Option C

14 Ecology and conservation

14.1 Species and communities

Essential idea: Community structure is an emergent property of an ecosystem.

Limiting factors

- **Biotic limiting factors**: include interactions between organisms, such as competition or predation
- **Abiotic** limiting factors: include physical components of the environment, such as temperature, salinity, pH, oxygen, carbon dioxide, light, hydrostatic pressure, water current, wind velocity, substratum type, rainfall amount, and humidity.

Animals and plants are affected by similar limiting factors (usually biotic ones such as competition) and also ones they do not have in common (usually abiotic ones).

- Limiting factors in plants include light, water, nutrients, carbon dioxide, and temperature.
- In animals, limiting factors include food, space, mates, and water.

Zones of stress and limits to tolerance

NATURE OF SCIENCE

Use models as representations of the real world – zones of stress and limits of tolerance graphs are models of the real world that have predictive power and explain community structure.

The law of tolerance states that an organism or population has certain minimum, maximum, and optimum environmental factors that determine success. These critical minimal and critical maximum limits are a species' limits of tolerance.

- The range of tolerance is the range between critical minimal and critical maximum limits of environmental factors affecting an organism.
- The distribution of a species can be plotted on a graph, which represents the frequency at which individuals of the species are found under a range of environmental factors.
- Graphs are usually shown as bell-shaped curves.

The graph showing limits of tolerance (Figure 14.1) can be divided into sections:

- Optimum zone of tolerance: the central portion, where conditions exist that favour maximum fitness, growth, abundance, and survival.
- Zones of stress: either side of the optimal zone, where fewer individuals occur and survival is lower. Organisms are unable to reproduce in zones of stress.
- Zones of intolerance: beyond the critical minimum and critical maximum limits of environmental factors. Organisms cannot occur here.

Key definitions

Limiting factors – something present in the environment in such short supply that it restricts life processes; it is a variable that restricts the rate of photosynthesis.

Biotic – the living part of an ecosystem (the community).

Abiotic – the non-living components of an ecosystem.

Key fact

The distribution of species is affected by limiting factors.

Key facts

The concept of tolerance suggests

- that there are levels of environmental factors beyond which a population cannot survive
- that there is an optimum range of these environmental factors within which species can exist and thrive.

Expert tip

Species distribution graphs are models that attempt to reflect the real world, although, without complete data for a given species, such models remain generalized representations of reality.

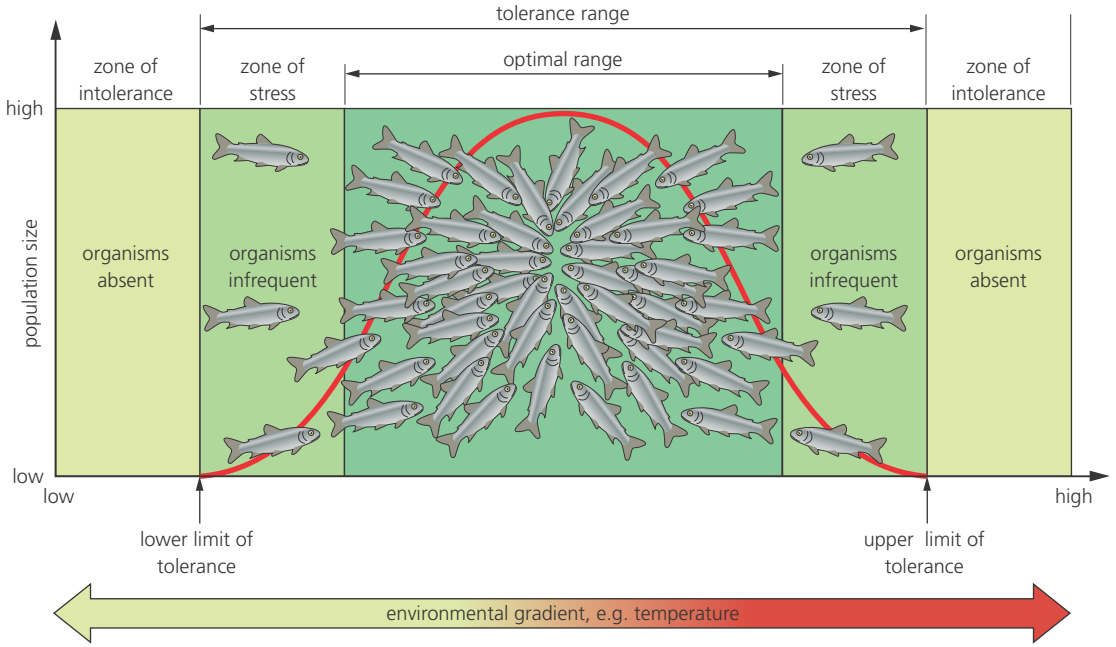


Figure 14.1 Graph showing zones of stress and limits of tolerance model

APPLICATIONS

Limits of tolerance of crop plants to salinity

Plants that can grow in soil or water of high salinity (high NaCl levels) are called halophytes. Plants that are not salt tolerant are called glycophytes; these are damaged fairly easily by high salinity.

- High concentrations of salts in the soil make it harder for roots to extract water, due to osmotic effects, and high concentrations of salts can be toxic within the plant.
- Relatively few plant species are halophytes – perhaps only 2% of all plant species. Most plant species are glycophytes.

Investigations have been carried out into salt tolerance for a variety of different plant species, including both wild and crop species. Species studied were:

- Cereal crop plants: rice (*Oryza sativa*), durum wheat (*Triticum turgidum* ssp. *durum*), and barley (*Hordeum vulgare*).
- Wild-growing plants: tall wheatgrass (*Thinopyrum ponticum*); arabidopsis (*Arabidopsis thaliana*), a small wild-growing cress plant, which was the first plant to have its genome sequenced (Topic 3, page 79; Option B, pages 76–77); alfalfa (*Medicago sativa*), a plant in the pea family; and saltbush (*Atriplex amnicola*), a plant endemic to the floodplains of Western Australia.

The results show that plants vary greatly in their tolerance of salinity, as reflected by their different amounts of growth (Figure 14.2).

- Of the cereals, rice is the most sensitive and barley the most tolerant.
- Tall wheatgrass is a halophytic relative of wheat and is one of the most tolerant of the species; its growth proceeds at concentrations of salt as high as in seawater.

