



[Notes] Topic 1: Ecology & Climate Change (I)

[IB Biology - 1st Assessment 2025]

Overview

Topic 1A A4.2 Conservation of biodiversity

- **Theme & Level of Organization.** Unity and diversity – Ecosystems
- **Guiding Questions.** (1) What factors are causing the sixth mass extinction of species? (2) How can conservationists minimize the loss of biodiversity?
- **Linking Questions.** (1) In what ways is diversity a property of life at all levels of biological organization? (2) How does variation contribute to the stability of ecological communities?



Topic 1B B4.2 Ecological niches

- **Theme & Level of Organization.** Form and function – Ecosystems
- **Guiding Questions.** (1) What are the advantages of specialized modes of nutrition to living organisms? (2) How are the adaptations of a species related to its niche in an ecosystem?
- **Linking Questions.** (1) What are the relative advantages of specificity and versatility? (2) For each form of nutrition, what are the unique inputs, processes and outputs?

Topic 1C C4.1 Populations and communities

- **Theme & Level of Organization.** Interaction and interdependence – Ecosystems
- **Guiding Questions.** (1) How do interactions between organisms regulate sizes of populations in a community? (2) What interactions within a community make its populations interdependent?
- **Linking Questions.** (1) What are the benefits of models in studying biology? (2) What factors can limit capacity in biological systems?

Acknowledgement

1. Notes adapted from <SaveMyExams> <https://www.savemyexams.com/dp/>

Topic 1A _ A4.2 Conservation of biodiversity

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Content Statements

A4.2.1 – Biodiversity as the variety of life in all its forms, levels and combinations

A4.2.2 – Comparisons between current number of species on Earth and past levels of biodiversity

A4.2.3 – Causes of anthropogenic species extinction

A4.2.4 – Causes of ecosystem loss

A4.2.5 – Evidence for a biodiversity crisis

A4.2.6 – Causes of the current biodiversity crisis

A4.2.7 – Need for several approaches to conservation of biodiversity

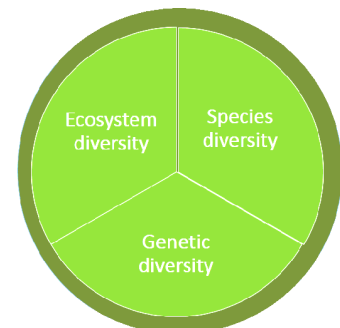
A4.2.8 – Selection of evolutionarily distinct and globally endangered species for conservation prioritization in the EDGE of Existence programme

A4.2.1 – Biodiversity as the variety of life in all its forms, levels and combinations

A4.2.2 – Comparisons between current number of species on Earth and past levels of biodiversity

Biodiversity

- Biodiversity can be thought of as the **variety of life** that exists in a specified area. This can refer to global biodiversity, or to the biodiversity of a smaller region.
- Biodiversity is very important for the **resilience of ecosystems**. The more biodiverse an ecosystem is, the more stable and resistant to change it will be.
- Biodiversity can be studied at three different levels: (i) ecosystem, (ii) species and (iii) genetic.



[https://www.researchgate.net/figure/The-three-components-of-biodiversity-UNEP-WCMC-2015_fig1_312948089]

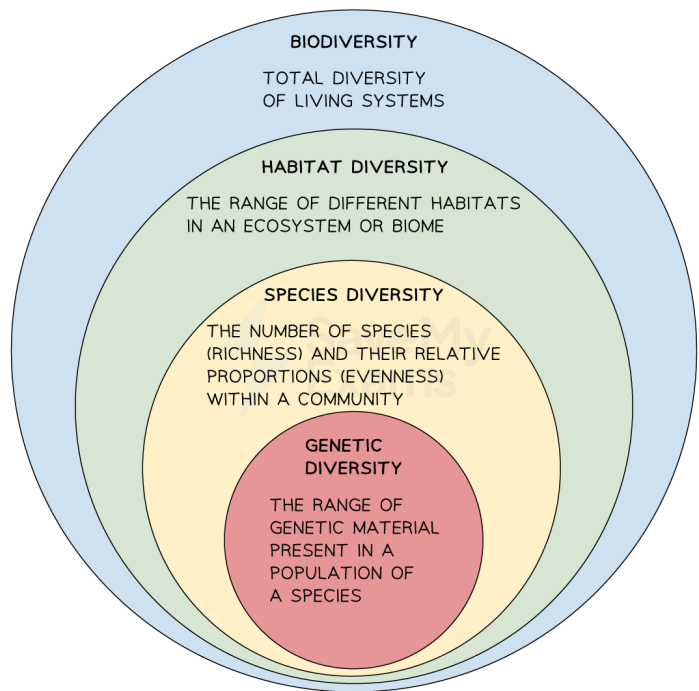
Species diversity

- Species diversity can be measured in two ways:
 - Species **richness** is the **number of species** within an ecosystem.
 - Species **evenness** is the **number of individuals** of each species within an ecosystem.
- For an ecosystem to have **high species diversity** it must have **high species richness** and **high species evenness**.
 - An ecosystem would not be species diverse if it had 1000 species, but only had a few individuals of 500 of those species; this would be high richness but low evenness.
 - An ecosystem would not be diverse if it had 10 species and had thousands of individuals of each species; this would be high species evenness but low species richness.
- Ecosystems with **high species diversity** are usually more stable than those with lower species diversity as they are **more resilient** to environmental changes.

- For example in the pine forests of Florida the ecosystem is **dominated by one or two** tree species. If a pathogen comes along that targets one of the two dominant species of trees, then the whole population could be wiped out and the ecosystem it is a part of could collapse.

Genetic diversity

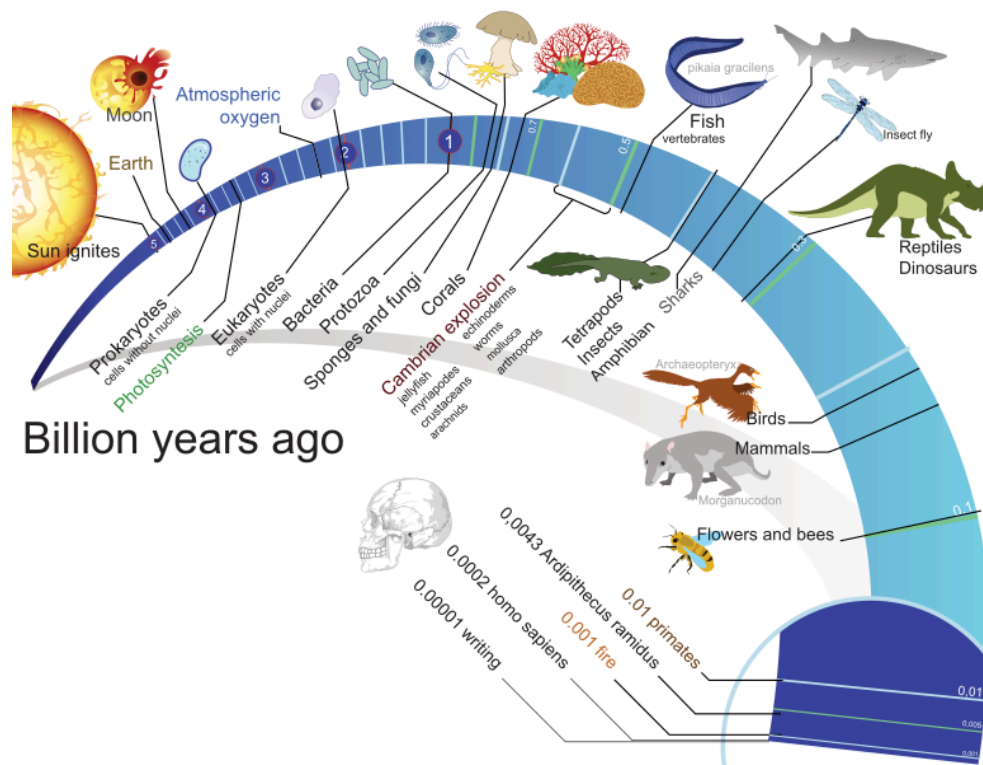
- The genetic diversity is the **number of different alleles of genes** that are present. This can be in an entire species or in a local population.
- Factors that contribute to genetic diversity include:
 - The proportion of genes that have more than one allele.
 - The number of different alleles that each gene has.
- There can be genetic differences or diversity **between populations** of the same species. This may be because the two populations live in different areas and so are subject to slightly different **selection pressures** that affect the **allele frequencies** in their populations.
- There can be genetic differences **between individuals** within a population. Genetic diversity in a species is important as it can help the population **adapt** to, and survive, **changes in the environment**.
- As seen in the diagram on the right, there are different levels of biodiversity, such as ecosystem (habitat) diversity, species diversity, and genetic diversity.



Biodiversity Comparisons

Biodiversity change over time

- Current estimates for global species diversity vary, but recent estimates suggest that there could be around 8.7 million species on Earth. Around 1.2 million species have currently been recorded and classified, meaning that if estimates are correct, there are still many more species to be discovered.
- The number of species on Earth has **not always been the same**. The fossil record shows that:
 - Many species that have existed in the past are no longer present. This is due to **extinction**.
 - There are **many more species alive today** than have been alive in the past. The process of **speciation** leads to an increase in the number of species. Speciation gives rise to new species over time, increasing global biodiversity.
- When speciation occurs **at a higher rate than extinction**, global **biodiversity will increase**.
- Despite many extinctions occurring over recent years, periods of speciation in the past mean that global biodiversity levels are still higher than ever before.



[https://en.m.wikipedia.org/wiki/File:Timeline_evolution_of_life.svg]

[NOS] Classification is an example of pattern recognition but the same observations can be classified in different ways

- The accuracy of the estimated number of species on Earth is dependent on the **process of classification**.
 - If species are classified correctly then estimates will be more accurate.
 - If species are incorrectly classified together then estimates will be too small.
 - If species are incorrectly separated then estimates will be too large.
- Classification can be **subjective**. It is not always easy to determine the **point at which one species has become two**, or whether similar organisms are of **the same species**, or are **two different species**.
- It can be said that **taxonomists** are either:
 - 'Lumpers'. Lumpers focus on similarities more than differences, and are more likely to **classify species together**.
 - 'Splitters'. Splitters focus on differences, and are more likely to **classify species separately**.

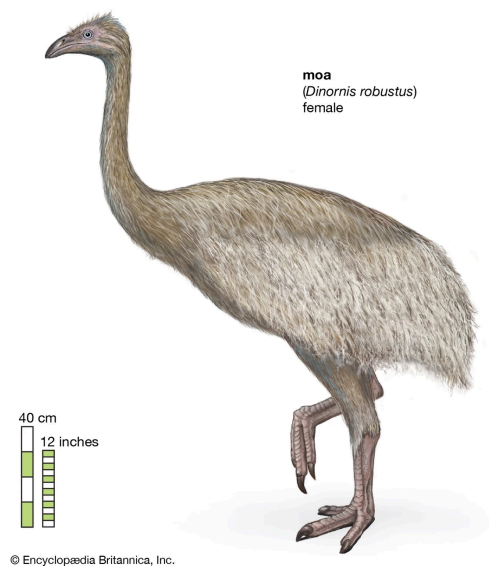
Anthropogenic Species Extinction

Anthropogenic extinction

- Extinction that has been caused by human activities is referred to as **anthropogenic extinction**.
- Scientists believe that we are currently experiencing a **mass extinction event**, and that human activities are playing a large role.
- There have been five mass extinction events in the past, so the current round of extinctions could be the sixth.

Anthropogenic extinction case study: North Island giant moas

- The North Island giant moa (*Dinornis novaezealandiae*) was a large, flightless, herbivorous bird that lived in New Zealand until the year 1300. It was once thought to be several different species of moa due to size differences between larger females and smaller males, hence the image on the right is being labelled with a different species name.
- Humans arrived in New Zealand between 1200-1300, and it is thought that the moas were **hunted to extinction by humans** by 1300.



[<https://dinopedia.fandom.com/wiki/Moa>]

Anthropogenic extinction case study: Caribbean monk seals

- Caribbean monk seals (*Neomonachus tropicalis*) lived in the oceans around the gulf of Mexico and the Caribbean, and were declared extinct in 2008, though it is believed that they may have gone extinct before this.
- Their docile nature and their habit of lying out on the rocks meant that these seals were easy for European colonists to **hunt for their oil and meat**.



[https://naturerules1.fandom.com/wiki/Caribbean_Monk_Seal]

Anthropogenic extinction case study: student choice

- A third case study should be chosen and researched.
- Consider the following factors:
 - The species chosen should be from a local or familiar region
 - The species must have gone extinct due to human activities
 - The case studies above give an indication of the level of detail required

- Examples of extinct species from different parts of the world include:
 - Baiji (*Lipotes vexillifer*), a species of river dolphin
 - Passenger pigeon (*Ectopistes migratorius*)
 - Paradise parrot (*Psephotellus pulcherimus*)
 - Golden toad (*Incilius periglenes*)
 - St Helena darter (*Sympetrum dilatatum*), a species of dragonfly

A4.2.4 – Causes of ecosystem loss

A4.2.5 – Evidence for a biodiversity crisis

Ecosystem Loss: Causes

- The term **ecosystem** is used to describe all of the **living organisms in an area**, along with **their interactions with each other** and the **non-living environment**.
- Human activities are responsible for **damaging and destroying many ecosystems** around the world. e.g. the destruction of habitat during **deforestation**.

Anthropogenic ecosystem loss case study: mixed dipterocarp forest in Southeast Asia

- Dipterocarps are a family of trees that occur in the tropics, and that once formed a crucial part of a complex rainforest ecosystem that dominated Southeast Asia.
- These rainforests (as seen in the diagram on the right) are being gradually lost, with some parts of Southeast Asia having lost more than 50% of their forests.
- Forest is often lost due to a practice known as clear-cutting, where all of the trees in an area are cut down and removed. This provides timber and clears land for agriculture, e.g. palm oil plantations.



[Credit: Dr Stephen Burchett]

Anthropogenic ecosystem loss case study: student choice

- A **second case study** should be **chosen and researched**.
- Consider the following factors:
 - The ecosystem chosen should be from a **local or familiar region**.
 - The ecosystem loss must be due to **human activities**.
 - The case studies above give an indication of the level of detail required.
- Examples of ecosystem loss from different parts of the world include:
 - Great Barrier Reef, Australia
 - Northern Great Plains, North America
 - Mangrove forests, various locations

Biodiversity Loss: Evidence

The evidence for biodiversity loss

- To fully understand the nature and extent of the biodiversity crisis, **solid evidence** on the world's changing biodiversity is required.
- For such evidence to be trustworthy, it needs to contain sufficient data and it needs to come from reliable sources:
 - **Many reliable biodiversity surveys** need to have been carried out in a **wide range of habitats**.
 - **Repeat** survey data is needed over a period of time.
 - Both **species richness** and **species evenness** need to be assessed.
 - To maximise the volume of data, '**citizen scientists**' can help with survey work. Citizen scientists are members of the public who help to gather data.
 - Data need to be expertly analysed
- Drawing together these large bodies of evidence is a huge task, and such work is often carried out by organisations that work across multiple governments, e.g.
 - **IPBES**. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
 - **IUCN**. International Union for the Conservation of Nature

IPBES

- IPBES is an organisation that works to **gather information, recommend policies**, and **communicate findings** relating to global biodiversity and ecosystems.
- The **2019 IPBES report** contained a comprehensive summary of findings from research as well as policy recommendations for governments.
 - Data is gathered by scientists, government bodies, and local individuals
 - Studies are carried out in a range of habitats where regular samples are taken

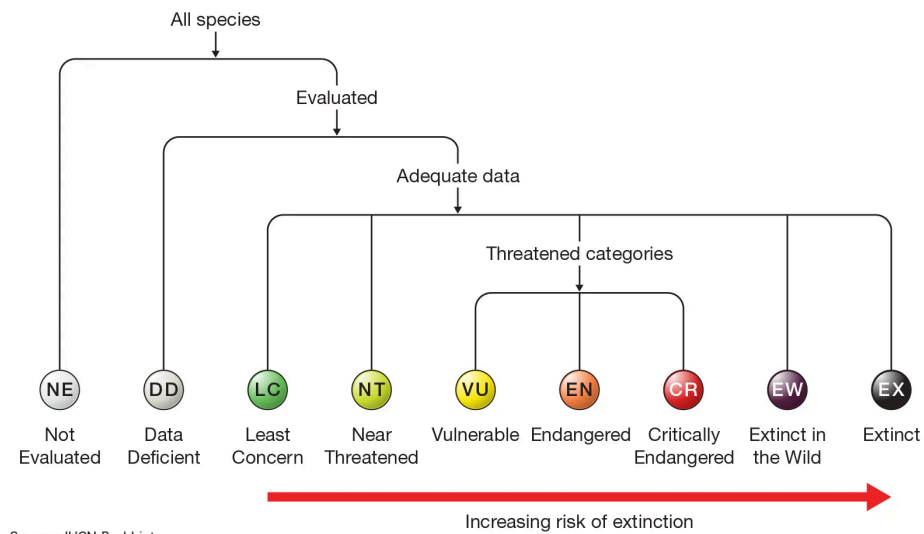


IUCN

- The IUCN is a network of organisations and individual experts that seeks to gather knowledge of the natural world and to propose helpful environmental policies.
- The **IUCN red list** is a list of the world's most threatened species. It has assessed more than 150 000 species, and has listed more than 42 000 as threatened.
- The IUCN red list has been compiled by **scientists and scientific organisations** all around the world, and is used by many groups to inform conservation efforts.
- The IUCN categorises species on the basis of their risk of extinction. This data can be represented visually to give an immediate picture of the level of risk being faced by many species as seen in the diagram below.
- Species that have been assessed are categorised by the IUCN as:
 - LC = least concern
 - NT = near threatened
 - VU = vulnerable
 - EN = endangered
 - CR = critically endangered
 - EW = extinct in the wild
 - E = extinct



- Species can also be classed as DD (data deficient) when there is not enough data on which to base a category choice, or as NE (not evaluated).



