Exam Papers Practice

Boost your performance and confidence with these topic-based exam questions

Practice questions created by actual examiners and assessment experts

Detailed mark schemes

Suitable for all boards

Designed to test your ability and thoroughly prepare you

Populations & Communities

IB Biology - Revision Notes

www.exampaperspractice.co.uk

Populations in Ecosystems

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

CC BY 2.0, via Wikimedia Commons

Gannets are sea birds. Populations gather on sea cliffs to breed during nesting season.

Exam Tip

The specification uses the phrase 'reproductive isolation' to describe two populations of the same species that are separate from each other, i.e. isolated, and that are not interbreeding, i.e. reproducing. While this does make sense in this context, it is worth noting that '**reproductive isolation**' is more frequently used among biologists to describe the point in the speciation process at which two populations have diverged to become two different species.

Estimating Population Size

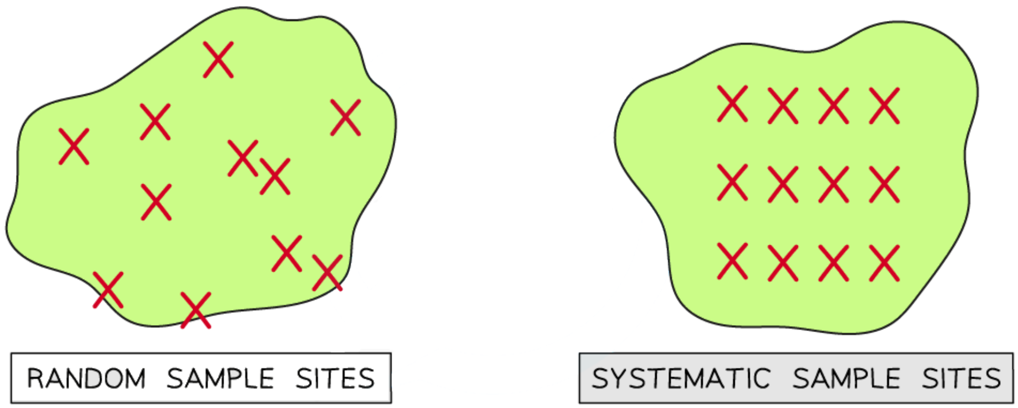
Random Sampling

- Finding 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
  - **Random**
  - **Systematic**
- In **random sampling** the positions of the sampling points are selected **at random**
  - This method avoids **bias** by the person that is 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 & systematic sampling diagram



Random sampling involves selecting sample sites at random 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

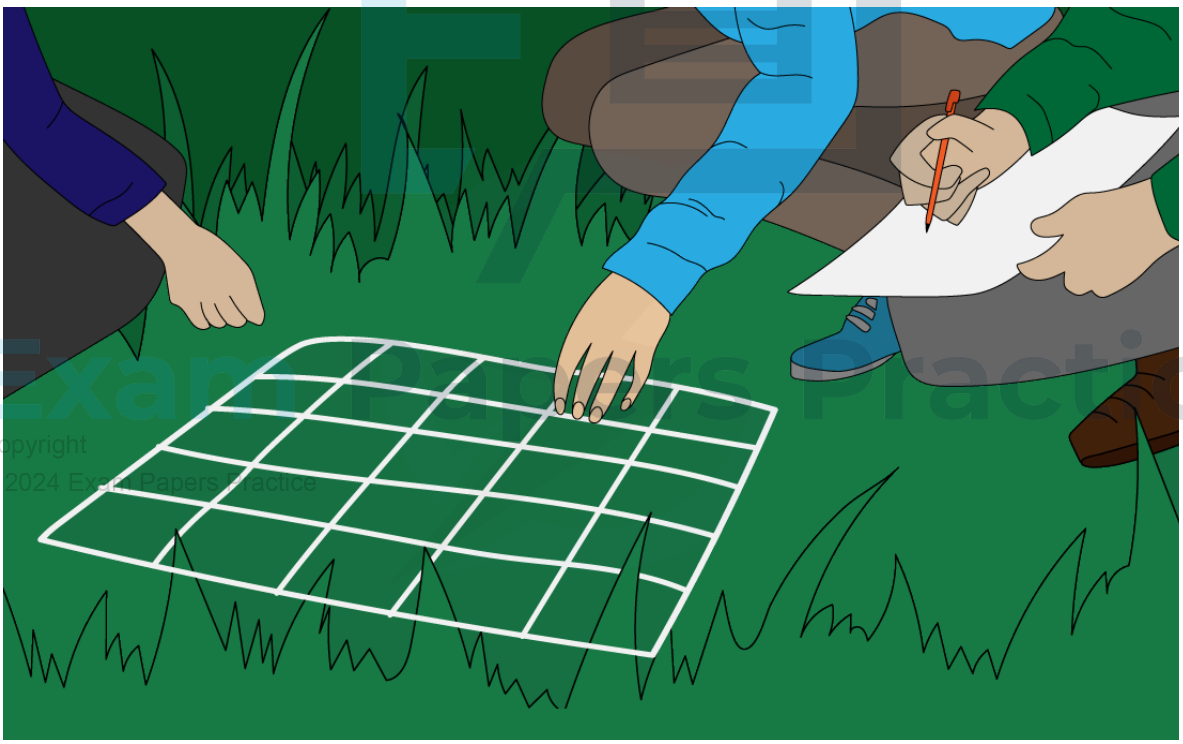
- A population estimate that is based on sampling makes the assumption that **individuals are distributed evenly across the sample site**, e.g.
  - Random sampling may happen to miss an area of a site in which no individuals are present; this will result in an overestimate of population size
  - Random sampling may happen to miss an area of a site where many individuals are present; this will result in an underestimate of population size
- There are many factors that 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 population size and a true population size**
  - This occurs when a sample is **not truly representative** of 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

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 **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 co-ordinates, or **systematically**, e.g. along a transect

