

MODULE 1: ZOOLOGY, HISTORY, & EVOLUTION

BIO2202-LEC-Sec1-MN: GENERAL ZOOLOGY LECTURE

Midterms (2nd Semester) – Bachelor of Science in Biology (Section 1)



INTRODUCTION TO FIELDS OF ZOOLOGY

- **Zoology** is the scientific study of **behavior, structure, physiology, classification**, and distribution of **animals**.
- The term Zoology came from the Greek words “**zōion**” or “**zoon**”, meaning **animal**, and “**logos**” which is “**to study**”.
- It is one of the **broadest fields** in all science due to the **variety and complexity** of animal life and processes.
- There are more than **1.4 million** described **species** of animals.
- Many more (**an estimated 6–7 million**) are yet to be described.
- Most zoologists **specialize** by studying the particular **functional, structural, or ecological aspects** of one or more animal groups.

MAIN SPECIALIZATIONS IN ZOOLOGY

Anatomy	• Study of the structure of entire organisms and their parts.
Cytology	• Study of the structure and functions of cells .
Comparative Genomics and Bioinformatics	• Study of the structure, function, and evolution of the genetic composition of groups of animals using computer-based computational methods .
Ecology	• Study of the interaction of organisms with their environment .
Embryology	• Study of the development of an animal from the fertilized egg to birth or hatching.

MAIN SPECIALIZATIONS IN ZOOLOGY

Genetics	• Study of the mechanisms of transmission of traits from parents to offspring.
Histology	• Study of biological tissues and composition
Molecular Biology	• Study of subcellular details of structure and function.
Parasitology	• Study of animals that live in or on other organisms at the expense of the host.
Physiology	• Study of the function of organisms and their parts .
Systematics	• Study of classification of, and the evolutionary interrelationships among, animal groups.

- Other zoologists may choose to **specialize in a particular group** of animals.

SPECIALIZATIONS BASED ON TAXONOMY

Entomology	• The study of insects
Herpetology	• The study of amphibians and non-avian reptiles
Ichthyology	• The study of fishes
Mammalogy	• The study of mammals
Ornithology	• The study of birds
Protozoology	• The study of protozoa

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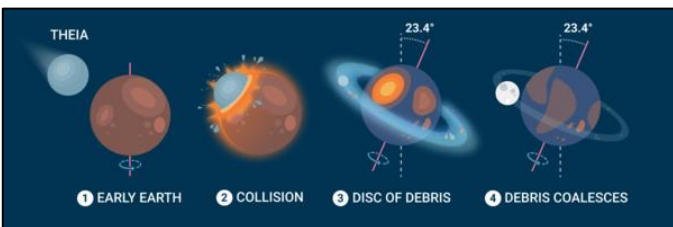
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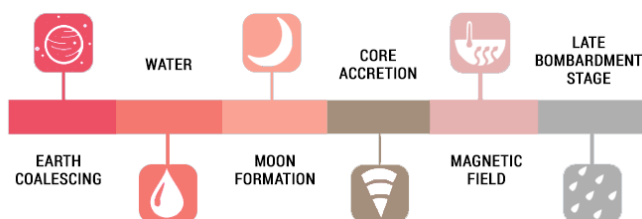


ORIGINS AND FORMATION OF EARTH

- **4.6 billion years ago**, Earth had just **formed**—hot, volcanic, and partially molten.
- **Solar system bodies frequently collided** with this new Earth.
- **Giant Impact Hypothesis (Collision Theory)** - huge collision took place about **4.5 billion years ago**.
- A body the size of Mars called **Theia** hit the Earth and sent **debris into orbit** around Earth.
- This debris eventually **coalesced** to form **our moon named Luna**.



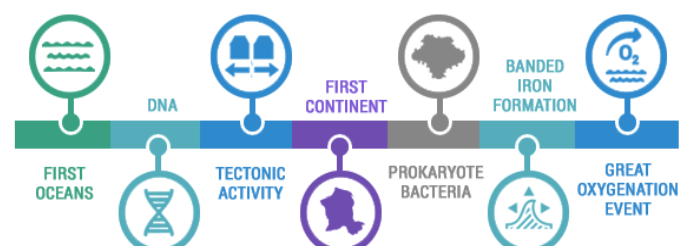
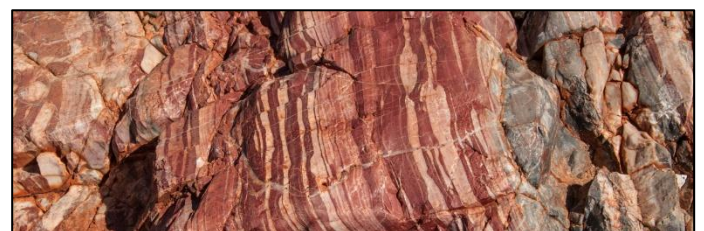
- Earth **gradually cooled** as **carbon dioxide (CO₂)** from the atmosphere was **absorbed** into the molten Earth and sequestered into **calcium carbonate**.
- **Water vapor** began to condense into **liquid water**, and **rigid slabs of rock** started to form a **crust** and began a history of **tectonic shifting**.
- **Crustal plate shifting** has influenced the **geology of the earth and life** on the earth ever since.
- This period of history, called **the Hadean eon**, lasted until about 4 billion years ago (**violent, molten, and primordial** formation stage of Earth).



- The 4-billion-year threshold marks the **beginning of the Archaean eon (4–2.5 billion years ago)**.
- Over the next 1.5 billion years, **Earth's temperature cooled** to near modern levels, and **liquid water became prevalent**.
- **Deep ocean basins formed**, and **archaeon rock formations were laid down** in various continents.



- The Archaean eon began with an **atmosphere** that consisted primarily of **CO₂, hydrogen, and water vapor**, but the atmosphere slowly changed.
- Rock formations (3 billion years ago) show **banded iron**, which requires **molecular oxygen (O₂)** from **photosynthesis**.
- **Microfossils of bacteria-like single cells** and evidence of **organic carbon** are all **evidences that life arose about 3.8 billion years ago**.
- Since that time, the **evolution of life-forms** has shaped the history of the earth.



