Overview
(/study/app/bio/sid-422-cid-755105/o
Table of contents
Notebook
Glossary
Reading assistance
Teacher view
0 (https://intercom.help/kognity)

Index

D4. Continuity and change: Ecosystems / D4.1 Natural selection

The big picture

? Guiding question(s)

- What processes can cause changes in allele frequencies within a population?
- What is the role of reproduction in the process of natural selection?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

The icy landscape of Antarctica may seem bleak and desolate, but it is home to penguins, orca, whales and many other animals. These animals have numerous adaptations that help them to survive in this harsh environment. Take the example of penguins – birds quite different from other birds.

Penguins are flightless birds – their wings are modified into flippers. Specialised for aquatic life, their fusiform and streamlined bodies, webbed feet and flat-feathered flippers make them expert swimmers. A layer of blubber under their skin insulates them from the frigid air and water temperatures. Countershading – dark on the back and white on the underside –

Student view

Overview
(/study/ap
422-
cid-
755105/o

helps in camouflage (**Figure 1**), making it difficult for predators to spot them as they swim in the water. Thus, penguins are well-adapted for life in the Antarctic. **Video 1** illustrates their incredible swimming strategy.

Figure 1. Countershading helps in camouflage.

Credit: imageBROKER/Juergen & Christine Sohns, Getty Images

Video 1. Penguins, such as these Gentoo penguins (*Pygoscelis papua*), are expert swimmers.

More information for video 1

The video captures Gentoo penguins swimming in the ocean, likely filmed from a boat. At the start, a single Gentoo penguin leaps out of the water, briefly disappears beneath the surface, and then suddenly reemerges, repeating the motion in a rhythmic pattern. Soon, several other penguins join in, all gracefully jumping in and out of the water.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

The video also features slow-motion sequences that highlight the penguins' agile and coordinated swimming. Their sleek movements and quick dives showcase their remarkable ability to navigate both above and below the surface with ease.

In ever-changing environments, adaptations enable organisms not only to survive, but to thrive and reproduce. Failure to adapt to an environment would lead to a species dying out sooner rather than later. How do adaptations arise in a population? What processes cause changes in the frequencies of alleles in a population (see subtopic D3.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43252/))? What is the role of reproduction in the process of natural selection?

Prior learning

Before you study this subtopic make sure that you understand the following:

- evolution as change in the heritable characteristics of a population (see section A4.1.1 (/study/app/bio/sid-422-cid-755105/book/evolution-as-change-in-heritable-characteristics-id-43790/))
- mutations (see section D1.3.2 (/study/app/bio/sid-422-cid-755105/book/gene-mutations-id-43806/))
- reproduction (see section D3.1.2 (/study/app/bio/sid-422-cid-755105/book/asexual-and-sexual-reproduction-id-45736/)).

D4. Continuity and change: Ecosystems / D4.1 Natural selection

Natural selection

D4.1.1: Natural selection as the mechanism driving evolutionary change D4.1.2: Variation generated by mutation and sexual reproduction
D4.1.3: Overproduction of offspring and competition for resources D4.1.4: Abiotic factors as selection pressures

Learning outcomes

By the end of this section you should be able to:

- Recognise that natural selection is the mechanism that drives evolutionary change.
- Explain the roles of mutation and sexual reproduction in generating variation.

Student
view

Overview
(/study/app/bio/sid-422-cid-755105/o

- Identify and explain the biotic and abiotic factors that promote natural selection.

There are 18 species of penguins, which live primarily in the southern hemisphere. The different species vary in several ways. For example, the adult emperor penguins (*Aptenodytes forsteri*) are the tallest – about 1.2 m in height – while the adult fairy penguins (*Eudyptula minor*) are the shortest, at only 0.3 m. We find incredible diversity in the entire living world, not just in penguins. Insects are the most diverse, with more species of insects than there are species of all other animals. For instance, it is estimated that there are 20 000 species of butterflies alone! What led to this amazing diversity of life?

Natural selection

Earth is home to an estimated 8.7 million species, with many forms of life yet to be discovered. Within a species, differences are seen between the individuals. These differences are called variations. Some of these variations are favourable, resulting in individuals better adapted to the environment. These individuals in turn pass on these variations to their offspring. Over a period of time, the frequency of favourable variations in the population increases while the frequency of unfavourable variations decreases. This process, by which better-adapted organisms are more likely to survive and reproduce than those less adapted to their environment, is known as natural selection (see section A4.1.1 (/study/app/bio/sid-422-cid-755105/book/evolution-as-change-in-heritable-characteristics-id-43790/)) and was proposed by Charles Darwin, a British naturalist.

The key components of Darwin's theory of natural selection are as follows.

- Variations are seen among organisms in a population. Heritable or genetic variations (see section D4.1.4–6 (/study/app/bio/sid-422-cid-755105/book/biological-fitness-id-46651/)) are passed on to the offspring.
- Due to overproduction (see later in this section), there is competition for resources leading to a struggle for existence.
- In the struggle for existence, organisms with traits that are better suited to the environment survive and reproduce. This is often referred to as 'survival of the fittest' (see section D4.1.4–6 (/study/app/bio/sid-422-cid-755105/book/biological-fitness-id-46651/)).
- The organisms that survive pass on these variations to their offspring.

Student view

- Over a period of time, the frequency of occurrence of favourable variations in the population increases.
- Natural selection eventually causes the population to become better adapted to its environment.

The forces of natural selection operate continuously on the genetic variations present in a population. Isolation of these populations by geographical or other barriers (see section A4.1.17 (/study/app/bio/sid-422-cid-755105/book/checklist-id-46656/)) prevents interbreeding. In the isolated populations, environmental differences cause natural selection to favour different traits. Over generations, the accumulation of the differences happens to such an extent that the isolated populations are considered as separate species. For instance, the different species of Darwin's finches (see section A4.1.9 (/study/app/bio/sid-422-cid-755105/book/adaptive-radiation-and-barriers-to-id-43796/)) seen in the Galapagos islands have originated from one ancestral species. Isolation and differing environments led to the evolution of several similar-looking species with distinct beak shapes. Yet another example is the *anole* (Genus) lizards of the Caribbean islands (**Figure 1**), where the forces of natural selection acting on variations in limb length, toe pad size and body shape have led to multiple species.

Thus, the mechanism of natural selection enables evolutionary change. Over a period of billions of years, natural selection has led to the amazing biodiversity that exists on Earth today.

Overview
(/study/ap
422-
cid-
755105/o

Figure 1. Natural selection in action. *Anole* lizards are native to the Caribbean islands. In 2017 the islands were struck by two hurricanes in rapid succession. Researchers studying the lizards found that the anoles after the storms had bigger toe pads, shorter hindlimbs and longer forelimbs — features that helped them to cling on better.

Credit: Amanda K / 500px, Getty Images

Nature of Science

Aspect: Theories

A paradigm shift is a fundamental change in ideas or approaches. Darwin's theory of evolution is considered to be a paradigm shift and represents a major change in how evolution is explained. Until Darwin, scientists believed that species had always existed in their current form. Though Lamarck was one of the first people to come up with an explanation for evolution (see section A4.1.1 (/study/app/bio/sid-422-cid-755105/book/evolution-as-change-in-heritable-characteristics-id-43790/)), there were flaws in his argument and many of his ideas were later disproved by several scientists, including August Weismann. Darwin's theory of

Student
view

Overview (/study/app/bio/sid-422-cid-755105/o

natural selection provided a convincing mechanism to explain evolution and, later, replaced Lamarckism. While today Darwin's theory is widely accepted, there was a time when it was the cause of dissent, even in the scientific community. The concept that all organisms descended from a common ancestor and gradually changed over time through the process of natural selection, i.e. descent with modification, and the idea that humans were 'related' to apes was a paradigm shift from earlier theories such as creationism, and thereby unacceptable to much of the population.

Role of mutation and sexual reproduction in variation

Biodiversity (see section A4.2.2 (/study/app/bio/sid-422-cid-755105/book/title-to-come-id-43810/)) refers to the diversity of life on Earth and encompasses genetic diversity, species diversity and ecosystem diversity. Genetic variation refers to the differences in the genomes among individuals of the same species, and is an essential prerequisite for natural selection. **Figure 2** shows natural selection acting on the variation in the neck length in a population of giraffes.

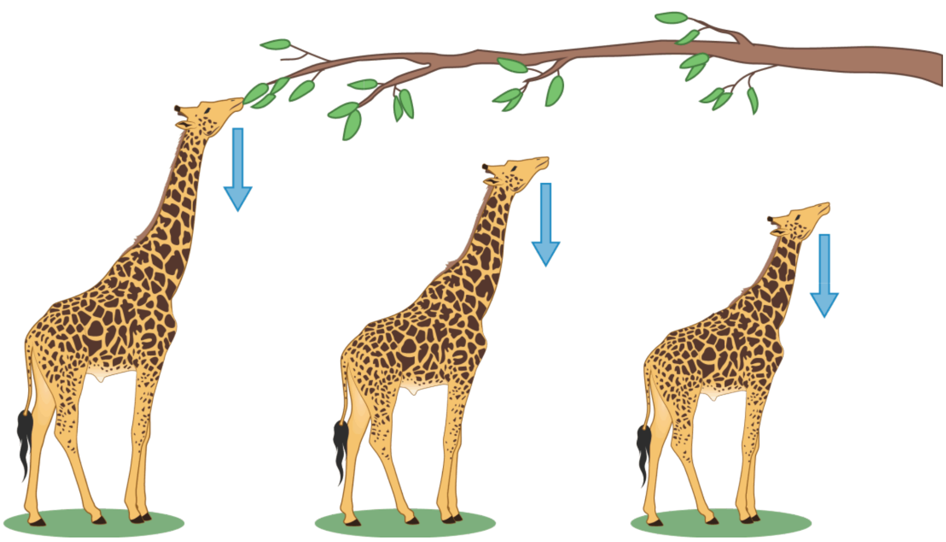


Figure 2. Natural selection acts on the variation present in the population.

In the absence of this variation in a population – for example, if the lengths of the giraffe necks were exactly the same – natural selection would not act.

Genetic variation arises due to mutation and sexual reproduction.

Student view

Overview (/study/app/bio/sid-422-cid-755105/o

Mutation

Mutations are errors in copying the genetic information during DNA replication (see subtopic D1.3 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43250/)), resulting in alleles or the many alternate forms of a gene. Thus, mutation introduces new alleles into a population, resulting in variation.

Most mutations are neutral to an organism; however, some could be harmful and some beneficial. For example, a chance mutation in a population of bacteria could make a few individuals resistant to a particular antibiotic. Following exposure to the antibiotic, the resistant bacteria are more likely to survive, reproduce and pass on the favourable trait.

It is important to note that only mutations in the cells that produce the gametes (see section D3.1.14 (/study/app/bio/sid-422-cid-755105/book/puberty-and-gametogenesis-hl-id-45735/)) can be inherited. In other cells of the body, these mutations would be 'dead-end' mutations and have no value in introducing variation into the population.

Aspect: Patterns and trends

Recent studies have shown that the impact of mutations is dependent on many factors and is less simplistic than previously thought. The impact of a mutation can be compounded or reduced by the presence of other mutations. For example, consider the hypothetical example of an insect that is able to feed on a toxic plant. It is able to do so due to the cumulative effect of mutations across a number of genes. The environment plays an important role in determining the effects of the mutation. In this case, the mutations would be helpful only if the insect and its descendants start living in an area where the toxic plant is the only food source. In addition, size and composition of the population determines the direction of natural selection and thereby the impact of mutation.

Sexual reproduction

Sexual reproduction (see section D3.1.2 (/study/app/bio/sid-422-cid-755105/book/asexual-and-sexual-reproduction-id-45736/)) introduces genetic variation in a population in two ways. The formation of gametes involves crossing over and the independent assortment of homologous chromosomes, both of which result in unique allele combinations (see section

Student view

Overview (/study/app/bio/sid-422-cid-755105/o

D2.1.11 (/study/app/bio/sid-422-cid-755105/book/meiosis-id-43812/)). In addition, random fertilisation leads to unique and new combinations of the alleles of both parents. In a population of many reproducing individuals, the alleles are mixed again and again each time reproduction occurs, resulting in endless variation.