Frame quadrat diagram



A frame quadrat can be used to measure abundance and distribution

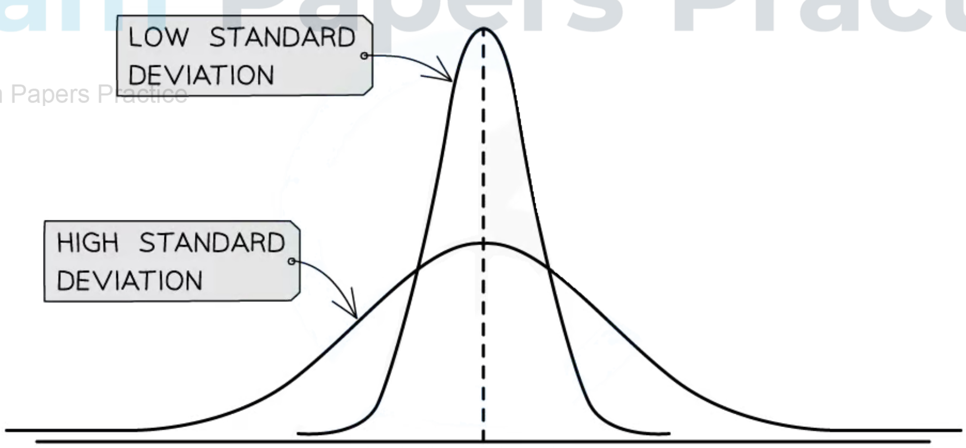
- Scientists can record **different types of data** from a frame quadrat depending on the aim of a study and the species involved
  - **Presence or absence** of a species

- **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

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

Small vs large standard deviation graph



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

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**; 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

$$\textbf{Population size} = M \times \frac{N}{R}$$

- 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 first sample (**M**) = 236
- No. caught in 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)

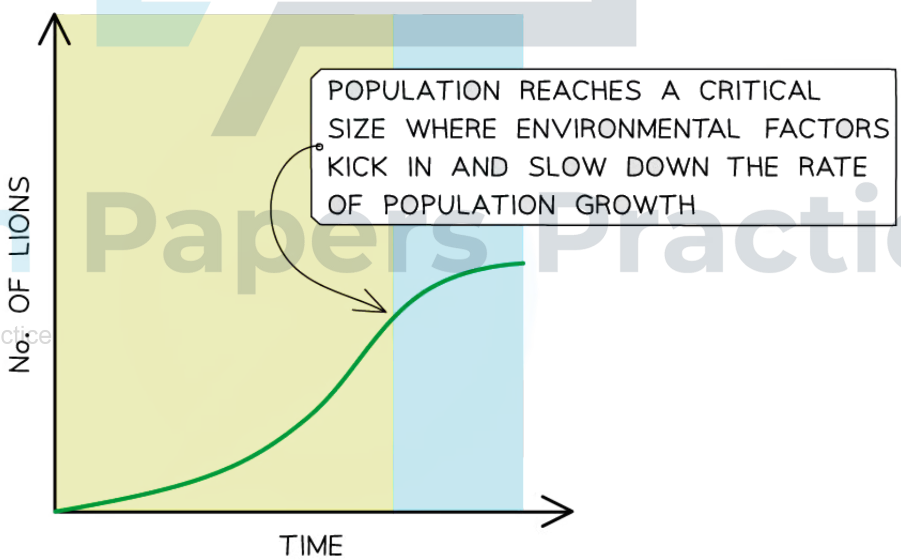
- The Lincoln index makes some **assumptions** about the population and the capture-mark-release-recapture method:
  - The marked individuals **disperse** and **mix** back in fully with the **main population**
  - The marking doesn't affect the **survival rates** of the marked individuals, e.g. doesn't 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

Limiting Population Size

Carrying Capacity

- The **maximum number of individuals of a species that an ecosystem can support** is known as its **carrying capacity**
  - 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 below 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 graph



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
    - Energy that an individual puts towards competing for resources will not be available for growth and reproduction, so this will reduce carrying capacity
  - **Predation**
    - 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

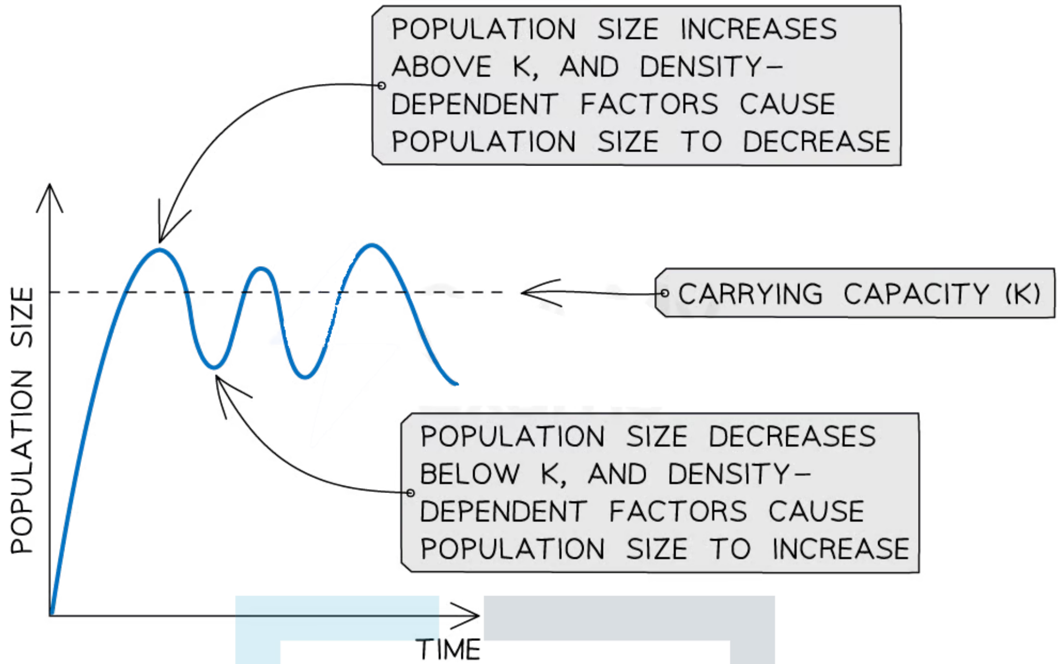
Density Dependent Factors

- Population density can be defined as follows:

  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 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 population size is controlled by negative feedback it will **fluctuate around its carrying capacity**

Density-dependent factors & population size graph



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

Limiting Population Size: Examples

Predator-Prey Relationships

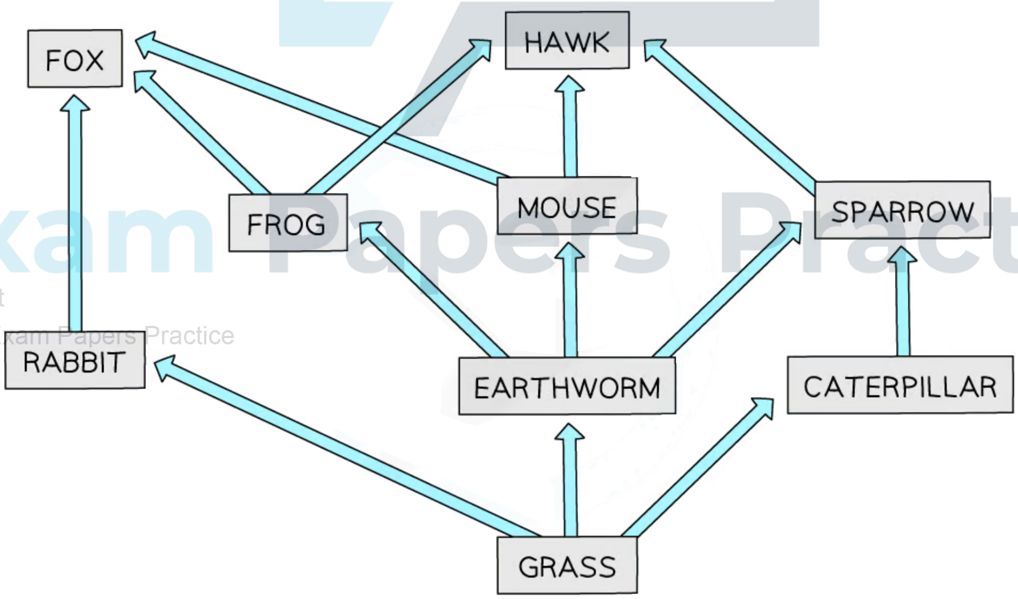
- Consumers that kill and eat other animals are known as **predators**, and the animals that are eaten are known as **prey**
- In a stable community the predator and prey population sizes rise and fall in a **predator-prey cycle** that **limits the population sizes of both predators and prey**
- The graph below 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**

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
- 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

Food web diagram



The effects of a top-down control factor on a food web can be complex, as every food chain is connected to several others

- 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** is thought to secrete allelochemicals into the surrounding soil that limit the growth of other plants

CC BY-SA 2.0, via Geograph

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

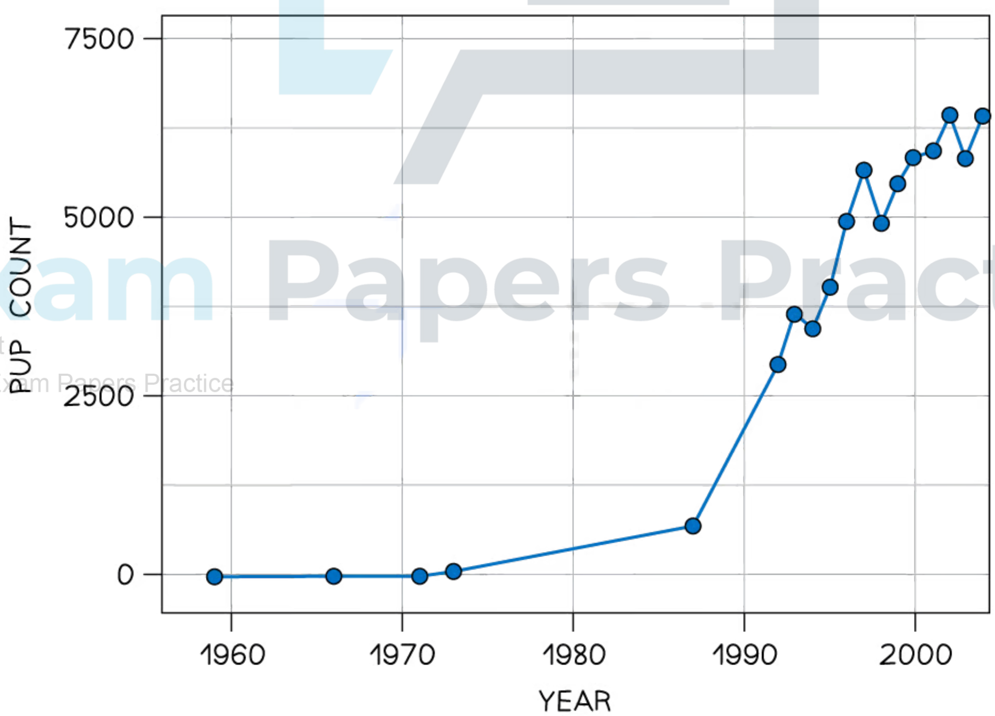
- The **secretion of antibiotics** is a **form of allelopathy** found in some microorganisms, e.g. the antibiotic penicillin was discovered in *Penicillium* fungus
  - Antibiotics are also secreted by some bacteria species
- Antibiotics **kill bacteria** by, e.g. preventing cell wall formation or inhibiting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