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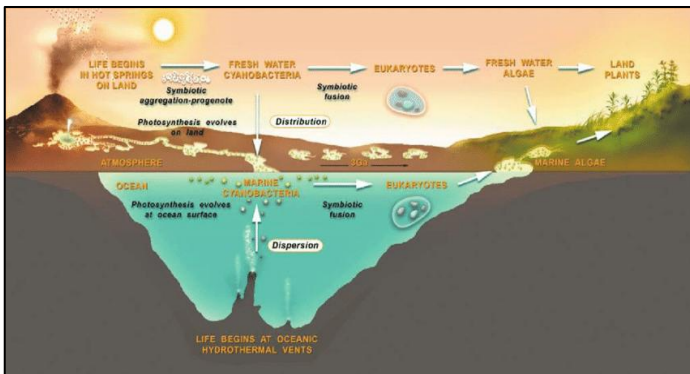
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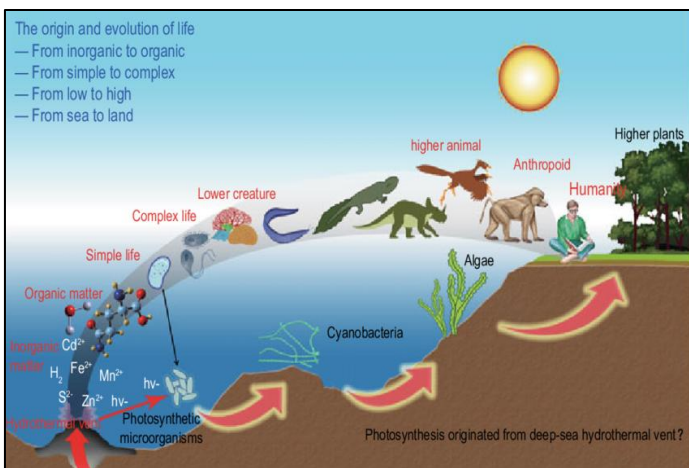


THE HYDROTHERMAL VENT THEORY

- The **hydrothermal vent theory** suggests that life on Earth may have originated in **deep-sea hydrothermal vents**.
- These vents, found at tectonic plate boundaries, release **mineral-rich, heated water** into the ocean depths.
- This water provides a **source of energy and nutrients** for **chemosynthetic organisms (chemoautotrophs)**.



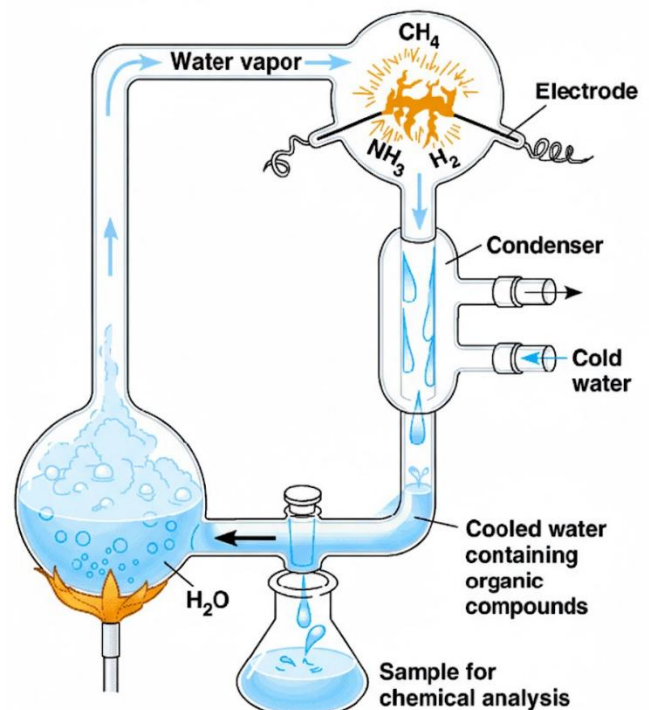
- Eventually, **organisms disperse to the ocean surface** where sufficient light is available for photosynthesis to evolve (**photoautotrophs**).
- Life transitioned **from water to land** through a gradual process to **escape intense aquatic competition and predators**, while taking advantage of **untapped resources (heterotrophs)**.



FORMATION OF ORGANIC MOLECULES

1. The Miller-Urey Experiment

- **Stanley Miller and Harold Urey (1953)** were the first scientists to demonstrate that **organic molecules** could form in a **reducing atmosphere** and in a **presence of an energy source**.
- The experimental setup had all the gases thought to be present at that time, **no oxygen**, and **simulated lightning** by bombardment of energy in the form of **sparks**.
- This experiment successfully provided the **building blocks of life (organic molecules)**.
- The **primordial soup** contained **simple carbon compounds** such as **formaldehyde** and **hydrogen cyanide** (precursors of DNA and RNA).
- These further formed more complex molecules **formic acid** and **urea**, and **amino acids glycine** and **alanine** (precursor of proteins).



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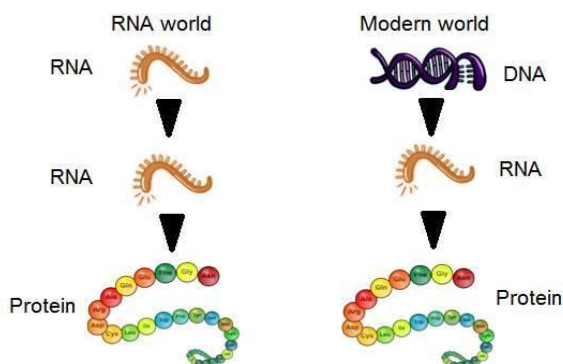
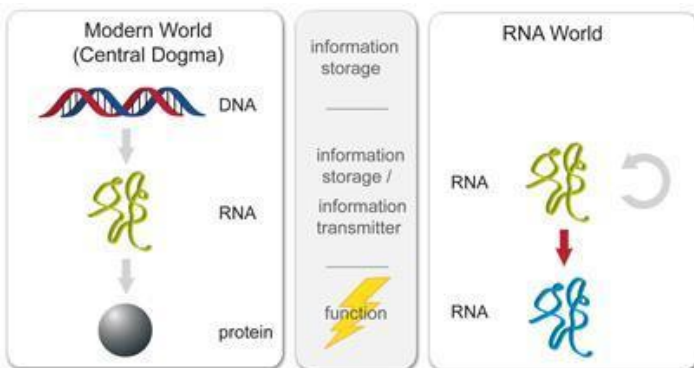
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2. The RNA World Hypothesis

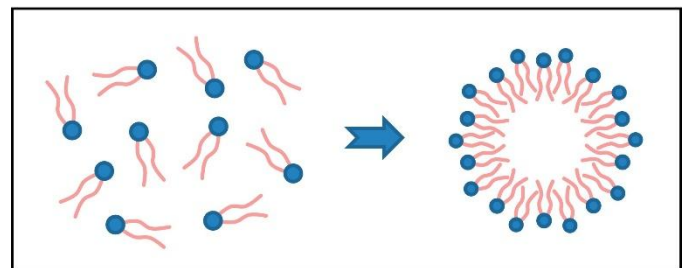
- **John Sutherland and colleagues (2009)** demonstrated the **formation of nucleic acids** from **hydrogen cyanide, hydrogen sulfide, and ultraviolet light** using metal catalysts.
- These observations lend support to life originating in an **“RNA world.”**
- This “RNA world” may have **kickstarted evolution**, as some could **replicate themselves** with the help of **minerals/clay surfaces**.
- **RNA** is capable of **carrying genetic information** and **functioning as enzymes** (ribozymes).
- RNA developed the ability to **catalyze peptide bonds**, leading to the **creation of the first proteins (before DNA)**.
- The **transition from RNA-based life-forms to DNA-based life-forms** would have occurred because of the **stability of double strands**.



