Estimating and Exploring Populations

Techniques:

a. Line Transects
b. Capture–mark–release–recapture
c. Random Sampling using Quadrats
d. Association Tests using Chi-squared

Line Transects using Quadrats

Using line transects with quadrats is a straightforward but effective way to study the distribution and abundance of plants or animals in an area. Here's a short guide on how to do it:

- Select a Location: Choose an area you'd like to study, such as a field, forest, or shoreline.
- Set Up the Transect: Lay down a straight line, called a transect, using a measuring tape. This could be as short as 10 meters or as long as 100 meters, depending on your study needs.
- Place Quadrats: Decide on regular intervals (e.g., every 5 meters) to place a square frame known as a quadrat along the transect line.
- Examine Each Quadrat: At each quadrat location, identify and count the species inside the frame. Note other details like soil condition or light exposure, if relevant.
- Record Data: Jot down your findings in a notebook for each quadrat.
- Analyze: Count how often each species appeared in your quadrats and note any patterns in distribution along the transect.
- This method allows you to collect systematic data on the types and numbers of species in a given area, helping you understand its ecological makeup.

Estimation of population size by random sampling

How it works: Random sampling is a technique for estimating population size where a small portion of the population is studied to gain information about the whole. A section of the area is selected at random and the organisms within this section are counted. This is usually done using quadrats:

- Quadrats are generally square sample areas marked out using a framed structure.
- Quadrats are placed in a marked out habitat according to random numbers obtained using a random number table or a random number generator on a calculator
- The baseline of this habitat can be marked out using a measuring tape
- A first number is determined for the distance along the measuring tape on along the y-axis) and the second distance is randomly determined along the x-axis
- The quadrat is placed at the point where the two numbers meet
- Within each quadrat, the individual species are identified and the density, frequency, % coverage or abundance of each species is counted or estimated.
- This will be repeated with enough replicate squares to calculate a reliable estimate of the populations of these species in the area.

Example: Suppose you wanted to estimate the number of oak trees in a large forest. You could randomly select several small areas (say, each measuring 10m x 10m), count the number of oak trees within these plots, and then use this data to extrapolate and estimate the total number of oak trees in the whole forest.

Assumptions:

- Each individual in the population has an equal chance of being selected.
- The samples are representative of the whole population.
- The area or habitat is homogeneous.
- There is no immigration or emigration during the study period.

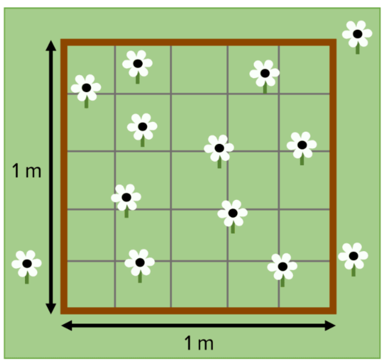
Random quadrat sampling to estimate population size for sessile (non-moving) organisms

How it works: Random quadrat sampling is a method used to estimate the abundance and distribution of sessile (non-moving) organisms. A quadrat is a square frame of a known size that is randomly placed in the study area. The organisms within this quadrat are counted.

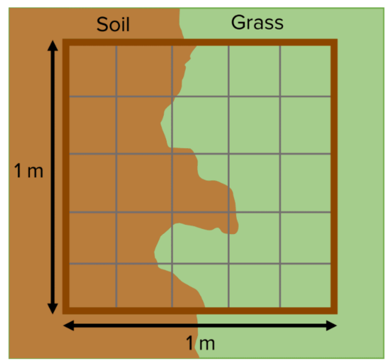
Example: A common example of this is counting the number of plants in a field. A quadrat (say, a 1m x 1m square) is randomly placed in a field, and the number of a particular species of plant within this quadrat is counted. This process is repeated several times, and the average is calculated to estimate the plant population in the whole field.

Assumptions:

- The organisms are distributed randomly within the habitat.
- Quadrats are representative of the whole population.
- The placement of quadrats is truly random.



10 daisies in the quadrat therefore 10 daisies per m^2



14 out of 25 squares.

$$\frac{14}{25} \times 100 = 56\%$$

MME Revise. "Investigating Ecosystems." MME Revise, n.d., https://mmerevise.co.uk/gcse-biology-revision/investigating-ecosystems/.

Capture–mark–release–recapture and the Lincoln index to estimate population size for motile organisms

How it works: Capture-mark-release-recapture (CMRR) is a method used for estimating the size of wildlife populations. Initially, a sample of organisms is captured, marked in some harmless way, and then released back into the population. After a suitable time, a second sample is captured, and the number of marked individuals within this sample is counted.

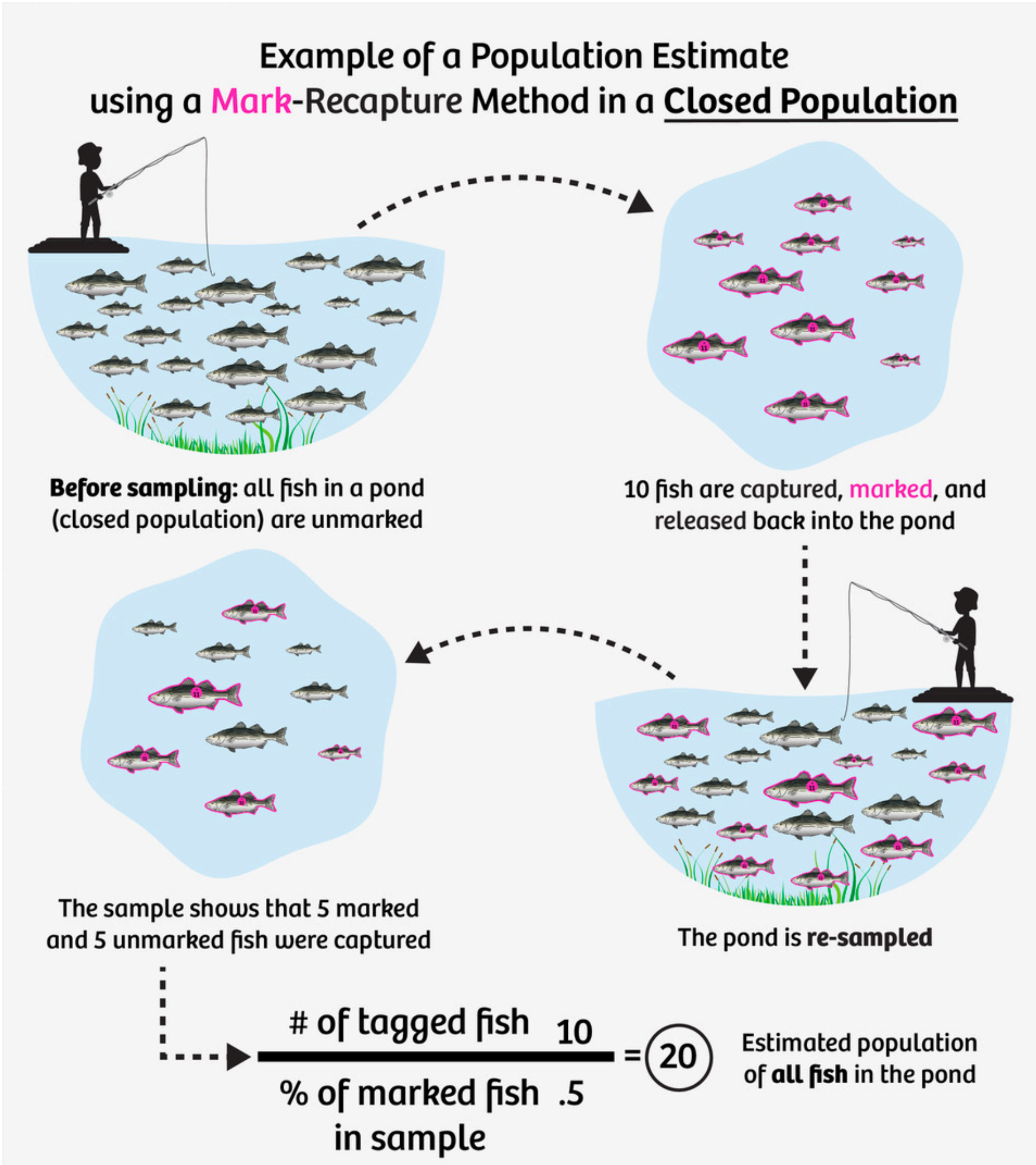
The Lincoln Index is then used to estimate the total population size using the formula:

Estimated population size = (number marked first time x total number caught second time) / number marked the second time.

Example: For example, a researcher might capture and mark 50 butterflies, then release them back into the wild. A few days later, the researcher captures another sample of butterflies, this time catching 60 butterflies, 10 of which are marked from the previous capture. Using the Lincoln Index, the researcher could estimate the total population of butterflies as (50 x 60) / 10 = 300 butterflies.

Assumptions:

- The marked individuals have had enough time to mix back into the population.
- There is no significant death, birth, immigration or emigration during the study period.
- Marking does not affect the individual's chance of being recaptured.
- All marks are still visible and identifiable at the time of recapture.



"FISHBIO Fisheries Research, Monitoring, and Conservation." *Using Mark-Recapture to Estimate Population Size | FISHBIO Fisheries Research, Monitoring, and Conservation*, FISHBIO, 2023, www.fishbio.com/using-mark-recapture-estimate-population-size/. Accessed 28 June 2023.

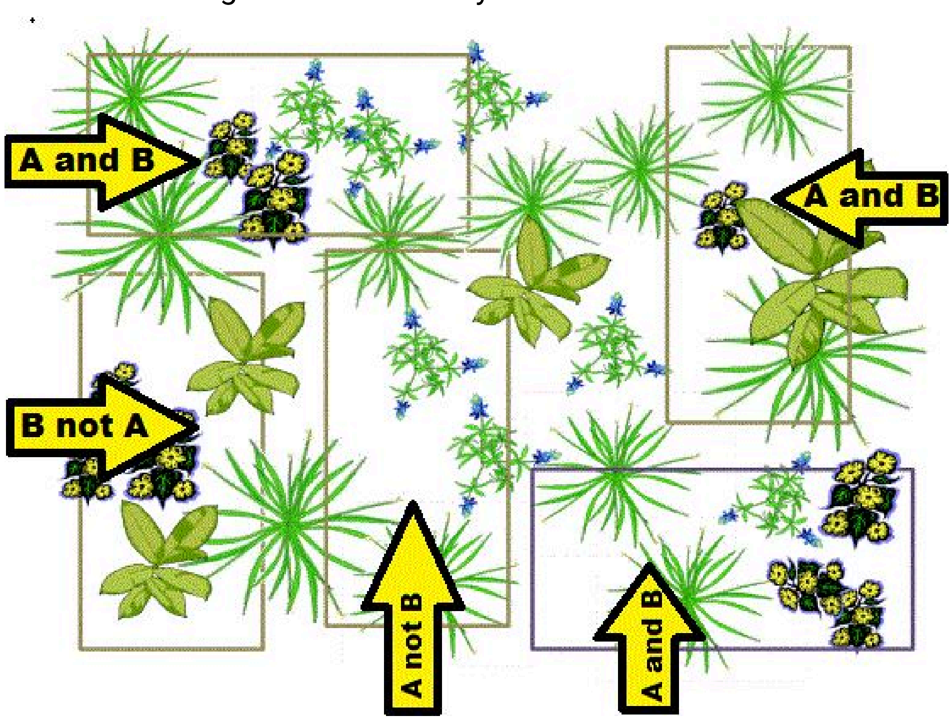
Use of the chi-squared test for association between two species

How it works: The Chi-squared test is a statistical method that can be used to determine if there is a significant association between two species. It tests the null hypothesis, which assumes there is no relationship between the two species.

Example: Suppose a biologist is studying a forest and wants to see if there is an association between the presence of a particular bird species and a specific tree species. They can collect data on the presence or absence of the bird and the tree in several locations within the forest. The data can then be tabulated and analysed using the Chi-squared test.

Assumptions:

- The samples are randomly selected.
- Each observation is independent of all others.
- The data used is categorical (not numerical).
- The expected frequency of each category is at least 5.
- The categories are mutually exclusive.



Biology for Life. "X^2 Test for Independence." Biology for Life, Biology for Life, URL: https://www.biologyforlife.com/x2-test-for-independence.html.

Energy Flow in Ecosystems

C4.2.1: Ecosystems as Open Systems

Open Systems vs. Closed Systems

Open Systems:

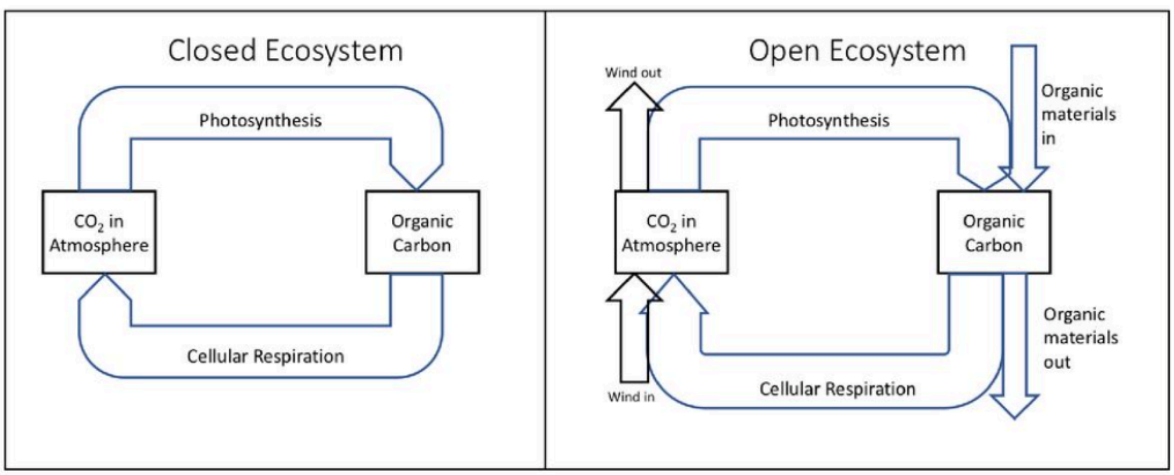
Definition: An open system allows both energy and matter to flow in and out of the system boundaries.

Characteristics:

- Interacts with its surroundings or other systems.
- Constantly exchanges energy and matter with its environment.
- More adaptable to external changes due to its interactive nature.

Example:

- A pond: Receives water from rainfall or a stream (matter) and gets energy from the sun. It loses water through evaporation and might also lose nutrients as water flows out.



Closed Systems:

Definition: A closed system allows only energy to pass through its boundaries, not matter.

Characteristics:

- There's limited or no exchange of matter with the environment.
- Over time, the resources (matter) within a closed system can become depleted since no new matter is introduced.
- Can exchange energy, such as heat or light, with its surroundings.

Examples:

- A terrarium (with a sealed lid): Plants inside will recycle the carbon dioxide and oxygen, and the water cycle operates inside, but no new matter enters the system. However, it does still receive light energy from outside.
- Earth (to some extent): While Earth is mostly a closed system in terms of matter—very little matter enters or leaves Earth—it is open concerning energy, receiving energy from the Sun and radiating energy back into space.

Relation to Ecosystems:

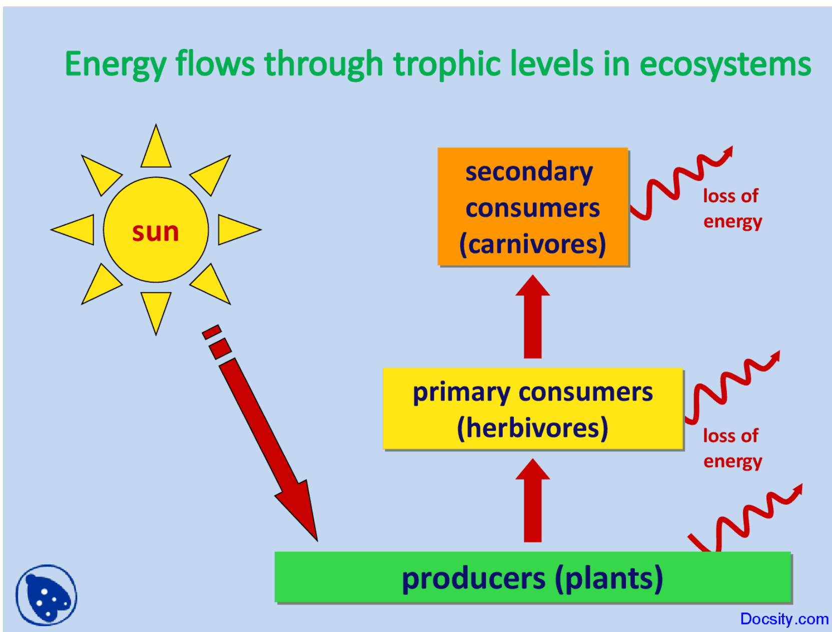
- Almost all natural ecosystems function as open systems as they continuously interact with neighboring ecosystems and the broader environment,

- These interactions are vital for nutrient cycling, genetic diversity, and ecological resilience. For instance, a forest ecosystem not only receives nutrients from decomposed organic matter within its boundaries but also from rivers flowing into it or animals migrating into the area.

C4.2.2: Sunlight as the Principal Source of Energy

- Photosynthesis Foundation: Sunlight fuels the process of photosynthesis, where primary producers (like plants and algae) convert sunlight into chemical energy stored in glucose and other organic molecules.

- Food Chain Initiation: These primary producers form the base of the food chain, supplying energy to herbivores, which in turn feed carnivores. The energy stored in organic molecules is transferred through the trophic levels of an ecosystem.



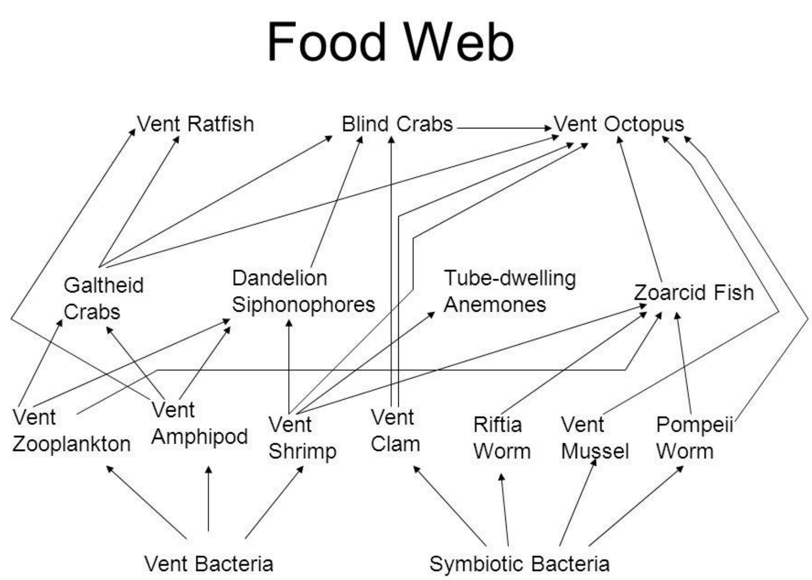
Exceptions to Sunlight-Dependent Ecosystems:

Deep-Sea Hydrothermal Vent Ecosystems:

- Description: These are found deep in the ocean, far from the reach of sunlight. The ecosystems around these vents are fueled by the chemicals that are emitted from the Earth's crust.

- Primary Producers: Instead of photosynthetic plants or algae, the base of the food chain in these ecosystems consists of chemosynthetic bacteria. These bacteria use the chemicals, especially hydrogen sulfide, from the venting fluids to produce organic material through a process called chemosynthesis.

- Fauna: These ecosystems host a variety of unique organisms such as giant tube worms, clams, and certain species of shrimp, which thrive in the extreme conditions around these vents.



Cave Ecosystems:

- Dark Zone Environment: Deep within caves, areas termed the "dark zone" receive no sunlight at all. In these regions, traditional photosynthesis is absent.

    - Blind cavefish: These fish have adapted to a life without light by losing their eyes and pigmentation.
    - Cave-dwelling insects: Many have elongated limbs and antennas to navigate the dark.
    - Nutrient Sources: Without sunlight and photosynthesis, cave organisms rely on nutrients brought in from external sources, usually as organic matter from the outside or through bacteria that depend on chemoautotrophy.
    - Interconnectedness: Despite the absence of photosynthesis, cave ecosystems demonstrate the profound interconnectedness of life. The limited resources mean species have co-evolved intricate relationships, ranging from symbiotic partnerships to specialized predator-prey dynamics.

C4.2.3: Flow of Chemical Energy Through Food Chains

Definition: As one organism consumes another in a food chain, the chemical energy stored within the consumed organism is transferred to the consumer.