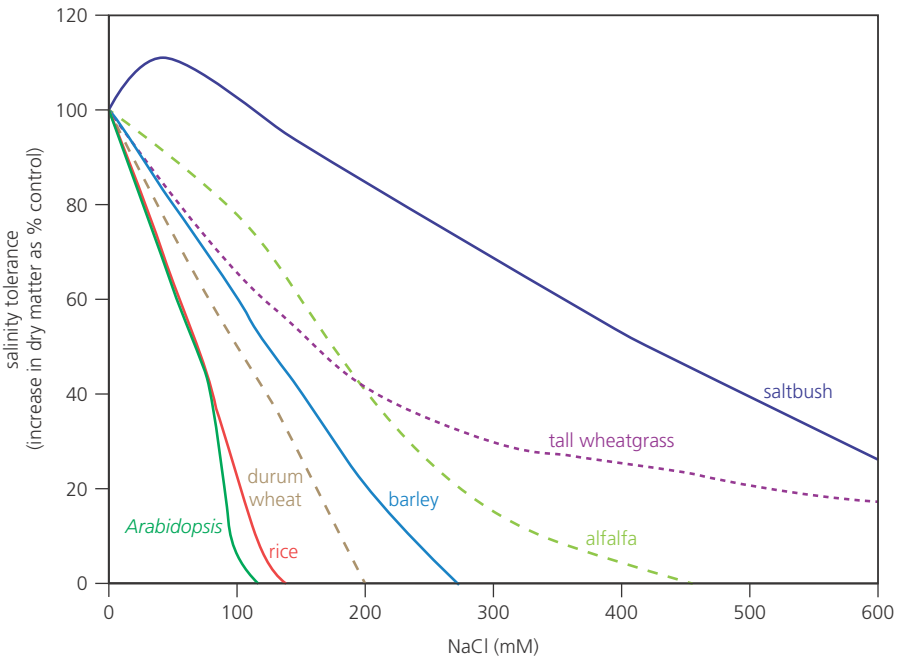


Figure 14.2 Response of a range of plant crop species to varying concentrations of NaCl after three weeks of treatment

- The variation in salinity tolerance in the other species is even greater than in the cereals. Alfalfa is very tolerant and halophytes, such as saltbush, continue to grow successfully at salinities greater than that of seawater.

A significant proportion of recently cultivated agricultural land has become saline due to land clearing or irrigation, both of which cause the water table to rise, concentrating salt in the root zone.

Expert tip

- Irrigated land has twice the productivity of land supported by rainfall and produces one-third of the world's food.
- Understanding the response of wild and crop plants to salinity offers the prospect of reducing the impact of salinity stress on plants, improving the performance of species that are important in agriculture.
  - Crossing tall wheatgrass with its domesticated relative, wheat, can give wheat traits such as stress tolerance to saline conditions.
  - Using knowledge of the genome of *Arabidopsis* (a salt-sensitive species) to compare it with more salt-tolerance species, such as its close relative *Thellungiella halophila* (saltwater cress), could give a more detailed understanding of the molecular basis of saline tolerance.

Correlating the distribution of animal species with an abiotic variable

Transects can be used to study the distribution of animals and plants along environmental gradients. Quadrats (page 124, this chapter) are used to sample plants, algae, and other immobile organisms along a transect. There are different types of transect:

- Line transects are made by placing a tape measure in the direction of the gradient. All organisms touching the tape are recorded.
- Belt transects are used to take larger samples; this is a band of chosen width, usually between 0.5 m and 1 m, placed along the gradient.
- Continuous transects are used if the whole transect is sampled. If samples are taken at points of equal distance along the gradient, it is called an interrupted transect.
- Horizontal distances are used if there is no visible vertical change in an interrupted transect, such as along a shingle ridge succession. If there is a climb or descent in an interrupted transect, then vertical distances are normally used, such as on a rocky shore.

Expert tip

You know need to know how to use a transect to correlate the distribution of plant or animal species with an abiotic variable.

Key definition

Transect – arbitrary line through a habitat, selected to sample the community.

The niche concept

Communities are made up of many interacting species. Each species plays a unique role within a community, because of the unique combination of its spatial habitat and interactions with other species. A complete description of a species' place within a community is known as its 'niche'.

- An organism's niche depends both on where it lives (its habitat) and its role in the environment.

- No two species have the same niche, because the niche completely defines a species.
- Species with overlapping niches will compete with each other (see page 86).

A niche describes the particular set of abiotic and biotic conditions and resources to which an organism or population responds.

The **fundamental niche** can be described as where and how an organism could live, and the **realized niche** as where and how an organism does live (Figure 14.3).

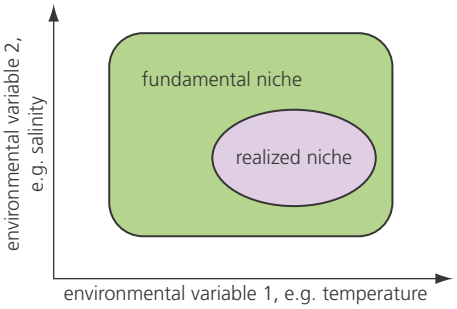


Figure 14.3 Fundamental and realized niches

Fundamental niche	Realized niche
defines the physical conditions under which a species might live, in the absence of interactions with other species	interactions such as competition, predation, disease, and parasitism may restrict the environments in which a species may live; these more restricted conditions are the realized niche
may not be fully occupied, due to the presence of competing species, the absence of required positive species interactions, or dispersal limitations	is defined by the presence of competing species, the absence of required positive species interactions, or dispersal limitations

Table 14.1 Comparing fundamental and realized niches

Investigating fundamental versus realized niche

Two species of barnacle can be used to investigate the difference between fundamental and realized niche.

- One species, *Semibalanus (Balanus) balanoides*, is most abundant on the middle and lower intertidal area of a rock shore
- Another species, *Chthamalus stellatus*, is most common on the upper intertidal area of the shore.

An experiment can be carried out to investigate the reasons why *Semibalanus* and *Chthamalus* do not grow together.

Experiment 1: *Chthamalus* is removed from the upper area of shore. Over time, no *Semibalanus* replaces it (Figure 14.4).

Conclusion:

- *Semibalanus* cannot survive in an area that regularly dried out and experienced desiccation due to low tides.
- *Semibalanus*' realized niche is the same as its fundamental niche.