Overproduction and competition for resources promote natural selection

The work of Malthus on human population growth helped Darwin to frame his theory of natural selection. Malthus was an economist who stated, in his *Essay on the Principle of Population*, that growth of the human population was exponential whereas the increase in food production happened in a linear manner. In other words, the food produced would not meet the demands of the population, resulting in poverty, famine and even wars.

Darwin stated that, in nature, there is a tendency towards overproduction – plants and animals can produce far more offspring than can possibly survive. For example, many species of fish lay thousands of eggs. Oysters can lay between 60 and 80 million eggs at a time. In both these cases, however, only a fraction survives up to adulthood.

All living organisms need resources – food, water, shelter, space and, even, mates. These factors are termed limiting factors, as they determine the carrying capacity of the environment (see section C4.1.5 (/study/app/bio/sid-422-cid-755105/book/population-dynamics-id-46389/)). Overproduction leads to competition for these limited resources. Organisms who are 'fit' – that is, have favourable variations that enable them to meet these needs – survive and reproduce. Others die or produce fewer offspring. This keeps the population size relatively stable. In other words, overproduction and the subsequent competition for resources leads to differential survival and differential reproduction, thereby promoting natural selection.

Over time, the offspring of the survivors make up a larger proportion of the population. The population will now be better adapted to the environment and may look entirely different from the ancestral population. Eventually this would result in the evolution of a new species (see section A4.1.6 (/study/app/bio/sid-422-cid-755105/book/speciation-id-43794/)).

Student view

Overview
(/study/ap
422-
cid-
755105/o

Abiotic factors as selection pressures

Selection pressures are factors that lead to differential survival or reproduction, which in turn cause a change in the genetic composition of a population. Selection pressure could include both density-dependent and density-independent factors.

Density-dependent factors (see section C4.1.6 (/study/app/bio/sid-422-cid-755105/book/population-dynamics-id-46389/)) are factors that affect the size of the population and depend on the density of the population in a given area. Picture a population of carp (a type of fish) living in a pond with access to a fixed supply of food. As long as the population density is low, there will be enough food available for the carp. However, as the number of carp in the pond increases, competition for food may result in starvation and death of some of the carp. The population density becomes too great for the fixed amount of food to support. **Figure 3** illustrates some examples of density-dependent factors.

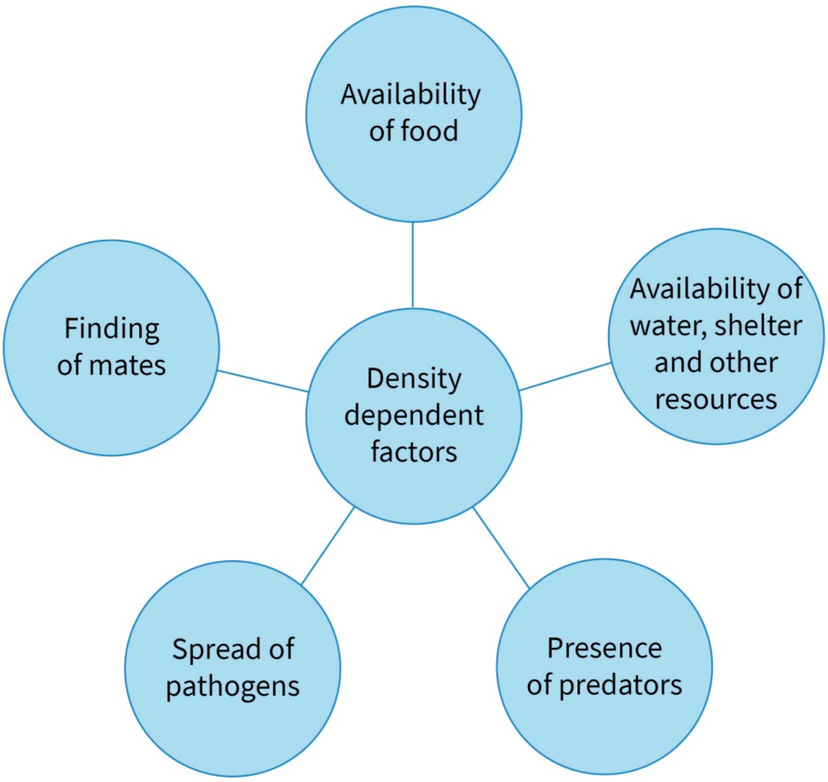


Figure 3. Density-dependent factors.

More information for figure 3

The image is a diagram illustrating density-dependent factors affecting a population. At the center is a circle labeled "Density dependent factors." Five spokes extend from this central circle to other circles, each labeled with a different factor. These factors are: "Availability of food," "Finding of mates," "Availability of water, shelter and other resources," "Spread of pathogens," and "Presence of predators." The diagram visually represents the idea that these factors depend on the density of the population and affect its size and distribution.

Student
view

Overview (/study/ap 422- cid- 755105/o

[Generated by AI]

Density-independent, abiotic factors are physical factors that affect the size of the population, irrespective of the population density. Factors such as the availability of oxygen, temperature and even natural disasters like wildfires, hurricanes and volcanic eruptions would affect all the individuals in a population, regardless of their density. Returning to the carp example: a decrease in the dissolved oxygen levels of the water would affect all the carp in the pond, irrespective of how many carp are present in the pond, and would lead to an overall decline in their population. **Figure 4** illustrates some examples of density-independent factors.

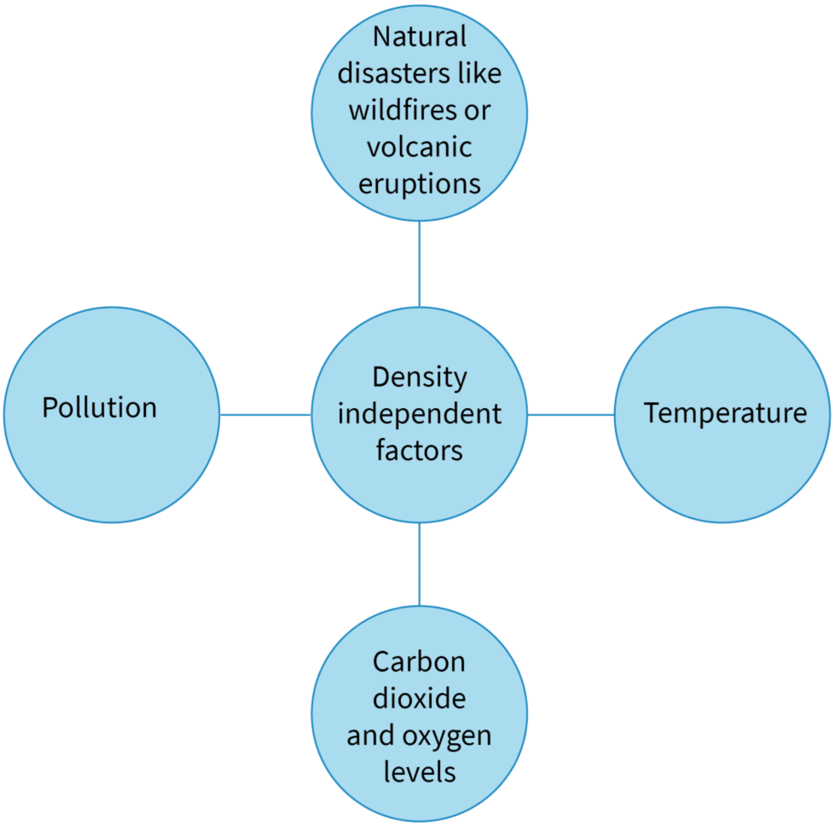


Figure 4. Density-independent factors.

More information for figure 4

The diagram is a central node structure illustrating 'Density independent factors' at its core. Four branches extend from the central node, each leading to a circle with a factor written inside:

1. Top: 'Natural disasters like wildfires or volcanic eruptions' is highlighted, suggesting these are abiotic factors that do not depend on population density.
2. Right: 'Temperature' is noted as a factor impacting populations regardless of density, aligning with examples of climate effects.

Student view

Overview
(/study/app/bio/sid-422-cid-755105/o

3. Bottom: 'Carbon dioxide and oxygen levels' are listed, emphasizing their relevance in environments like aquatic settings.
4. Left: 'Pollution' is identified as having widespread effects on populations regardless of their density.

These factors encompass environmental influences affecting populations independently of their size, part of a larger discussion on ecological balance and species survival.

[Generated by AI]

High or low temperatures are other density-independent factors that can significantly affect population size. Dinosaurs, for example, flourished in the warm temperatures for millions of years. However, about 66 million years ago, there was a sudden drop in the global mean temperatures. Dinosaurs across habitats perished, leading to their extinction.

Polar bears (*Ursus maritimus*) are an example of a species that is affected by the rising temperatures (**Figure 5**). They depend on the Arctic sea ice to hunt, to breed and, if pregnant, to den. Global warming has led to melting of the Arctic sea ice and a decrease in the ice coverage. This in turn has affected the polar bear population adversely.

Figure 5. Melting of the Arctic ice makes the polar bears vulnerable to extinction.

Credit: Paul Souders, Getty Images

Student view

It is important to understand that density-dependent and density-independent factors are often inter-linked.

Watch **Video 1** and answer some questions about variation and evolution in the activity below.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 30 minutes
- **Activity type:** Pair activity

Video 1 shows natural selection in action. Watch the video, then form pairs to discuss and answer the following questions.

Natural Selection and the Rock Pocket Mouse — HHMI BioInteractive...

Video 1. Natural selection and the rock pocket mouse.

1. What were the variations seen in the pocket mice? What led to these variations?
2. Why did the variations spread rapidly in the population?
3. Identify the selection pressures that acted on the mice.

Overview
(/study/ap
422-
cid-
755105/o

4. Explain why evolution is not considered to be a ‘random’ event.
5. The video states that this is ‘a perfect example of Darwin’s theory of natural selection’. Do you agree with this statement? Justify your answer.

5 section questions

Biological fitness

D4.1.5: Differences between individuals as the basis for natural selection

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

Learning outcomes

By the end of this section you should be able to:

- Explain that differences in adaptation, survival and reproduction form the basis of natural selection.
- Recall that heritable changes lead to evolutionary change.

The exotic-looking white tigers you see in **Figure 1** are tigers with white fur and black or brown stripes. The white fur is a result of a rare genetic mutation. Similar to tigers in their strength, agility and speed, in the wild these animals are at a disadvantage. They have lower chances of survival despite their apparent beauty. This leads us to an interesting question: what, in nature, determines the fitness of the animal?

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Figure 1. White tiger, a variant of the mainland Asian tiger (*Panthera tigris tigris*).

Credit: seng chye teo, Getty Images

The concept of biological fitness

The variation in individuals leads to differences in their ability to survive and reproduce allowing populations to adapt over time. These differences form the basis of natural selection.

To understand how natural selection works, it is important to understand the concept of fitness. In our day-to-day lives, 'fitness' often refers to individuals who are physically fit and healthy. The meaning of the term in the evolutionary context is quite different. Biological fitness is the ability of an organism to reproduce and pass on its genetic material to its offspring.

Biological fitness is relative and is determined by the following factors.

- The environment in which the individual (genotype) lives.
  The fitness of individuals varies as the environmental conditions change, and need not be the same across environments. For example, the fittest genotype among polar bears today may not be the fittest genotype in the future as more and more ice melts.
- The survival value of an individual.
  The survival value refers to traits that enable individuals to survive and reach reproductive age. These could include mechanisms to avoid predators or higher disease resistance.

Student
view

- The reproductive potential of an individual.
  The capacity of an individual to produce offspring is known as the reproductive potential. It is determined by traits such as the ability to attract mates, production of viable gametes and parental care. For example, individuals with a brighter plumage may have greater chances of attracting mates and thereby produce more offspring.