Components of a Food Chain:

Primary Producers: These are typically plants or algae that use sunlight to produce food (glucose) through photosynthesis. They convert the sun's energy into chemical energy.

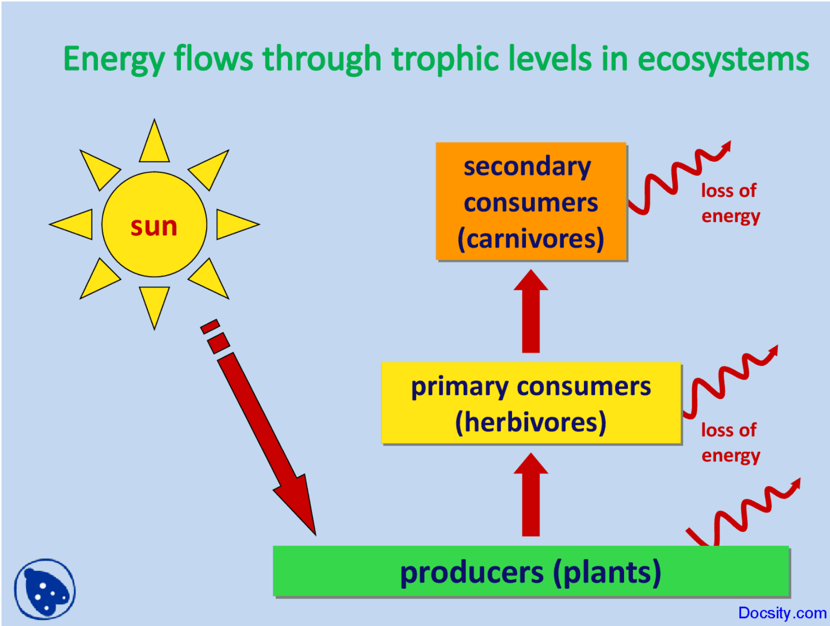
Primary Consumers: These are herbivores that eat primary producers. By consuming plants, they obtain the energy stored within them. Examples include rabbits, deer, and certain insects.

Secondary Consumers: These are carnivores that eat primary consumers. They get their energy from the herbivores they consume. Examples might be foxes, snakes, or birds of prey.

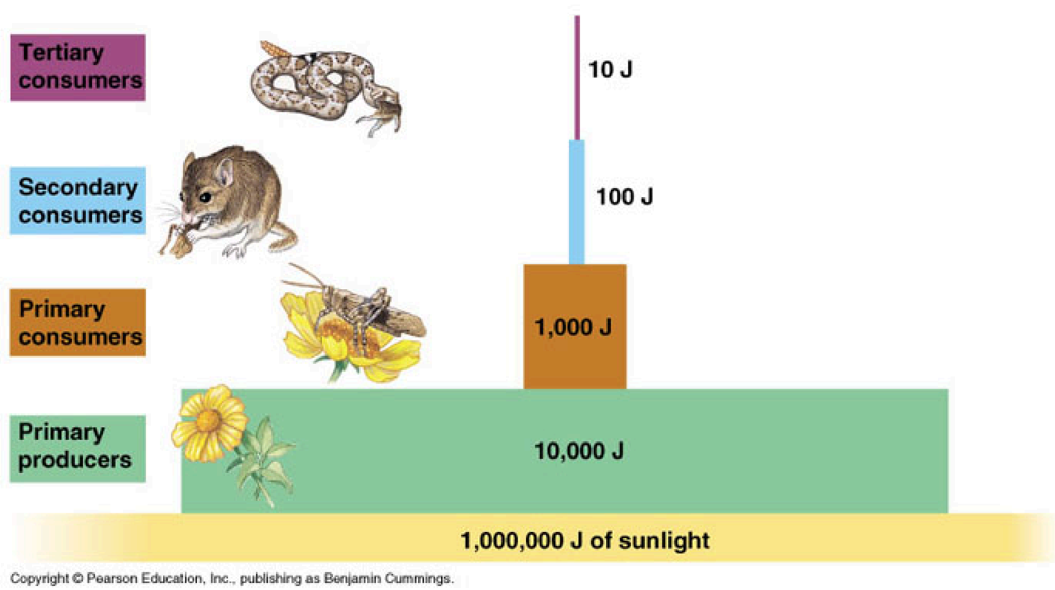
Tertiary Consumers: These are carnivores that eat secondary consumers. They are often top predators within their ecosystem. Examples include lions, eagles, or sharks.

Quaternary Consumers: In some larger ecosystems, there might be a level beyond tertiary consumers, though this is less common.

Energy Transfer Efficiency: While energy is transferred from one organism to another, it's crucial to understand that not all the energy from one trophic level gets transferred to the next. Typically, only about 10% of the energy is passed on, while the rest is lost primarily as heat or used up by the organism for its metabolic activities. This phenomenon is described by the 10% rule.



Ecological Implications: The energy transfer inefficiency explains why there are fewer organisms at higher trophic levels. It's also the reason why long food chains are rare; after several energy transfers, there's insufficient energy left to support another trophic level. This underlines the importance of primary producers, as they are the primary source of energy input into the ecosystem. Without an efficient base, the entire food chain could collapse.

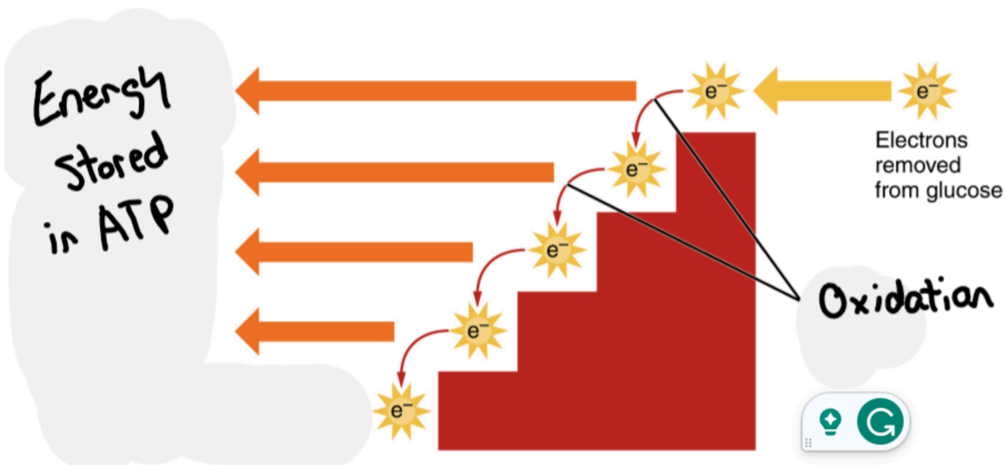


C4.2.7: Energy Source in Autotrophs

- Photoautotrophs use light as their external energy source, while chemoautotrophs use oxidation reactions.

- Chemoautotrophs Example: Iron-oxidizing bacteria that derive energy from the oxidation of iron compounds.

- Explanation: Oxidation reactions involve the loss of electrons and release energy, making them useful for powering cellular processes. This energy is transferred to ATP molecules.



C4.2.5: Supply of Energy to Decomposers

- Definition: Decomposers derive their energy from oxidation reactions using carbon compounds present in dead organic matter.
- Examples: Faeces, fallen leaves, dead animals, and other organic waste materials.
- Explanation: Decomposers like fungi and bacteria break down dead organic matter, recycling nutrients and energy within the ecosystem.

C4.2.6: Autotrophs and Their Role in Energy Conversion

Definition: Autotrophs are organisms that can produce their own food from the substances available in their surroundings using light or chemical energy. Unlike heterotrophs, they do not need to ingest other organisms.

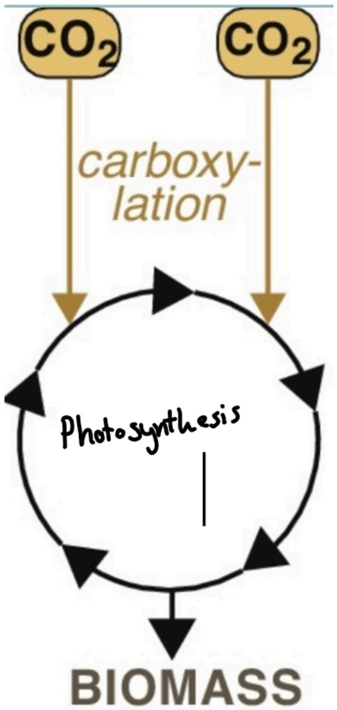
Key Concepts:

Types of Autotrophs:

- Photoautotrophs: These organisms utilize light as their primary energy source. Examples include most plants, algae, and certain bacteria like cyanobacteria.

- Chemoautotrophs: These organisms derive energy from chemical reactions, often involving inorganic substances. Certain bacteria, especially those in extreme environments like deep-sea vents, are chemoautotrophs.

Carbon Fixation:



- Carbon fixation is the process of converting inorganic carbon (usually in the form of carbon dioxide) into organic compounds. It's the first step in making carbon accessible to life in the form of complex molecules.

- In plants and photoautotrophic organisms, this process happens through photosynthesis. The energy from sunlight drives the conversion of carbon dioxide and water into glucose (a simple sugar) and oxygen.

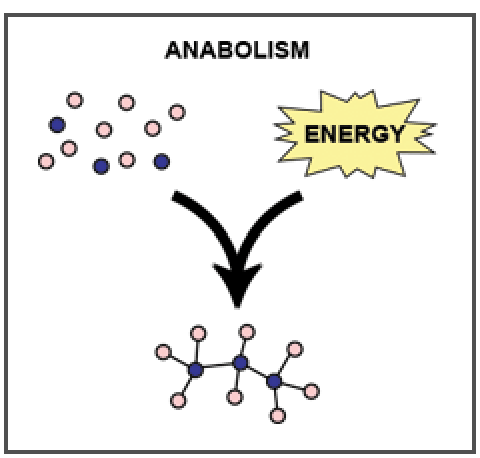
- In chemoautotrophs, chemical reactions provide the necessary energy for carbon fixation.

Anabolic Reactions:

- Anabolism refers to the pathways in organisms where complex molecules are constructed from simpler ones, usually requiring energy.

- For instance, the glucose produced from photosynthesis can be used to synthesize larger carbohydrates, proteins, lipids, and nucleic acids. These are the macromolecules essential for the structure and function of cells.

- The energy required for these anabolic reactions comes from the stored chemical energy produced by autotrophs during carbon fixation.



C4.2.9: Release of Energy through Oxidation of Carbon Compounds in Cell Respiration

Definition: Cellular respiration is a metabolic process where cells oxidize organic compounds, primarily glucose, to produce energy in the form of ATP (adenosine triphosphate). Both autotrophs (organisms that produce their own food) and heterotrophs (organisms that consume other living things for food) undergo cellular respiration to meet their energy needs.

Key Concepts:

Oxidation of Glucose:

- The primary molecule oxidized during cellular respiration is glucose. Its oxidation refers to the process where electrons are transferred from glucose to molecules of oxygen, producing carbon dioxide, water, and releasing energy.

Energy Capture:

- The ultimate goal of cellular respiration is to produce ATP, the cellular "currency" for energy. ATP powers almost every activity of the cell, from muscle contraction to molecule synthesis.

Autotrophs vs. Heterotrophs:

- While autotrophs generate their organic molecules through photosynthesis or chemosynthesis, they still rely on cellular respiration to extract the energy stored in these molecules.

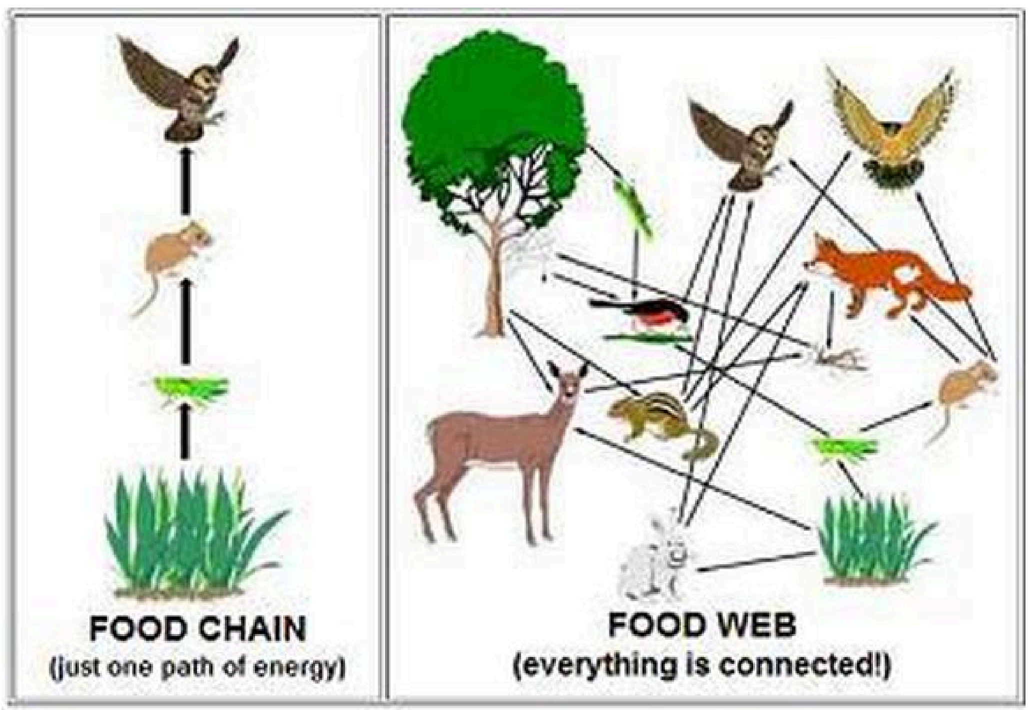
- Heterotrophs, on the other hand, obtain organic molecules by consuming other organisms and then use cellular respiration to derive energy from these molecules.

Mode of Nutrition	Energy Source	Carbon Source	Types of Organisms
Autotroph			
*Photo*autotroph	Light	CO_2	Plants, algae, cyanobacteria
*Chemo*autotroph	Chemicals (inorganic)	CO_2	Certain prokaryotes (e.g. *Sulfolobus*)
Heterotroph			
*Photo*heterotroph	Light	Organic compounds	Certain prokaryotes (e.g. *Rhodobacter*)
*Chemo*heterotroph	Organic compounds	Organic compounds	Animals, fungi, protists, many types of prokaryote

(Bioninja)

C4.2.4: Food Chains and Food Webs

- Food Chains: Sequential series of organisms through which energy flows in one direction. Each step is a trophic level.
    - Example: In a pond ecosystem: Algae → Small Fish → Large Fish → Heron.
- Food Webs: Complex networks of interconnected food chains that show the multiple feeding relationships in an ecosystem.
    - Significance: Demonstrates the interdependence of species. A change in one population can ripple through the web.
- Arrows in Food Chains and Webs: Essential to indicate the direction of energy flow. They point from the food source to the consumer.



C4.2.8: Heterotrophs

- Differentiation: Unlike autotrophs (like plants) that produce their own food through processes such as photosynthesis, heterotrophs rely on consuming organic substances, whether from plants, animals, or both.

- Nutritional Modes: Heterotrophs can be classified based on their source of nutrition:

    - Herbivores: Consume plant material.
    - Carnivores: Consume animal flesh.
    - Omnivores: Consume both plants and animals.
    - Decomposers: Break down dead organic material.

- Digestion and Assimilation:

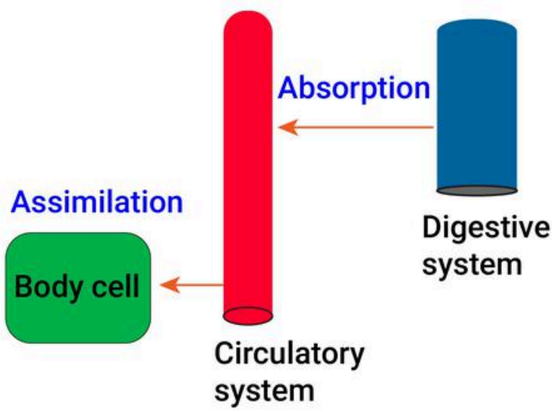
    - Complex Carbon Compounds: Many of the foods consumed by heterotrophs, such as proteins, fats, and nucleic acids, are complex molecules. To utilize the energy and nutrients within these foods, they need to be broken down.

    - External Digestion: Organisms like fungi secrete enzymes into their surroundings to break down complex organic matter. Once these materials are broken down, the simpler molecules are absorbed.

    - Internal Digestion: Animals like mammals, birds, and reptiles ingest food and break it down internally within specialized organs (e.g., stomach, intestines). Enzymes play a critical role in this breakdown.

    - Assimilation and Synthesis: Post-digestion, the simpler molecules are absorbed into the organism's cells. Here, they are reassembled or modified to produce the specific carbon compounds the organism requires. For instance, amino acids absorbed from digested proteins can be used to construct new proteins that the organism needs.

- Digestion is merely a preparatory step. The ultimate goal is to provide cells with the building blocks they need. Once inside cells, these simpler molecules become substrates in various metabolic pathways, leading to the synthesis of essential molecules for growth, repair, and reproduction.



C4.2.10: Trophic Levels

- Role of Producers: Organisms, usually green plants, that produce organic compounds from inorganic substances using light energy.
- Consumer Levels:
    - Primary Consumers: First level of consumers. Directly feed on producers.
    - Secondary Consumers: Predators that feed on primary consumers.
    - Tertiary Consumers: Apex predators that feed on secondary consumers.
- Diet Diversity: Some animals, like omnivores, can switch between consumer levels depending on food availability.

C4.2.11: Energy Pyramids

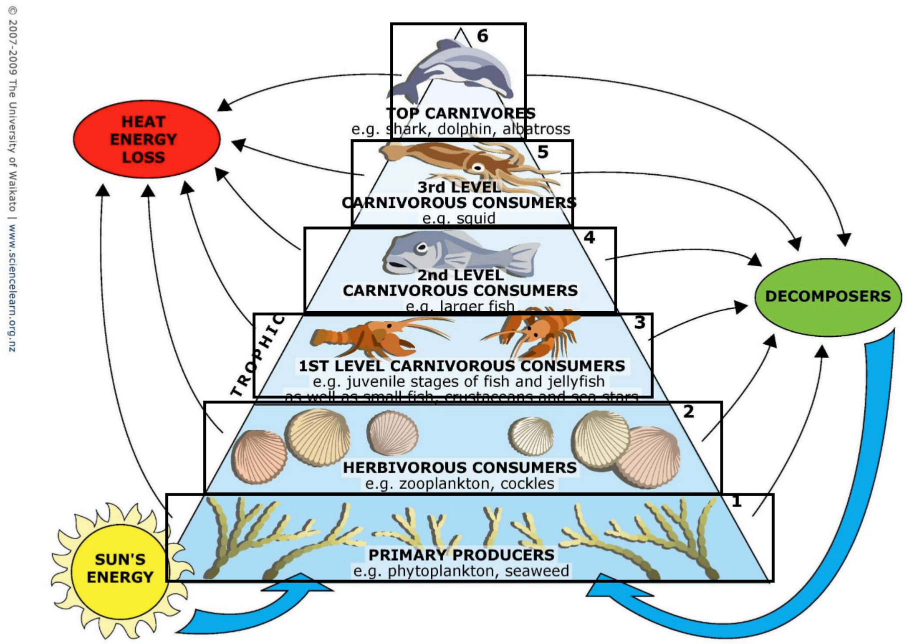
- Visual Representation: Energy pyramids graphically depict the distribution of energy across different trophic levels in an ecosystem. Each level represents a trophic stage, and its size corresponds to the amount of energy it holds.
- Energy Reduction:
    - As you move up the pyramid from producers to apex predators, there's a notable decrease in energy. This phenomenon results from the energy used by organisms for various life processes and the energy lost as heat.
    - While the general rule is that about 10% of the energy is passed on to the next trophic level, this percentage can vary based on specific ecosystems and conditions. The other 90% of energy is consumed by the organism's metabolic activities, growth, reproduction, or lost as waste and heat.