Source: IUCN Red List

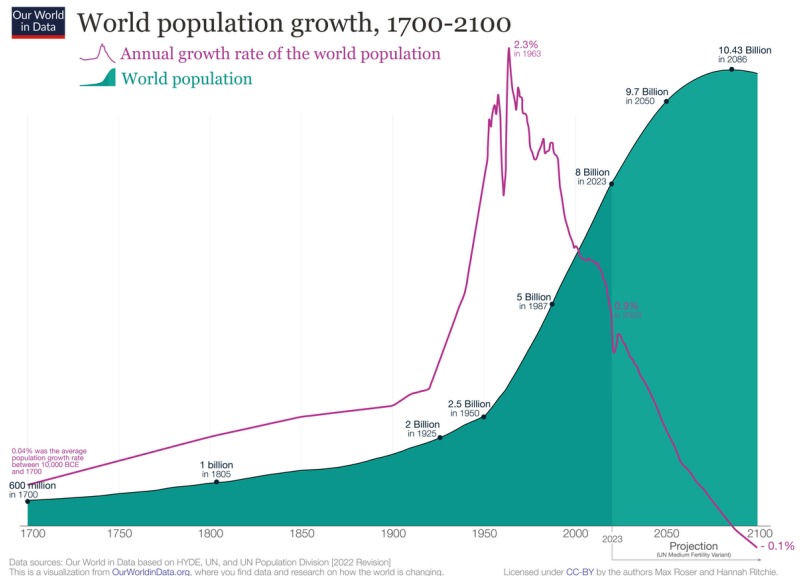
[<https://www.britannica.com/topic/IUCN-Red-List-of-Threatened-Species>]

[NOS] To be verifiable, evidence usually has to come from a published source, which has been peer-reviewed and allows methodology to be checked

- Collecting data on global biodiversity is a huge task, and while qualified scientists can collect a great deal of data, this may not be enough to gain an overall picture of changes occurring at a **national or international level**.
- To solve this problem, organisations will sometimes ask the public to help with data collection; such members of the public are described as 'citizen scientists'.
- Citizen scientists are **often untrained**, and may not always collect valid data as a result, so there will be a certain amount of **trade-off between the quality and the quantity of the data**.
- Good experimental design and high-quality data analysis** can help to mitigate the effects of using citizen scientists.

The causes of biodiversity loss

- It is widely agreed among scientists that there is a **biodiversity crisis** underway due to the rate at which extinctions are occurring.
- The **growth of the global human population** is likely to be the main cause of this crisis.
 - There are currently more than 8 billion people on Earth.
 - The global population continues to increase.
 - Even though birth rates are now decreasing, people are living longer so births are occurring at a higher rate than deaths and the population continues to grow.
- Projections (as seen in the graph on the right) suggest that the human population will continue to increase until the year 2100 due to birth rates being higher than death rates.



[https://en.wikipedia.org/wiki/Projections_of_population_growth]

Biodiversity crisis as a result of human population growth. multiple reasons, e.g.

- **Overexploitation** of resources
 - Overfishing of the oceans are causing a decline in fish populations
 - Hunting of animals for resources such as ivory from tusks, oil from whales, or fur from beavers
- **Urbanisation**, or the building of towns
 - Direct **loss of habitat** for buildings
 - **Fragmentation** of habitat into smaller pieces by, e.g. roads
 - Less land is available for agriculture, so this expands elsewhere
- **Deforestation and habitat loss**
 - Land is cleared for agriculture, timber, mining, or quarries
 - Agriculture may look good for living organisms, but it often involves the planting of monocultures with very low biodiversity, and it leads to loss of soil micro-organisms
- **Pollution**
 - Microplastics have been found in remote environments
 - Fertilisers and organic waste can be washed off farmland into bodies of water
- Increase in numbers of **pests**
 - Biodiversity loss has led to an increase in pest species that damage crops, e.g. the cotton bollworm (*Helicoverpa armigera*)
 - Higher biodiversity increases the number of pest predators
 - Pests will gather in larger numbers in areas of monoculture

- **Invasive species**

- When humans **travel around the world** they often **bring species with them**, either by accident or on purpose. These 'alien' species can have damaging effects on the habitats to which they are introduced.
- Examples include
 - Grey squirrels and signal crayfish in the UK
 - Cane toads in Australia
 - Rats in the Galapagos Islands
- **Disease**
 - Diseases can wipe out large numbers of species, e.g. the chytrid fungus is thought to have wiped out 90 species of amphibian so far
 - Human-caused climate change can increase the ranges of some diseases
 - Humans living closely with animal species can result in new diseases as pathogens transfer between hosts

A4.2.7 – Need for several approaches to conservation of biodiversity

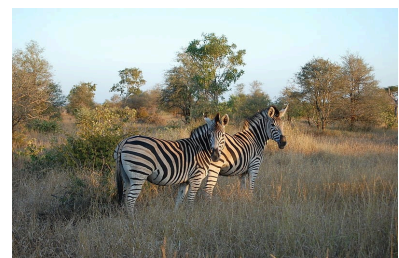
Conserving Biodiversity

- As human activities continue to cause a decline in biodiversity, the need for **solutions** to this problem increases.
- The **problem is complex**, and there is no one simple solution, so a **mixture of different approaches** is needed.
- The complexities are often due to conflicts between the needs of the natural world and the needs of humans; these conflicts are not always easy to resolve.
- Examples of different approaches to dealing with the biodiversity crisis include
 - **In situ conservation**, e.g. (i) Protected areas, (ii) Rewilding and (iii) Reclamation
 - **Ex situ conservation**, e.g. (i) Zoos, (ii) Botanic gardens, (iii) Seed banks and (iv) Tissue banks

In situ conservation

1. Protected areas

- A protected area is a **defined geographical space**, such as a national park or nature reserve, that is **managed and protected** for the purposes of conservation.
- **National parks** are **government-controlled areas** within countries where the wildlife and environment are protected. The diagram on the right shows Kruger National park which is the largest national park in South Africa.
- Nature reserves are smaller regions than national parks, and can be on **privately or publicly owned land**.
- Restrictions inside protected areas could include
 - **Humans access** is strictly controlled
 - Industrial activities such as **agriculture** and **building** are tightly regulated
 - **Hunting** is limited or completely prohibited



2. Rewilding

- This is the **restoration of ecosystems** to a point at which they can sustain themselves; such **sustainable ecosystems** are by their nature **biodiverse habitats**.
- Rewilding can be allowed to occur on private or publicly owned land.
- Rewilding can be **active or passive**.
 - Active rewilding involves human intervention, e.g. removing human features such as roads, and reintroducing locally extinct species.
 - Passive means leaving an area alone to allow ecological processes to gradually restore themselves, e.g. stopping the management of land to allow natural **succession** to occur. Do note that passive rewilding will not work for the restoration of some habitat types, e.g. grassland habitats often require grazing to prevent the dominance of tree species.

3. Reclamation

- Reclamation refers to the **reclaiming and restoration of areas that have been damaged by human activities**, e.g. abandoned quarries or areas where deforestation has taken place.
- Such projects aim to **restore previously existing ecosystems**.

Ex situ conservation

1. Zoos

- **Captive breeding programmes** in zoos can increase the number of individuals of a species.
 - This can be carried out by **artificial insemination**, allowing the flow of genes between individuals that may be living in different zoos.
 - This prevents problems that can arise from **low genetic diversity**.
 - This can avoid difficulties with captive breeding.
 - Captive breeding can lead to the release of individuals **back into the wild**.
- Zoos are an invaluable resource for **scientific research**.
 - Scientists are able to closely study animal genetics, behaviours and habitat requirements.

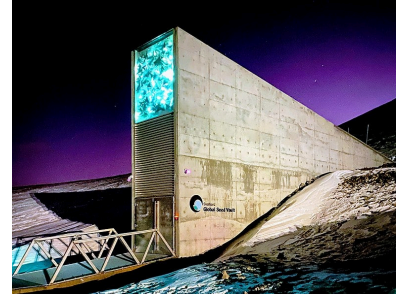
2. Botanic gardens

- Botanic gardens are the plant equivalent of zoos.
- They use cuttings and seeds collected from the wild to **establish a population of the endangered species** in captivity.
 - Methods of tissue culturing and cloning can also be used to obtain large numbers of plants from a small sample size.
- The captive population can be used in the future for **reintroduction into habitats** where they have become rare.
- **Research** is a major role of botanic gardens.
 - Scientists can investigate reproduction and growth in different plant species so that they can be grown in captivity.
 - Habitat requirements can be assessed so that new habitats can be found if necessary.

3. Seed banks

- A seed bank is a facility that conserves plant diversity by **drying and storing seeds** in a **temperature-controlled** environment.
 - **Cool, dry conditions** generally increase the length of time for which seeds remain viable.

- Seeds can only be stored for so long; after a certain period of time the stored seeds are grown into plants and fresh seeds for storage are taken from those plants.
- If the plant species goes extinct then the seeds can be used to grow them again.
- Usually, seeds of the same species are collected from different sites to **maintain genetic diversity**.
- The Svalbard Global Seed Vault in Norway (as shown on in the diagram the right) contains seeds from almost 1 million plant species.
 - It is located in the Arctic Circle with ideal environmental conditions.
 - Many organisations send seeds from crop plants to be stored there for safekeeping.



4. Tissue banks

- Tissue banks, or frozen zoos, **store genetic material** from animals at very low temperatures.
 - It is thought that properly frozen tissue samples can last indefinitely.
 - Ideally, samples are collected from different individuals of the same species to **maintain genetic diversity**.
 - Two different types of tissue can be stored in tissue banks
 - Germplasm
 - This includes **reproductive tissue**, such as sperm cells, egg cells, and embryos.
 - This material can be used by zoos in captive breeding programmes.
 - In theory, IVF could be carried out with a suitable surrogate species to bring back an extinct species from this tissue.
 - Somatic tissue
 - This is non-reproductive tissue, or **body cells**.
 - This type of tissue contains the **full genome** of the species, and can be used for DNA research.
 - It is thought that such tissue could be used for cloning extinct species in the future.

A4.2.8 – Selection of evolutionarily distinct and globally endangered species for conservation prioritization in the EDGE of Existence programme

Conserving Biodiversity: Selecting Species

Prioritising species for conservation

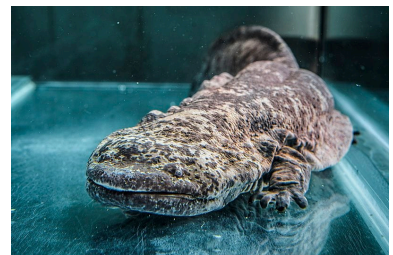
- There are so many species that need protection that it can seem like an impossible task to decide where to allocate the limited resources available.
- The **Evolutionarily Distinct and Globally Endangered (EDGE)** programme works together with the **Zoological Society of London (ZSL)**, to carry out research and to highlight the needs of certain species.
- Priority is decided on the basis of a species being
 - **Evolutionarily distinct**
 - Species have **few close evolutionary relatives**
 - Species are **unusual** in appearance, behaviour, and DNA
 - Species represent a part of Earth's evolutionary tree that is not represented anywhere else

- **Globally endangered**
 - The **IUCN red list** is used to provide information about the **threat level** of an evolutionarily distinct species.
 - A species must be globally threatened, not just threatened on a local level.
- A species must be both evolutionarily distinct and globally endangered to be prioritised by the EDGE programme.
 - Examples of priority EDGE species include
 - Largetooth sawfish (*Pristis pristis*) is not only number 1 on the EDGE Shark list, but also has the highest-ranking score of any EDGE species.

[<https://www.edgeofexistence.org/species/largetooth-sawfish/>]



- Chinese giant salamander (as seen in the diagram on the right) is both evolutionarily distinct and globally endangered, and is a focal species for the EDGE programme
 - Purple frog
- The EDGE of existence programme highlights the needs of EDGE species to local, government, and international conservation organisations to ensure that such species are not lost before their plight is even recognised.



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- **Guiding Questions.** (1) What are the advantages of specialized modes of nutrition to living organisms? (2) How are the adaptations of a species related to its niche in an ecosystem?
- **Linking Questions.** (1) What are the relative advantages of specificity and versatility? (2) For each form of nutrition, what are the unique inputs, processes and outputs?



Content Statements

B4.2.1 – Ecological niche as the role of a species in an ecosystem

B4.2.2 – Differences between organisms that are obligate anaerobes, facultative anaerobes and obligate aerobes

B4.2.3 – Photosynthesis as the mode of nutrition in plants, algae and several groups of photosynthetic prokaryotes

B4.2.4 – Holozoic nutrition in animals

B4.2.5 – Mixotrophic nutrition in some protists

B4.2.6 – Saprotrophic nutrition in some fungi and bacteria

B4.2.7 – Diversity of nutrition in archaea

B4.2.8 – Relationship between dentition and the diet of omnivorous and herbivorous representative members of the family Hominidae

- **[AOS]** Students should examine models or digital collections of skulls to infer diet from the anatomical features. Examples may include *Homo sapiens* (humans), *Homo floresiensis* and *Paranthropus robustus*.
- **[NOS]** Deductions can be made from theories. In this example, observation of living mammals led to theories relating dentition to herbivorous or carnivorous diets. These theories allowed the diet of extinct organisms to be deduced.

B4.2.9 – Adaptations of herbivores for feeding on plants and of plants for resisting herbivory

B4.2.10 – Adaptations of predators for finding, catching and killing prey and of prey animals for resisting predation

B4.2.11 – Adaptations of plant form for harvesting light

B4.2.12 – Fundamental and realized niches

B4.2.13 – Competitive exclusion and the uniqueness of ecological niches

B4.2.1 – Ecological niche as the role of a species in an ecosystem

Ecological Niches

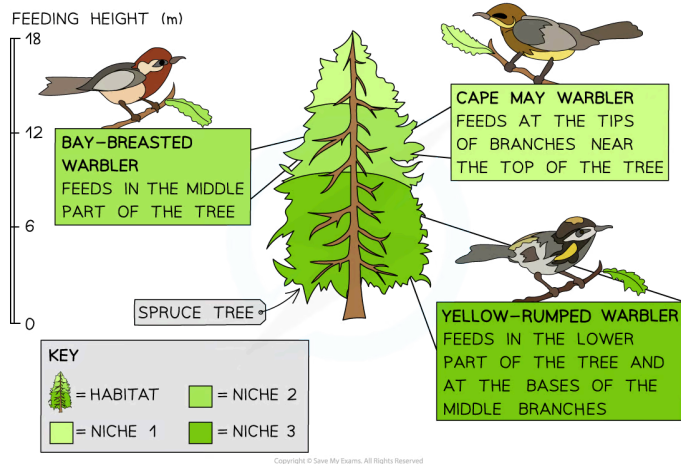
- The place where a species lives is known as its habitat
- Species will occupy a specific niche within a habitat
- The term niche can be defined as the role of a species within its habitat
- The role of a species includes
- What it eats
 - Which other species depend on it for food
 - What time of day a species is active
 - Exactly where in a habitat a species lives
 - Exactly wherein a habitat a species feeds
- **No two species can fill the same niche within a habitat.** If this ever happens, the two species will be in direct competition with each other for resources, and one of the two species will out-compete the other, causing it to die out in that particular habitat
- It can sometimes seem as though species are occupying the same niche, but there will still be subtle differences in their role; e.g. they might feed at different times of day, or have different food sources.

