TOPIC 5: ON THE WILD SIDE

For the Edexcel Biology A Level (SNAB)

TOPICS COVERED

- Ecosystems and Species Distribution
- Succession
- Chloroplasts and the Reactions of Photosynthesis
- Energy Transfer and Feeding Relationships
- Climate Change: Evidence, Processes and Consequences
- Mathematical Modelling
- Carbon Cycle and Sustainability
- Adaptation and Speciation including Genomic Evidence for Evolution

Ecosystems

Key Terminology

Term	Definition
Biosphere	The part of the Earth and its atmosphere inhabited by living organisms
Abiotic Factors	Non-living physical and chemical factors of an ecosystem
Biotic Factors	Factors determined by living or once-living organisms
Ecosystem	All the communities, living organisms and environmental factors in a particular area. These factors are interacting and interdependent, making up a self-contained system which is self-supporting in terms of energy flow
Community	All the organisms of all the species living in a habitat
Population	All the organisms of a species living in a habitat
Habitat	The place with a distinct set of conditions where an organism lives.
Edaphic	Factors connected with the soil composition
Succession	A series of progressive changes in the composition of an ecological community over time

Species Distribution

The abundance and distribution of organisms in a habitat are controlled by complex interaction of biotic and abiotic factors. Biotic factors are usually density dependent, whilst abiotic factors are physical or chemical. Species survive in a habitat due to the adaptations they possess which enable them to cope with the factors in their niche.

Biotic Factors	Abiotic Factors
• Competition for resources such as water, light and space – can be inter or intraspecific • Grazing, Predation or Disease • Parasitism – one species benefits to the detriment of another • Mutualism – both species benefit • Vegetation • Anthropogenic – arising from human activity	• Solar Energy Input – affected by latitude, season, clouds etc and affects germination and photosynthesis • Climate – rainfall, wind and temperature • Topography – altitude, slope and aspect • Oxygen concentrations • Edaphic factors – soil composition, pH, mineral ions • Pollution • Catastrophe – earthquakes, floods, volcanic eruptions, fires

Succession is the process by which communities in a habitat change over time. **Primary succession** starts in newly formed habitats where there had never before been a community – e.g. bare rock left by a retreating glacier, rock created during a volcanic eruption, a new sand dune. Unless prevented, succession continues until a stable climax community is reached.

Colonisation	Pioneer species - lichin or algae - colonise bare rock. These are the only species which can cope with the extremes of temperature, lack of water or soil. The pioneers start to break up the rock surface, allowing organic material to accumulate with the beginnings of rock to form soil. Wind-blown moss spores start growing
Succession Continues	Mosses build up more organic matter which can hold water, leading to the development of soil which allows for small plant species to arrive, germinate and survive. As conditions improve, large plant species can colonise, outcompeting existing species to replace the existing community
Climax Community	Through several seral stages, the arriving organisms modify the environment, creating opportunities for other species to colonise. As succession continues, biodiversity increases The final seral stage is stable at the climax community, often a forest land dominated by trees. The climax community may vary in other biomes e.g. tundra or savannah

Secondary succession occurs where an existing community has been cleared. When plants start to grow in a cleared forest after a fire, or on the banks of a river, this is a sign of secondary succession. Adaptations of a pioneer species include rapid growth and abundant seed production. **Deflated succession** is when a community remains stable only because human activity prevents succession from running its course, in order to maintain high biodiversity. e.g. grazing.

