

Topic 7: Genetics, Populations, Evolution and Ecosystems

Evolution

Populations and species

A **population** is a group of organisms of the same species occupying a particular space at a particular time. A **species** is defined as a group of similar organisms that can reproduce to form **fertile offspring**. For example, a horse and a donkey can reproduce but the resulting offspring, a mule, is infertile so these organisms are classed as different species.

The **gene pool** is the term used to describe all of the alleles within a population. The higher the genetic diversity, the larger the gene pool. When organisms migrate into the population (gene flow), the gene pool gets bigger. Over time, the **frequency of different alleles** changes in response to changes in the environment – this is the basis of **evolution**. For example, as global temperatures rise, we expect to see alleles that allow plants to tolerate the heat to become more common.

Hardy-Weinberg Principle

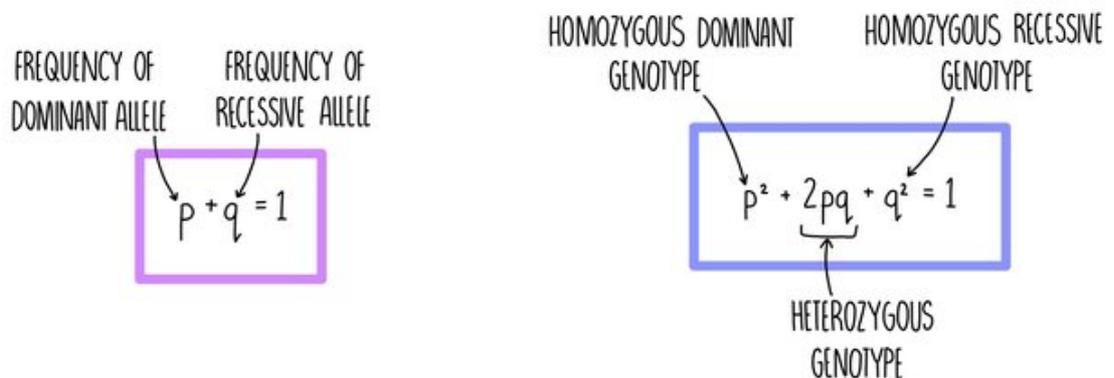
Evolution can be described as a **change in allele frequency over time**. As organisms become more and more adapted to their environment, the alleles which give rise to favourable characteristics become increasingly common in the population. The prevalence of an allele in the population is referred to as **allele frequency** which can be given as a decimal (e.g. 0.6) or a percentage (60%).

Allele frequency can be calculated using the **Hardy-Weinberg equations**. The Hardy-Weinberg principle predicts that the allele frequency will **not change** between generations. However, it makes the following **assumptions**:

1. The population is large
2. No immigration or emigration is occurring
3. Mating is random
4. No new mutations have arisen
5. No natural selection has occurred

If the **allele frequencies change** from one generation to the next within a large population, then we know that **mutation, migration, non-random mating** or **natural selection** has taken place.

The Hardy-Weinberg principle uses **two equations** which you'll need to learn for the exam:



Hardy-Weinberg Principle: Worked Example

Sickle cell anaemia is a recessive disorder which causes red blood cells to misfold into long, thin sickle-shaped cells which are unable to transport oxygen efficiently. Sickle cell anaemia is more prevalent in Africa compared to other parts of the world because people who are heterozygous for the sickle cell gene are less likely to develop malaria, since the malarial parasite is unable to infect the abnormally-shaped red blood cells. In a population of sub-Saharan Africa, 3 in 100 children are born with sickle cell anaemia. Calculate the frequency of the heterozygous phenotype.

- Firstly, we need to work out the frequency of the recessive allele (q). We know that the frequency of the homozygous recessive phenotype is 0.03 (3 in 100), which is represented by q^2 in the HW equation. We can work out q by square-rooting q^2 .
Square root of 0.03 = 0.17.
- Now that we know the frequency of the recessive allele (q), we can work out the frequency of the dominant allele (p) since $p + q = 1$. To work out p we just need to subtract q from 1.
 $1 - 0.17 = 0.83$.
- Finally, we can calculate the frequency of the heterozygous phenotype ($2pq$) by doing $2 \times 0.83 \times 0.17 = 0.28$. This tells us that 28% of the population will have the heterozygous phenotype.

Variation

Individuals within a population of a species may show a wide range of variation in phenotype due to having **different alleles** (e.g. eye colour in humans) and **environmental influences** (e.g. piercings). Most phenotypic variation is affected by both genes and the environment.

