A2 Biology notes – AQA unit 4: Populations and Environment

Populations and Communities:

- The area of the earth inhabited by living organisms is known as the biosphere. This encompasses land (to a depth of several metres), bodies of water, and the atmosphere to a height of a few kilometres.
- The biosphere is divided into large sub-units known as biomes. Examples of biomes include deserts, tundra, and aquatic environments. Terrestrial biomes (i.e. on land) correspond roughly to climatic regions, as the climate is often the defining factor of a biome.
- Within biomes are ecosystems. These are stable, self-sustaining communities of organisms which interact with each other and their surroundings – the term 'ecosystem' describes both biotic (living) and abiotic (non-living) aspects of an environment.
- A population is a group of individuals of the same species inhabiting an area. A community is a group of interacting populations (comprising all the living things) within an area.
- An organism's environment is made up of two types of factor;
  - Biotic factors: these are the result of other living organisms. Biotic relationships include mutualism, disease and predation.
  - Abiotic factors: non-living factors, such as temperature, wind or oxygen level.

Ecological Niches:

- A species' ecological niche is defined by the sum of the biotic and abiotic conditions that a member of the species needs to survive and reproduce. This includes resources and physical space.
- The potential environments in which a species is capable of living form its fundamental niche. Geographical barriers or interspecific competition can prevent a species from occupying the entire of its fundamental niche: the part that is occupied in reality is known as the realised niche.
- As members of the same species will share a niche, intraspecific competition will occur in a habitat where resources are scarce. This limits the growth of a population and can lead to behavioural traits such as territoriality. Different species which share a niche compete interspecifically. The competitive exclusion principle states that competing species cannot permanently cohabit, as one will always be a stronger competitor.
- Time also forms an important part of an ecological niche: two species may appear to have the same niche (and so should not both survive by the competitive exclusion principle), but be active at different times of the day or year, so avoid competition.

Investigating populations:

- When a population is sampled, precautions must be taken to ensure that the sample is representative of the population. This means that the sampling method must be random, unbiased by equipment or procedure, and large enough to provide an accurate estimate. This means that each individual has an equal chance of selection.
- Transect sampling is used to investigate the change in a community over a linear sequence. Line transects use a tape or string along the ground – organisms touching the string are counted. Belt transects record individuals within a narrow strip of set

width. Transects can be continuous, or interrupted (i.e. samples are taken at discrete points along the line or belt).

- Randomly placed quadrats can be used to sample plants and immobile animals. As the area of the quadrat is known, population density (no. of organisms per unit area) can easily be calculated. A running mean – calculating a mean after each sample – can determine the required number of samples; when this is constant the sample size is sufficient.
- A frame quadrat divided into a grid can be used to estimate the percentage cover of an immobile organism, or the frequency of occurrence (no. of squares present vs. number absent).
- Population size of mobile organisms can be estimated using the mark-release-recapture technique. A sample is captured and marked (ensuring the organisms are not hindered), then released. After a period of time, another sample is taken, and the number of marked organisms recaptured is counted. The population size can be estimated by multiplying the total number of marked organisms by the size of the second sample, and dividing by the number of marked organisms recaptured. This method assumes that the marked organisms disperse evenly.

Analysing and Interpreting data:

- Standard error is a measure of the reliability of a calculated mean: $SE = \frac{s}{\sqrt{n}}$ where s is the standard deviation and n is the sample size. It is proportional to the standard deviation and inversely proportional to the sample size: the most reliable samples are large and consistent.
- In a normal distribution (a typical bell-shaped curve), one can be 95% certain that the actual mean for a data set lies within two standard errors of the calculated mean.
- Spearman's rank correlation coefficient is a hypothesis test used to identify correlations in bivariate data (data with two variables). Each set is ranked separately, and the difference in rank is compared for pairs of data. The equation $r = 1 - \frac{6\sum d^2}{n^3 - n}$, where d is the difference in rank for each pair and n is the number of pairs, can be used to determine the correlation: 1 is a perfect positive correlation; -1 is a perfect negative correlation; 0 indicates no correlation.
- A Chi-Squared test indicates the likelihood of a hypothesis's validity by comparing observed and expected values. The equation used is $\chi^2 = \sum \frac{(O-E)^2}{E}$, where O is an observed value and E is the expected one. The χ^2 value is compared to statistical tables, which give the probability of the given value occurring for the number of degrees of freedom (i.e. n – 1) in the test.

Variation in population size:

- When a population colonises a new area, the growth curve is typically sigmoid:
  - Growth is initially slow to the small number of reproducing individuals.
  - After a period of time, exponential (ever-increasing) growth begins at the biotic potential (maximum growth rate); birth rates exceed death rates and the population size doubles at regular intervals.
  - Limited resources prevent exponential growth from continuing indefinitely: it eventually slows until the population reaches a stable (but dynamic level). At this point, birth and death rates are equal.