Population Growth Curves: Skills

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

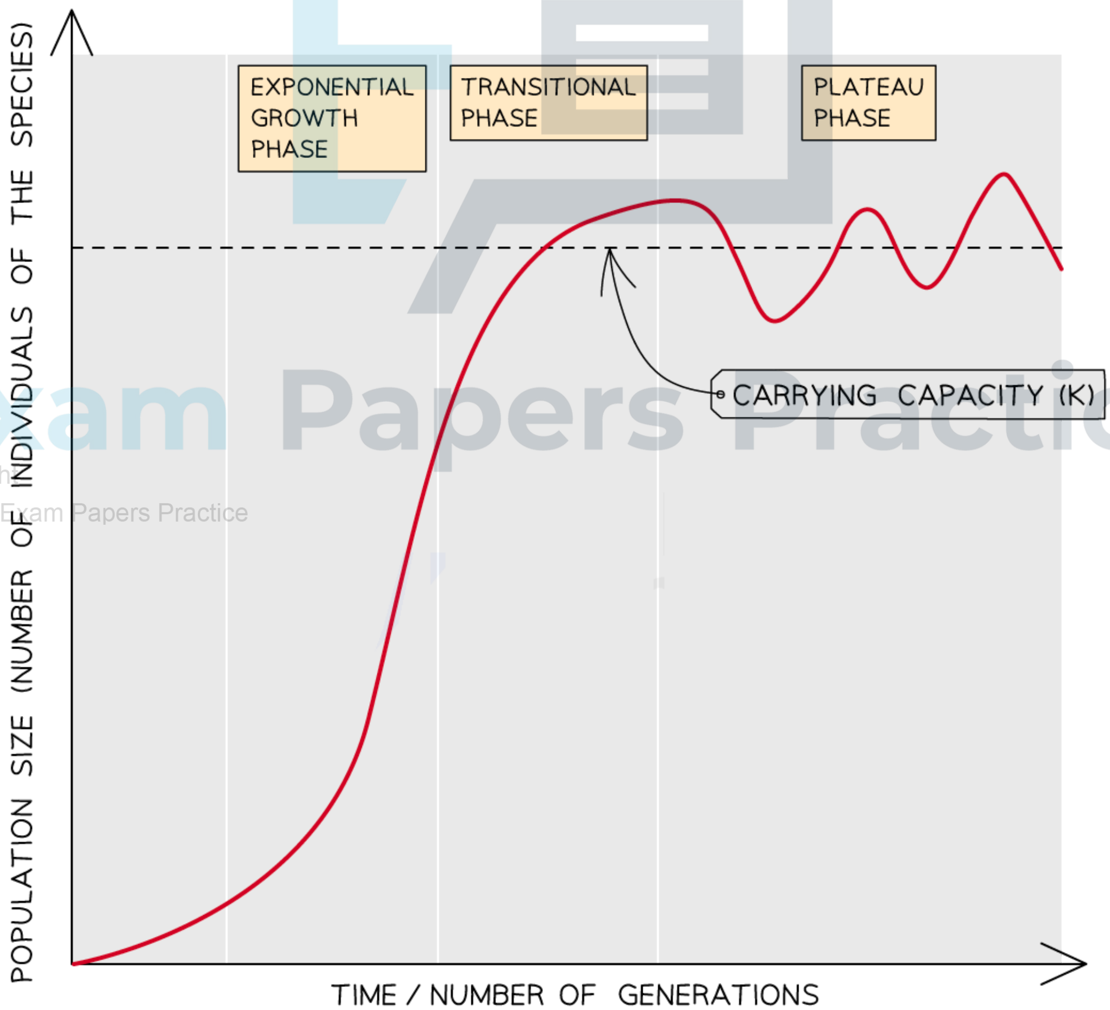
Antarctic fur seal growth curve graph



The Antarctic fur seal population in Cape Shirreff, Antarctica, followed a classic growth curve between 1960 and the early 2000s

- The population growth curve shown above is an example of a **sigmoid**, or **s-shaped**, growth curve
- Such curves contain three phases:
  - **Exponential phase**
    - Also known as the **logarithmic phase**
    - Here 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 cause 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

Population growth curve graph



Sigmoidal population growth curves show an exponential growth phase, a transitional phase and a plateau phase

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

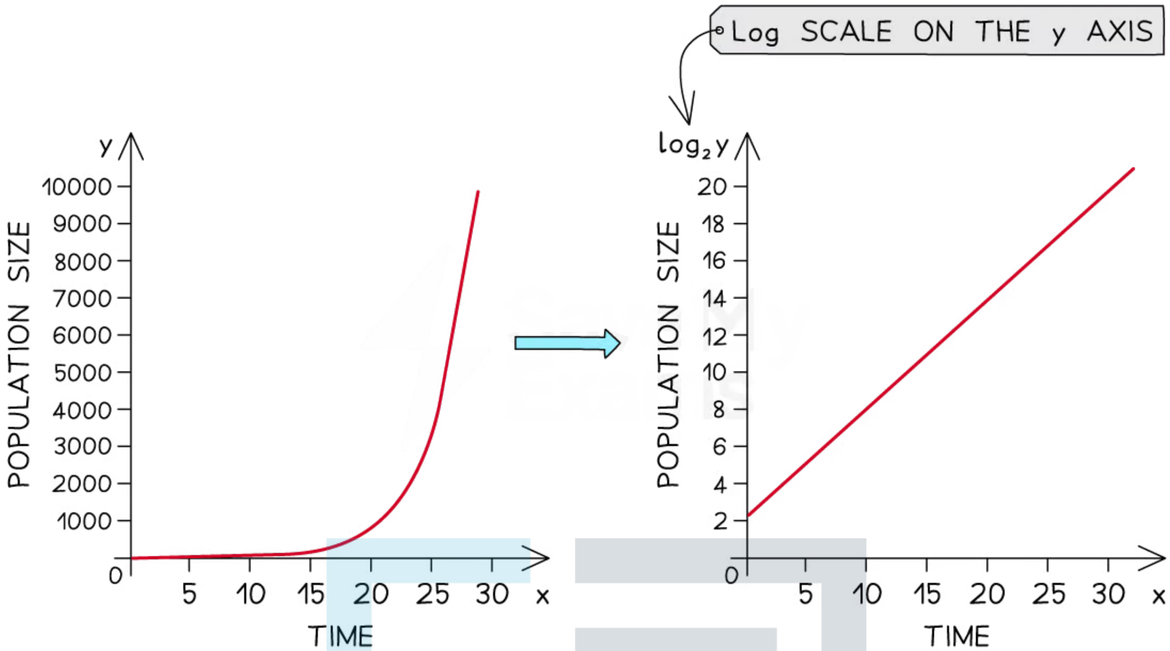
- There are **few real-world situations** where populations follow perfect sigmoid growth curves, and the seal population example given above soon showed population decline rather than remaining at a plataeu