Experiment 2:

Semibalanus is removed from the upper and middle areas. Over time *Chthamalus* replaces it in the middle intertidal zone, whereas there was little effect on the survival of *Chthamalus* in the upper intertidal zone (Figure 14.5).

Conclusion:

- *Semibalanus* is a more successful competitor in the middle intertidal zone and usually excluded *Chthamalus*, but does not compete with *Chthamalus* in the upper zone due to low population densities.
- The fundamental niche and realized niche for *Chthamalus* are not the same, and that the species' realized niche is smaller due to **interspecific competition** leading to **competitive exclusion**.

Key definitions

Fundamental niche – describes the full range of conditions and resources in which a species could survive and reproduce.

Realized niche – describes the actual conditions and resources in which a species exists due to biotic interactions.

Expert tip

You need to be able to analyse data that illustrate the distinction between fundamental and realized niche.

Key definitions

Interspecific competition – competition between two species.

Competitive exclusion – when one species outcompetes and excludes another, when their niches overlap.

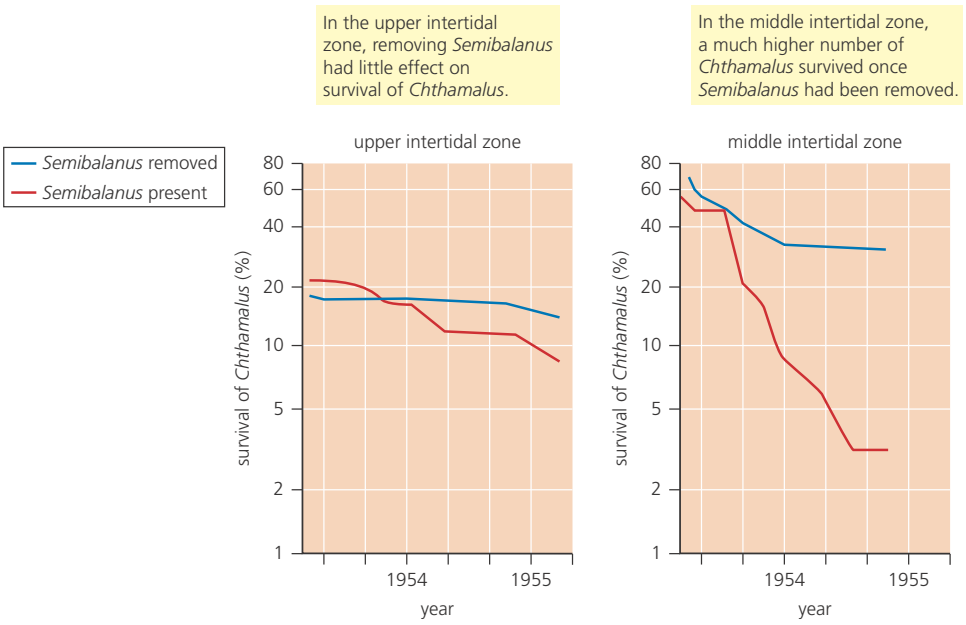
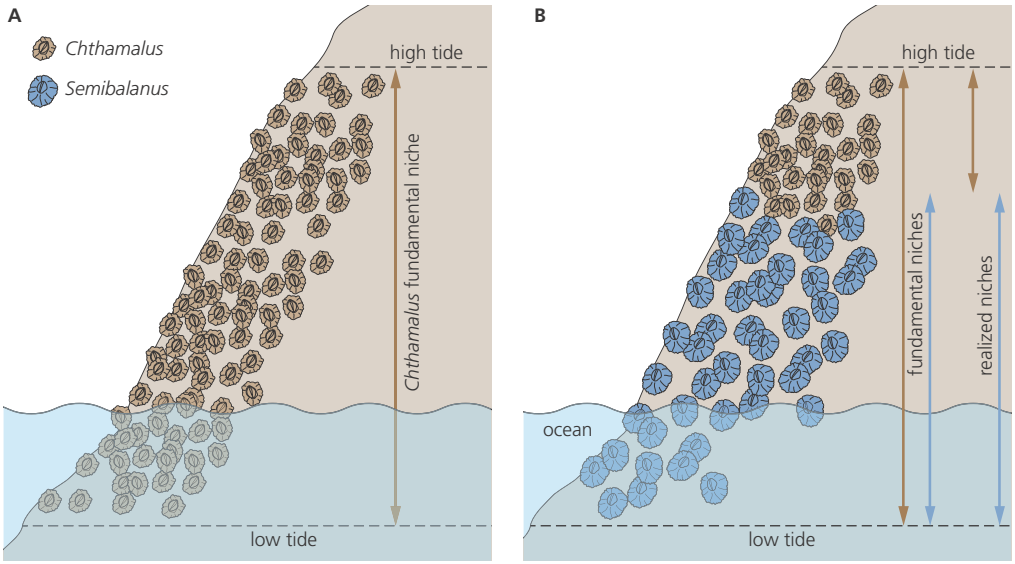


Figure 14.4 The effect of *Semibalanus* removal from the upper shore (left) and middle shore (right)



Semibalanus sp. (left hand photo), easily crowded out from more exposed positions on the shore, and *Chthamalus* sp. (right hand photo), able to withstand prolonged exposure and so can survive higher on rocky shorelines.





Figure 14.5 A. The results of a second experiment, where *Semibalanus* is removed from the upper and middle shore. B. Summary of the results from the two experiments: the fundamental and realized niche for both species of barnacle.

Competitive exclusion

Competition can be either within a species (**intraspecific competition**) or between different species (interspecific competition).

- Interspecific competition exists when the niches of different species overlap (Figure 14.6).
- No two species can occupy the same niche, so the degree to which niches overlap determines the degree of interspecific competition.

Key definition

Intraspecific competition – competition between individuals of the same species.

Key fact

Two species cannot survive indefinitely in the same habitat if their niches are identical.