- The maximum sustainable population of an environment is known as the carrying capacity. If this capacity is exceeded, resources can become scarce, resulting in a sharp population decline (boom and bust). If the environment is damaged, its carrying capacity can be permanently lowered.
- The factors which limit the size of a population are known as environmental resistance. Environmental factors can be classified into two types:
    - Density-dependent (i.e. their effects increase as population density does), such as food availability, disease and intraspecific competition. These factors are normally biotic.
    - Density-independent: examples include temperature and weather conditions. These are normally abiotic factors.
- Interspecific interactions can also affect the size of populations. These can benefit both species (e.g. mutualism), only one (predation, disease), or neither species (competition).
- Predator-prey relationships fall into two main categories:
    - Seasonally peaking population sizes: at a certain point in the year, conditions become more favourable, causing growth of the prey population. This is quickly followed by a peak in the predator population size. As conditions become less favourable, both populations decline.
    - Oscillating populations. These occur over long periods of time: when predator numbers are low and prey is abundant, the predator population grows. This causes a decrease in the size of the prey population, which causes a decline in predator population; this continues.

Human Populations:

- The population size of the human race is roughly 7 billion. Since the industrial revolution it has been exponentially increasing; this will continue until the carrying capacity is reached. Scientific advancements are increasing the earth's carrying capacity, but human actions such as global warming may have a negative effect.
- A survival curve can be used to analyse a population; it plots age against proportion of survivors. Economically developed populations show low infant mortality rates; the majority of deaths are age-related. Less economically developed populations show the majority of deaths in early life.
- Population pyramids can be used to show demographic trends (trends in age or sex). Developed countries show a relatively even distribution until old age, whilst population pyramids for less developed countries show a skew to the younger end of the pyramid due to high birth rates and infant mortality.
- As technology, healthcare and nutrition improves, human populations tend to change from having high birth and death rates to low ones. This change is known as a demographic transition. During the transition the population size rises sharply as death rates fall, but restabilises when birth rates follow suit.

Adenosine Triphosphate:

- Adenosine triphosphate (ATP) is a nucleotide. Its structure comprises of a ribose molecule (a pentose sugar), to which the base adenosine is bonded. Also bonded to the sugar are three phosphate groups.
- The bond between the second and third phosphate groups is easily broken by hydrolysis, forming ADP (adenosine diphosphate) and inorganic phosphate. This is an exergonic reaction; it releases approximately 30 kilojoules per mole of ATP.

- The ease at which energy can be obtained from ATP (the reaction only requires one step) means that ATP is used to drive many biological processes: all endergonic metabolic reactions are powered by ATP hydrolysis. The inorganic phosphate formed from ATP hydrolysis can be used to attach to other molecules (this is known as phosphorylation), changing their chemical properties.
- ATP is being constantly used by the body's cells, though only a small quantity (about 100g) is stored at any one time. This store is in dynamic equilibrium: hydrolysed ATP is constantly replenished from ADP and inorganic phosphate. This reaction is catalysed by the enzyme ATP synthase, and the energy required to power it is generated by respiration.

Photosynthesis – Overview:

- Plant materials are rich in carbohydrates, sugars and fats, yet plants do not ingest or digest food. This is because plants are autotrophs: they synthesise the food they require themselves. The process by which this synthesis occurs is known as photosynthesis.
- Plants photosynthesise by taking water and carbon dioxide, and using them to form simple sugars such as glucose, as well as oxygen (a waste product). This is an endergonic reaction – it is powered by energy from sunlight. Photosynthesis is a complex procedure with many steps, but the overall reaction may be summarised as follows:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + O_2$$

- Some glucose from photosynthesis is used immediately in respiration. Some, however, is stored in starch or lipids, or used to make structural materials such as proteins or cellulose.
- Photosynthesis is essential to life on earth as it is the only biotic method of fixing solar energy. Furthermore, it has enriched the earth's atmosphere with oxygen, allowing complex organisms to evolve.
- Photosynthesis takes place in the chloroplasts of a plant cell, in two main stages:
    - The light dependent reactions, in which is broken down into hydrogen and oxygen using light energy. These reactions occur in the thylakoid membranes in the grana.
    - The light-independent reactions: hydrogen reacts with carbon dioxide to form carbohydrates; water is reformed. These reactions take place in the stroma (the matrix of the chloroplast).

Photosynthesis I – Light-Dependent Reactions:

- When sunlight falls on a plant, different wavelengths are absorbed by pigments in the tissues. The most important plant pigment is chlorophyll; this takes part in photosynthesis directly. It absorbs light mainly in the red-orange and blue-violet parts of the spectrum, hence the green colour of most plants (as green wavelengths are reflected). Other pigments, called accessory pigments, absorb light of other wavelengths and convey the energy to chlorophyll.
- The absorption spectrum of a pigment describes the range of wavelengths which the pigment absorbs. It is closely related to the action spectrum of a plant: this is the range of wavelengths which induce photosynthesis.
- When light is absorbed by a chlorophyll molecule, it excites an electron. This causes it to leave the chlorophyll molecule; it enters the electron transport chain. This is a

series of molecules, each of which has a greater affinity for the electrons than the previous; the electrons move along the chain in a series of redox reactions.