Feeding Niche Diagram

- Feeding location is an example of a feature that may differ between niches

Adaptations to Ecological Niches

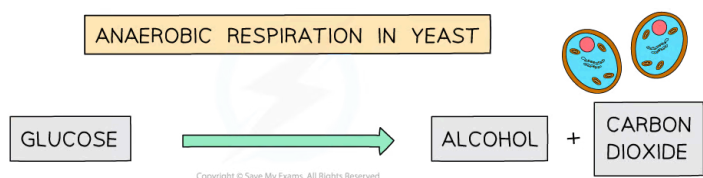
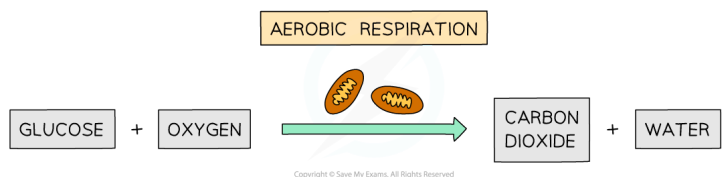
- Species can only survive in habitats in which they are **well adapted to their niche**. They must be adapted to the habitat.
- Abiotic factors, e.g. plants must have enough light for photosynthesis in order to produce carbohydrates. Aquatic organisms must be able to absorb enough oxygen from the surrounding water for respiration.
- Biotic factors, e.g. a prey organism being camouflaged to avoid predation. A plant growing fast enough to out-compete nearby plants for sunlight.



B4.2.2 – Differences between organisms that are obligate anaerobes, facultative anaerobes and obligate aerobes

Anaerobes and Aerobes

- All living organisms carry out some form of respiration.
 - Aerobic respiration **requires oxygen**.
 - Anaerobic respiration does not require oxygen.



- Some organisms can survive using **either aerobic or anaerobic** respiration, while some can only survive using one type or the other; organisms are said to be either
 - Obligate anaerobes
 - Facultative anaerobes
 - Obligate aerobes

Obligate Anaerobes

- These are single-celled organisms that **can only carry out anaerobic respiration**. They **cannot tolerate oxygen**.
- Early bacteria were obligate anaerobes; they were able to survive in the atmosphere of early Earth due to its lack of oxygen.
- Photosynthesis has since introduced oxygen to the Earth's atmosphere, meaning that obligate anaerobes **can now only be found in oxygen-free environments**, e.g. lower layers of soil, deepwater, and inside the bodies of other groups of organisms.

Facultative Anaerobes

- These organisms **mainly respire aerobically** but have the ability to **switch fully to anaerobic respiration** in the absence of oxygen.
- The switch to anaerobic respiration has no negative effects on facultative anaerobes. Examples of facultative anaerobes include (i) Brewer's yeast, *Saccharomyces cerevisiae* and (ii) *Escherichia coli*, a species of bacteria.

Obligate Aerobes

- These organisms **cannot survive in the absence of oxygen**; they rely on **aerobic respiration** to release energy from food. They may be able to carry out anaerobic respiration in some cells for short periods, but the damaging effects are too great to do this for longer than a few seconds. Examples of obligate aerobes include (i) Most animals, (ii) Most fungi (not yeast) and some bacteria, e.g. *Mycobacterium tuberculosis*.

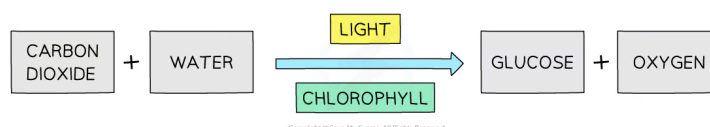
B4.2.3 – Photosynthesis as the mode of nutrition in plants, algae and several groups of photosynthetic prokaryotes

Methods of Nutrition

- Organisms need energy in the form of **ATP** to survive.
- The energy stored in ATP comes from other organic molecules, such as carbohydrates, and is **transferred** during the process of respiration.
- The way by which an organism **gains organic molecules to fuel respiration** is known as its method or mode of nutrition.
- There are two main modes of nutrition: autotrophy and heterotrophy:
- An **autotroph** synthesises, or produces, its own organic molecules from simple inorganic substances in its environment. e.g. Autotrophs that use light energy are known as photoautotrophs, while those that use energy from oxidation of chemicals are known as chemoautotrophs.
- A **heterotroph** gains organic molecules from the tissues of other organisms.

Photosynthesis

- Photosynthetic organisms are autotrophs that **use light energy to convert carbon dioxide from the air into organic molecules such as carbohydrates**.
- **Photosynthetic pigments** such as **chlorophyll** absorb light energy, enabling this because photosynthetic organisms **make their own organic molecules** without relying on other organisms, they are known as **producers**.



- Photosynthesis is a crucial process because it **transfers light energy into a chemical form** that can be used by living organisms.

- Producers can then be eaten by other living organisms, continuing the process of energy transfer.
- Besides providing the crucial bridge between non-living matter and living organisms, photosynthesis is also responsible for the **release of oxygen into Earth's atmosphere**, enabling aerobic respiration.
- Photosynthetic organisms include:
 - **Plants**, both terrestrial and aquatic
 - **Algae**, including single-celled algae and multicellular seaweeds.
 - **Photosynthetic bacteria** such as cyanobacteria.

B4.2.4 – Holozoic nutrition in animals

B4.2.5 – Mixotrophic nutrition in some protists

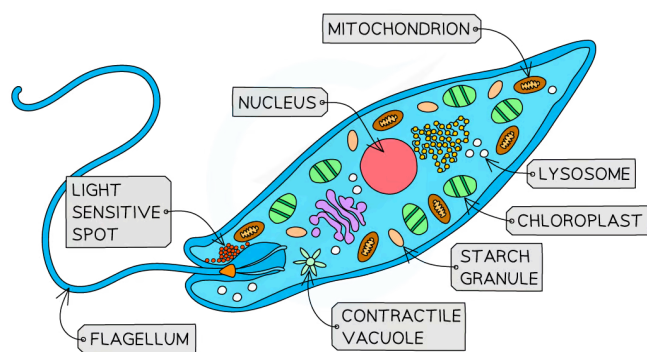
B4.2.6 – Saprotrophic nutrition in some fungi and bacteria

Holozoic Nutrition

- **Heterotrophs** are organisms that gain organic molecules **from the tissues of other organisms**. e.g. animals are all heterotrophs.
- Organisms that use holozoic nutrition are heterotrophs that gain organic molecules by **ingesting, digesting, absorbing, and assimilating molecules from the tissues of other organisms**.
 - Ingestion = eating
 - Digesting = breaking down larger molecules into smaller molecules.
 - Absorbing = the transport of molecules from the digestive tract into the cells.
 - Assimilation = using molecules to build cells and tissues
- Holozoic nutrition **involves internal digestion**. e.g., houseflies, that secrete enzymes onto their food before absorbing the products; animals like this are heterotrophs, but they do not use holozoic nutrition as digestion takes place externally.

Mixotrophs

- Some organisms can use **more than one method of nutrition**, such as auto- and heterotrophy; these organisms are referred to as **mixotrophs**.
- **Obligate mixotrophs** must constantly have access to **both methods of nutrition**.
- **Facultative mixotrophs** can survive using one method of nutrition, supplemented by the other.. e.g. **Euglena** is a single-celled eukaryotic organism found in freshwater that uses both **autotrophy** and **heterotrophy**.
 - Euglena cells can take in bacterial cells by endocytosis, and then digest them using digestive enzymes stored in lysosomes.
 - Euglena cells also contain a light-sensitive spot that enables them to position themselves so that maximum light reaches their chloroplasts.



- Other examples of mixotrophs include

- Carnivorous plants. These plants build organic molecules using both **photosynthesis** and using molecules from the **tissues of digested insects**.
- Corals. Coral polyps gain organic molecules from their **symbiotic photosynthetic algae** and by **filter feeding** from the surrounding water.
- Marine plankton, e.g., Dinoflagellates. These are microscopic organisms that float in the water of the ocean.
- Many are mixotrophs, e.g., **feeding on bacteria** while also carrying out **photosynthesis**.

Saprotrophs

- Saprotrophs are heterotrophs that ingest the tissues of dead organisms and waste material by **secreting enzymes onto their food and digesting it externally** before absorbing the products of this digestion. Note that this is different from holozoic nutrition, as digestion occurs **externally**. Examples of saprotrophs include **fungi** and **bacteria**. These organisms can be described as **decomposers**.
- Saprotrophs secrete a **wide range of digestive enzymes** that allow them to hydrolyse a large variety of biological molecules and release a large range of products. Examples of these products include **mineral ions**, such as ammonium ions and phosphate ions.
- Importantly, not all of the products of external digestion get absorbed by saprotrophs, **leaving some minerals in the surrounding soil** for absorption by other organisms, such as plants.
- Without saprotrophs, the nutrients locked up in dead and waste matter **would never be released**, and plants would not have access to sufficient minerals. This is why saprotrophs are **essential to ecosystems and food webs**.

B4.2.7 – Diversity of nutrition in archaea

Nutrition in Archaea

- The archaea area is a diverse group of single-celled organisms that comprise one of the three domains.
- Different groups of archaea vary metabolically, e.g.
 - Phototrophic archaea
 - Chemotrophic archaea. This includes chemoautotrophs and chemoheterotrophs.
 - Heterotrophic archaea

Phototrophic Archaea

- Phototrophic archaea **use energy from light to generate ATP**. e.g., Halobacterium uses a pigment called bacteriorhodopsin to absorb light energy and to pump H⁺ ions across a membrane, the resulting ion gradient leads to the production of ATP by the enzyme ATP synthase in a similar way to **oxidative phosphorylation** and **photophosphorylation**.
- Note that this is not the same as oxygen-releasing photosynthesis, and Halobacterium are not considered autotrophic but could instead be described as **photoheterotrophs**.
- While they use light energy to produce ATP, Halobacterium gains carbon compounds to build their cell structure from other organisms.

Chemotrophic Archaea

- Some archaea can produce their own carbon compounds using **chemosynthesis**. These archaea are **chemoautotrophs**.
 - They use energy released from **chemicals** in the environment.
 - They produce their **own carbon compounds**.
- Chemosynthesis releases energy from chemicals which is transferred to carbon compounds.

- These carbon compounds can then be used for **ATP production**.
- Chemicals that can act as energy sources for chemosynthetic archaea include: (i) Hydrogen gas, (ii) Ammonia, (iii) Methane and (iv) Hydrogen sulfide
- Some chemotrophic archaea use energy from chemicals to **directly drive ATP production** in a similar way to the phototrophic archaea described above.
- These archaea are **chemoheterotrophs**. they use chemicals to produce ATP but gain their carbon compounds from other organisms.

Heterotrophic Archaea

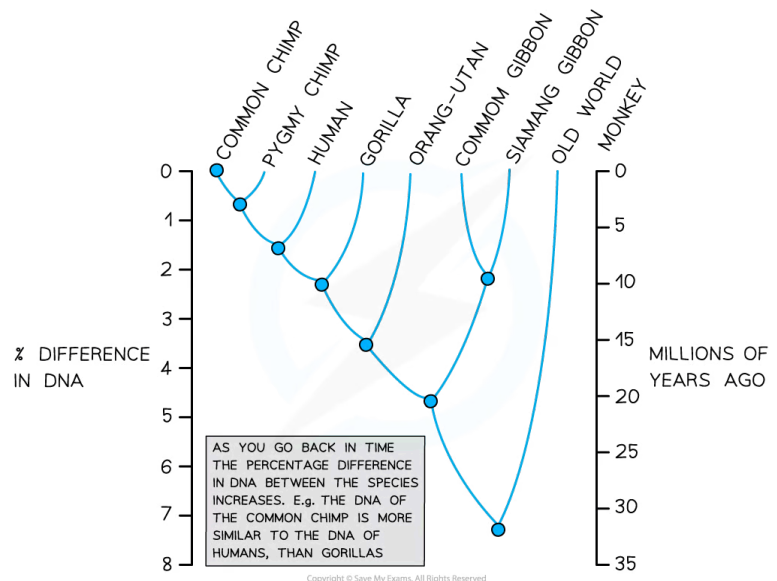
- Heterotrophic archaea gain their carbon compounds from other organisms and then **use these carbon compounds to generate ATP**. e.g., Archaea that break down and absorb carbon compounds in dead plant material.

B4.2.8 – Relationship between dentition and the diet of omnivorous and herbivorous representative members of the family Hominidae

- **[AOS]** Students should examine models or digital collections of skulls to infer diet from the anatomical features. Examples may include *Homo sapiens* (humans), *Homo floresiensis* and *Paranthropus robustus*.
- **[NOS]** Deductions can be made from theories. In this example, observation of living mammals led to theories relating dentition to herbivorous or carnivorous diets. These theories allowed the diet of extinct organisms to be deduced.

Nutrition in Hominidae

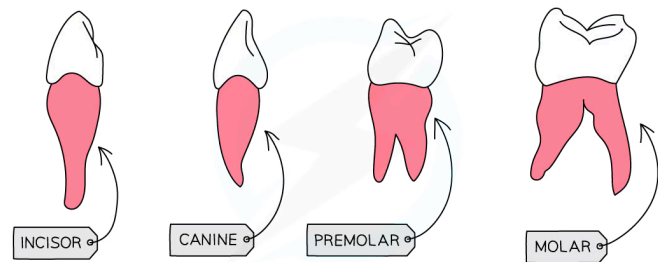
- Humans are part of the **Hominidae** family, along with chimps, gorillas, orangutans, and gibbons
- The evolutionary tree on the right shows the Primate order, which contains the Hominidae family on the left-hand side.



- Most existing hominids are **omnivores**, meaning their nutrition comes from a combination of animal and plant material, e.g.
 - Chimps are mainly frugivores, meaning their main diet consists of fruit, though they eat other plant matter and some small mammals.
 - Gorillas are mainly herbivores, feeding primarily on leafy vegetation, though they sometimes eat insects.
- The **study of the skulls** of existing hominid species shows that **the jaw and dentition, or teeth, of each species are specialized for their particular diet**, e.g.
 - Chimps have relatively small jaw muscles, which are only strong enough to chew softer fruit and animal tissue, while gorillas have very strong jaw muscles for biting and grinding tough vegetation.
 - Chimps have small incisor teeth and long canine teeth, enabling them to bite and tear meat, while gorillas have large molar and premolar teeth for grinding vegetation.

- Incisor teeth are chisel-shaped for cutting and biting.
- Canine teeth are pointed for holding and tearing.
- Premolars and molars are flat and ridged for grinding.

- Species will often have different combinations of teeth types and sizes to enable them to better chew and digest their diet



- We know a **relationship exists between diet and dentition** in currently existing hominid species, and it is possible to apply this principle to **extinct hominid species**.
 - The skulls and jaws of extinct species are often well-preserved and can be studied.
 - This allows scientists to **find out about the diet of these extinct species** and the **ecosystem structure** in which they lived.
- It is worth noting that while dentition can sometimes be clearly linked to diet, **teeth don't always give a perfect indication of what a species eats**, e.g.
 - Existing humans eat quite a lot of meat but have teeth that are more similar to plant-eaters.
 - Orangutans and gorillas have pointed canines but do not eat meat.
 - Male chimps have longer canines than females despite not having a different diet.
- Teeth **may play a role in other processes**.
 - e.g., Defending territory, or competing for mates, so are not always a perfect indicator of diet, and other factors would have to be considered when drawing conclusions about the diet of human ancestors.
 - e.g. Scientists can **study fossil teeth under a microscope** to look for **patterns of abrasion** which may indicate diet more clearly.
- Examples of extinct hominids include:
 - *Australopithecus africanus*
 - *Paranthropus robustus*
 - *Homo floresiensis*
 - *Homo neanderthalensis*
- Fossil evidence from *Paranthropus robustus* suggests they had a diet of tough plant material.
 - Their skull shape was similar to that of modern gorillas, which are **robust in shape** and had **attachment points for large jaw muscles** for chewing tough vegetation.
 - **Large molars and premolars** for grinding vegetation
 - **Thick tooth enamel** protects the tooth from being damaged by tough plant matter.
- Fossil evidence from *Homo floresiensis* suggests that they were primarily plant eaters, but that they may have eaten some meat.
 - They had **large premolar teeth** and **small canines**.
 - Their jaws were **square and robust**, a feature that is similar to plant-eating gorillas.
 - **Tooth abrasion** suggests a fibrous, plant-based diet.
 - Their **skulls are more similar in shape to humans** than other human ancestors, suggesting a reduction in the biting forces used.
 - Evidence of hunting/cutting tools provides additional evidence of meat-eating behaviour.