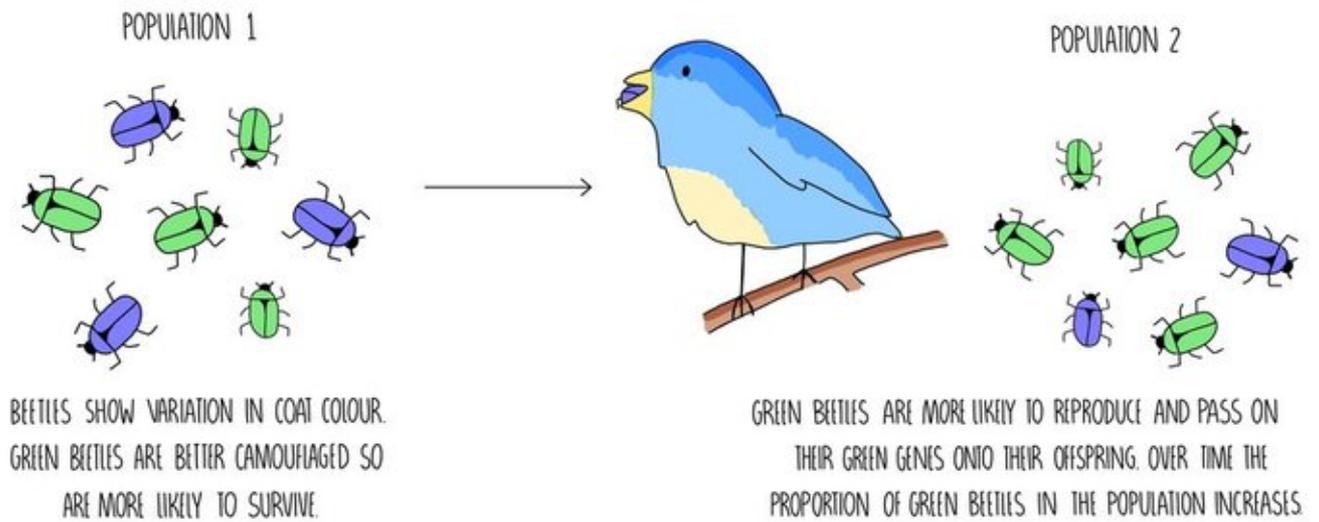
Genetic variation is caused by:

- **Mutations** – this most commonly occurs when mistakes are made during DNA replication. It is a random process but the frequency of mutations changes if a person has been exposed to mutagenic agents (e.g. radiation).
- **Crossing over** – this event takes place in prophase I of meiosis. Alleles are exchanged between homologous chromosomes, producing new combinations of alleles in the gametes.
- **Independent assortment** – this takes place in metaphase I and II of meiosis. Chromosomes align randomly on the spindle fibre, so the chromosomes are shuffled around in different combinations depending on the order in which they line up.
- **Random fertilisation of gametes** – the particular gametes which are involved in fertilisation is a random process.

Natural Selection

Natural selection is the process by which species **evolve**. Evolution is the **change in allele frequency** within a population over time. It can be broken down in the following steps:

- There is **variation** within the population (because different individuals have **different alleles**). Gene **mutations** cause new alleles to appear in the population - some of these may be harmful but some may be beneficial.
- Organisms with alleles which give them **characteristics most suited** to their environment are more likely to **survive to reproductive age** and pass on their genes to their offspring, compared to individuals which do not have the beneficial allele.
- A greater proportion of individuals in the next generation have **inherited the advantageous allele**. These organisms are also more likely to **survive and reproduce**. They will also pass on the advantageous allele to their offspring.
- Over time, the **frequency of the advantageous allele increases** in the population - this is **evolution**.

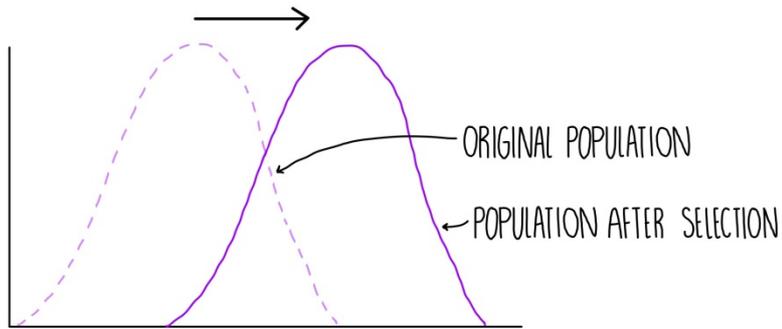


Types of selection

Natural selection can occur in different ways – it might push a phenotype in a particular direction (e.g. necks of giraffes increasing in length) or it may make the mean phenotype (e.g. birth weight) more common.