The example given in **Figure 2** illustrates the concept of biological fitness. Both the brown beetles and the green beetles live on rotting wood and have common aerial predators. The brown beetles can blend in while the green beetles stand out and are easily spotted by predators. The fitness of the brown beetles is higher as they have a greater chance of surviving and reproducing.

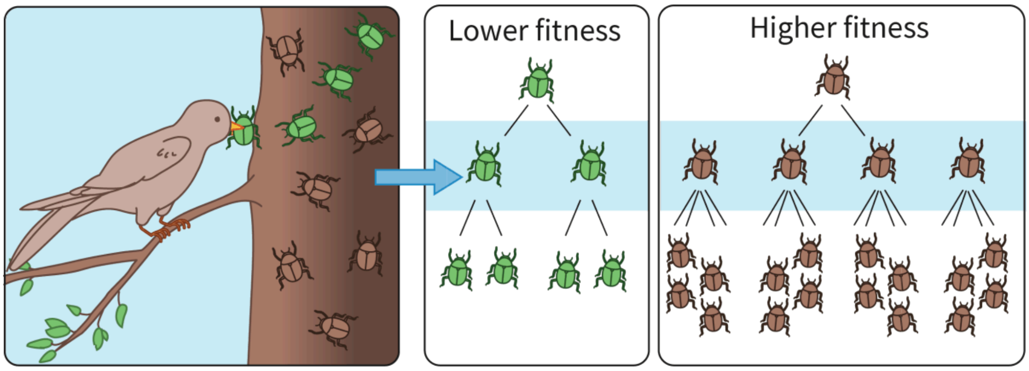


Figure 2. Fitness in beetles.

More information for figure 2

The diagram illustrates the concept of biological fitness using beetles of different colors. On the left, a bird is depicted picking off green beetles from a tree trunk, while brown beetles remain camouflaged. In the center panel labeled "Lower fitness," green beetles are shown in a simple branching diagram to indicate their reduced survival and reproduction compared to brown beetles. On the right, under "Higher fitness," brown beetles are shown in a branching diagram indicating greater survival and reproduction rates.

This visual represents how brown beetles blend into their environment, leading to higher fitness due to increased survival against predators such as birds, compared to the more visible and hence more frequently predated green beetles.

[Generated by AI]

Overview
(/study/ap
422-
cid-
755105/o

Role of intraspecific competition in driving natural selection

Competition occurs when organisms belonging either to the same species or to different species compete for the same resources. When individuals of the same species compete with each other for resources such as food, water, space, sunlight or mates, it is known as intraspecific competition. On the other hand, when individuals belonging to different species compete, it is called interspecific competition. **Video 1** is an example of intraspecific competition.

Video 1. The dance of the adders (*Vipera berus*) - an example of intraspecific competition.

Here are two examples of intraspecific competition:

- Two trees of the same species, growing in close proximity to each other, compete for water, nutrients and sunlight. One may out-compete the other by growing taller or by increasing the spread of the leaf canopy.
- The dance of adders is seen between rival males to establish their supremacy and attract females. The ‘dance’ continues until one of them slithers away defeated or out-competed.

Intraspecific competition is density dependent. As the population size increases and reaches the carrying capacity of the environment, the competition for resources intensifies. Individuals with higher fitness have a greater chance of acquiring resources and reproducing than individuals with lower fitness. This leads to:

Student
view

Overview
(/study/ap
422-
cid-
755105/o

- a decrease in the growth rate of the population as the weaker or less fit individuals begin to die.
- the traits possessed by individuals with higher fitness value being passed on to offspring and becoming more prevalent in the population over a period of time. This in turn causes the population to be better adapted to the environment and, in the long run, could lead to the emergence of a new species.

Thus, intraspecific competition paves the way for natural selection.

Heritable traits lead to evolution

The traits favoured by natural selection must have two features.

1. The trait is beneficial to the organism and increases the chance of their survival and reproduction in a particular environment.
2. The trait is heritable. In other words, the characteristic is encoded in the genetic material so that it can be passed on to the offspring. Skin colour, colour of the fur and shape of the ears are examples of heritable traits.

Acquired traits are traits acquired in the lifetime of an individual due to environmental factors. These traits are often physical or behavioural and are reflected only in the phenotype of an organism. If these phenotypic characteristics do not have corresponding genotypic alterations – that is, are not encoded in the base sequence of the DNA – they cannot be passed on to the offspring. Thus, acquired traits are not heritable. For instance, a person who works out at a gym may have an impressive set of muscles, but these would not be passed on to their offspring. The beautiful pink colour of the feathers of flamingos depends on the pigments present in their diet and, hence, is an acquired trait.

Theory of Knowledge

Humans are believed to be the dominant species on Earth. Do you think that the definition of biological fitness in humans should be different from that of other organisms?

A topic of long-standing discussion, nature versus nurture, looks at the relative contribution of genes (nature) versus the environment (nurture) on human behaviour. Do factors such as upbringing, education, cultural influences and social environment play a role in determining fitness in humans?

Student
view

Overview
(/study/app
422-
cid-
755105/o

Play the peppered moth game in the activity below to enhance your knowledge of natural selection.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Communication skills — Applying interpretive techniques to different forms of media
- **Time required to complete activity:** 20 minutes
- **Activity type:** Pair activity

Peppered moths (*Biston betularia*) are a particularly interesting example of natural selection. The moths exist in two variant forms — light-coloured ones and dark-coloured ones. In pre-Industrial Revolution England the light-coloured moths predominated, while post Industrial Revolution the frequency of the dark-coloured moths increased.

Play the 'Peppered Moth Game' to analyse the reasons for the change.

Begin by reading about:

- the Peppered Moth (https://askabiologist.asu.edu/peppered-moths-game/peppered-moth.html)
- the process of Natural Selection (https://askabiologist.asu.edu/peppered-moths-game/natural-selection.html)
- and the work done by Dr. Kettlewell (https://askabiologist.asu.edu/peppered-moths-game/kettlewell.html). (https://askabiologist.asu.edu/peppered-moths-game/kettlewell.html)

Then play the Peppered Moth Game (https://askabiologist.asu.edu/peppered-moths-game/play.html).

Form pairs to discuss and answer the following questions.

1. Explain the reasons for the differences in the survival rates of the light and dark moths in both environments.
2. Analyse the changes in the fitness level of the light moths in a) the light forests and b) the dark forests.

5 section questions

Student
view

Sexual selection: a special case of natural selection

D4.1.7: Sexual selection in animal species D4.1.8: Modelling of sexual and natural selection

Learning outcomes

By the end of this section you should be able to:

- Define sexual selection as a special case of natural selection.
- Describe the effects of sexual and natural selection through simulation of selection pressure.

One of nature's extravagances, the tail of the peacock is a thing of beauty. The peacock's train is long, with iridescent feathers. These feathers are known for their ornamental eyespots (**Figure 1**). However, what led to the development of such elaborate tails?

Figure 1. Breath-taking beauty!

Credit: Richard I'Anson, Getty Images

Overview (/study/app/bio/sid-422-cid-755105/o

Sexual selection

Sexual selection is a special case of natural selection, where the focus is on finding a mate and reproducing. Sexual selection could be intrasexual selection or intersexual selection.

Intrasexual selection

Intrasexual selection refers to the competition between individuals of one sex to mate with the opposite sex. Intrasexual selection is usually male–male competition to mate with a female, though female–female competition is also seen. Contests of strength seen in male deer and male elephant seals are examples of intrasexual selection (**Figure 2a**).

Intersexual selection

Intersexual selection refers to individuals of one sex, often the females, choosing an individual of the opposite sex as a mate. This in turn exerts strong selection pressures on the characteristics of the opposite sex. Examples include courtship dances, mating calls, elaborate plumage and large genitalia (**Figure 2b**).

Credit: Claus Cramer / 500px, Getty Images

Student view

Overview
(/study/ap
422-
cid-
755105/o

Credit: TeeJe, Getty Images

Figure 2. a) The huge antlers of a deer are not only a sign of good health but also a powerful weapon during rutting. **b)** The elaborate tail feathers of a male bird of paradise are used to entice its mate. Intrasexual selection has led to evolution of weapons while intersexual selection has led to ornamentation.

In intersexual selection, mates are selected on the physical and behavioural characteristics they possess, which are often taken as markers of overall fitness. In males, this takes the form of size, strength or elaborate ornamentation. For example, peacocks advertise their fitness by spreading their brilliant blue and green tail feathers and strutting back and forth. The peahens prefer peacocks with larger and more colourful feathers – they carefully examine the quality of the ornate plumage before making a choice. Thus, the peahen's preference ensures that males with larger and showier feathers pass on their genes,

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/natural-selection-id-43805/print/) Assign

Student view

Overview (/study/ap 422-cid-755105/o

including genes that will increase the ability to survive and reach reproductive age. Similarly, differences in the courting songs of some birds, the croaks of the frogs or the large antlers of deer are used by the females to gauge fitness and eventually choose mates.

Credit: Gerard Soury, Getty Images

Credit: Martin Ruegner, Getty Images

Figure 3. Courtship rituals. **a)** The display of tail feathers by the male peacock has to meet the approval of the peahen. **b)** The male European tree frog (*Hyla arborea*) croaks to attract the female.

Birds of paradise are a prime example of intersexual selection. Found in the forests of Papua New Guinea, there are close to 40 species of birds, all very different from one another. The males are flamboyant and showy, and come in a variety of body shapes, sizes and colours.

Student view

Overview
(/study/ap
422-
cid-
755105/o

For example, the ribbon-tailed *Astrapia* (*Astrapia mayeri*) has white tail feathers nearly a metre in length. The females are generally more subdued with greys and browns. They aren’t the ones that have to attract a mate in this species! The courtship ritual of the males is elaborate, often consisting of spreading of feathers, bird song and special dance moves, all in an effort to entice a female. The female selects the most impressive male, ensuring that his genes pass on to the next generation. In a way, the females decide how the males evolve!

See the elaborate courtship dance of birds of paradise in **Video 1**.

Video 1. Courtship rituals: birds of paradise.

Darwin realised that the elaborate adaptations in animals were less to do with daily survival and more due to sexual selection. Sexual selection leads to differences between the sexes and is thought to be the chief cause of sexual dimorphism in animals.

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/biological-fitness-id-46651/print/) Assign

Aspect: Hypotheses

The mating displays of birds of paradise have been studied by ornithologist Edwin Scholes III. According to him, the courtship performance can be broken down into ‘modules’ or steps. The males create unique performances by rearranging and reorganising these steps. If the females prefer these courtship organisations, the displays become more and more prevalent within the population. Modularity of the courtship ritual thus allows new behavioural characteristics to develop quickly and

Student
view

Overview
(/study/ap
422-
cid-
755105/o

spread through the population, speeding up the process of evolution. This is an example of a hypothesis — a provisional explanation made by scientists to explain patterns seen in nature.

Modelling of sexual and natural selection

Guppies are tropical, freshwater fish that are now found throughout the world. Often referred to as rainbow or million fish, they have been used to study evolution in the wild. In the 1970s, biologist John Endler began studying guppies living in the streams of Trinidad. He was struck by the range of colouration in guppies living in different streams as well as different parts of the same stream (**Figure 4**). Some of the guppies were brightly coloured with spots while others were dull and drab. Further studies revealed that in parts of the stream where there were numerous predators, the guppies were drab and dull. On the other hand, in parts of the stream where there were fewer predators, the guppies were brightly coloured.

Figure 4. Colour variations are common in male guppies, with females demonstrating a distinct preference for the more brightly coloured males.

Credit: sommail, Getty Images

The range of colours seen in male guppies is thought to be the result of natural selection. The drab colours would have helped the guppies to camouflage. If that were the case, why did the bright colours and spots evolve at all?

Student
view

Overview (/study/ap 422- cid- 755105/o

Endler's experiments

To answer these questions, Endler carried out a series of experiments. In one experiment, he cultivated guppies in ponds.