- Some fossils are available to view as part of digital collections, e.g. From the Smithsonian Institution, the Paleontological Research Institution, and the North Carolina School of Science and Mathematics.
- Consider examining 3D specimens of *Homo sapiens*, *Homo floresiensis*, and *Paranthropus robustus* to infer diet from anatomical features.



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Paranthropus robustus (left) had a skull ridge for the attachment of large jaw muscles and a robust skull shape similar to modern gorillas, while *Homo floresiensis* (right) had small canine teeth and a skull similar in shape to modern humans

[NOS] Deductions can be made from theories

- Scientists begin their work by **making observations**, e.g. observing how the teeth of existing Hominids relate to their diet.
- Observations can then be used to **develop theories**, e.g., the diet of extinct Hominids can be **deduced** by looking at their dentition.
- While such theories and deductions are a valuable part of the scientific process, it is important that **new evidence is taken into account** as it arises, e.g. Discrepancies between the dentition and diets of modern hominids tell scientists that their deductions about extinct species may be flawed and that **additional sources of evidence** may be needed.

B4.2.9 – Adaptations of herbivores for feeding on plants and of plants for resisting herbivory

Adaptations for Herbivory

- **Herbivores** are heterotrophs that feed on **plants**.
- Different organisms have **different adaptations** that allow them to survive on plant tissues. Adaptations are **characteristics** that **aid an organism's survival** in its environment.
- Examples of adaptations for herbivory include those in insects and mammals.

Herbivory in Insects

- Aphids have specialised mouth parts known as **stylets** that are able to pierce plant tissues to reach the sugary sap inside the phloem.
- Insects such as caterpillars, grasshoppers and beetles have mouth parts called **mandibles** which allow them to cut through leaves.

Herbivory in Mammals

- Grazing animals such as sheep and horses have **flat teeth** for grinding plant matter.
- **Ruminant mammals** such as cattle and deer have digestive systems adapted to improve their digestion of tough plant material; they have **stomachs with several compartments** from which they can **regurgitate and re-chew their food**, breaking down plant matter into smaller pieces to aid digestion.
- Ruminants have **specialised communities of bacteria** that live in their digestive tracts, aiding the breakdown of cellulose. The bacteria have the enzymes needed to break down cellulose, while the herbivores do not.
- Some mammals have the ability to **neutralise toxins** produced by plants, e.g.
 - Some deer produce proteins in their saliva that bind to toxins called tannins.
 - Proboscis monkeys have gut bacteria that can neutralise certain toxins found in leaves.
- Mammals may use '**cautious sampling**' when they first encounter a new plant, meaning that toxic chemicals will not be consumed in large enough quantities to be dangerous.



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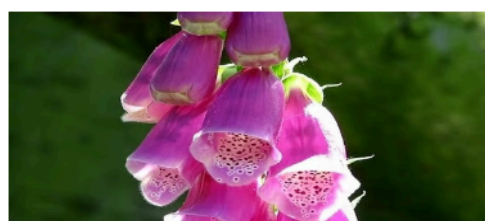
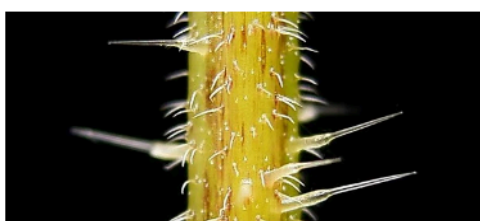


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Aphids (left) feed by inserting their stylets into the phloem of plant stems, while caterpillars (right) cut through leaves with their sharp mandibles

Plant Adaptations against Herbivory

- Herbivory causes damage to plants, reducing their leaf surface area available for photosynthesis and their ability to transport substances.
- Plants are unable to move away from herbivores, so they have other methods of deterring animals that might attempt to eat them:
- **Mechanical deterrents**, e.g.
 - Cacti have **sharp spines** to deter herbivores that might attempt to eat their succulent stems.
 - Nettles have tiny hairs that contain **toxins which irritate the skin**.
 - **Thick bark** prevents insects such as aphids from piercing plant stems.
 - **Many tiny hairs** on leaves may make it more difficult for insects to bite into/pierce plant tissues.
- **Toxic secondary compounds**, e.g.
 - Foxgloves produce a toxic compound known as **digitalis**, which can affect the heartbeat of humans and animals.
 - Deadly night shade can produce a toxin known as **atropine** which can cause muscle paralysis by blocking the binding of neurotransmitters.
 - Many plants produce chemicals called **tannins**, which can deter herbivores by their bitter taste and negatively impact the efficiency of digestive processes.
 - **Alkaloid chemicals**, such as caffeine and nicotine, can deter insect herbivory, having toxic effects on growth and nerve impulse transmission.



Predator & Prey

- **Predators** are animals that hunt and eat other animals or consume the tissues of recently dead animals.
- **Prey** are animals that are hunted and consumed by predators.
- The features of predators and prey are different, allowing them to **adapt** to their different roles.
 - The adaptations of predators assist them in catching prey.
 - The adaptations of prey assist them in avoiding predation.

Adaptations of Predators and Prey

- Chemical. Chemical compounds that assist in the catching of prey or the avoidance of predation
- Physical. Physical features, such as specially adapted sense organs, assist in catching prey or avoiding predation.
- Behavioural. Behaviours that aid the catching of prey or the avoidance of predation

Predator Adaptations

A. Chemical Adaptations of Predators

- Some predators produce **venom** which can make prey easier to subdue and catch, e.g.
 - **Snakes** can produce venoms that act in different ways to kill prey, e.g. Snakes such as adders and rattlesnakes produce **haemotoxic venoms** that damage the circulatory system, e.g. by interfering with blood clotting. Snakes such as mambas and cobras produce **neurotoxic venoms** that interfere with nerve impulses' passage.
 - **Scorpions** can produce neurotoxic venom, which they can use to subdue larger prey animals.
 - **Spider** venom can contain various toxins, which they may use to subdue their prey.
- Some predators may use a strategy known as **chemical mimicry** to attract prey animals e.g., bolas spiders release chemical pheromones normally used by female moths to attract mates, enabling them to catch male moths as prey.

- A strategy known as 'chemical crypsis', or **scent camouflage**, allows ambush predators to lie in wait for prey without being detected, e.g. the prey of pirate perch fish seem to be unable to detect their presence; scientists think that this could be due to the production of a chemical which acts as camouflage.



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Predators may use chemical, physical, and behavioural adaptations to assist them as they hunt and consume prey organisms. Adders (left) produce toxic venom, mantis shrimps (centre) have front limbs specially adapted for speed, and lions (right) co-operate with each other during pack hunting.

B. Physical Adaptations of Predators

- Predators have **sense organs** that help them to detect the presence of prey, e.g.
 - Birds of prey have **excellent vision** that allows them to detect small prey animal movement from a distance.
 - The eyes of predators are often located in the fronts of their skulls, giving **good distance perception**.
 - Snakes have an organ in the roof of the mouth known as the Jacobson's organ that allows them to use their tongues to **detect chemicals that may be released by prey animals**.
 - Bats can detect and process information generated by soundwaves bouncing off prey organisms, allowing them to find prey using **echolocation**.
- Predators have **body structures** that allow them to catch and kill prey effectively, e.g.
 - Cheetahs can run at high speeds as a result of their **long limbs** and **flexible spines**.
 - Swordfish can swim at 60 mph due to their **streamlined body shape**.
 - Mantis shrimps can move their **modified front limbs** at 50 mph to catch their prey.
 - Carnivorous mammals have **large canine teeth**, which allow them to catch and hold on to prey.

C. Behavioural Adaptations of Predators

- **Ambush predators** lie in wait without moving for extended periods, e.g.
 - Puff adders can remain motionless for weeks at a time while they wait for prey to come near.
 - Mantis shrimps (also mentioned above) hide in cracks between rocks before they reach out and grab prey at high speeds.
 - Crocodiles can approach their prey from underwater before bursting out of the water at high speed.
- **Pack predators** cooperate with each other to increase their chance of success, e.g., orcas, wolves and lions.
- **Pursuit predators** chase after their prey, either using a **burst of speed**, e.g., cheetahs, or **persistence in hunting** over long distances, e.g., wolves and painted dogs

Prey Adaptations

A. Chemical adaptations of prey

- Some prey animals produce **toxins that deter predators** by tasting bad, or by causing harm when consumed, e.g.
 - Poison dart frogs produce toxins in their skin that can kill predators.
 - Skunks can produce chemicals that smell unpleasant to deter predators.
 - Tiger moths contain chemicals that cause them to taste unpleasant to their bat predators.
- The **scent camouflage** mechanism described above can also be used by prey animals, e.g.
 - Puff adders (described above as ambush predators) are also prey for animals such as mongooses; they produce chemicals which prevent their predators from detecting them while they lie in wait for prey.
 - Harlequin filefish take on the scent of the corals on which they feed, meaning that predators are unable to detect their presence.

B. Physical Adaptations of Prey

- As with predators, prey have **sense organs that are adapted to detect predators**, e.g. prey tend to have eyes positioned on the sides of their skulls, giving a wide field of vision.
- Prey animals have **body features** which allow them to avoid or deter predators, e.g.
 - Prey animals may use **camouflage**. Some insects have bodies that allow them to appear to be a leaf or a stick.
 - **Mimicry** allows prey animals to look like predators. Owl butterflies have wing patterns that resemble the eyes of owls, causing potential predators to avoid them.
 - A strategy known as 'aposematism' involves the development of **bright warning colours**, sending predators a message about chemical defences, such as the brightly coloured skin of poison dart frogs.
 - Certain types of mimicry allow prey animals to **resemble species with chemical defences**, without needing to invest in the production of toxins, e.g., kingsnakes mimic the striping colour and pattern of venomous coral snakes.
 - Prey animals may use **mechanical defences**, such as tough exoskeletons in insects and crustaceans, tough shells in turtles, and spines in porcupines and hedgehogs.

C. Behavioural Adaptations of Prey

- Prey animals sometimes have **innate preferences for dark, sheltered places**, e.g., Insects such as woodlice that will move around constantly until they encounter a dark hiding place.
- Prey will often **move away** when they detect the presence of predators, e.g., Rabbits will run into their burrows when they see birds with the wing shape of predators.
- Prey **may avoid locations or times of day where predators are present**, e.g., Desert rodents may spend the daytime in an underground burrow and only emerge at night
- Prey animals will often **group together** in large groups; this will reduce their chance of being caught, as well as potentially confusing predators, e.g.
 - Shoals of fish and large groups of birds move together in ways that **make individual animals difficult to pick out**.
 - Some prey animals will 'mob' a predator, e.g., gulls may group together to **attack a predator and drive it away**.
 - Some individuals may be able to **warn others in a group** of the presence of a predator, e.g. by using a warning call by running away.
- **Bluffing** techniques may allow prey animals to convince predators that they are not what they seem, e.g.
 - Opossums, some species of snake, and some species of shark may **pretend to be dead**. It is thought that this behaviour causes predators to lose interest.

- Frill-necked lizards may use their large neck frill to **pretend to be larger than they really are**.



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Prey animals can use chemical, physical, or behavioural defences against predation. Poison dart frogs (left) produce toxins in their skin, owl butterflies (centre) physically resemble a predator, and grass snakes (right) can use apparent death behaviour.

B4.2.11 – Adaptations of plant form for harvesting light

Plant Adaptations for Harvesting Light

- Plants rely on the process of photosynthesis to produce carbon compounds, and their **leaves are well adapted** to carry out this process.
- Plants also have adaptations **at the level of the whole organism** that **maximise their ability to absorb light energy** for photosynthesis. These whole organism adaptations can be described as **adaptations of 'form'**.
- Form adaptations in a forest ecosystem allow plants to **compete effectively** with other plants for light.

A. Trees

- Trees in a forest make up the uppermost layer of plants, known as the **canopy**.
 - Some trees may grow above the main canopy; these trees are described as being emergent trees.
 - Some trees form a layer beneath the main canopy, known as the understory.
- The strategy of maximising height allows the tallest trees to **gain the most sunlight**, as there are no other plants between them and the sunlight.
- Trees can carry out **photosynthesis at a high rate**, providing them with the molecules they need to grow quickly and compete effectively with other plants.

B. Lianas

- Lianas are woody vines that **use the trunks of trees as their main supporting structure** to gain height, allowing their leaves to reach the forest canopy where they can **absorb light for photosynthesis**.
- Lianas germinate on the forest floor, growing toward the base of tree trunks before growing upwards.
- The roots of lianas are in the soil, allowing them to **gain nutrients and moisture from the soil**.
- Lianas **compete with trees** for light, and for nutrients and moisture.

C. Epiphytes

- Epiphytes use the height of trees to increase their absorption of sunlight by **growing high up in tree branches**, but they do not begin their lives on the forest floor, and often **gain their nutrients from high in the canopy**, e.g.

- Moss gains water and nutrients from rainwater that runs across the tree bark on which it grows.
- Bromeliads collect rainwater in amongst their leaves.
- Some species of orchid have aerial roots which absorb moisture directly from the air
- Epiphytes have the **advantage of height for gaining light energy**, but do not need to expend their energy on upward growth.



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Trees (top left) use height to maximise their light absorption, epiphytes (top right) grow in the branches of tall trees to gain light, strangler epiphytes (bottom left) grow in the branches of trees but grow their roots down into the soil to allow absorption of light and nutrients, and shade-tolerant herbs have large leaves to maximise surface area for light absorption

D. Strangler Epiphytes

- Some epiphytes **grow roots downward to the forest floor**, allowing them to **gain nutrients and water from the soil**, while still taking advantage of **height from trees to absorb sunlight**.
 - Note that this is different to lianas as strangler epiphytes begin their lives in the canopy and not on the forest floor.
- An example is the strangler fig, which begins its life in the canopy and is able to grow both upwards and downwards to maximise its access to resources. Strangler figs can kill their tree hosts by taking all of their resources.

E. Shade tolerant shrubs & herbaceous plants

- Shade tolerant plants grow on the forest floor and are adapted to absorb the limited range of light wavelengths that reach the ground through the leaves of the canopy and understory.
 - Shade-tolerant plants may contain different photosynthetic pigments, allowing them to absorb different wavelengths of light.
- Plants that grow on the ground often have especially large leaves, maximising the surface area available for light absorption.
- Flowers produced by these ground-living plants are often very brightly coloured or strongly scented to attract pollinators in low light levels.

- Do note that the terms 'shrub' and 'herbaceous plant' refer to the structure of the plant tissue.
 - Shrubs are not all like trees but they do have woody stems.
 - Herbaceous plants, or 'herbs', lack the woody stems of shrubs and trees, and rely on soft tissues with turgid cells for support.