Photosynthesis and Energy Transfer

Key Terminology and Equations

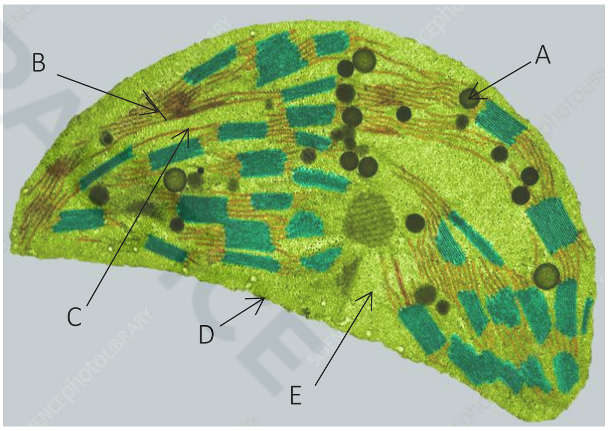
Term	Definition
Photosynthesis	The transfer of light energy to chemical potential energy in glucose using carbon dioxide and water by chlorophyll-containing organisms
Primary Productivity	The rate at which energy is incorporated into organic molecules in an ecosystem
Autotrophs	Producers; organisms which make their own organic compounds from inorganic ones
Photosystem	Clusters found in thylakoid membranes which contain photosynthetic pigments, surrounding a primary chlorophyll molecule
Photophosphorylation	The production of ATP using energy from light
Light Dependent Reactions	Using light and hydrogen from photolysis of water to produce NADPH, ATP and O_2
Light Independent Reactions	Using NADPH and ATP from the LDRs to reduce carbon dioxide to carbohydrates
ATP	The energy currency of the cell; a nucleotide of ribose, $3PO_4^{3-}$ and adenine, which is a chemical potential energy store
Carbon Fixation	The incorporation of inorganic CO_2 into organic molecules during the Calvin cycle
Herbivores	Primary consumers; heterotrophs which depend on autotrophs for organic matter
Carnivores	Secondary consumers which feed on primary consumers
Trophic Level	The position of a species in a food chain
Detritivores	Primary consumers that feed on dead organic material
Decomposers	Species of bacteria and fungi that feed on the dead remains of organisms
Gross Primary Productivity	The rate at which energy is incorporated into organic molecules in an ecosystem

$GPP\ (kJ\ m^{-2}\ y^{-1}) = \frac{\text{Energy (MJ)}}{\text{Area (m}^2) \times \text{Time (y)}}$	NPP = GPP – Plant Respiration	Energy Transfer in Consumption = Energy Stored × Efficiency

Photosynthesis

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6H_2O$ is the overall equation for photosynthesis. This is an endothermic reaction, as the energy of the products is higher than that of the reactants, meaning light energy is required. This light energy is transferred to chemical potential energy in glucose and other carbohydrate.

Photosynthesis occurs in the chloroplast – these structures are found in high abundance in palisade mesophyll cells.	
A	Starch Grain – stores product of photosynthesis
B	Granum – stack of thylakoids joined together
C	Thylakoid – structure whose membrane contains chlorophyll and is involved in the LDR, and whose internal thylakoid space contains enzymes for photolysis. Thylakoids together form a system of interconnected flattened sacs
D	Chloroplast Membrane – a double membrane; the inner membrane contains proteins which regulate movement of substances through the chloroplast, including products of GALP
E	Stroma – fluid which contains enzymes for the LIRs
The chloroplast also contains a DNA loop with genes for some of its proteins	

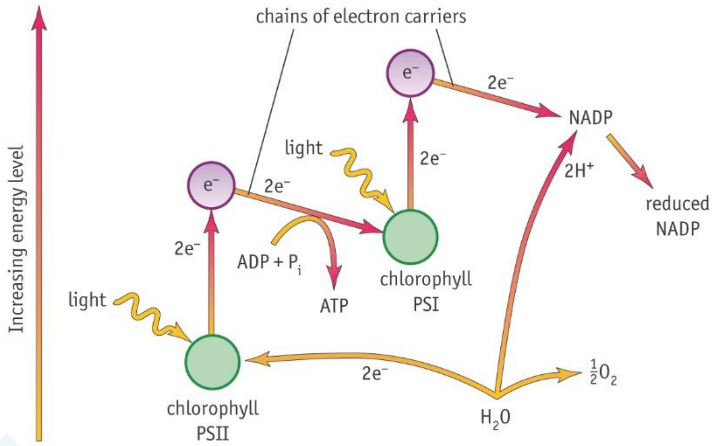


Photosynthesis is a series of reactions catalysed by enzymes, occurring in two stages: the light dependent reactions, which use light energy and hydrogen from photolysis of water to produce NADPH, ATP and O_2, and the light independent reaction, which use the NADPH and ATP to reduce CO_2 to carbohydrates. Although the overall equation suggests CO_2 and H_2O react, they never actually come into direct contact.