- Chlorophyll in plants is found in two photosystems. Electrons from photosystem II inter an electron transport chain where the energy released from each reaction is used to pump hydrogen ions across the thylakoid membrane. The chemiosmotic gradient caused is used to power the synthesis of ATP (this is known as photophosphorylation). The electrons in PSII are replaced by the photolysis of water: $2H_2O \rightarrow 4H^+ + 4e^- + O_2$. Once the PSII electrons leave the electron transport chain, the enter photosystem I, where they are excited again. From there, they either re-enter the first electron transport chain (cyclic photophosphorylation) or enter a second (non-cyclic photophosphorylation). The final electron acceptor in the second chain is the coenzyme NADP (nicotinamide adenine dinucleotide phosphate). It combines with two electrons, and a hydrogen ion from the photolysis of water to form reduced NADPH (also called reduced NADP).
- Overall, the light-independent reaction breaks down water and generates ATP, NADPH and oxygen. The oxygen is a waste product and leaves the plant, whilst the ATP and NADPH diffuse into the stroma for use in the light-independent reactions.

Photosynthesis II – Light-Independent Reactions:

- The light-independent reactions of photosynthesis were identified by Melvin Calvin using a 'lollipop' apparatus consisting of a transparent bulb containing a photosynthetic alga. A radioisotope of carbon was added, and samples were taken at regular intervals. This led to the discovery of a series of reactions by which carbon dioxide is fixed to carbohydrates, known as the Calvin Cycle.
- The main stages of the Calvin cycle are as follows:
    - Carbon dioxide combines with a five-carbon compound, ribulose bisphosphate (RuBP) to form a six-carbon intermediate. This reaction is catalysed by the enzyme RuBisCO. The six-carbon intermediate is unstable and immediately breaks down into two three-carbon molecules: glycerate 3-phosphate (G3P).
    - G3P is reduced to a phosphorylated three-carbon sugar (a triose phosphate or TP) known as glyceraldehyde 3-phosphate or GALP. This reaction uses NADPH as a reducing agent (so NADPH is oxidised back to NADP) and requires energy from the hydrolysis of ATP – both of these molecules are generated in the light-dependent reactions.
    - Approximately one sixth of the TP is converted to glucose and used to make carbohydrates, lipids and amino acids. The rest is converted back to RuBP, using energy from ATP hydrolysis, allowing the cycle to continue.
- The light-independent reactions are so named because they do not require direct input of light. However, they do require a constant supply of NADPH and ATP from the light-dependent reactions, so outside of experimental conditions, the light-dependent and light-independent reactions occur simultaneously during daylight hours.

Factors Affecting Photosynthesis:

- The rate of photosynthesis of a plant can be estimated by the volume of oxygen taken in, the volume of carbon dioxide released, or the amount of carbohydrate produced over a given time. Oxygen liberation is not always an accurate measurement as some oxygen is used in respiration.

- A plant's rate of photosynthesis is affected by internal and external factors, such as temperature, CO_2 concentration, and light intensity:
    - Increased temperature has little effect on light-dependent reactions as these are driven by light, not heat. However, the reactions in the Calvin cycle are enzyme-catalysed, so are affected by temperature accordingly. The optimum temperature is usually between 25^{o}C and 30^{o}C.
    - Increasing CO_2 concentration in the atmosphere increases the rate of photosynthesis. However, at concentrations above 0.1% (atmospheric concentration is about 0.04%), the leaves of plants can be damaged. Hence, the optimum concentration is just under 0.1%
    - The rate of photosynthesis is directly proportional to the light intensity until the plant's pigments become saturated with light.
- The light intensity at which a plant's photosynthesis is perfectly balanced by its respiration is known as the light compensation point. In order for a plant to survive, the light intensity must exceed the light compensation point.
- In natural conditions the photosynthesis of a plant is affected by a number of factors. However, the rate of photosynthesis is determined by the factor with the least favourable value; if this factor (known as the limiting factor) does not improve, the rate of photosynthesis will not change.