Stage 1

Endler built artificial ponds and stocked them with guppies. There was considerable variation among the male guppies at this point. Endler calculated the mean number of spots on the male guppies. The guppies were left to breed for 6 months. It is important to note that in these 6 months, the guppies were able to reproduce several times.

At the end of 6 months, Endler noticed that there was an increase in the mean number of spots on the male guppies. This suggested that the highly spotted males were more attractive to the females and hence had more offspring. This was sexual selection in action.

Stage 2

Endler now divided the population into three groups and placed them in three separate ponds (A, B and C).

- In pond A, he did not add any other fish.
- In pond B, he added *Rivulus*, a genus of fish that feeds sporadically on juvenile guppies and is probably the least dangerous of all guppy predators.
- In pond C, he added pike cichlids, a type of fish that are voracious predators of guppies.

He left the populations in the three ponds alone for nearly 20 months. During this period, the guppies bred several times. He then carried out his final analysis and found that in ponds A and B the mean number of spots had increased, while in pond C the mean number of spots had decreased.

He concluded that in ponds A and B, in the absence of predators, sexual selection favoured the males with spots. The population, within a short period of time, had evolved into one of brightly coloured males. In pond C, natural selection favoured individuals with drab colours (who could hide from the predator) and the population, over the same period of time, had evolved into one of dull-coloured males.

Student view

Try the activity below in which you will analyse data from a similar experiment.

Overview
(/study/ap
422-
cid-
755105/o

Activity

- **IB learner profile attribute**: Inquirer
- **Approaches to learning:** Research skills — Comparing, contrasting and validating information
- **Time required to complete activity:** 15—20 minutes
- **Activity type:** Individual activity

The details of a hypothetical experiment are given below.

There are two pools, A and B, each stocked with 100 guppies. There are four types of guppies: drabbest, drab, bright and brightest. Answer the questions by analysing the variations seen at the start and end of the experiments.

Dataset A

Pool A started with an even mix of the four types of guppies. Guppy predators such as cichlids and *Rivulus* were added to the pool. The data collected after 60 weeks is as follows.

Number of weeks: 60

Number of generations: 5

Number of guppies: 160

Brightest: 24

Bright: 16

Drab: 40

Drabbest: 80

Calculate the percentage of each of the four types of guppies seen at the end of 60 weeks.

Identify and explain the factors that contributed to the change in the composition of the population.

Predict future changes in the composition of the population, justifying your answer.

Dataset B

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Pool B started with a population of 100 guppies. Most of the guppies were drab, with a few bright ones. *Rivulus* was added to the pool. The data collected after 57 weeks is as follows.

Number of weeks: 57

Number of generations: 5

Number of guppies: 232

Brightest: 202

Bright: 18

Drab: 7

Drabbest: 5

Calculate the percentage of each of the four types of guppies seen at the end of 57 weeks.

Identify and explain the factors that contributed to the change in the composition of the population.

Draw conclusions regarding the causes for the variations in the composition of the population after analysing the data from both datasets A and B.

5 section questions

D4. Continuity and change: Ecosystems / D4.1 Natural selection

Gene pools and changes in their composition (HL)

D4.1.9: Concept of the gene pool (HL) D4.1.10: Allele frequencies of geographically isolated populations (HL)

D4.1.11: Changes in allele frequency in the gene pool (HL)

Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Define the concept of a gene pool.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

- Describe the changes that occur in allele frequencies in geographically isolated populations.
- State the causes for the changes in allele frequency in the gene pool.

The black-footed ferret (*Mustela nigripes*) is a carnivore that preys on prairie dogs (genus *Cynomys*). In the early 20th century, the decimation of the prairie dog population and conversion of the prairies to farmland led to a significant decrease in the population of the ferrets, too. In 1979, the black-footed ferrets were declared extinct. The discovery of a small population in the wild led to a captive breeding program. Slowly, as the numbers increased, the ferrets were released into the wild (**Figure 1**). Yet, these populations are vulnerable to disease and biologists have concerns about their longevity. Despite a growing increase in numbers, why are scientists worried about the future of these animals?

Student
view

Overview
(/study/app
422-
cid-
755105/o

Figure 1. Saving the black-footed ferret.

Credit: Mark Newman, Getty Images

Gene pool

Evolution is often defined as a change in the genetic composition of a population over time. A population (see section C4.1.1 (/study/app/bio/sid-422-cid-755105/book/population-sizes-and-random-sampling-id-44711/)) is defined as a group of interbreeding organisms belonging to the same species living in a given area. The gene pool is the sum total of all the alleles of all the genes present in a population.

The gene pool is an indicator of the genetic variation that exists in a population. A large gene pool indicates extensive genetic variation. This in turn indicates a greater ability of the population to adjust and adapt to changes in the environment. For example, when a pathogen is introduced into a large population, there is a greater chance that some individuals already have a version of a gene that enables them to resist the pathogen, survive and reproduce. On the other hand, a small gene pool indicates lower genetic variation. This in turn makes the population less able to adapt when faced with environmental changes.

Allele frequency

The allele frequency is the relative frequency of a particular allele (in comparison to the other alleles of the same gene) in a population. Its value can range from 0 (meaning that it is not present in any individuals) to 1 (meaning that it is present in all individuals) and can be expressed as a decimal, fraction or percentage.

The allele frequency can be calculated if you know the different genotypes associated with the allele in a population. In general:

$$\text{frequency of allele X} = \frac{\text{number of copies of allele X in population}}{\text{total number of copies of the gene in the population}}$$

Keep in mind that there could be more than two alleles for a gene, like in the case of human blood groups (see section D3.2.9 (/study/app/bio/sid-422-cid-755105/book/allele-combinations-id-46205/)).

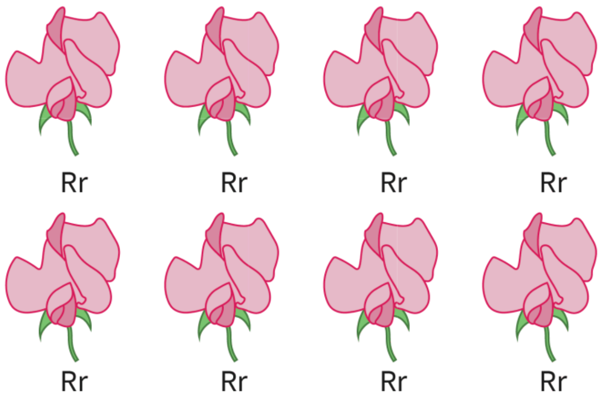
Student
view

Overview
(/study/ap
422-
cid-
755105/o

Calculating allele frequency

Consider, for example, a small population of eight plants of *Mirabilis jalapa*. Both **R** and **r** are alleles of the gene for flower colour. Due to incomplete dominance (see section 3.2.10 (/study/app/bio/sid-422-cid-755105/book/allele-combinations-id-46205/)) there are three phenotypes – red (**RR**) flowers, pink (**Rr**) flowers and white (**rr**) flowers.

The frequency of the allele can be calculated as shown in **Figure 2**.



More information

The image is a diagram that consists of eight pink flowers arranged in two rows, four flowers per row. Beneath each flower, the text 'Rr' is written, representing a genotypic label for each individual flower. The flowers have green stems and leaves, and the primary focus is on the repeated 'Rr' labeling, indicating a genetic notation, possibly referencing allele frequency or genetic combinations. This seems to relate to the concept of allele frequency as stated in the text prior to the image.

[Generated by AI]

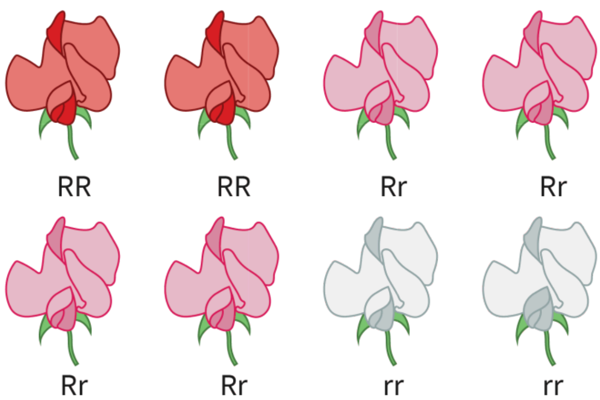


Figure 2. The allele frequency remains constant from one generation to the next with both the alleles being equally represented.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Let’s suppose we check the allele frequency of the plants after a few generations. The current generation is as shown in **Figure 3**. You will notice that the allele frequency has changed.

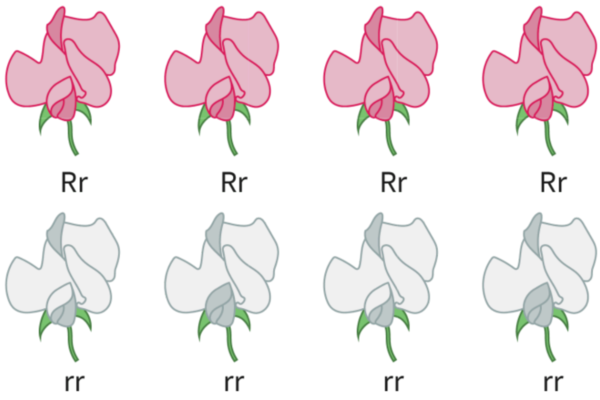


Figure 3. The allele frequency has changed, with the frequency of **r** increasing.

More information for figure 3

The image depicts an illustration of six flowers organized in two rows. The top row contains four pink flowers labeled with the allele combination 'Rr' beneath each. The bottom row contains two gray flowers labeled 'rr' beneath each. The flowers appear to be the same type, differentiated by color and allele labeling. This arrangement visually represents the allele frequency of the plants, with more occurrences of the 'Rr' allele combination than the 'rr' combination, highlighting the increase in the frequency of 'r'.

[Generated by AI]

Allele frequency in geographically isolated populations

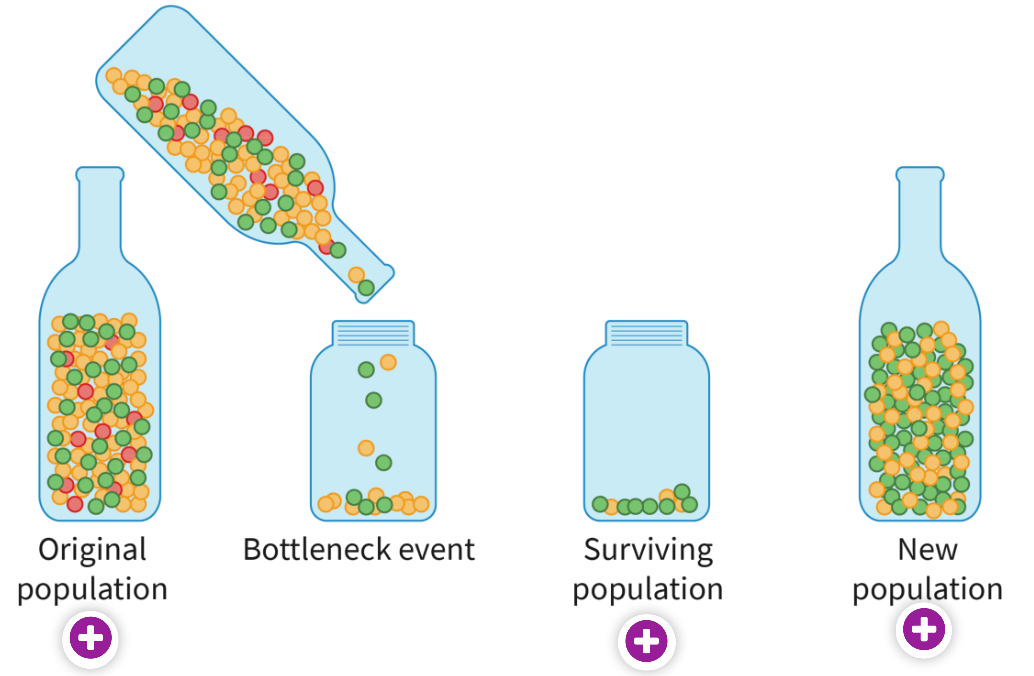
The frequency of alleles in the gene pool can change due to both natural selection and chance or random events. Genetic drift is the change in allele frequencies in the gene pool of a population due to chance events. The impact of genetic drift is greater if the populations are small and/or geographically isolated from each other.