The Light-Dependent Reactions

In the thylakoid membranes, photosynthetic pigments are arranged in clusters around a primary chlorophyll molecule called photosystems. When light is absorbed by PSI and PSII chlorophyll, the LDRs can begin

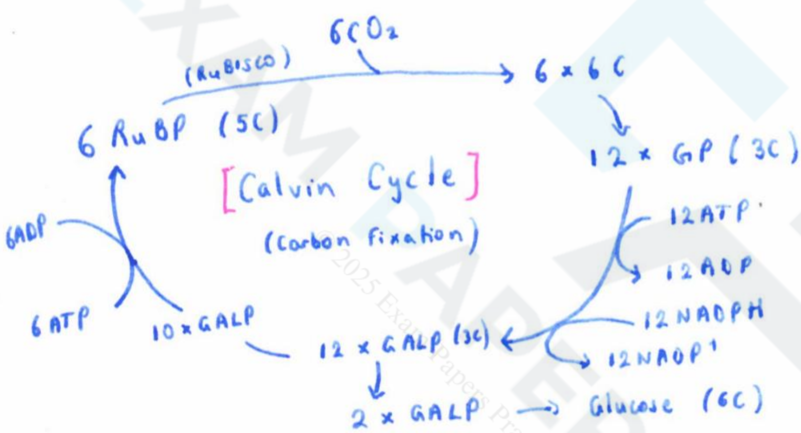
1. Light energy excites an electron pair in PSII to a higher energy level
2. The electrons pass along an electron transport chain though a series of electron carriers in the membranes. This movement by redox reactions releases energy which is used to synthesis ATP by photophosphorylation
3. 2 H_2O molecules bind to an enzyme at the reaction centre. Photolysis – splitting of water into O_2, $4e^-$ and $4H^+$ - occurs in the thylakoid space
4. The electrons from PSII replace those lost by PSI, which is also oxidised when light strikes the reaction centre
5. The electrons from PSI that pass along the electron transport chain combine with $NADP^+$ and H^+ from photolysis to form NADPH



The ATP and NADPH produced is then used in the light-independent reactions. Phosphorylation of ADP requires energy, here provided by light, and hydrolysis of ATP by ATPase provides an immediate energy supply for biological processes.

The Light-Independent Reactions

The LIRs occur in the stroma, with the reactions forming the Calvin cycle.



1. CO_2 combines with 5C RuBP; this reaction is catalysed by RUBISCO, the most abundant enzyme on earth

2. The unstable 6C intermediate breaks down into 3GP

3. 3C GP is reduced to 3C GALP, using 2H from NADPH and energy from ATP

4. 2 out of 12 GALP are used to make hexoses

5. 10 GALP is used to recreate 5C RuBP by arrangement, with $6P_i$ from ATP.

The glucose produced can be used in respiration, or can be polymerised to make either starch or cellulose. It can also be stored in sink cells after transport through the phloem as sucrose. Some of the glucose is converted into the variety of chemicals needed for plant growth, such as fats, amino acids and nucleic acids. For this, additional compounds such as nitrates and phosphates need to be taken in through the roots.

Energy Transfer and Feeding Relationships

Producers, or autotrophs, are organisms that can make their own organic compounds from inorganic compounds. Some of energy is transferred by ingestion by heterotrophs – organisms which depend on producers for food. Primary consumers eat plants, whilst secondary consumers feed on primary consumers, and so on. Feeding relationships can be shown in a food chain, and the position occupied by a species is its trophic level. In actuality, interconnected feeding relationships are illustrated on food webs.

Detritivores are primary consumers that feed on dead organic matter, whilst decomposers are bacteria and fungi which feed on remains of organisms. These species play an important role in recycling of organic matter.

The productivity of an ecosystem will depend on how much energy is captured by the producers and how much is transferred to higher trophic levels. Only 40% of energy reaching a leaf is absorbed by chlorophyll, and some energy is lost during photosynthesis. Limiting factors such as temperature and light intensity affect the rate of photosynthesis.

- The rate at which energy is incorporated into organic molecules is the gross primary productivity. GPP is expressed in kJ m^{-2} y^{-1}. The efficiency of photosynthesis is calculated by GPP divided by energy from light.
- Net primary productivity is calculated by GPP - plant respiration, as some energy is required by plants for growth. The NPP is available to the rest of the ecosystem.

Transfer of energy from producers to primary consumers is also inefficient, as energy is lost when not all food is eaten, some food remains undigested and much food consumed is used in respiration.

Transfer of energy from primary consumers to secondary consumers is more efficient, as protein can be more easily digested than cellulose. The energy entering a trophic level ends up transferred to the surroundings by respiration, transferred to the next trophic level or transferred to decomposers. This loss of energy is the reason why food chains often have only 4-5 trophic levels.