Cellular Respiration I – Glycolysis:

- Cellular respiration is the process by which ATP is synthesised using energy from the breakdown of organic compounds such as glucose. It occurs in every cell of every living organism.
- There are two types of cellular respiration: aerobic, which requires oxygen and generates relatively large quantities of ATP, and anaerobic respiration, which is quicker and uses no oxygen, but generates far less ATP.
- Aerobic respiration involves a series of reactions which occur mainly in the mitochondria. In these reactions, glucose and oxygen combine to from carbon dioxide and water, releasing energy. The water and carbon dioxide leave the cell as waste products. The reactions can be summarised by this equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

- The first stage in both aerobic and anaerobic respiration is known as glycolysis. In eukaryotes, this occurs in the cytosol, and involves the splitting of a glucose molecule into two molecules of pyruvate, a three-carbon compound.
- The main stages in glycolysis are as follows:
    - ATP is hydrolysed, phosphorylating glucose to glucose 6-phosphate. An enzyme converts the glucose 6-phosphate to fructose 6-phosphate, and this is phosphorylated again to form fructose 1,6-diphosphate.
    - The phosphorylations provide the activation energy for the splitting reaction: the fructose 1,6-diphosphate splits into two molecules of glyceraldehyde 3-phosphate (GALP).
    - In a series of reactions, each GALP molecule is converted to glycerate 3-phosphate (GP) and then to pyruvate. This is a redox reaction – the GALP is oxidised. The oxidising agent in this reaction is NAD (nicotinamide adenine dinucleotide); this is reduced to NADH. The energy released in this reaction is sufficient to synthesise two molecules of ATP per pyruvate molecule.

- Overall from glycolysis, two molecules of pyruvate and two molecules of NADH are formed, which, if oxygen is present, diffuse into the mitochondria to continue respiration. Four molecules of ATP are produced, but as the process requires an initial input of two ATP molecules, the net result is two ATP molecules per glucose molecule.
- The method by which ATP is produced in glycolysis – obtaining a phosphate group from another molecule – is known as substrate-level phosphorylation.

Cellular Respiration II – Link Reaction/Krebs Cycle:

- If oxygen is present, pyruvate molecules diffuse into the mitochondrial matrix, where thy take part in the link reaction. During this reaction, pyruvate combines with a coenzyme: coenzyme A. This forms acetyl coenzyme A (acetyl CoA). During this reaction, a carbon dioxide molecule is removed, as is a hydrogen molecule, which reduces NAD to NADH. For this reason, the link reaction is known as oxidative decarboxylation.
- The acetyl CoA then takes part in a series of reactions known as the Krebs cycle, summarised as follows:
    - Acetyl CoA combines with a four-carbon compound known as oxaloacetate. The coenzyme A component detaches and is recycled; the two-carbon acetyl fragment is used to form citrate (citric acid), a six-carbon carboxylic acid.
    - The citrate undergoes oxidative decarboxylation to form the five-carbon ∝-ketoglutarate and CO_2; this reduces NAD to NADH.
    - The ∝-ketoglutarate undergoes a second oxidative decarboxylation to form succinate (four-carbon) and carbon dioxide. Again, NAD is reduced. Also, this reaction is sufficiently exergonic to power the synthesis of an ATP molecule by substrate-level phosphorylation.
    - The succinate is oxidised to malate. This reduces FAD (flavine adenine dinucleotide) to $FADH_2$. The malate is then oxidised to regenerate the oxaloacetate, again reducing NAD. The regeneration of the oxaloacetate allows the cycle to continue.
- Two turns of the Krebs cycle occur for each glucose molecule. This generates two ATP molecules by substrate-level phosphorylation, but also generates many NADH and $FADH_2$ molecules. These are reducing agents which act as carriers of hydrogen and electrons to the next stage of aerobic respiration: the electron transport chain.

Cellular Respiration III – the Electron Transport Chain:

- In eukaryotes, the electron transport chain is located on the inner membrane of the mitochondria. The NADH and $FADH_2$ molecules generated in the earlier stages of respiration move to the inner membrane and take part in the electron transport chain.
- The NADH and $FADH_2$ molecules donate hydrogen molecules to the carrier molecules in the chain in a redox reaction. The hydrogen molecules pass along the chain in a series of exergonic redox reactions, splitting into protons and electrons. The final acceptor of protons and electrons is oxygen, which is reduced to water. This reaction is catalysed by the enzyme cytochrome oxidase.
- The energy released an individual redox reaction in the electron transport chain is not sufficient to synthesise ATP. This energy is in fact used to pump protons across the mitochondrial membrane via active transport. This generates a concentration gradient known as a chemiosmotic gradient. The mitochondrial membrane is

impermeable to H^+ ions, except at structures known as stalked particles; these contain the enzyme ATP synthase. The movement of H^+ ions through the stalked particles drives the reaction between ADP and inorganic phosphate.

- The synthesis of ATP using energy released from redox reactions is known as oxidative phosphorylation. Theoretically, one glucose molecule can produce up to 32 ATP molecules by oxidative phosphorylation. This gives a gross yield of 38 ATP molecules per glucose molecule, and a net yield of 36.

