C4.1 Teacher view

Populations and communities

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The big picture

? Guiding question(s)

- How do interactions between organisms regulate sizes of populations in a community?
- What interactions within a community make its populations interdependent?

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

Ecology is a branch of biology that aims to understand the interactions between living organisms and their environment. Within an ecosystem, different species interact with one another and their non-living surroundings, resulting in the formation of complex feeding relationships. These complex interactions play a vital role in maintaining the structure and health of the ecosystem.

For instance, in an Antarctic food web (**Figure 1**), krill consume large amounts of phytoplankton as a significant part of their diet. Other larger organisms such as the emperor penguin (*Aptenodytes forsteri*) rely on krill as a primary food source, while leopard seals (*Hydrurga leptonyx*) feed on both penguins and krill. Orcas (*Orcinus orca*), the top predators of the region, prey on leopard seals. Each species in this web plays a distinct role in shaping the balance that sustains the ecosystem.

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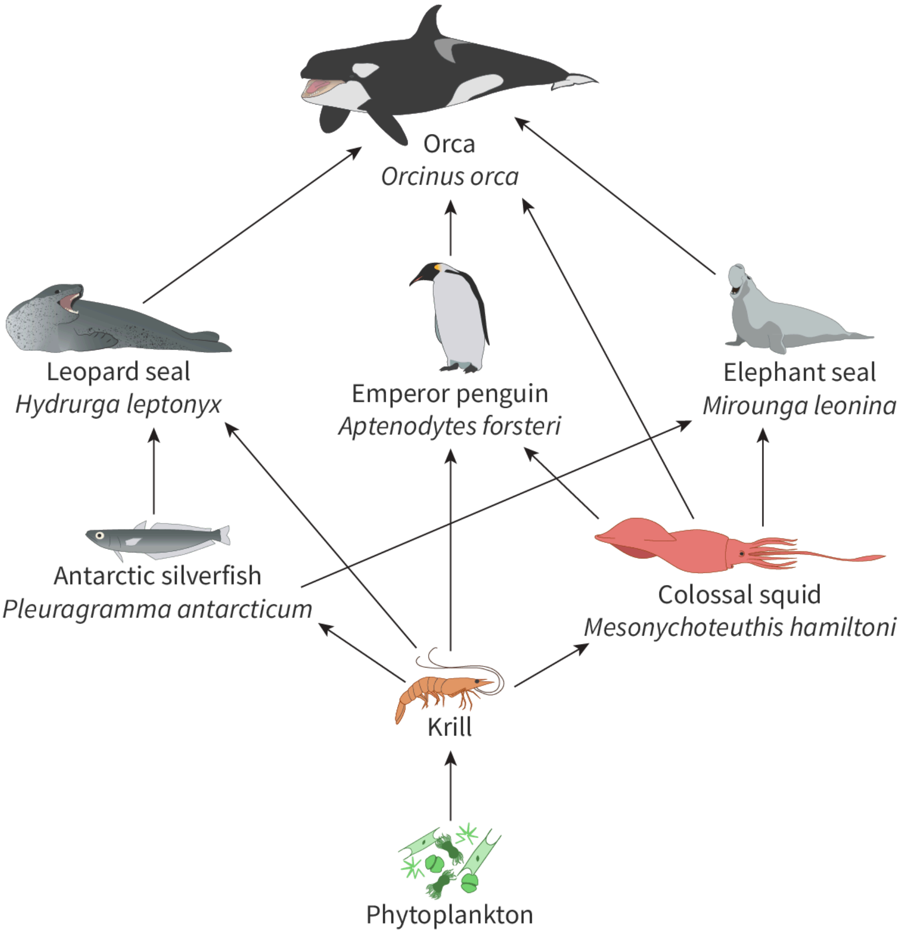

Figure 1. Food web of an Antarctic ecosystem.

More information for figure 1

This diagram illustrates the food web of an Antarctic ecosystem, highlighting the interdependence among various species. At the base, phytoplankton is consumed by krill, which are small crustaceans critical to the ecosystem. Krill, in turn, serve as a primary food source for several species, including the Antarctic silverfish (Pleurogramma antarcticum), emperor penguin (Aptenodytes forsteri), and colossal squid (Mesonychoteuthis hamiltoni). The emperor penguin is also preyed upon by leopard seals (Hydrurga leptonyx), while the colossal squid is a part of the diet for elephant seals (Mirounga leonina). Leopard seals further feed on Antarctic silverfish and krill. The apex predators in this system are orcas (Orcinus orca), which prey on leopard seals and other penguins. The interconnected arrows indicate the predator-prey relationships among these species, underscoring the delicate balance and intricate interactions within the Antarctic ecosystem.

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In a terrestrial ecosystem, the balance of nature is maintained through the interplay of various ecological roles. Predators act as key regulators, managing the population sizes of their prey, while herbivores play a vital role in shaping and controlling the vegetation within the community. In turn, non-living factors such as water availability, temperature and soil nutrients affect the distribution and abundance of all

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species. Understanding and investigating these relationships is essential for monitoring ecosystems over time, particularly in the aftermath of disturbances such as wildfires or deforestation, and for effectively guiding conservation initiatives.

Estimating the size of a population enables scientists to study the dynamics of populations and communities. However, counting every individual in an ecosystem is often impractical, time-consuming and very expensive. For instance, it is now known that the Antarctic region is inhabited by 20 million penguins of eight different species, and counting every single one would be an enormous and tedious task (**Figure 2**). So how were scientists able to overcome these challenges to uncover this information? This subtopic explores the different types of relationship that shape the balance of ecosystems and outlines some of the methods used to study the sizes of populations.

Figure 2. Emperor penguins (*A. forsteri*) and chicks in the Antarctic region.

Credit: Raimund Linke, Getty Images

Prior learning

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

- Species as groups of organisms with shared traits (see section A3.1.1—4 (/study/app/bio/sid-422-cid-755105/book/what-is-a-species-id-43227/)).
- Biological species concept (see section A3.1.1—4 (/study/app/bio/sid-422-cid-755105/book/what-is-a-species-id-43227/)).
- Roles of reproductive isolation and differential selection in speciation (see section A4.1.6—7 (/study/app/bio/sid-422-cid-755105/book/speciation-id-43794/)).
- Biodiversity as the variety of life in all its forms, levels and combinations (see section A4.2.1—2 (/study/app/bio/sid-422-cid-755105/book/title-to-come-id-43810/)).

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Practical skills

Once you have completed this subtopic, go to Practical 7: Measuring percentage cover to assess the distribution and abundance of plants in a habitat (/study/app/bio/sid-422-cid-755105/book/measuring-percentage-cover-id-46706/).

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

Population sizes and random sampling

C4.1.1: Populations C4.1.2: Estimation of population size by random sampling

Section Student… (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/population-sizes-and-random-sampling-id-44711/print/) Assign

Learning outcomes

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

- Define the term population.
- Outline reasons for estimating population samples.
- Analyse and explain the importance of using random sampling techniques in ecological studies.

Imagine an environment where a single species holds the key to shaping the structure of the entire ecosystem. Such a phenomenon occurs in the Galapagos Islands, an archipelago in the Pacific Ocean with extraordinary ecological significance. These islands are home to multiple populations of giant tortoises (*Chelonoidis niger*) that have captured the attention of ecologists for over a century (**Figure 1**). How do scientists distinguish between different populations of tortoises? Furthermore, why have ecologists devoted such a lot of time to studying these creatures? The answers to these questions lie in the unique characteristics and behaviours shown by each group of giant tortoises. Over time, through meticulous observation and analysis, scientists have unravelled the subtle yet crucial differences that exist among these populations.

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Figure 1. A giant Galapagos tortoise (*C. niger*).

Credit: Manfred Gottschalk, Getty Images

Populations

In the field of ecology, having a clear understanding of the concept of a population is crucial for understanding the dynamics of a species and species diversity. As outlined in section A3.1.1–4 (/study/app/bio/sid-422-cid-755105/book/what-is-a-species-id-43227/), the concept of species can be determined based on multiple aspects. A population refers to a group of organisms of the same species that typically interbreed, sharing a common gene pool. Within a species, populations can show variations due to geographic or environmental factors. One key factor that distinguishes populations is reproductive isolation, which is the inability of organisms of the same species to successfully breed due to geographical isolation, behavioural isolation or temporal isolation. These barriers, outlined in section A4.1.8 (/study/app/bio/sid-422-cid-755105/book/types-of-speciation-allopatric-vs-sympatric-hl-id-43795/), restrict gene flow between organisms, leading to the accumulation of different genetic variations and the emergence of distinct populations. Over time, these distinct populations may accumulate enough variations to result in speciation, as discussed in section A3.1.5–7 (/study/app/bio/sid-422-cid-755105/book/what-chromosomes-tell-us-id-43228/).

Random sampling

Estimating the size of a population is essential for understanding species dynamics, assessing ecological health and directing conservation efforts. However, directly counting every individual in a population is often impractical and, in most cases, impossible. Therefore, scientists use sampling techniques to estimate population sizes, which provide a representative snapshot of the entire population.

Let’s consider a study aiming to estimate the population size of white-tailed deer (*Odocoileus virginianus*) in a large forest of North America (**Figure 2**). Directly counting every single deer is not practical due to the vast size of the forest and the elusive nature of the deer. To overcome this challenge, researchers can use random sampling methods to achieve an accurate estimate.

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Figure 2. White-tailed deer (*O. virginianus*) in Minnesota, USA.

Credit: Stan Tekiela Author / Naturalist / Wildlife Photographer, Getty Images

Theory of Knowledge

Bias is the predisposition to favour or presenting information in a subjective or unfair manner. It can be unintentional or intentional, leading to an unbalanced representation of ideas or perspectives. Recognising and addressing bias is essential for promoting objectivity and fairness in various fields.

Random sampling involves the unbiased selection of organisms, where each individual has an equal chance of being chosen. By randomly selecting individuals, scientists can minimise bias and obtain a representative sample, ensuring that the estimate accurately reflects the overall population. Targeting specific traits or characteristics of the deer in the sampling process could lead to an estimate that does not accurately represent the entire population. For example, if only deer with larger antlers or those that are more visible were chosen, the population size estimate would be skewed and would not reflect the true diversity and distribution of the deer in the whole forest.

Watch **Video 1** to learn more about sampling techniques.

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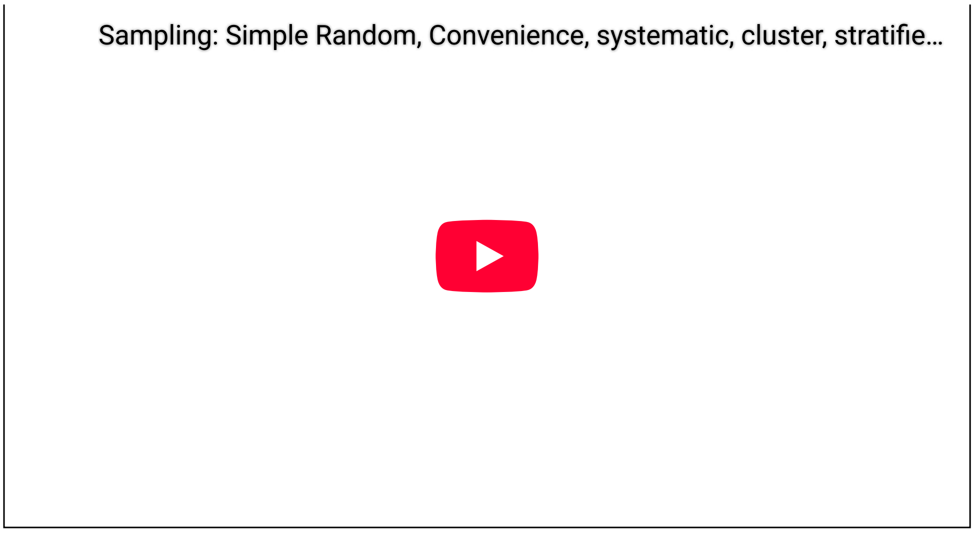

Video 1. Carrying out sampling.

To collect a random sample of white-tailed deer, researchers must first divide the forest area into smaller, more manageable sections. This can be accomplished using a grid system with GPS coordinates or by assigning letters to columns and numbers to rows of the grid. These designations are then randomised using an app to select the sites where deer samples are going to be gathered from. **Figure 3** demonstrates how this system enables random sampling, with shaded regions indicating the selected sampling sites.

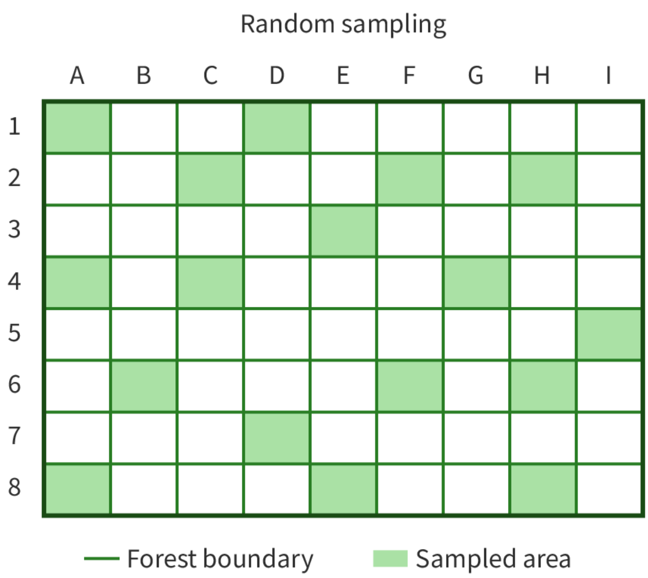

Figure 3. Random sampling of a large forested area.

More information for figure 3

The image is a diagram illustrating a grid system used for random sampling in a forested area. The grid is labeled with letters A to I along the top and numbers 1 to 8 along the side. Each square within the grid represents a section of the forest. Some squares are shaded to indicate selected sampling sites. The caption at the top reads "Random sampling," and a legend at the bottom explains that the solid line represents the forest boundary while the shaded areas represent sampled sites. This system demonstrates how researchers divide the forest into sections and randomly select specific areas for sampling.

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Within each selected sample site, ecologists must implement additional techniques to accurately count and gather sufficient data on the populations inhabiting them. The following section explores two techniques commonly used in ecological studies.

Nature of Science

Aspect: Measurement

Random sampling involves selecting a representative subset of a population instead of measuring the entire population. However, this approach inevitably introduces a concept known as sampling error. In this context, sampling error refers to the discrepancy between our estimated value and the true value of the population size.

Suppose you want to estimate the average height of all students in your school. Rather than measuring every student's height, which would be time-consuming, you randomly select a sample of students and measure their heights. The average height of this sample serves as an estimate for the average height of the entire student population. However, sampling errors arise because the average height of the sample may not perfectly match the average height of the entire student population. Measuring the height of only three students is unlikely to accurately represent the height of all students in the school.

The accuracy of the estimate depends on the sample size and the degree of variation within the population. Generally, a larger sample size leads to a more accurate estimate. Large populations with high degree of variation may require larger samples to ensure that the data accurately reflects the true characteristics and variability of the entire population. By understanding sampling error and using appropriate sampling techniques, scientists can make reliable inferences about populations based on representative subsets.

Try the activity below to explore different sampling techniques.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Research skills — Using search engines and libraries effectively
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual/group activity

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In this activity, you will explore different sampling techniques commonly used in biology to gather population data. Sampling is vital for making inferences about larger populations based on a subset of data.

Instructions

Individually or in small groups, conduct research to find information on three different sampling techniques used in biology. Examples include random sampling, stratified sampling, cluster sampling and others. Look for reliable sources such as scientific articles, textbooks or reputable websites to gather information about each technique.

Create a concept diagram titled 'Population Sampling Techniques' to compare and contrast all techniques. Include the following components:

- Columns: Create three columns, labelling each with the name of a sampling technique you researched.
- Rows: Create a row for each of the following categories: Description, Advantages, Disadvantages, Example and Sources.

Complete the concept diagram using the information you found. If possible, discuss your findings with the class and incorporate any relevant information shared by your classmates. Ensure you cite your sources appropriately and present your findings clearly and concisely.