TRANSITION TO CELLS AND DIVERSITY

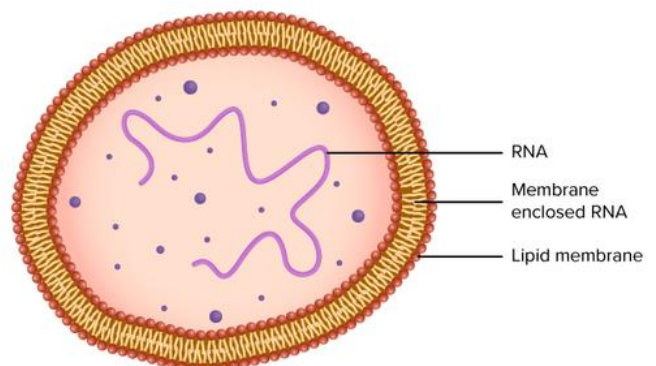
3. Protocells (First Cell-Like Structures)

- **Cells** require **membranes** & must **process energy**.
- **Membranes** allow organic compounds to interact, serving as **surfaces for reactions**.
- **Membranes of early life-forms** may have been comprised of **fatty acids** rather than phospholipids.
- Fatty acids can spontaneously form **micelles or vesicles, trapping RNA and other molecules** to form protocells.
- Inside protocells, molecules could **interact more efficiently**, protected from the outside environment.
- At some point, **membranes enclosed metabolic bubbles**, and the **simplest form of bacterial life** began.



Lipids in water will form a spontaneous micelle (the fatty acid tails are non-polar / hydrophobic)

Addition of a polar organic mixture causes lipids to coalesce into spherical bilayers (cell / vesicle)



MODULE 1: ZOOLOGY, HISTORY, & EVOLUTION

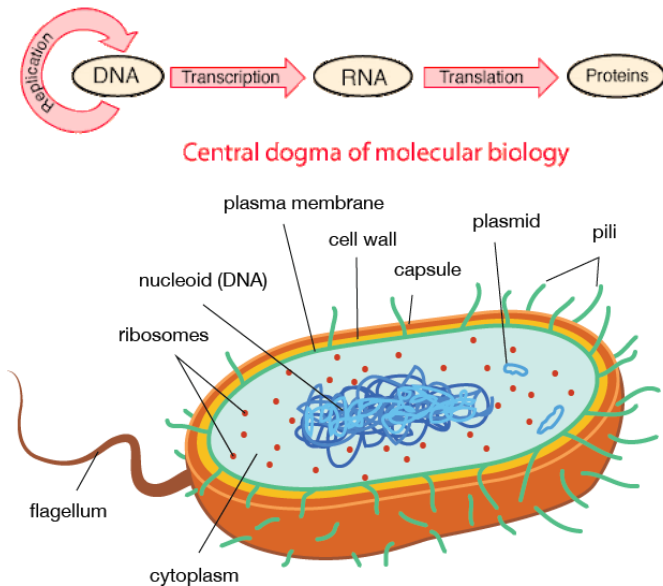
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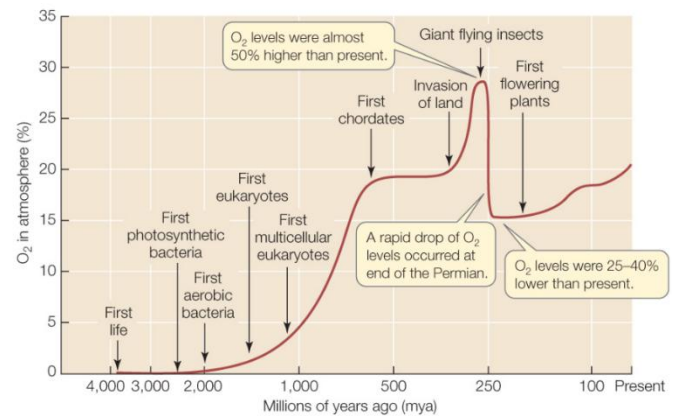
4. Transition to True Cells

- Over time, protocells evolved from **RNA-based systems to DNA + protein-based life** (more stable and better catalysts).
- These protocells begin to develop **rudimentary metabolism**, such as the ability to **synthesize membrane components**.
- Metabolism** became **more complex** (using energy from sunlight or chemicals).
- Membranes became more sophisticated, leading to the **first prokaryotic cells** (about 3.5 billion years ago).

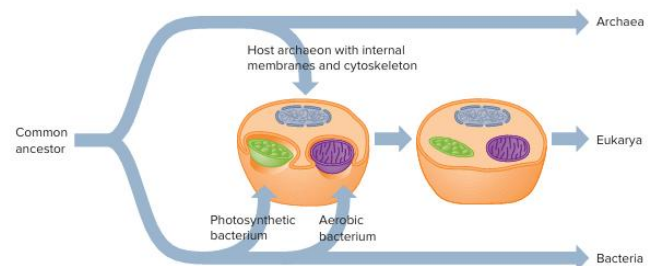


5. The Rise of Diversity

- The first cells were **simple, anaerobic (no oxygen needed), prokaryotic-like** organisms.
- Cyanobacteria** are considered the first and only prokaryote evolving **oxygenic photosynthesis** and is responsible for the **Great Oxygenation Event on Earth** (approximately 2.4 billion years ago).
- The **rise of toxic oxygen** resulted in the **extinction of anaerobic species**.



- Eukaryotes (cells with nuclei)** appeared later (approximately 2 billion years ago), likely through **endosymbiosis**.
- Endosymbiotic Theory** - **mitochondria and chloroplasts** in eukaryotic cells were once **separate prokaryotic microbes** engulfed a host cell.



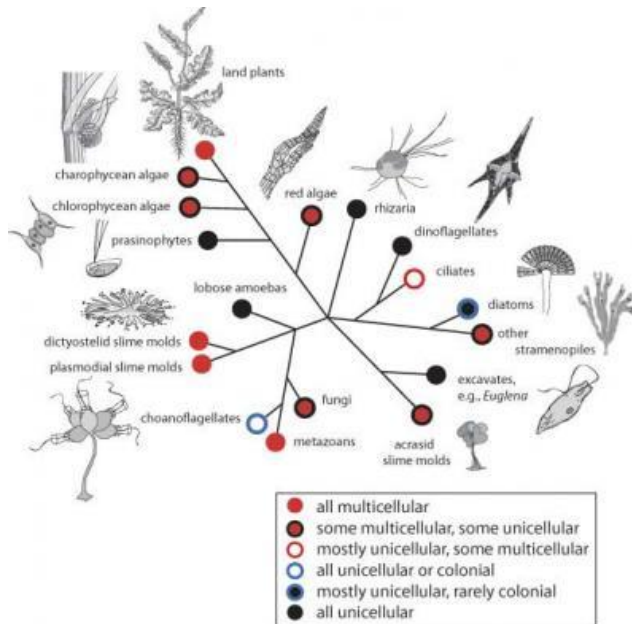
6. Multicellularity and Animal Origins

- Multicellular eukaryotes first originated about **1.2 billion years ago** when **cells of a dividing protist remained associated** following cell division.
- Multicellularity then **originated over-and-over** within at least four of the five supergroup lineages.
- Because multicellularity arose multiple times this suggests that there is **selective advantage**.
 - Defense** (larger organism is less vulnerable to predation)
 - Subdivision of labor in organisms** (specialized functions for each type of cell).

