - lose potassium → kill parasites (prevents spread of infection)
    - immune system can fight infection, many RBCs uninfected
  - o homos RBCs don't sickle, parasites rapidly multiply

**Fixation:** change in a **gene** pool from a situation where there exists at least two variants of a particular **gene (allele)** to a situation where only one of the alleles remains

- genetic variability of population dramatically changes (lose one, every allele is one that has been fixated)
- e.g. if select against 10% B<sub>2</sub> per generation, will disappear quickly (*slide 14*)
- as we fixate on perfecting one characteristics (inbreeding), can remove other beneficial traits, increase susceptibility, decrease diversity – e.g. rice
- fixation on survivor genes in resistant disease/bacteria; not diluted
- selection can result in fixation

#### Effectiveness of selection against *recessive*

- 100% het population to start (homo recessive die), let mate randomly
- homozygous recessives die (in this example), removing genes from pool
- results = mathematical predictions
- recessive allele is detrimental
- if start with 50/50, lethal recessive allele will decrease to about 10%
  - doesn't fully disappear, plateaus
  - always a few hets carrying allele
  - tried with beetle, worked
- viable allele rises to about 90%
- selection does NOT remove alleles (not fixation), but changes freqs

#### Effect of selection for *heterozygous* (e.g. sickle cell anaemia)

- start with pop 50/50 homozygous for each condition
  - o plateaus at lower freq of viable allele than expected
- if start with all homos, plateaus at 80%
- lethal allele maintained at level higher than expected (20%)
- allele can only be present in het form (homo recessive is lethal)
- certain situations where being a het is advantageous, conserves lethal recessive allele because having that allele adds something for survival