5 section questions

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

Estimating population sizes

C4.1.3: Random quadrat sampling C4.1.4: Capture—mark—release—recapture and the Lincoln index

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/estimating-population-sizes-id-46388/print/) Assign

Learning outcomes

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

- Outline how quadrat sampling is used to estimate the population size for sessile organisms.
- Outline how the capture-mark-release-recapture method and the Lincoln index are implemented to estimate the population size of a motile species.

Estimating population size for sessile organisms

Student view

Imagine exploring a vibrant coral reef or the dense floor of a lush forest floor, where life exists in many different forms. How can we manage to make accurate estimations of the number of organisms in such a crowded environment? What techniques can scientists use to collect the necessary data? The answer depends on the nature of the organism being observed.

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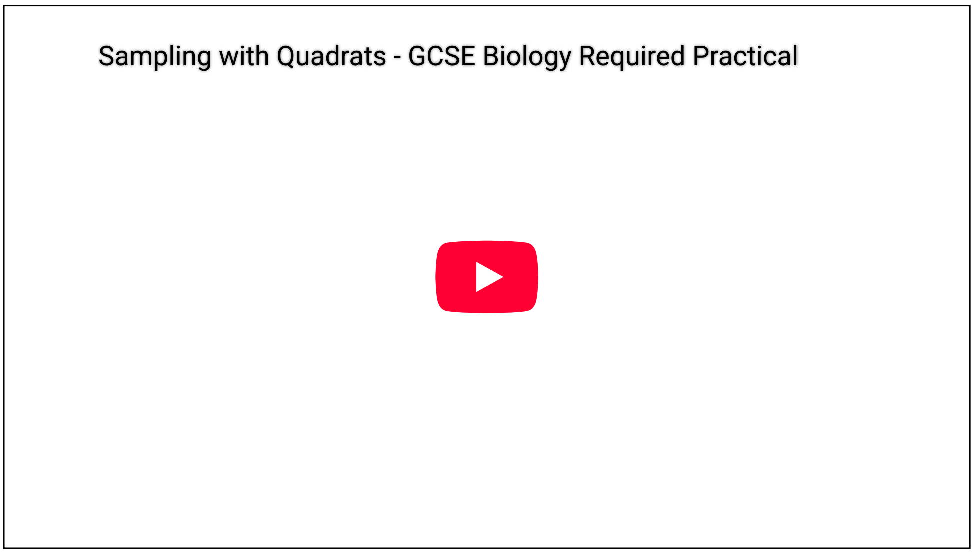
Quadrat sampling is a technique particularly useful to study populations of sessileorganisms, such as plants and corals. A quadrat, a square frame of known area, is randomly placed over a section of the habitat being studied and the number of organisms of interest that fall within the quadrat is recorded (**Figure 1**). The size of the quadrat typically depends on the dimensions of the organisms and the overall size of the area. Find out more on how to use a quadrat here (https://www.nhbs.com/blog/how-to-use-a-quadrat).

Figure 1. Grid quadrats.

Credit: Marci Russell

When conducting quadrat sampling, the first step is to randomly place quadrats over multiple sections of the study area. This can be achieved using a random sampling approach, such as the one described in section C4.1.1–2 (/study/app/bio/sid-422-cid-755105/book/population-sizes-and-random-sampling-id-44711/). Once the quadrats are in position, the observer carefully counts and records the number of organisms found within each quadrat. This counting process enables the estimation of population sizes and the analysis of spatial distribution patterns within the population. **Video 1** demonstrates how population size can be estimated using random quadrat sampling.



Video 1. Estimating population size using random quadrat sampling.

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In cases where an organism is found partially inside the quadrat, it is crucial for researchers to establish a consistent counting criterion. Generally, if an organism touches the lines of the quadrat and more than half of its total area falls within the frame, it is included in the count. Following a standardised approach to counting ensures data consistency, enabling reliable data collection and facilitating accurate estimations and analyses of population characteristics (**Figure 2**).

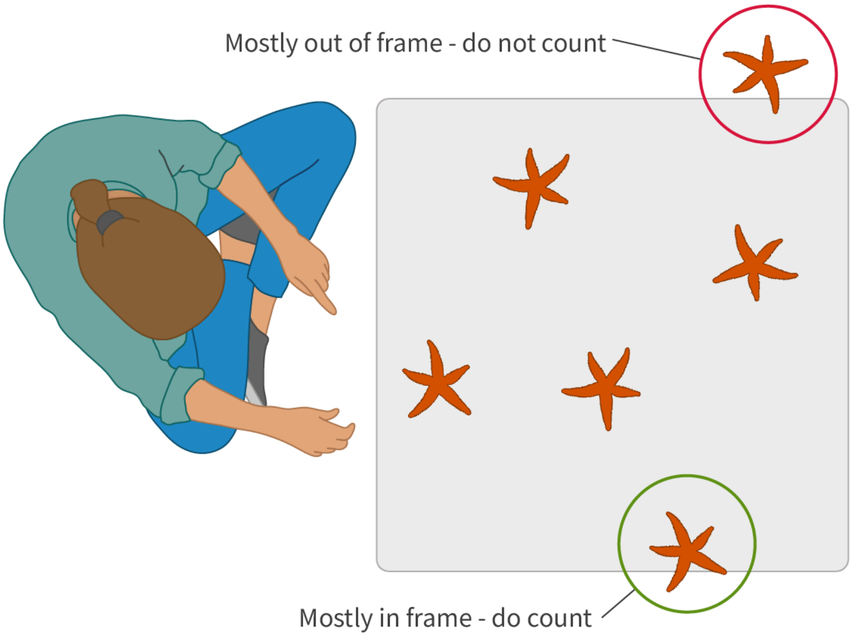

Figure 2. Random sampling and counting of quadrats.

Another approach to conducting quadrat sampling involves the use of photographs and grids. Scientists can capture high-resolution images of the habitat under study and overlay a grid system onto the photo, where each square of the grid represents a virtual quadrat of known area. This non-intrusive method is particularly useful for studying organisms that are difficult to physically access or study in situ. The use of photographs and grids expands the applicability of quadrat sampling, allowing for broader research possibilities and facilitating studies in diverse and challenging environments.

To ensure accuracy and representativeness, it is important to sample an appropriate number of quadrats across the area of study. The number of quadrats being sampled should be large enough to minimise the effects of uncertainty, but not too large so that the task becomes impossible to carry out. In general terms, a minimum of 10 samples is recommended to obtain reliable estimates of population size and distribution. However, the required number of quadrats may vary depending on the habitat and the species under study. Habitats with high diversity or rare species may require a larger number of quadrats, while uniform habitats or abundant species may require fewer samples. Collecting data from multiple samples allows scientists to obtain more accurate estimates of population size and its distribution patterns.

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Once data is collected, the mean number of organisms per quadrat is calculated by adding up the counts and dividing by the total number of sampled quadrats. This mean value can then be extrapolated to estimate the population size for the entire study area.

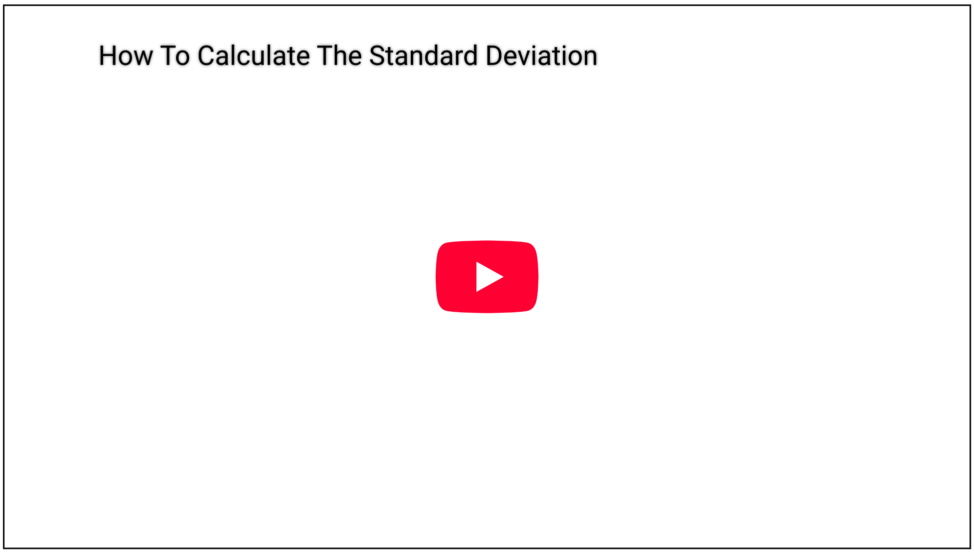
Quadrat sampling is a crucial method for understanding population dynamics, assessing ecological patterns and monitoring changes over time. By conducting repeated randomly sampled measurements of the same habitat over time, scientists can track changes in population size, assess the consistency of distribution patterns and potentially detect ecological shifts.

Practical skills

- **Tool 3**: Mathematics — Applying general mathematics
- **Inquiry 2:** Collecting and processing data — Processing data

The mean number of individuals per quadrat is not enough to fully understand the population dynamics. To gain a comprehensive understanding, we must consider another important measure: the standard deviation. In the context of quadrat sampling, the standard deviation measures how much variation there is in the number of individuals within each quadrat. A small standard deviation indicates a relatively consistent number of individuals across all quadrats, whereas a large standard deviation suggests significant variability from one quadrat to another. This information is important and useful for understanding the distribution and abundance of the species in a given area.

While memorising the formula for standard deviation is not necessary, it is important to know how to obtain this number using a calculator. This skill enables you to determine the level of variation within the population and evaluate the reliability of data collected through quadrat sampling. **Video 2** demonstrates how to calculate the standard deviation from a random set of numbers (see section 1.5.4 (/study/app/bio/sid-422-cid-755105/book/data-analysis-id-46700/) for data processing).



Video 2. How to calculate the standard deviation.

Student view

Estimating population size for motile organisms

Estimating the number of motile organisms in a given area can be a challenging task. When analysing organisms such as birds or fish, the capture-mark-release-recapture method and the Lincoln index are often employed to generate accurate estimates.

The capture-mark-release-recapture method (**Figure 3**) involves capturing a significant sample of the population and marking them in a way that does not harm or compromise the survival of organisms. These marked individuals are then released back into the population, allowing them to interact naturally with unmarked individuals. After a suitable period of time has passed (typically a few days or weeks), a second sample is collected and the numbers of marked and unmarked individuals are recorded.

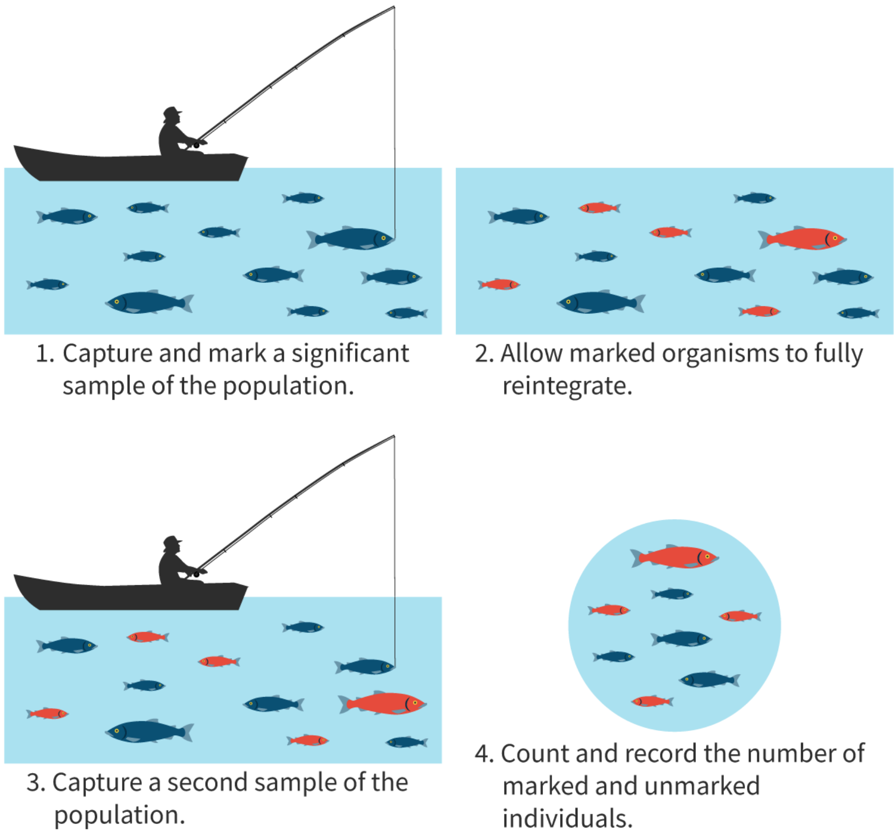


Figure 3. The capture-mark-release-recapture method.

More information for figure 3

The image is a diagram demonstrating the capture-mark-release-recapture method in four sequential steps involving fish.

1. **Capture and Mark (Top Left):** A person in a boat on the water is fishing. The water contains several fish, mostly unmarked, and some are being marked. The step is captioned as "1. Capture and mark a significant sample of the population."

2. **Release and Integrate (Top Right):** The previously marked fish have been released back into the water with other unmarked fish. There are both marked and unmarked fish visible, showing reintegration. Caption: "2. Allow marked organisms to fully reintegrate."

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3. **Recapture (Bottom Left):** The person in the boat is capturing fish again from the water. This reflects capturing a second sample of the population. Caption: "3. Capture a second sample of the population."

4. **Count and Record (Bottom Right):** A circular zoom shows a mixture of marked and unmarked fish in the water, illustrating counting and recording. Caption: "4. Count and record the number of marked and unmarked individuals."

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Using the collected data, the Lincoln index provides an estimate of the population size through the following formula, which you need to memorise:

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

Where:

M = number of individuals captured and marked in the first sample
N = total number of individuals captured in the second sample
R = number of recaptured individuals that were already marked.

Assumptions and limitations

When estimating population sizes, it is important to acknowledge the assumptions and limitations associated with the chosen technique. In the case of the capture-mark-release-recapture method, several assumptions should be considered:

- Firstly, this method assumes that the marking technique does not have any influence on the behaviour or survival of the organism.
- Secondly, it assumes that the marked individuals fully reintegrate into the population and have equal chances of being captured compared to unmarked individuals.
- Finally, the method assumes that there are no births, deaths, immigrations or emigrations during the study period.

Similarly, the Lincoln index also has its own set of limitations:

- It relies on the assumption that the marked individuals used in the estimation process are representative of the entire population.
- Furthermore, it assumes that the ratio of marked to unmarked individuals in the second sample accurately reflects the ratio of the population.

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Despite these limitations, it is possible to enhance the accuracy of the Lincoln index by increasing the sample size and conducting repeated sampling to estimate a mean value.

Several factors determine whether a sample is considered significant in this method. Level of mobility, population density and availability of resources to perform the study are some of the factors that play a role in determining how big of a sample is required. Statistical techniques can be used to determine the appropriate sample size based on the desired level of accuracy and statistical significance.

Worked example 1

Imagine you are studying a population of dolphins in a coastal region. In the first capture, you catch and mark 48 dolphins. You release these back into the population and a second sample is captured after a few weeks. In this second capture, you catch a total of 112 dolphins, of which 29 are marked from the first capture. Apply the Lincoln index to estimate the size of the population.

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

Where:

M = Number of marked individuals in the first capture = 48
N = Total number of individuals in the second capture = 112
R = Number of recaptured individuals that were marked = 29

$$\begin{aligned}\text{Population size estimate} &= 48 \times \frac{112}{29} \\ &= 185.38 \\ &\approx 185 \text{ individuals}\end{aligned}$$

Try the following activity in which you will model the capture-mark-release-recapture method.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Designing procedures and models, Reflecting on the credibility of results
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual/pair/small group activity

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This activity will give you an opportunity to explore population ecology and understand how scientists use mathematical formulas to study and analyse natural populations. The objective of this assignment is to simulate the capture-mark-release-recapture method and apply the Lincoln

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index to estimate population size.