- Base of Pyramid:

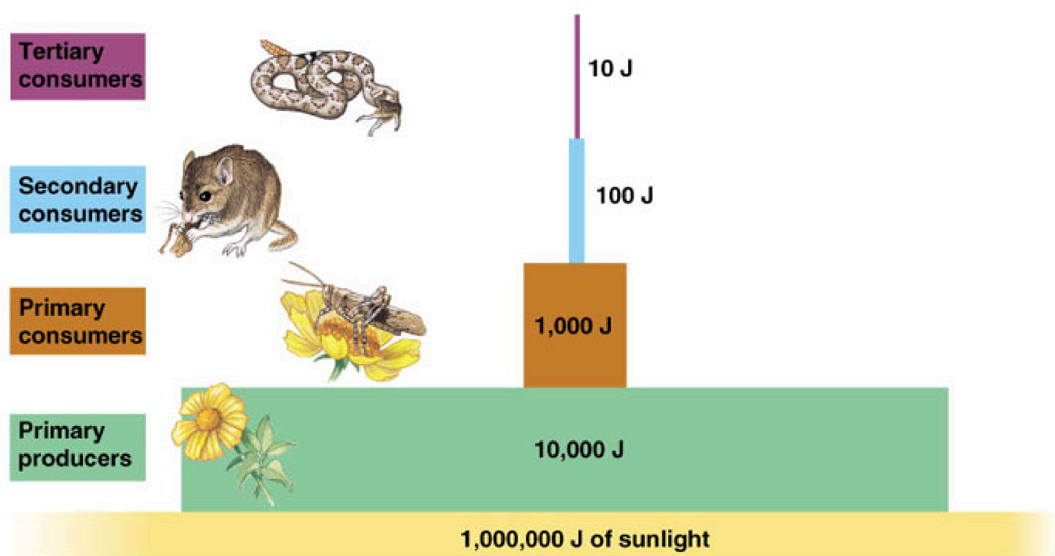
    - This level is thick and broad, indicating that it possesses the highest energy content. It represents the producers, usually autotrophic organisms like plants in terrestrial ecosystems and phytoplankton in aquatic ones.
    - Producers capture sunlight and convert it into chemical energy through the process of photosynthesis, thereby setting the base energy available for the entire ecosystem.

- Implications:
    - Energy pyramids not only offer a visual representation of energy distribution but also highlight the fragility of ecosystems. A disruption at any trophic level, especially the base, can have cascading effects throughout the food chain. As such, energy pyramids serve as essential tools for conservation and ecological studies.

Example of an Energy Pyramid (Not to scale)



Energy Pyramids (A bit more to scale)



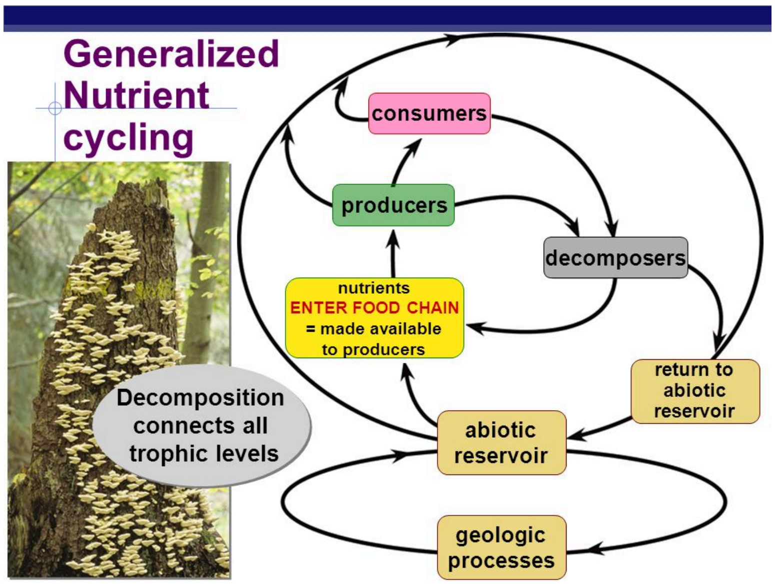
C4.2.12: Energy Loss in Food Chains

- Mechanisms of Loss:
    - Life Processes: Every organism uses energy to maintain its life processes. Activities such as movement, growth, reproduction, and basic metabolic activities all consume energy.
    - Heat Production: During cell respiration, when energy is converted to ATP, not all the energy from glucose is transformed into ATP. A significant portion is lost as heat, especially in warm-blooded animals that use energy to maintain their body temperature.
    - Undigested Material: Not all the food consumed by an organism is digestible. The indigestible components, like cellulose in many animals, are egested and don't contribute to the organism's energy.

- Energy Inefficiencies:
    - The transfer of energy between trophic levels is never 100% efficient. A vast majority of the energy is lost at each stage, which is why food chains typically have only a few trophic levels.
    - As an energy rule of thumb, only about 10% (though this can vary) of the energy at one level is available to the next. This inefficiency is due to the combined effects of metabolic processes, heat production, and energy spent on activities that don't contribute to growth.

- Role of Decomposers:
    - Function: Decomposers and detritus feeders, such as fungi and bacteria, play an integral role in breaking down dead organic matter. They feed on dead tissues and waste products of organisms.
    - Nutrient Cycling: Through decomposition, these organisms ensure the return of essential minerals and nutrients to the soil or water, making them available for plants and primary producers. This cyclical nature ensures the sustainability of ecosystems.
    - Energy Role: While decomposers play a crucial role in nutrient cycling, they don't typically contribute to the primary energy flow in the main food chain. Their function is more about recycling materials than energy transfer.

- Understanding Decomposers in Energy Transfers:
  - It's essential for students to recognize that, although decomposers aren't typically represented in primary food chains or energy pyramids, their role in ecosystems is vital.
  - They indirectly influence the energy dynamics by ensuring that primary producers have the nutrients they need to photosynthesize and grow.
  - By understanding the role of decomposers in energy transformations, students can appreciate the interconnectedness of all organisms in an ecosystem and how energy and nutrients are cyclically transformed and transferred.



C4.2.13: Heat Loss

- Metabolic Heat:
    - Respiration: One of the primary sources of heat in organisms is cellular respiration. As cells break down glucose to produce energy in the form of ATP, not all the energy from glucose is captured efficiently. A significant portion is inevitably lost as heat.

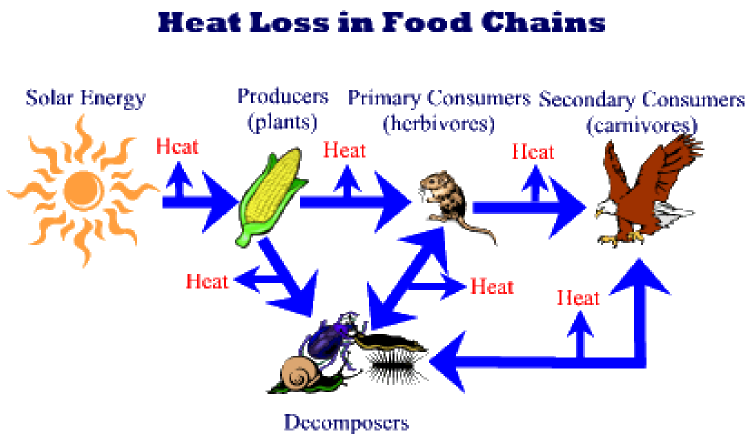
    - Heat's Role: This heat is essential for warm-blooded organisms (endotherms) like birds and mammals, as it helps in maintaining their body temperature. However, it also represents an inefficiency in the energy transfer process.

- ATP and Heat Production:
    - ATP Production: This process isn't flawless in its efficiency, leading to the release of heat.

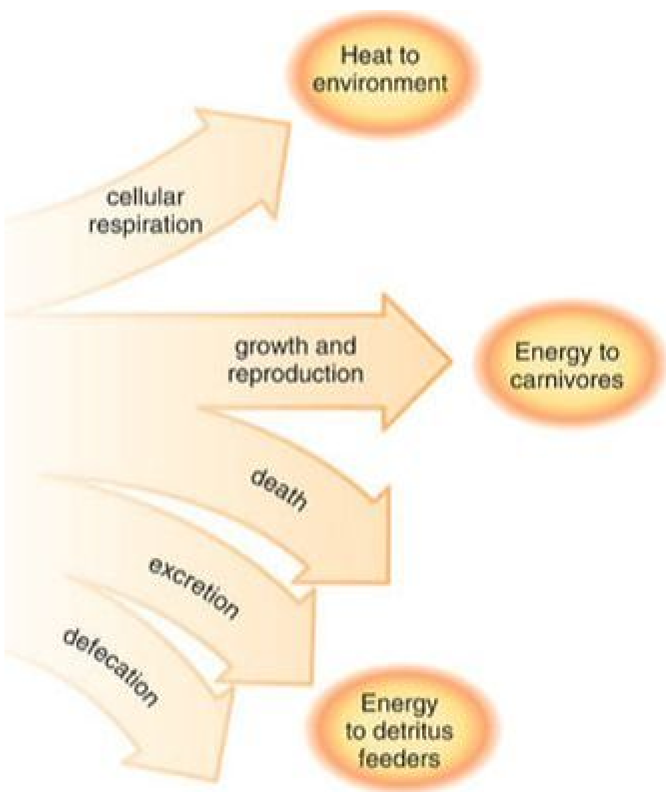
    - ATP Utilization: Similarly, when cells use ATP to fuel cellular activities not all of this energy is utilized for the intended cellular function; a part of it dissipates as heat.

- Biological Implications:
    - While this heat production might seem like a drawback, it's essential for certain organisms to maintain their body temperatures. For ectotherms (cold-blooded organisms), this isn't as crucial since they rely more on environmental sources for heat.

    - This principle underlines the inherent inefficiencies in biological systems, emphasizing the need for organisms to intake a substantial amount of energy (often in the form of food) to compensate for these losses and maintain their metabolic activities.



C4.2.14: Trophic Level Restrictions



- Energy Diminution:
  - Basic Principle: As you move up each trophic level in a food chain, there's a substantial loss of energy. Typically, only about 10% of the energy from one level is passed on to the next. This principle is why we often see a diminishing number of organisms as we ascend the food chain.
  - Energy vs. Biomass: Though the energy content per unit mass remains consistent across trophic levels, the total available energy diminishes. This is reflected in the reduction of biomass as we move to higher trophic levels.

- Biomass Implications:
    - Fewer Organisms: Due to the limited available energy at higher trophic levels, there's a supportable limit to how many organisms can exist there. This is why we might observe millions of phytoplankton in a region of the ocean, but only a few apex predators like sharks.

- Ecosystem Dynamics:
    - Energy Flow: The flow of energy from the base to the apex of food chains is like a pyramid. There's a wide base consisting of primary producers that harness energy directly from the sun, and a narrow top with apex predators.

- Ecological Consequences:
    - Understanding the limitations imposed by energy availability at different trophic levels is crucial for conservation efforts. Overfishing, for instance, can have drastic repercussions. Removing a large number of organisms from a higher trophic level can disrupt the delicate energy balance and impact the entire ecosystem

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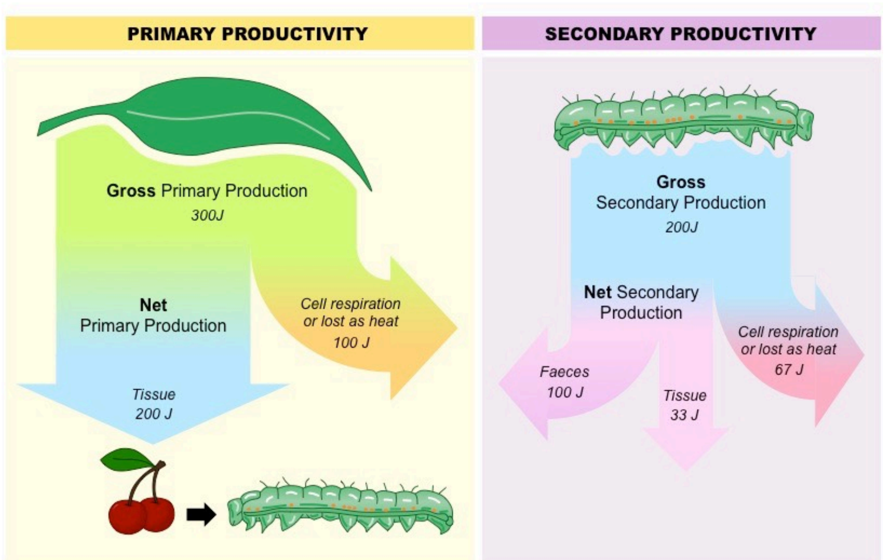
C4.2.15: Primary Production

- Concept of Primary Production:
    - Primary production refers to the rate at which primary producers (typically plants and algae) convert carbon dioxide into organic carbon compounds through photosynthesis. This conversion forms the foundational energy source for all other organisms in an ecosystem.
- Rate of Production:
    - It measures how quickly primary producers synthesize organic matter. High rates of primary production mean a robust and thriving ecosystem, capable of supporting a diversity of life forms.
- Measurement Units:
    - Primary production is quantified in terms of the mass of carbon produced per unit area over a specific time span. The most common units are grams per square meter per year (g m^−2 yr^−1). It essentially gauges how much carbon is locked into organic matter within a given area and time frame.
- Factors Influencing Primary Production:
    - Light Intensity: Plants require light for photosynthesis. Hence, the availability and intensity of sunlight directly affect the rate of primary production.
    - Nutrient Availability: Essential nutrients like nitrogen and phosphorus are crucial for plant growth. Their presence in the soil or water can accelerate or hinder primary production.
    - Temperature: Since enzyme-driven reactions power photosynthesis, temperature can influence their rate and efficiency, thereby affecting primary production.
- Biomass Accumulation:
    - As primary producers create organic matter, it leads to an accumulation of biomass. This biomass increase occurs not just when plants grow but also when they reproduce. The resultant organic matter serves as a food source for primary consumers, facilitating the upward flow of energy in an ecosystem.
- Variation Across Biomes:
    - Different biomes, whether they are deserts, rainforests, or tundras, have varying capacities for primary production. For instance, rainforests, with their abundance of sunlight and rainfall, have high primary production rates. In contrast, deserts, with scarce water, have lower rates. Students should appreciate these variations, as they are fundamental to understanding the dynamics and health of different ecosystems.



C4.2.16: Secondary Production

- Definition of Secondary Production:
    - Secondary production refers to the amount of organic matter, or biomass, produced by heterotrophs (organisms that derive their nutrients from other organisms). It encompasses the energy derived from consuming primary producers (like plants) or other consumers.

- Biomass of Consumers:
    - This metric provides a tangible measure of the organic content in consumers, which can range from herbivorous insects to apex predators. Essentially, it reflects the net gain in an organism's weight (excluding bones) over a given time period.

- Conversion of Consumed Biomass:
    - While primary producers convert inorganic carbon (from CO_2) into organic carbon through photosynthesis, consumers incorporate the organic carbon they ingest into their own bodies. But, they don't use all of it. A lot gets expended as energy for various activities or lost during metabolism.

- Energy Expenditure in Heterotrophs:

  - Heterotrophs, unlike autotrophs, expend energy on a range of activities. These include searching for food, evading predators, reproduction, and physiological processes like thermoregulation. These expenditures reduce the amount of energy that gets stored as biomass.

- Efficiency Differences between Primary and Secondary Production:
  - While primary producers like plants directly harness energy from the sun, secondary producers rely on the energy stored in the organisms they consume. As energy moves up the food chain, more of it gets lost to metabolic processes and other activities, rendering secondary production less efficient than primary.
  - An important point of inefficiency is cell respiration. As heterotrophs respire, they convert some of the carbon compounds they've consumed back into carbon dioxide and water. This process releases energy, much of which is lost as heat, and therefore does not contribute to biomass. Hence, there's a significant reduction in biomass from primary to secondary production levels.

Aspect	Primary Production	Secondary Production
Definition	Production of organic matter by producers (like plants).	Production of biomass by consumers from the food they eat.
Organisms	Autotrophs (plants, some bacteria).	Heterotrophs (animals, some fungi).
Energy Source	Sunlight or chemicals. Through Photosynthesis or Chemosynthesis.	Organic matter from food. Digestion and growth
Efficiency	Direct conversion from light/chemical energy.	Lower due to energy expenditure & loss during consumption.
Units	g m−2 yr−1	g m−2 yr−1
Role in Food Chain	Base (support all other levels).	Use energy from primary producers and pass it to higher levels.

B4.1.1 - Habitat

Habitat as the place in which a community, species, population or organism lives

A description can include:

Geographical Location	Physical Location	Type of Ecosystem
The broad area on Earth where a species lives, like the Arctic for polar bears.	The specific environment within that area, such as sea ice platforms in the Arctic for polar bears.	The community of living things interacting in an area, like the Arctic marine ecosystem which includes polar bears, seals, and more.

B4.1.3 - Abiotic Variables Affecting Species Distribution

These are non-living variables that affect species distributions.

Some Examples:

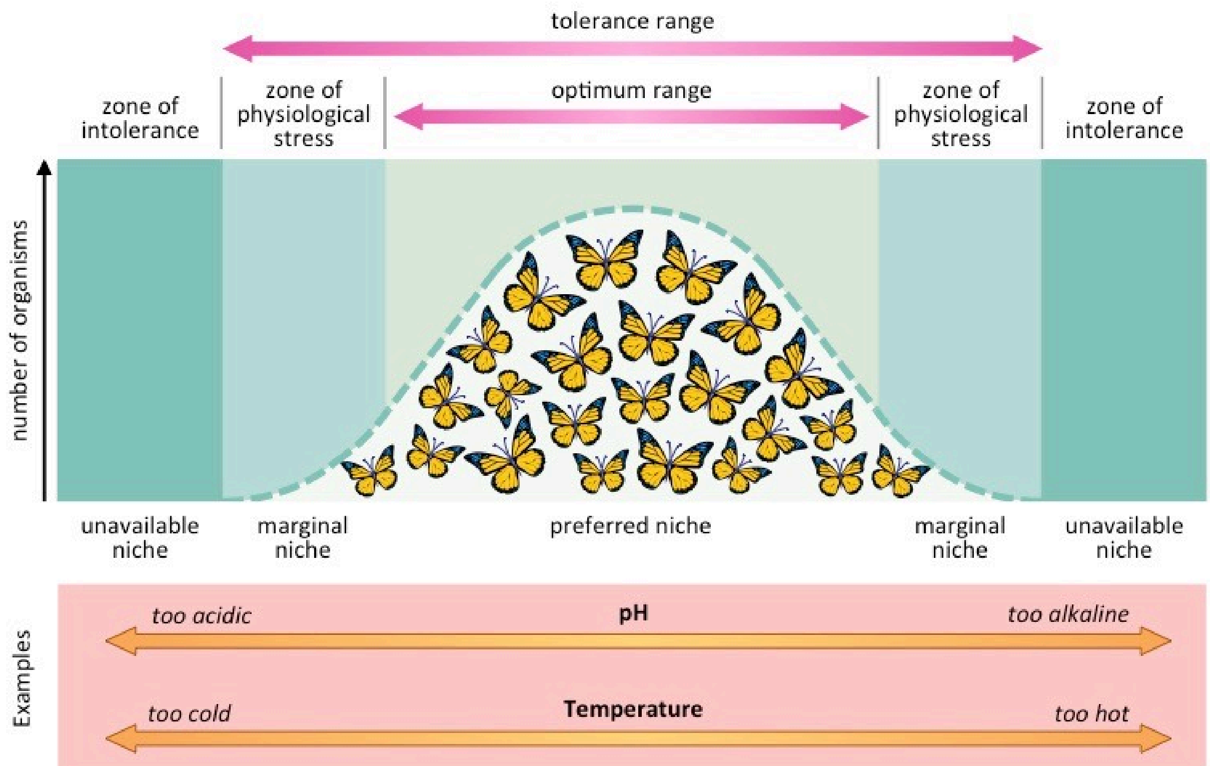
Temperature: Affects metabolic rates; for instance, cacti are adapted to hot deserts, while polar bears are suited for cold Arctic climates.

Water Availability: Plants like succulents store water for arid conditions, while camels have adaptations to conserve water in deserts.

Soil Composition: Certain plants thrive in specific soil types; for example, heather plants prefer acidic soils.

Light Intensity: Deep-sea creatures have adaptations for low light, while sunflowers turn to maximize sunlight exposure.

Species adaptations determine their tolerance range, dictating where they can thrive based on these abiotic factors.



B4.1.5 - Conditions required for coral reef formation

Water Depth: Corals need sunlight since many contain photosynthetic algae called zooxanthellae. Therefore, most coral reefs form in shallow waters, typically at depths less than 50 meters.

pH: Corals prefer slightly alkaline conditions. A pH of around 8.1-8.4 is ideal. Acidic conditions can hinder the corals' ability to produce calcium carbonate, which they need to build their skeletons.

Salinity: Coral reefs thrive in saline waters, with an ideal salinity range of 32 to 42 parts per thousand (ppt). Fluctuations outside this range can stress corals.

Clarity: Clear water is crucial as it allows sunlight to penetrate, benefiting the photosynthetic zooxanthellae. Turbid or murky waters can hinder light penetration, affecting coral health.