Genetic drift can occur in two situations: the bottleneck effect and the founder effect.

Bottleneck effect

At times, events such as earthquakes or a tsunami can lead to a sudden decrease in the population. The handful of survivors left behind may not represent the genetic diversity of the original population. While the population may rebound and increase in numbers, the reduction in genetic variation makes them less adaptable, as seen in the black-footed ferrets. This is known as the bottleneck effect. **Interactive 1** illustrates an example of the bottleneck effect.

Student
view



Interactive 1. Bottleneck Effect.

More information for interactive 1

This interactive illustrates the bottleneck effect, a key concept in population genetics where a sudden, drastic reduction in population size leads to a significant loss of genetic diversity. The image explains the concept using glass bottles and coloured marbles, and the hotspots provide information about diversity.

The first bottle is labelled “Original population” and represents a large, genetically diverse population. This is seen by the large number of differently coloured beads representing a population with varied genetic traits. The next bottle is labelled “Bottleneck event” which is a catastrophic event that drastically reduces the population. Only a small, random subset of individuals survives. The third bottle is labelled “Surviving population” and shows that a tiny group or single lineage emerges from the bottleneck, while certain alleles are lost. Specifically, the red marbles were lost in the bottleneck. The last bottle is labelled “New Population”, and it shows that the population rebounds in numbers over time, but the genetic diversity remains low. The final stage may show a larger group, but with reduced genetic variation compared to the original population.

There are 3 Hotspots represented by plus signs at various places. Hotspot 1 is below the first bottle- Original population. Hotspot 2 is below the third bottle- Surviving population. Hotspot 3 is below the last bottle- New Population. Clicking on the hotspots reveals the numbers of different colored marbles present in each bottle.

The following items are revealed at respective hotspots:

Hotspot 1: Orange 60, Green 30, Red 10

Hotspot 2: Orange 3, Green 7, Red 0
Hotspot 3: Orange 40, Green 60, Red 0

This interactivity demonstrates that random survival during the bottleneck alters allele frequencies, and that reduced diversity limits the population’s ability to adapt and evolve in response to new challenges.

Overview (/study/ap 422- cid- 755105/o

For example, in the 1800s, the hunting of northern elephant seals (*Mirounga angustirostris*) reduced their population to a mere 20 individuals. Today, conservation efforts have led to an increase in their numbers to over 30 000 individuals. Yet, the gene pool of the entire population is more or less the gene pool of the random survivors. In other words, the genetic make-up of the current population comprises mainly of the alleles of the survivors, indicating a loss in genetic diversity (**Figure 4**). For instance, the killing of individuals could have led to the loss of many alleles and/or changed the frequency of others. Similarly, as the population recovers and increases in number, certain other alleles may become more common or over-represented in the gene pool.

Figure 4. Studies of northern elephant seals have revealed a high degree of similarity in the alleles, indicating a loss of genetic variation.

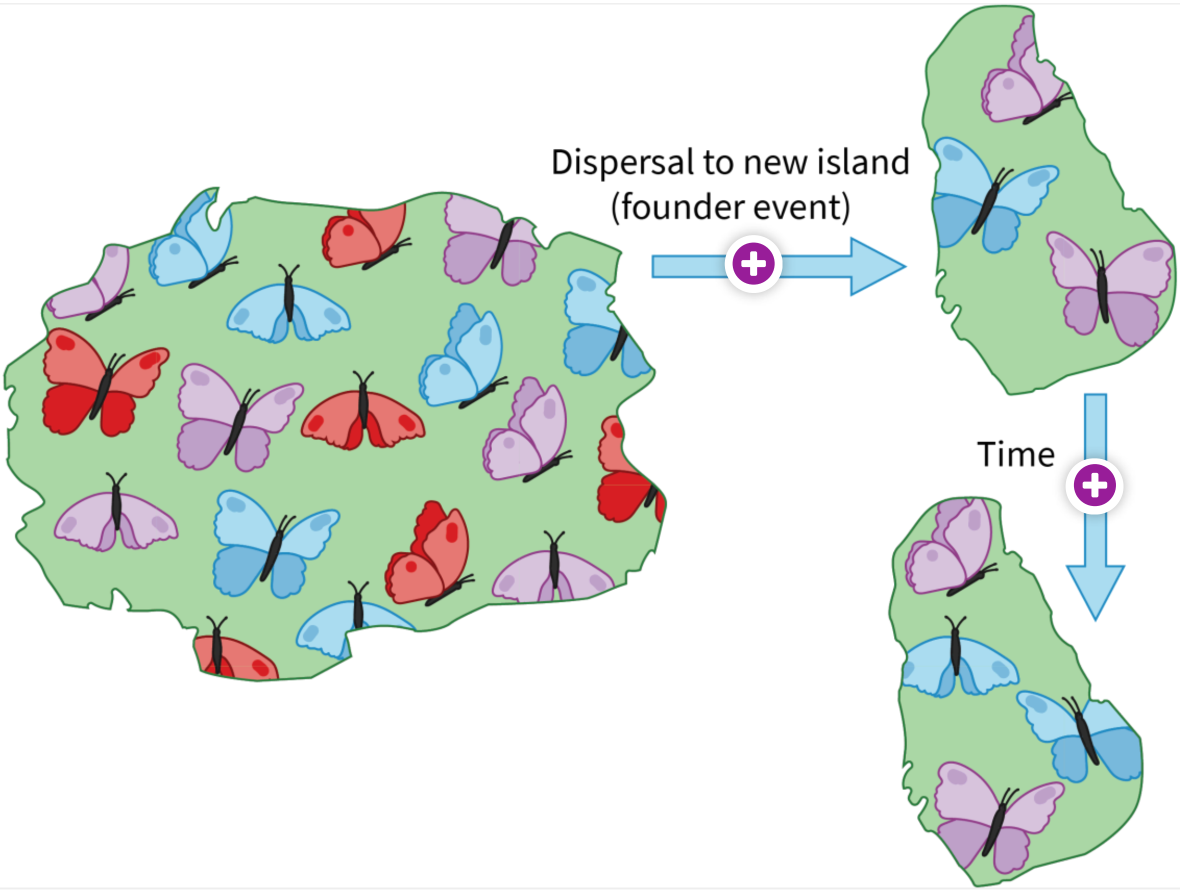
Credit: Jeff Foott, Getty Images

Founder effect

Suppose a small subset of the population breaks away from the larger population to colonise a new area. The population that branches off may not be an exact genetic representation of the original population. Genetic variation could be lower. Less frequent (or rarer) genes may be under-represented or absent altogether while others may be over-represented. As the population increases, the composition of the gene pool would be very different from the original population. In other words, the genotypes and phenotypes may be very different. This is known as the founder effect. **Interactive 2** illustrates an example of the founder effect.

Student view

Overview
(/study/ap
422-
cid-
755105/o



Interactive 2. Founder Effect.

More information for interactive 2

The interactive represents the founder effect, a genetic phenomenon that occurs when a small group of individuals from a larger population establishes a new, isolated colony. The phenomenon is explained with the help of butterflies in the interactive.

The left side of the illustration displays a large island with many butterflies of different colors (red, purple, blue), representing a genetically diverse population. An arrow labeled "Dispersal to new island (founder event)" points to a smaller, separate island with only a few butterflies (blue and purple), showing reduced genetic diversity. A second arrow labeled "Time" points downward to a third image of the same island, now with butterflies that differ slightly in appearance from the original population, indicating genetic divergence over time due to isolation. Unique alleles may become more common due to genetic drift.

There are 2 Hotspots represented by plus signs at various places. Hotspot 1 on the arrow labeled as dispersal to new island. Hotspot 2 on the arrow labeled as time. Clicking on the hotspots reveals what is happening in that place.

The following items are revealed at respective hotspots:

Hotspot 1: A subset of the butterfly population colonises a new island. There is loss of variation.

Student
view

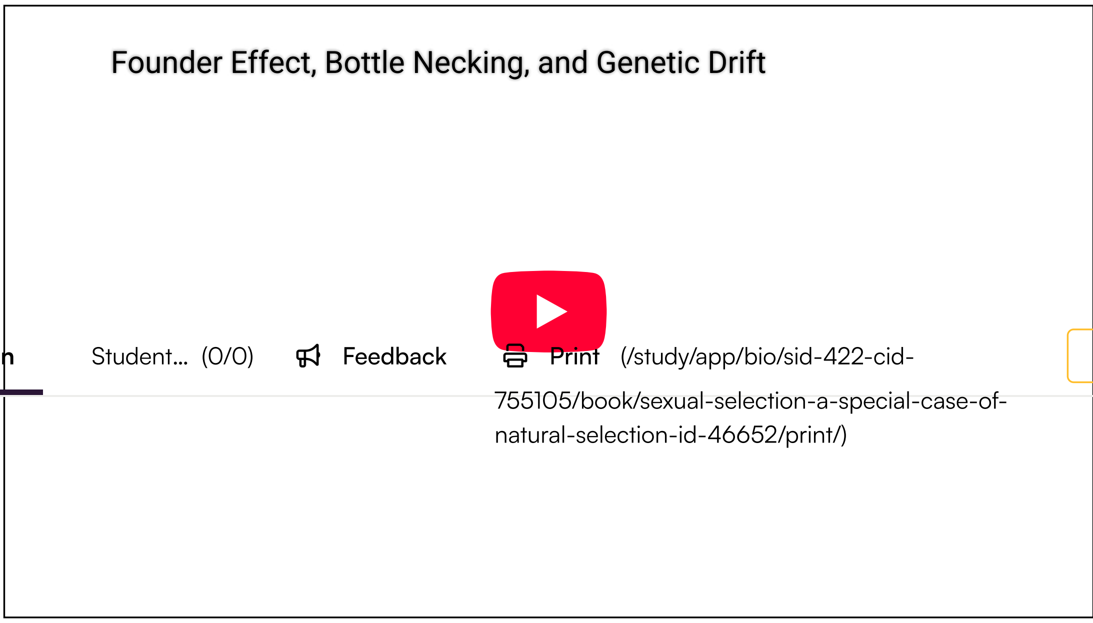
Overview
(/study/ap
422-
cid-
755105/o

Hotspot 2: Over time, the population increases. The genetic composition of the gene pool is different from that of the ancestral population.

This illustration demonstrates how isolated populations develop unique traits.

In 1652, a shipload of Dutch immigrants landed in South Africa. They were the founders of the Afrikaner population of South Africa. The ship contained individuals suffering from a genetic disorder known as Huntington's disease, symptoms of which normally appear only after the age of 40. Today the Afrikaner population has a higher than usual incidence of Huntington's disease, with most cases being traced back to the founders, indicating an increase in the frequency of the harmful allele.

Video 1 illustrates the mechanism of genetic drift.



Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/sexual-selection-a-special-case-of-natural-selection-id-46652/print/) Assign

Video 1. Founder effect and bottleneck effect.

Databases in determining allele frequencies

Several databases allow you to compare the frequency of a particular allele across many populations.

Practical skills

Tool 2: Technology — Applying technology to collect data

Student
view

Overview (/study/app/bio/sid-422-cid-755105/o

Inquiry 3: Concluding and evaluating — Concluding

The lactase gene (LCT) encodes for the lactase enzyme, needed for the digestion of lactose. It is estimated that two-thirds of the world population are lactase non-persistent and unable to digest lactose, while others are lactase persistent. This difference is due to single-nucleotide polymorphisms (SNPs; see section D1.3.1 (/study/app/bio/sid-422-cid-755105/book/gene-mutations-id-43806/)) in the regulatory region of the MCM6 gene, located upstream of the LCT gene.