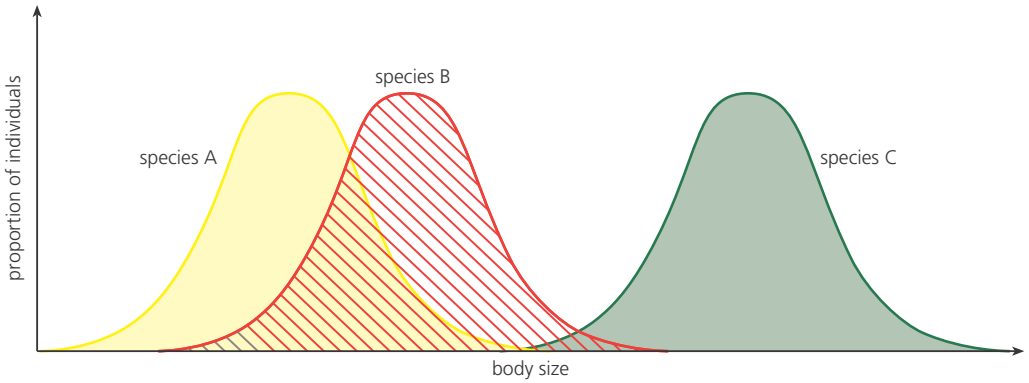
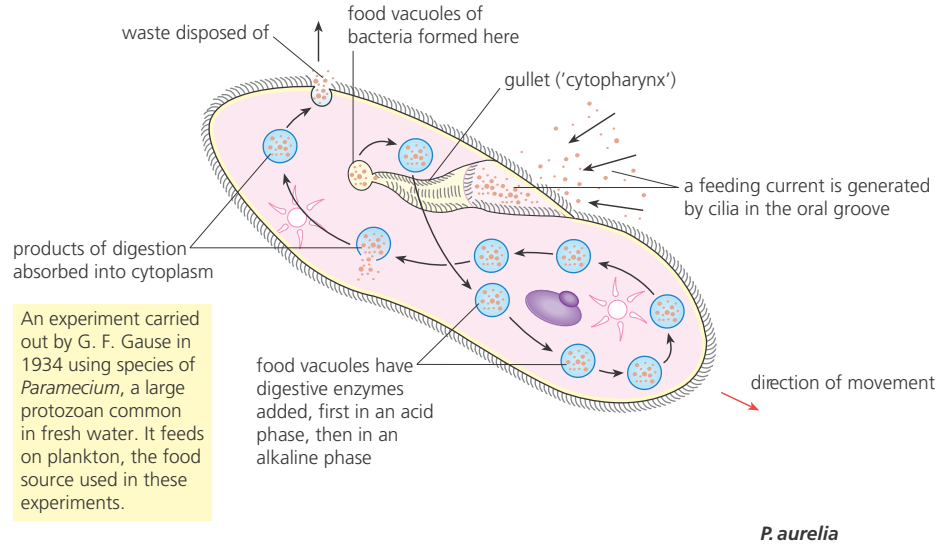


Figure 14.6 The niches of species A and species B, based on body size, overlap with each other to a greater extent than with species C. Strong interspecific competition will exist between species A and B but not with species C.

If two species share the same resource at the same place and the same time:

- the dominant species will outcompete the other
- the inferior competitor will either die out or move away to avoid the competition
- this is known as competitive exclusion (Figure 14.7)
- competitive exclusion can cause closely related species, living together in the same habitat, to evolve clearly defined but separate niches.



An experiment carried out by G. F. Gause in 1934 using species of *Paramecium*, a large protozoan common in fresh water. It feeds on plankton, the food source used in these experiments.

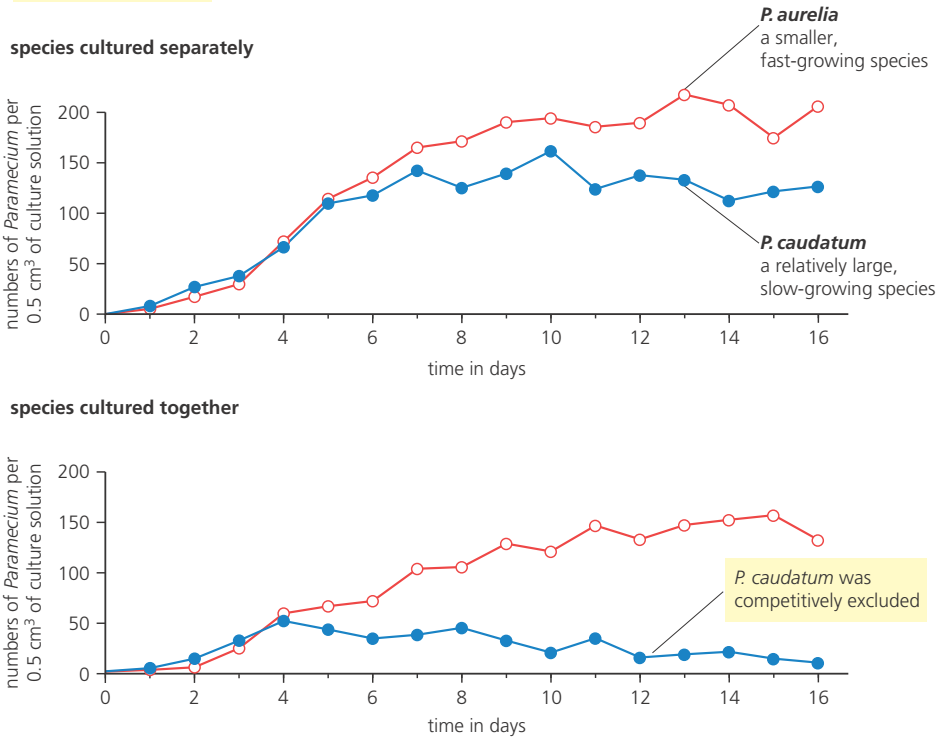


Figure 14.7 Population growth curves for two species of *Paramecium*. If two species with very similar niches are grown separately, both can survive and flourish (top graph). If the two species are grown in a mixed culture, the superior competitor – in this case *P. aurelia* – will eliminate the other

Interactions within communities

Interactions between species in a community can be classified according to their effect (Figure 14.8):

- *Parasitism* is a relationship where one organism – the parasite – benefits at the expense of another – the host – from which it derives its food.
- *Mutualism* is an interaction in which both species derive benefit. This is a specific type of symbiotic relationship between algae and reef-building coral animal species (see below).
- *Predation* is when one animal (or sometimes a plant) eats another animal.
- *Herbivory* is when an organism feeds on a plant.

Expert tip

You need to be able to give local examples to illustrate the range of ways in which species can interact within a community.