MODULE 1: ZOOLOGY, HISTORY, & EVOLUTION

BIO2202-LEC-Sec1-MN: GENERAL ZOOLOGY LECTURE

Midterms (2nd Semester) – Bachelor of Science in Biology (Section 1)

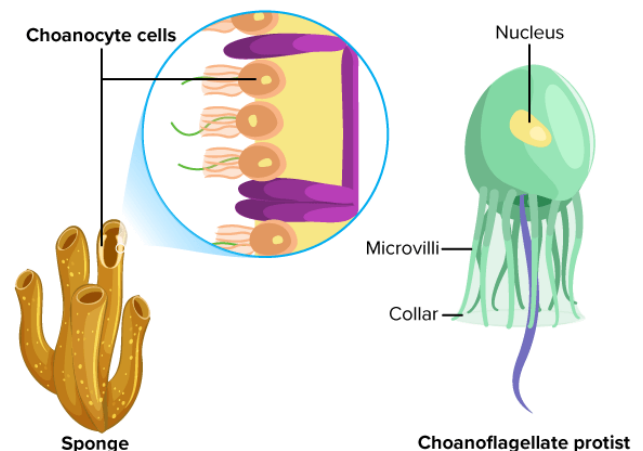


7. Crossroads between Protists and Multicellular Animals

- **Animal multicellularity** originated between 800 and 635 million years ago (mya).
- The emergence of animal multicellularity corresponds to the **accumulation of relatively high levels of O₂** in the atmosphere and within the depths of the oceans.
- **Molecular oxygen** apparently needed to be in **high enough concentrations**:
 - To diffuse through cell layers of early animals
 - O₂ is also required in the **synthesis of collagen**.
- In 1874, **Ernst Haeckel** first suggested that a **hollow colony of undifferentiated cells could arise** when a single cell divided but remained linked.
- Flagellated protist opisthokonts, called **choanoflagellates**, form **colonies** and **resemble the feeding cells of sponges** (choanocytes).
- **Animals and choanoflagellates also share** membrane components, signaling

pathways, and other genetically regulated functions that are probably **bacterial in origin**.

- It is very likely that these genes (more than 4% of the entire genome) were acquired from **bacterial prey** through **horizontal gene transfer**.



DOMAINS OF LIFE AND ITS CHALLENGES

- Studies of **ribosomal RNA** lead systematists to conclude that **all life shares a common ancestor**.
- There are **three major evolutionary lineages**, which we refer to as **domains**.

THE THREE DOMAINS OF LIFE	
Bacteria	• Domain containing the most abundant organisms (prokaryotes).
Archaea	• More similar to the Eukarya in regard to the structure of chromatin and regulation of gene function (extremophiles).
Eukarya	• Contains organisms with compartmentalized cells (eukaryotes). • True multicellularity, tissues, organs, and organ system.

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BIO2202-LEC-Sec1-MN: GENERAL ZOOLOGY LECTURE

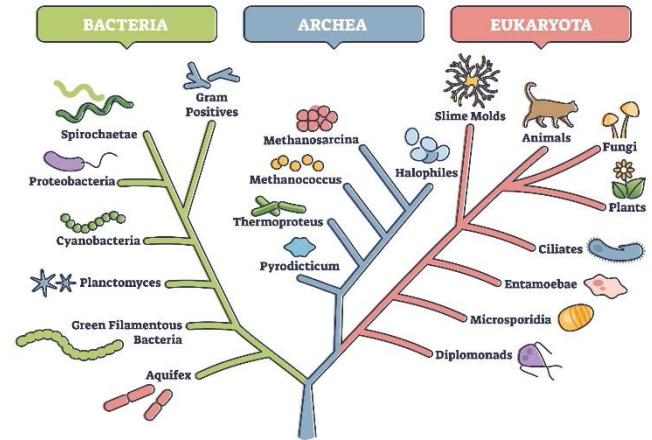
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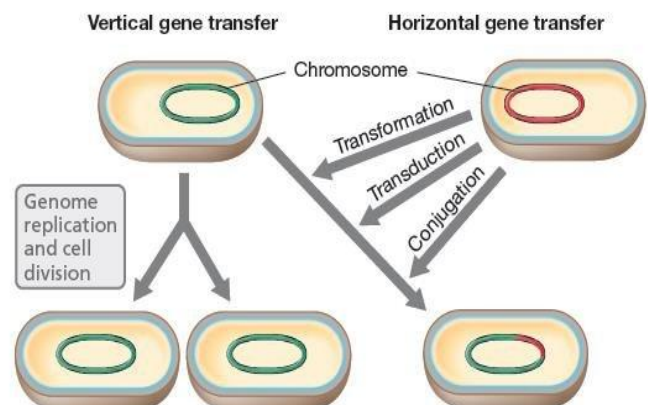
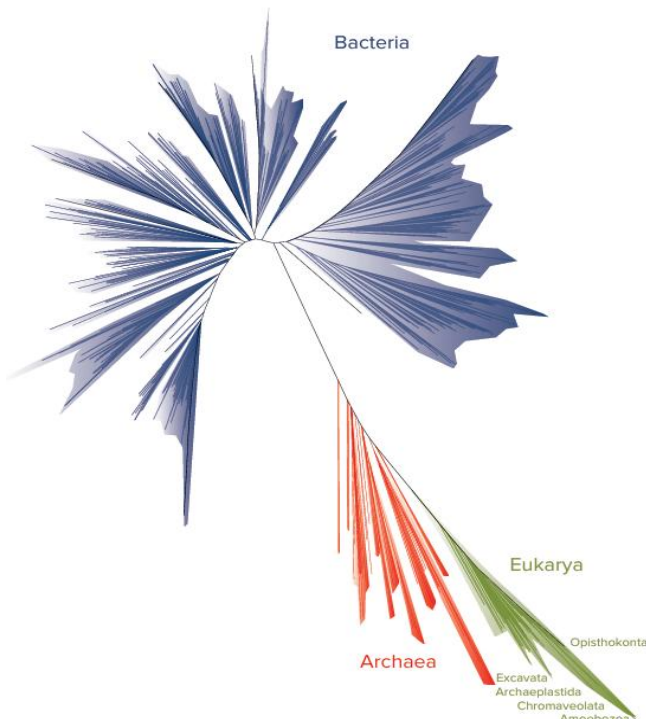
- Within the eukaryotic branch are **five lineages** that include the following:

THE FIVE LINEAGES OF DOMAIN EUKARYA	
Opisthokonta	Animals (Metazoa) and true Fungi.
Excavata	Unicellular protists with asymmetrical, “excavated” feeding groove on one side of the cell.
Archaeplastida	Land plants, green algae, red algae, and glaucophytes.
Chromalveolata	Important photosynthetic organisms, such as diatoms, brown algae, and significant disease agents.
Amoebozoa	Unicellular protists that exhibit pseudopodia which extend like tubes or flat lobes.