Materials

- small paper squares of any size, ideally more than 80. Other small materials such as gummies or coins can also be used.
- a small bag or container
- a pen or pencil (avoid using markers on paper)

Instructions

Fill the bag or container with your paper squares. Imagine that each square represents an organism within a population, and the bag represents the whole habitat. This modelling activity is summarised here (https://www.pbslearningmedia.org/resource/mgbh.math.sp.fishsample/random-sampling-how-many-fish/).

1. Reach into the bag and randomly draw and mark a sample of paper squares. Remember to record the number of marked individuals before releasing them back into the bag. Now, give the bag a good shake so that the paper squares mix and redistribute within the rest of the squares.
2. Draw a second sample of paper squares from the bag. This time, make sure to record the number of both marked and unmarked squares.
3. Use the Lincoln index formula to estimate the size of your population.
4. Count the actual number of paper squares within your population and compare it to your estimate. How much do the numbers differ? What changes can you make to improve the accuracy of your estimate?

5 section questions

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

Population dynamics

C4.1.5: Carrying capacity and competition for limited resources C4.1.6: Negative feedback control of population size C4.1.7: Population growth curves
C4.1.8: Modelling of the sigmoid population growth curve

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Learning outcomes

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

- Define carrying capacity and explain why population growth slows down as the carrying capacity is reached.
- Distinguish between density-dependent and density-independent limiting factors.
- Compare and contrast exponential and sigmoidal population growth models.

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- Evaluate the use of models as representations of natural phenomena.

Populations of all species can grow when resources are abundant. Have you ever wondered, however, how many organisms an ecosystem can truly accommodate? Is there a maximum limit to the number of humans that the Earth can sustain? It turns out that every environment has a limit, known as the carrying capacity. But what exactly influences this capacity? Is it solely determined by resource availability? This section will explore the factors that regulate the growth of populations, and discuss different models that are used to represent population growth.

Carrying capacity

Carrying capacity refers to the maximum population size that a given environment can sustain over a certain period of time. It is greatly influenced by the availability of resources that play a crucial role in determining the number of individuals or species that an ecosystem can support. The carrying capacity of an ecosystem is dynamic, meaning that it varies over space and time depending on the abundance of limiting resources.

Let's consider the example of bats in different habitats. In a habitat with abundant flying insects and numerous suitable roosting sites, the carrying capacity for bats may be high. However, in another habitat where there is an abundance of food but fewer suitable shelters, the carrying capacity may be lower. This example demonstrates that carrying capacity is not solely determined by the availability of one resource, but rather by the combination of many limiting factors.

When resources such as food, water and space are limited, competition arises between individuals who rely on these resources for survival. This competition can be interspecific, occurring between members of different species, or intraspecific, happening among members of the same species.

Population density

The density of a population is the number of individuals per unit area or volume (**Figure 1**). It provides a measure of how closely packed individuals are within a given space. For example, the density of palm trees in a coastal region of Hawaii can be determined by estimating the number of trees per square kilometre, while the density of *Escherichia coli* bacteria in a test tube can be expressed as the number of bacteria per millilitre of growth medium.

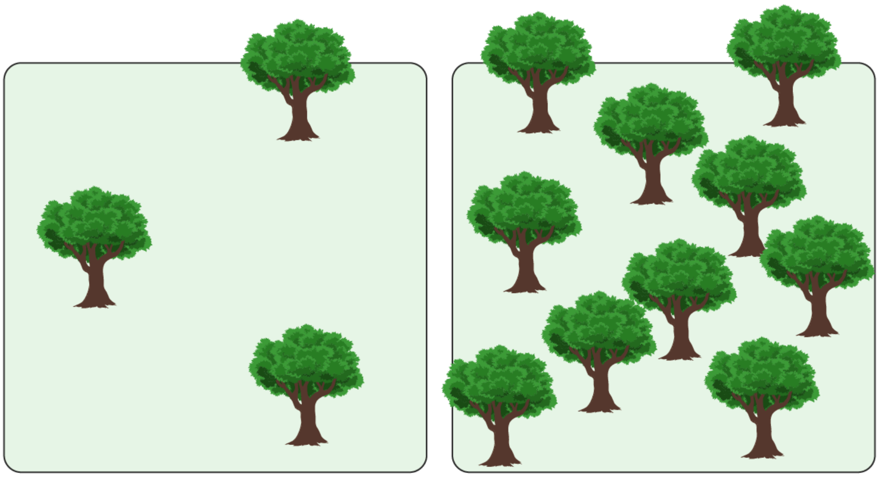

Figure 1. High versus low population density.

Density-dependent factors

The size of a population is influenced by both density-dependent and density-independent limiting factors. Density-dependent factors have a greater impact on population size as the population density increases. These factors include competition for resources, predation, disease and parasitism. As the population size increases, the availability of resources becomes limited, leading to intensified competition among individuals. This competition can result in reduced reproductive success, decreased growth rates and increased mortality. Additionally, a higher population density facilitates the spread of diseases and increases the likelihood of predation, leading to a decline in population growth. Density-dependent factors act as negative feedback mechanisms that help regulate and control population size, keeping it closer to the carrying capacity of the environment. Other negative feedback mechanisms are further outlined in section D3.3.1–2 (/study/app/bio/sid-422-cid-755105/book/homeostasis-and-negative-feedback-id-46245/).

Concept

In biology, negative feedback refers to a regulatory mechanism that counteracts or reverses a change in a biological system, helping to maintain homeostasis or equilibrium. It involves a response that opposes the initial change, thereby stabilising the system and keeping it within a certain range.

In a forest ecosystem, foxes (*Vulpes vulpes*) are natural predators of rabbits (*Oryctolagus cuniculus*). When the rabbit population is abundant, there is ample food available for the foxes, leading to an increase in the number of foxes. As the fox population grows, it puts greater pressure on rabbit populations through predation, causing a decline in rabbit numbers. With fewer rabbits available, the foxes experience a decrease in their food supply, negatively affecting their survival and reproduction (**Figure 2**). This scarcity of prey forces the fox population to decrease in response. As the fox population declines, the predation pressure on rabbits decreases, allowing the rabbit population to recover over time.

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Figure 2. A black red fox vixen (*V. vulpes*) carrying a rabbit (*O. cuniculus*) with one of its cubs.

Credit: Michael J. Cohen, Photographer, Getty Images

These fluctuations in population sizes help maintain a relative balance in the ecosystem, ensuring the survival of both predator and prey species (**Figures 3 and 4**). The role of predator–prey interactions in the regulation of population sizes is further discussed in section C4.1.16–18 (/study/app/bio/sid-422-cid-755105/book/control-of-populations-id-46392/).

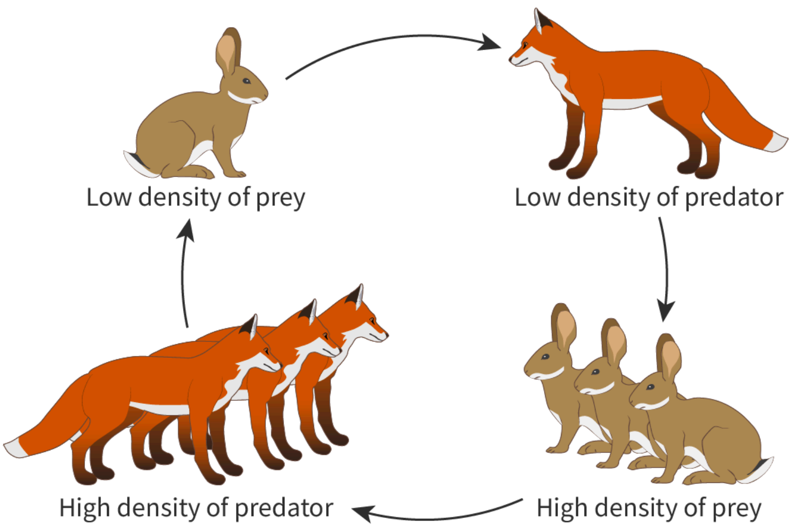

Figure 3. Cycle of predator—prey interactions and its effects on population density.

More information for figure 3

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This image is a diagram depicting the cycle of predator-prey interactions. It features visual representations of rabbits (prey) and foxes (predators) to illustrate fluctuations in their respective population densities. Starting with a single rabbit labeled "Low density of prey," an arrow points to a single fox labeled "Low density of predator." A second arrow follows, leading to three rabbits, labeled "High density of prey." Another arrow points from the high prey density back to a group of three foxes tagged as "High density of predator." Finally, an arrow leads from this group of foxes back to the single rabbit with "Low density of prey," completing the cycle. The illustration shows the interactive dependency where increased prey density leads to increased predator density, which then reduces prey density, subsequently lowering predator density, and so on.

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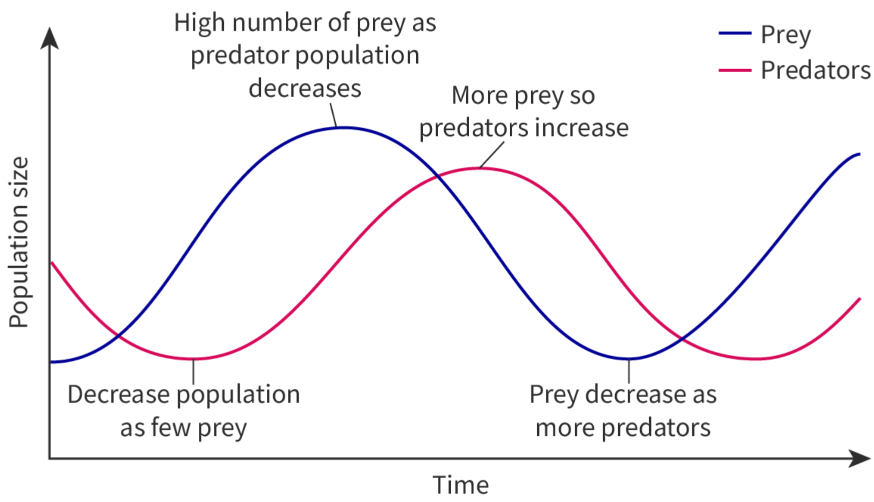

Figure 4. Predator—prey dynamics.

More information for figure 4

The graph displays the dynamics between predator and prey populations over time. The X-axis represents time, while the Y-axis represents population size. Two curves are shown: a blue wave indicating prey population and a red wave indicating predator population. Initially, the prey population is high as the predator population decreases. As a result, the prey population decreases due to fewer predators. Following this, an increase in prey leads to a growth in predators. Eventually, as predators increase, the prey population decreases again due to more predators, creating a cyclical pattern of fluctuation between the two populations. Key annotations include 'Decrease population as few prey', 'High number of prey as predator population decreases', 'More prey so predators increase', and 'Prey decrease as more predators'.

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Density-independent factors

Density-independent factors can have an impact on population size regardless of its density. These factors are external to the population and can cause sudden and drastic changes. Examples of density-independent factors include natural disturbances such as floods, droughts, hurricanes and earthquakes. These events can directly affect the survival rates of individuals by destroying habitats, leading to significant fluctuations in population size.

Additionally, anthropogenic events, which are human-induced, can also act as density-independent factors. Habitat destruction, caused by activities such as deforestation or urbanisation, can disrupt the population dynamics of various species. Pollution, including air and water pollution, can have detrimental effects on the health and reproduction of organisms, affecting population size. Climate change is another significant density-independent factor, as it alters environmental conditions such as temperature and precipitation patterns, which can directly affect populations.

These density-independent factors can alter the availability of resources, therefore changing the carrying capacity of an ecosystem.

Try the drag and drop activity in **Interactive 1** to test your understanding of density-dependent and density-independent factors.

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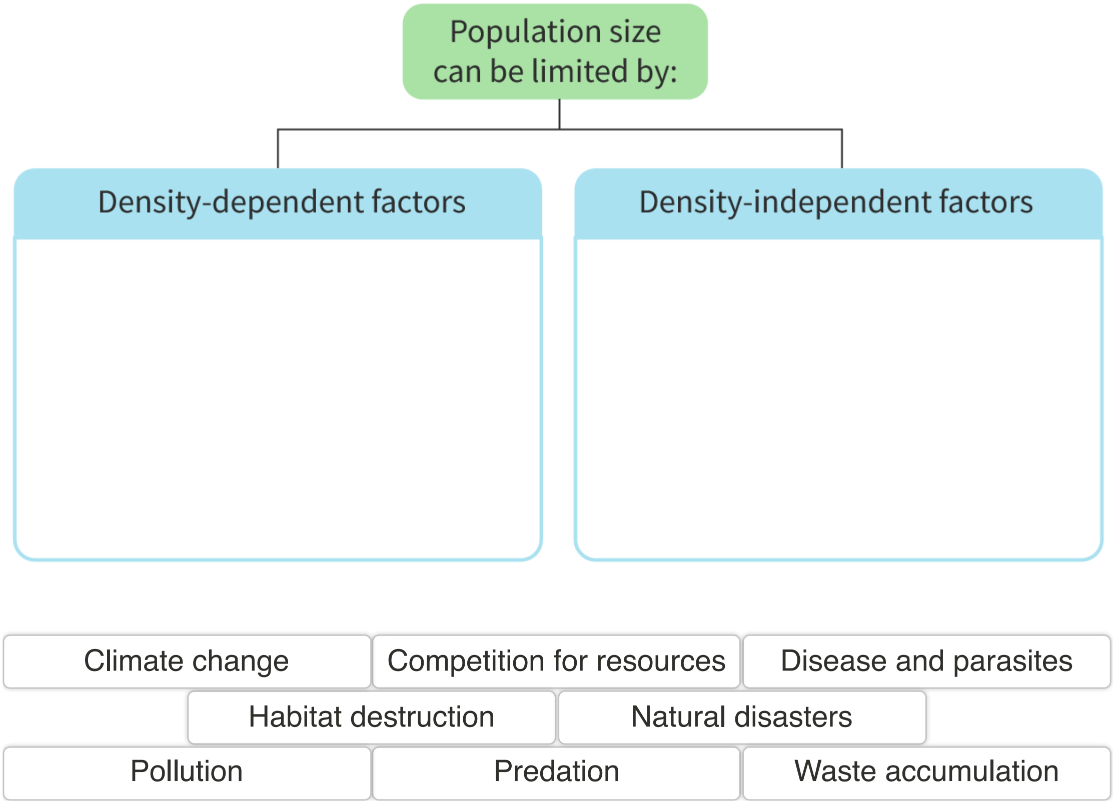

Check

Interactive 1. Population Regulation: Density-Dependent and Independent Factors.

Exponential population growth

Exponential growth, which is represented by a J-shaped curve, occurs in populations under ideal conditions where resources are unlimited and abiotic factors are favourable (**Figure 5**). This pattern is often observed in bacterial populations grown under laboratory settings. Bacteria can reproduce rapidly and continuously in nutrient-rich environments as long as resources are readily available.

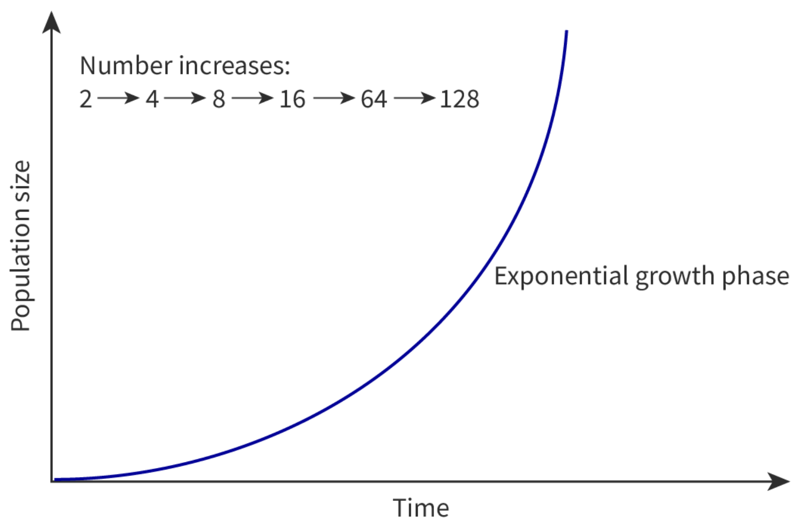

Figure 5. Exponential (J-shaped) population growth.