Figure 14.8 Interactions between species. Top left: herbivory – caterpillars of the monarch butterfly feeding on milkweed leaves. Top right: predation – African lion at the moment of capture of prey (kudu – a savannah herbivore). Bottom left: parasitism – sheep tick (an ectoparasite) attached to the skin of a cat where it has fed on a blood meal. Bottom right: mutualism – mushroom of fly agaric fungus takes sugars and amino acids from a tree's roots in return for essential ions, via its hyphae attached below ground.

APPLICATIONS

The symbiotic relationship between zooxanthellae and reef-building coral reef species

Reef-building corals have a **symbiotic** relationship with a microscopic unicellular algae called zooxanthellae. The interaction in coral reefs is **mutually** beneficial.

- The animal that makes the coral reef is a cnidarian (Figure 14.9) – a group that also includes sea anemones and jellyfishes.

Key fact

Interactions between species in a community can be classified according to their effect.

Key definitions

Symbiosis – a long-term biological interaction between different species.

Mutualism – both organisms gain from a relationship.

- The polyps secrete a protective skeleton of calcium carbonate, which forms the foundation of the coral reef ecosystem.
- Algae live within the cells of the coral's endodermis (the innermost lining of the animal) (Figure 14.10).
- The coral provides the algae with a protected environment and the carbon dioxide needed for photosynthesis.
- The algae produce oxygen, utilize the coral's waste carbon dioxide and provide the coral with a food source.

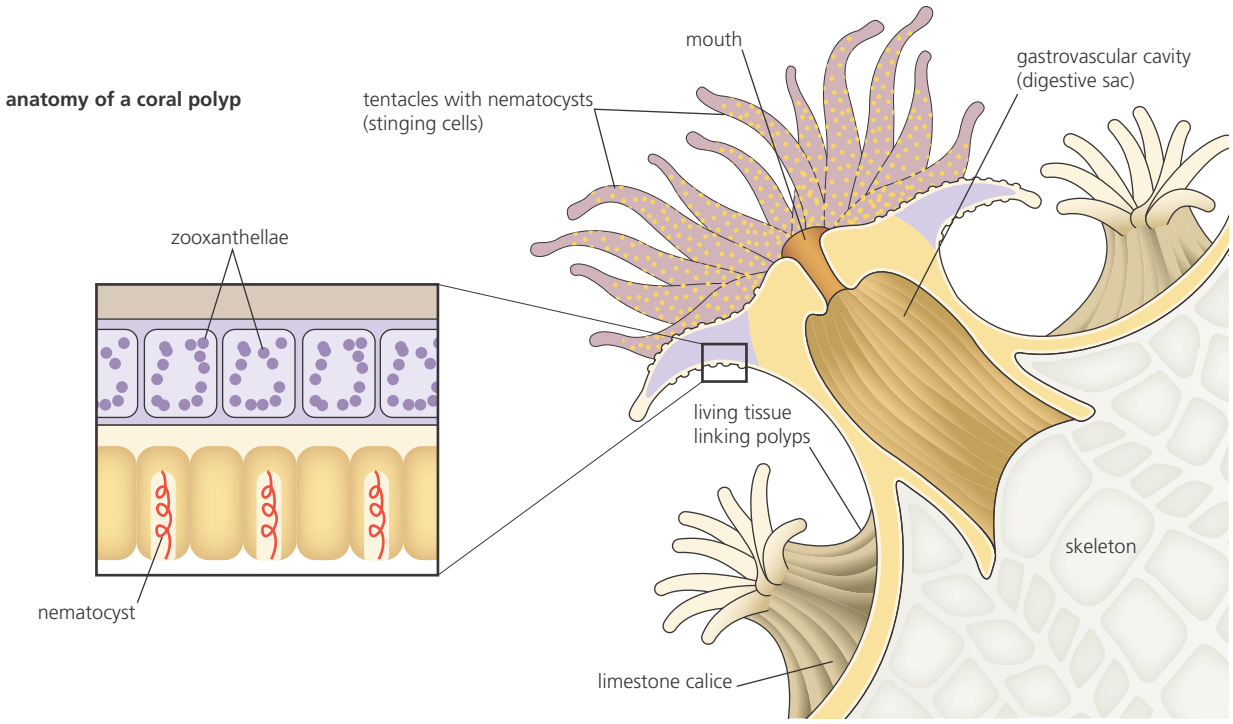


Figure 14.9 The zooxanthellae living within the polyp animal photosynthesize to produce food for themselves and the coral polyp, and in return are protected

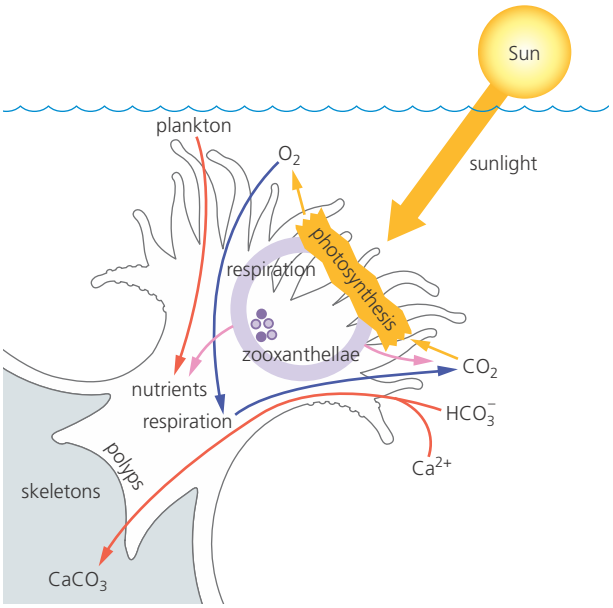


Figure 14.10 The symbiotic relationship between coral and zooxanthellae

Keystone species

Certain **keystone species** are vital for the continuing function of the ecosystem and, without them, the ecosystem can collapse. A keystone species may be only a relatively small part of the ecosystem in terms of biomass or productivity, but still plays a fundamental role in the community. An example of a keystone species is the agouti of tropical South and Central America (see Figure 14.11), which feeds on the nuts of the Brazil nut tree.