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**:

Exponential population growth on a logarithmic scale graph



An exponentially growing population plotted with a log scale on the y axis will appear as a straight line

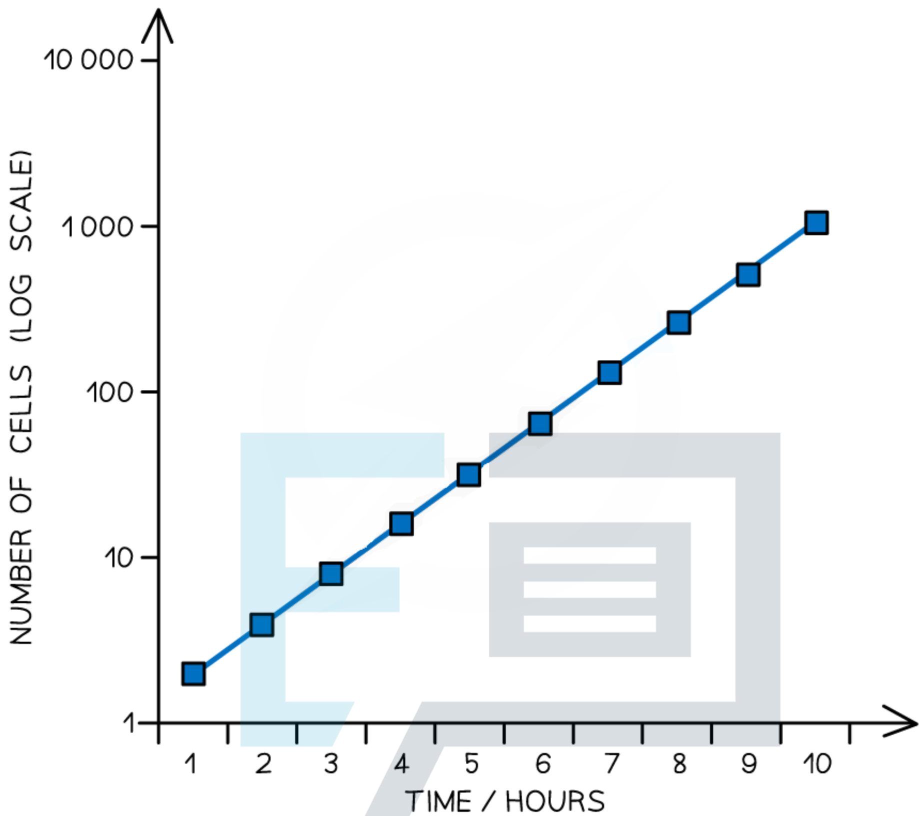
Modelling the Sigmoid Growth Curve

- Organisms that grow and reproduce under **laboratory conditions** can be used to **model the sigmoid population growth curve**
- Suitable organisms include:
  - Yeast
  - 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** to show how the population of microorganism changes over time

Yeast population growth on a logarithmic scale graph



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**
- 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

CC BY-SA 3.0, via Wikimedia Commons

Duckweed grows on the surface of fresh water, and its easily distinguishable thalli can be easily counted in a laboratory setting

Populations: Intraspecific Relationships

Competition & Cooperation

Intraspecific relationships

- **Intraspecific** relationships involve interactions **between individuals of the same species**
  - 'Intra' = within
- 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

- In this type of relationship, **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
  - **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

CC BY 4.0, via Wikimedia Commons

Orca can cooperate with each other during hunting to create a wave that can wash seals into the water. This particular seal eventually escaped on this occasion, but working together increases the chances of hunting success for the orca.

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:
    - Light
    - Minerals
    - Water
    - Space
  - Animals will compete with members of the same species for:
    - Food
    - Mates
    - 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
  - **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
- Note that 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

Public domain, via pxhere

Red deer males bellow to show their dominance as part of their competition for females