Cellular Respiration IV – Anaerobic Respiration:

- Without oxygen, the final hydrogen acceptor, the stages of respiration after glycolysis will not occur; glycolysis is the sole method of ATP production. Because of this, the reduced NAD produced is not oxidised during oxidative phosphorylation; it must be regenerated by other means.
- The process by which NAD is regenerated in anaerobic respiration is known as fermentation. There are two types of fermentation:
    - Alcoholic fermentation, which occurs in plants and fungi. Pyruvate is decarboxylated, forming ethanal and carbon dioxide. The ethanal is then reduced to ethanol, using NADH as the reducing agent – this regenerates NAD.
    - Lactate fermentation, which occurs in animals. In this reaction, pyruvate is converted to lactic acid in a single step by the enzyme lactate dehydrogenase. Again, this oxidises NADH to NAD.
- Some organisms are entirely anaerobic; they can function indefinitely using glycolysis alone as a source of ATP. Aerobic organisms can normally only function for a short period of time anaerobically: ethanol, for example, will kill yeast at high enough concentrations, and lactic acid causes muscle fatigue and cramps in animals.

Energy transfer:

- The vast majority of terrestrial life is powered ultimately by solar energy which is fixed by photosynthesis in autotrophs (literally 'self-feeders'). Primary consumers feed on the autotrophs; secondary consumers feed on these, and so on: energy is transferred from one organism to another.
- Food chains outline feeding relationships, but only give a very limited part of an ecosystem. Food webs with different trophic levels are more useful, but these also have limitations: they are only qualitative representations; they require similar species to be grouped to avoid complication; they often omit organisms such as decomposers.
- Food chains and webs are normally limited to four or five trophic levels, as large quantities of energy are lost as heat between each level.
- Pyramids can be used to give information about each trophic level in a food chain:
    - A pyramid of numbers shows the number of organisms at each trophic level in an ecosystem. These can be misleading, as animals often have greatly differing sizes.
    - Pyramids of biomass are more common and useful. They show the dry mass at each trophic level at a given time. This can give a flawed picture as the biomass may have accumulated over many years.
    - The most useful pyramid is one which shows the energy entering a trophic level over a period of time – usually one year.

- Energy flow diagrams are quantitative representations of energy transfer. They show the energy (in $kJm^{-2}y^{-1}$) entering and leaving each part of an ecosystem.
- The primary productivity of an autotroph describes the amount of energy which is stored as plant tissues: this is typically around 2% of the solar energy per square metre. Secondary productivity is similar, but for the next trophic level. The energy consumed is divided into respiratory energy, energy lost in urine and faeces, and secondary productivity. In general, roughly 90% of the energy is lost between trophic levels.

Increasing Crop and Animal Production:

- Factors in the soil which affect crop production are known as edaphic factors. These include the soil structure (e.g. proportions of sand or clay), water and air content, chemical composition and pH. Farmers improve soil by ploughing (to remove weeds, aerate and loosen), liming (to regulate pH), drainage and irrigation, and fertilisation.
- Fertilisers can be natural or artificial. They contain the nutrients vital to plant growth: nitrogen, potassium and phosphorous. However, these nutrients can dissolve in water and run off (this is known as leaching), causing eutrophication. Humus, which has a slight negative charge, helps to prevent leaching.
- Pests are organisms which have an undesirable effect on production. They can be controlled in a variety of ways:
    - Cultural methods: these include weeding, crop rotation (this avoids build-up of specific pests), erection of physical barriers and strategically planting crops when pest species are dormant.
    - Chemical methods: pesticides can kill either by contact or consumption. Systemic pesticides also exist – these are taken into a plant to poison its consumers. However, improper use can result in bioaccumulation, killing beneficial species.
    - Biological control: the use of one species to control another. Care must be taken to avoid the introduced species having its own negative effects.
- Factors to consider when choosing a method of pest control include cost, effectivity, negative side-effects, and specificity.
- Intensive farming of animals involves restricting them and giving them specific diets, so they gain weight and can be slaughtered earlier. This increases productivity, as less energy is lost: movement is restricted, the animals are kept warm, and animals are genetically selected for efficiency. However, this often raises ethical concerns due to the harsh treatment of animals.

Nutrient Cycling:

- As the earth is effectively a closed system, it follows that all the chemical elements necessary for the structure and function of living organisms are present on the earth. These elements constantly cycle through the earth's systems (the atmosphere, hydrosphere, biosphere and lithosphere).
- Unlike energy, which is often dissipated as heat so cannot be reused, elements are always returned to the ecosystem. The cycles that elements participate in are known as biogeochemical cycles.
- Biogeochemical cycles involving vital elements are known as nutrient cycles. Examples include the carbon and nitrogen cycles. There are two phases to a nutrient cycle:

- The biotic phase: elements are incorporated into organisms; they are in the biosphere. They may move from produces to consumers, but ultimately end in decomposers, which release the elements to the abiotic phase.
- The abiotic phase: elements are present as inorganic ions, compounds or molecules. They can be in solution in water (the hydrosphere), gases (the atmosphere), or in rocks and sediments (the lithosphere). Elements from the atmosphere may be fixed by primary producers, re-entering the biotic phase.

- Within nutrient cycles exist reservoirs and exchange pools. A reservoir for an element has a high residence time – the element remains there for a long period. Examples include sediments in rocks. An exchange pool has a low residence time for nutrients. Examples include most living organisms, as well as clouds.