PHYLOGENETIC TREE



- Taxonomies are **traditionally built** assuming that genes are passed through **vertical transfer (VGT)**.
- Vertical Gene Transfer** - passing of genetic material from **one generation to the next, from parent to offspring**, through reproduction (**sexual or asexual**).
- Recent rRNA studies** have found evidence that genes have moved **between species**.
- Horizontal or Lateral Gene Transfer (HGT or LGT)** - genetic material is passed between organisms that are **not parent and offspring**.
- HGT results in species that are in **different lineages sharing genes**.
- HGT is especially **prevalent in prokaryotes (bacteria and archaea)**.



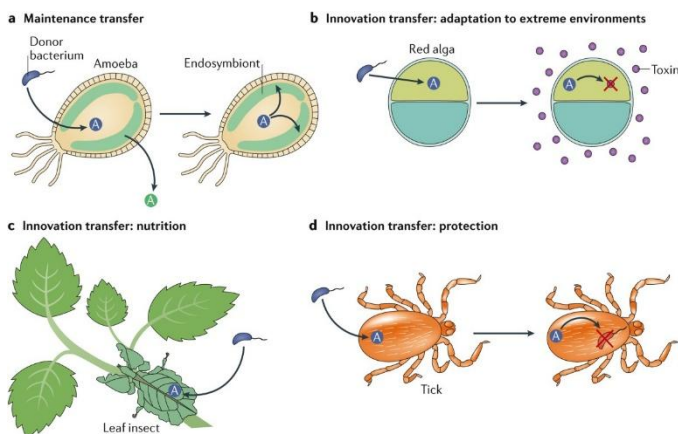
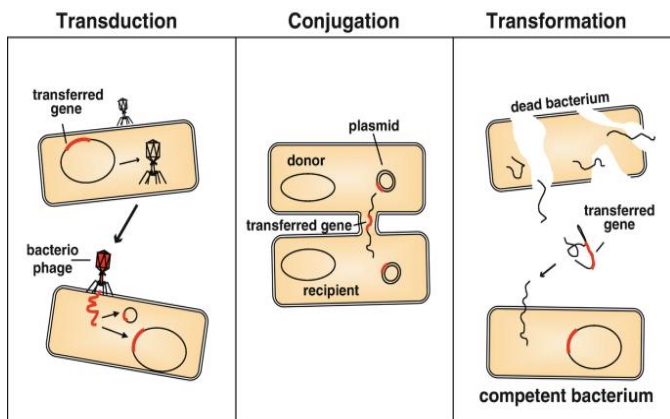
MODULE 1: ZOOLOGY, HISTORY, & EVOLUTION

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Midterms (2nd Semester) – Bachelor of Science in Biology (Section 1)



- Now, it is increasingly recognized as a **significant factor in the evolution of eukaryotes**, including multicellular organisms.
- Horizontally transferred genes bring **inconsistencies into species phylogenies**.
- This means that no **single gene or group of genes** might adequately **represent the evolution of entire genomes**.
- As a result of HGT, **evolutionary biologists** developed **phylogenomics** to view the **base of the tree of life as a web or net** rather than a set of two or three distinct lineages.
- The existence of **natural horizontal transfer** has also important implications for **artificial gene transfer in medicine and agriculture**.



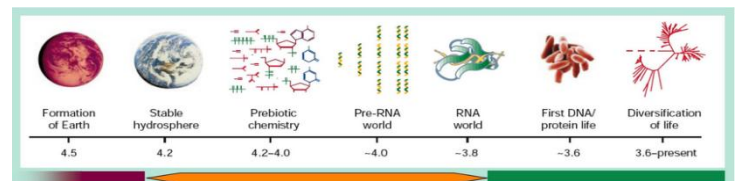
Nature Reviews | Microbiology

THE UNIT AND CHARACTERISTICS OF LIFE

- The **definition of life** must be based on the **common history of life** on earth.
- Life's history of descent with modification** gives it an **identity and continuity** that separates it from the nonliving world.

RECAP OF THE HISTORY OF LIFE

4.6 billion years ago	Earth forms from cosmic dust and rock.
4.4-4.0 billion years ago	Liquid water appears as the planet cools.
3.8-3.5 billion years ago	The first life forms (probably simple single-celled prokaryotes like bacteria).



- The most **outstanding general features in life's history** include the following:

GENERAL FEATURES OF LIFE

Cellular Unit	- The cell is known as the structural and functional unit of life because all living beings are formed of cells. - Major parts include the nucleus, cytoplasm, and cell membrane.
Chemical Uniqueness	- Living systems demonstrate a unique and complex molecular organization. - Living systems assemble macromolecules such as nucleic acids, proteins, carbohydrates, and lipids.

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BIO2202-LEC-SecI-MN: GENERAL ZOOLOGY LECTURE

Midterms (2nd Semester) – Bachelor of Science in Biology (Section 1)

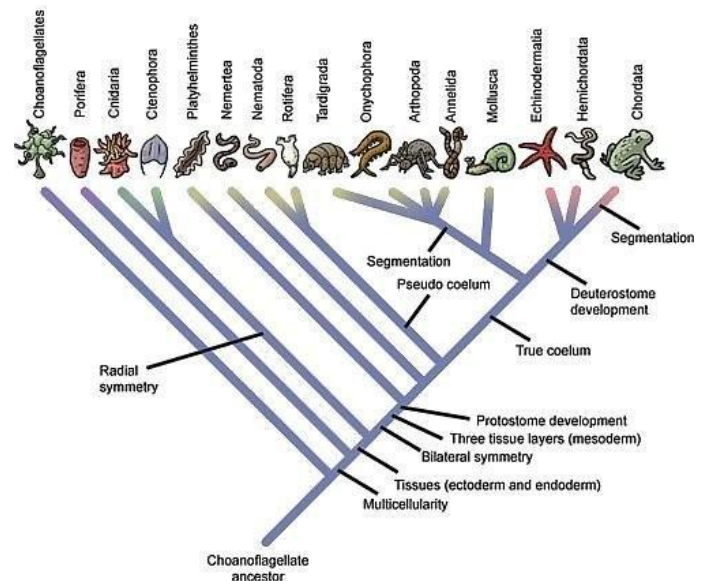


GENERAL FEATURES OF LIFE

Complexity and Hierarchical Organization	- Living systems demonstrate a unique and complex hierarchical organization. - In living systems, we find a hierarchy of levels that includes, in ascending order of complexity: macromolecules, cells, tissues, organs, organ systems, organisms, populations, and community.
Reproduction	Life does not arise spontaneously but comes only from prior life, through reproduction. Species may split to produce new species through a process called speciation.
Development	- All organisms pass through a characteristic life cycle. - Development describes the characteristic changes that an organism undergoes from its origin to its final adult form. - Development usually features changes in size and shape, and differentiation of structures within an organism.
Movement	- Living systems and their parts show precise and controlled movements. - Such movements at the cellular level is essential for reproduction, growth, and many responses to stimuli.