Temperature: Corals are sensitive to temperature changes. Most coral reefs thrive in waters between 23°C to 29°C. Prolonged exposure to temperatures outside this range can lead to coral bleaching, where corals expel the zooxanthellae.

Question:

How do you think global warming is affecting coral?

B4.1.6 - Abiotic factors as the determinants of terrestrial biome distribution

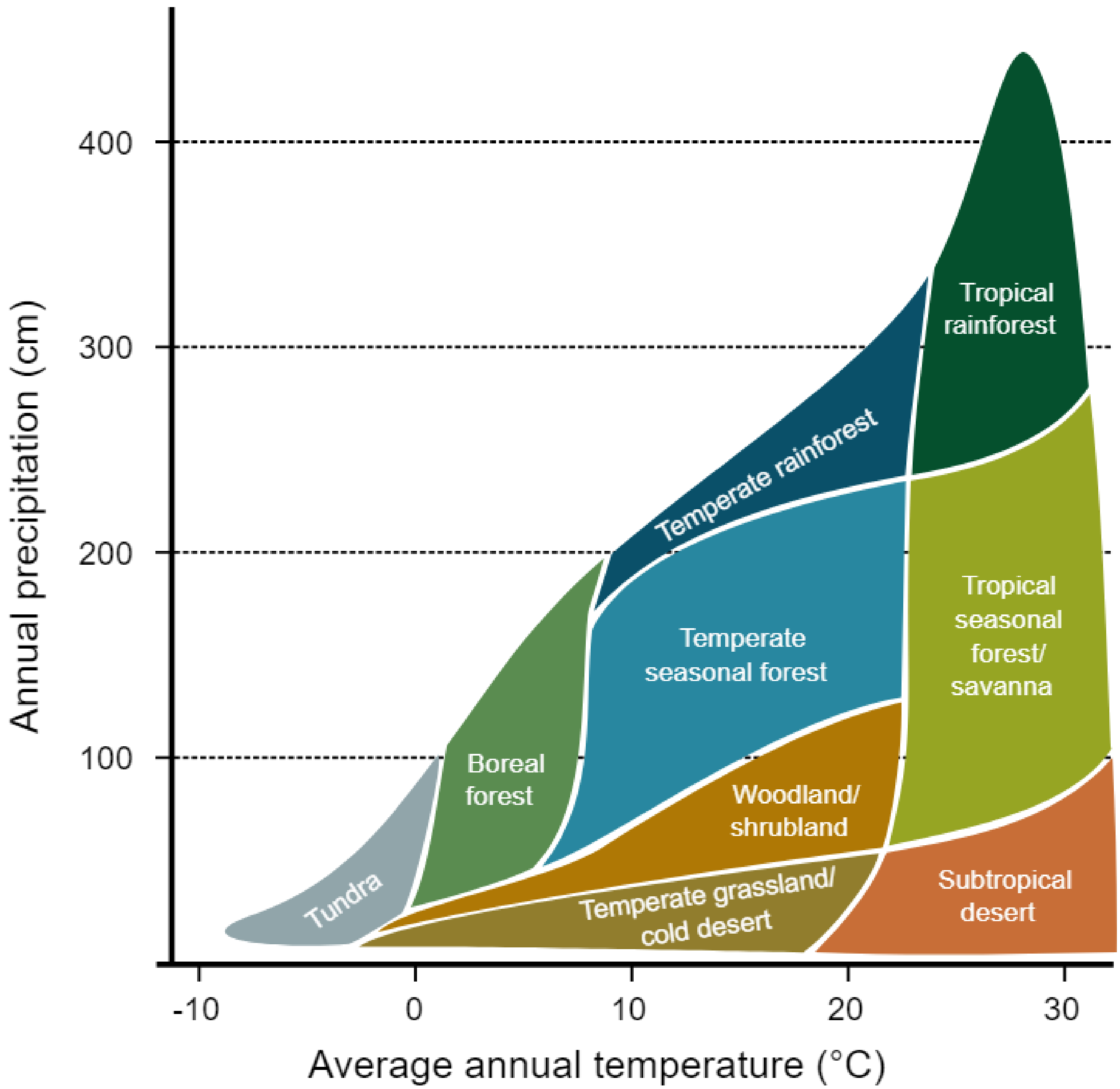


Figure 2. Precipitation and temperature are the two most important climatic variables that determine the type of biome in a particular location. Credit: "Climate influence on terrestrial biome" by Navarras is in the Public Domain, CC0

To understand how abiotic factors determine biome distribution, consider a graph where:

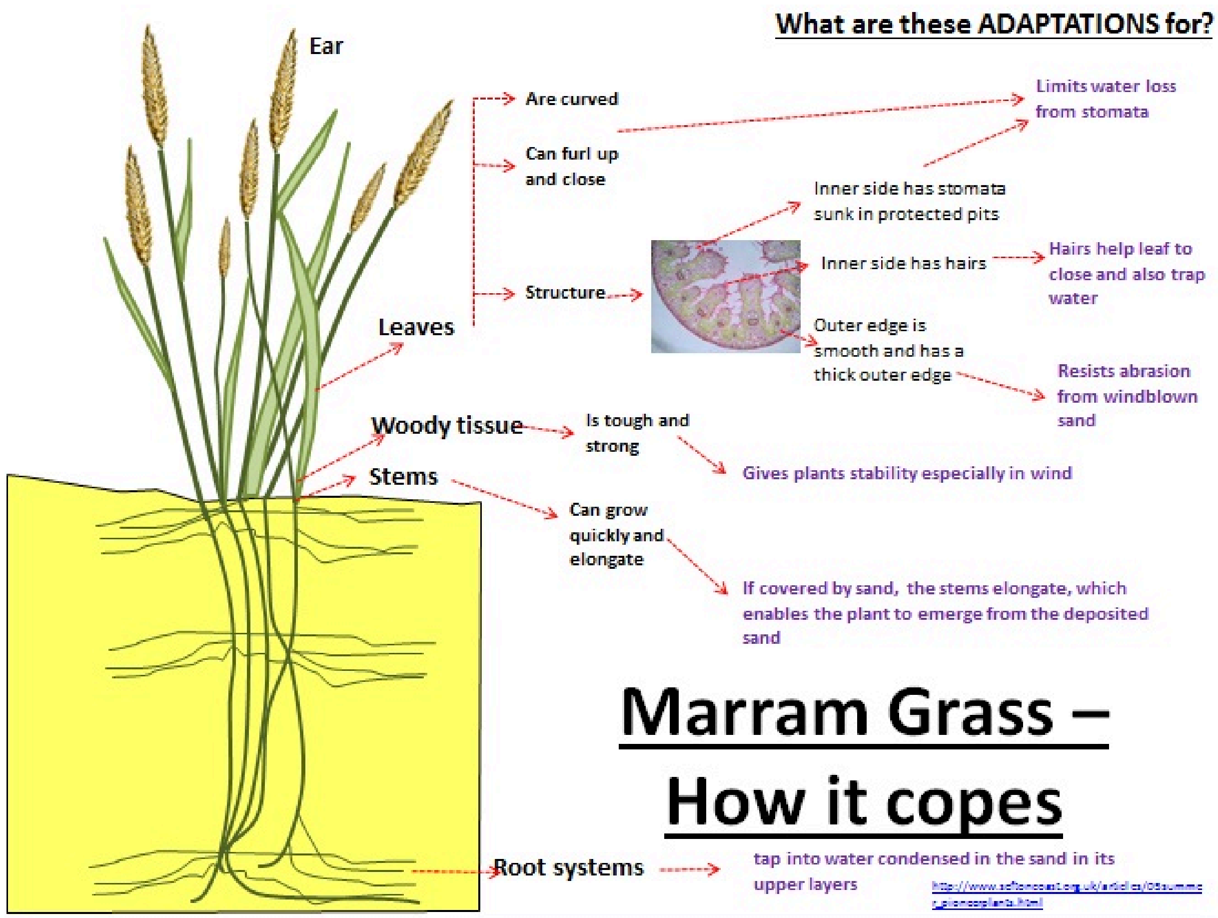
Horizontal Axis (X-axis): Represents temperature, ranging from cold to hot.
Vertical Axis (Y-axis): Represents rainfall, ranging from low to high.

Biome Distribution	Average Rainfall and Temperature
Tundra	Less than 100 cm of rain and average temperature between -10 and 0 C.
Subtropical Deserts	less than 100 cm of rain and temperatures between 20-30C
Tropical Rainforests	250 to 450 cm of rain and an average temperature between 23 and 32 C
Grasslands	10 to 50 cm of rain and an average temperature between -4 and 20C.
Boreal Forest	20 to 200 cm of rainfall and an average temperature between - and 9C.
Temperate seasonal Forests	Between 50 and 200 cm of rainfall and an average temperature between 5 and 20 C.

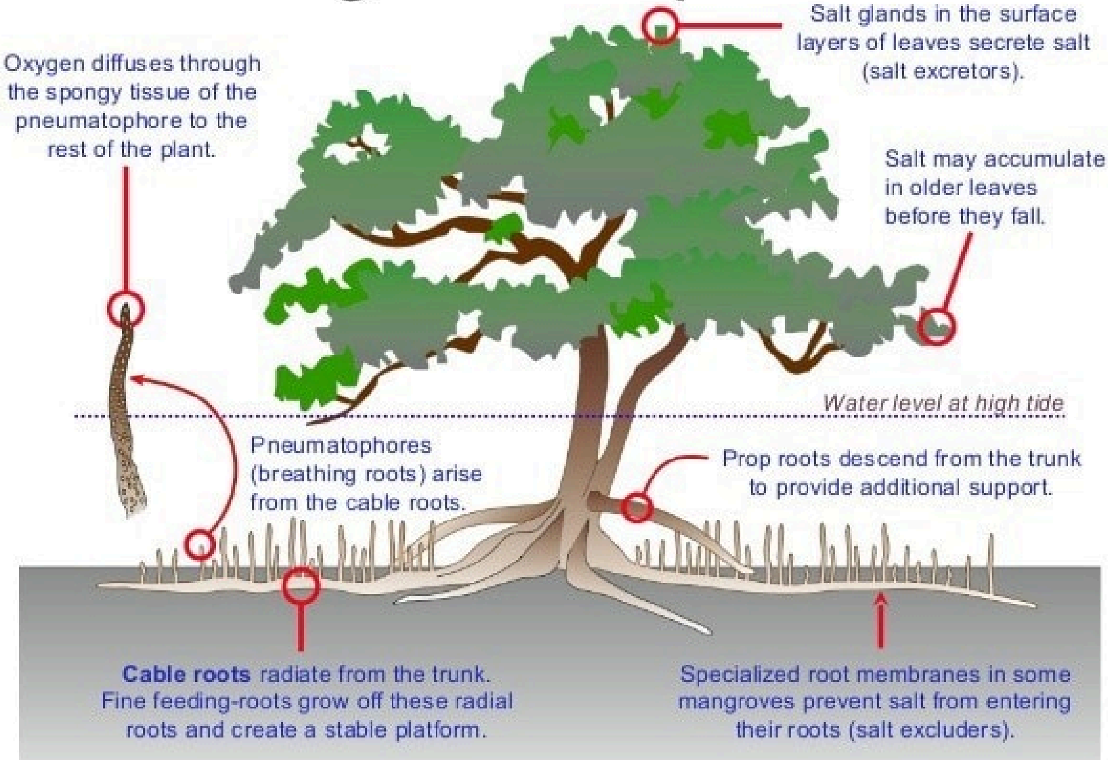
B4.1.2 - Adaptations of organisms to the abiotic environment of their habitat
Include a grass species adapted to sand dunes and a tree species adapted to mangrove swamps.

Mangrove Trees and Marrem Grass Adaptations

Mangrove Trees	**Marram Grass**
Adapted to waterlogged and anoxic soil tolerates brackish waters.	Extensive roots and horizontal stems (rhizomes) for moisture access and stability on sand dunes.
Ultra-filtration in roots or special glands on leaves to manage salt.	Can withstand burial by sand and elongate leaves to reach above sand.
Laterally spreading roots with vertical anchors; aerial roots for oxygen; prop/stilt roots for stability.	Deep roots reach the water table in arid environments.
Seeds (propagules) grow while attached to parent, float to find suitable ground.	Leaves roll up, thick waxy cuticle, and sunken stomata for water conservation
	Grows upwards out of dune tops to remain above shifting sands.


What are these ADAPTATIONS for?
Ear
Leaves
Are curved
Can furl up and close
Structure
Limits water loss from stomata
Inner side has stomata sunk in protected pits
Inner side has hairs
Hairs help leaf to close and also trap water
Outer edge is smooth and has a thick outer edge
Resists abrasion from windblown sand
Woody tissue
Is tough and strong
Gives plants stability especially in wind
Stems
Can grow quickly and elongate
If covered by sand, the stems elongate, which enables the plant to emerge from the deposited sand
Marram Grass –
How it copes
Root systems
tap into water condensed in the sand in its upper layers

Mangrove Adaptations



B4.1.7- Biomes as groups of ecosystems with similar communities due to similar abiotic conditions and convergent evolution

Biomes are large areas on the Earth's surface that are characterized by similar conditions, which in turn influence the types of ecosystems found within them. These climatic conditions foster the development of specific plant and animal communities that are adapted to those conditions. Here's a brief summary of the climate conditions characterizing each of the mentioned biomes:

Biome	**Climate**	**Typical Vegetation**
Tropical Forest	Warm temperatures year-round, high humidity, significant rainfall	Dense canopies of broadleaf evergreen trees, abundant undergrowth, variety of epiphytes
Temperate Forest	Moderate temperatures with distinct seasonal changes, moderate to high precipitation	Deciduous trees that shed leaves in autumn, mixed with some evergreens
Taiga (Boreal Forest)	Cold temperatures, especially in winter, moderate precipitation mostly as snow	Coniferous trees like pines, spruces, and firs
Grassland	Moderate to warm temperatures with distinct dry and wet seasons, moderate precipitation	Dominantly grasses with few trees and shrubs
Tundra	Very cold temperatures, especially in winter, low precipitation levels	Low-growing plants like mosses, lichens, grasses, and dwarf shrubs

Hot Desert	Extremely hot temperatures, very low precipitation levels	Sparse vegetation with cacti, succulents, and shrubs adapted to arid condition

Echidnas, anteaters, and armadillos are excellent examples of convergent evolution, where unrelated species evolve similar traits as a response to similar environmental challenges or ecological niches, despite being located in different geographical areas or belonging to different evolutionary lineages.

Similar Ecological Niches:

- All three of these animals are specialized in feeding on ants and termites, which is reflected in their anatomical and behavioral adaptations.

Anatomical Adaptations:

- Long, Sticky Tongues: They have long, sticky tongues that are adept at capturing insects.
- Strong Forelimbs and Claws: They have strong forelimbs and claws for breaking into termite mounds or ant nests.

Geographical Distribution:

- Their geographical distribution also showcases convergent evolution, as they have evolved similar ant/termite-eating specializations independently on different continents.

The North American kangaroo rat, Australian hopping mouse, and the jerboas from North Africa and Asia are fascinating examples of convergent evolution in action across different continents.

Morphological Adaptations:

- Elongated Hind Legs: All three species have developed elongated hind legs that enable them to hop or leap across their sandy habitats. This mode of locomotion is energy-efficient and helps them cover ground quickly to escape predators or search for food.
- Compact Bodies: They possess compact bodies, which reduce water loss and help in conserving energy.
- Fur-covered Feet: Their fur-covered feet provide protection against the hot sand of their desert habitats.

Behavioral Adaptations:

- Nocturnal Behavior: These animals are primarily nocturnal, which allows them to avoid the extreme daytime temperatures of the desert.
- Burrowing: They burrow into the ground to escape the heat during the day and to retain moisture.

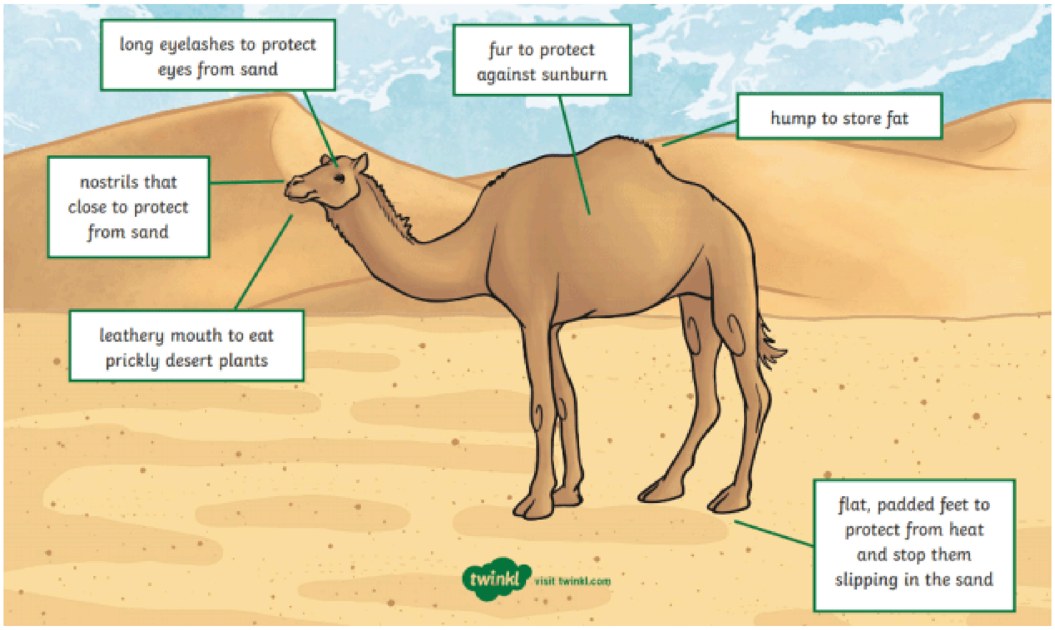
Physiological Adaptations:

- Water Conservation: They have evolved physiological mechanisms to conserve water, such as highly concentrated urine and dry feces. Some of these species obtain the majority of their water from the metabolic breakdown of their food.

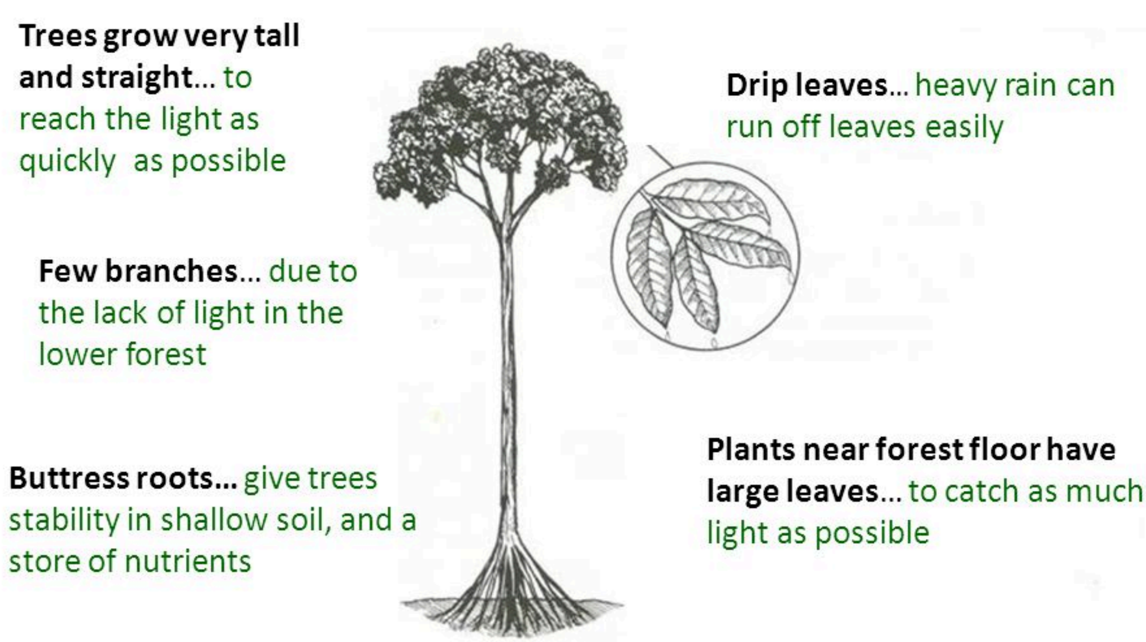
Dietary Adaptations:

- Seed Eating: They primarily feed on seeds, which are a good source of both food and water. The seeds also provide them with the necessary energy to survive in harsh, arid conditions.

- B4.1.8 - Adaptations to life in hot deserts and tropical rainforest- Include examples of adaptations in named species of plants and animals.