The Nitrogen Cycle:

- Nitrogen is an element vital to life on earth. It is included in all amino acids, proteins, nucleic acids and their products.
- One method by which nitrogen in organisms returns to the abiotic phase is by saprobiotic nutrition. This involves saprobionts which break down organic matter and tissues into soluble substances. Decomposers break down nitrogen-containing compounds such as amino acids or urea, releasing ammonia; this process is known as ammonification. Ammonia can be taken up by plants, returned to the atmosphere, or converted to other forms of nitrogen.
- Ammonia can be converted to nitrites (NO_2^-) by nitrifying bacteria such as *Nitrosomonas*. Other nitrifying bacteria convert the nitrites into nitrates (NO_3^-). These can be absorbed by plants and reincorporated into the food chain. Nitrifying bacteria are known as chemoautotrophs because they gain energy from the redox reactions involved in nitrifications. These reactions require oxygen – nitrification is an aerobic process.
- Denitrifying bacteria live in the soil in anaerobic environments. They return nitrogen to the atmosphere by converting nitrates and nitrites to atmospheric nitrogen (N_2).
- Atmospheric nitrogen is inert and cannot be used by plants. The process by which atmospheric nitrogen becomes available to plants is known as nitrogen fixation. This is carried out by nitrogen-fixing bacteria such as *Rhizobium*: atmospheric nitrogen and hydrogen are converted to ammonia. These bacteria can be found free in the soil, but normally inhabit the root nodules of leguminous plants in a mutualistic relationship. Nitrogen-fixation can also occur by non-living processes. Examples include lightning, which provides the energy required to oxidise nitrogen, or artificial processes such as the Haber Process, which produces ammonia on an industrial scale.

The Carbon Cycle:

- Another element essential to life is carbon. Carbon is a key component of all major biological molecules. Land organisms mainly obtain carbon from the atmosphere in the form of carbon dioxide (this makes up around 0.04% of the atmosphere). Aquatic organisms usually obtain carbon from hydrogencarbonate (HCO_3^-) ions dissolved in the sea. CO_2 from the atmosphere dissolves in the oceans, so there is a correlation between atmospheric and marine carbon content.
- Carbon in the abiotic phase is fixed by photosynthesis in autotrophs, and converted to organic molecules. It then passes along the food chain. The main route by which carbon returns to the atmosphere or oceans is respiration.

- When organisms die, decomposers normally break down their tissues and release CO_2. If the bodies are not broken down, they will eventually be incorporated into sediments and may become fossil fuels.
- Carbon dioxide is sometimes naturally liberated from the lithosphere by weathering – which breaks down sedimentary rocks, or by volcanic activity. However, human activities such as burning fossil fuels have a much greater effect on atmospheric CO_2 concentration. Deforestation and cement production also contribute to the rising CO_2 levels.

Global Warming

- Global warming describes the rise in average temperature of the Earth's atmosphere and oceans. In the past 100 years, this has been an increase of $0.74 \pm 0.18^{o}C$ on average.
- Global warming has been linked to levels of greenhouse gases in the atmosphere. These gases absorb some of the long-wave infrared radiation emitted by the earth and re-emit it back. The most significant greenhouse gases are CO_2 (produced by aerobic respiration and by human activities) and methane (produced by anaerobic bacteria found in mud and the guts of ruminants), as well as CFCs (chlorofluorocarbons), water vapour and ozone.
- If temperatures increase, crop yields in areas with below-optimum temperatures will increase, as in these areas temperature is a limiting factor to the rate of photosynthesis. However, in areas with optimal temperatures, global warming will decrease crop yields. Furthermore, temperature changes are related to soil structure, water availability, and pest populations: these will have an effect on crop yields.
- Global warming is likely to extend the territories of disease-carrying pests such as mosquitoes and ticks. This will increase infection rates, especially in countries which cannot afford remedial action.
- Temperature rises will also have an effect on the habitats, reproductive cycles and distributions of wild animals and plants. Dramatic changes such as glacial melts or forest fires could cause massive changes to habitats, and polar species are at risk of extinction.

Eutrophication:

- Leaching of fertilisers can cause bodies of water to become overly rich in nutrients. This effect is known as eutrophication. Eutrophication can cause an algal bloom, smothering plants and blocking out light; plant species die. Aerobic bacteria feed on the detritus and dead algae, using up all the oxygen in the water. This can cause the death of aquatic organisms.
- The biological oxygen demand (BOD) of an aquatic habitat is the mass of oxygen used by $1dm^3$ of water in darkness over 5 days at $20^{o}C$. Eutrophication increases BOD, as does increased concentrations of other pollutants such as sewage.
- Water quality can be monitored by examining the types of organism present. Indicator species need a specific habitat to survive: mayfly nymphs require very clean water with plentiful oxygen, whereas rat-tailed maggots can survive in almost anaerobic conditions.