Climate Change

Key Terminology

Term	Definition
Climate Change	A change in global climate patterns, attributed largely to the increased levels of atmospheric greenhouse gases
Greenhouse Effect	The trapping of infrared radiation by greenhouse gases in the troposphere
Phenology	Study of seasonal events in the lives of organisms

Evidence for Climate Change and the Greenhouse Effect

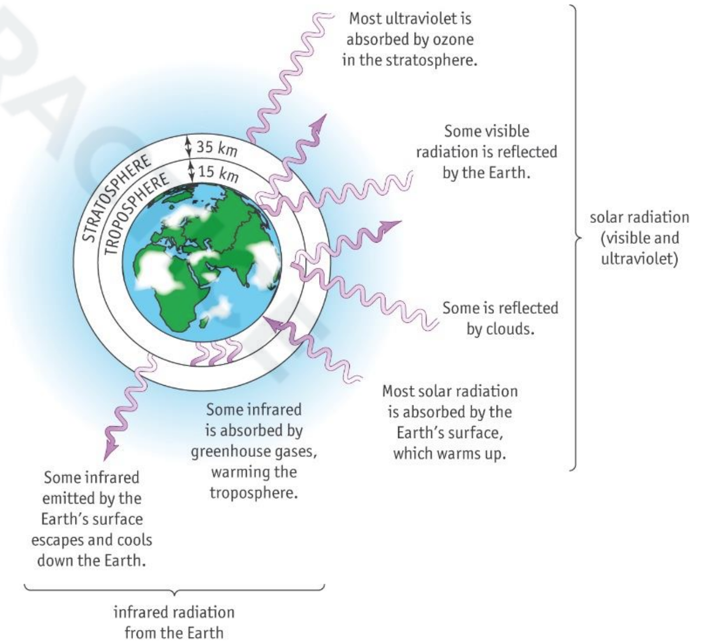
- Recent data shows evidence of changing rainfall patterns, with some increase in the number of wet days and also the average amount of rainfall on these days. In summer, there is a decrease in total average rainfall. These observations are consistent with climate model simulations of anthropogenic climate change
- Historical records for temperature date back to the 17th century
- *Dendrochronology – 800 Years Back*: Every year, trees produce a new layer of xylem vessels, with wide vessels in spring and narrow vessels in summer, producing characteristic tree rings. A core sample of a tree can be taken and analysed. A record of tree ring patterns can be built up from a known year, before matching other samples to patterns to build up a database which extends further back by cross-dating. If a ring is wider in a particular year, this indicates that conditions in that year are better for tree growth
- *Pollen – 20000 Years Back*: Pollen is produced in vast quantities by plants, and has a tough outer layer. It is resistant to enzyme and chemical decay so remains intact. Each plant has a unique type of pollen, meaning identification of species of origin is possible. Core samples are taken from peat bogs – acidic and anaerobic environments with low rate of decomposition – with an auger, and the age of a layer is determined by C14 dating. Samples are washed with corrosive chemicals and pollen is analysed. The species of plant has a known niche with particular environmental conditions – therefore the time when the layer was made had conditions which allowed its growth
- *Ice Cores – 400000 Years Back*: Ice cores are produced in the polar regions. The frozen water contains bubbles of trapped air, from which data for CO_2 concentrations and average air temperature can be collected

The atmosphere is a thin layer of gases, primarily made of nitrogen and oxygen, but also containing lower quantities of greenhouse gases such as carbon dioxide, methane, nitrous oxides and CFCs, which trap infrared radiation. The atmosphere plays an important role in keeping Earth's average temperature stable.

The Sun radiates energy as visible light, and the Earth absorbs some of this energy, before radiating energy back to space as infrared radiation. Some of this IR is absorbed by greenhouse gases, warming the troposphere and the Earth.

CO_2 is released by the combustion of fossil fuels, and is responsible for a great contribution to the greenhouse effect due to its vast abundance relative to the other greenhouse gases.

Methane originates from many sources, such as incomplete combustion, cattle farming, paddy field agriculture and anaerobic decay at landfill sites. CH_4 has a much higher warming potential.



There appears to be a strong correlation between CO_2 levels and temperature across the last 400000 years as shown by climate proxies. Pre-industrial factors affecting CO_2 concentration include changes in the Earth's orbit, volcanic eruptions and changes in solar activity. The causal link to global warming is a widely accepted theory.