Rainforest trees - adapted to their natural environment



Populations, Communities, and Interactions

C4.1.1—Populations as interacting groups of organisms of the same species living in an area

Populations

A population is a group of organisms of the same species that live in a specific area and interact with one another. They share a gene pool and have the ability to interbreed.

Characteristics of Populations:

Size: The number of individuals in a population.
Density: The number of individuals per unit area/volume.
Birth and death rates: Determines the growth of the population.

Factors Affecting Population Size:

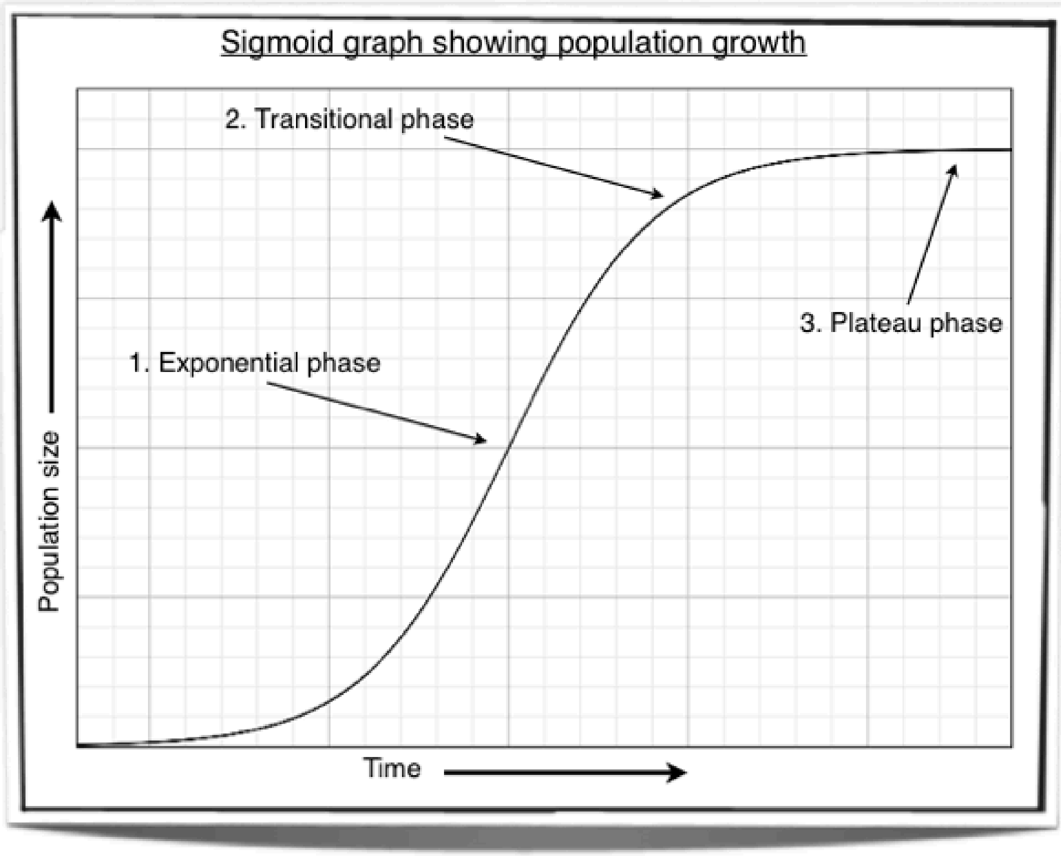
Natality (birth rate): Increase in population size.
Mortality (death rate): Decrease in population size.
Immigration: Organisms entering the population from elsewhere.
Emigration: Organisms leaving the population.

Population Interactions:

Populations don't just exist; they interact with each other and the environment. This can affect population dynamics (changes over time). These interactions can include:

Competition: Occurs when resources are limited.
Predation: One organism (predator) feeds on another (prey).
Symbiosis: Close, long-term interactions between species, including mutualism (both benefit), commensalism (one benefits, the other isn't harmed or helped), and parasitism (one benefits, the other is harmed).

C4.1.7—Population growth curves



Exponential (or J-shaped) Growth:

- Occurs under ideal conditions with unlimited resources.
- Population size increases rapidly and continuously over time.

Logistic (or S-shaped) Growth:

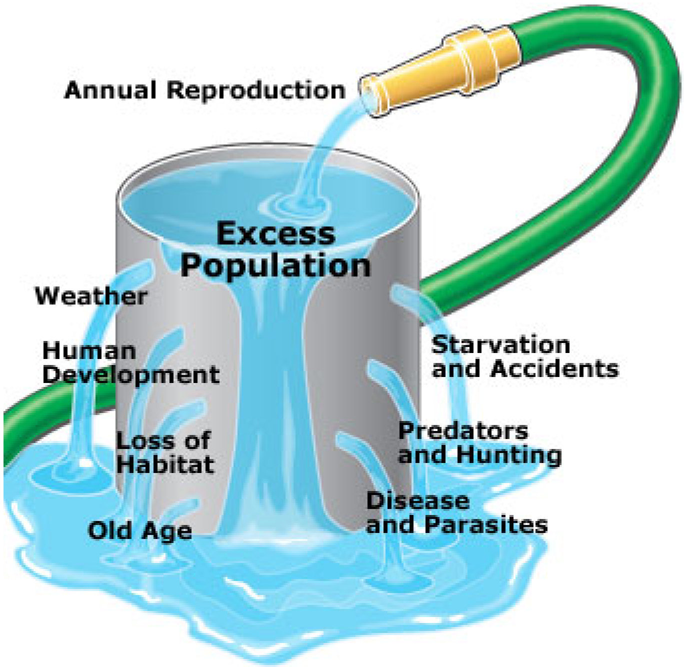
- Considers limits on population growth due to resource constraints.
- Initial exponential growth is followed by a slowdown, and eventually, the population stabilizes near the carrying capacity.

Carrying Capacity (K):

- Maximum population size that an environment can sustainably support given the available resources.
- Above this point, limiting factors (like food and space) reduce population growth.

C4.1.5—Carrying capacity and competition for limited resources

Carrying Capacity (K)



Definition: Carrying capacity refers to the maximum number of individuals of a particular species that a specific environment can support over a prolonged period without degradation of that environment.

Factors Influencing Carrying Capacity: These include food availability, water, living space, predators, disease, and the state of the environment.

Limiting Factors:

- Environmental factors that restrain population growth.
- Can be density-dependent (e.g., competition, predation) or density-independent (e.g., weather, natural disasters).

Competition for Limited Resources

Intra-specific Competition: Competition among members of the same species. As resources become scarcer, intra-specific competition intensifies. This can lead to reduced growth, survival, and reproduction rates for individuals.

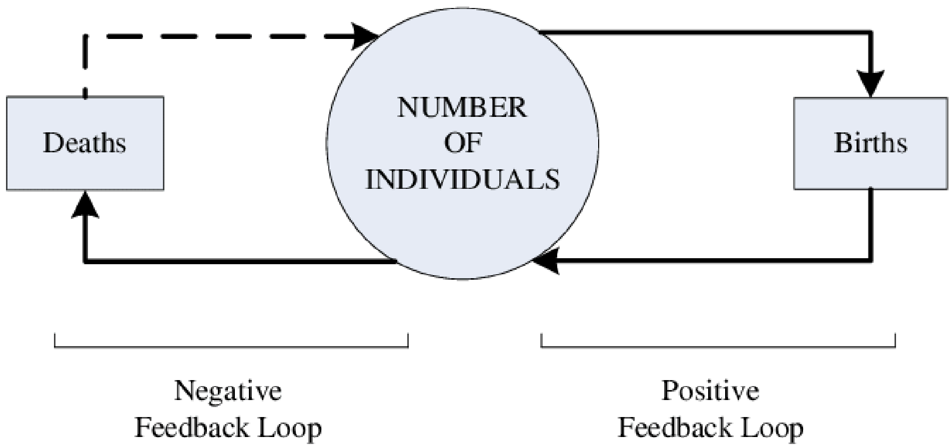
Inter-specific Competition: Competition between different species for shared resources. When two species compete for the same limited resource, one species will often be more efficient and outcompete the other, which can lead to the competitive exclusion principle.

Density-dependent Factors: Factors that have a greater impact as the population density increases. Competition for resources, predation, and disease are examples. These factors play a significant role in slowing population growth as it approaches carrying capacity.

Effects of Competition**:** Intense competition can lead to decreased population size, decreased growth rate, or migration out of an area. It can also drive evolutionary changes as species adapt to reduce competition.

C4.1.6—Negative feedback control of population size by density-dependent factors

Definition of Negative Feedback: A mechanism where a change in a given direction results in effects that counteract or oppose that change, bringing the system back toward equilibrium.



Examples of Density-dependent Factors:

Competition for Resources: As population size increases, individuals compete more intensely for limited resources such as food, water, and shelter. This increased competition can decrease birth rates or increase death rates.

Predation: In many ecosystems, as the population of a prey species increases, the population of predators may also increase because more food is available. This can then lead to a higher predation rate, acting as a check on the prey population.

Disease: Higher population densities can lead to more rapid spread of contagious diseases, which can reduce the population size.

Parasitism and Herbivory: Just like diseases, the impact of parasites and herbivores can become more pronounced as the host or plant population density increases.

Waste Accumulation: In some cases, the waste products of organisms can accumulate in an area. Higher densities can lead to more rapid accumulation of waste, which can negatively impact the environment and reduce its carrying capacity.

Negative Feedback Mechanism:

1. Population Increase: As a population grows, the density of the population also increases.
2. Density-dependent Factor Activation: As a result of increased density, density-dependent factors (like competition, predation, or disease) become more pronounced.
3. Population Decrease: These factors then serve to reduce population size by decreasing birth rates, increasing death rates, or both.
4. Restoration of Equilibrium: As the population size decreases, the effects of the density-dependent factors lessen, leading to the potential for population growth again. The system tends toward equilibrium around the carrying capacity.
5. Density-dependent Factors: Factors that have a greater impact as the population density increases. Competition for resources, predation, and disease are examples. These factors play a significant role in slowing population growth as it approaches carrying capacity.

C4.1.9—Community as All Interacting Organisms in an Ecosystem:

- A community refers to all the interacting organisms in an ecosystem.
- It encompasses various forms of life, including plants, animals, fungi, and bacteria.
- Communities are essential components of ecosystems, where organisms of different species coexist and interact within a given geographical area.

C4.1.10—Competition versus Cooperation in Intraspecific Relationships:

Intraspecific Competition (Within the Same Species):

- Occurs when individuals of the same species compete for limited resources such as food, water, and mates.

<u>Reasons for intraspecific competition include:</u>

- Limited resources: When there are not enough resources to satisfy the needs of all individuals, competition arises.
- Reproductive competition: Individuals may compete for the opportunity to mate and pass on their genes.
- Territorial disputes: Competition for territory can be fierce, especially among territorial species.

<u>Examples of Competition:</u>

- Lions in a pride competing for access to the same prey.
- Trees in a forest competing for sunlight, nutrients, and space.

Intraspecific Cooperation (Within the Same Species):

- Cooperation involves individuals of the same species working together for mutual benefit.

Reasons for cooperation include

- Enhanced survival: Group living can provide protection from predators and improve foraging efficiency.
- Reproductive benefits: Cooperative breeding can increase the chances of offspring survival.
- Resource sharing: Individuals may cooperate to share limited resources

Examples of Cooperation:

- Honeybees in a hive working together to collect nectar and care for the colony.
- Wolves in a pack hunting together to bring down larger prey.

C4.1.11—Interspecific Relationships Within Communities:

Interaction Type	Description	Example
Herbivory	Consumption of plant material by herbivores	Grazing of grass by cows, deer, or insects
Predation	One organism capturing and consuming another for sustenance	A lion preying on a wildebeest
Interspecific Competition	Different species competing for the same limited resources	Multiple bird species competing for nesting sites in a tree
Mutualism	Symbiotic relationship where both species benefit	Bees obtaining nectar and pollinating flowers
Parasitism	One organism benefiting at the expense of another	Ticks feeding on the blood of mammals
Pathogenicity	Harm caused by pathogens to their host species	Bacteria causing tuberculosis in humans

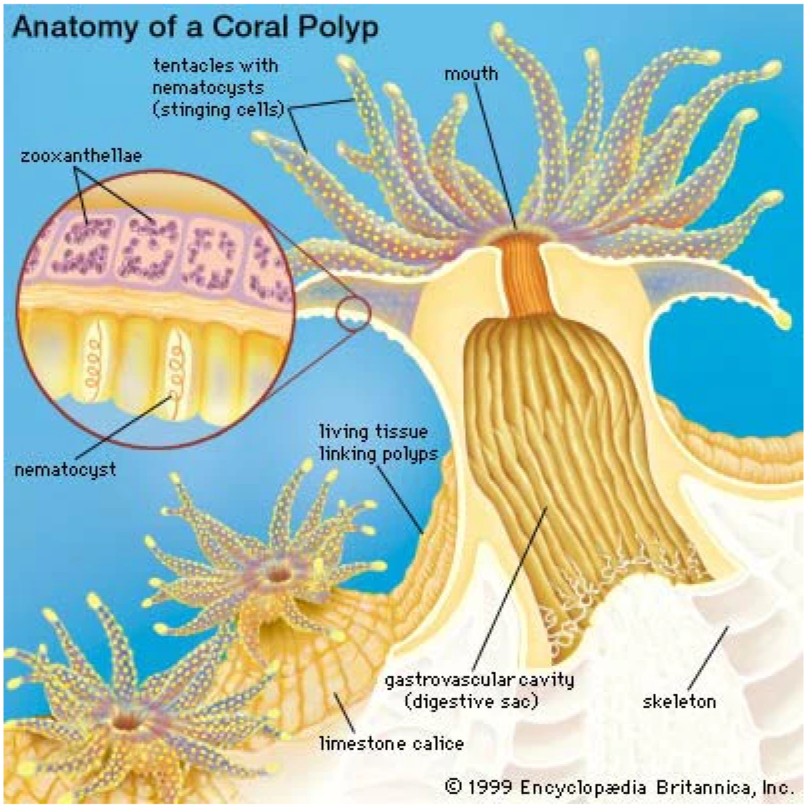
These ecological interactions play crucial roles in shaping the structure and dynamics of communities and ecosystems. Understanding these relationships is fundamental for ecology and biodiversity conservation.

Table 1: Effects of Different Biological Interactions on Involved Species

Interaction Type	Effect on Species 1	Effect on Species 2
Herbivory	+	-
Predation	+	-
Interspecific Competition	-	-
Mutualism	+	+
Parasitism	+	-
Pathogenicity	-	+

C4.1.12—Mutualism as an interspecific relationship that benefits both species:

Symbiotic Relationship	Host Organism	Symbiont	Benefits to Host	Benefits to Symbiont
Root Nodules	Fabaceae (Legumes)	Rhizobia bacteria	Fixes atmospheric nitrogen into usable form.	Receive carbohydrates and a protective environment.
Mycorrhizae	Orchidaceae (Orchids)	Mycorrhizal fungi	Provides carbon and nutrients for germination; aids in nutrient absorption.	Habitat and nutrients from the adult orchid.
Zooxanthellae	Hard corals	Photosynthetic algae (Zooxanthellae)	Receive oxygen and organic compounds from photosynthesis.	Protected environment and compounds for photosynthesis.



Anatomy of a Coral Polyp
tentacles with
nematocysts
(stinging cells)
mouth
zooxanthellae
living tissue
linking polyps
nematocyst
gastrovascular cavity
(digestive sac)
skeleton
limestone calice
© 1999 Encyclopædia Britannica, Inc.

C4.1.13—Resource competition between endemic and invasive species:

Endemic Species - An endemic species is one that is found naturally in only one geographic area and nowhere else in the world.

Invasive Species - An invasive species is a non-native organism that spreads rapidly in a new area, often causing harm to the environment, economy, or human health.

European Starlings in North America

- European Starlings were introduced in the late 19th century when 100 birds were released in Central Park, New York, by a group aiming to establish all the birds mentioned in Shakespeare's works in the United States.

- The species quickly adapted to various climates across North America and their population burgeoned to millions.

Ecological Impact:

- Starlings are aggressive competitors for nesting sites. They often displace native birds such as bluebirds, martins, and woodpeckers by taking over their nesting cavities.

- They form large flocks that can disrupt ecosystems by outcompeting native bird species for food resources, including insects and fruit.

C4.1.14—Tests for interspecific competition:

Laboratory Experiments: In a controlled lab setting, researchers can grow two species of plants in the same soil medium to assess competition for nutrients. By varying the density of one species and observing the growth response of the other, they can infer competitive interactions.

Field Observations by Random Sampling: Scientists may use random quadrats in a natural meadow to record the presence and growth of two flower species that potentially compete for pollinators. By analyzing the patterns of co-occurrence and the abundance of flowers, they can suggest a competitive relationship.

Field Manipulation by Removal of One Species: Ecologists might selectively remove an invasive shrub from a forest understory to see if the native shrub species, which is currently sparse, will recover. The recovery and spread of the native shrub after the removal would indicate that interspecific competition was likely limiting its success.

C4.1.17—Top-down and bottom-up control of populations in communities:

- In top-down control, predators control the population of prey,
- In bottom-up control, the availability of resources controls the population.
- The dominant control type in a community depends on various factors, including the specific species and environmental conditions.

Factor	**Top-Down Control Likely to be Dominant**	**Bottom-Up Control Likely to be Dominant**
Resource Availability	Less significant when resources are abundant; predators control species abundance.	Most significant when resources are scarce; availability of nutrients controls.
Ecosystem Complexity	More evident in complex ecosystems with diverse interactions and multiple trophic levels.	More evident in simpler ecosystems with fewer trophic levels.
Human Impacts	Reduction in top predators due to human activity can lessen top-down control.	Human activities that alter resource availability can increase bottom-up control.
Temporal and Spatial Factors	Seasonal or spatial changes can temporarily shift dominance to predators.	Seasonal or spatial variation in resource availability can shift control.

C4.1.16—Predator–prey relationships as an example of density-dependent control of animal populations:

The reintroduction of wolves to Yellowstone serves as an example of density-dependent population control through the following points:

- **Increased Predation**: Higher elk densities make them easier prey for wolves, leading to higher predation rates.
- **Wolf Population Growth**: More elk means more food for wolves, potentially increasing the wolf population, which in turn increases predation pressure on elk.
- **Elk Behavior Changes**: As elk numbers rise, competition and vulnerability increase, leading to changes in their behavior and habitat use, which affect their survival rates.
- **Resource Competition Among Elk:** Larger elk populations face greater food competition, resulting in weaker individuals that are more prone to predation.
- **Predator-Prey Feedback Loop**: A larger elk population can support more wolves, but as wolves control elk numbers, the wolf population may also eventually decline, allowing elk numbers to recover, which illustrates a density-dependent regulation cycle.

Links to Videos:
Wolves in Yellowstone National Park
Other Effects of Wolves on the Yellowstone National Park Ecosystem

D4.2.1—Sustainability as a Property of Natural Ecosystems

Ecosystem Sustainability:

- Definition: The ability of an ecosystem to maintain ecological processes, functions, biodiversity, and productivity over time.
- Long-term Continuity Examples:
    - Forests: Ancient forests, such as the Amazon rainforest or old-growth forests in the Pacific Northwest, demonstrate sustainability through their complex biodiversity and resilience to natural disturbances.
    - Deserts: Deserts like the Sahara have persisted for millions of years supporting unique ecosystems.