More information for figure 5

This graph illustrates exponential population growth, typical of a J-shaped curve. The x-axis represents time, while the y-axis represents population size. The curve starts low and ascends sharply, demonstrating rapid growth. The y-axis is labeled 'Population size' and the x-axis is labeled 'Time.' Annotations on the graph show population numbers increasing in powers of two: 2, 4, 8, 16, 64, 128. There is a label 'Exponential growth phase' towards the upper right of the curve, indicating the ongoing rapid increase in population as theoretically unlimited resources are available.

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However, in natural ecosystems, exponential growth is limited by factors such as the amount of nutrients, competition for resources, predation and parasitism. These factors prevent sustained exponential growth over an extended period. In nature, the assumption of unlimited resources and maximum reproductive capacity is highly unrealistic.

Sigmoid population growth

Sigmoid population growth, represented by an S-shaped curve, occurs in environments with a limited number of resources (**Figure 6**). Initially, a population experiences exponential growth when resources are abundant and competition is low. However, as the population size increases, density-dependent factors come into play, limiting the rate of population growth. The scarcity of resources intensifies competition among individuals, leading to a gradual decrease in the growth rate.

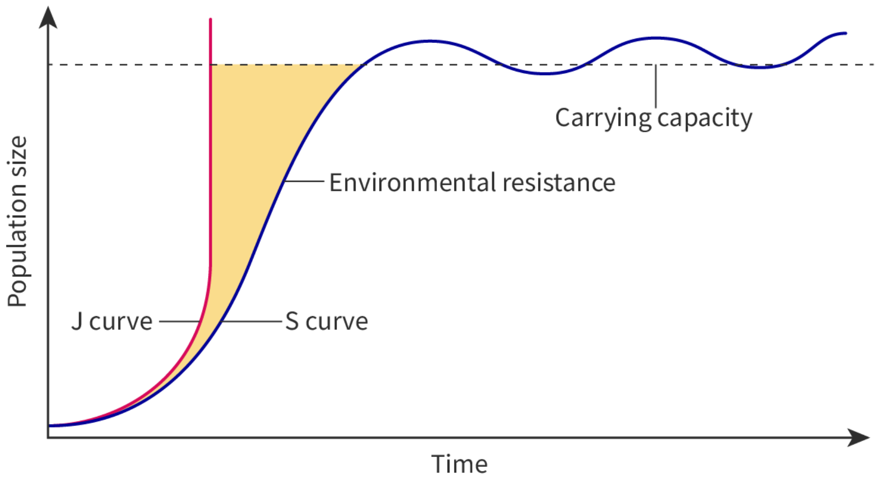

Figure 6. Sigmoid (S-shaped) population growth.

More information for figure 6

This graph illustrates sigmoid population growth, featuring an S-shaped curve over time. The X-axis represents time, while the Y-axis indicates population size. Initially, the curve exhibits a steep rise, labeled as the J curve, indicating rapid population growth. As resources become limited, the growth slows and transitions into the S curve, reflecting the impact of environmental resistance and

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density-dependent limitations. The curve eventually levels off at the carrying capacity of the environment, where the population size stabilizes. The carrying capacity is depicted as a horizontal dashed line at the top of the graph. The yellow area between the J curve and the S curve shows the environmental resistance faced by the population as it grows.

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Over time, the population reaches a steady-state equilibrium around the carrying capacity of the environment. At this point, the birth rate equals the death rate and the population stabilises. The S-shaped curve represents the transition from rapid exponential growth to a more gradual increase until reaching the carrying capacity.

Sigmoid population growth is a common pattern observed in natural populations and provides insights into how populations interact with their environment and the constraints imposed by limited resources.

One example of sigmoidal growth can be observed in the population of wolves on Isle Royale, a small island in the United States. In the late 1940s, a few pioneering wolves reached the island by crossing an ice bridge and established a population. With an abundant availability of prey resources, the wolf population experienced rapid growth. As the wolf population approached the carrying capacity of the island, the growth rate gradually slowed down and eventually levelled off, resulting in a sigmoidal growth curve.

Currently, the population of wolves on Isle Royale is regulated by predator–prey interactions with the moose population. When the wolf population is high, predation on moose increases, which in turn reduces the moose population. As the moose population declines, the wolf population also decreases due to reduced availability of prey. This dynamic interaction helps maintain both populations fluctuating around the carrying capacity of the island.

Nature of Science

Aspect: Models

Models serve as simplified representations of complex systems, aiming to capture the fundamental aspects of a phenomenon. These are valuable tools that help us make predictions and understand how different factors might influence the system under study. Nonetheless, it is crucial to acknowledge that models are not perfect representations of reality and may omit or oversimplify certain factors. When studying population growth, additional variables such as disease, resource competition and environmental changes significantly contribute to actual population dynamics, but their comprehensive inclusion in the model may be limited.

The graph in **Figure 7** presents the growth curve of harbour seals (*Phoca vitulina*) in Washington, USA (**Figure 8**). As observed, the data points deviate slightly from the expected sigmoidal growth model line. This discrepancy arises because multiple factors, such as environmental conditions

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and human impacts, can influence population size in ways that are not fully captured by the model. Nevertheless, the graph demonstrates the overall trend of sigmoid growth, reflecting the typical pattern observed in population dynamics.

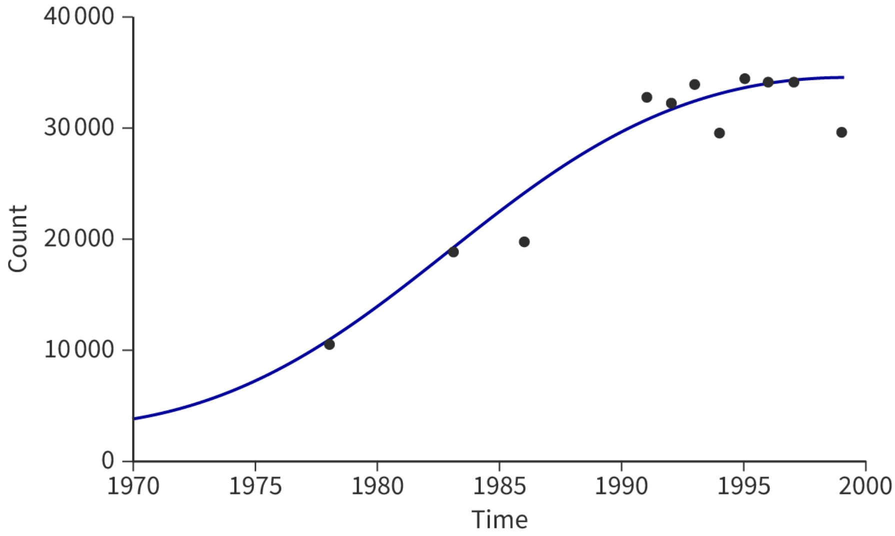

Figure 7. Sigmoid growth curve of harbour seals (*P. vitulina*) in Washington, USA.

More information for figure 7

The graph displays the sigmoid growth curve of harbour seals in Washington, USA, from 1970 to 2000. The X-axis represents time in years, ranging from 1970 to 2000, while the Y-axis represents the count of harbour seals, ranging from 0 to 40,000. The data points, shown as black dots, indicate the actual counts of harbour seals at different times. A blue sigmoidal line highlights the expected growth trend. The curve shows a slow initial growth, followed by a rapid increase around 1985, and then a plateau near 2000. This graph illustrates deviations between the actual data points and the model's predicted line, demonstrating the complexity and variability in population dynamics due to external factors.

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Figure 8. Harbour seals (*P. vitulina*).
Credit: James Warwick, Getty Images

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Graphing population growth

To analyse population growth patterns, it is important to plot actual population data on a graph and interpret the results. When creating a population graph, it is recommended to use a logarithmic scale for the population size on the *y*-axis and a non-logarithmic scale for time on the *x*-axis. By accurately representing the population data on the graph, you can assess the growth pattern of the population and compare it to the expected exponential growth model.

Using a logarithmic scale for the *y*-axis allows for a better visualisation of changes in population size, especially when dealing with large variations in numbers. It compresses the data, making it easier to observe patterns and trends. On the other hand, a non-logarithmic scale for the *x*-axis maintains a linear representation of time, ensuring accurate interpretation of the data over the specified time intervals.

By analysing the population graph, you can identify whether the population growth follows the expected exponential model or deviates from it. Deviations may indicate the influence of other factors that affect population dynamics, such as density-dependent limitations or environmental constraints. It allows for a more comprehensive understanding of population dynamics and the factors driving population growth or decline.

Collecting data on population growth

To explore population growth, you are encouraged to collect data of your own using model organisms such as yeast (*Saccharomyces cerevisiae*) or duckweed (*Lemnoideae*). These organisms are particularly suitable for this task as they show rapid growth under controlled experimental conditions. Start by establishing a population of yeast or duckweed in a suitable growth medium, and record the population size at regular time intervals. Once you have collected the data, use a spreadsheet program to plot the population growth and analyse the pattern over time.

International Mindedness

Issues surrounding the increasing global human population are a matter of international concern. While population growth rates may vary significantly among countries, the consequences and challenges associated with human population growth extend beyond national boundaries. Addressing the challenges associated with an expanding population requires global cooperation and a shared responsibility for sustainable solutions.

Try the activity below to plot the data on population growth of yeast.

Activity

- **IB learner profile attribute:** Thinker

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- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

A controlled experiment was set up to study population growth of yeast. Yeast cells were cultivated in a suitable growth medium and changes in population size were monitored over a period of time**. Interactive 2** represents samples of the yeast population observed through a microscope on gridded glass slides. The volume of yeast placed on each of the slides represents only 1/1000 of the total volume from the original population.

Interactive 2. Yeast Cell Samples *(S. cerevisiae)*.

More information for interactive 2

The interactive slideshow consists of microscopy images of yeast cultures at different time intervals. There are six slides in total. In each slide, there are three samples, namely Sample A, Sample B, and Sample C. Each sample is represented by a four-by-four grid, with yeast cells represented as small yellow-colored dots. However, the population size (number of yeast cells) and the time intervals are different in each slide.
Read below for the information about each slide:
Slide 1: In slide 1, the population size at 0 hours is provided. At this time interval, there are 9 yeast cells in Sample A, 10 yeast cells in Sample B, and 11 yeast cells in Sample C.
Slide 2: Slide 2 provides information about population size at 24 hours. At this stage, there are 26 yeast cells in Sample A, 27 yeast cells in Sample B, and 25 yeast cells in Sample C.
Slide 3: This slide represents population size at 48 hours. At this stage, there are 50 yeast cells in Sample A, 51 yeast cells in Sample B, and 52 yeast cells in Sample C.
Slide 4: This slide provides data regarding population size at 72 hours. At this stage, there are 85 yeast cells in Sample A, 86 yeast cells in Sample B, and 87 yeast cells in Sample C.
Slide 5: This slide provides information about population size at 96 hours. At this stage, there are 80 yeast cells in Sample A, 79 yeast cells in Sample B, and 78 yeast cells in Sample C.
Slide 6: This slide provides the data for population size at 120 hours. At this stage, there are 77 yeast cells in Sample A, 79 yeast cells in Sample B, and 80 yeast cells in Sample C.
This interactive slideshow helps viewers to compare growth stages and estimate population size via cell counts. Slides at 0 hours show sparse cell distribution (lag phase). Slides at 24-72 hours show an exponential increase in cell density (log phase). Slides at 96-120 hours show stabilisation (stationary phase due to resource limits).
This interactive teaches users to collect data, graph trends and analyse limits.

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Procedure

1. Carefully observe each sample and count the number of yeast cells (small circles) present at the beginning of the experiment (time 0). Record your results in **Table 1**.
2. Repeat the counting step for samples at 24, 48, 72, 96 and 120 hours, recording the cell counts in **Table 1** each time.
3. Calculate the average number of yeast cells for each time interval by taking the sum of the counts and dividing by the number of samples. Record these average values in **Table 1**.
4. Keep in mind that the counts obtained from the glass slides represent only a fraction of the entire yeast population. To estimate the population size at each time point, multiply the average counts by 1000 to account for the sample size used. Record these estimates in **Table 1**.
5. Use a spreadsheet program to create a graph that illustrates the estimated yeast population sizes over time. Remember to include a clear and descriptive title for the graph, as well as properly labelled axes with appropriate units.

Table 1. Yeast cell population counts over time.

	Number of cells over time (hours)					
	0	**24**	**48**	**72**	**96**	**120**
Sample A						
Sample B						
Sample C						
Average						
Population estimate						

Questions

1. Determine which **time interval** demonstrates the most rapid growth by examining the population estimates on the graph.
2. Identify the time point at which the growth rate of the yeast population begins to slow down based on the graph.
3. Suggest the potential factor(s) that may have contributed to the decline in growth rate.
4. Explain reasons why it is important to collect several samples to estimate the size of the yeast population.

Now try this next activity in which you will be investigating the effects of anthropogenic activity on the carrying capacity of an ecosystem.

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Activity

- **IB learner profile attribute:**
    - Knowledgeable
    - Communicator
- **Approaches to learning:**
    - Research skills — Using a single, standard method of referencing and citation; Using search engines and libraries effectively
    - Communication skills — Using digital media for communicating information
    - Thinking skills — Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 40 minutes
- **Activity type:** Pair/group activity

In this activity you will be working in small groups (2—4 people), to investigate how a specific anthropogenic disturbance can impact the carrying capacity of an ecosystem.

Instructions

1. With your group, choose one ecosystem and one associated disturbance from the following list:
    - **Forest ecosystem**: deforestation (clear-cutting, selective logging), forest fragmentation, forest degradation (unsustainable harvesting practices, wildfire suppression).
    - **Marine ecosystem**: overfishing, coral reef destruction (blast-fishing, coral mining), marine pollution (oil spills, plastic debris), coral bleaching (due to rising ocean temperatures), ocean acidification.
    - **Grassland ecosystem**: conversion to agricultural land (ploughing, grazing), overgrazing, habitat fragmentation (construction of roads, fences).
    - **Freshwater ecosystem**: damming and river channelisation, water pollution (industrial and agricultural runoff, sewage discharge).
    - **Desert ecosystem**: mining activities (extracting minerals).
2. Investigate how your chosen disturbance affects the carrying capacity of the ecosystem. Focus on researching the following aspects:
    - How does the assigned human activity affect the availability of key resources (e.g. food, water, space)?
    - How does it affect competition between species or individuals within the ecosystem?
    - Are there any direct or indirect effects on population sizes or growth rates of organisms?
    - How does the disturbance affect the interaction between predator and prey populations, if applicable?
3. Create a visual outcome that showcases your research and understanding in a creative manner. You can choose to create a presentation, infographic or any other visual representation that effectively communicates your findings and arguments. The outcome should include:
    - Clear explanation of the assigned human activity and its impacts on carrying capacity.
    - Evidence-based arguments supported by relevant data and examples.

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- Visual elements (graphs, diagrams, images) to enhance understanding and engagement.
- Clear organisation and presentation of information.
- A list of resources with appropriate citations.

4. If possible and appropriate, present your findings with the class. Discuss with your classmates the potential consequences of altering carrying capacity, emphasising the importance of sustainable practices to maintain ecological balance.

5 section questions

Intraspecific interactions

Learning outcomes

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

- Describe the impact of intraspecific competition and cooperation on the survival and reproduction of a population.
- Define communities as diverse collections of populations that interact and contribute to the functioning of ecosystems.

Have you ever wondered how individuals of the same species interact with each other in their struggle for survival? Intraspecific relationships, such as competition and cooperation, are fascinating drivers of population dynamics. Competition for limited resources can shape the adaptation of individuals and regulate population size. Consider how male lions (*Panthera leo*) compete for dominance and access to resources, influencing their breeding success and overall population density. However, it is important to note that intraspecific relationships are not solely about competition. Cooperation also plays a crucial role, as observed in the social behaviour of bees. In a bee colony, individual bees work together in a highly organised manner, with each bee having specific roles that ensure the survival of the entire colony. But how do these intraspecific relationships, encompassing both competition and cooperation, contribute to the thriving of organisms in their respective environments?

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Competition and cooperation

Intraspecific relationships, which occur among individuals of the same species, play a crucial role in driving population dynamics and resource use. Intraspecific competition occurs when members of a species compete for limited resources such as food, water and space. This competition can lead to a variety of outcomes, including the adaptation of individuals to different niches, the displacement of less-competitive individuals and the regulation of population size. Consider for instance, a population of birds, in which competition for nesting sites and territories influences breeding success and overall population density.