Ecological succession:

- Ecosystems constantly change their biotic and abiotic factors. The change in an ecosystem from initial colonisation to a stable state is known as ecological succession.
- There are two main types of succession:
  - Primary succession: when a newly formed habitat is colonised. Examples include sand dunes and volcanic islands.
  - Secondary succession: colonisation of a devastated habitat, such as the aftermath of a flood or forest fire.
- The first species to colonise a habitat are known as pioneer species. These are tolerant of hostile conditions, and alter them: they increase soil nutrient content and structure, produce humus, and change the pH. These conditions are more favourable to other species; these species colonise the habitat and outcompete the pioneer species. In turn, these species are succeeded, until a stable state with a high ecological diversity is reached. This is known as a climax community. Secondary succession is normally faster than primary succession, as soil is already present.
- Human activity can prevent ecological succession occurring naturally. This is known as deflected succession and leads to a plagioclimax: a stable but altered state. Examples of deflected succession include agricultural ecosystems, which are ploughed regularly and weeded. Conservation biologists work to maintain ecological diversity and protect endangered species.
- Some ecologists believe that for each climatic region there is only one stable climax state, known as a climatic climax. The climatic climax has a high species diversity, as this increases stability due to alternative links between species: even if one species becomes extinct, another is likely to be able to fulfil its role in the ecosystem.

Evolution in Outline:

- It is generally believed that all species are descended from previous species by a process known as evolution. This is the gradual change in a population's genotype over time; if populations are isolated this can result in the formation of new species.
- Evolution was proposed by Charles Darwin using the mechanism of natural selection, based upon three observations:
  - Organisms within a population display natural variations which are inherited.
  - Organisms produce more offspring than is required to replace their parents.
  - On average, populations tend to remain at a stable size; they do not increase indefinitely.
- Darwin concluded that intraspecific competition causes many individuals to die. Variation gives certain organisms a survival advantage; these organisms survive and reproduce, passing on the advantageous characteristics; the average characteristics of the species change over time.
- Darwin's theories are now widely accepted, despite initial rejection. They have been slightly adapted to account for modern developments such as genetic theory; the globally accepted theory of evolution is known as Neo-Darwinism.

Inheritance:

- In the mid-19th Century, Gregor Mendel carried out experiments on inheritance in garden peas. One example of such an experiment is that investigating height, as follows:

    - A pure-bred tall plant was crossed with a pure-bred short plant, ensuring that no contamination occurred. The offspring were known as the first filial generation.
    - The individuals from the first filial generation pollinated one another; this is known as a self-cross. The second set of offspring was known as the second filial generation.
- From Mendel's experiment, the entire of the first generation was tall. However, the second filial generation was divided between tall and short plants in the ratio 3:1. This led to two conclusions:
    - Characteristics are not continuously blended, but are determined by discrete 'factors.'
    - One 'factor' is dominant and is expressed, but the other is still carried – each organism has a pair of factors. In order for the recessive factor to be expressed the dominant one must be absent.

Monohybrid Inheritance:

- Mendel's experiments were an example of monohybrid inheritance: inheritance involving a single characteristic determined by a single gene. Mendel's 'factors' are alleles; a specific sequence of bases which can result in certain characteristics being expressed in an organism's phenotype.
- By convention, alleles are represented by letters; capital for dominant and lowercase for recessive. Mendel's initial pea plants were homozygous dominant and recessive respectively (TT or tt). Thus, the first filial generation was entirely heterozygous (Tt) and, assuming random fertilisation, the second filial generation was divided between TT, Tt and tt in the ration 1:2:1. As both TT and Tt lead to tallness being expressed, the ratio of tall to dwarf peas would have been 3:1.
- An organism displaying dominant characteristics in its phenotype can be identified as homozygous or heterozygous using a test cross: it is crossed with a homozygous recessive organism. If the unknown organism is homozygous, all of its offspring will be heterozygous so will invariably express the dominant allele. If the organism is heterozygous, there will be a 1:1 split between heterozygous and homozygous recessive offspring; the phenotypes will also be split 1:1.

Codominance and Multiple Alleles:

- Codominance occurs when neither allele of a gene is dominant or recessive: a heterozygous organism will show a mixture of the alleles' characteristics in its phenotype. Instead of using upper- and lowercase letters =, a superscript is used: for example, C^R and C^W are used to denote the codominant alleles for red and white flower colour in *Antirrhinum* plants: a heterozygous plant will have pink flowers.
- Sometimes there can be more than two alleles for a particular gene – this phenomenon is known as multiple alleles. An example is the human ABO blood group system which has three alleles: I^A, I^B and I^O. I^A and I^B are mutually codominant; an I^AI^B person will have blood group AB. However, both I^A and I^B are dominant over I^O: an I^AI^O person has blood group A.