WHAT MAKES AN ORGANISM AN ANIMAL?

- Animals form a **distinct branch on the evolutionary tree of life**.
- It is a large and old branch that originated in the **Precambrian seas over 600 million years ago**.
- Animals form part of an even larger limb known as **eukaryotes**, organisms whose cells contain **membrane-enclosed nuclei**.
- Perhaps the most distinctive characteristic of the animals as a group is their **means of nutrition**, which consists of **eating other organisms**.
- Therefore, **animals are multicellular, eukaryotic, heterotrophic organisms**.



MODULE 1: ZOOLOGY, HISTORY, & EVOLUTION

BIO2202-LEC-Sec1-MN: GENERAL ZOOLOGY LECTURE

Midterms (2nd Semester) – Bachelor of Science in Biology (Section 1)



SYSTEMATIC NAMING OF ORGANISMS

- **Nomenclature** - the assignment of a **distinctive name** to each species.
- The adoption of a system of **binomial nomenclature** is due to **Swedish botanist and physician Karl von Linné** or **famously known as Carolus Linnaeus (1707 – 1778)**.
- He attempted to describe the entire known natural world and gave **every species a two-part name**.
- In **1735**, Linnaeus published **Systema Naturae**, where unwieldy names mostly used at the time, were supplemented with concise and now familiar "binomials," composed of the **generic name (genus)**, followed by a **specific epithet (species)**.

PARTS OF A SCIENTIFIC NAME

Genus	• Noun (Generic name)	<i>Panthera</i>
Species	• Adjective or descriptor (specific epithet)	<i>leo</i>

- Although the system, now known as binomial nomenclature, was developed by the **Bauhin brothers (Gaspard Bauhin and Johann Bauhin)** almost two hundred years earlier, **Linnaeus was the first to use it consistently**, and may be said to have **popularized it**.



Carolus Linnaeus



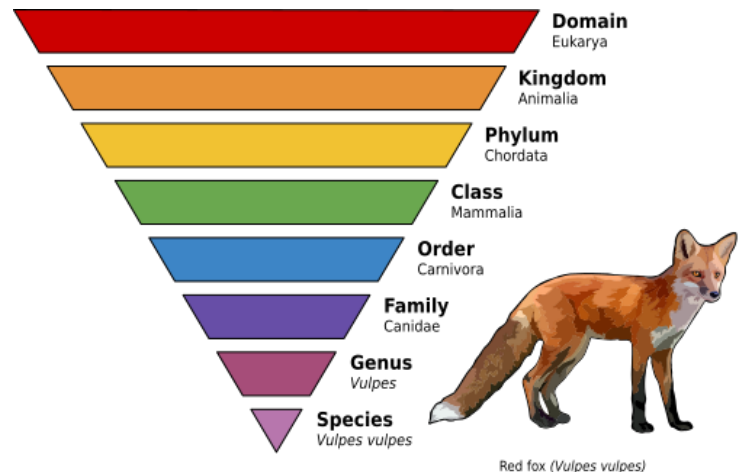
Gaspard Bauhin



Jean Bauhin

THE TAXONOMIC HIERARCHY (LION)

Domain	• Eukarya
Kingdom	• Animalia
Phylum	• Chordata
Class	• Mammalia
Order	• Carnivora
Family	• Felidae
Genus	• <i>Panthera</i>
Species	• <i>leo</i>



CONCEPT AND THEORIES OF EVOLUTION

- **Evolution** - the process where **living organisms are transformed into different forms** by the **accumulation of changes** over **successive generations**.
- **Organic evolution**, according to **Charles Darwin**, is "**descent with modification**." This simply means that **populations change over time**.
- Populations consist of individuals of the **same species but share a unique set of genes**.
- Even though **Charles Darwin** originated the **theory of evolution by natural selection**, his ideas were influenced by **scientists who preceded him**.

MODULE 1: ZOOLOGY, HISTORY, & EVOLUTION

BIO2202-LEC-Sec1-MN: GENERAL ZOOLOGY LECTURE

Midterms (2nd Semester) – Bachelor of Science in Biology (Section 1)

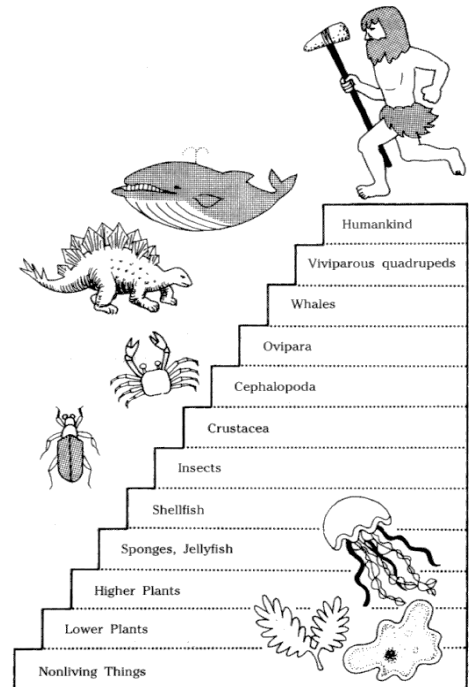


PRE-DARWINIAN EVOLUTION THEORIES

- Some of the earliest references to evolutionary change are from the **ancient Greeks**.
- Empedocles (495–435 B.C.)** claimed that the Earth had given birth to living creatures, but that the **first creatures** had been **disembodied organs**.
- These **organs finally joined into whole organisms**, through the **force of Love**,
- In **On Nature**, he pictured Earth in its early days populated by **bizarre creatures** – **cattle with human heads, arms without shoulders**, etc.
- These strange lifeforms, being **monstrous and unfit for life**, became **extinct**, leaving the creatures we now see.



- The Greek philosopher **Aristotle (384–322 B.C.)** perceived a “**ladder of life**,” where simple organisms gradually change to more elaborate forms.
- Scala Naturae** places **humans at the pinnacle of complexity**, with **plants and minerals at the bottom**,
- In this theory, **organisms progress** from simple to complex based on their **souls and functions**.
- While useful for its time, this suggests a **linear progression**, as if **all life leads to humans**, which is a **misconception**.



- Georges-Louis Buffon (1707–1788)** observed **structural variations** in particular organs of related animals, convincing him that **change must have occurred during the history of life** on earth.
- Buffon believed that as **animals migrated to different parts of the world**, the **environment**—specifically the **climate** and the **food available**—**physically changed them**.
- He called these changes **degenerate**- for example, he described **apes as degenerate humans**.