Community: Interspecific Relationships

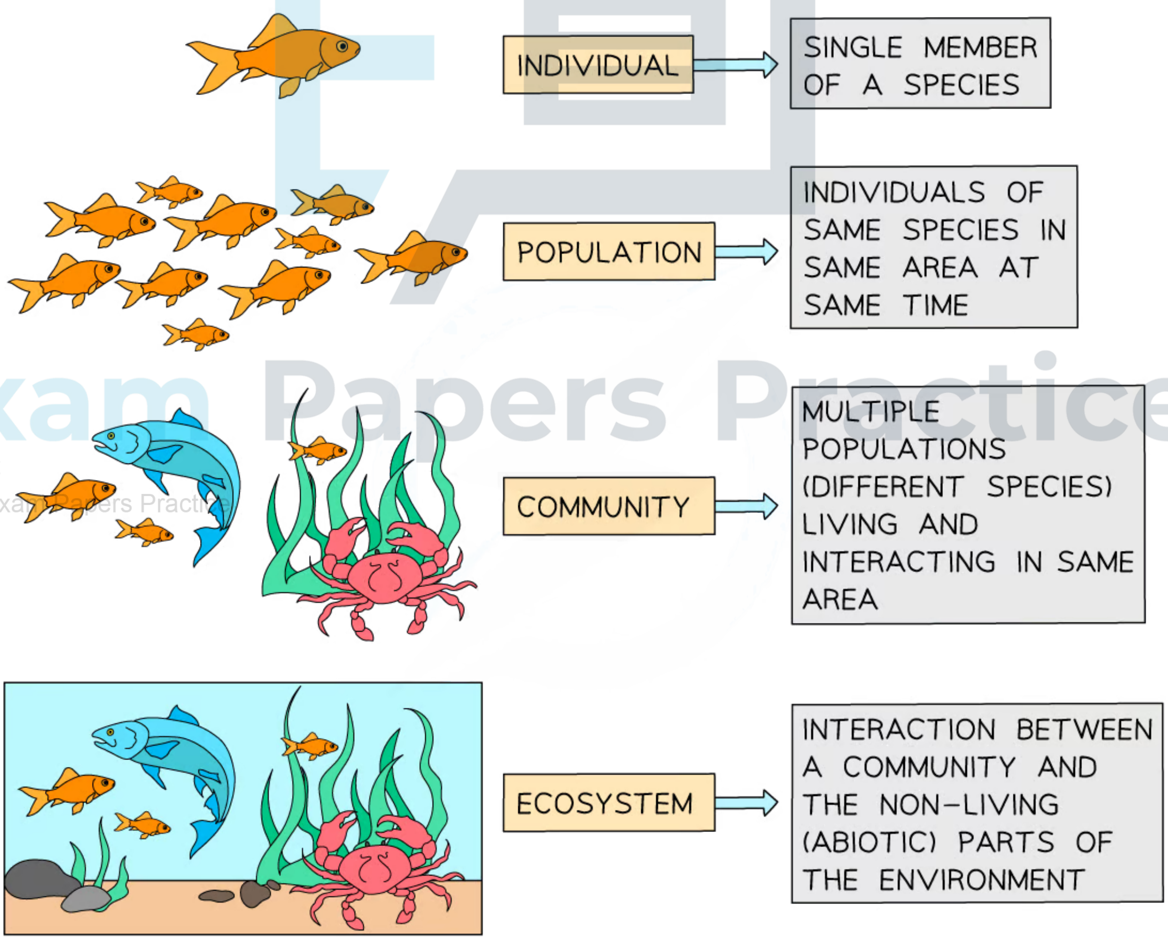
Community in an Ecosystem

- 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**

Levels of organisation within ecosystems diagram



A community is all of the populations of living organisms interacting in an area. 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
  - 'Inter' = between
- There are several types of interaction that can occur between different species:

Types of interactions between species table

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 Red and grey squirrels compete for food and territory
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 Oxpecker birds remove parasites from large mammals, providing the birds with food
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 Fleas live on the bodies of mammals, feeding on their blood
Pathogenicity	An infectious microorganism (pathogen) lives inside a host organism, causing disease	*Mycobacterium tuberculosis* bacteria cause the disease tuberculosis in human hosts Dutch elm disease is caused by a fungal pathogen that causes elm trees to lose their leaves and die

Mutualism

- Mutualism occurs **between members of different species**, and is an example of **cooperation**; **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

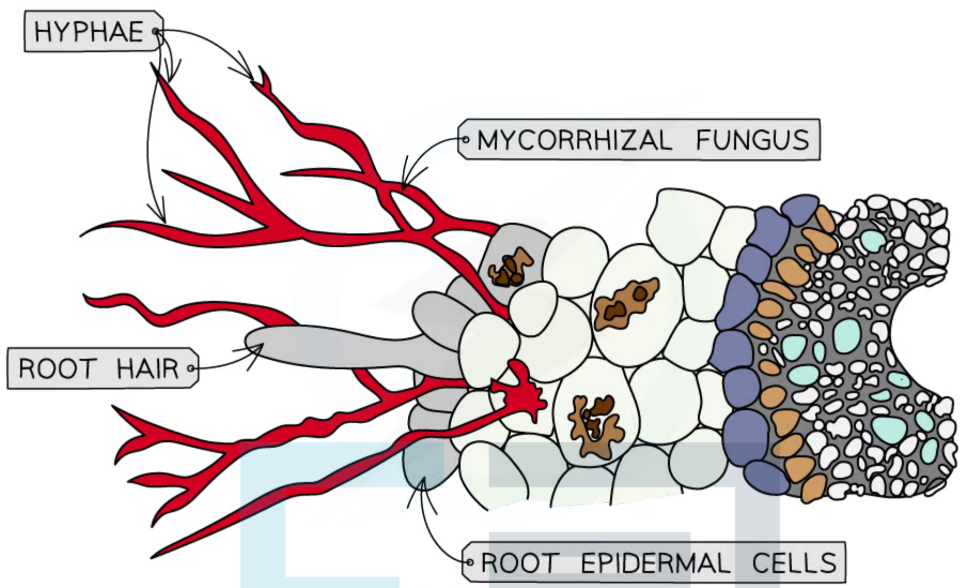
Root nodules in Fabaceae

- 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

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 are known as **mycorrhizae** (singular mycorrhiza)