Use the Allele Frequency Database (ALFRED) to study the allele frequency of this allele.

1. Visit https://alfred.med.yale.edu/ALFRED/index.jsp (https://alfred.med.yale.edu/ALFRED/index.jsp)

2. Using the 'Search' feature, type in the name of the SNP or gene of interest and click 'Submit'. In this case, type in **MCM6** (this is the gene we are interested in) and choose the "site" option below the search bar.

3. A page showing the search results will come up. In this case, two results will show, both of which are the same. Click on the ALFRED UID and a table of search results will be displayed. (Within ALFRED, you can search for a gene, allele or SNP. Typing in the name of the gene, for example, will give you multiple results since one gene can have several alleles/SNPs.) Make sure that the allele name(s) displayed coincides with your allele of interest. Here, we are interested in studying SNP **-13910**. Selecting this option from the table will take you to the 'Polymorphism Information' page.

4. On the 'Polymorphism Information' page, you will see information about your chosen allele including the frequency of this SNP in certain populations.

5. In the frequency data section, you can choose to view the SNP's frequency either in tabular or graphical format. For easy visualisation, in this case we will use the graphical format.

6. Examine the data carefully. Use the information above about lactase non-persistence and lactase persistence to answer the following questions.

a. Which are the populations with the highest prevalence of lactase persistence?

b. Which are the populations with the highest prevalence of lactase non-persistence?

7. Now go back to the 'Polymorphism Information' page and click on the 'tabular format' under 'Frequency Data'. You will see the same data in the form of a table,

8. Explain the implications of these frequencies on the global population.

In a similar manner, study the allele frequencies of SNP rs12913832 in the HERC2 gene, determining blue or brown eye colour in humans.

Student view

Overview
(/study/app
422-
cid-
755105/o

Neo-Darwinism

Darwin introduced natural selection as a mechanism that leads to evolution. However, at the time Darwin established his theory, he like many others had no real understanding of genetics. Mendel had yet to publish the results of his experiments on pea plants. So while Darwin stated that natural selection acted on heritable traits, he was unable to explain the mechanism of how heritable traits passed on from one generation to the next – that is, how variation arose in the population and how heritable traits disappeared and reappeared.

Modern synthesis or neo-Darwinism is the combined work of many scientists and tries to explain natural selection on the foundation of Mendelian genetics.

The theory states the following.

- Evolution is the change in the genetic composition of the gene pool of a population. Neo-Darwinism clarifies that the phenotype (see section D3.2.4 (/study/app/bio/sid-422-cid-755105/book/expression-of-phenotypes-id-46204/)) is largely a product of the genotype. Natural selection, therefore, increases the frequency of beneficial alleles (and reduces the frequency of harmful alleles), resulting in microevolution.
- Apart from natural selection, other factors such as genetic drift and gene flow can bring changes in the gene frequency of a population.
- Mutation (see section D4.1.2 (/study/app/bio/sid-422-cid-755105/book/natural-selection-id-43805/)) is the ultimate source of genetic variation.
- Thus, microevolution results in changes in the frequency of alleles in a population over many generations. These changes gradually add up and over a long period of time lead to large changes such as the formation of a new species (macroevolution).

Try the modelling activity below to enhance your understanding of the founder effect and bottleneck effect.

Activity

- **IB learner profile attribute:** Communicator
- **Approaches to learning:** Communication skills — Clearly communicating complex ideas in response to open-ended questions

Student
view

Overview
(/study/ap
422-
cid-
755105/o

- **Time required to complete activity:** 20—30 minutes
- **Activity type:** Group activity

Form groups of four. Use any scrap materials, such as marbles of different colours, building blocks, buttons and so on. Construct models to illustrate the concepts of the founder effect and the bottleneck effect. Describe and explain the concepts using the model. Make sure that you highlight the differences between the founder effect and the bottleneck effect.

5 section questions

D4. Continuity and change: Ecosystems / D4.1 Natural selection

Types of selection; Hardy-Weinberg equilibrium; Artificial selection (HL)

D4.1.12: Directional, disruptive and stabilising selection (HL) D4.1.13: Hardy—Weinberg equation (HL)
D4.1.14: Hardy—Weinberg conditions required for genetic equilibrium in a population (HL) D4.1.15: Artificial selection (HL)

Higher level (HL)

Learning outcomes

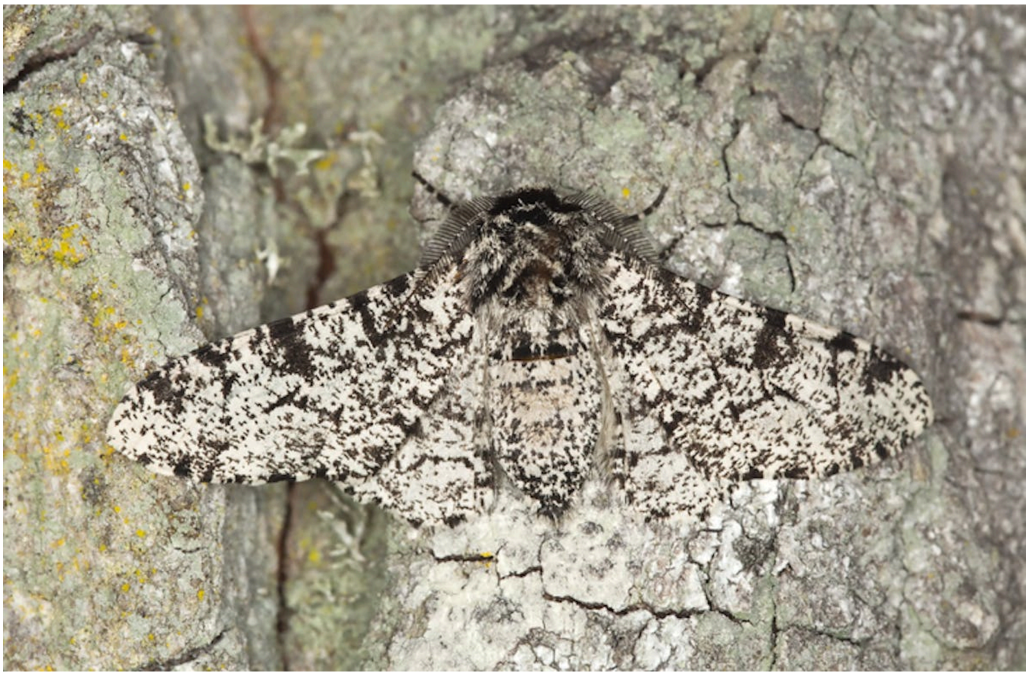
By the end of this section you should be able to:

- Differentiate among directional, disruptive and stabilising selection.
- Define Hardy—Weinberg equilibrium.
- Identify the Hardy—Weinberg conditions that need to be maintained for genetic equilibrium in a population.

Look at the photos given in **Figure 1**. In the first instance, the light-coloured peppered moths (*Biston betularia*) are well camouflaged, unlike the dark ones. Natural selection would clearly favour the light-coloured moths. In the second instance, the deposition of soot on the tree trunks gives the selective advantage to

Student
view

the dark-coloured moths. In this setting, it is evident that natural selection will favour the dark-coloured moths. How does natural selection impact the distribution of the phenotypes in this population?



Credit: Henrik_L, Getty Images

Credit: Tamara Zerbe, Getty Images

Figure 1. a) Before the Industrial Revolution. **b)** After the Industrial Revolution.

Types of natural selection

As you have learned, natural selection acts on the variation present in the population, bringing a change in the allele frequency. There are three types of natural selection – stabilising selection, directional selection and disruptive

Overview
(/study/ap
422-
cid-
755105/o

selection – all of which result in changes in the allele frequency.

Stabilising selection favours the average individuals with intermediate forms of the trait and eliminates the extreme forms. As selection favours the moderate phenotype, over a period of time, most of the individuals look similar to each other, with a loss in genetic diversity. For instance, studies have shown that high and low birth weights in babies are often associated with increased mortality rates. Babies with average birth weights thus have a selective advantage.

Directional selection favours one extreme form of the trait over all the other forms of the trait. Directional selection is seen when the environment changes. The peppered moth simulation activity that you did earlier represents directional selection. A typical example is that of giraffes, where the change in the environment gave a selective advantage to the giraffes with long necks (that is, the extreme variation of the trait was selected). Over a period of time, this gave rise to populations with longer necks. Drug resistance in bacteria (see section C3.2.14 (/study/app/bio/sid-422-cid-755105/book/antibiotics-and-antibiotic-resistance-id-43959/)) is another example of directional selection, where selection favours individuals carrying the genes for antibiotic resistance. Look at **Figure 2** for a further example of directional selection.

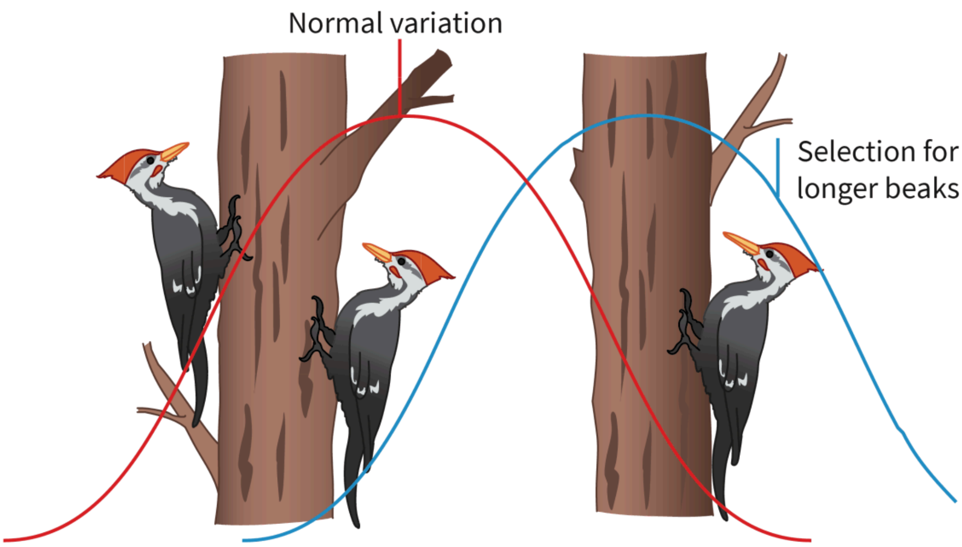


Figure 2. An example of directional selection. Woodpeckers drill holes with their beaks to feed on insects. A change in the environment results in insects burrowing deeper into the bark. Woodpeckers with longer beaks have the selective advantage over ones with average-sized or shorter beaks.

More information for figure 2

The image is a diagram illustrating directional selection in woodpeckers. It shows two woodpeckers positioned on separate trees. The left woodpecker represents normal variation with a shorter beak, correlated with a red bell curve labeled "Normal variation." The right woodpecker has a longer beak,

Student
view

Overview
(/study/ap
422-
cid-
755105/o

associated with a blue bell curve labeled "Selection for longer beaks." The diagram visually represents how, over time, selective pressures favor woodpeckers with longer beaks in response to environmental changes, such as insects burrowing deeper into the bark.

[Generated by AI]

Disruptive selection is when both the extreme forms of the trait are favoured over the intermediate forms of the trait. For example, imagine a population of mice living in an area with sandy beaches and dark-coloured rocks. The fur colour of the mice ranges from cream to tan to dark brown. In the sandy areas, the cream-coloured mice have an advantage, while in the rocky areas, the dark brown mice have an advantage from aerial predators (**Figure 3**). However, the tan-coloured mice are at a disadvantage as they can be easily spotted in both the areas. Thus, selection favours the extreme forms of the phenotype and eliminates the intermediate forms. Disruptive selection acting over a period of time could eventually lead to the formation of a new species.