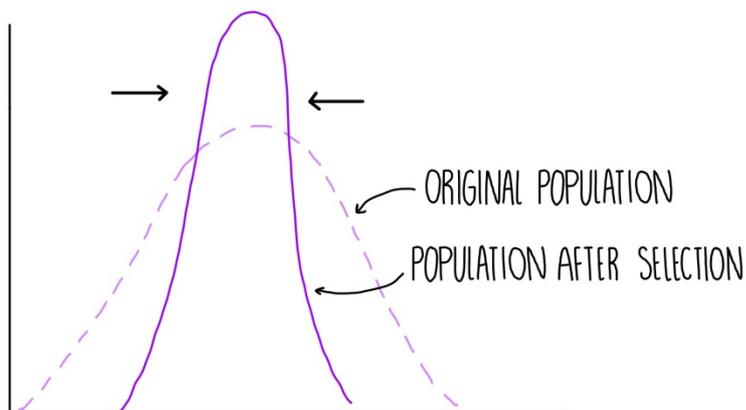
Directional selection

- Alleles for an **extreme phenotype** are more likely to be selected for
- Usually triggered by a **change in the environment**.
- E.g. development of **antibiotic resistance** in bacteria
 - A mutation in a bacterium enables it to develop resistance to an antibiotic.
 - When antibiotic is used (the selection pressure), the resistant bacterium survives while the rest are killed.
 - The bacterium can grow without competition and reproduce, passing on its resistance allele to its offspring
 - This produces a population of bacteria which carry the antibiotic resistance allele



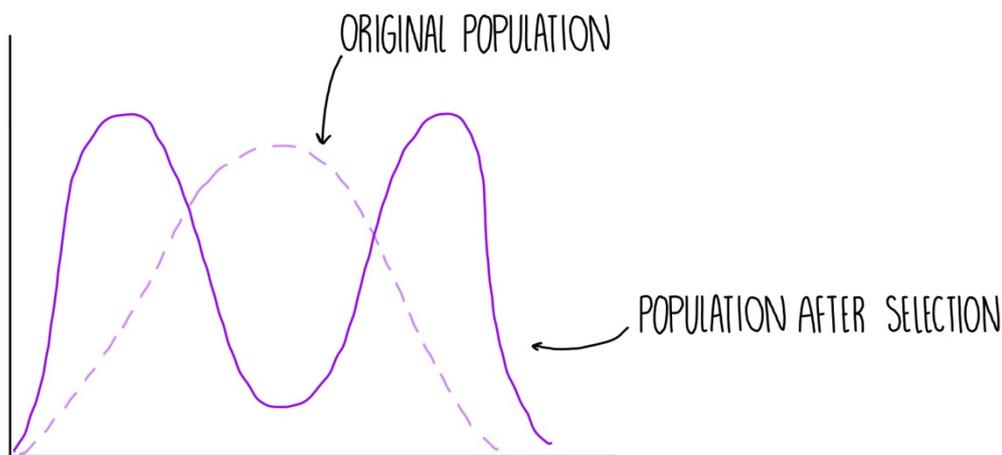
Stabilising selection

- Alleles for an **average phenotype** are more likely to be selected for.
- Occurs when environmental conditions remain **stable**
- Reduces the range of possible phenotypes
- E.g. **human birth weight**
 - Underweight babies are less likely to survive as they lose a lot of body heat.
 - Overweight babies are more likely to lead to childbirth complications.
 - Alleles for a mean birth weight are more likely to survive and reproduce, passing on their average weight alleles onto their offspring



Disruptive selection

- Alleles for an **extreme phenotype** are selected for and alleles for the mean phenotype are selected against
- Occurs when environmental conditions are changing
- May lead to speciation
- E.g. oyster shell colour – light-coloured oysters are better camouflaged in the shallow waters while the darker shells blend in better in the shadows. Medium-coloured oysters are more likely to be noticed by predators so less likely to survive and reproduce.



Reproductive Isolation and Speciation

Speciation refers to the **development of a new species**. It occurs when two groups of a population become **reproductively isolated** from each other. Reproductive isolation prevents the transfer of genes (**reduced gene flow**) between the two groups so **natural selection acts separately** on the two sub-populations. The frequency of alleles within their gene pools will change differently. Eventually the two groups will become so different that they will **no longer be able to breed** with each other - they are now classed as separate species.