Alongside competition, cooperation is also observed within ecological communities, where individuals, regardless of species, collaborate to increase their chances of survival and reproduction. One example of intraspecific cooperation can be observed in the social amoeba *Dictyostelium discoideum* (**Figure 1**). When faced with starvation, individual amoebas aggregate to form a multicellular structure consisting of spores on top of a stalk. Scientists consider the development of the stalk as an altruistic behaviour, as the cells comprising it sacrifice themselves to aid in spore dispersal.

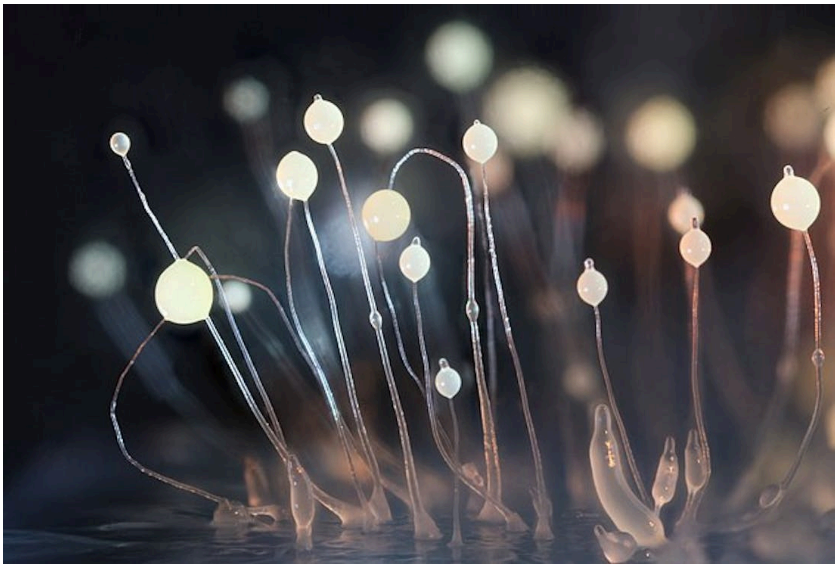

Figure 1. Fruiting bodies of the amoeba *D. discoideum* as an example of intraspecific cooperation.

Communities

Communities consist of a diverse array of populations within a specific area, ranging from plants and animals to fungi and bacteria. These populations interact and coexist, forming complex ecological relationships and contributing to the overall functioning of the ecosystem.

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An excellent example of a highly diverse community can be found in the Coral Triangle, located in the western Pacific Ocean (**Figure 2**). This ecosystem is home to a wide variety of species. The foundation of the reef is built by coral polyps, which create the physical structure. Fish, such as clownfish and parrotfish, inhabit and rely on the coral for food and shelter. Crustaceans, molluscs and numerous other organisms contribute to the reef's diversity and ecological processes.

Figure 2. The Coral Triangle is an example of an ecosystem holding a large community of organisms.

Credit: Darryl Leniuk, Getty Images

In a terrestrial ecosystem, plants harness energy from the Sun through photosynthesis, providing the foundation for the community's food web. Animals, including herbivores, carnivores and omnivores, directly or indirectly rely on plants for nourishment. Fungi, as decomposers, are essential in breaking down organic matter and returning nutrients to the soil. Bacteria contribute to nutrient cycling and engage in symbiotic relationships. Each population within the community has unique characteristics that contribute to the overall diversity and stability of the ecosystem. These roles and interactions are further explored in subtopic B4.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43537/). Recognising the interconnectedness and interdependence among populations is vital for understanding the complexity of ecological communities and promoting the conservation of biodiversity.

Try the activity below to create a food web based on an ecosystem of your choice.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Designing procedures and models
- **Time required to complete activity:** 30 minutes
- **Activity type:** Pair/group activity

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In small teams, choose a **specific** ecosystem and research multiple populations within the community. Provide at least one specific example of each of the following.

- A producer
- A primary consumer
- A secondary consumer
- An apex predator
- A detritivore or decomposer

Create a food web based on your research and present it to the class, highlighting the interconnectedness within the ecosystem.

5 section questions

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

Interspecific interactions

C4.1.11: Herbivory, predation, interspecific competition, mutualism, parasitism and pathogenicity

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

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Learning outcomes

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

- Distinguish between multiple interspecific interactions.
- Discuss the ecological significance of interactions between species.
- Outline examples of herbivory, predation, competition, parasitism, pathogenicity and mutualism.

Interspecific ecological interactions refer to the relationships that occur between different species within an ecosystem. From competition to cooperation, these interactions intricately shape the distribution, abundance and evolution of species. But how exactly do these diverse interactions influence the flow of resources, energy and information? What mechanisms drive these connections? This section will explore some of the different relationships that can occur among members of different species within a community.

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Concept

Symbiotic relationships are associations between different species in an ecosystem where they have close and long-lasting connections. These interactions involve mutual dependence and the exchange of important resources or services. In symbiotic relationships, the involved species, known as symbionts, interact intimately with each other, often resulting in coevolution and adaptation. Some examples of relevant symbiotic relationships covered in this section include mutualism and parasitism.

Herbivory

Herbivory is a fundamental feeding relationship in which an animal, referred to as a herbivore, consumes plant material as its primary source of nutrients. This interaction is widespread in nature and plays a significant role in shaping ecosystems. One example of this interaction can be observed between the giant panda (*Ailuropoda melanoleuca*) and bamboo plants (*Phyllostachys* spp.). Giant pandas have particularly adapted to feed exclusively on bamboo, relying on its nutritional content for their sustenance (**Figure 1**). The coexistence of giant pandas and bamboo plants exemplifies the complex dynamics of herbivory, demonstrating how herbivores have evolved specialised traits to effectively extract nutrients from plant sources.

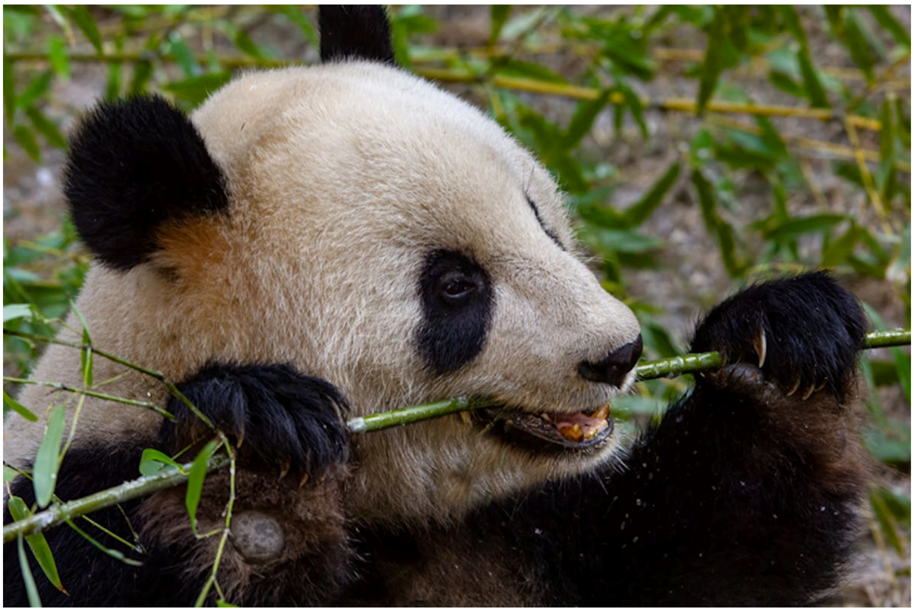

Figure 1. A giant panda (*A. melanoleuca*) feeding on bamboo.

Credit: Gerald Corsi, Getty Images

Predation

Predation is an ecological interaction where a predator captures and consumes its prey. This interaction is widespread in different ecosystems and holds significant implications for both predator and prey populations. A well-known example of predation involves the interaction between grizzly bears (*Ursus*

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arctos horribilis) and salmon (*Oncorhynchus* spp.). Grizzly bears, as predators, heavily rely on salmon as a source of energy (**Figure 2**). The predation exerted by bears plays a key role in shaping the behaviour, population size and reproductive success of salmon.

Figure 2. A grizzly bear (*U. arctos horribilis*) preying on salmon.

Credit: Ron Crabtree, (https://www.gettyimages.com/detail/photo/grizzly-bear-feeds-on-a-jumping-salmon-alaska-royalty-free-image/dv1620005)Getty Images

Interspecific competition

Interspecific competition occurs when different species compete for limited resources within an ecosystem. This competitive interaction has significant implications for species distribution, abundance and the evolution of traits related to resource acquisition. A well-documented example of interspecific competition is observed between the Eastern grey squirrel (*Sciurus carolinensis*) (**Figure 3**) and the American red squirrel (*Tamiasciurus hudsonicus*) (**Figure 4**) in North America. The competition for similar food resources between these two species greatly affects the growth and survival of populations.

Figure 3. The Eastern grey squirrel (*S. carolinensis*).

Credit: Marco Pozzi Photographer, (https://www.gettyimages.com/detail/photo/squirrel-royalty-free-

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image/150845932)Getty Images

Figure 4. The American red squirrel (*T. hudsonicus*).

Credit: Gerry Legere / 500px, Getty Images

Parasitism

Parasitism is a type of symbiotic interaction in which one organism, known as the parasite, benefits at the expense of its host. Parasites live on or within the host, extracting nutrients and resources that often result in harm or disease. Tapeworms (*Cestoda*) provide a well-known example of parasitism, as they reside in the intestines of their host organisms and absorb nutrients from their digestive systems (**Figure 5**). Parasites have evolved diverse adaptations to exploit their hosts while minimising damage that could potentially lead to their host's death.

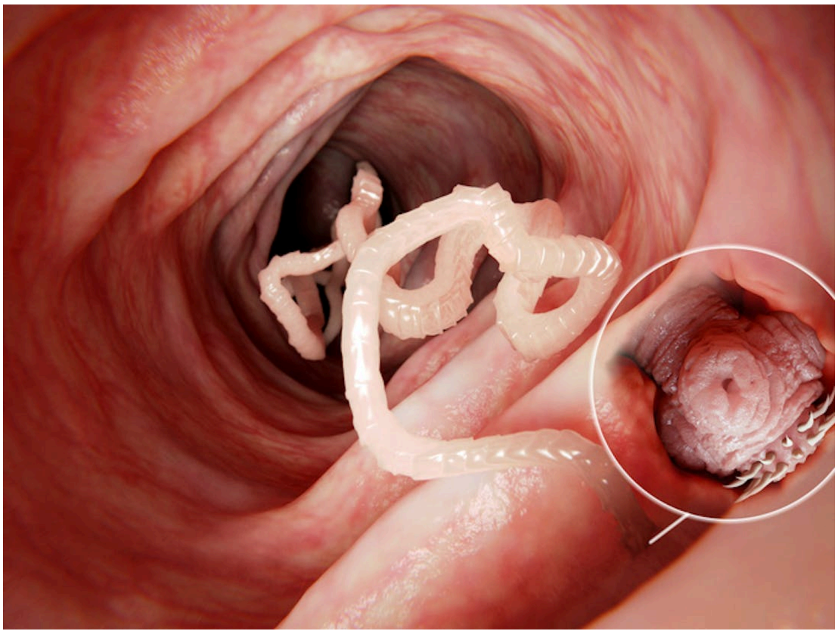

Figure 5. Tapeworms are parasites that can inhabit the human gut.

Credit: JUAN GAERTNER/SCIENCE PHOTO LIBRARY, Getty Images

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Pathogenicity

A pathogen is a microorganism, such as a virus (though the debate is still active as to whether viruses are living or non-living, they are pathogens and, as such, are included here), bacterium, fungus or other infectious agent, capable of causing disease in its host. Pathogens typically invade and multiply within the host's tissues, disrupting normal physiological functions and leading to various symptoms of illness. Unlike parasites, pathogens often have a direct and immediate detrimental effect on the host's health and can easily spread from one host to another. Notable examples of pathogens include influenza viruses, *Salmonella* bacteria and *Candida* fungi.

Mutualism

Mutualism is a symbiotic interaction between two or more species, where both parties obtain benefits from the relationship. One well-known mutualistic interaction occurs between bees and flowering plants. As bees obtain plant nectar, they inadvertently facilitate the pollination of plants, helping with their reproduction.

Root nodules in Fabaceae

The exchange of resources is a common context for mutualistic interactions. A good example of this exchange is observed in legume plants, which belong to the Fabaceae family (**Figure 6**). These plants contain root nodules filled with nitrogen-fixing bacteria that play a vital role in converting atmospheric nitrogen into a usable form. While the bacteria provide legume plants with a valuable source of nitrogen, the plants provide the bacteria with carbohydrates and other compounds necessary for their growth and survival. This mutualistic relationship contributes to the overall nitrogen balance in ecosystems and enhances the growth and productivity of legume plants.

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Figure 6. Root nodules growing in Fabaceae plants.

Credit: Tomasz Klejdysz, Getty Images

Mycorrhizae in Orchidaceae

The mutualistic relationship between mycorrhizae fungi and orchids is a remarkable example of mutualism in the plant kingdom. These specialised fungi colonise orchid roots, forming a mutually beneficial interaction that is vital for the survival of both partners.

In this relationship, fungi aid orchids with nutrient acquisition by extending their hyphae into the soil, increasing the surface area for nutrient absorption. This allows the fungi to access nutrients that orchid roots cannot reach. In return, orchids provide the fungi with organic compounds produced through photosynthesis (**Figure 7**).

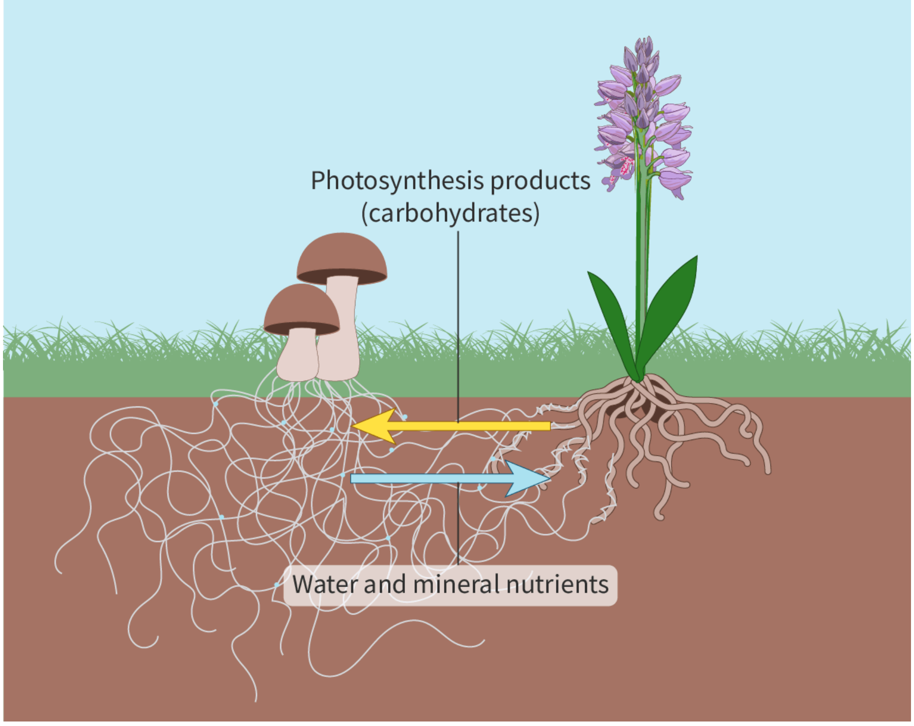

Figure 7. Exchange of nutrients between mycorrhizae and orchids.

More information for figure 7

The diagram illustrates the nutrient exchange between mycorrhizal fungi and an orchid. It shows two main components: a pair of mushrooms representing the fungi on the left and an orchid plant on the right. Beneath the soil surface, the fungi's hyphae are depicted as a network of spaghetti-like strands extending towards the orchid roots. This network facilitates the transfer of nutrients.