Mycorrhizae diagram



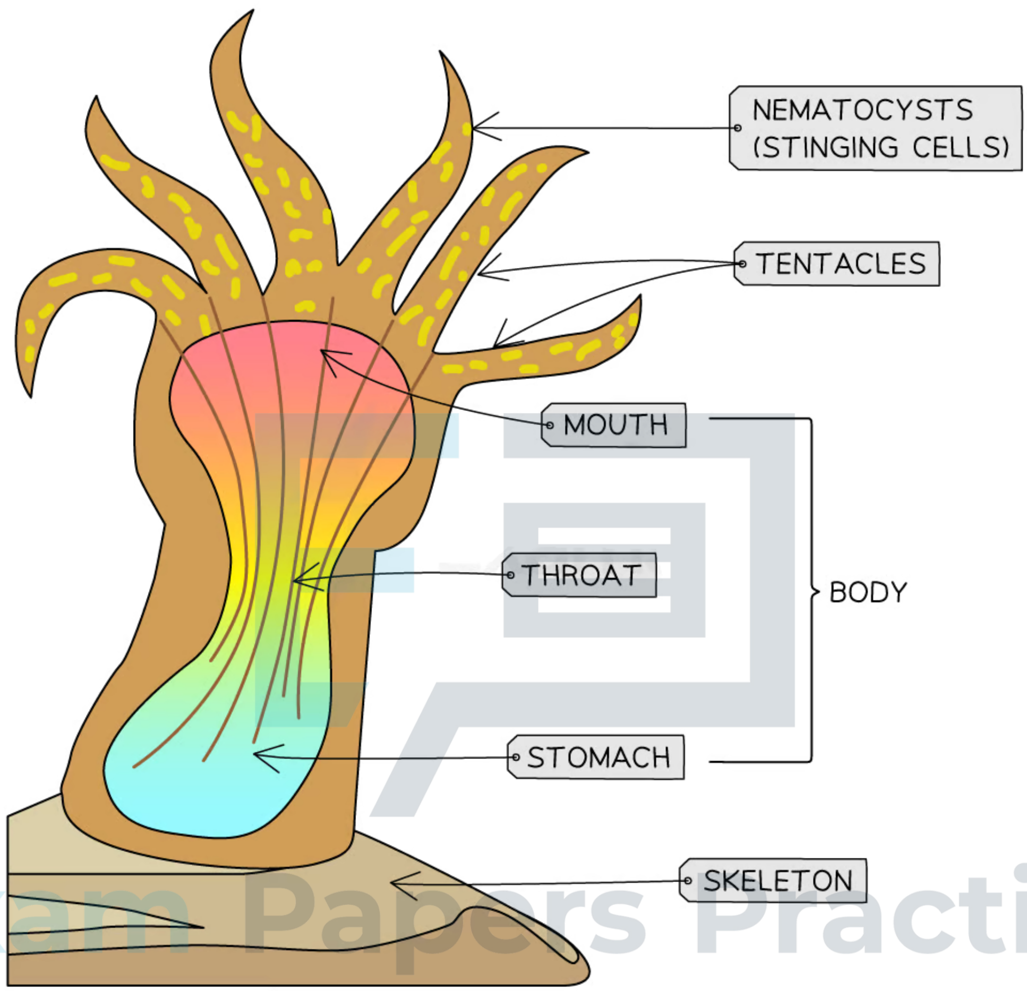
Mycorrhizae are interactions between fungal hyphae and the roots of plants

- 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

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 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

Coral polyp diagram



The tentacles of coral polyps contain algae cells with which they have a mutualistic relationship