- The Brazil nut tree (*Bertholletia excelsa*) is a hardwood species that is found from eastern Peru and northern Bolivia across the Brazilian Amazon.
- The agouti is a large forest rodent, and the only animal with teeth strong enough to open the Brazil nut tree's tough seed pods, to access the nuts inside.
- The agouti does not immediately eat all of the nuts within the seed pod, but buries many of them around the forest floor for times when the Brazil nuts are less abundant.
- The agouti does not remember to dig up and feed on all of these buried seeds, and the remaining ones are able to germinate and grow into adult plants.
- Without the agouti, the Brazil nut would not be able to distribute its seeds and the species would eventually die out.
- Without the Brazil nut tree, other animals and plants that depend on it would be affected, such as harpy eagles that use them for nesting sites.



Figure 14.11 An agouti – a keystone species

Brazil nuts are one of the most valuable non-timber products found in the Amazon: they are used as a protein-rich food source, and their extracted oils are a popular ingredient in many cosmetic products. The sale of Brazil nuts provides an important source of income for many local communities.

Key fact

Community structure can be strongly affected by keystone species.

Key definition

Keystone species – species that have a key role in an ecosystem.

QUICK CHECK QUESTIONS

APPLICATIONS

1 The Pompeii worm (*Alvinella pompejana*) lives in deep sea hydrothermal vents. They are believed to be one of the most heat-tolerant animals on Earth.

An investigation removed worms from deep sea vents and subjected them to three different thermal regimes: a constant mild 20°C exposure, and two heat exposures (42°C and 55°C) followed by a 3-hour recovery period at 20°C. Cells were removed from animals following heat treatment to establish the amount of cell death. The survival of all animals was established by observing movements, just before sampling their body fluid for cells. mRNA was extracted from the gills and tested for gene transcripts of the *hsp70* stress gene; hsp70 proteins are known to be activated in response to environmental stresses, such as temperature.

Results of the experiment are shown in Figure 14.12.

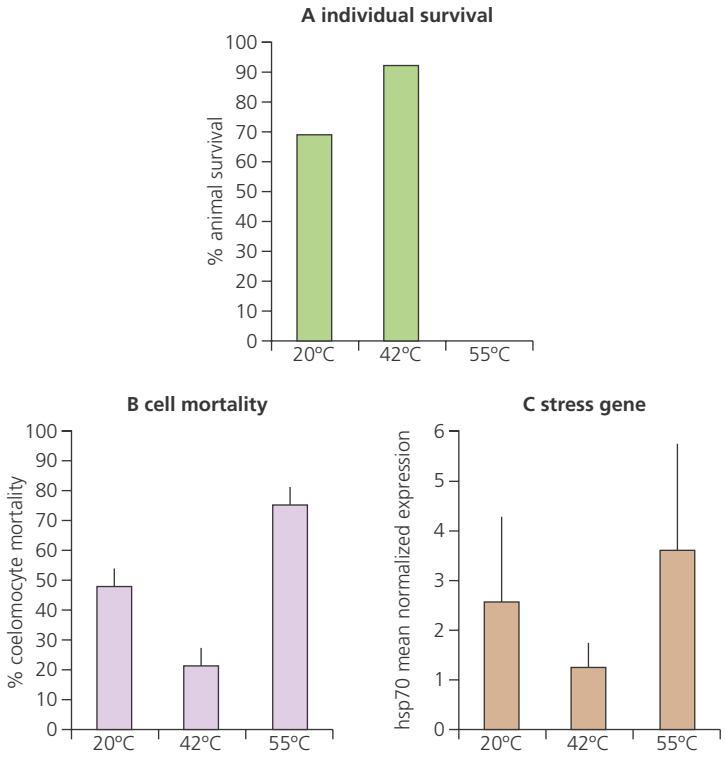


Figure 14.12 Survival of Pompeii worms under different temperatures (A). Percent death of cells that circulate within the body fluid of Pompeii worms (B). Activation of *hsp70* gene compared to normal untreated animals (C)

a Analyse and explain the results. What do the results indicate about the optimal range, lower limit of tolerance and upper limit of tolerance of the Pompeii worm?

b How does the genetic analysis of mRNA support the overall conclusions of the experiment?

2 Figure 14.13 shows the results of a belt transect study of a seashore community. The data are plotted as kite diagrams, where the relative width of each 'kite' represents the abundance of an organism at any one point along a transect.

a Suggest which abiotic factor could be correlated with the distribution of animal and plants along the transect.

b From the data in Figure 14.13, suggest one plant and one animal species that appear to be well adapted to the degree of exposure experienced at:

i a high-water location on the shore

ii a low-water location on the shore.