Climate change remains a controversial issue, as theories can never be proven, only disproven, and there is incomplete knowledge of how climate systems work, with predictions used in models. Conclusions reached may depend on who is reaching those conclusions – people are influenced by their values, and political and economic interests. People also use ethical arguments when considering how much action should be taken against climate change – do we have the right to choose for ourselves whether we should use fossil fuels, or do we have a duty to protect the environment?

Mathematical Modelling

Models are frequently used by biologists to predict future changes, and is based on the principle of extrapolation, where a trend is extended, assuming that there is enough data to establish the trend accurately and present trends continue.

Climate models are incredibly sophisticated, and consider many factors which affect climate. These are listed to the right in order of significance. The purpose for these models is simple - the world needs to be prepared for the different eventualities of climate change, and such stark representations of worst-case scenarios are useful in enabling action. Different outcomes map the possible outcomes of certain preventative actions, or indeed inaction.

Solar Output
Cloud Cover
Reflectivity
Water Vapour
CO_2
CH_4, CFCs, NO_X
Aerosol
Ice and Snow

Models have limitations, as there is limited data, limited knowledge of how climate systems work, and changing trends in factors, such as rate of ice loss and greater rate of carbon dioxide emission. Furthermore, extrapolation is not always reliable. Despite this, models continue to become more accurate as out understanding of climate systems improves. Comparison of different models, and input of historical data, checks their accuracy.

Impacts of Climate Change

Changing Distribution of Species

Climate change will cause the balance between species in communities to shift. Changing species distribution correlates closely to changing abiotic factors, such as rainfall, soil moisture, winds and sea levels.

Animals may migrate to avoid changing conditions	Some species may benefit from the changing conditions and become dominant	New crops such as citrus and olive plants can be grown in warmer areas
Alien or exotic species may invade from other regions, and outcompete endemic or resident species	Organisms under pressure from climate change may find it impossible to find new areas, and their populations will die out. Trees are particularly vulnerable as their lifecycle is too long to cope with rapidly changing climate	Pests and diseases may spread to new areas and reduce crop yields

Altered Development and Life Cycles

As temperature initially increases, there is an increased rate of enzyme-substrate collision due to greater KE of molecules. If temperature continues above optimum temperature, the bond holding the enzyme in its tertiary structure break and the substrate no longer fits in the active site – the enzyme is denatured.

Q_{10} is a ratio which describes what happens when temperature is increased by 10°C.

$$Q_{10} = \frac{\text{Rate of Reaction at Temperature T + 10°C}}{\text{Rate of Reaction at Temperature T}}$$

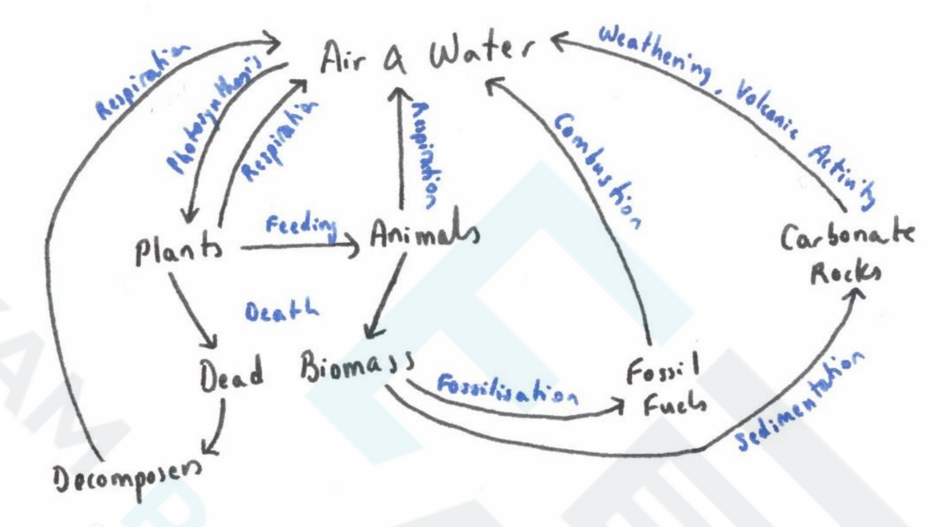
In the tropics, many plants are at the limit of temperature tolerance, and a small rise in temperature may result in a decrease in population size. If CO_2 concentration rises, rate of photosynthesis also increases as it is a limiting factor: however, this rate will not increase indefinitely as eventually other factors become limited. It is probable that crop production in temperate regions would increase, whilst tropical regions suffer.