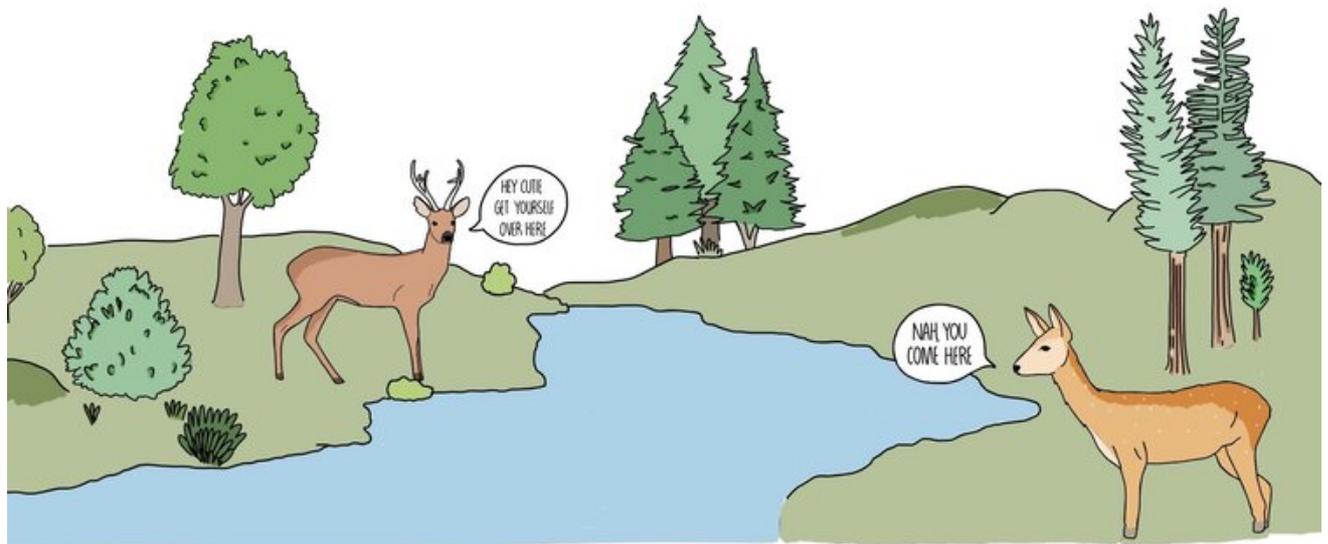
Organisms may become reproductively isolated from each other due to the following changes:

- **Behavioural changes** - e.g. some organisms may develop new courtship behaviours which are unattractive to the main population
- **Mechanical changes** - e.g. changes to the structure of the genitalia may prevent some organisms from reproducing successfully
- **Temporal changes** - e.g. some plants may begin to produce pollen at different times of the year

Allopatric and Sympatric Speciation

Speciation can be classed as allopatric or **sympatric** - **allopatric speciation** involves organisms becoming geographically separated from one another whereas **sympatric speciation** occurs in the absence of a geographical barrier.

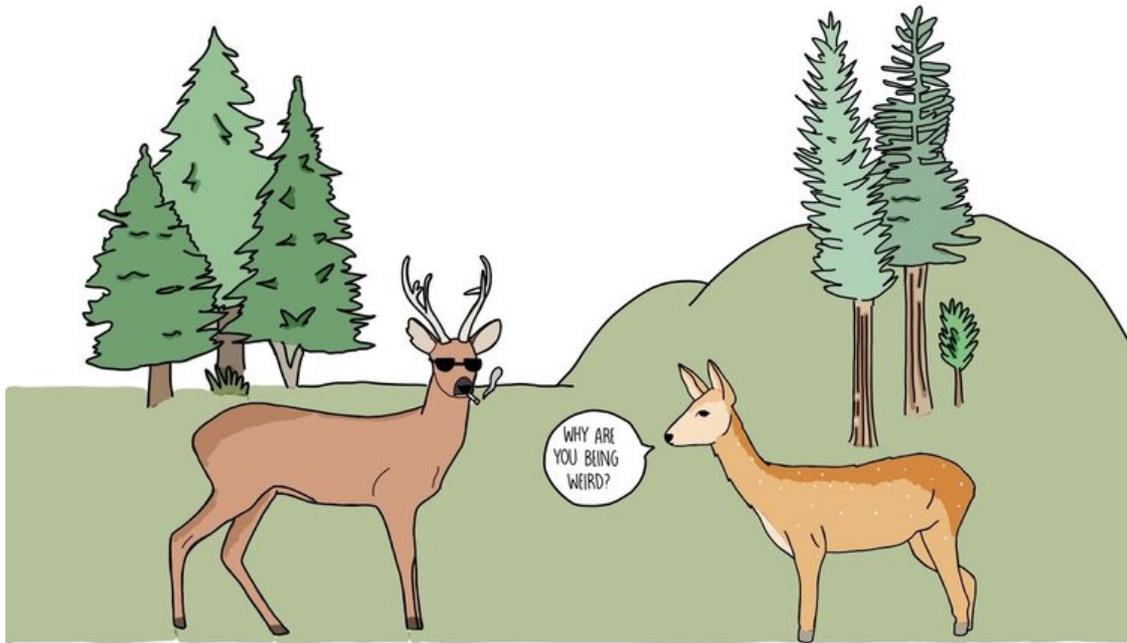
Allopatric speciation occurs when two groups of the same species become separated by a **geographical barrier**, such as a mountain range or a stream. The two groups become **reproductively separated** and cannot exchange alleles with each other. Since the two populations are living in different areas, they will experience different selection pressures so different changes to allele frequencies will occur. The two groups will evolve differently and will form two distinct species.