Sex Linkage:

- An organism's gender is determined by a pair of sex chromosomes. These are known as heterosomes because they look different; other chromosomes are known as autosomes. In mammals and some insects the heterozygous (XY) combination is male and the homozygous the female. In birds it is the opposite, and in some insects there is no Y chromosome: females are XX and males are XO.

- Genes located on the sex chromosomes are known as sex-linked genes. In humans, the Y chromosome is much smaller than the X chromosome and has not been found to contain any sex-linked genes. Thus, all human sex-linked characteristics are X-linked.
- X-linked recessive characteristics are more likely to be expressed in males. This is because males have no alternative allele to counteract the recessive allele, whereas females have two X chromosomes and thus two alleles for X-linked genes. This means that conditions such as haemophilia and red-green colour blindness are much more common in males than in females.

Population Genetics and the Hardy-Weinberg Principle:

- Population genetics is the study of the genetic composition of populations. In population genetics, the 'gene pool' refers to the sum of all of the alleles in a population, and 'allele frequency; is the proportion of a given allele in a population.
- In a hypothetical situation where the frequency of a dominant allele 'A' is represented by p and that of the recessive allele 'a' is represented by q, the total allele frequency must be 1, so $p + q = 1$. Thus, $p^2 + 2pq + q^2 = 1$. This is known as the Hardy-Weinberg principle: p^2 represents the frequency of AA, $2pq$ that of Aa and q^2 that of aa. This can be used to work out genotype frequencies given an allele frequency, and vice versa.
- The Hardy-Weinberg principle states that allele frequencies in a population will remain constant providing that the population is large (so the effect of genetic drift is negligible), without mutation, immigration or emigration, and with random mating and no natural selection. Measuring allele frequencies in an otherwise ideal population can thus be used to measure the rate of evolutionary change.

Natural Selection:

- Darwin proposed that the populations of organisms were prevented from exponential growth by intraspecific competition. Certain characteristics gave organisms an advantage, making them more likely to reproduce: they have a high natality rate. Organisms with disadvantageous characteristics have a higher mortality rate. The difference in mortality and natality rates results in natural selection of advantageous characteristic: the advantageous alleles increase in frequency.
- Natural selection results in the concept of 'survival of the fittest.' The term 'fittest' describes organisms which can produce the greatest number of surviving offspring: these organisms can pass on their alleles the most effectively.
- Natural selection results in the phenotype distribution of a population changing. This can occur in three different ways:
    - Stabilising selection this normally takes place in an unchanging environment, and selects against the extremes in a population. This reduces the variation in a phenotype: it minimises the spread around the mean. Examples include birth weight in humans.
    - Directional selection: this favours one extreme and disfavours the other, shifting the mean. It normally occurs in a changing environment. The neck of a giraffe is thought to have arisen by directional selection.

- Disruptive selection this favours both extremes and disfavours the mean, eventually leading to a bimodal distribution. If the two groups become reproductively isolated, it can result in the formation of new species.

- The variation between individuals within a species is ultimately a result of mutations. Most mutations are harmful; the organism displaying the mutation is unlikely to survive. However, occasionally a mutation can be beneficial and be passed on.
- One example of natural selection is antibiotic resistance in bacteria. This arises from a random mutiation leading to resistance. Antibiotics will not affect an individual with this resistance, so it will survive and have a selective advantage. Due to the incredibly fast reproductive capabilities of bacteria, this can lead to a new strain developing very quickly.
- A second example is the peppered moth. This has two phenotypes with regards to colour: pale and melanic (dark). Before the industrial revolution, pale moths were well-camouflaged against birch trees and had a clear survival advantage over melanic ones, which would have been eaten by predators. However, pollution caused a colour change in the bark of trees in some areas, and this favoured the melanic variety as they were camouflaged better. This caused a change in phenotype frequency of up to 98% melanic in high pollution areas.

Speciation:

- Organisms are classified as being members of the same species if they are able to reproduce to produce fertile offspring. Organisms of one species are reproductively isolated from other species: they do not, under normal conditions, interbreed.
- Normally, members of a species inhabit separate populations known as demes. Demes have separate gene pools, but normally interbreed occasionally; the populations are still considered to be of the same species.
- Sometimes, two demes can become reproductively isolated from one another. Over time, this can result in speciation: the two populations evolve into different species. If the demes are physically separated, the speciation is known as allopatric speciation. If they are reproductively isolated by other means, it is known as sympatric speciation.
- There are several mechanisms by which demes can become reproductively isolated:
    - Geographic isolation: when a physical barrier such as a mountain, river or ocean separates demes.
    - Temporal isolation: when organisms breed at different times of the year.
    - Ecological isolation: when organisms occupy different habitats in the same area.
    - Behavioural isolation: when behavioural traits such as courtship rituals differ between demes.
    - Mechanical isolation: when organisms cannot mate due to physical differences.
    - Genetic isolation: where two organism’s genes are incompatible. This is similar to hybrid isolation where, though offspring may be produced, any such offspring are infertile.