B4.2.12 – Fundamental and realized niches

A. Niche

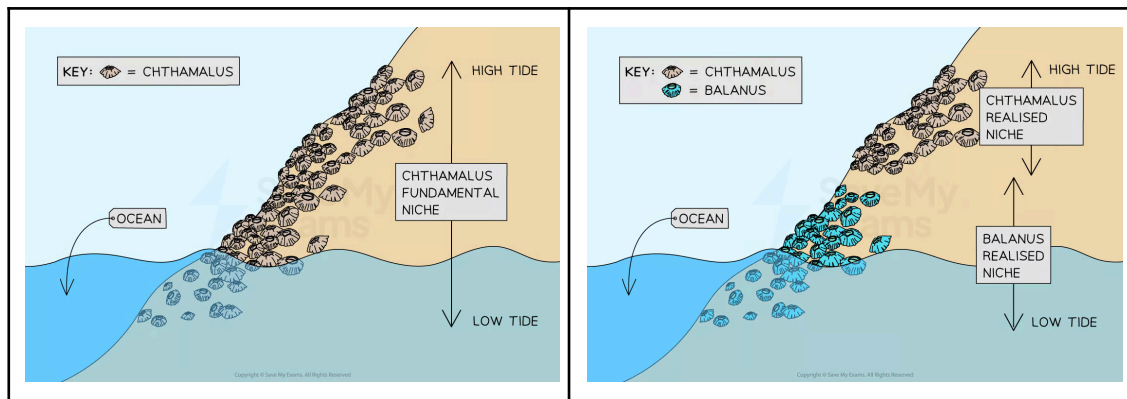
- The niche of a species can be defined as **the role of a species within its habitat**.
- A species' role takes into account.
 - The **biotic interactions** of the species, e.g. the organisms it feeds on and the organisms that feed on it
 - The **abiotic interactions**, e.g. how much oxygen and carbon dioxide the species exchanges with the atmosphere

B. Fundamental vs Realised Niche

- The fundamental niche of species is **the full range of conditions and resources in which a species could survive and reproduce, based on its adaptations and tolerance limits**.
- The realised niche is **the actual conditions and resources in which a species exists, due to biotic interactions**.
- An example of a fundamental niche compared to a realised niche can be seen in the case of the barnacle species *Chthamalus dalli*.
 - Its fundamental niche includes a wide range of rocky intertidal areas in the Pacific Northwest, where it can attach to a variety of substrates and tolerate a wide range of temperature and salinity conditions.
 - However, in reality, the realised niche of this species is much smaller due to **competition** with other barnacle species, such as *Balanus glandula*, for space and resources.
 - As a result, the actual range of *Chthamalus dalli* is **restricted** to areas where *Balanus glandula* is absent or scarce, such as higher up on the shore, where it is exposed to air for longer periods of time and can avoid competition with *Balanus glandula* for **space** and **resources**.
 - Therefore, the realised niche of *Chthamalus dalli* is smaller than its fundamental niche due to the biotic interactions with other species.

• **Fundamental vs Realised Niche**

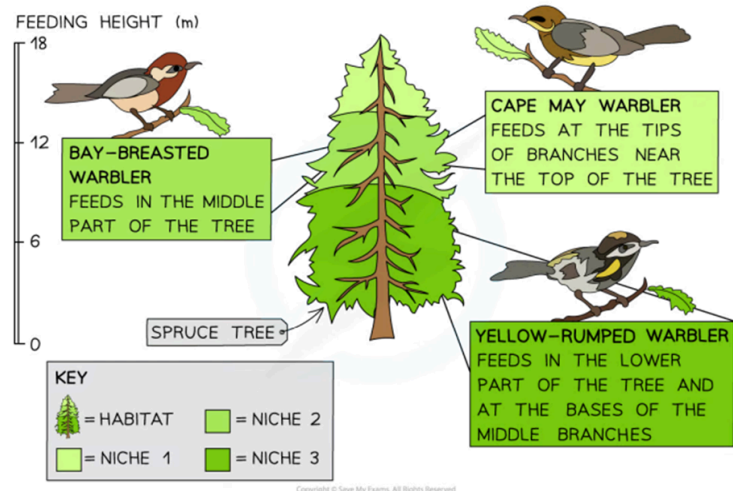
Fundamental Niche	Realised Niche
The niche a species would occupy if there were no limiting factors in the environment or resources the species could use	The niche that a species actually occupies, in the presence of competitor species
The potential distribution of a species	The actual distribution of a species
No competition for resources, no predation	Competition for resources and predation occurs
Large in size	Small in size



B4.2.13 – Competitive exclusion and the uniqueness of ecological niches

Competitive Exclusion

- A niche can only be occupied by one species, meaning that every individual species has its own unique niche.
- If two species try to occupy the same niche, they will compete with each other for the same resources.
- The eventual result of this competition will be that:
 - One of the species will be more successful and out-compete the other until the second species is either: (i) forced to occupy a new, slightly different niche or (ii) made locally extinct.
 - Both species are forced into a smaller part of their fundamental niches.
- Eliminating a competing species from its niche is known as competitive exclusion.



A possible consequence of different species of warbler competing for the same resources is that the most successful competitor will exclude other species from their niche, pushing them into slightly different niches, e.g. the location in which they feed may change

Example of Competitive Exclusion

- A classic example of competitive exclusion is between two species of single-celled free-living protozoans are (i) *Paramecium aurelia* and (ii) *Paramecium caudatum*
- When each species is grown separately from each other, both species will thrive.
- When the two species are grown in the same habitat, they compete for resources, and eventually, *P. aurelia* outcompetes *P. caudatum* for these resources, which leads to *P. caudatum*'s elimination.
- It is worth noting that this example involves both species being grown under laboratory conditions. It is rare in nature that two species will occupy exactly the same niche.

Topic 1C _ C4.1 Population and communities

- **Theme & Level of Organization.** Interaction and interdependence – Ecosystems
- **Guiding Questions.** (1) How do interactions between organisms regulate sizes of populations in a community? (2) What interactions within a community make its populations interdependent?
- **Linking Questions.** (1) What are the benefits of models in studying biology? (2) What factors can limit capacity in biological systems?



Content Statements

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

C4.1.2 – Estimation of population size by random sampling

- **[NOS]** Students should be aware that random sampling, instead of measuring an entire population, inevitably results in sampling error. In this case the difference between the estimate of population size and the true size of the whole population is the sampling error.

C4.1.3 – Random quadrat sampling to estimate population size for sessile organisms

- **[AOS]** (1) Students should understand what is indicated by the standard deviation of a mean. (2) Students do not need to memorize the formula used to calculate this. In this example, the standard deviation of the mean number of individuals per quadrat could be determined using a calculator to give a measure of the variation and how evenly the population is spread.

C4.1.4 – Capture–mark–release–recapture and the Lincoln index to estimate population size for motile organisms

- **[AOS]** (1) Students should use the Lincoln index to estimate population size. Population size estimate = $M \times (N/R)$, where M is the number of individuals caught and marked initially, N is the total number of individuals recaptured and R is the number of marked individuals recaptured. (2) Students should understand the assumptions made when using this method.

C4.1.5 – Carrying capacity and competition for limited resources

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

C4.1.7 – Population growth curves

- **[NOS]** The curve represents an idealized graphical model. Students should recognize that models are often simplifications of complex systems.
- **[AOS]** Students should test the growth of a population against the model of exponential growth using a graph with a logarithmic scale for size of population on the vertical axis and a non- logarithmic scale for time on the horizontal axis.

C4.1.8 – Modelling of the sigmoid population growth curve

C4.1.9 – Competition versus cooperation in intraspecific relationships

C4.1.10 – A community as all of the interacting organisms in an ecosystem

C4.1.11 – Herbivory, predation, interspecific competition, mutualism, parasitism and pathogenicity as categories of interspecific relationship within communities

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

C4.1.13 – Resource competition between endemic and invasive species

C4.1.14 – Tests for interspecific competition

C4.1.15 – Use of the chi-squared test for association between two species

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

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

C4.1.18 – Allelopathy and secretion of antibiotics

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

C4.1.2 – Estimation of population size by random sampling

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-

Populations

- A population can be defined as **a group of organisms of the same species living in an area at one time**.
 - Members of a population **interact** with each other and can **breed together**.
 - A population can be isolated from other populations of the same species due to living in a different area.
 - This **isolation** means that **members of separate populations cannot breed together**, and **gene exchange** cannot take place between them.



Estimating Population Size

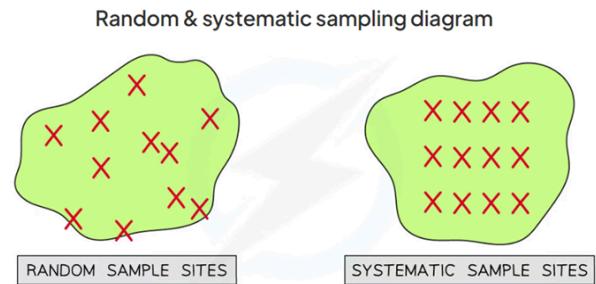
Random Sampling

- To find out about the **abundance** and **distribution** of populations can be achieved by counting all of the organisms present in a habitat.
- This is possible for areas that are very small or where the species involved is very large.
- For larger and more complex habitats, it is not possible to find, identify, and count every organism that is present.
- When this is the case, **sampling** can be used to make an **estimate** for the total species numbers.
 - Sampling involves measuring **small samples** of a population that act to **represent the whole population**.

Sampling

- Sampling is a method of investigating the **abundance and distribution of populations**.
- There are two different types of sampling: (i) **random** and (ii) **systematic**.
- In **random sampling**, the positions of the sampling points are selected at **random**.
 - This method avoids **bias** by the person carrying out the sampling.
 - Bias **can affect the results**, e.g. A student might choose to carry out samples in a particular location because it looks interesting, and this might give the impression that the habitat contains more species than it really does.
- In **systematic sampling**, the positions of the sampling points are located at **fixed intervals** throughout the sampling site.
 - This avoids accidentally missing out sections of habitat due to chance.
 - Systematic sampling allows researchers to investigate the **effect of the presence of certain environmental features** on species distribution, e.g. by taking samples **along a line** that extends away from an environmental feature such as a river. A line of this type is known as a **transect**.
- When a sampling area is **reasonably uniform**, then **random sampling** is the best choice.

- Random sample sites can be selected by
 - Laying out a **grid** over the area to be studied
 - Generating **random number co-ordinates**
 - Placing sample sites in the grid squares that match the random number co-ordinates.
- Random sampling involves selecting sample sites randomly, while systematic sampling involves placing sample sites at regular intervals.



[NOS] Students should be aware that random sampling, instead of measuring an entire population, inevitably results in sampling error.

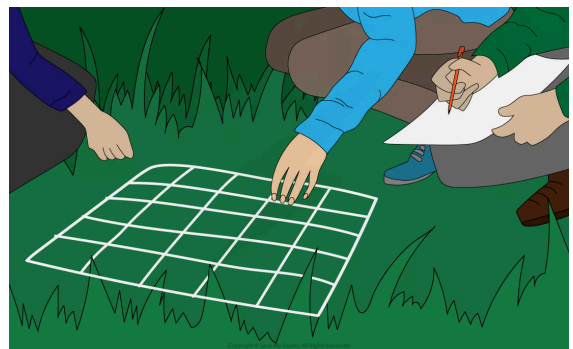
- A population estimate that is based on sampling makes the assumption that individuals are distributed evenly across the sample site, e.g.
 - Random sampling may happen to miss an area of a site in which no individuals are present; this will result in an overestimate of population size.
 - Random sampling may happen to miss an area of a site where many individuals are present, resulting in an underestimate of population size.
- many factors influence the distribution of a population, so an even distribution is very unlikely, and so the chance of sampling error occurring when calculating such an estimate is very high.
 - A sampling error is the difference between an estimated and true population size.
 - This occurs when a sample does not truly represent a whole population.
- Sampling error can be minimised by good investigation design, e.g. carrying out the right type of sampling and taking a large enough sample size.
- When scientists write about their findings, they must include details of any experimental methods used; this allows their readers to evaluate any error that may be present in the results.

C4.1.3 – Random quadrat sampling to estimate population size for sessile organisms

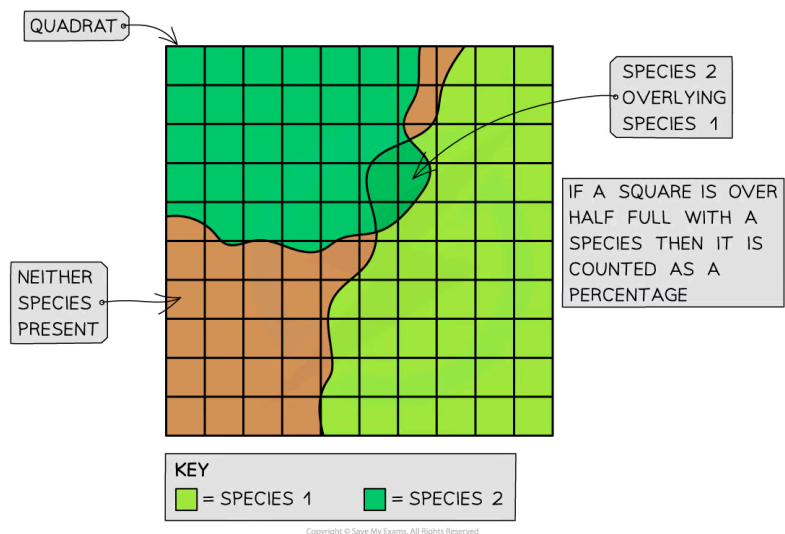
- **[AOS]** (1) Students should understand what is indicated by the standard deviation of a mean. (2) Students do not need to memorize the formula used to calculate this. In this example, the standard deviation of the mean number of individuals per quadrat could be determined using a calculator to give a measure of the variation and how evenly the population is spread.

Random Quadrat Sampling

- Sampling using frame quadrats. A **frame quadrat** is a **square frame** that is placed within the area to be studied to provide a sample.
 - Quadrats are used to study the distribution of sessile organisms.
 - Quadrats can be **of different sizes** depending on the species being studied.
 - A 1 m² quadrat can be used to study small organisms such as herbaceous plants in a grassland or limpets on a rocky shore.
 - A 400 m² quadrat can be used to study large organisms such as trees. Quadrats like this will usually be marked out with string rather than a frame.



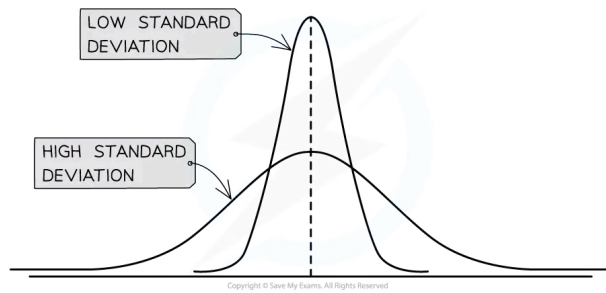
- Frame quadrats can be placed in a habitat **randomly**, e.g. using random coordinates, or **systematically**, e.g. along a transect.
- A frame quadrat can be used to measure abundance and distribution.
- Scientists can record **different types of data** from a frame quadrat depending on the aim of a study and the species involved.
 - **Presence or absence** of a species.
 - **Species frequency**: how many individuals are in the quadrat.
 - **Species abundance**: measured on a scale called the **ACFOR** scale on which species are recorded as being abundant, common, frequent, occasional, rare, or none.
 - **Percentage cover**: the percentage of the quadrat covered by a species.
 - Quadrats can be divided up into smaller squares to allow percentage cover to be assessed more easily.
- Abundance in a frame quadrat can be assessed by measuring percentage cover.



Analysing Results

- Quantitative investigations of variation can involve the interpretation of **mean values** and their **standard deviations**.
 - A mean value describes the **average value** of a data set.
 - Standard deviation is a **measure of the spread or dispersion of data around the mean**
 - A **small standard deviation** indicates that the results **lie close to the mean**, so there is little variation.
 - A **large standard deviation** indicates that the results are **more spread out around the mean**, so there is a lot of variation.
- In the quadrat study described here, a mean could be calculated for the number of individuals of a species found in each quadrat, and then the standard deviation could be calculated to find out how spread out the data points are around the mean.
 - This would give an indication of **how evenly distributed the population is** across the habitat.

- A small standard deviation shows that data are closely grouped around the mean while a large standard deviation shows that data are spread widely around the mean.



C4.1.4 – Capture–mark–release–recapture and the Lincoln index to estimate population size for motile organisms

- **[AOS]** (1) Students should use the Lincoln index to estimate population size. Population size estimate = $M \times (N/R)$, where M is the number of individuals caught and marked initially, N is the total number of individuals recaptured and R is the number of marked individuals recaptured. (2) Students should understand the assumptions made when using this method.