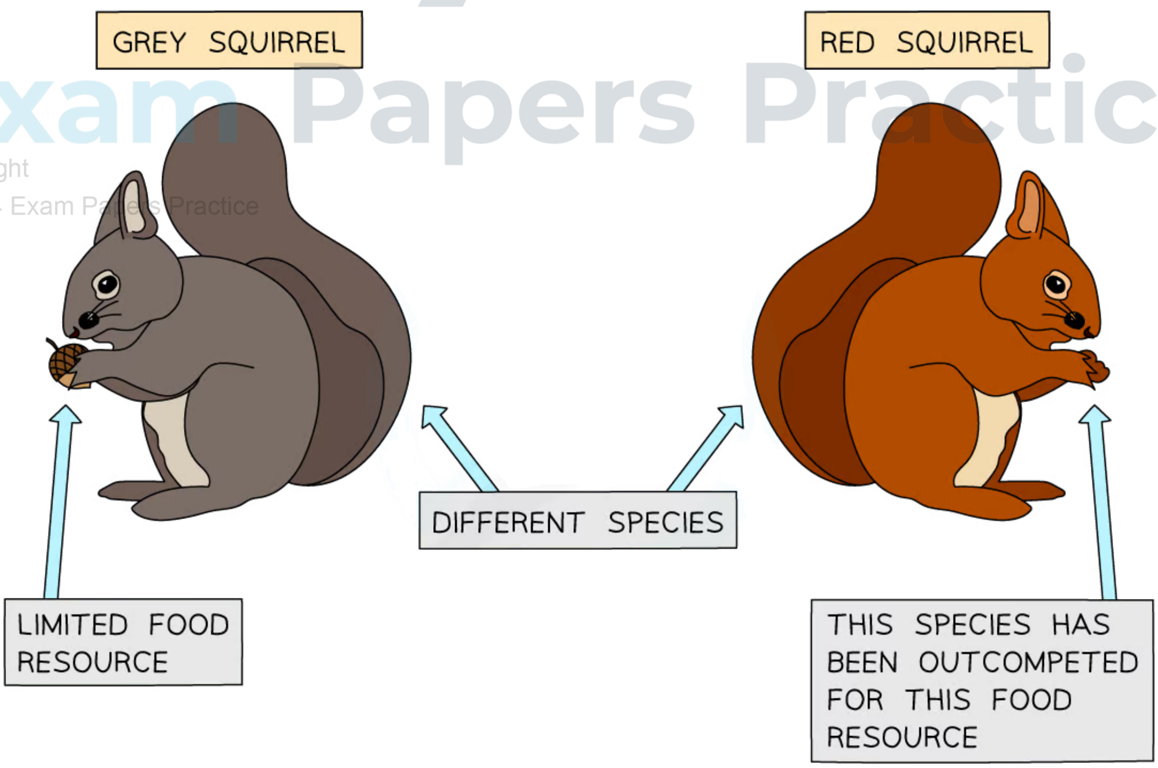
Exam Tip

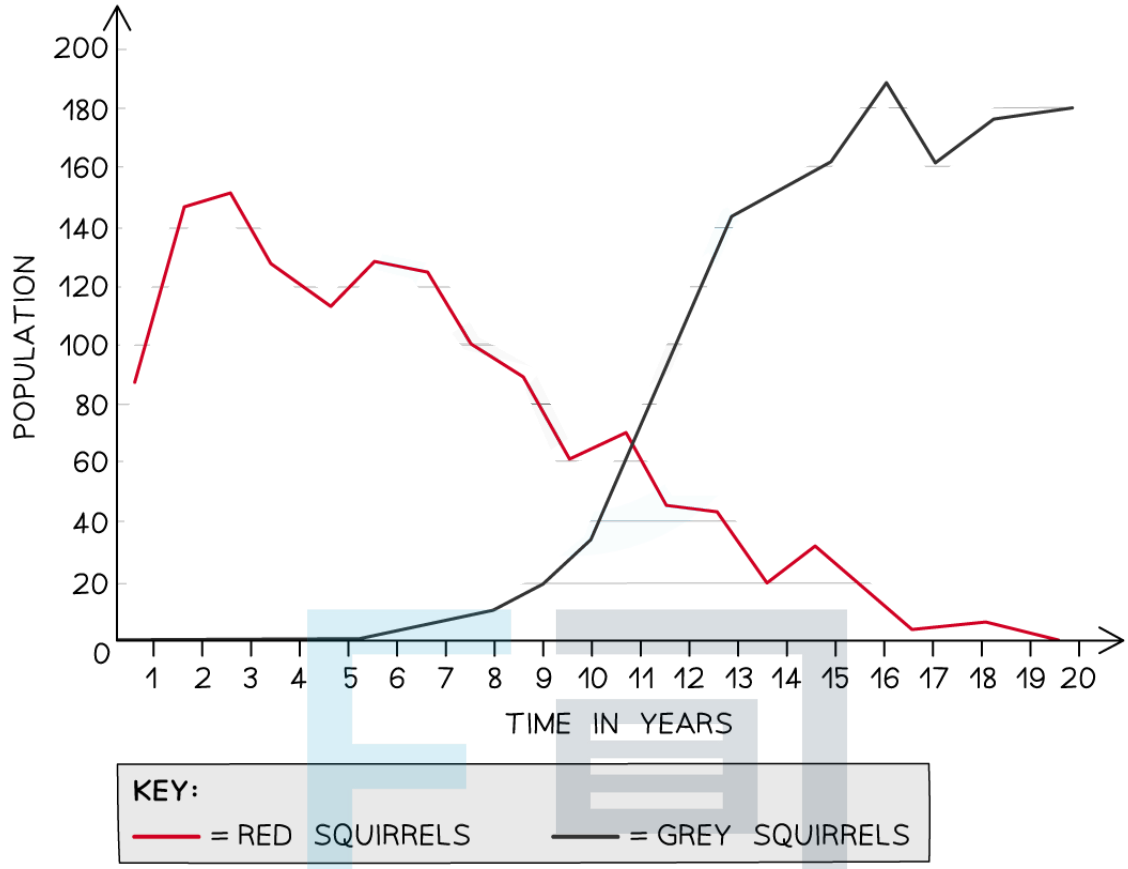
Note that Latin names, e.g. Fabaceae, are not essential when answering exam questions; you will be credited for either Latin or common names of organisms.

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

Red and grey squirrel population diagram





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.

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

Interspecific Competition

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
  - In a laboratory
  - 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

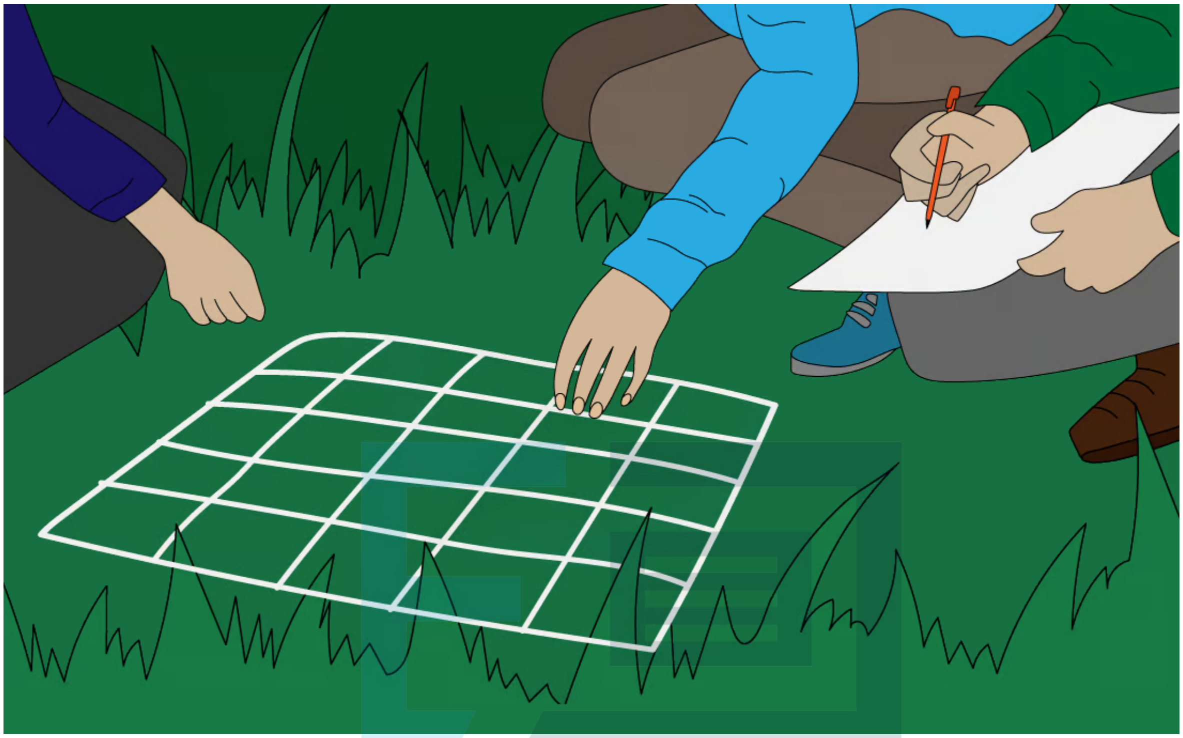
Chi-Squared Test: Skills

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 so 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**

Using a quadrat diagram



Random sampling with quadrats can be used to study the distribution of organisms

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

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:

$$\frac{\text{row total x column total}}{\text{overall total}}$$

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

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 ÷ 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
Dog whelks only	21	16.24	4.76	22.66	1.4
Both dog whelks and limpets	7	11.76	-4.76	22.66	1.93
Neither dog whelks nor	8	12.76	-4.76	22.66	1.78

limpets					

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) x (2 - 1)

= 1 x 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

Exam Tip

When calculating a chi-squared value it is very helpful to create a table like the one seen in the worked example. This will help you with your calculations and make sure you don't get muddled up!