There are arrows indicating the direction of nutrient movement: - A yellow arrow points from the orchid roots towards the fungi, labeled with "Photosynthesis products (carbohydrates)." This shows that the orchid provides the fungi with necessary organic compounds. - A blue arrow directs from the fungi to the orchid roots, labeled "Water and mineral nutrients," illustrating how the fungi help the orchid by transferring essential soil nutrients.

The diagram highlights the mutualistic relationship and dependency between the mycorrhizal fungi and the orchid, enhancing both their survival capabilities.

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Zooxanthellae in hard corals

Another example of mutualism is found between algae and corals in marine ecosystems. Within this interaction, single-celled, photosynthetic algae called zooxanthellae live within the tissues of hard corals and provide them with essential nutrients from photosynthesis that support coral growth, reproduction and overall health. They also provide vibrant pigments that protect corals from excessive UV radiation from the Sun (**Figure 8**). In return, hard corals offer the zooxanthellae a sheltered environment and access to sunlight for effective photosynthesis.

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Refer to section B4.1.5 (/study/app/bio/sid-422-cid-755105/book/coral-reef-formation-id-44706/) for an overview of the conditions required for coral reef formation.

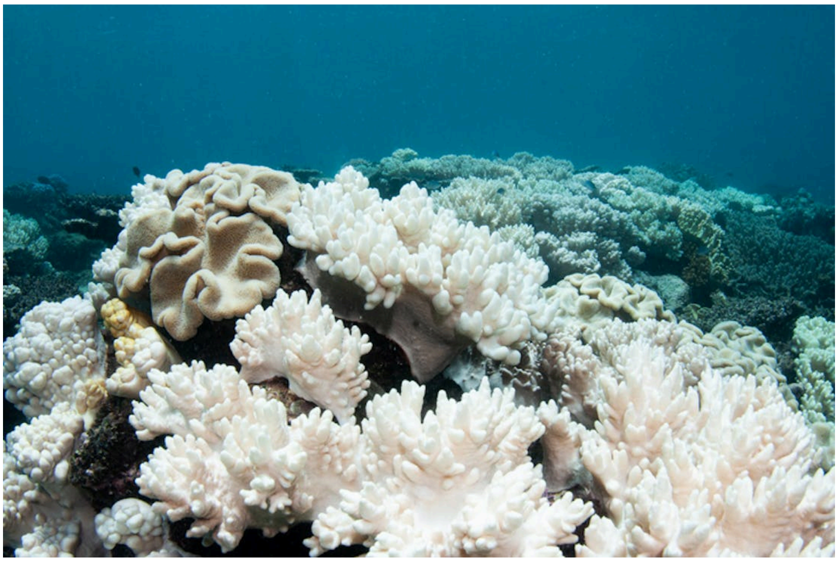

Figure 8. Coral bleaching on the Great Barrier Reef.

Credit: Brett Monroe Garner, Getty Images

Try the drag and drop activity in **Interactive 1** to identify the type of biotic interaction shown in the images.

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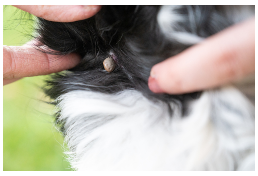
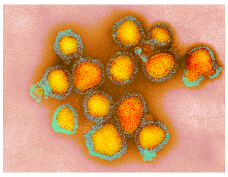


A tick attaching itself to a dog and feeding on its blood.



The influenza virus causing flu-like symptoms in humans, such as fever, cough, and fatigue.

A lion hunting and capturing a zebra for its meal.

Bees and flowers - bees collect nectar from flowers for food while unintentionally pollinating the flowers in the process.

A cow grazing on grass in a field, obtaining nutrients from the plants.

Two male deer fighting for dominance and access to mates during the breeding season.

Two bird species competing for food.

Pathogenicity

Parasitism

Predation

Mutualism

Herbivory

Interspecific competition

Intraspecific competition

Check

Rights of use

Interactive 1. Identify the type of biotic interactions.

More information for interactive 1

This is an interactive drag-and-drop screen with 7 images on the screen, along with text.

In the top row, the first image is a close-up of a dog's fur. Attached to the fur, you can feel a small, oval-shaped tick. A caption below reads, A tick attaching itself to a dog and feeding on its blood.

The second image is a microscopic view of many small, round particles with protruding spikes. These represent the influenza virus. The caption below reads: The influenza virus causes flu-like symptoms in humans, such as fever, cough, and fatigue.

The third image is a grassy plain with a zebra running. Behind it, a lion is in pursuit, appearing to be chasing the zebra. A caption below reads, A lion hunting and capturing a zebra for its meal.

In the second row, the first image is of bright yellow flowers with several bees and a few fuzzy, striped flies hovering around them, some appearing to be landing on the flowers. A caption below reads: Bees and flowers—bees collect nectar from flowers for food while unintentionally pollinating the flowers in the process.

The second image is of a black and white cow standing in a green field, its head lowered as if it is eating grass. The caption below

Student view

reads, A cow grazing on grass in a field, obtaining nutrients from the plants.

The third image is a natural landscape with two male deer with large antlers facing each other, seemingly engaged in a fight. The background shows a hazy, open area. A caption below reads, Two male deer fighting for dominance and access to mates during the breeding season.

In the third row, there's only one image, a bird feeder hanging from a wooden support against a blurred green background, suggesting foliage. The feeder appears to be a mesh bag containing seeds or suet. Two small birds are interacting near the feeder. The caption below reads, Two bird species competing for food.

There are eight rectangular buttons with labels:

Left Column: Parasitism, Mutualism, and Interspecific Competition.

Right Column: Pathogenicity, Predation, Herbivory, and Intraspecific Competition.

Read below for answers.

Top row: The first gap is parasitism, the middle one is pathogenicity, and the last one is predation.

Middle row: The first gap is mutualism, the middle one is herbivory, and the last one is intraspecific competition.

The third row is interspecific competition.

Try the activity below to compare and contrast various interspecific interactions.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Research skills — Comparing, contrasting and validating information
- **Time required to complete activity**: 10 minutes
- **Activity type:** Pair/group activity

In pairs or small groups, create a Venn diagram to compare and contrast one of the following sets of interactions:

- Parasitism and pathogenicity
- Parasitism and predation
- Mutualism and cooperation
- Herbivory and predation
- Interspecific and intraspecific competition

5 section questions

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

Invasive species

Learning outcomes

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

- Evaluate the impact of invasive species on endemic species.
- Outline the role of human activities in the introduction and spread of invasive species.
- Assess the presence of interspecific competition using different testing methods.

Humans have played a significant role in introducing species to new environments. While some introductions have been successful and beneficial, others have resulted in the emergence of invasive species. For instance, consider the case of potatoes, which were brought to Europe by Spanish Conquistadors from Peru. This introduction allowed Europeans to savour delicious potato-based meals. However, not all introductions yield positive outcomes. Certain species become invasive, rapidly spreading and causing harm to native ecosystems. What sets these invasive species apart? What factors contribute to their ability to establish and dominate new habitats? This section will delve into the factors that distinguish invasive species from non-invasive ones.

Competition between endemic and invasive species

The presence and introduction of invasive species poses a significant threat for the balance of ecosystems worldwide. Unlike native species that have evolved and adapted to specific regions, invasive species are introduced to new environments where conditions are favourable for them to rapidly establish and spread. Due to their highly efficient use of resources, invasive species can lead to the rapid decline and even extinction of endemic species. This competitive advantage is based on the principle of competitive exclusion, which is further described in section B4.2.12–13 (/study/app/bio/sid-422-cid-755105/book/competitive-exclusion-id-46396/).

Video 1 outlines the distinction between native species, non-native species, invasive species and pests.

Video 1. Understanding species: native, non-native, invasive and pest.

Concept

An invasive species, also known as an alien or non-native species, refers to any plant, animal or microorganism that is introduced to an ecosystem outside its native range and has the potential to cause harm. While not all introduced species become invasive, invasive species lack natural predators and competitors in their new environment, allowing them to rapidly spread and harm native biodiversity.

Human activities play a significant role in the introduction and spread of invasive species. Trade, transportation and intentional or accidental releases, and other human behaviours contribute to the introduction of non-native species into new habitats. Once established, these species can have detrimental impacts on native biodiversity, causing them to become invasive. This often requires the implementation of challenging and expensive management strategies to mitigate their effects.

One example of an invasive species is *Caulerpa taxifolia*, commonly known as killer algae (**Figure 1**). Originally native to the tropical waters of the Indian Ocean, the introduction of this seaweed species into the Mediterranean Sea has had devastating consequences. Killer algae secrete a toxin that deters molluscs, herbivorous fish and sea urchins, and it lacks natural predators outside its native range.

In its new habitat, *C. taxifolia* competes with native marine plants, such as *Posidonia oceanica* (commonly known as Neptune grass) and *Cymodocea nodosa* (commonly known as narrow-leaved seagrass), forming dense mats that smother and displace these native species. Its rapid growth, coupled by the absence of predators, allows it to spread unchecked, causing declines in native biodiversity and threatening the ecological integrity of affected areas.

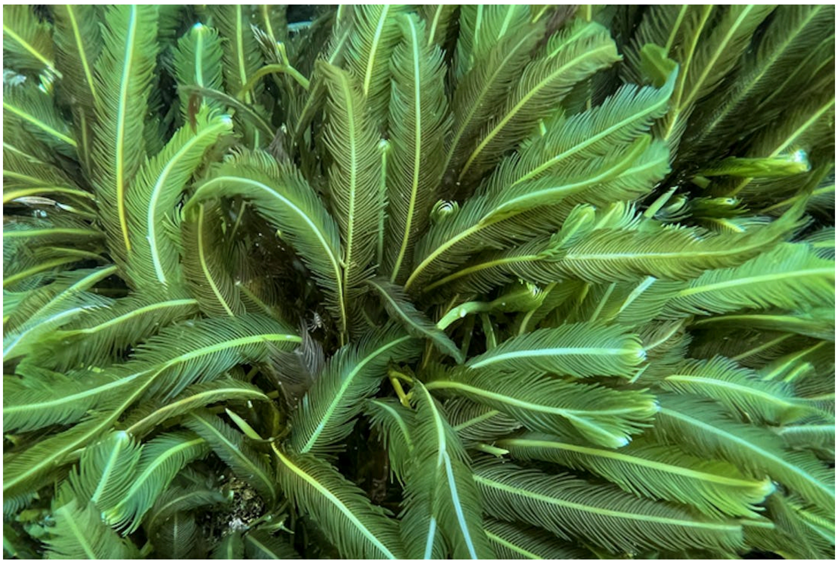


Figure 1. The killer algae *Caulerpa taxifolia.*

Credit: DigiPub, Getty Images

Testing for interspecific competition

To investigate competition between species, researchers employ various testing methods to gather evidence and explore potential interactions. Laboratory experiments provide controlled conditions where variables can be manipulated to observe their effects on species' success. Field observations, conducted through random sampling, allow researchers to gather data on species abundance and distribution, offering insights into potential competition.

One approach to assessing the impact of a species involves selectively removing it from the community. By removing a particular species, researchers can closely observe the responses of remaining organisms, shedding some light on the impact of competition on their distribution and overall success. While the success of certain species in the absence of another may indicate interspecific competition, it is important to note that this correlation does not provide definitive proof. Nevertheless, by observing patterns and changes in community dynamics after removal, scientists can gather evidence and make inferences about the potential role of competition in shaping distribution and success of the species within the community.

In 1966, Robert Paine conducted a scientific experiment (see **Video 2**), where the removal of starfish from their environment allowed for the tracking of responses among the remaining species in the community structure.

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Video 2. Removing starfish unveiled the dynamics of a coastal ecosystem.

Nature of Science

Aspect: Hypotheses

Experiments and observations are important tools for testing hypotheses and building scientific knowledge.

Experiments involve deliberately manipulating variables in a controlled setting to analyse the effects on the system being studied. By conducting experiments, scientists can establish cause-and-effect relationships and gather quantitative data to support or reject their hypotheses. Observations, on the other hand, involve gathering data by systematically recording and analysing natural phenomena or events in their existing environment. Field observations, such as observing the absence or presence of species in different habitats, allow researchers to gather qualitative or quantitative data to support or generate hypotheses.

Understanding the difference between experiments and observations is crucial. Experiments involve controlled conditions and deliberate manipulation of variables, whereas observations rely on natural settings and the collection of data as it naturally occurs.

Try the following research activity to learn more about invasive species.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills — Using search engines and libraries effectively
- **Time required to complete activity:** 30 minutes
- **Activity type:** Pair/group activity

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In pairs or small groups, investigate a specific example of an invasive species and prepare a 2-minute persuasive argument for why their species is harmful to the ecosystem and why it should be eradicated. In your argument, be sure to include the direct effects of such species on another species and indirect effects on the entire ecosystem.

Some examples of species that could be researched include the Asian carp and the zebra mussel (*Dreissena polymorpha*) in the Great Lakes, the Burmese python (*Python bivittatus*) in the Florida Everglades, lionfish in the Caribbean or Japanese knotweed (*Reynoutria japonica*) in the UK.

5 section questions

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

The chi-squared test

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

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Learning outcomes

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

- Apply the chi-squared test to determine an association between species.
- Interpret the results of a chi-squared test to generate accurate conclusions.
- Evaluate the validity of the chi-squared test as a statistical method for analysing associations between species.

In the field of community ecology, observations alone may not be sufficient to establish that an observed association between two species is significant. Once ecologists collect data from both populations, how can they confidently determine that this association is not occurring by chance? How do scientists distinguish between a true relationship and a random occurrence? The chi-squared test is a tool that can help us assess the significance of such observed associations.

The chi-squared test for association

The chi-squared test (x^2) is a statistical analysis used to determine whether there is a significant association between two categorical variables. In the context of community ecology, this test can help scientists determine whether there is an association between the presence of two species. Often referred to as the test of independence, it analyses whether the relationship between two species occurs due to chance. This test is also employed in other areas of biology, such as the chi-squared goodness of fit test, which is further discussed in section D3.2.18–21 (:sectionlink:141455).

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Data for conducting the test of independence can be obtained through quadrat sampling. When two species are significantly associated with each other, they tend to be found within the same quadrats, indicating a positive association. Conversely, a negative association occurs when species are less likely to be found together in the same quadrats. Negative associations often arise due to competition for the same limited resources. These associations can be attributed to mechanisms such as competitive exclusion or resource partitioning, as described in section B4.2.12–13 (/study/app/bio/sid-422-cid-755105/book/competitive-exclusion-id-46396/).

When performing a chi-squared test, two possible hypotheses must be established:

- The null hypothesis (H_0): The distribution of species X and Y is not associated.
- The alternative hypothesis (H_A): The distribution of species X and Y is associated (either positively or negatively associated).

The chi-squared test compares the observed quadrat sample values to expected values (assuming species are not associated) to establish whether there is a significant association. This test is only valid if all the expected frequencies are five or larger and the sample was taken at random from the population.

Method for chi-squared test

To examine an association between species X and Y, the following steps should be followed:

Step 1

Construct a contingency table and input the observed values to summarise the observed frequencies of species X and Y. This table should have two columns representing the presence or absence of species X, and two rows representing the presence or absence of species Y. Each cell in the table will display the number of quadrats falling into a specific combination of X and Y categories (**Table 1**).

Table 1. Contingency table of observed values.

	Species X present	Species X absent	Total
Species Y present			
Species Y absent			
Total			

Fill in the table with the observed frequencies corresponding to the counts of the obtained data. Determine the totals for each row and column in the contingency table. Add up the frequencies for each level of species X and Y separately. The sum of the row totals and column totals should be equal and should match the grand total displayed in the lower right cell of the table.

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Step 2

Calculate each of the expected frequencies assuming independent distribution between species X and Y. Expected frequencies are obtained from the values on the contingency table using the following equation:

$$\text{expected frequency} = \frac{\text{row total} \times \text{column total}}{\text{grand total}}$$

Expected frequencies can be organised in a contingency table of expected values.

Step 3

Calculate the number of degrees of freedom from the equation below:

$$\text{degrees of freedom} = (m - 1)(n - 1)$$

where:

m = number of rows in the contingency table
n = number of columns in the contingency table

The degrees of freedom indicate the number of independent pieces of information available for the analysis and play a crucial role in interpreting the chi-squared test results. When testing for an association between two different species, the degrees of freedom must always be 1.