D4.2.2—Requirements for Sustainability in Ecosystems

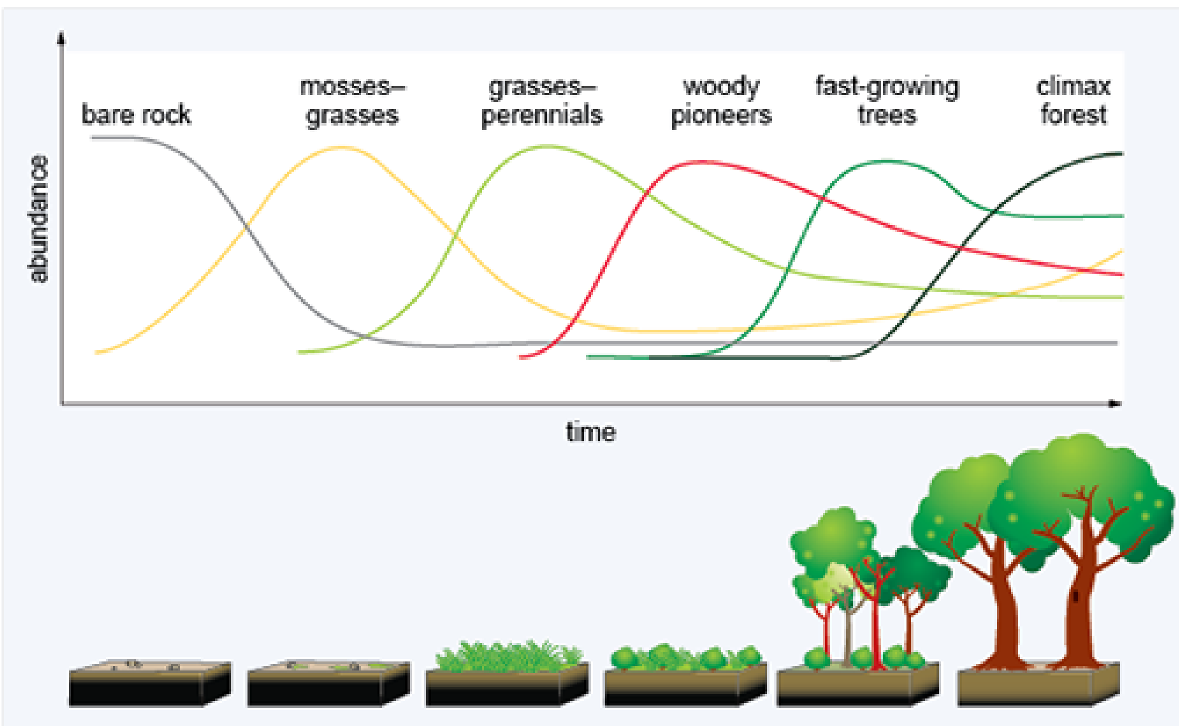
Key Requirements:

- Energy Supply: The continuous input of energy (primarily from the sun) drives ecological processes like photosynthesis.
- Nutrient Recycling: Efficient recycling of nutrients, such as carbon, nitrogen, and phosphorus, is crucial for ecosystem health.
- Genetic Diversity: A diverse gene pool in a population enhances resilience to environmental changes and diseases.
- Climatic Stability: Ecosystems require certain climatic conditions to be maintained within specific tolerance levels for long-term sustainability.

D4.2.12 (HL) — Ecological Succession and Its Causes

Succession Triggers:

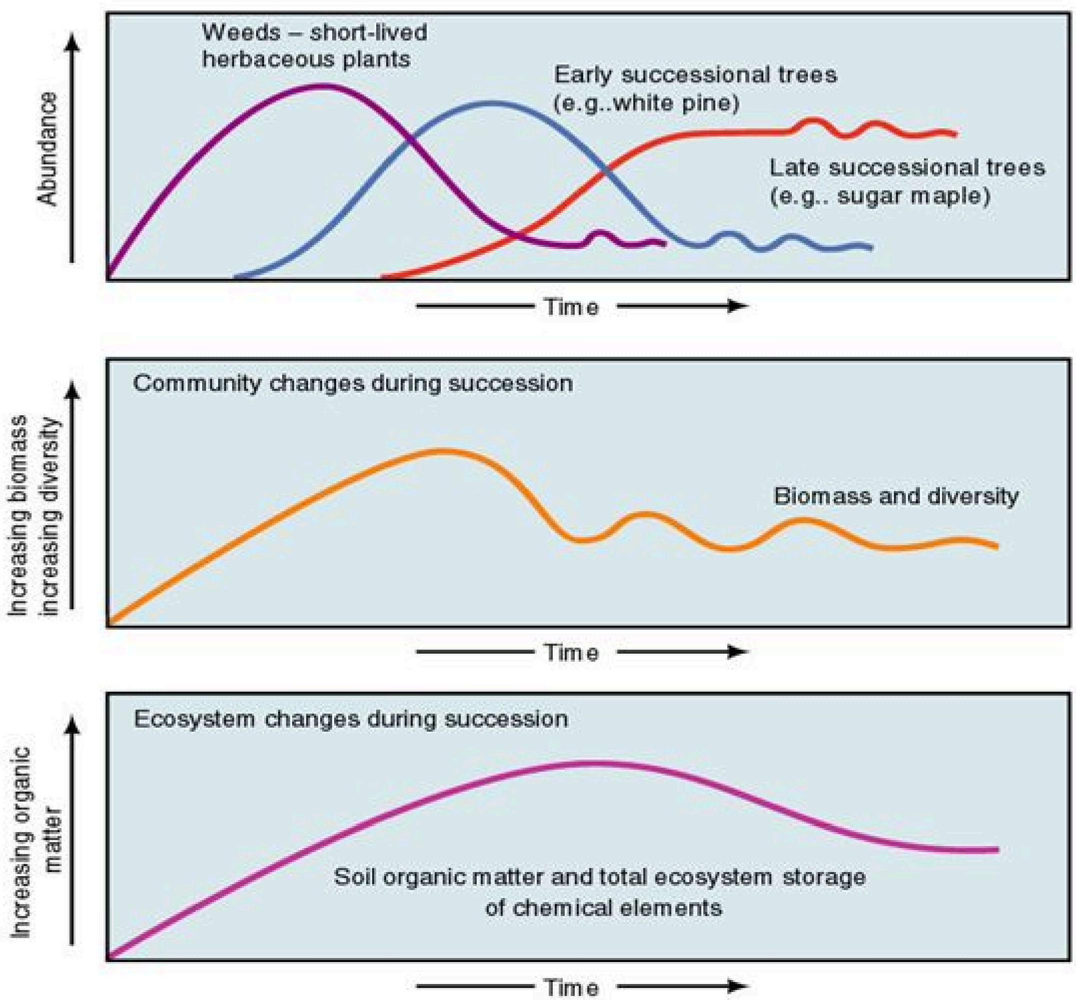
- Abiotic Factors: Changes in climate, natural disasters like wildfires or volcanic eruptions, and human-induced changes such as pollution or deforestation.
- Biotic Factors: Introduction or removal of species, changes in species interactions, disease outbreaks.

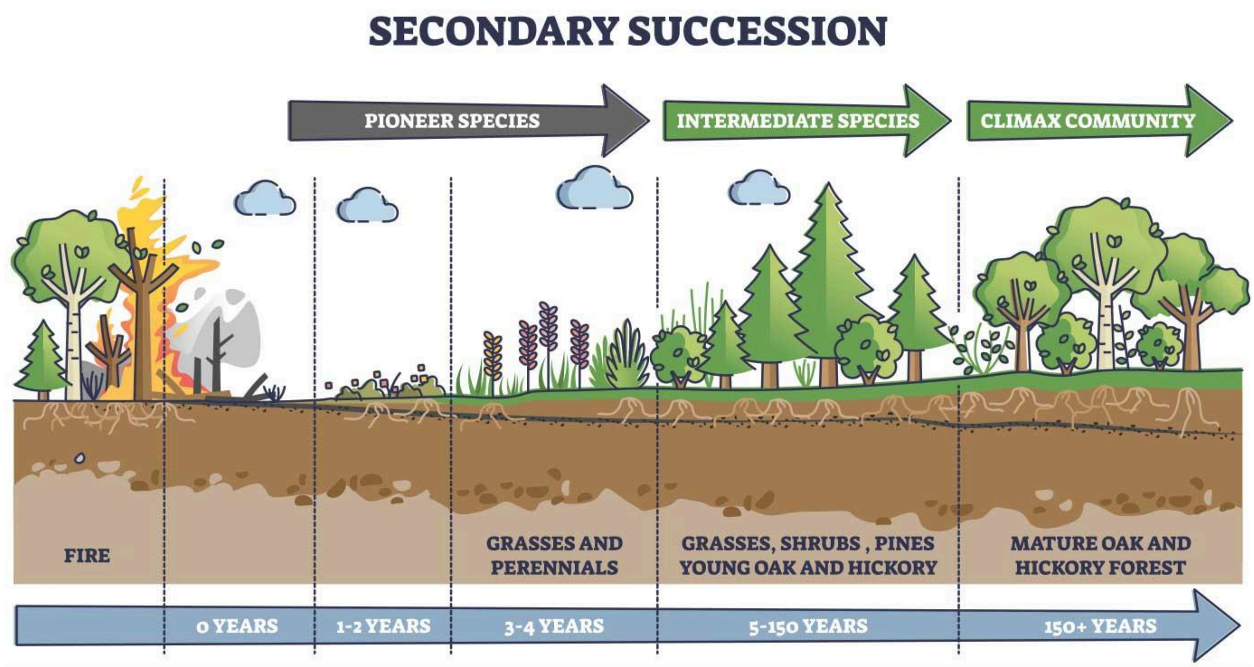


D4.2.13 (HL) — Changes During Primary Succession

Terrestrial Example:

- Early Stages: Lichens and mosses colonize bare rock, beginning soil formation. These are often called pioneer species.
- Intermediate Stages: Grasses and herbaceous plants increase soil depth, leading to increased primary production.
- Later Stages: Shrubs and then trees establish, increasing species diversity, complexity of food webs, and efficiency of nutrient cycling. This creates stable ecosystems as the diversity increases.
- Remember that species are competing for resources and against each other.


Weeds – short-lived herbaceous plants
Early successional trees (e.g..white pine)
Late successional trees (e.g.. sugar maple)
Abundance
Time
Community changes during succession
Increasing biomass increasing diversity
Biomass and diversity
Time
Ecosystem changes during succession
Increasing organic matter
Soil organic matter and total ecosystem storage of chemical elements
Time

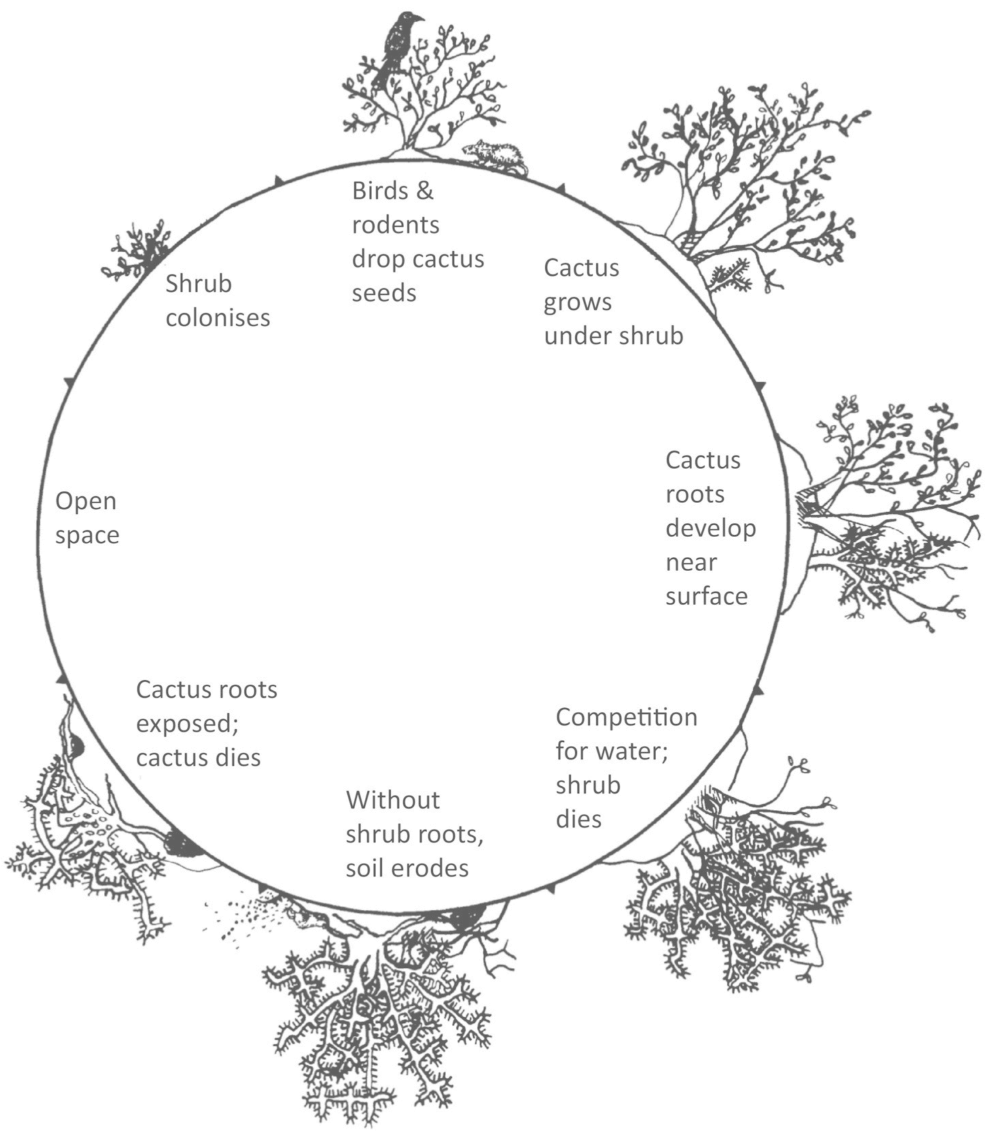


- Key ideas - the soil is still present (so no pioneer species needed)
- This usually means the process happens faster.

D4.2.14 (HL) — Cyclical Succession in Ecosystems

Understanding Cyclical Succession:

- Concept: In some ecosystems, there is no final climax community but rather a continuous cycle of different communities.
- It could correspond to weather cycles or other factors that favor one species to be dominant for a given time and drastically change in the next cycle.
- Example



A4.1 Evolution Topics

A4.1.1 Evolution Definition

- Concept: Evolution is the change in the heritable characteristics of a population over generations.

- Key Insight: Changes that are not genetic (e.g., muscle gained from exercise) are not passed down and thus do not constitute evolution.

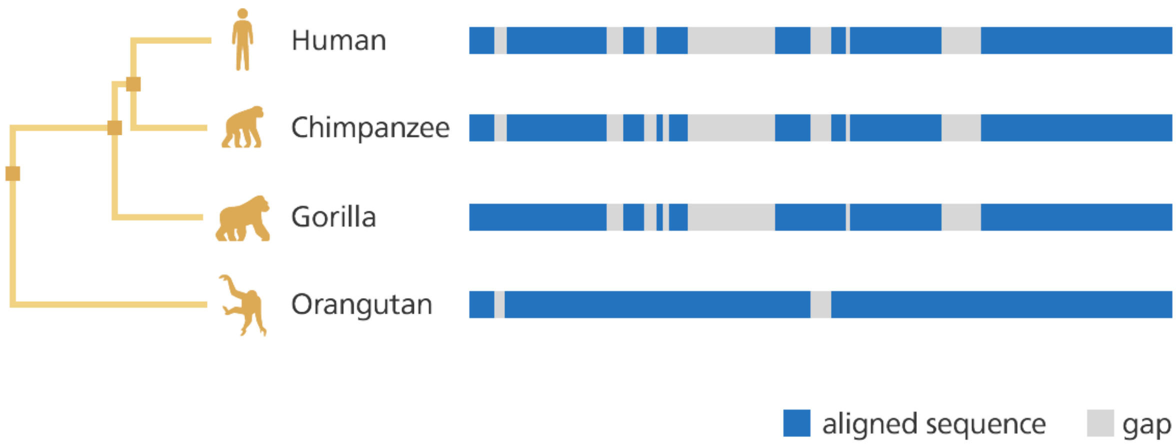
A4.1.2 Evidence from Molecular Biology

- DNA/RNA and Proteins:
    - Comparison of base sequences in DNA or RNA and amino acid sequences in proteins across different species.

    - Common Ancestry: Similarities in these sequences suggest a shared evolutionary history.

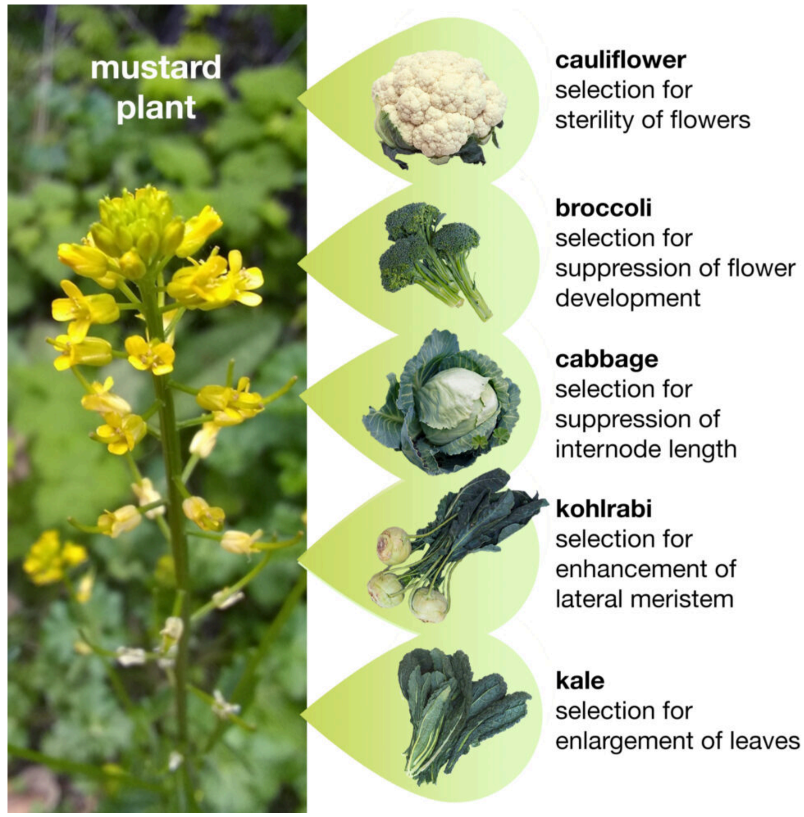
Baleen	GGATGCCCCCC	C	AATCCAG
Tooth	GGATGCCCTCC		AATCCAG
Hippo	GGATGCCCCCC		AATCCAG
Cow	GGATGCCCCAC		AACCCAG
Pig	GGATGCCCCCC		AACTCAG
Camel	GGATGCCCACC		AATCCAG
Dog	GGATGCCCCAC		AATCCAG
Human	GAATGCCCCAC		AACCCAG
Mouse	GACTGAATCAG		AATTCAC
Rat	GACTGAATCAG		AATTCAC

- Significance: Molecular evidence is a powerful tool for tracing and confirming evolutionary relationships.