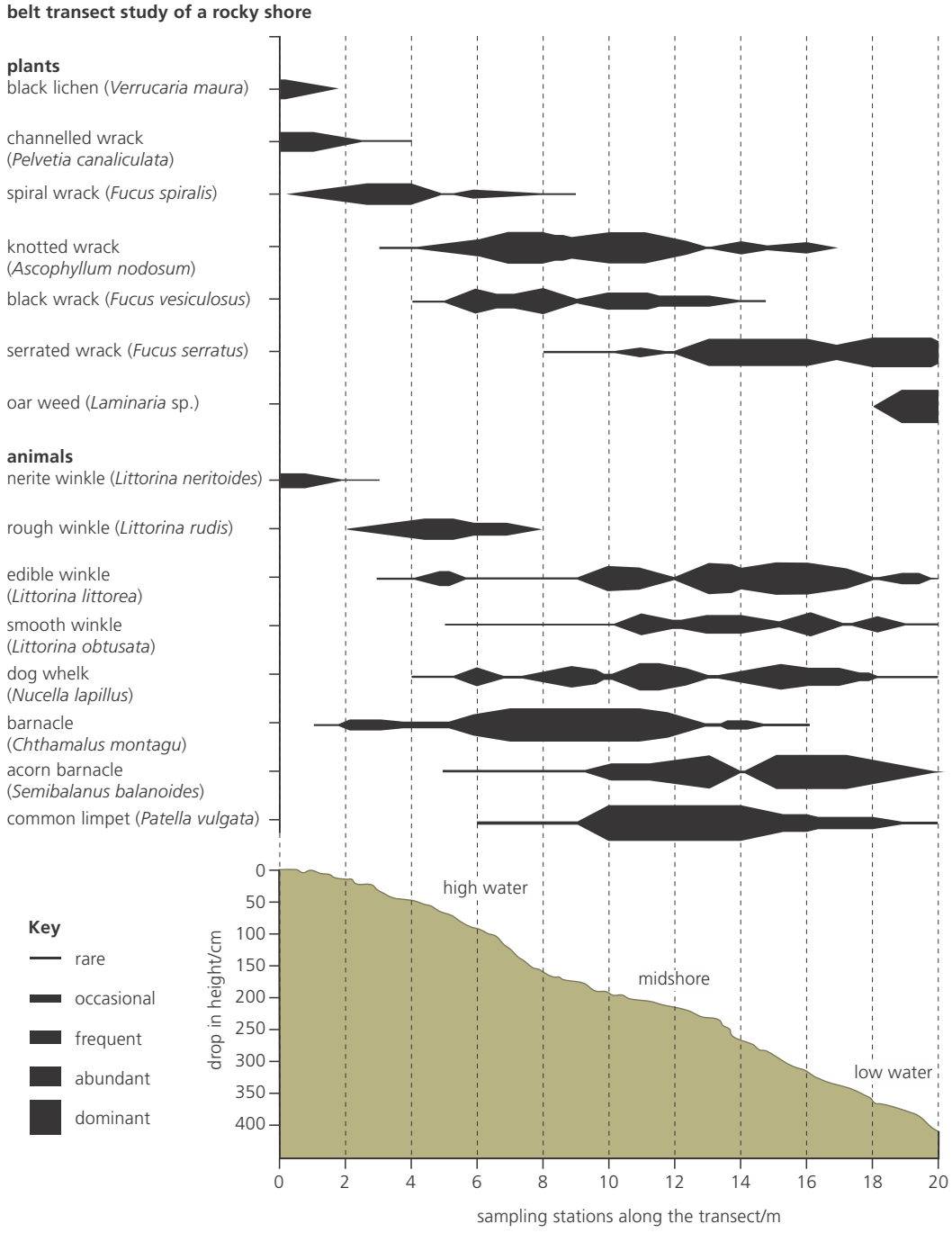


Figure 14.13 Profile and belt transect analysis of a rocky shore community

3 *Galium* (bedstraw) is a matt-forming herb, found on grassland, moors, heaths, and woods. Ecologists have noticed that two species, *Galium saxatile* and *G. sylvestre*, do not grow together. *G. saxatile* is found on acidic peat soils and *G. sylvestre* on limestone soils.

An experiment is carried out to investigate the fundamental and realized niches of these species. Seeds are taken of both species and planted separately in boxes containing both types of soil. Figure 14.14 shows the results of the experiment.

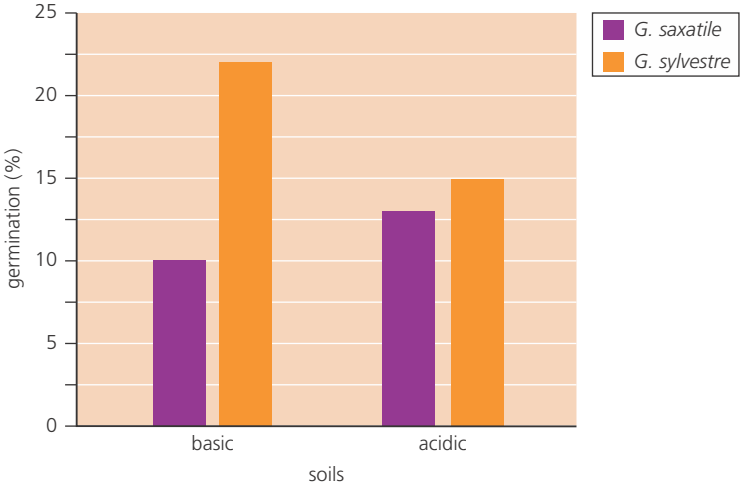


Figure 14.14 Percentage seed germination by heath bedstraw (*Galium saxatile*) and white bedstraw (*G. sylvestre*) in basic calcareous soils and acidic peat soil

a Describe the results of this experiment.

b Suggest a reason for the results, and what they indicate about the fundamental and realized niches of both species.

4 State four different ways in which species can interact within a community. Give examples from your local environment to illustrate these interactions.

14.2 Communities and ecosystems

Essential idea: Changes in community structure affect and are affected by organisms.

Trophic levels in a community

The first **trophic level** of a **food chain** is the that of the producers, because this is where energy enters the ecosystem as sunlight energy and is converted to chemical energy in glucose. Herbivores constitute level 2, because here energy has been transferred twice. The third trophic level, where the energy has been transferred three times, may consist of omnivores or carnivores.

The different trophic levels in a community are:

- trophic level 1: producers
- trophic level 2: primary consumers
- trophic level 3: secondary consumers
- trophic level 4: tertiary consumers.

Food chains do not tend to consist of more than 4 or 5 levels (see Topic 4, page 125). Energy is lost between each trophic level, ultimately as heat energy from respiration.

Key definitions

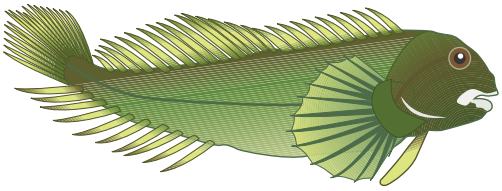
Trophic level – the position that an organism occupies in a food chain, or a group of organisms in a community that occupy the same position in food chains.

Food chain – a sequence of organisms within a habitat in which each is the food of the next, starting with a producer, which is photosynthetic.

Food webs

All ecosystems contain multiple food chains. A **food web** shows all the possible food chains in a community (Figure 14.15).

common blenny
(*Blennius pholis*)
(×2)