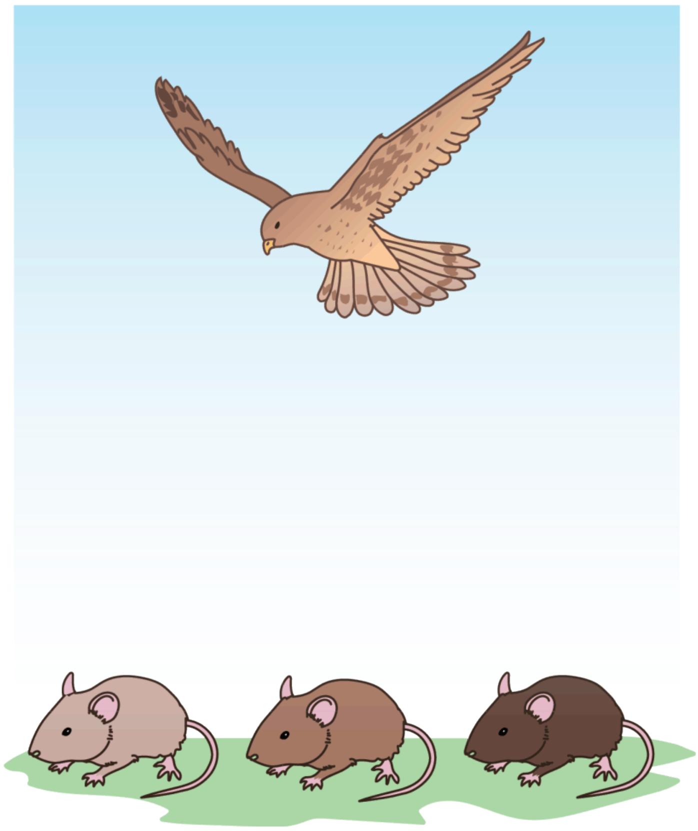
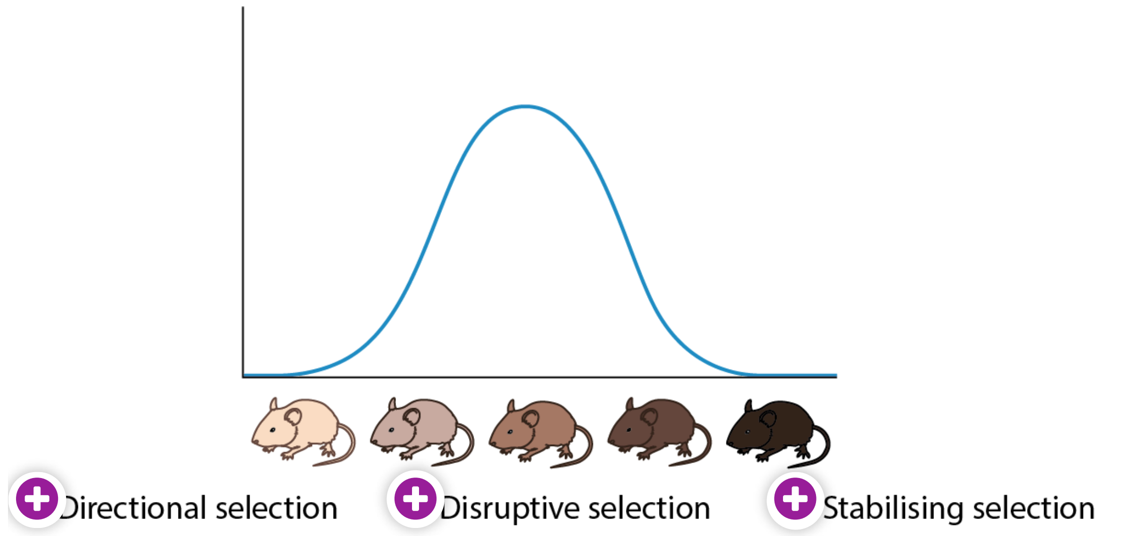


Figure 3. Disruptive selection. The extreme variants — the cream-coloured mice and the dark brown mice — have a selective advantage over the tan-coloured mice.

All three types of selection lead to changes in the frequency of alleles. Over a period of time, significant changes in the composition of the gene pool of a population could lead to the emergence of new species.

Student
view

The three types of selection are summarised in **Interactive 1**.



Interactive 1. Three Types of Natural Selection.

More information for interactive 1

The interactive image is a conceptual biology diagram illustrating three types of natural selection—directional selection, disruptive selection, and stabilising selection. The interactive uses graphs and cartoon mice of different colours to visually represent variations in a population.

In the middle of the interactive is a blue-coloured bell curve, shown on a standard XY graph, with the x-axis likely representing phenotypic variation and the y-axis representing fitness or frequency of each trait. Beneath the graph are five cartoon mice, each coloured differently. From left to right, the colours of mice include: Pale cream, light brown, medium brown, dark brown and almost black. Each mouse represents a different variation in fur colour, moving from light on the left to dark on the right.

Below the mice, there are three labels. From left to right, these labels are: Directional selection, Disruptive selection and Stabilising selection. Each of these labels has a hotspot, indicated by a plus sign. Clicking on these hotspots further reveals the graph of the corresponding type of natural selection.

Read below for the description of the graph in each hotspot:

Hotspot 1: Disruptive Selection

Clicking on the hotspot near the disruptive selection reveals a line graph. The graph consists of a dotted red bell-shaped curve in the centre, which indicates the original trait distribution before selection. There is also a solid red M-shaped curve with two peaks, indicating the new trait distribution after disruptive selection. The solid line overlaps with the dotted line, with the two peaks of the solid line being one on each side of the peak of the dotted line. Beneath the graph, there are two cartoon mice, a light-brown coloured mouse on the left and an almost black coloured mouse on the right. This indicates that disruptive selection favours extreme traits at both ends of the spectrum (light and dark fur in this case). Over time, the population evolves into two distinct groups, one with light fur and the other with dark fur.

Hotspot 2: Directional selection

Clicking on the hotspot near the directional selection reveals a line graph with two overlapping bell curves. A dotted red curve on the left, indicates the original trait distribution before selection and a solid red curve on the right, indicates the new trait distribution after directional selection. Below the graph, there are 3 cartoon mice: a medium-brown mouse, a dark-brown mouse and an almost-black mouse. The

Overview
(/study/ap
422-
cid-
755105/o

graph indicates that the fur colour has shifted from left to right (from light colour to dark colour.). Directional selection indicates that extreme traits become more advantageous over time and the population shifts toward that trait. In this case, darker fur (almost black) gives mice a better chance at survival, possibly due to environmental changes (e.g. darker ground or surroundings).

Hotspot 3: Stabilising Selection

Clicking on the hotspot near the stabilizing selection reveals a line graph with two overlapping bell curves. A dotted red curve that is wider and shorter, indicates the original trait distribution before selection. A solid red curve that is taller and narrower, indicates the new distribution after stabilising selection. There is a medium brown-coloured mouse beneath the graph, aligned with the peak of both curves. This indicates that stabilising selection favours average traits (mice with medium brown fur in this case) over extreme traits. Over time, medium brown mice increase in population, while light and dark-coloured mice at both ends become less common.

This interactive is designed to visually explain the three types of natural selection—Directional, Disruptive, and Stabilising—through an engaging combination of graphs and illustrated mice with different fur colours. The graphs in hotspots help users understand how populations evolve under different environmental pressures.

Hardy—Weinberg equation

Ideally, dominant alleles should drive out recessive alleles (see section D3.2.5 (/study/app/bio/sid-422-cid-755105/book/innate-and-adaptive-immune-systems-id-45757/)) over time. Yet scientists observed that both dominant and recessive alleles continue to persist in populations. What leads to the maintenance of variation in a population? The answer to this query came from the independent efforts of a British mathematician, G. Hardy, and a German doctor, G. Weinberg.

The Hardy–Weinberg principle states that in a stable population, the frequency of the alleles would remain constant generation after generation, provided certain conditions are met. This law is mathematically expressed in the form of a binomial equation.

Let us consider a single gene with two alleles, **R** and **r**. The combinations of these alleles would result in three genotypes: **RR**, **Rr** and **rr**.

By convention, the frequency of **R** is denoted by p and the frequency of **r** by q.

In a gene pool, p and q represent 100% of the alleles of a specific gene.

Therefore, this can be expressed as:

$$p + q = 1 \text{ (that is, 100\%)}$$

Student
view

Now square both sides of the equation:

Overview
(/study/ap
422-
cid-
755105/o

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

Expand out the brackets to give:

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

In the equation:

- p^2 represents the frequency of individuals homozygous for one allele, i.e. the frequency of the genotype **RR**
- q^2 represents the frequency of individuals homozygous for one allele, i.e. the frequency of the genotype **rr**
- *2pq* represents the frequency of heterozygous individuals, i.e. the frequency of the genotype **Rr**.

Thus, the Hardy–Weinberg equation helps to calculate the genotype frequencies of homozygous dominant individuals, heterozygous individuals and homozygous recessive individuals.

Worked example

Question

A population of 100 mice can be either black or white. The black allele (**B**) is dominant over the white allele (**b**). If the frequency of **B** is 0.6, determine:

1. the frequency of **b**
2. the frequencies of the various genotypes
3. the number of individuals per genotype.

Step 1

Let p be the frequency of **B** and q be the frequency of **b**.

- $p + q = 1$

$q = 1 - 0.6 = 0.4$

Step 2

The frequency of the individuals (genotypes) can be obtained using the equation $p^2 + 2pq + q^2 = 1$, where

- p^2 is the frequency of the dominant homozygous individuals (**BB**).

$p^2 = (0.6)^2$

$p^2 = 0.36$

Student
view

Overview (/study/ap 422- cid- 755105/o

- $2pq$ is the frequency of the heterozygous individuals (**Bb**).

$2pq = 2 \times 0.6 \times 0.4$

$2pq = 0.48$

- q^2 is the frequency of the recessive homozygous individuals (**bb**).

$q^2 = (0.4)^2$

$q^2 = 0.16$

You can check your answer at this stage by substituting the values in the formula:

- $p^2 + 2pq + q^2 = 1$

$0.36 + 0.48 + 0.16 = 1$

Step 3

Multiplying the frequency by the total population will give you the number of individuals with that genotype.

- p^2 × total population = 0.36 × 100 = 36 black mice with **BB** genotype.
- $2pq$ × total population = 0.48 × 100 = 48 black mice with **Bb** genotype
- q^2 × total population = 0.16 × 100 = 16 white mice with **bb** genotype.

Conditions that affect the Hardy—Weinberg equilibrium

The Hardy–Weinberg equilibrium refers to a state of genetic equilibrium where the frequency of the alleles remains the same generation after generation. The Hardy–Weinberg equilibrium stands true if the following conditions are met.

- There are no mutations. Mutations bring in new alleles and disrupt the equilibrium of the frequencies of the alleles.
- There is random mating. In most populations, non-random mating is the norm as reproduction involves 'selecting' a mate. This in turn leads to sexual selection.
- Natural selection cannot occur.
- No genes should enter or leave the population. Breeding between two populations transfers new alleles, resulting in gene flow, and disrupts the Hardy—Weinberg equilibrium. Hybridisation (see section A4.1.10 (/study/app/bio/sid-422-cid-755105/book/adaptive-radiation-and-barriers-to-id-43796/)), especially in plants, can also introduce new genes into the population.
- The population must be large. In small populations, genetic drift or chance events cause changes in the allele frequencies.

Student view

Overview
(/study/ap
422-
cid-
755105/o

To summarise, a population at Hardy–Weinberg equilibrium is at genetic equilibrium and is not evolving. However, in most natural populations none of these conditions are met. For instance, mating is non-random, mutations are frequent, populations migrate resulting in gene flow and natural selection acts on favourable traits. Changes in the frequency of the alleles indicate evolution at work.

Identify the types of selection shown in **Interactive 2**. Drag and drop the examples to complete the table.

Directional selection	Disruptive selection	Stabilising selection

In a bird species, the dull and brightly coloured males are more successful than the intermediate-coloured males in obtaining mates

Brown mice blend in better with the forest floor as compared to white mice or black mice

Starlings (birds) with a clutch size of 4–5 eggs have more surviving young than ones that lay 1–2 eggs or 7–8 eggs

An increase in the length of the giraffe neck

Pesticide resistance in insects

Check

Interactive 2. Types of Natural Selection.