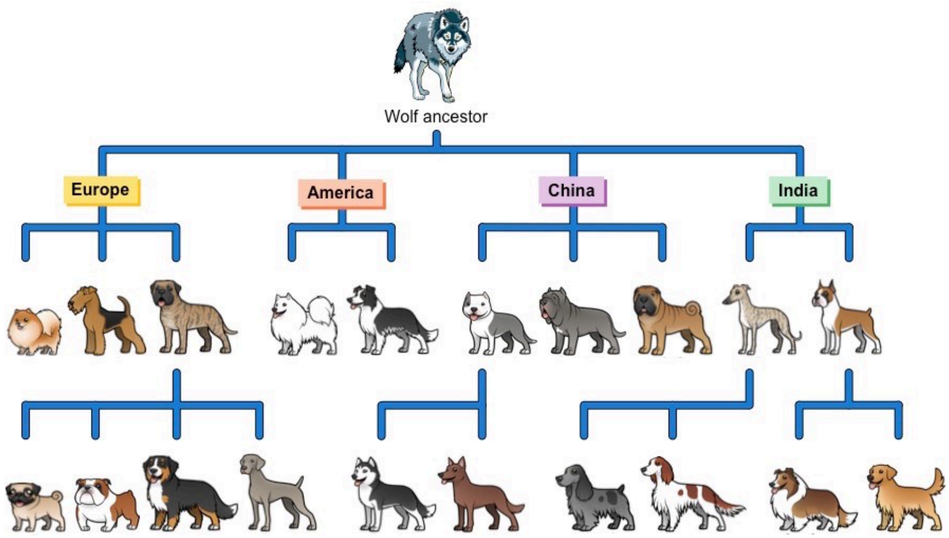


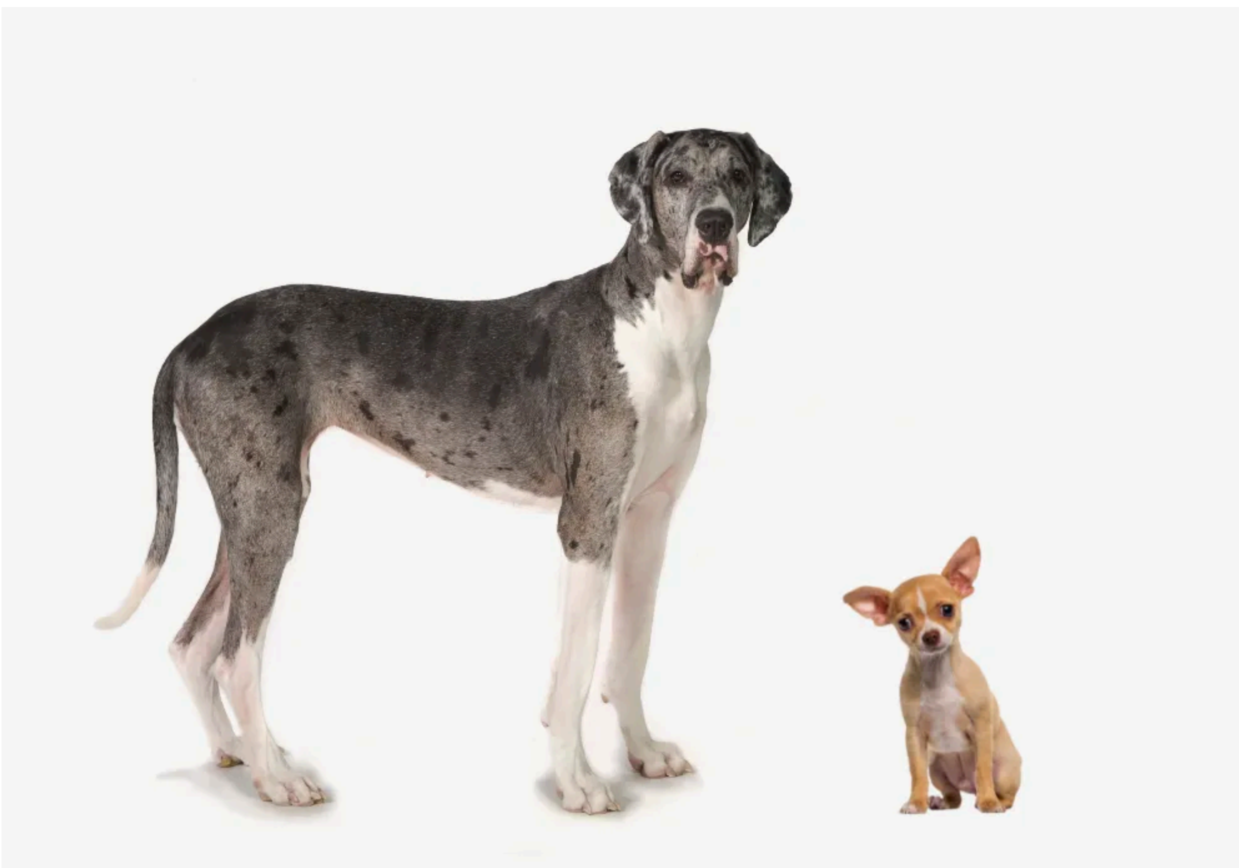
A4.1.3 Selective Breeding as Evidence

- an evolutionary process in which humans consciously select for or against particular features in organisms – for example, by choosing which individuals to save seeds from or breed from one generation to the next.



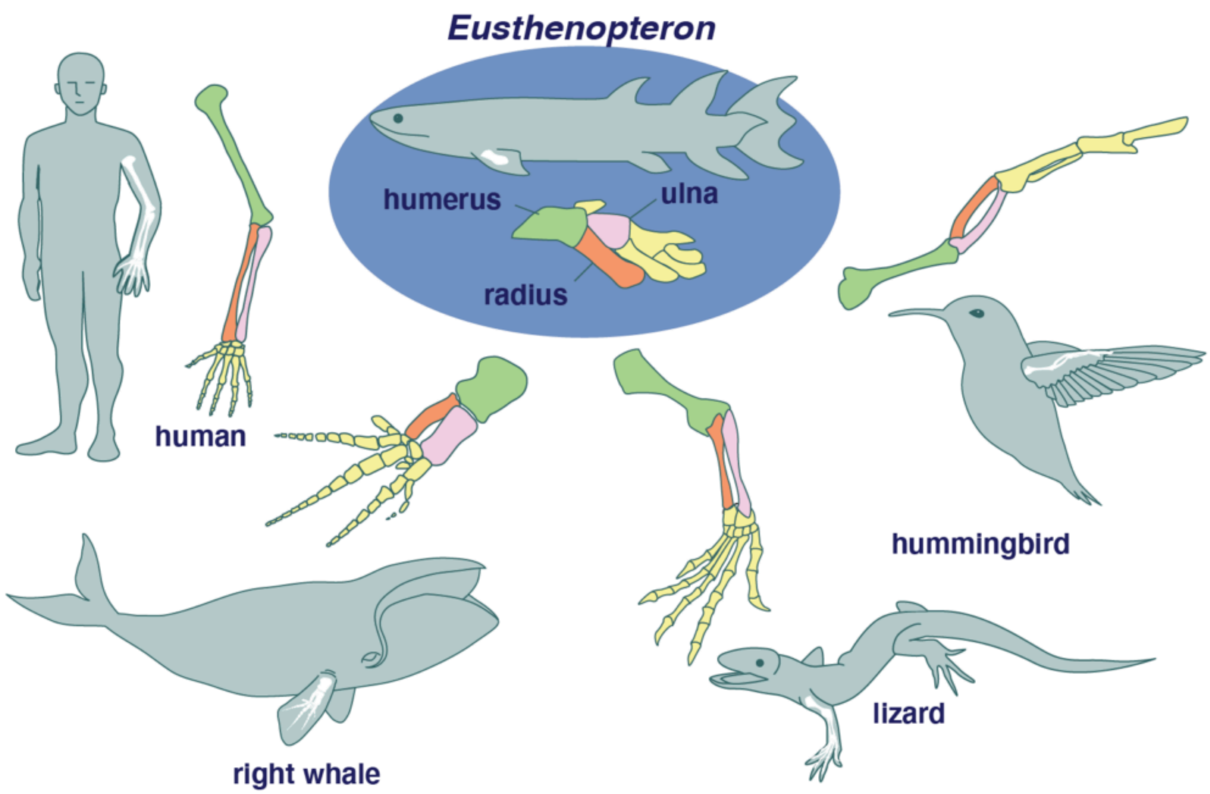
- Domestication and Variation:
  - Observing the variation between different breeds of domesticated animals and crop plants.
  - Rapid Evolutionary Changes: Differences between domesticated varieties and their wild ancestors showcase how quickly evolutionary changes can occur under artificial selection.
  - Humans select the changes. In a sense, humans are the “environment” in this situation.


Wolf ancestor
Europe
America
China
India



A4.1.4 Homologous Structures

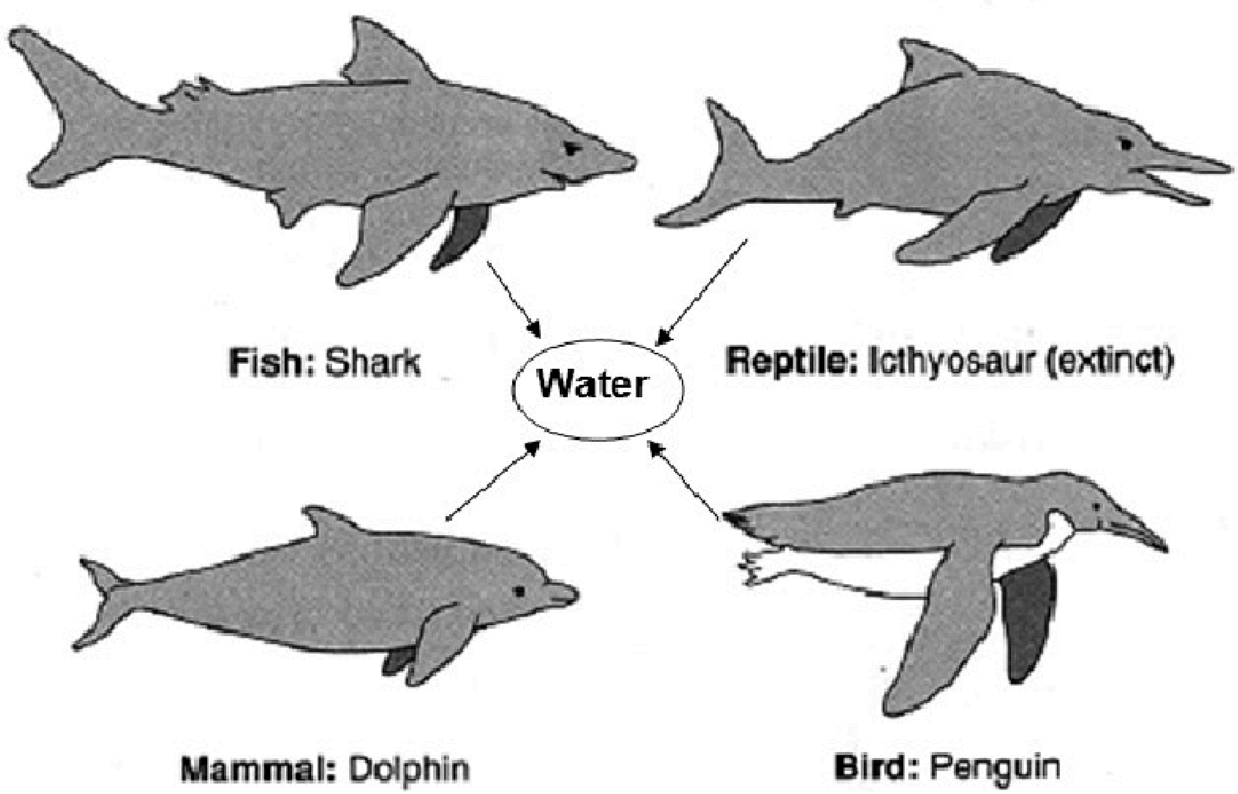
- Definition: Structures in different species that are similar due to common ancestry.
- Example: Pentadactyl Limbs
  - Shared structure among vertebrates (e.g., humans, whales, bats).
  - Variation in Function: Despite similar bone structure, these limbs perform different functions in different species, indicating a divergent evolutionary path from a common ancestor.



A4.1.5 Convergent Evolution

- Analogous Structures:
    - Structures in different species that have similar functions but evolved independently, indicating different evolutionary origins.
    - Example Requirement: Understand at least one example, such as the wings of birds and insects.

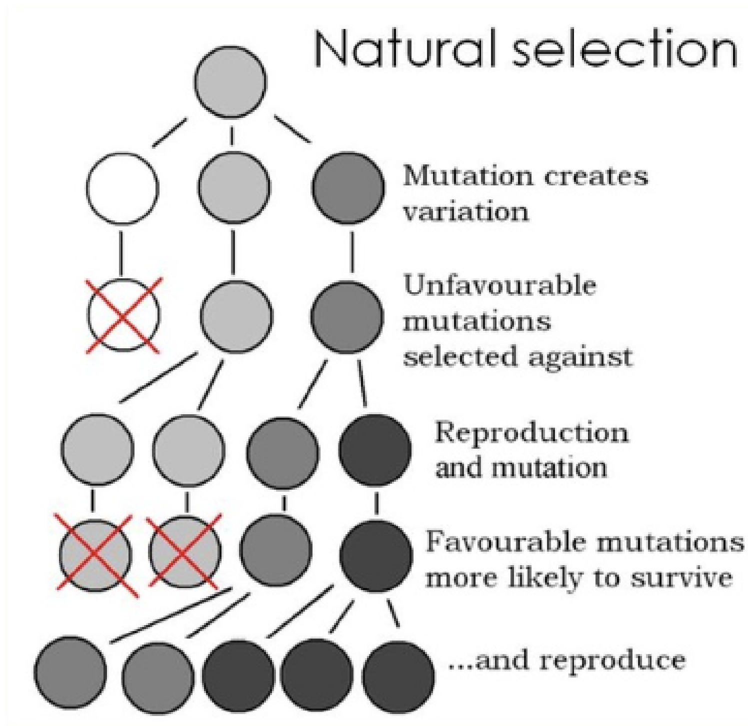
- Understanding Convergence:
    - Key Point: Similar environmental pressures can lead to the evolution of similar adaptations in unrelated species.
    - Distinction: Unlike homologous structures, analogous structures do not imply a common ancestor.



D4.1.1—Natural selection as the mechanism driving evolutionary change

- Natural selection operates continuously over billions of years: Natural selection is a fundamental process in evolution that operates constantly, generation after generation, for an extremely long time. It doesn't stop, and its effects accumulate over geological time scales.

- It results in the biodiversity of life on Earth: Natural selection is responsible for the incredible diversity of life forms on Earth. It shapes the traits and characteristics of organisms, leading to the adaptation of species to their specific environments. This process, when repeated over countless generations, leads to the variety of species we see today.



D4.1.2—Roles of mutation and sexual reproduction in generating the variation on which natural selection acts

- Mutation generates new alleles by introducing changes in DNA sequences: Mutations are random changes in the DNA sequence of an organism's genes. These changes can lead to the creation of new genetic variations (alleles) that were not present in the parental generation. Mutations are the ultimate source of genetic diversity in populations.

- Sexual reproduction generates new combinations of alleles through the shuffling of genetic material during meiosis and fertilization: Sexual reproduction involves the formation of offspring by the fusion of genetic material from two parents. During meiosis, genetic material is shuffled and recombined, resulting in unique combinations of alleles in the offspring. This recombination enhances genetic diversity within a population.

D4.1.3—Overproduction of offspring and competition for resources as factors that promote natural selection

- Overproduction of offspring: Many species produce more offspring than can survive and reproduce successfully. This overproduction leads to competition among the offspring for limited resources. Not all individuals will survive to reproduce, and this competition is a driving force behind natural selection, favoring individuals with advantageous traits.
- Competition for resources: Within a population, individuals must compete for essential resources like food, shelter, mates, and territory. Those individuals with traits that provide them with a competitive advantage in acquiring these resources are more likely to survive and reproduce, passing on their advantageous traits to the next generation.

- Examples of limiting resources: Limiting resources can vary depending on the species and its habitat. For example, food sources can be limited during periods of scarcity, nesting sites may be in high demand, access to water can be crucial for survival, sunlight is essential for photosynthesis in plants, and territory can provide safety and access to resources. The availability and competition for these resources play a significant role in natural selection by influencing which individuals are more successful in reproduction.

D4.1.4—Abiotic factors as selection pressures

- Abiotic factors include non-living environmental factors that can affect survival and reproduction: Abiotic factors encompass all the non-living elements and conditions within an ecosystem that can influence the distribution and abundance of species. These factors can have direct or indirect effects on an organism's ability to survive and reproduce.

- Examples of density-independent factors: Density-independent factors are abiotic factors that affect populations regardless of their size or density. Examples include:

    - High or low temperatures: Extreme temperatures can stress organisms, affecting their metabolism, behavior, and ability to find food or water. This stress can lead to natural selection because individuals with traits that better enable them to tolerate or adapt to temperature extremes are more likely to survive and reproduce. Over time, the population may evolve to have traits that make them better suited to the prevailing temperature conditions.

    - Natural disasters (e.g., wildfires, floods): Sudden, catastrophic events like wildfires and floods can destroy habitats and directly impact populations by causing mass mortality. Natural selection comes into play as individuals with traits that increase their chances of surviving or escaping these disasters, such as better mobility or fire-resistant features, are more likely to pass on their genes to the next generation. Over time, the population may evolve to exhibit traits that enhance survival in the face of such disasters.

    - Droughts: Prolonged periods of water scarcity can limit access to a critical resource for many species. In this case, natural selection favors individuals with adaptations that help them conserve water or extract moisture from their environment more efficiently. Traits such as water-retaining structures, efficient water use, or behaviors that minimize water loss can provide a survival advantage in drought-prone environments. As a result, these traits become more prevalent in the population over generations due to natural selection.

- Hurricanes: Violent storms like hurricanes can disrupt ecosystems and displace or harm organisms in their path. Natural selection occurs as individuals with traits that enhance their ability to withstand or recover from such disturbances, like sturdy structures or behaviors that allow them to find shelter quickly, are more likely to survive. These survivors go on to reproduce and pass on their advantageous traits to their offspring. Over time, the population may evolve to exhibit traits that improve resilience in the face of hurricane events.

D4.1.5—Differences between individuals in adaptation, survival, and reproduction as the basis for natural selection

- Intraspecific competition: Intraspecific competition refers to competition among individuals of the same species. When resources are limited, individuals within a population must compete for access to these resources, including food, mates, and territory. This competition can be intense and shapes the distribution of traits within a population.

- Fitness: Fitness is a measure of an organism's ability to survive and reproduce successfully in its specific environment. Individuals with traits that enhance their fitness are better suited to their surroundings and are more likely to leave offspring. Natural selection acts to increase the prevalence of these advantageous traits over time.

- Natural selection favors traits that enhance an organism's fitness, leading to their increased representation in future generations: Over successive generations, traits that confer advantages in terms of survival and reproduction become more common within a population. This process is driven by the differential reproductive success of individuals with those traits.

D4.1.6—Requirement that traits are heritable for evolutionary change to occur

- Heritability: Heritability refers to the extent to which traits are passed from one generation to the next through genetic inheritance. Traits that have a high heritability are more likely to be subject to evolutionary change through natural selection.

- Characteristics acquired during an individual's lifetime due to environmental factors are not heritable because they are not encoded in the base sequence of genes: Traits acquired during an organism's lifetime through experiences or environmental factors are not passed on to offspring through genetic inheritance. These acquired characteristics do not contribute to the genetic diversity of a population.

D4.1.7—Sexual selection as a selection pressure in animal species

- Sexual selection: Sexual selection is a specific form of natural selection where differences in physical and behavioral traits between males and females of a species affect an individual's success in attracting a mate. It can lead to the evolution of elaborate and sometimes costly traits that enhance an individual's reproductive success.

- Examples: Sexual selection can be observed in various animal species. Examples include:
    - The evolution of the elaborate plumage in male birds of paradise: Male birds of paradise have evolved intricate and vibrant plumage to attract females during courtship displays.
    - The development of colorful and showy displays or behaviors in males to attract females: Many species exhibit extravagant courtship rituals and displays, such as the peacock's tail feathers or the dances of some insects, to compete for mates.

D4.1.8—Modelling of sexual and natural selection based on experimental control of selection pressures - "Students should interpret data from John Endler’s experiments with guppies.

- John Endler's experiments with guppies: John Endler conducted groundbreaking experiments involving guppy populations in Trinidadian streams. His research focused on the interplay between sexual and natural selection, which became a classic example in evolutionary biology.

- Interpreting data from the experiments: Endler's experiments involved manipulating the presence of predators in different sections of streams, affecting the level of natural selection on guppies. He observed how guppy populations in high-predation and low-predation environments evolved distinct traits over time. These traits included coloration, size, and behavior.

- Significance: Endler's research provides valuable insights into the mechanisms of evolution, particularly the role of predation as a selection pressure and how it interacts with sexual selection. Students can interpret his data to understand how different selection pressures can lead to the evolution of specific traits in a population. For example, guppies in high-predation areas tended to have drabber colors and larger body sizes, which provided a survival advantage by making them less visible to predators.

- Modeling of sexual and natural selection: Endler's experiments illustrate the complex relationship between natural selection (predation) and sexual selection (mate choice). Guppy traits were shaped not only by the need to avoid predators but also by the preferences of mates for certain traits, such as bright coloration. This balance between survival and reproduction highlights the dynamic nature of evolution.

D4.1.9 (HL)—Concept of the Gene Pool

- Definition: A gene pool consists of all the genes and their different alleles present in a population.

- Key Points:
  - Represents genetic diversity within a population.
  - Includes every allele at every gene locus in all individuals of the population.

D4.1.10 (HL)—Allele Frequencies of Geographically Isolated Populations

- Explanation:
  - Allele frequencies can vary in populations that are geographically isolated.
  - Isolation can lead to genetic differences due to limited gene flow.
  - Limited gene flow can lead to speciation and the formation of a new species.