Step 4

Determine the critical region for the chi-squared test by referring to a table of chi-squared values (**Table 2**). Use the degrees of freedom that were calculated earlier and select a significance level (p) of 0.05 (5%). The critical region consists of any chi-squared value that exceeds the corresponding value from the table.

Table 2. Chi-squared distribution table.

Degrees of freedom	Probability									
	0.95	**0.90**	**0.80**	**0.70**	**0.50**	**0.30**	**0.20**	**0.10**	**0.05**	**0.01**
1	0.004	0.02	0.06	0.15	0.46	1.07	1.64	2.71	**3.84**	6.64
2	0.10	0.21	0.45	0.71	1.39	2.41	3.22	4.60	5.99	9.21
3	0.35	0.58	1.01	1.42	2.37	3.66	4.64	6.25	7.82	11.34

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4	0.71	1.06	1.65	2.20	3.36	4.88	5.99	7.78	9.49	13.28
5	1.14	1.61	2.34	3.00	4.35	6.06	7.29	9.24	11.07	15.09
6	1.63	2.20	3.07	3.83	5.35	7.23	8.56	10.64	12.59	16.81
7	2.17	2.83	3.82	4.67	6.35	8.38	9.80	12.02	14.07	18.48
8	2.73	3.49	4.59	5.53	7.34	9.52	11.03	13.36	15.51	20.09
9	3.32	4.17	5.38	6.39	8.34	10.66	12.24	14.68	16.92	21.67
10	3.94	4.86	6.18	7.27	9.34	11.78	13.44	15.99	18.31	23.21
	Nonsignificant								**Significant**	

Step 5

Calculate the chi-squared statistic by using the following equation, which you need to know:

$$X^2 = \Sigma \frac{(O - E)^2}{E}$$

where

O = observed frequency
E = expected frequency
Σ = the sum of

Step 6

Interpret your results: Compare the calculated chi-squared value with the critical region obtained from the chi-squared table.

- If the calculated chi-squared value **exceeds the critical value**, there is evidence at the 5% significance level to support the presence of an association between the two species. This means that **the null hypothesis can be rejected with 95% confidence**, suggesting that the observed association is unlikely to have occurred by chance alone.
- If the calculated chi-squared value is **equal to or below the critical value**, it suggests that **there is insufficient evidence at the 5% significance level to reject the null hypothesis.** In such cases, no significant association between the two species is detected.

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Worked example 1

The presence or absence of two species of coral, A and B, was recorded in 60 quadrats (1 m^2) on a coral reef.

Two hypotheses were established:

- H_0 = There is no significant association between the distribution of coral species A and B.
- H_A = There is a significant association between species of coral A and B.

1. Construct a contingency table to summarise the observed frequencies of coral species A and B.

Observed frequencies

	Coral A present	Coral A absent	Total
Coral B present	28	12	40
Coral B absent	4	16	20
Total	32	28	60

2. Calculate the expected frequencies.

$$\text{Expected frequency} = \frac{\text{row total} \times \text{column total}}{\text{grand total}}$$

Expected frequencies

	Coral A present	Coral A absent	Total
Coral B present	$= \frac{(32\times40)}{60} = 21.3$	$= \frac{(28\times40)}{60} = 18.7$	40
Coral B absent	$= \frac{(32\times20)}{60} = 10.7$	$= \frac{(28\times20)}{60} = 9.3$	20
Total	32	28	60

3. Obtain the number of degrees of freedom (df). In this case, the degrees of freedom would be:

$$df = (\text{number of of rows} - 1)\ (\text{number of columns} - 1) \qquad df = (2-1) \times (2$$

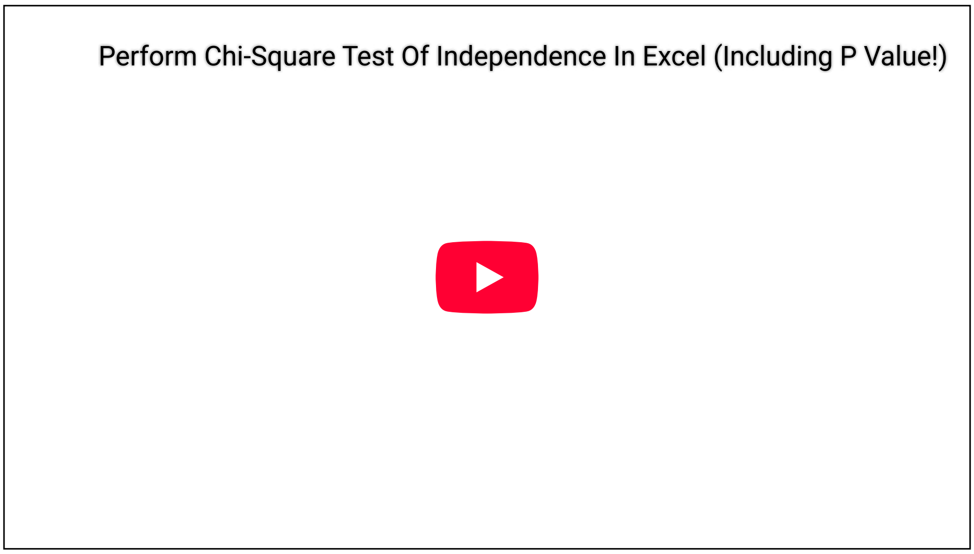
Student view

4. Determine the critical region. Consult a chi-squared table with 1 degree of freedom and a significance level (α) of 0.05.
   The critical value is shown to be **3.84**.
5. Calculate the chi-squared statistic.

$$X^2 = \Sigma\frac{(O-E)^2}{E} \qquad X^2 = \frac{(28-21.3)^2}{21.3} + \frac{(12-18.7)^2}{18.7} + \frac{(4-10.7)^2}{10.7} + \frac{(16 -}{9.}$$

6. Compare the calculated chi-squared value with the critical region. In this case, our chi-statistic of 13.5 is higher than the critical value of 3.84. This means that **we can reject the null hypothesis and conclude that there is a significant association between the presence of coral species A and B.**

Video 1 showcases a demonstration of calculating the chi-squared test of association using a spreadsheet program.



Video 1. Step-by-step guide for calculating the chi-squared test of independence using MS Excel.

Limitations of the chi-squared test

The chi-squared test of independence, like any statistical test, has some limitations that must be considered. One limitation is its sensitivity to sample size. For the expected frequencies to be accurately calculated, it is recommended to have sample sizes of at least 50 or larger. However, it is important to note that excessively large sample sizes can lead to trivial relationships erroneously appearing as statistically significant. Therefore, it is crucial to interpret the results of this test in the context of both the sample size and the practical significance of the observed relationship.

Another limitation is that the chi-squared test can establish a statistical association between two variables but cannot determine a causal relationship. To establish causation, additional studies and evidence are necessary to investigate the underlying mechanisms and factors driving the observed

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associations.

Furthermore, the chi-squared test assumes that the samples being compared are independently and randomly collected. However, in ecological studies where spatial or temporal dependencies exist, this assumption may not always hold true. Therefore, it is important to consider and account for these dependencies when interpreting the results.

Additionally, the chi-squared test does not account for other potential factors that might influence the results. Different conditions or environmental factors can affect the organisms being studied, sometimes leading to spurious associations.

Try the activity below in which you can apply your understanding of the chi-squared test of independence.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 15 minutes
- **Activity type:** Individual activity

You are studying an association between two species of flowering plants, the bell heather (*Erica cinerea*) and the common heather (*Calluna vulgaris*) in a heathland ecosystem. Your team conducted random quadrat sampling in different areas of the heathland and recorded the presence or absence of each species within the quadrats. Your dataset consists of a total of 100 quadrats, and the recorded observations are as follows:

- Bell heather present, common heather present = 30 quadrats
- Bell heather present, common heather absent = 20 quadrats
- Bell heather absent, common heather present = 15 quadrats
- Bell heather absent, common heather absent = 35 quadrats

Based on this data, determine whether there is a significant association between the bell heather and the common heather.

5 section questions

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

Student view

Control of populations

Learning outcomes

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

- Evaluate the influence of predator—prey interactions on population dynamics using real case studies.
- Discuss the implications of top-down and bottom-up control in population regulation within communities.
- Compare and contrast allelopathy and antibiotic secretion mechanisms of competitive advantage in different organisms.

We now have learned that ecosystems have a limited carrying capacity and consist of multiple interacting species within a community. This prompts us to wonder what factors influence the growth rate of each interacting population. What exactly determines the maximum size a population can reach? This section will explore a number of the factors that regulate population sizes.

Density-dependent control of populations

Population control in ecology refers to the regulation of the size and growth of populations within an ecosystem. It is a fundamental concept in maintaining ecological balance and preventing detrimental effects such as resource depletion and overexploitation. Various factors influence population control; however, predators play a crucial role in regulating prey populations by exerting selective pressure and preventing unchecked growth.

Predator–prey relationships are one example of how animal populations are regulated by density-dependent factors and negative feedback. As the predator population grows, their increased predation exerts pressure on the prey population, leading to a decline in prey numbers (**Figure 1**). With fewer prey available, the predator population experiences reduced food availability, which can eventually result in a decrease in their numbers. This dynamic interaction between predators and prey forms a fluctuating cycle of population regulation.

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Figure 1. A cheetah (*Acinonyx jubatus*, predator) preying on a gazelle (*Eudorcas thomsonii*, prey).

Credit: James Warwick, Getty Images

A well-studied example of a predator–prey relationship is the interaction between cheetahs (*A. jubatus*) and gazelles (*E thomsonii*). When the population of gazelles increases it provides a plentiful food source for cheetahs, leading to a rise in the cheetah population. However, as cheetah numbers grow, the increased predation pressure causes a decline in the gazelle population due to higher rates of predation. This reduction in gazelle numbers ultimately impacts the cheetah population as their food supply decreases (**Figure 2**). Such predator–prey dynamics are observed in diverse ecosystems worldwide and play a crucial role in maintaining the balance and stability of ecological communities.

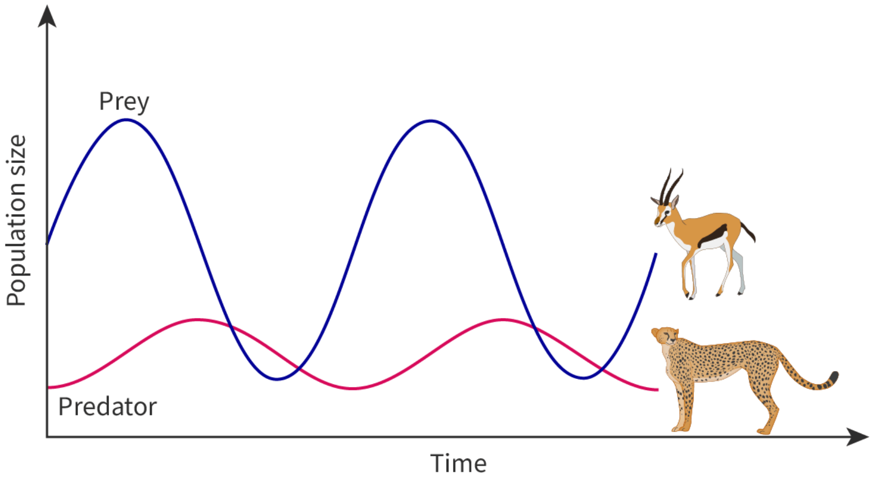

Figure 2. Predator—prey relationships as an example of density-dependent population control.

More information for figure 2

The graph illustrates predator-prey population dynamics over time. The X-axis represents time, while the Y-axis indicates population size. Two oscillating curves are depicted: a blue curve representing the prey population and a red curve for the predator population. The prey curve shows cyclical peaks and troughs with larger amplitude compared to the predator curve. As the prey population

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increases, the predator population subsequently rises. This leads to a decrease in prey numbers, eventually causing a downturn in predator population as well, forming a cyclical pattern. Illustrations of a gazelle (prey) and a cheetah (predator) are present near the respective curves to signify the species involved.

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Top-down and bottom-up control of populations

Understanding the control of populations within a community involves exploring the concepts of top-down and bottom-up control. These concepts highlight different mechanisms through which population dynamics can be influenced.

Top-down control occurs when the abundance or behaviour of lower trophic levels in a food chain is regulated by the presence and activities of organisms at higher trophic levels.

Predators, positioned at the top of the food chain, play a significant role in exerting top-down control. By consuming and limiting the abundance of their prey, predators indirectly shape the structure and dynamics of lower trophic levels.

An example of top-down control can be observed in the Yellowstone National Park ecosystem. The reintroduction of grey wolves (*Canis lupus*) in the mid-1990s had a profound impact on the ecosystem (**Figure 3**). As the wolf population increased, their predation on elk (*Cervus canadensis*) intensified, leading to a decrease in the elk population. With fewer elk browsing on vegetation, the growth of woody plants and saplings increased, leading to changes in the composition and structure of the plant community. This cascading effect demonstrates how the presence of predators at the top of the food chain can indirectly shape the abundance and behaviour of their prey, ultimately influencing the entire ecosystem. **Video 1** provides further details of the ecological cascade that occurred after the reintroduction of wolves to Yellowstone National Park.

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Video 1. The wolves of Yellowstone (*C. lupus*) as an example of top-down control of populations.

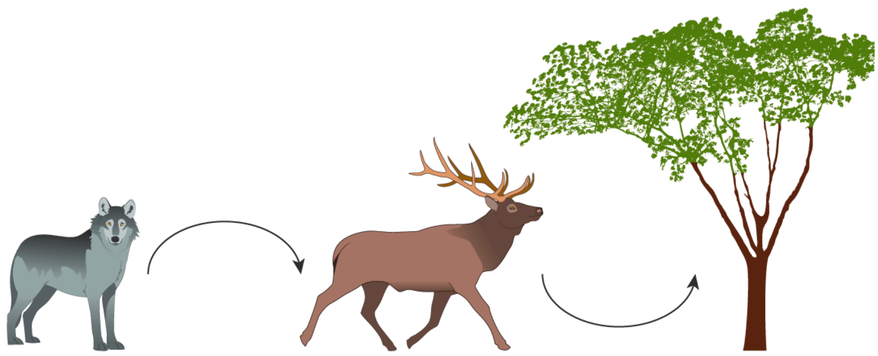

Figure 3. Grey wolves (*C. lupus*) exert top-down control in Yellowstone National Park.

More information for figure 3

The image is a diagram depicting the ecological impact of grey wolves in Yellowstone National Park. It illustrates the top-down control exerted by wolves on the ecosystem. The diagram shows three main components with arrows indicating the flow of influence. On the left, there is a grey wolf labeled "More wolves." An arrow points from the wolf to an elk in the center labeled "Less elk," showing the predatory relationship. Another arrow extends from the elk to a tree on the right labeled "More plants." This demonstrates how the reduction in elk numbers due to wolf predation allows for more plant growth, as there are fewer elk to consume the vegetation. The circular flow of these elements visually communicates the ecological cascade effect triggered by the presence of wolves in the park.

[Generated by AI]

Bottom-up control occurs when the availability of resources at lower trophic levels influences the abundance and distribution of organisms at higher trophic levels. Factors such as nutrient availability, climatic conditions and primary productivity are factors that can exert bottom-up control. For example, in a terrestrial ecosystem, the availability of soil nutrients can determine the growth and productivity of plants. The abundance of plants, in turn, influences the abundance of herbivores that rely on them for food. This cascading effect can further affect the populations of predators that depend on herbivores as their prey (**Figure 4**).

Understanding both top-down and bottom-up control is crucial for studying the dynamics of populations within ecological communities. These controls can operate simultaneously or dominate in different ecosystems, shaping the interactions and population sizes of organisms at various trophic levels.