Plant species that rely on rainfall-related cues for germination may be vulnerable, and changes to flowering or fruiting may also be seen. Animals are likely to be affected if temperature acts as an environmental cue for development or behaviour, such as spawning, hatching and growth. These are phenological changes in seasonal behaviour. For many species, such behaviour is synchronised with the environment in order to maximise chance of survival, by intake of food, or reproduction, by pollination. If there is misalignment, this may risk species survival.

The Carbon Cycle

Key Terminology

Term	Definition
Carbon Cycle	The circulation of carbon through habitats
Biofuels	Any fuel whose energy is produced through biological carbon fixation, with organic matter derived from recently living organisms



Microbes play a vital role in carbon cycling, by allowing breakdown of plant material and releasing carbon as CO_2.

The rising CO_2 levels suggest that the carbon cycle is not in balance, primarily due to combustion of fossil fuels and deforestation. This release of carbon from sinks, where the atoms have been out of circulation, causes an exponential rise in atmospheric CO_2. Rising temperature itself may release carbon from permafrost. There is evidence of a rise in carbon dioxide dissolving in oceans.

- **Biofuels** are sources of energy produced from recent photosynthesis, providing a renewable resource that is supposedly carbon neutral. Examples include biodiesel and ethanol. However, there are significant drawbacks, including the destruction of mature forest releasing CO_2, loss of biodiversity in this clearing, food insecurity, release of CO_2 during farming, transport and processing, and vast water demand.
- **Reforestation** is the planting of new trees, with the idea of locking up carbon dioxide as it would at first act as a net absorber. There is a limit to the amount of CO_2 absorption as eventually the greater biomass leads to greater decay. There are also space limitations and the fact that this would act as a longer-term solution – more pressingly, fossil fuel use must cease

Adaptation and Speciation

Key Terminology

Term	Definition
Allele Frequency	The relative frequency of a particular allele in a population
Allopatric Speciation	Two populations become reproductively isolated after geographical isolation, which prevents mating and gene flow between the groups
Sympatric Speciation	Two populations become reproductively isolated in the same environment without a geographical barrier

Species change over time as they adapt to changing environments. There is a struggle for existence, with intraspecific competition for resources as well as the threat of predation. Variation, created by mutation, allows for the survival of the fittest – favourable alleles become more frequent over time, causing evolution.

Evidence for Evolution: Genomics and Proteomics

Today, new papers are sent to other researchers for peer review, where reviewers would examine the paper critically to ensure that the methodology, statistical analysis and therefore any conclusions drawn are valid. After this, the paper is published, or presented at a scientific conference.

- The fact that DNA, protein synthesis and cell behaviour is essentially the same in all organisms reveals genetic continuity, supporting Darwin's idea that all organisms stem from a current ancestor

- **DNA Hybridisation**: DNA from two species is heated then combined. Certain sequences are complementary, but some DNA is not. The DNA is the denatured again. The higher the temperature, the more closely related two species are, as more of the DNA is complementary and so more hydrogen bonds need to be broken.
- **DNA Profiling**: DNA can be cut be restriction enzymes and used to produce fragments which produce a DNA profile. If mutations have occurred, the sites of cutting, and therefore the profiles, will change. The difference in fragment lengths provides information about the relatedness between organisms.
- **DNA / Protein Sequencing**: By comparing DNA base sequences or amino acid sequences in proteins of different species, it is possible to determine how closely related organisms are. If there are few differences, they are likely to have a more recent common ancestor.
- **DNA Molecular Clocks**: As species evolve, they accumulate random mutations at a random rate. The molecular change in DNA over time can be used as molecular clock, which can be used to pinpoint events in evolution. By comparing the number of differences between species, it is possible to calculate how long ago they shared a common ancestor. Phylogenetic trees support the Theory of Evolution

Speciation

Speciation occurs when an isolating mechanism prevents gene flow between two populations.

Allopatric speciation occurs when geographical isolation prevents mating between populations – the different selection pressures cause speciation over time.

Sympatric speciation can occur when populations overlap, with a behavioural or anatomical barrier instead:

- Ecological Isolation – Species occupy different parts of the habitat
- Temporal Isolation – Reproduce at different times
- Behavioural Isolation – Species do not respond to each others' courtship behaviour
- Physical Incompatibility – Physical barriers to copulation
- Hybrid Inviability – Hybrids do not survive long enough to reproduce
- Hybrid Sterility – Hybrids cannot reproduce