D4.1.11 (HL)—Changes in Allele Frequency and Natural Selection

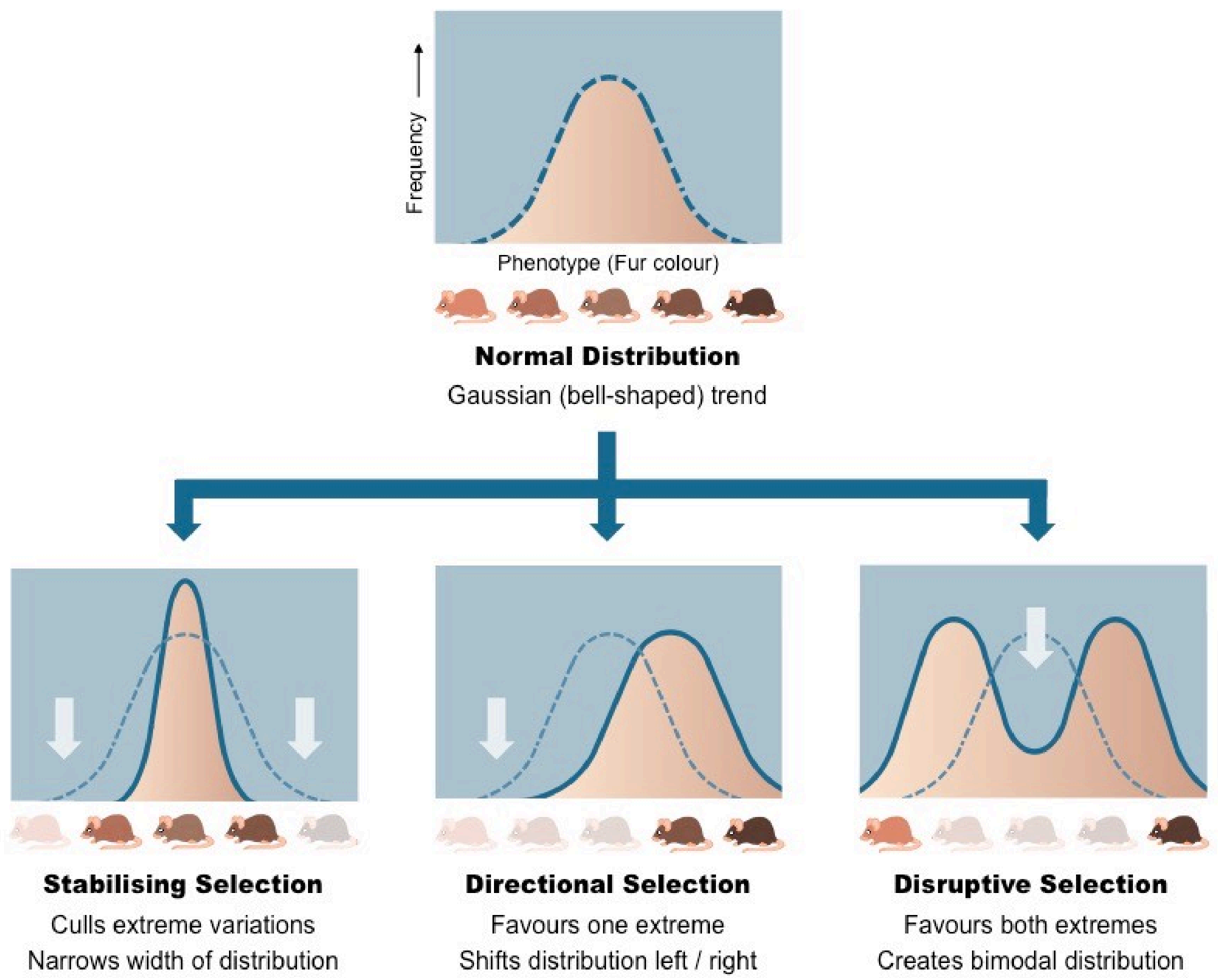
- Natural Selection:
  - Darwin's theory of evolution; better-suited traits for the environment are passed on.
  - Neo-Darwinism integrates genetics with natural selection.

- Impact on Gene Pool:
  - Allele frequencies change in response to natural selection. Some alleles become more common in certain populations.

  - Heritable traits that aid survival and reproduction become more common.

D4.1.12 (HL)—Types of Selection

Directional Selection: Favors one extreme of a trait.
Disruptive Selection: Favors both extremes of a trait.
Stabilizing Selection: Favors the average form of a trait.
Common Outcome: All result in a change in allele frequency.



D4.1.13 (HL)—Hardy–Weinberg Equation

- Equation: $p^2 + 2pq + q^2 = 1$
- Concepts:
  - p and q represent the frequency of two alleles.
  - $p + q = 1$ (sum of allele frequencies is always 1).
- Application: Used to calculate allele or phenotypic frequencies.

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

Where:

p = the frequency of allele A

q = the frequency of allele a

p^2 = the frequency of individual AA

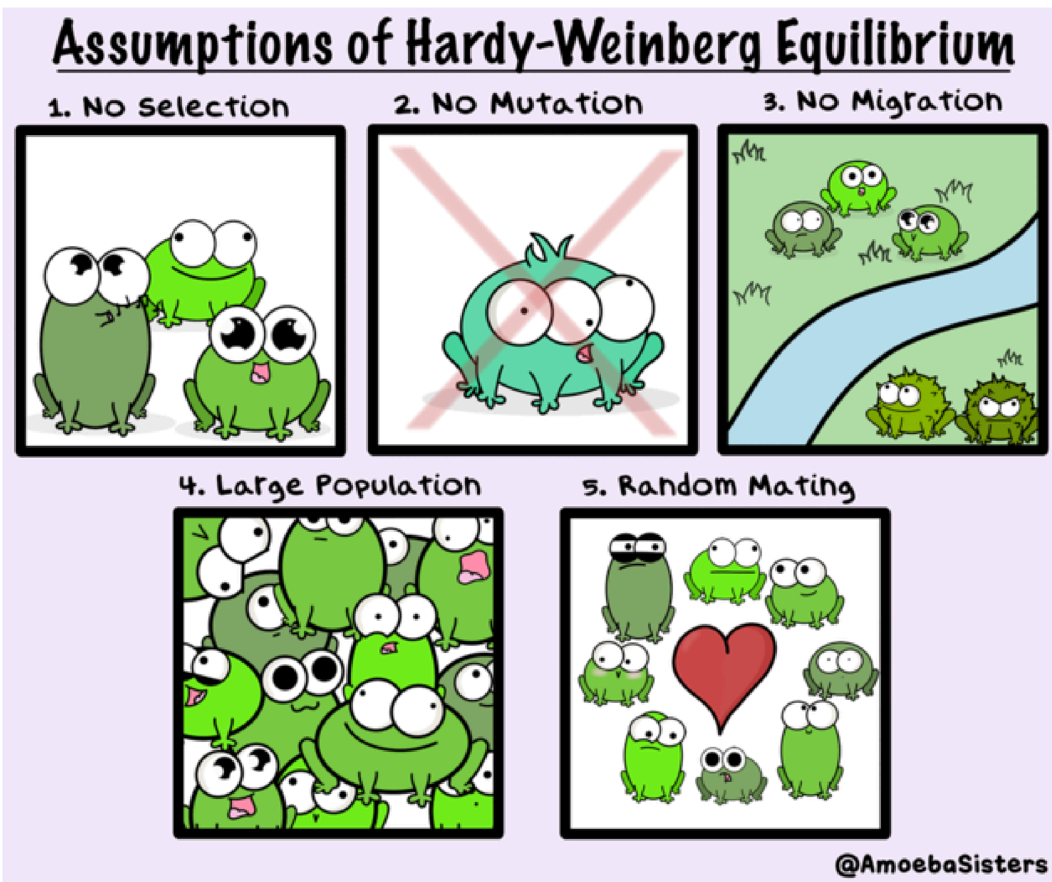
q^2 = the frequency of individual aa

$2pq$ = the frequency of individual Aa

D4.1.14 (HL)—Hardy–Weinberg Equilibrium Conditions

- Equilibrium Conditions:
    - Large population size.
    - Random mating.
    - No mutation.
    - No migration.
    - No natural selection

- Significance:
    - Deviation from the Hardy-Weinberg equation indicates a violation of these conditions.



A4.1.6—Speciation by Splitting of Pre-existing Species

- Concept Expansion:
  - Mechanism: Occurs when a species diverges into two or more distinct species.
  - Microevolution vs. Macroevolution: Microevolutionary changes (like small genetic mutations) over long periods lead to macroevolutionary outcomes, such as speciation.

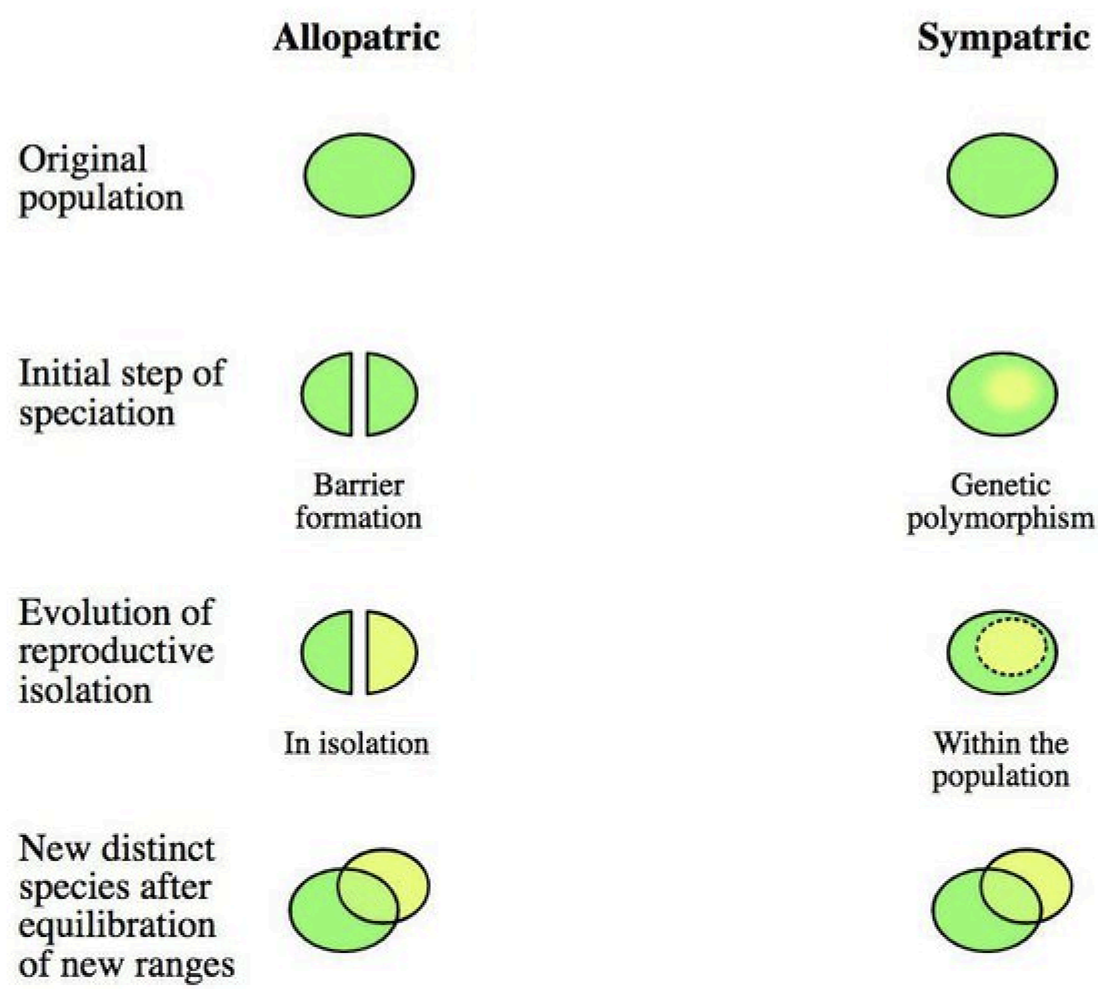
- Importance in Evolution: Demonstrates the dynamic nature of species, leading to biodiversity over geological timescales.

A4.1.7—Roles of Reproductive Isolation and Differential Selection in Speciation

- Reproductive Isolation:
  - Types: Geographic, behavioral, temporal, mechanical, and gametic isolation.
  - Result: Prevents gene flow between populations, leading to speciation.
- Differential Selection:
  - Process: Different environmental pressures result in different adaptations.
  - Outcome: Populations evolve to suit their specific environments, eventually becoming distinct species.

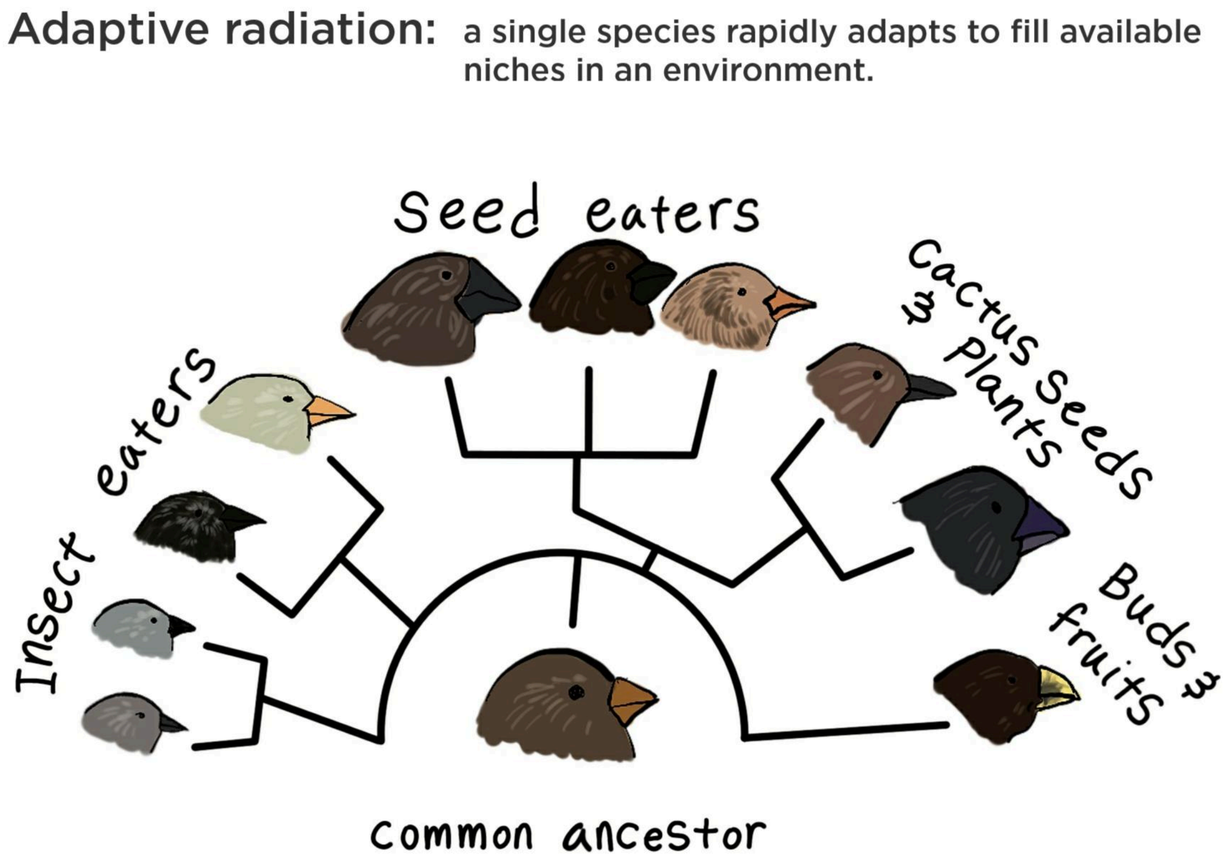
A4.1.8—Sympatric and Allopatric Speciation

- Allopatric Speciation:
    - Causes: Geographic barriers like mountains, rivers, or human activities.
    - Evolutionary Pathways: Geographic isolation leads to independent evolution.
- Sympatric Speciation:
    - Causes: Genetic mutations, changes in habitat preference, or behavioral changes.
    - Unique Aspects: Species evolve from a common ancestor without physical barriers.



A4.1.9—Adaptive Radiation

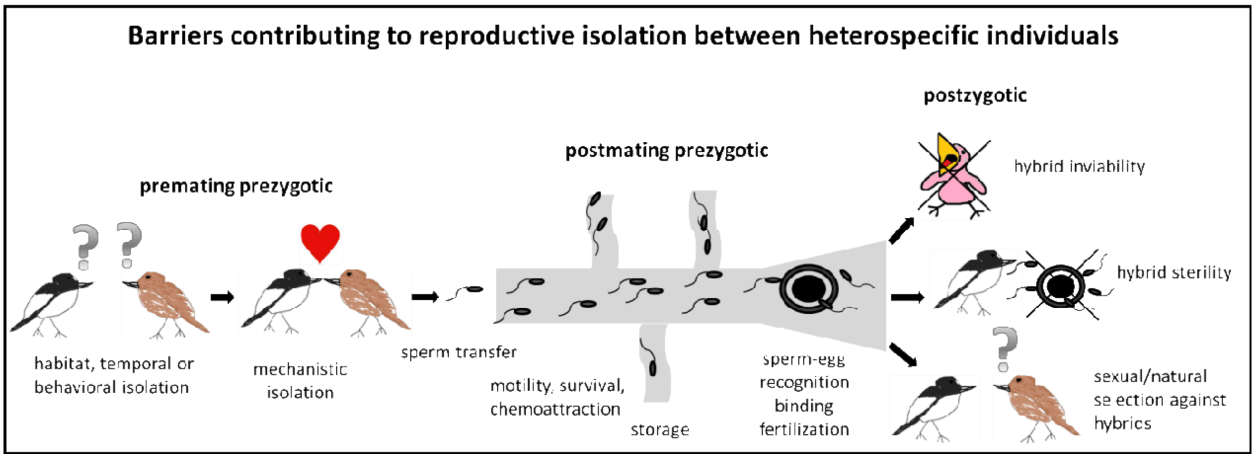
- Detailed Explanation:
    - Trigger: Often follows mass extinctions or colonization of new environments.
    - Process: A single species evolves into multiple species, each adapted to a specific ecological niche.
    - Examples: Darwin's finches, cichlid fish in African lakes.



A4.1.10—Barriers to Hybridization

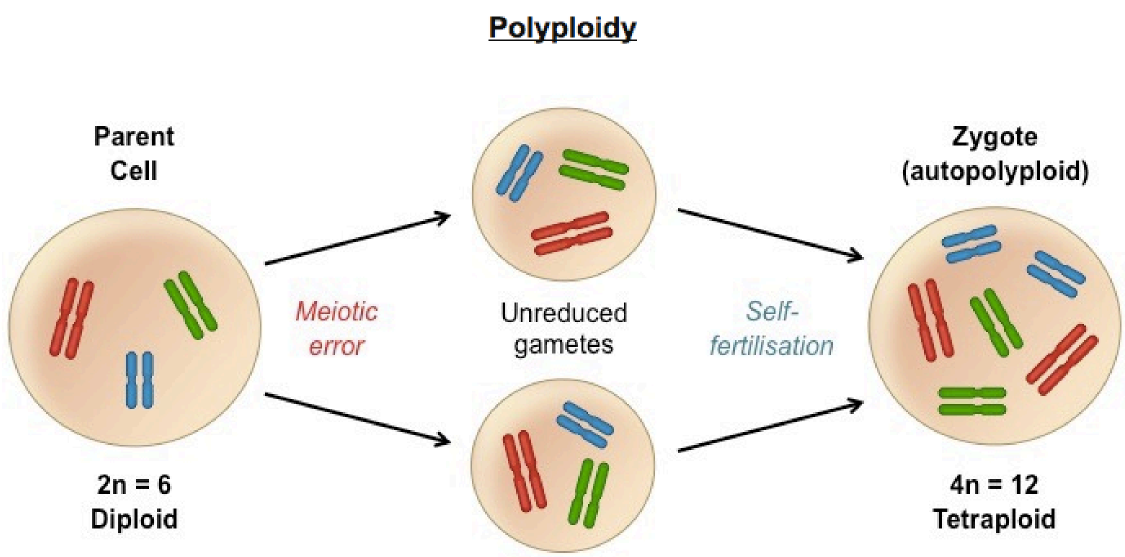
- Expanded Explanation:
    - Prezygotic Barriers: Prevent mating or fertilization (e.g., different mating rituals, incompatible reproductive organs).

    - Postzygotic Barriers: After fertilization, hybrids may be inviable or sterile.
- Hybrid Sterility: Hybrids like mules can't reproduce, preventing gene flow between parent species.



A4.1.11—Abrupt Speciation in Plants

- Polyploidy:
  - Definition: The possession of more than two complete sets of chromosomes.
  - Significance in Plants: A common mechanism for rapid speciation, especially in plants.
- Hybridization in Plants:
  - Process: Cross-breeding of closely related species.
  - Result: Can lead to new species that are reproductively isolated from the parent species.



A3.1.4—Biological Species Concept

- In-depth Understanding:
  - Limitations: Does not apply well to asexual organisms, fossils, or species that can hybridize.
  - Alternative Definitions: Morphological, ecological, and phylogenetic species concepts offer different perspectives.

A3.1.5—Difficulties in Distinguishing Species

- Concept Clarification:
    - Speciation as a Continuum: Evolutionary changes accumulate gradually, making it challenging to pinpoint when exactly a new species forms.
    - Interbreeding Populations: During the speciation process, there might still be gene flow between diverging populations, complicating the distinction.
    - Arbitrary Decisions: Scientists often make subjective decisions based on genetic, morphological, or ecological differences to classify distinct species.