Artificial selection

For hundreds of years, long before people knew about the concept of natural selection, farmers, animal breeders and horticulturists had been selecting traits to be represented in the next generation. This process is known as artificial selection

Student
view

Overview (/study/app/bio/sid-422-cid-755105/o

or selective breeding (see section A4.1.3 (/study/app/bio/sid-422-cid-755105/book/evidence-from-sequence-data-id-43791/)).

Artificial selection is similar to natural selection except that it is perpetuated by humans. Humans select organisms with desirable traits, from high yield for crop products or milk to disease resistance and faster growth rate. This is followed by breeding for several generations until the favourable traits manifest strongly in the offspring. The selection of some traits over others leads to a change in the frequency of alleles. As a result, the descendant plants and animals are genetically different from the ancestral wild population.

Some common examples of artificial selection are given below.

- Dogs evolved from wolves due to domestication. The breeds that we have today — such as Great Danes, terriers and chihuahuas — are a result of selective breeding.
- Many crop plants seen today — including wheat, maize and rice — are products of artificial selection. Traits such as higher number of kernels per ear of corn, insect resistance and shorter stems to withstand wind and rain have been selected.
- Cattle have been selectively bred for centuries to increase their milk and meat production.

It is important to note that artificial selection is the intentional selection of desirable traits by humans. It should not be confused with 'unintentional' evolution that results from human activity. The continued use of antibiotics has resulted in a tremendous selection pressure on bacteria and led to the evolution of antibiotic-resistant organisms. A similar case is seen in pesticide-resistant insects. Here, evolution is the result of natural selection operating on the variations present in the population.

Try the activity below to practise using the Hardy–Weinberg equations.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Experimenting with new strategies for learning
- **Time required to complete activity:** 30 minutes
- **Activity type:** Group activity

Student view

Overview
(/study/app/bio/sid-422-cid-755105/o

Form groups of four. Write down the questions one at a time on any vertical writing surface (such as a whiteboard) so that you are standing while solving the questions. If you do not have a whiteboard, paste a chart paper on the wall.

As you solve the problems, discuss and think aloud to explain your reasoning.

Apply the Hardy—Weinberg equation to solve the following questions.

1. The fur colour of a population of cats is black or white. Black fur colour is dominant over white. The allele frequencies for black and white fur colour in one generation was 0.6 and 0.4. In the next generation, there were 800 cats, with 672 black cats and 128 white cats. Is the population in genetic equilibrium?
2. In a population of beetles, green colour dominates over red colour. In the population, there are 1024 individuals that are homozygous dominant, 512 individuals that are heterozygous and 64 individuals that are homozygous recessive. Calculate the frequency of the dominant and recessive alleles.
3. In a population of rabbits, straight ears dominate over floppy ears. The frequency of the recessive allele for floppy ears is 0.04. Calculate the frequency of the three genotypes. Round your answers if needed.
4. In humans, brown eyes (**B**) are dominant over blue eyes (**b**). People with brown eyes have the genotypes **BB** or **Bb**, while people with blue eyes have the genotype **bb**. The frequency of the **BB** genotype is 0.35. Find the frequency of the heterozygous brown-eyed individuals.

5 section questions

D4. Continuity and change: Ecosystems / D4.1 Natural selection

Summary and key terms

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/gene-pools-and-changes-in-their-composition-hl-id-43804/print/) Assign

- Natural selection acts on the variations generated due to mutation and sexual reproduction in a population. Over a period of time, it leads to evolution of new forms of life and is responsible for the biodiversity seen on Earth.

Student view

Overview
(/study/ap
422-
cid-
755105/o

- Overproduction and the subsequent competition for resources exerts strong selection pressure, leading to differential survival and reproduction. Density-independent abiotic factors also exert selection pressures.
- The survival value and reproductive potential of a genotype determines the biological fitness of the individual.
- Only heritable traits are passed on from one generation to another.
- Sexual selection is a special case of natural selection, wherein mates are selected based on characteristics they exhibit. John Endler's experiments on guppies model the forces of natural selection and sexual selection acting on a population.

Higher level (HL)

- Both genetic drift and natural selection result in changes in the frequencies of alleles of a gene pool. Genetic drift is a random event, while natural selection is directional.
- Neo-Darwinism explains natural selection using the fundamentals of genetics.
- Natural selection can be directional, stabilising or disruptive — all three lead to changes in the frequency of alleles.
- According to the Hardy—Weinberg law, if certain conditions are met, the frequencies of alleles will remain constant from one generation to another and the population is at genetic equilibrium. These conditions include no mutations, random mating, no natural selection, no gene flow and large populations; these conditions are normally never seen in natural populations.
- Artificial selection works in a manner similar to natural selection, the only difference being that the desired traits are selected by humans.

Student
view

Overview
(/study/app
422-
cid-
755105/o

Key terms

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. Natural selection acts on the ____________ present in a population. ____________ results in the formation of new alleles while sexual reproduction results in new combinations of alleles.
2. ____________, or the tendency to have more offspring than can reach reproductive age, leads to competition for resources such as food and water.
3. Selection pressures could include both ____________ factors, such as food and mates, and ____________ factors, such as volcanic eruptions and floods.
4. The ____________ of an organism depends on both the survival value and the reproductive potential of the genotype.
5. John Endler's experiments showed that ____________ influenced the colouration of guppies as females were attracted to the brightest colours. He also showed that the brightest colours were easier to see and attracted greater ____________.

sexual selection | density-dependent | Overproduction | variation | biological fitness | Mutation | predation | density-independent

Check

Interactive 1. Mechanisms of Evolution and Selection Types.

Student
view

Overview
(/study/app/sid-422-cid-755105/o

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

6. [HL] A is the sum total of all the genes and their alleles present in the population.
7. [HL] is due to chance events that cause changes in the allele frequencies, especially in small populations. A catastrophe that leads to a sudden decrease in the population, resulting in loss of genetic variation, is called the effect.
8. [HL] A small population that migrates to a new area and tends to mate within the community is an example of the effect.
9. [HL] Natural selection could be disruptive, directional or stabilising. Birds that lay too few eggs or too many eggs have increased chances of losing offspring. This is an example of selection. In squirrels, medium tails are of the least use – short tails prevent predators from catching them while long tails help them balance. This is an example of selection. Over centuries, there has been a progressive increase in the height of horses, a clear illustration of selection.
10. [HL] The adaptation of wild animals to urbanisation is an example of selection, while the breeding of high-yielding hens is an example of selection.

bottleneck | natural | stabilising | gene pool | founder | artificial | disruptive | directional | Genetic drift

Check

Interactive 2. Mechanisms of Evolution and Selection Types continued.

D4. Continuity and change: Ecosystems / D4.1 Natural selection

Checklist

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/checklist-id-46656/print/) Assign

Student view

Overview
(/study/ap
422-
cid-
755105/o

What you should know

After studying this subtopic you should be able to:

- Recognise that natural selection is the mechanism that drives evolutionary change.
- Explain the roles of mutation and sexual reproduction in generating variation.
- Identify and explain the biotic and abiotic factors that promote natural selection.
- Explain that differences in adaptation, survival and reproduction form the basis of natural selection.
- Recall that heritable changes lead to evolutionary change.
- Define sexual selection as a special case of natural selection.
- Describe the effects of sexual and natural selection through simulation of selection pressure.

Higher level (HL)

- Define the concept of a gene pool.
- Describe the changes that occur in allele frequencies in geographically isolated populations.
- State the causes for the changes in allele frequency in the gene pool.
- Differentiate among directional, disruptive and stabilising selection.
- Define Hardy-Weinberg equilibrium.
- Identify the Hardy-Weinberg conditions that need to be maintained for genetic equilibrium in a population.

D4. Continuity and change: Ecosystems / D4.1 Natural selection

Investigation

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/investigation-id-46657/print/) Assign

Student view

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills – Combining different ideas in order to create new understandings

- **Tool 3:** Mathematics – Graphing, Plot linear and non-linear graphs showing the relationship between two variables with appropriate scales and axes
- **Inquiry 3:** Concluding and evaluating – Interpret processed data and analysis to draw and justify conclusions; Compare the outcomes of an investigation to the accepted scientific context
- **Time required to complete activity:** 30–45 minutes
- **Activity type:** Pair activity

Simulation: effect of natural selection on the frequency of alleles

Introduction

Evolution can be defined as the change in allele frequency over a period of time. The following activity simulates the effect of natural selection on the frequency of alleles responsible for colour.

Your task

A population of brown and green beetles lives on a rotting log of wood. The colour of the beetles is determined by two alleles: **B** (brown) and **b** (green). Selection pressure is exerted due to predation by birds who find it easier to spot the green beetles. Study the effect of natural selection on allele frequency.

Resources

- An opaque bag.
- Beads of two colours.

(Brown and green beads have been used to make the instruction explicit; you can substitute with marbles/buttons/blocks/beans of two different colours.)

The bag of beads represents the gene pool of the population of beetles. Each bead represents an allele (**B** or **b**). The combinations of these alleles are the genotypes and are as follows:

- Two brown beads represent homozygous dominant brown beetles (**BB**).
- One brown and one green bead represents heterozygous brown beetles (**Bb**).

Overview (/study/ap 422- cid- 755105/o

- Two green beads represent homozygous recessive green beetles (**bb**).

Stage 1

1. Put 50 brown beads and 50 green beads into an opaque bag.
2. Shake the bag. Without looking into the bag, remove two beads at random. The two beads represent the genotype of the first beetle.
3. Draw three columns – **BB**, **Bb** and **bb** – on a large sheet of paper. Place the paper on a flat surface. Pull out beads in sets of two, and place them in the relevant column to record the genotype. For example, if you pull out two green beads, you will place them in the column **bb**.
4. Continue until you have beads to represent the genotypes of 50 individuals on your paper.
5. Now simulate the selection pressure exerted by a predator. Remove 25% of the brown beetles and 100% of the green beetles. (If the number is a fraction, round off to remove an entire beetle.)
6. Count the number of brown and green beads that remain. Use the data provided in **Table 1** to record your results.
7. Calculate the allele frequency and record it in a data table similar to the one below.

Table 1. Allele frequencies

	Allele B		**Allele b**	
Generation	Number of brown beads	Frequency = number of brown beads/total number of beads (100)	Number of green beads	Frequency = number of green beads/total number of beads (100)
Initial	50	0.5	50	0.5
1				
2				
3				
4				

Student view

Overview
(/study/ap
422-
cid-
755105/o

	Allele B		Allele b	
5				

Stage 2

1. Place 100 beads into the bag in proportions that represent the allele frequency you calculated in step 7. For example, if the allele frequency for **B** was 0.7, you would place $0.7 \times 100 = 70$ brown beads and 30 green beads in the bag.
2. Repeat steps 2–7 for the new bag of beads.
3. Continue the cycle until you collect data for five generations.

Stage 3

1. Graph your results. Plot the generation number on the *x*-axis and the frequency of the allele on the *y*-axis.

Stage 4

1. Analyse the data and answer the following questions:
   - Did the frequency of alleles change over time? Why or why not?
   - Did the recessive allele disappear from the population due to higher selection pressure?
   - What is the trend that you see in your graph? Explain the trend in terms of natural selection.

D4. Continuity and change: Ecosystems / D4.1 Natural selection

Reflection

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/reflection-id-46899/print/) Assign

Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are

Student
view

Overview (/study/ap 422- cid- 755105/o

in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

Reflection

Now that you've completed this subtopic, let's come back to the guiding questions introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43238/).

- What processes can cause changes in allele frequencies within a population?
- What is the role of reproduction in the process of natural selection?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

Once you submit your response, you won't be able to edit it.

0/2000

Submit

Student view

Rate subtopic D4.1 Natural selection

Help us improve the content and user experience.

Overview
(/study/ap
422-
cid-
755105/o

Student
view