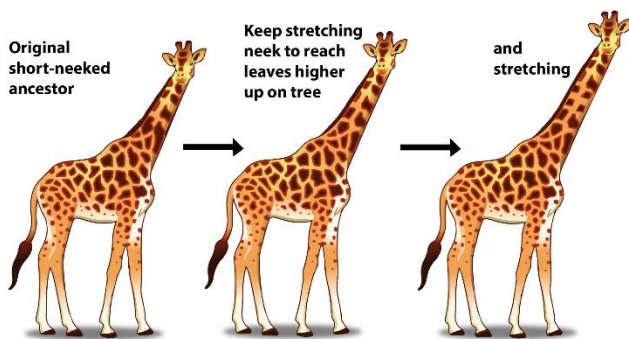
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BIO2202-LEC-Sec1-MN: GENERAL ZOOLOGY LECTURE

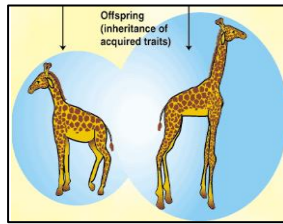
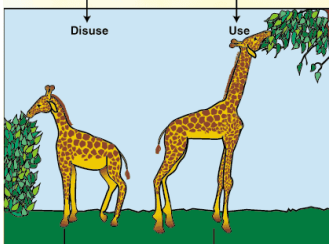
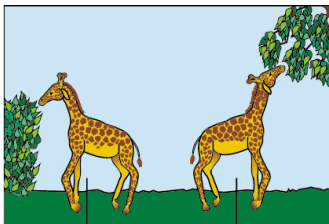
Midterms (2nd Semester) – Bachelor of Science in Biology (Section 1)



- **Jean Baptiste Lamarck (1744–1829)** believed that organisms **develop new organs, or modify** existing organs, as **needs arise**.
- **Theory of Inheritance of Acquired Characteristics** - Lamarck's assertion was that that evolution occurred when an organism **used a body part in such a way that it was ultimately altered** during its lifetime, and this acquired change could be **inherited by its offspring**.



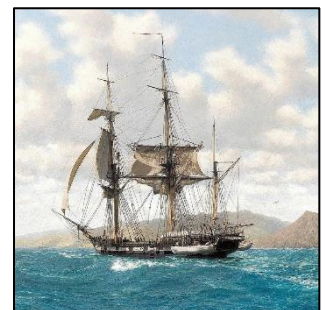
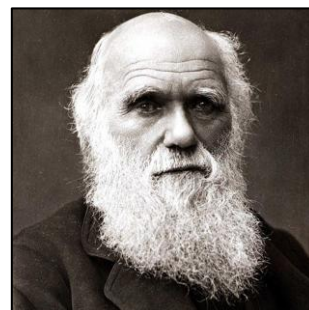
- Lamarck also hypothesized that **disuse** resulted in the **degeneration of organs**.
- **Theory of Use and Disuse** - parts that are not used regularly **weaken, shrink, and** may eventually **disappear**.
- Lamarck thought that “**need**” was **dictated by environmental change** and that **change** involved movement toward **perfection**.



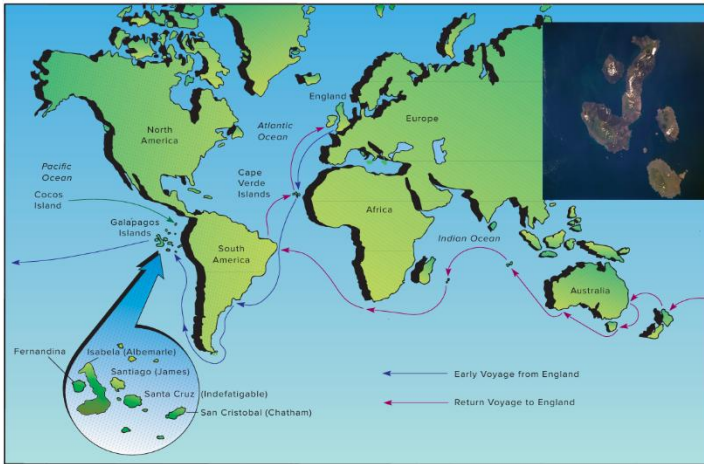
- Lamarck's acceptance of a theory of inheritance that we now know is **largely incorrect** led him to erroneous conclusions about how evolution occurs.
- We now know that **random changes in the structure of DNA (mutation) and chance processes** involved in the assortment of genes into gametes result in **variation among offspring**.

THE JOURNEY OF CHARLES DARWIN

- **Charles Robert Darwin (1809–1882)** was offered a chance to work as an unpaid **naturalist on the HMS Beagle**, a naval vessel embarking on an exploratory voyage around the world.
- During **nearly five years at sea** – Darwin took advantage of countless opportunities to **observe and collect plant and animal life** (both living and fossilized) to study later.
- Most important, Darwin spent **five weeks** on the **Galápagos Islands**, a group of volcanic islands 900 km off the coast of Ecuador.
- At the end of the voyage and by 1842, Darwin had developed the **groundbreaking theory of evolution through natural selection** but delayed their publication because of uncertainty about how they would be received.
- His book, **On the Origin of Species by Means of Natural Selection**, was published in **1859** and revolutionized biology.



Midterms (2nd Semester) – Bachelor of Science in Biology (Section 1)



Variation exists	In any group of animals, plants, or other organisms, individuals are a little different from each other (color, size, speed, etc.).
Competition happens	Resources like food, water, and shelter are limited, so not everyone survives or reproduces.
Survival of the better suited	Individuals with traits that help them survive or reproduce in their environment are more likely to pass those traits on to the next generation.
Over time, populations change	Helpful traits become more common, and less helpful traits may disappear.

-
- Galapagos Islands**
Chelonoidis spp.
- The map illustrates the distribution of various tortoise species across the Galapagos archipelago. Each island group is associated with one or more species, represented by small illustrations of the tortoises. Dashed lines connect the species names to their respective islands.
- Pinta** (*abingdonii*) - Santa Cruz Island
 - Wolf Volcano** (*becki*) - Santa Cruz Island
 - Darwin Volcano** (*microphyes*) - Santa Cruz Island
 - Fernandina** (*phantasticus*) - Santa Cruz Island
 - Alcedo Volcano** (*vandenburghi*) - Santa Cruz Island
 - Cerro Azul Volcano** (*vicina*) - Santa Cruz Island
 - Sierra Negra Volcano** (*guntheri*) - Santa Cruz Island
 - Santiago** (*darwini*) - San Cristóbal Island
 - Pinzon** (*duncanensis*) - San Cristóbal Island
 - Santa Cruz** (*donfaustoi*) - Santa Cruz Island
 - San Cristóbal** (*chathamensis*) - San Cristóbal Island
 - Santa Fe** (*undescribed*) - Santa Fe Island
 - Española** (*hoodensis*) - Española Island
 - Floreana** (*niger*) - Floreana Island

The diagram illustrates the evolution of lateralized predation in fish. At the top left, two fish heads are shown with arrows indicating the direction of eye use: 'Lefty' (left eye) and 'Righty' (right eye). The main diagram shows a prey fish being attacked by two juvenile predators (bilateral predation) and then by one adult predator (lateralized predation).