Estimating Population Size: Motile Organisms

Capture-mark-release-recapture

- The sampling methods described above are only useful for **non-motile** (sessile) organisms.
- Different methods are required for estimating the number of individuals in a population of motile organisms. The **mark-release-recapture** method can be used.
- The mark-release-recapture method is carried out as follows:
 - The **first large sample is taken**, and as many individuals as possible are caught, counted and **marked** in a way that won't affect their survival. e.g. if studying a species of beetle, a small amount of brightly coloured non-toxic paint can be applied to their wing cases.
 - The marked individuals are **returned to their habitat** and allowed to randomly mix with the rest of the population.
 - When a sufficient time period has passed, **another large sample is captured**.
 - The number of marked and unmarked individuals within the sample are **counted**.
 - The proportion of marked to unmarked individuals is used to calculate an **estimate of the population size** using a statistical measure known as the Lincoln index.

where:

M = number of marked individuals in the first sample

N = total number of individuals in the second sample (marked and unmarked)

R = number of marked individuals recaptured in the second sample

Worked Example

- Scientists wanted to investigate the abundance of leafhoppers in a small grassy meadow. They used nets to catch a large sample of leafhoppers. Each insect was marked on its underside with non-toxic, waterproof paint and then released back into the meadow. The following week, another large sample was caught using sweep nets.
- Use the figures below to estimate the size of the leafhopper population in this meadow.
 - No. caught and marked in the first sample (M) = 236
 - No. caught in the second sample (N) = 244
 - No. of marked individuals recaptured in the second sample (R) = 71

Answer

- Step One: Write out the Lincoln index equation and substitute in the known values.

$$N = M \times \frac{N}{R}$$

$$N = 236 \times \frac{244}{71}$$

- Step Two: Calculate the population size estimate (N).

$$N = 236 \times 3.44$$

$$N = 811.84$$

= 812 (to the nearest whole organism)

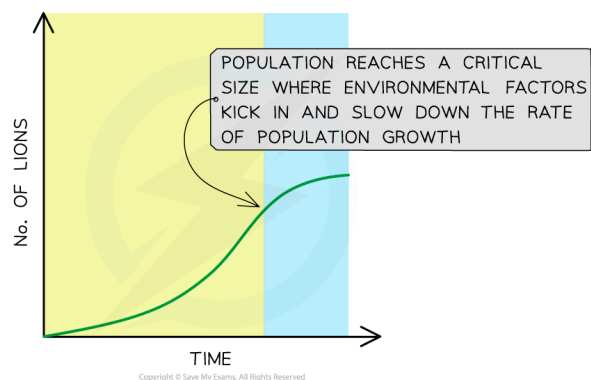
Lincoln Index

- The Lincoln index makes some **assumptions** about the population and the capture-mark-release-recapture method:
 - The marked individuals **disperse** and **mix** back in fully with the **main population**.
 - The marking doesn't affect the **survival rates** of the marked individuals, e.g., it doesn't make them more **visible** and, therefore, more likely to be predated.
 - The marking remains visible throughout the sampling and doesn't rub off.
 - The **population** stays the **same size** during the study period, i.e.
 - There are no significant changes in population size due to births and deaths.
 - There are no migrations into or out of the main population.

C4.1.5 – Carrying capacity and competition for limited resources

Carrying Capacity

- The **maximum number of individuals of a species** an ecosystem can support is known as its carrying capacity. The carrying capacity is represented by the letter **K**.
- While every individual within a species population has the theoretical **potential to reproduce** and have **offspring** that will contribute to **population growth**, in reality, there are many factors that prevent every individual in a population from surviving and reproducing.
- This means that the **population size** of each species is **limited**, i.e. the ecosystem has a carrying capacity for that species.
- The graph on the right shows the population growth of a population of lions.
 - The point at which the graph starts to flatten out is the **carrying capacity** of this population.
 - At this point, the environmental factors that stop all individuals from surviving and reproducing mean that the population can no longer increase.
- Carrying capacity is reached when the growth of a population starts to level off.



Factors Affecting Carrying Capacity

- Abiotic factors involve the **non-living** parts of an ecosystem, e.g.
 - **Light availability.** A lack of light will reduce the carrying capacity for a plant population as it will limit photosynthesis.
 - **Temperature.** Low or high temperatures will influence carrying capacity as this will affect the rate at which the reactions of metabolism can occur.

- **Soil mineral availability.** Low mineral availability will reduce carrying capacity as it will affect the ability of plant populations to build biological molecules such as proteins and chlorophyll.
- Biotic factors involve the **living** parts of an ecosystem, e.g.
 - **Competition for resources.** A lack of resources will limit the carrying capacity of an ecosystem. The energy that an individual puts towards competing for resources will not be available for growth and reproduction, so this will reduce carrying capacity.
 - **Predation.** The energy that an individual puts towards avoiding predators will not be available for growth and reproduction, so this will reduce carrying capacity.
 - **Disease.** Energy that an individual puts towards fighting off disease will not be available for growth and reproduction, so this will reduce carrying capacity.

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

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

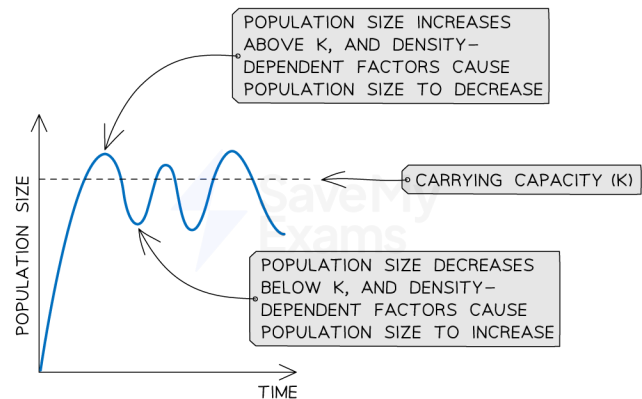
C4.1.17 – Top-down and bottom-up control of populations in communities

C4.1.18 – Allelopathy and secretion of antibiotics

Population Density

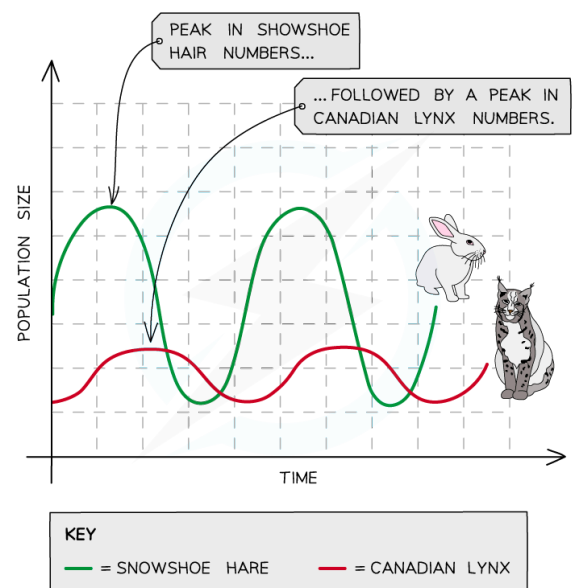
- Population density can be defined as **the number of individuals present per unit area of habitat**. Factors that influence the size of a population can be density-dependent or density-independent.
- **Density-dependent factors** have a **different effect at different population densities**, e.g.
 - Pathogens and pests will spread faster through a dense population, and so will have a greater effect on the population size.
 - Dense populations will be in increased competition for resources, so competition will have an increased effect at high densities.
 - Predators will be attracted to dense populations of prey organisms, so predation will have an increased effect at high densities.
- **Density-independent factors** have the **same effect on a population at any population density**, e.g.
 - A natural disaster, such as a flood, is equally likely to affect populations of different densities.
- Density-dependent factors tend to act to keep a population at or below its carrying capacity; this is a **negative feedback** effect.
- A negative feedback system acts to **keep conditions within narrow limits**. If conditions stray too far from an ideal value, then negative feedback causes a return to that value, e.g.
 - If a population increases above its carrying capacity, then density-dependent factors, such as the spread of disease, or competition for food, cause a **reduction in survival and reproduction**, resulting in a **decrease in the population size**.
 - If a population drops below its carrying capacity then the same density-dependent factors will lead to **increased survival and reproduction**, and there will be an **increase in population size**.
- When the population size is controlled by negative feedback it will **fluctuate around its carrying capacity**.
- Density-dependent factors tend to act to keep a population at or below its carrying capacity; this is a negative feedback effect.

- A population that is controlled by **positive feedback** will respond to a change in population size by **continuing to change in the same direction**, e.g.
 - An increase in population size means that more individuals are present, leading to increased reproduction, and a further increase in population size. This can continue until a density-dependent factor, such as competition for resources, starts to limit population growth.



Predator-Prey Relationships

- Consumers that kill and eat other animals are known as **predators**, and the animals that are eaten are known as **prey**.
- In a stable community the predator and prey population sizes rise and fall in a **predator-prey cycle** that **limits the population sizes of both predators and prey**.
- The graph on the right demonstrates some of the key patterns in predator-prey cycles:
 - The number of predators increases when there is more prey available.
 - The number of prey decreases in response to an increase in the number of predators.
 - The number of predators decreases in response to a decrease in the number of prey.
 - The number of prey increases in response to a decrease in the number of predators.
 - The cycle repeats.



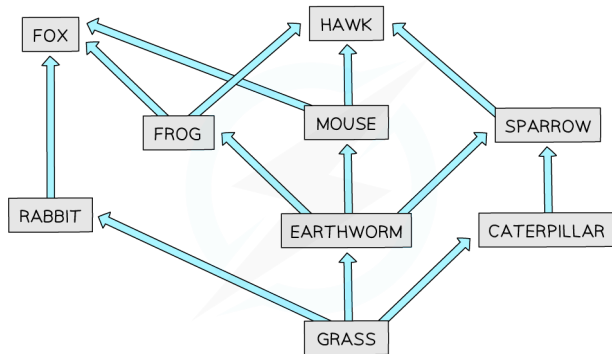
- The relationship between the **Canada lynx** and the **snowshoe hare** is a famous example of the predator-prey interaction.
 - It is worth noting that relationships of this kind, with a single predator species and a single prey species, are **unlikely to exist in this simple form in nature**. There will be **other predator and prey species**, as well as **additional factors that will affect the sizes of the respective populations**.
- The predator and prey populations are closely linked in a predator-prey cycle.

Control of Populations in Communities

Top-down & bottom-up population control

- Populations in a community can be controlled by either **top-down** or **bottom-up control** factors.
- A population that is **limited by predators**, e.g. the snowshoe hare in the example above, is controlled by a **top-down control**.
 - Plant populations being limited by herbivory is another example of top-down control.

- A population that is limited by the **availability of resources**, e.g. the lynx in the example above, is controlled by a **bottom-up control**. Plant populations being limited by light intensity is also a bottom-up control.
- The effects of a top-down control factor on a food web can be complex, as every food chain is connected to several others. e.g. in the food web shown below, a change in the fox population could lead to a **top-down cascade** of effects as follows:
 - A decrease in the fox population could lead to an increase in the rabbit population, which could lead to a decrease in the growth of grass.
 - Note that the grass → rabbit → fox food web does not exist in isolation, so this top-down effect will influence other parts of the food web as well.



- While it is possible for both top-down and bottom-up control factors to act on an ecosystem at the same time, the reality is that any one part of an ecosystem is likely to have **one control type that is dominant at any given time**, e.g.
 - A coastal seagrass ecosystem is likely to be mainly controlled by bottom-up nutrient availability.
 - Overfishing by humans may reduce the number of marine predators, temporarily leading to a switch to top-down control dominance.
- Note that top-down control may shape an ecosystem due to both **lethal and non-lethal effects**.
 - Predators kill prey, **influencing their numbers**, and so their effect on the rest of the ecosystem.
 - The presence of predators may **affect the behaviour of prey organisms**, affecting their choice of diet and where they choose to spend time; this can also alter the structure of an ecosystem.

Allelopathy & Antibiotic Secretion

- Species compete with each other for resources; this is **interspecific competition**.
- Some species have **strategies** which **increase their ability to outcompete** other species.
- Such strategies can work by either **increasing the survival chances** of a species, or by **decreasing the survival chances of a competing species**, e.g.
 - Camouflage increases a species' survival chances.
 - **Secretion of harmful chemicals** into the environment decreases the survival chances of a competitor. Such harmful chemicals are known as **secondary metabolites**, as opposed to primary metabolites which are molecules that are essential for survival.
- Allelopathy is an example of a strategy that involves damaging the survival of a competing species.
 - **Antibiotic secretion** in some bacteria is a well-known example of allelopathy.

Allelopathy

- Organisms that carry out allelopathy **secrete secondary metabolites that harm other organisms** into their surroundings, e.g. in plants:
 - Secreting harmful chemicals via roots into the soil
 - Releasing harmful gases via the stomata into the air

- Storing harmful chemicals in the leaves which are released when the leaves fall and break down
- Examples of plant species that carry out allelopathy include:
 - **Garlic mustard** produces a chemical called sinigrin which reduces seed germination and root growth in other plant species.
 - **Bracken ferns** are thought to release toxins into the surrounding soil, as well as containing toxic chemicals in their fronds which are released when they decay.
 - **Himalayan balsam**, as seen in the diagram on the right, is thought to secrete allelochemicals into the surrounding soil that limit the growth of other plants. Himalayan balsam shows allelopathy, a strategy that is thought to contribute to its success; it is a known invasive species in the UK, where it is often found along waterways.



Antibiotic Secretion

- The **secretion of antibiotics** is a **form of allelopathy** found in some microorganisms, e.g. the antibiotic penicillin was discovered in Penicillium fungus. Antibiotics are also secreted by some bacteria species.
- Antibiotics **kill bacteria** by, e.g. preventing cell wall formation or inhibiting protein synthesis; this **reduces interspecific competition**, and so increases survival and reproduction in the species that produces the antibiotic.

C4.1.7 – Population growth curves

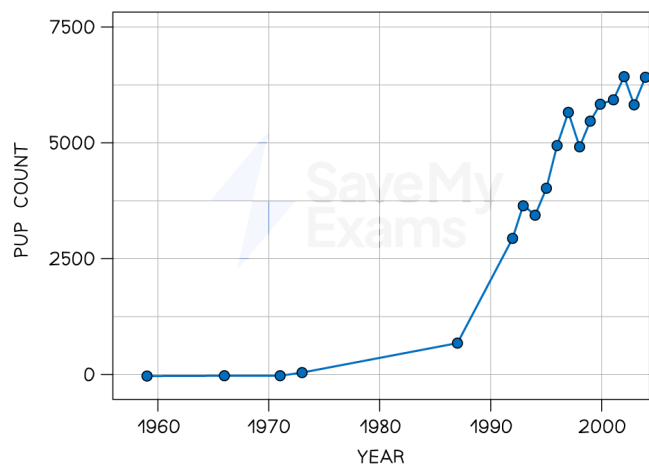
- **[NOS]** The curve represents an idealized graphical model. Students should recognize that models are often simplifications of complex systems.
- **[AOS]** Students should test the growth of a population against the model of exponential growth using a graph with a logarithmic scale for size of population on the vertical axis and a non- logarithmic scale for time on the horizontal axis.

C4.1.8 – Modelling of the sigmoid population growth curve

- **[AOS]** Students should collect data regarding population growth. Yeast and duckweed are recommended but other organisms that proliferate under experimental conditions could be used.

Population Growth Curves

- Populations of living organisms tend to follow a set growth pattern over time; this growth pattern gives rise to a **population growth curve** that can be plotted on a graph.
- Population growth curves can generally be seen in any newly established or recovering population, e.g.
 - **Antarctic fur seals** were hunted extensively during the 1800s, and underwent a population recovery following the end of this practice. The graph on the right shows the Antarctic fur seal population in Cape Shirreff, Antarctica, followed a classic growth curve between 1960 and the early 2000s.
 - The recovery of the seal population in some locations follows a classic growth curve, e.g. in the graph

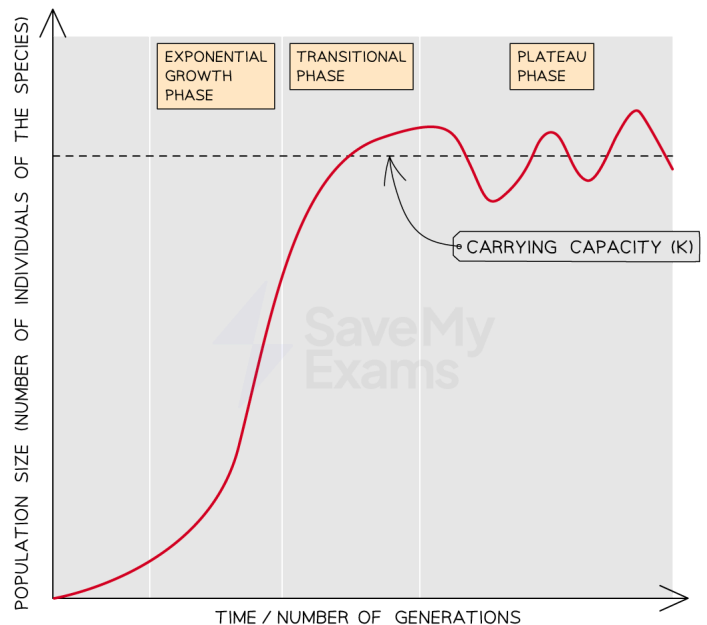


below for seals on Cape Shirreff, Antarctica. Pup count is used to represent the size of the seal population.

- This recovery has not continued throughout the early 21st century, with climate change having since caused severe declines in many seal populations.