ALLOPATRIC SPECIATION

Sympatric speciation is when speciation occurs in the **absence of a geographical barrier**. Random mutations may occur within the population which results in **behavioural, mechanical or temporal** changes (see above) which cause the organisms to become reproductively isolated.

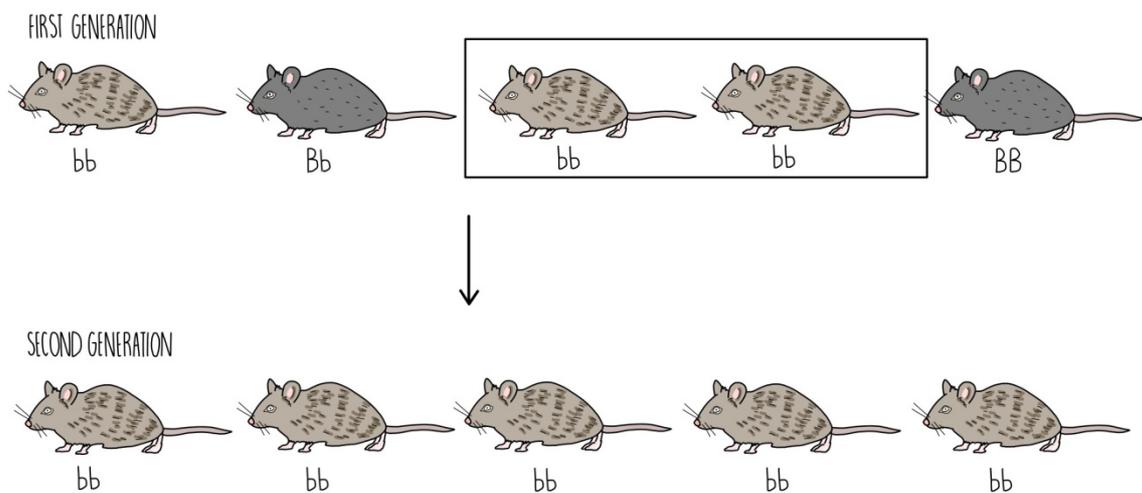
An example of sympatric speciation is **polyploidy**. Polyploidy occurs when a mutation causes an organism to have **multiple sets of chromosomes** instead of the usual diploid number - it is much more common in plants than animals. Organisms with different numbers of chromosomes cannot reproduce to form fertile offspring which means that polyploid organisms are **reproductively isolated** from diploid organisms. If a polyploid organism reproduces **asexually** then these organisms may eventually develop into a new species.



SYMPATRIC SPECIATION

Genetic drift

Genetic drift describes the **random changes** in allele frequencies that occur due to **chance** (rather than environmental factors). Its effect is **strongest in smaller populations**. For example, imagine that in a particular habitat, there are a very small population of mice made up of 3 brown mice and 2 black mice. Perhaps, just by chance, only a few of the brown mice manage to breed. That means that the next generation will look very different to the previous generation and will consist of mostly brown mice, due to luck.



Evolution is driven by both **natural selection** and **genetic drift**. Since chance has a larger effect in smaller populations, the effects of genetic drift are greater in small populations compared to larger ones.