1. Juvenile: A prey fish is shown being attacked by two juvenile predators, one from the left and one from the right, labeled 'Bilateral predation'.

2. Adult: A prey fish is shown being attacked by one adult predator from the right, labeled 'Lateralized predation'.

MODULE 1: ZOOLOGY, HISTORY, & EVOLUTION

BIO2202-LEC-Sec1-MN: GENERAL ZOOLOGY LECTURE

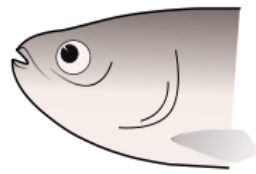
Midterms (2nd Semester) – Bachelor of Science in Biology (Section 1)



- The **feeding habits of fish** are closely tied to the **shape, position, and structure of their mouths**, because a fish's mouth is basically its "tool" for catching and processing food.

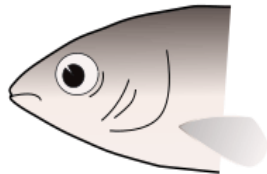
FISH MOUTH STRUCTURE AND POSITION

- Superior** – the mouth is positioned **towards the surface** and the fish feed on what is above them, e.g., garfish and snook.



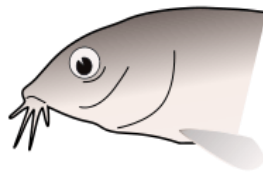
Upper / Superior Mouth

- Terminal** – the mouth is positioned in the **middle of the head** and the fish either chase prey or feed on what is ahead of them, e.g., tuna and tailor.



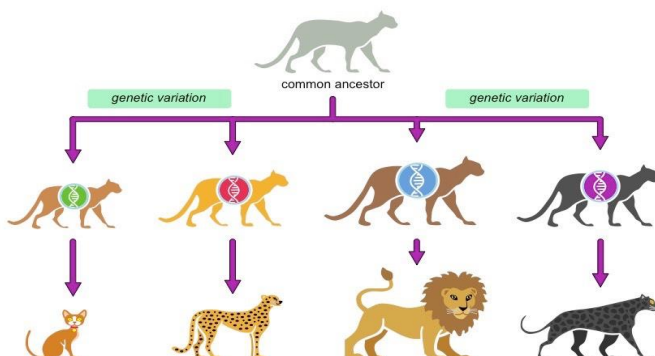
Final / Terminal Mouth

- Inferior** – the mouth is positioned towards the **bottom** and the fish prey upon or scavenge/graze benthic food sources, e.g., whiting and cobbler.



Bottom / Inferior mouth

- Speciation** is the evolutionary process by which **one species splits into two or more new species**.



TWO MAIN TYPES OF SPECIATION

Allopatric Speciation (Geographic Isolation)

- A population is **split by a physical barrier** (mountain, river, ocean) and each group evolves separately.
- No gene flow** between groups.
- Example are **squirrels** separated by the **Grand Canyon** evolving into different species.

Sympatric Speciation (No Physical Barrier)

- New species evolve **within the same geographic area**, often due to ecological niche differences, sexual selection, or genetic changes.
- They **still live together** but **stop interbreeding**.
- Example are **cichlid fish in the same lake** specializing in different food sources.



(a) Allopatric speciation



(b) Sympatric speciation

MODULE 1: ZOOLOGY, HISTORY, & EVOLUTION

BIO2202-LEC-SecI-MN: GENERAL ZOOLOGY LECTURE

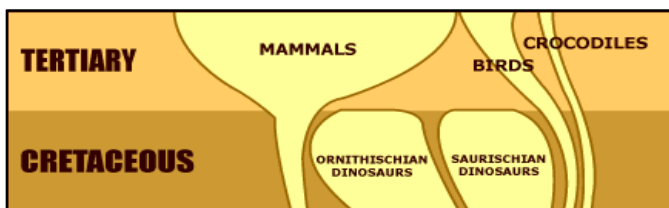
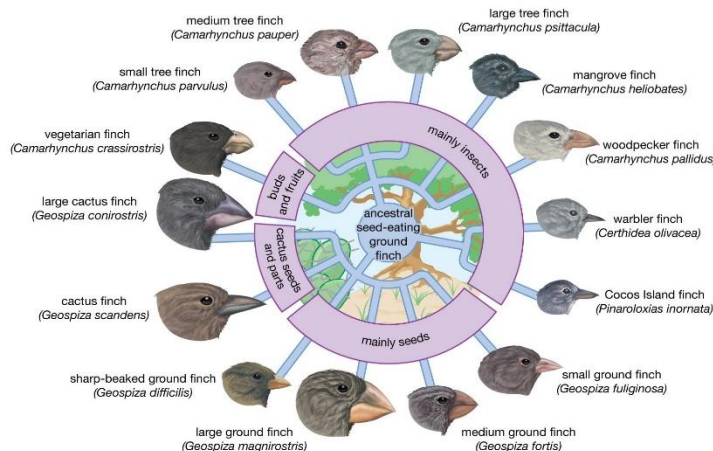
Midterms (2nd Semester) – Bachelor of Science in Biology (Section 1)



- **Adaptive radiation** is when one ancestral species rapidly **evolves into many new species**, each adapted to a different environment or way of life.

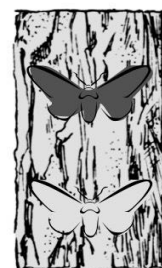
EXAMPLES OF ADAPTIVE RADIATION

Darwin's Finches	• On the Galápagos Islands, one ancestral finch species evolved into many species with different beak shapes for eating seeds, insects, or cactus flowers.
Hawaiian Honeycreepers	• Birds from one ancestor diversified into many with different bills, songs, and feeding habits.
Mammals after the Dinosaur Extinction	• Freed from competition with large reptiles, mammals spread into roles as grazers, predators, tree dwellers, and more.

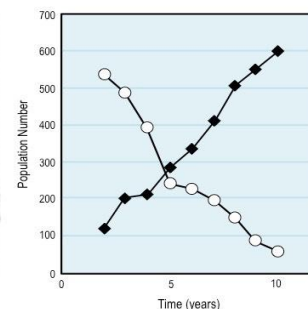


THE STORY OF THE PEPPERED MOTH

- **Before Industrialization (Pre-1800s)**
 - Most peppered moths had **light, speckled wings** that blended well with pale lichen-covered tree bark.
 - A **rare dark form (melanic form)** existed but was **uncommon** because it was **easier for birds to spot** on light trees.
- **During the Industrial Revolution (Mid-1800s)**
 - **Factories released soot**, blackening tree trunks and killing the pale lichens.
 - Now, **light moths stood out against the dark bark** and were eaten more by birds.
 - **Dark moths had better camouflage**, survived longer, and reproduced more.
 - Over decades, the **dark form became the dominant type** in polluted areas.



Pre-Industrial Revolution



Post-Industrial Revolution