Sigmoid Population Growth Curve

- The population growth curve shown above is an example of a **sigmoid**, or **s-shaped**, growth curve. Sigmoidal population growth curves show an exponential growth phase, a transitional phase and a plateau phase.
- **Exponential phase** (Also known as the **logarithmic phase**)
 - There are no factors that limit population growth, so the population increases **exponentially**. The number of individuals increases, and so does the rate of growth.
- **Transition phase**
 - **Limiting factors** start to act on the population, e.g. competition increases and predators are attracted to large prey populations.
 - The rate of growth slows, though the population is still increasing.
- **Plateau phase** (Also known as the **stationary phase**)
 - Limiting factors as the death rate to equal the birth rate and population growth stops.
 - This plateau occurs at the **carrying capacity**.
 - The population size often fluctuates slightly around the carrying capacity.



[NOS] The curve represents an idealised graphical model

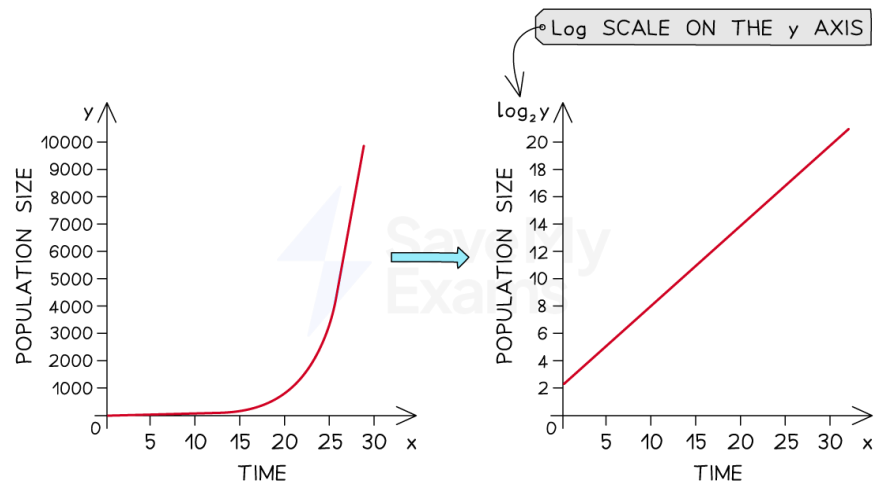
- Scientists use **models** to represent real world ideas, organisms, processes and systems that cannot be easily investigated.
- Models are useful for the purposes of **experimentation** and **testing predictions**, but they are **not perfect representations** of biological systems.
- Here, the population growth model is useful for conceptualising the different stages in the growth of a population, but scientists must always be aware that **real ecosystems are complex** and that there are **many factors** at play in determining population size.
- There are **few real-world situations** where populations follow perfect sigmoid growth curves, and the seal population example given above soon showed population decline rather than remaining at a plateau.

Exponential Population Growth

Testing for exponential growth with a logarithmic scale

- Population growth is exponential when the **speed of growth is proportional to the number of individuals**, i.e. a population of 20 individuals will reproduce at twice the rate of a population of 10 individuals.

- It is possible to assess whether or not exponential growth is occurring by plotting population size (y) against time (x) on a graph with a **logarithmic scale on the y axis** and a **non-logarithmic scale on the x axis**.
 - Logarithmic scales can be very useful when investigating factors that **vary over several orders of magnitude**, e.g. population size. 'Orders of magnitude' refers to whether values are measured in, e.g. tens, hundreds, thousands etc.; using a log scale allows tens and millions to be represented on the same easily visible scale.
 - The numbers in a logarithmic scale represents **logarithms**, or powers, of a base number.
 - If using a $\log_{10}$ scale, in which the base number is 10, the numbers on the y-axis represent a power of 10, e.g. $1=10^1$ (10), $2=10^2$ (100), $3=10^3$ (1000) etc.
 - Logarithmic scales allow for a wide range of values to be displayed on a single graph.
- An exponentially growing population plotted with a log scale on the y axis will appear as a **straight line** as seen on the right.

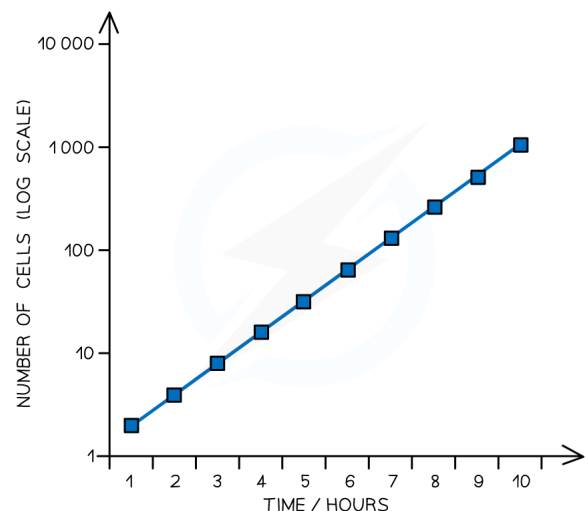


Modelling the Sigmoid Growth Curve

- Organisms that grow and reproduce under **laboratory conditions** can be used to **model the sigmoid population growth curve**. Suitable organisms include: (i) yeast and (ii) duckweed.

Modelling population growth curves using yeast

- The population growth rate of microorganisms, such as bacteria or yeast, can be investigated by growing the microorganisms in a broth culture.
- The **turbidity** of the suspension can then be used as a way of estimating the number of cells, i.e. the population size, of the microorganisms in the broth culture.
 - Turbidity is a measure of the **cloudiness of a suspension**, i.e. how much light can pass through it.
- As the microorganisms in the broth culture reproduce and their population grows, the suspension becomes **progressively more turbid**.
- This changing turbidity can be monitored by measuring **how much light can pass through** the suspension **at fixed time intervals** after the initial inoculation of the nutrient broth with the microorganisms.
- A **turbidity meter** or a **colorimeter**, connected to a datalogger, can be used to take these measurements.



- The results can then be used to **plot a population growth curve** (as seen in the graph above) to show how the population of microorganism changes over time.
- As seen in the graph on the right, turbidity measurements can be used to gain a measure of yeast population size over time. The resulting data can be plotted using a log scale to show exponential population growth.

Modelling population growth curves using duckweed

- Duckweed is a type of pond weed that grows on the surface of still bodies of fresh water.
- It is ideal for modelling population growth because it **reproduces quickly and asexually**, and newly produced fronds, also known as thalli (singular thallus), remain attached to the parent fronds in clusters, allowing for **easy counting** in a laboratory setting.
- Population growth can be modelled using duckweed as follows:
 1. Place a small number of duckweed fronds into a petri dish that contains distilled water mixed with liquid fertiliser
 2. Place the petri dishes in a brightly lit location, but out of direct sunlight
 3. Record the number of duckweed fronds present after 1 week
 4. Repeat the counting process once a week for a total of six weeks, topping up the dish with distilled water as needed
 5. Plot the results on a graph to show a population growth curve



C4.1.9 – Competition versus cooperation in intraspecific relationships

Competition & Cooperation

Intraspecific relationships

- Intraspecific relationships involve interactions between **individuals of the same species**.
- Intraspecific relationships can involve:
 - **Cooperation.** Both members of the relationship benefit from the interaction.
 - **Competition.** One member of a relationship outcompetes the other and is more successful.

Intraspecific cooperation

- **Members of a species work together** to aid survival of a group, e.g.
 - **Orcas** show cooperative hunting behaviour, working together to catch specific types of prey and then sharing the food that they catch.
 - The photograph on the right was taken off the west coast of Graham Land, Antarctica from on board the National Geographic Explorer expedition ship. It captures four killer whales swimming in close cooperation just below the surface of the water as they charge an ice floe bearing a crabeater seal. By



cooperatively hunting in this manner, the whales create a strong bow wave with which they hope to wash the seal off the ice floe. The seal, known informally as "Kevin", eventually escaped after enduring three dozen such attempts to make him into a shared meal.

- **Meerkats** divide the roles in their groups between multiple individuals, so some will watch for predators while others watch young or hunt for food.
- Many species of **ants** work together in large groups to build nests and provide food for developing young.

Intraspecific competition

- Individuals of the same species have the **same needs**, and so they are frequently in **competition with each other for the same resources**, e.g.
- Plants will compete with members of the same species for: (i) light, (ii) minerals, (iii) water and (iv) space.
- Animals will compete with members of the same species for: (i) food, (ii) mates and (iii) territory (which will increase access to food and mates).
- Examples of intraspecific competition include:
 - **Male red deer** fight with each other for access to females, and the dominant male will mate with all of the females in the group. Red deer males bellow to show their dominance as part of their competition for females.
 - **Robins** are aggressive towards other robins in order to defend their territory; they are so fiercely territorial against other robins that they will even attack bunches of red feathers.
 - **Oak trees** growing close to each other in a woodland will be competing for light, water, and minerals.
- Not all examples of intraspecific competition involve visible conflict; individuals with overlapping territories will be consuming the same resources, so the **food that is eaten by one individual will no longer be available for another**. These individuals are in competition with each other



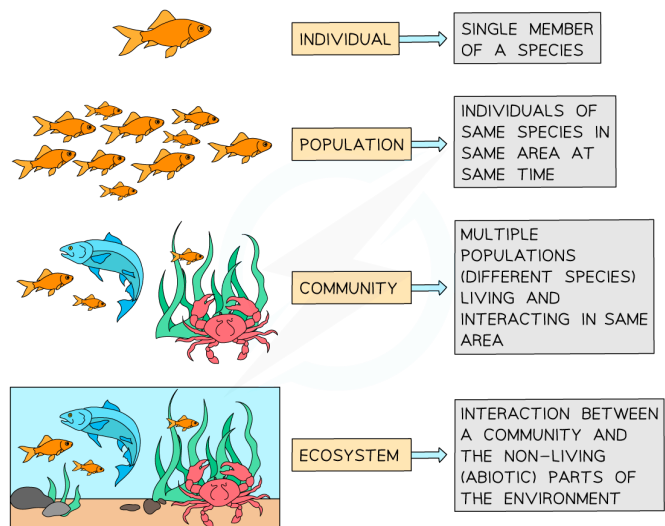
C4.1.10 – A community as all of the interacting organisms in an ecosystem

C4.1.11 – Herbivory, predation, interspecific competition, mutualism, parasitism and pathogenicity as categories of interspecific relationship within communities

Community in an Ecosystem

- **Species** do not exist by themselves in their own isolated environment. They **interact** with **other species**, forming **communities**.
- A community can be defined as **multiple populations of different species living and interacting in the same area**.
- For example, a garden pond **community** is made up of populations of fish, frogs, newts, pond snails, damselflies and dragonflies and their larvae, pondweed, water lilies, and all other populations living in the pond.
- Communities include populations from all groups of living organisms, e.g. plants, animals, fungi, and bacteria. Living communities interact with their **abiotic** environment to form an **ecosystem**.

- A **community** is all of the **populations of living organisms** interacting in an area (as seen in the diagram on the right). Communities **interact with their non-living environment** to form an **ecosystem**.



Interspecific Relationships within Communities

- **Interspecific relationships** are the interactions **between different species** that occur within a community.
- There are several types of interaction that can occur between different species.

Type of Interaction	Description	Example
Herbivory	An organism feeding on a plant	Cattle graze on grass Sea turtles feed on sea grass Honeybees consume nectar and pollen
Predation	An organism catching and consuming an animal, or consuming a recently dead animal	Dolphins catch and eat fish Lions hunt and eat zebra Red kites eating roadkill
Interspecific competition	Organisms of different species compete for the same resources	Oak and beech trees compete for light and minerals Lions and hyenas compete for prey
Mutualism	Organisms of different species work together for the benefit of both	Pistol shrimp share their burrows with goby fish, which provide a warning when predators are near
Parasitism	A parasite organism lives in or on a host organism, causing its host harm	Mistletoe plants grow in the branches of trees, taking water and nutrients from their hosts
Pathogenocicity	An infectious microorganism (pathogen) lives inside a host organism, causing disease	<i>Mycobacterium tuberculosis</i> bacteria cause the disease tuberculosis in human hosts

- **[Note]** When students are referring to organisms in an examination, either the common name or the scientific name is acceptable.

Mutualism

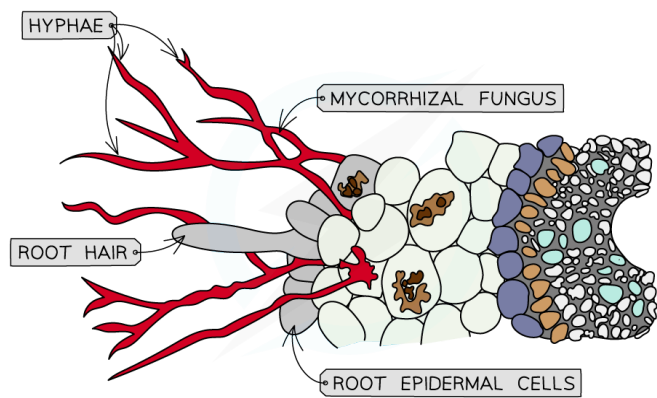
- Mutualism occurs **between members of different species**, and is an example of **cooperation where both members of a mutualistic relationship benefit** from the interaction.
- Examples of mutualism include:
 - Bacteria living in the root nodules of plants
 - Mycorrhizal relationships between fungi and plants
 - Coral polyps and algae

1. Root nodules in Fabaceae

- The Fabaceae, or legume, family of plants includes species of peas, beans, and clover.
- Many legumes have a **symbiotic** relationship with bacteria, which live in **nodules attached to the plant roots**. Nodules are small, sphere-like structures.
- The bacteria **convert nitrogen gas in the air into ammonia** (NH_3) which can then be converted again into **nitrates**.
 - The conversion of nitrogen gas into a form that is useful to plants is known as nitrogen fixation.
 - Rhizobium is an example of a genus that lives in root nodules and fixes nitrogen.
 - Nitrates can be used by plants to **build essential biological molecules** such as **proteins and nucleic acids**.
- The **bacteria also benefit from this relationship**, as they gain **carbohydrates** that are produced by the plant in photosynthesis.

2. Mycorrhizae in Orchidaceae

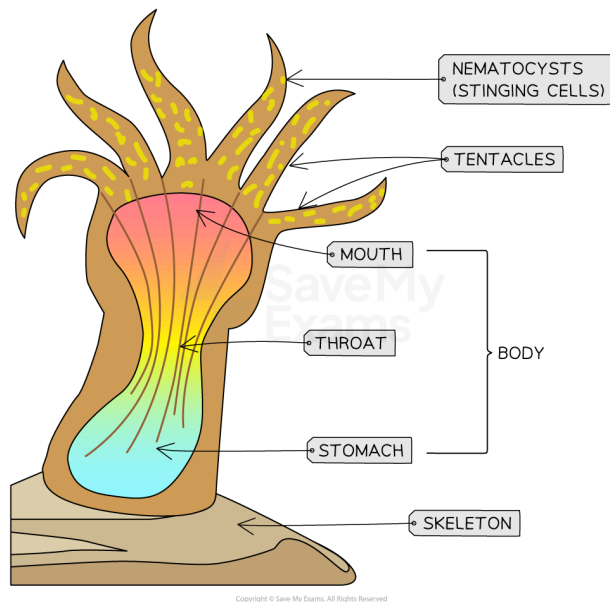
- Many plants have evolved symbiotic relationships with **fungi**.
- The fungi form long, thin filaments known as **hyphae**, which **interact with the roots** of the plants.
- These hyphae greatly **increase the surface area** of the root systems of the plants, increasing the amount of **water and mineral ions** that can be absorbed by the plant roots.
- In return the fungi receive **organic compounds, e.g. glucose**, from the plant.
- These relationships between plant roots and fungi (as seen in the diagram on the right) are known as **mycorrhizae** (singular mycorrhiza).



- The **orchidaceae**, or **orchid family**, are known to form many mycorrhizal relationships, e.g.
 - Orchid seeds may gain the nutrients needed for germination from mycorrhizae.
 - Some unusual orchids are unable to photosynthesis, relying on their mycorrhizal fungi to break down dead matter in the soil and provide them with all of their nutrients.
 - The orchid in this relationship is a **heterotroph** and **not an autotroph**.
 - The orchid does not benefit from this relationship until the orchid dies, at which point it can access the biological molecules in the orchid's tissues by decomposition.