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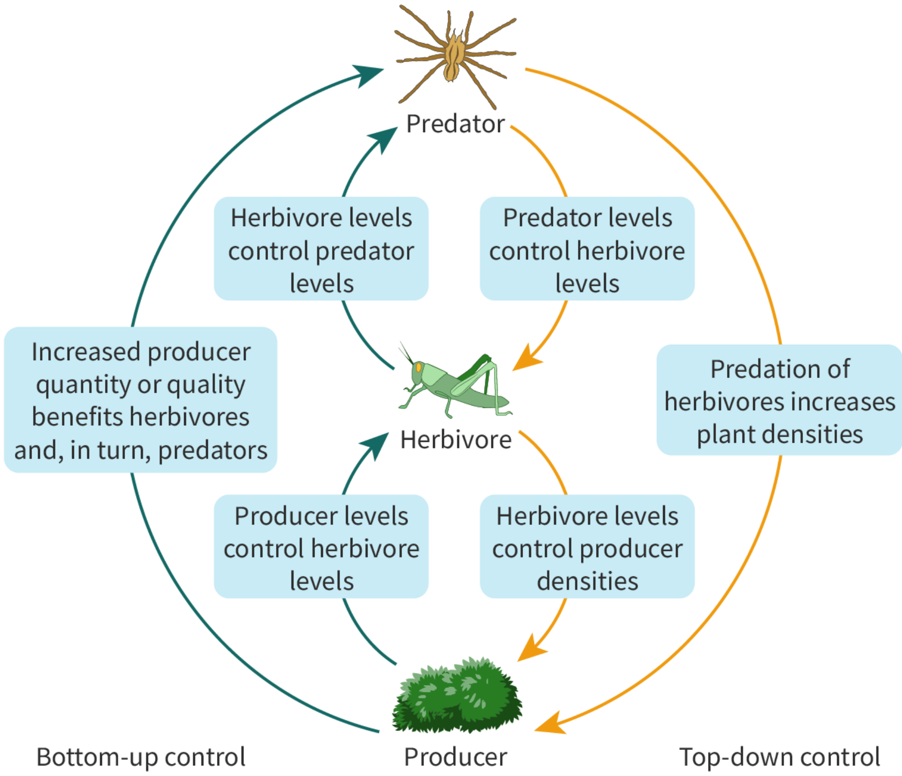

Figure 4. Bottom-up control versus top-down control of populations.

More information for figure 4

The image is a diagram that shows the interactions between producers, herbivores, and predators within an ecosystem, illustrating the concepts of bottom-up and top-down control. The diagram is circular, with arrows forming two interconnected loops.

- The bottom-up control is represented by a blue arrow loop starting at the producer, which is illustrated as plants at the bottom of the circle. The text says "Increased producer quantity or quality benefits herbivores and, in turn, predators." Arrows point upward to a grasshopper labeled as "Herbivore," with a text box stating "Producer levels control herbivore levels." Another arrow points from the herbivore to the top of the circle labeled "Predator," depicted by a spider, accompanied by the text "Herbivore levels control predator levels."

- The top-down control is represented by an orange arrow loop starting from the predator and moving down to the herbivore, where the text says "Predator levels control herbivore levels." An arrow points from the herbivore down to the producer with a text box stating "Herbivore levels control producer densities." At the producer level, a text box states "Predation of herbivores increases plant densities."

This diagram highlights the cyclical nature of ecological controls, showing how changes in population sizes at one trophic level affect other levels.

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Allelopathy and antibiotic secretion

Allelopathy and antibiotic secretion are two processes in which organisms release chemical substances into their environment to deter potential competitors. These chemical interactions can help shape the dynamics of an ecosystem and have important implications in both natural ecosystems and medical applications.

One example of allelopathy is observed in the black walnut tree (*Juglans nigra*). This tree releases a chemical compound called juglone into the soil, which acts as a potent inhibitor, suppressing the growth of nearby plants (**Figure 5**). Juglone inhibits key physiological processes in competing plants, such as root development and photosynthesis, effectively creating a zone of reduced plant diversity around the black walnut tree.

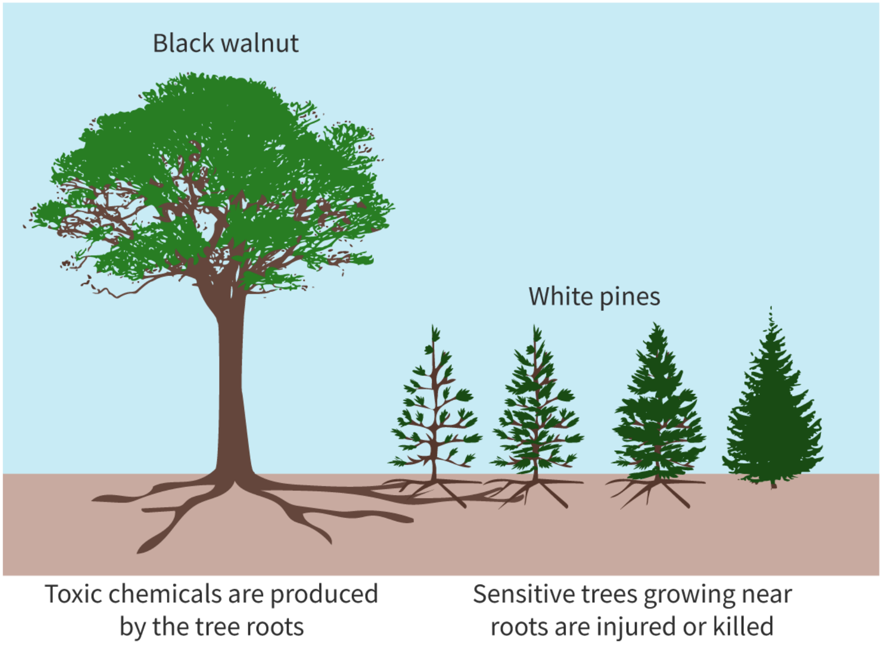

Figure 5. Juglone inhibits the growth of nearby competitors.

More information for figure 5

The image is an illustration showing a black walnut tree on the left and several smaller white pines on the right. The black walnut is labeled at the top, and its roots are visibly extending into the soil. Below the tree, the text reads: "Toxic chemicals are produced by the tree roots." To the right of the black walnut, three white pines are labeled, getting progressively smaller and weaker in appearance as they are closer to the black walnut. Underneath the white pines, the text reads: "Sensitive trees growing near roots are injured or killed." The image illustrates the impact of allelopathy, where the black walnut tree releases chemicals that inhibit the growth of nearby plants like white pines.

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When it comes to microorganisms, the secretion of antibiotics is a process that can hinder the growth of other bacteria. *Streptomyces* bacteria, commonly found in soil and marine environments, have the ability to synthesise a wide range of antibiotics, including streptomycin. This antibiotic secretion acts as a defence mechanism, granting *Streptomyces* with a competitive advantage. Streptomycin, in particular, has gained significant recognition in the field of medicine for its effectiveness in treating diverse bacterial infections.

Both allelopathy and antibiotic secretion involve the release of chemical compounds that serve as weapons against competitors. The study of allelopathy and antibiotic secretion sheds light on the dynamics of competition and coexistence, and their exploration continues to be an active area of research in ecology and medicine.

Try the activity below to model predator–prey relationships.

Activity

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

In this activity you will be working with a partner to model predator—prey interactions using paper squares.

Materials

- Masking tape
- 200 small-sized paper or cardboard squares (approximately 2 cm × 2 cm)
- 50 medium-sized paper or cardboard squares (approximately 6 cm × 6 cm)
- Writing utensils.

Instructions

1. Begin by creating a square with masking tape on a table or on the ground, measuring 30 cm by 30 cm. This square represents the habitat where owls and mice live. The smaller paper squares will represent the prey (mice), while the larger squares will represent the predator (owls).
2. With your partner, decide who will be playing the predator and who will be playing the prey.
3. The player acting as the mice will randomly toss three small squares into the habitat. Record the number 3 in the column labelled ‘Number of prey’ for generation 1 in a data table like **Table 1.**
4. The player acting as the owl will hold the large paper square 30 cm above the habitat and toss it onto a random spot within the area.
    - *If the large square touches one or more of the small squares*, it means the owl has caught and eaten one or more mice. Remove the eaten mice from the habitat, and

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update the number of remaining prey (small squares) in the ‘Prey remaining’ column, and write 1 in the ‘Predators remaining’ column.

- *If the large square does not touch any mice*, it means the owl failed to catch any prey. In this case, the predator has not eaten and will die. Remove the large square from the community and write 3 under ‘Prey remaining’, and write 0 under ‘Predators remaining’.

5. The number of mice doubles in each generation. Multiply the number of remaining small paper squares by 2 and write that number under ‘Number of prey’ for generation 2. Toss enough mice into the habitat to match that number.
   - *If the predator died*: for the purposes of this activity, assume that if a predator dies, a new predator will take its place. If this is the case, add one large square (representing a new predator) to the habitat. Write 1 under ‘Number of predators’ for generation 2 in the data table.
   - *If the predator survived:* The number of remaining owls doubles each generation. If the predator survived, add another large square to the habitat and write 2 under ‘Number of predators’ for generation 2.
6. Repeat steps 4—5 for a total of 10 generations. Keep track of the number of prey and predators for each generation in **Table 1**. If two predators happen to catch the same prey, only one predator can survive.

Table 1. Predator—prey model of owls and mice.

Generation	Number of prey	Number of predators	Prey remaining	Predator remaining
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Questions

1. Why is the initial ratio of 3 mice to 1 owl appropriate for starting the activity?
2. At which stage of the activity did the predator-to-prey ratio undergo a change?

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3. Discuss the reasons why populations of predators and their primary prey often show predictable cycles of increase and decrease.
4. If a sudden outbreak of disease resulted in the death of most mice in the community, what would be the expected impact on the owl population?
5. Describe additional community-level effects that would probably occur if the mouse population were to disappear.

Extension

To further analyse the dynamics of mice and owl populations, create a graph showing the changes in predator and prey over time.

1. Set up a graph with time (generations) on the *x*-axis and the number of predators and prey on the *y*-axis.
2. Mark the initial ratio of 3 mice to 1 owl on the graph using data points. Be sure to use different colours for predator and prey.
3. Plot the numbers for each subsequent generation.
4. Connect the data points with a line to show the trend of population changes over time.
5. Label the graph appropriately with a descriptive title, axes labels and legends to make it clear and easy to interpret.

5 section questions

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

Summary and key terms

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/summary-and-key-terms-id-46393/print/) Assign

- Population sizes can be estimated using random sampling techniques. Different methods are used to estimate population sizes for sessile and motile organisms.
- Carrying capacity refers to the maximum population size an environment can sustain.
- Factors that influence the sizes of populations are known as population limiting factors. Density-dependent factors are influenced by population density, while density-independent factors are not.
- Exponential growth of a population occurs in an environment with unlimited resources and a lack of competition, whereas sigmoidal growth occurs when competition for limited resources restricts population growth rate.
- Competition and cooperation can occur within a species and affect population growth and survival.
- Interactions between species include mutualism, parasitism, pathogenicity, competition, predation and herbivory.
- Invasive species can disrupt native populations and ecosystems.
- The chi-square analysis can be used to determine whether there is an association between two different species.
- Control of populations involves top-down and bottom-up control mechanisms.

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- Allelopathy and antibiotic secretion are processes where chemical substances are released to deter competitors.

Key terms

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

1. refers to the number of individuals per unit area or volume in a population.
2. The maximum population size that an environment can sustain, known as , depends on available resources.
3. Density- factors are influenced by population density, whereas density- factors are not.
4. Interactions between different species, such as competition and parasitism, are called .
5. is an example of a positive interaction between different species, where both parties benefit.
6. growth occurs when resources are unlimited, leading to a rapid increase in population size. On the other hand, growth occurs when limited resources increase competition between individuals.
7. is a process in which a plant releases chemical substances to inhibit the growth of neighbouring plants.
8. Introduction of an species can have detrimental effects on native populations and ecosystems.

Exponential | Population density | dependent | Mutualism | sigmoid | interspecific | invasive | carrying capacity | Allelopathy | independent

Check

Interactive 1. Key Terms Related to Ecology.

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

Checklist

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What you should know

After studying this subtopic you should be able to:

- Define the term population.
- Outline reasons for estimating population samples.
- Analyse and explain the importance of using random sampling techniques in ecological studies.
- Outline how quadrat sampling is used to estimate the population size for sessile organisms.
- Outline how the capture-mark-release-recapture method and the Lincoln index are implemented to estimate the population size of a motile species.
- Define carrying capacity and explain why population growth slows down as the carrying capacity is reached.
- Distinguish between density-dependent and density-independent limiting factors.
- Compare and contrast exponential and sigmoidal population growth models.
- Evaluate the use of models as representations of natural phenomena.
- Describe the impact of intraspecific competition and cooperation on the survival and reproduction of a population.
- Define communities as diverse collections of populations that interact and contribute to the functioning of ecosystems.
- Distinguish between multiple interspecific interactions.
- Discuss the ecological significance of interactions between species.
- Outline examples of herbivory, predation, competition, parasitism, pathogenicity and mutualism.
- Evaluate the impact of invasive species on endemic species.
- Outline the role of human activities in the introduction and spread of invasive species.
- Assess the presence of interspecific competition using different testing methods.
- Apply the chi-squared test to determine an association between species.
- Interpret the results of a chi-squared test to generate accurate conclusions.
- Evaluate the validity of the chi-squared test as a statistical method for analysing associations between categorical variables.
- Evaluate the influence of predator—prey interactions on population dynamics using real case studies.
- Discuss the implications of top-down and bottom-up control in population regulation within communities.
- Compare and contrast allelopathy and antibiotic secretion mechanisms of competitive advantage in different organisms.

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Practical skills

Once you have completed this subtopic, go to Practical 7: Measuring percentage cover to assess the distribution and abundance of plants in a habitat (/study/app/bio/sid-422-cid-755105/book/measuring-percentage-cover-id-46706/) in which you will use a quadrat to systematically sample for a sessile organism.

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

Investigation

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/investigation-id-46395/print/) Assign

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills – Designing procedures and models
- **Time required to complete activity:** 2 hours
- **Activity type:** Individual/pair activity

Your task

In this activity, you will focus on experimental design by planning an investigation to study the interactions between populations within a community and how these interactions regulate population sizes. Although you will not carry out the actual experiment, you will develop a detailed plan outlining the steps, variables and controls necessary to investigate the guiding questions of this subtopic. This activity will enhance your skills in experimental design and critical thinking.

Design an experiment to explore the interactions between two populations of your choice. If possible, find a local example to study. Your goal is to examine how this interaction influences population sizes. Follow the steps below to develop your experimental design:

1. **Research and background information:** Select two species that interact in a specific way, such as predator–prey, mutualistic or competitive interactions. Conduct research on these species to understand their characteristics, habitat requirements and the nature of their interaction.
2. **Hypothesis:** Formulate a hypothesis that predicts how the interactions between the chosen species will affect their population sizes. Consider the specific variables and factors that may influence the outcomes of the experiment.
3. **Variables and controls:** Identify the independent, dependent and control variables for your experiment. Determine how you will measure and manipulate these variables to accurately test your hypothesis. Consider including any necessary control groups to ensure accurate results.
4. **Experimental setup:** Design the experimental setup, including the materials and apparatus required. Consider the space, time and resources needed for the experiment. Think about any ethical

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considerations or safety precautions that should be taken.

5. **Data collection and analysis:** Outline the methods and procedures for collecting data during the experiment. Specify the types of data to be collected and the measurement techniques to be used. Consider the sample size, replicates and duration of the experiment. Discuss how the collected data will be analysed to draw conclusions.
6. **Expected results and interpretation:** Predict the expected results based on your hypothesis. Consider the possible outcomes and how they would support or refute your hypothesis. Discuss the potential sources of error or limitations in your experimental design.
7. **Conclusion and further considerations:** Summarise the main findings and conclusions you anticipate based on your experimental design. Reflect on the limitations of your investigation and suggest modifications of improvements for future experiments. Consider any ethical implications or real-life applications of your research.

Remember to document your experimental design clearly, providing sufficient details and justifications for each step. Discuss your plan with your classmates and instructor to gather feedback and refine your approach.

C4. Interaction and interdependence: Ecosystems / C4.1 Populations and communities

Reflection

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/reflection-id-46888/print/) Assign

Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

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

Reflection

Now that you've completed this subtopic, let's come back to the guiding question introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43544/).

- How do interactions between organisms regulate sizes of populations in a community?
- What interactions within a community make its populations interdependent?

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

You can use the following questions to guide you:

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

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

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Submit

Rate subtopic C4.1 Populations and communities

Help us improve the content and user experience.

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