3. Zooxanthellae in hard corals

- The coral reefs associated with the hard corals are produced by tiny animals known as coral polyps, which live in a **symbiotic relationship** with **zooxanthellae algae**.
 - Polyps are in the phylum cnidaria, along with jellyfish and sea anemones.
 - Their soft bodies have **tentacles** which contain stinging cells called **nematocysts**, and which also **contain the zooxanthellae cells**.
 - The polyps secrete calcium carbonate which forms the hard structure of the coral skeleton.
 - The tentacles of coral polyps contain algae cells with which they have a mutualistic relationship (as seen in the diagram on the right).
- The polyp's body provides **shelter and protection** for the algae.
- The algae carry out **photosynthesis** and produce **carbon compounds**, such as carbohydrates, which can be used by the polyp.

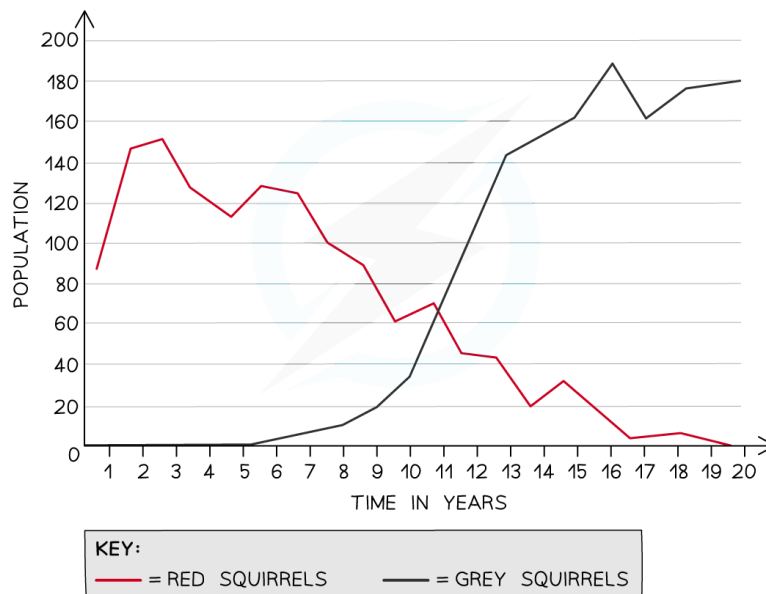
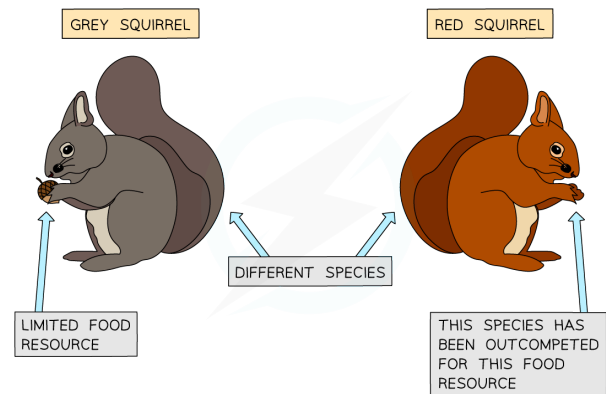


C4.1.13 – Resource competition between endemic and invasive species

Resource Competition: Endemic & Invasive Species

- A species that has **moved into an ecosystem where it was previously unknown** is an **invasive species**. Invasive species are sometimes referred to as alien species.
- An invasive species can occur naturally as a result of a species migrating or expanding their habitat, but most recorded incidents of invasive species have been **caused by humans**, e.g. humans have:
 - Knowingly collected and traded species between countries. e.g. bringing attractive plant species into gardens, or animals into zoos or as pets, which then escape into the wild.
 - Unknowingly provided transport for invasive species to a new ecosystem, e.g. rats on board ships.
 - Introduced alien species deliberately as biological control for pests.
- In a new ecosystem invasive species will have little or **none of the natural population controls** that existed in their previous ecosystem. They will have **no natural predators or competitors**.
- As a result they are able to **increase in number at a rapid rate**.
- This can affect the processes within an ecosystem.
 - **Competition** may occur between invasive species and native species that **occupy a similar niche**, with the **native species getting displaced** or pushed to extinction.
 - Many invasive species can be successful predators, causing a massive decline in their prey species.
 - Invasive species can **introduce new diseases**, to which the native species have **no natural immunity**.

- Grey squirrels were introduced into the UK from North America in the 1800s. They have been highly successful and have largely outcompeted the native UK red squirrels in interspecific competition. Note that red squirrel populations in the UK are not at zero, and are currently recovering in some locations (as seen in the graph below).



Invasive species & endemic species

- Endemic species** are found in a particular place and in no other location in the world, e.g. the Scottish crossbill is found in the conifer forests of Scotland and nowhere else, so is said to be endemic to Scotland.
- Endemic species are **especially vulnerable to the effects of invasive species**, as local extinction will mean that the species has gone entirely extinct. e.g. Australia is home to many endemic species that have **evolved over many years of isolation** from other continents.
 - The introduction of **invasive predators**, such as the European red fox and the domestic cat, has caused huge declines in native Australian species.
 - The red fox was introduced in the 1800s by European settlers for the purposes of fox hunting.
 - Cats are likely to have travelled on ships and been introduced by accident.
 - Evidence suggests that **more than 10 % of Australia's endemic mammal species have already gone extinct** since the arrival of European settlers.
 - Small mammals are at the highest risk due to being the best food source for the invasive predators.
 - Some species now only survive on the islands around mainland Australia where foxes and cats have not yet arrived.

- **[NOS]** Students should recognize that hypotheses can be tested by both experiments and observations and should understand the difference between them.
-

Tests for Interspecific Competition

- If two species occupy **very similar niches**, then competition can exist between them for resources; this is **interspecific competition**.
- One species may be slightly **better adapted** to compete than the other, so the second species may be **outcompeted**.
- The result of the interspecific competition could be that the second species is forced to **alter its distribution** within a habitat so that it **no longer directly competes** with the first species.
 - If this is not possible then the second species could become **locally extinct**.
- The second species has been forced out of its niche into an alternative niche due to competition; this is known as **competitive exclusion**.
 - The ideal niche is known as the fundamental niche while the new niche is known as the realised niche.

Testing for interspecific competition

- This competitive exclusion effect can be used to **test for the presence of interspecific competition**.
 - If the removal of a competitor species results in a change in species distribution then interspecific competition is likely to have been taking place, but if the removal of a competitor has no effect then distribution is likely to be the result of another factor.
 - Note that this effect **does not prove the presence of interspecific competition**, but does indicate that it could be occurring.
- There are different ways of carrying out such a test for the presence of interspecific competition, e.g.
 - In the **lab**, e.g. by culturing bacteria species on their own or together and measuring how this affects population size or colony distribution.
 - In the **field** with **random sampling** and then with **manipulation**, e.g.
 - By first carrying out random quadrat samples and recording the presence/absence of one or both species at different locations around a habitat.
 - By then removing one species from a small area and measuring the effect that this has on distribution of the second species.

[NOS] Students should recognize that hypotheses can be tested by both experiments and observations and should understand the difference between them

- A hypothesis (plural hypotheses) is a proposed explanation for an observation, that **can be tested by scientific investigation**.
- There are different ways of carrying out such tests, e.g. as described above, hypotheses can be tested either: (i) In a laboratory or (ii) In the field.
- Laboratory investigations are carried out under **controlled conditions** and on a **small scale**, e.g. growing bacteria in a lab, or plants in a greenhouse
 - Laboratory tests allow a **high level of control**, so only the **independent variable** is changed while other variables are carefully controlled.
 - Laboratory experiments are designed to represent real life, but the **results can never be directly applied to a real life situation**.
 - Organisms may not always behave in the same way in a lab as they do in their natural environment.

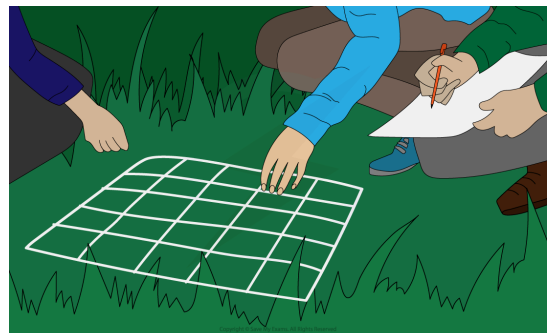
- Field tests are carried out in a **real-life setting**, and can be carried out on a **large scale** e.g. observing the growth of plants in an area of forest, or the distribution of species on a rocky shore.
 - It is **not possible to control factors** beyond the independent variable, so field experiments may not provide a perfectly valid set of results, and are very **hard to replicate** exactly.
 - Field experiments may provide a **more realistic representation** of the real world.

C4.1.15 – Use of the chi-squared test for association between two species

- **[AOS]** Students should be able to apply chi-squared tests on the presence/absence of two species in several sampling sites, exploring the differences or similarities in distribution. This may provide evidence for interspecific competition.

Chi-squared Test - Looking for associations between species

- The distribution of species in a habitat is **rarely random**. It usually depends on factors such as soil type, water availability, and competition.
- It is sometimes possible to observe an **association** between the distributions of different species within a habitat, e.g.
 - Species that are in a symbiotic relationship are likely to be **found next to each other**. We would say that there is a **positive association between the distributions of these two species**.
 - Species that are in **direct competition** for the same resources will exclude each other from their immediate surroundings and are likely to be **found in different parts of a habitat**. There might be a **negative association between the distributions of these two species**.
- If species have **no interaction** with each other, then there will be **no association between their distributions**, and any that appears to occur will be **due to chance**. We would say that such species have distributions that are **independent** of each other.
- **Random sampling with quadrats**, along with a statistical test called the **chi-squared test**, can be used to test for an **association between two species**.



The chi-squared test

- A statistical test called the **chi-squared test** determines whether or not there is a **significant difference** between the **observed and expected results** in an experiment.
 - Its purpose is to assess whether any difference in these results is **due to chance**, or **due to an association** between the variables being tested.
- A chi-squared test can be used to analyse data from quadrat sampling to determine whether or not there is a **statistically significant association** between the distributions of two species.
 - To the eye there may appear to be an association between the two species, but if it is **not statistically significant** then researchers can conclude that species distributions are independent of each other, and any appearance of association is **due to chance**.
 - If an association is **statistically significant** then it must be due to an **important factor**, such as a symbiotic relationship.
- A chi-squared test enables scientists to test hypotheses.
 - A **hypothesis** is a **testable statement** about the expected outcome of an experiment.
 - There are two types of hypothesis:

- A **null hypothesis** states that there is **no significant difference, or association**, between data sets e.g. that there is no association between the distributions of two species.
- An **alternative hypothesis** states that there is a **significant difference, or association**, between data sets e.g. that there is an association (either positive or negative) between the distributions of two species.
- The result of a chi-squared test enables scientists to either **accept** or **reject a null hypothesis**.

Using the chi-squared test to test for association

- Step 1: Construct a **contingency table** for your results.
 - This allows the number of quadrats that contain one, both, or neither species to be recorded.
- Step 2: Calculate the row, column, and overall totals for your contingency table.
- Step 3: Calculate the **expected values (E)** for your table.
 - The results recorded in the contingency table are the **observed values (O)**. To calculate the chi-squared value, we need to calculate the expected values for each data point.
 - The expected values are what we would expect to see **if the null hypothesis were correct**.
 - Note that this is the first step towards calculating the **chi-squared value**, the equation for which is:

$$\sum \frac{(O - E)^2}{E}$$

Σ = sum of O = observed value E = expected value

- Step 4: Calculate the **difference** between the observed and expected values.
 - Subtract the expected values from the observed values (O - E). Some of the resulting values will be negative.
- Step 5: Square each difference. This eliminates negative values.
- Step 6: Divide each squared difference by the expected value.
- Step 7: Add all of the results from Step 6 together. This gives the **chi-squared value**.
- Step 8: Calculate the **degrees of freedom**.
- Step 9: Establish a probability level or **p-value**.
 - As biologists, we work with a probability level of **0.05**, or **5%**.
 - This means that we can be 95 % certain that any significant difference or association is **not due to chance**.
 - Some studies require a higher level of certainty than this, e.g. medical researchers may use a smaller p-value.
- Step 10: Use a **critical values table** and the results of steps 8-9 to find the critical value.
 - In order to understand what the chi-squared value says about the data, a table relating chi-squared values to probability is needed; this critical values table displays the probabilities that the differences between expected and observed values are due to chance.
- Step 11: Compare the chi-squared value with the critical value to assess **the significance**.

Worked example

- A researcher decided to test for an association between the distribution of two types of mollusc on a rocky shore; limpets and dog whelks. Their null hypothesis was that there was no association between the distributions of limpets and dog whelks.
- They carried out 50 randomly placed quadrat samples on the rocky shore, recording either the presence or the absence of both limpets and dog whelks in each quadrat. They obtained the following results:
 - Quadrats containing limpets only: 14
 - Quadrats containing dog whelks only: 21
 - Quadrats containing both limpets and dog whelks: 7
 - Quadrats containing neither limpets nor dog whelks: 8
- Use the chi-squared test to determine whether or not there is a statistically significant association between the distributions of limpets and dog whelks.

Answer

- **Step 1: Construct a contingency table.**

	Limpets present	Limpets absent
Dog whelks present	7	21
Dog whelks absent	14	8

- **Step 2: Calculate the row, column, and overall totals for your contingency table.**

	Limpets present	Limpets absent	Row Total
Dog whelks present	7	21	28
Dog whelks absent	14	8	22
Column Total	21	29	50

- **Step 3: Calculate the expected values.**

The equation for working out the expected values is:
$$\frac{\text{row total} \times \text{column total}}{\text{overall total}}$$

e.g., to calculate the expected value for the category in which both dog whelks and limpets are present:

$$\frac{28 \times 21}{50} = 11.76$$

- **Step 4: Calculate the difference between the observed and expected values.**

$$O = 7$$

$$E = 11.76$$

$$O - E = 7 - 11.76 \\ = -4.76$$

- **Step 5: Square each difference.**

$$-4.76^2 = 22.66$$

- **Step 6: Divide each squared difference by the expected value**

$$22.66 \div 11.76 = 1.93$$

Repeat Steps 3-6 for all of the results in the contingency table:

	O	E	O-E	(O-E) ²	(O-E) ² /E
Limpets only	14	9.24	4.76	22.66	2.45
Dogwhelks only	21	16.24	4.76	22.66	1.4
Both dogwhelks and limpets	7	11.76	-4.76	22.66	1.93
Neither dogwhelks nor limpets	8	12.76	-4.76	22.66	1.78

- **Step 7: Add all of the results from step 6 together to obtain the chi-squared value.**
 $2.45 + 1.4 + 1.93 + 1.78 = 7.56$ (this is the chi-squared value)
- **Step 8: Calculate the degrees of freedom.**
 - Degrees of freedom can be calculated using the following equation:
Degrees of freedom = (number of columns - 1) x (number of rows - 1)
 - Columns and rows refer to the original contingency table
 - In this example, there are 2 columns and 2 rows in the contingency table
 - Degrees of freedom = $(2 - 1) \times (2 - 1)$
 $= 1 \times 1$
 $= 1$
- **Step 9: Determine the probability level.** As biologists, we work at a **probability of 0.05**, or **5%**
- **Step 10: Use a critical values table and the results of steps 8-9 to find the critical value.**

Degrees of freedom	Probability that the difference between O and E is due to chance			
	0.1	0.05	0.01	0.001
1	2.71	3.84	6.64	10.83
2	4.6	5.99	9.21	13.82
3	6.25	7.82	11.34	16.27
4	7.78	9.49	13.28	18.46

With **degrees of freedom** as **1**, and a **probability level** of **0.05**, the **critical value** can be read from the table as **3.84**.

- **Step 11: Compare the chi-squared value with the critical value to assess significance.**
 - The chi-squared value of 7.56 **is larger than** the critical value of 3.84.
 - This means that **there is a significant association** between the two species (see section below on statistical significance).

Statistical significance

- The chi-squared value, once calculated, can be compared to a critical value. This allows **statistical significance** to be assessed.
- If the **chi-squared value is larger than the critical value**, there **is** a statistically significant difference between observed and expected values, or a statistically significant association between two sets of results. In this case, the **null hypothesis can be rejected**.
- If the **chi-squared value is equal to or smaller than the critical value**, there **is no** statistically significant difference between observed and expected values, or no statistically significant association between two sets of results. In this case, the **null hypothesis can be accepted**.
- To determine the critical value biologists generally use a probability level, or p-value, of 0.05, or 5%.
 - This means that if a difference or association is shown to be statistically significant at this level, there is only a 5% probability (i.e. probability = 0.05) that this result might be due to chance.