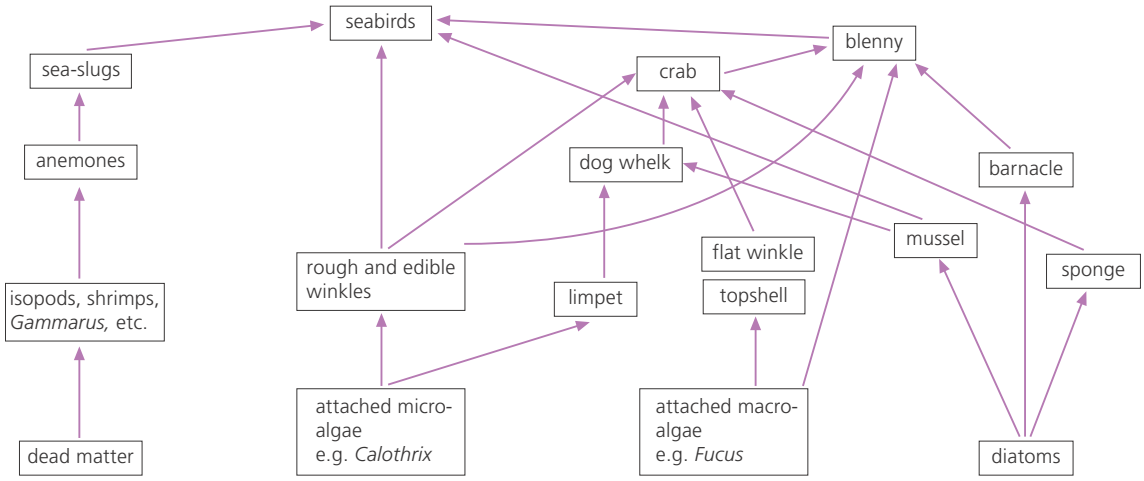


Figure 14.15 Simplified food web for a community of a rocky shore

A species can occupy different trophic levels

In a trophic level, all organisms are the same number of energy transfers away from the original source of energy. For studies of whole communities, it is necessary to designate a trophic level to each organism being studied. Many organisms can occupy different trophic levels, depending on the item of diet under consideration.

In Figure 14.15, the blenny (a small marine fish of inshore waters) can occupy several different trophic levels, depending on its diet:

- a primary consumer when it is eating *Fucus* (brown seaweed)
- a secondary consumer when it is eating winkles
- a tertiary consumer when it is eating crabs.

Energy flow through ecosystems

The transfer of energy in food chains is inefficient (Topic 4, page 124).

The first law of thermodynamics states that:

- energy cannot be created or destroyed
- the total amount of energy in a system does not change.

The second law of thermodynamics states that:

- the transfer of energy is inefficient
- energy is gradually dissipated from usable energy, such as ATP, to a less useful (simpler) form – heat.

Expert tip

All food webs are simplified models of real ecosystems, as it is very difficult (if not impossible) to include all species and interactions.

Key definition

Food web – interconnected food chains.

Expert tip

In terrestrial food webs, as well as aquatic ones, it is common to find the top carnivores feeding at trophic levels between 2 and 5, at any one time.

Key fact

Most species occupy different trophic levels in multiple food chains.

Expert tips

The transfer of energy can be summarized as follows:

- Energy enters as sunlight energy and is converted to new biomass and heat.
- Light energy starts the food chain but is then transferred from producer to consumers as chemical energy.
- Initial absorption and transfer of energy by producers is also inefficient due to reflection, transmission, light of the wrong wavelength, and inefficient transfer of energy in photosynthesis (second law).
- Energy is inefficiently moved through food chains in the process of respiration and production of heat energy (second law).
- As a result of the inefficient transfer of energy, food chains tend to be short.

Gross primary production (GPP) is equivalent to the rate of photosynthesis.

- Much of the energy stored by GPP is used in respiration and ultimately lost as heat from the producers.
- The remaining energy is stored in new biomass: this is known as **net primary production (NPP)**.

NPP can be calculated as follows:

NPP = GPP – R

where R = respiratory loss.

NPP is the rate at which plants accumulate new biomass. It represents the actual store of energy contained in potential food for consumers.

Producers are eaten by primary consumers (herbivores). Only a relatively small proportion of this energy is passed on to the next trophic level (see Figure 14.16). Around 90% of energy is lost between trophic levels due to:

- biomass not being ingested (eaten)
- food not being digested (and therefore not being absorbed into consumers for assimilation)
- excretion
- loss as heat from respiration
- loss as inedible parts, such as bones, teeth and fur.

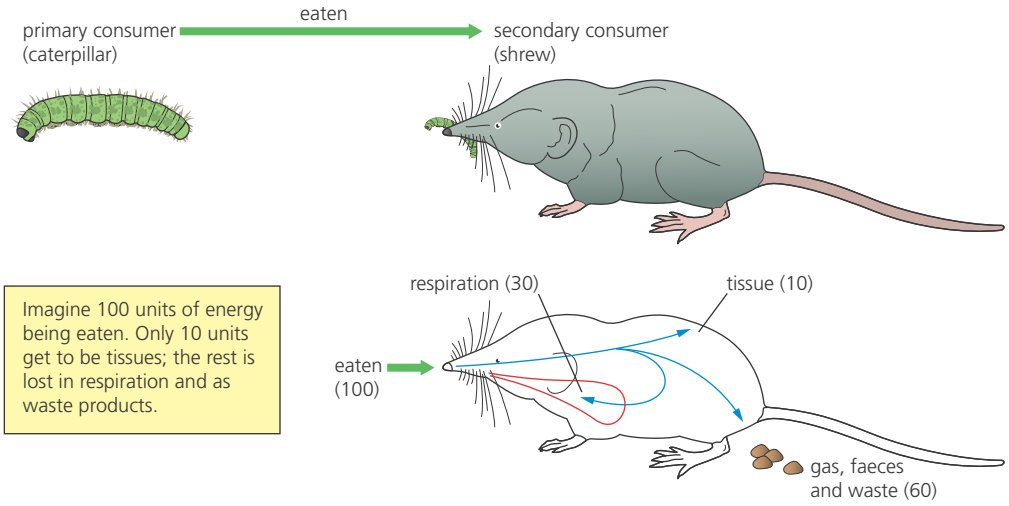


Figure 14.16 Loss of energy between trophic levels

The percentage of ingested energy converted to biomass is dependent on the respiration rate.

- Animals with greater respiration rates will pass on less energy than ones with a lower metabolic rate.
- Ectothermic animals (see Expert tip, below), such as snakes and reptiles, lose less heat from respiration than endothermic animals, such as mammals, that can maintain their body temperatures at constant levels.

Expert tip

- An ectothermic animal is one that is 'cold blooded', i.e. relies on external sources, such as sunlight or a heated rock surface, to regulate body temperature.
- An endothermic animal is one that is 'warm blooded', i.e. can maintain a constant body temperature independent of the environment.

Key definitions

Gross primary production (GPP) – the amount of glucose produced by the plant in a specific area in a specific period of time.

Net primary productivity (NPP) – the gain by producers in energy or biomass per unit area per unit time remaining after allowing for respiratory losses.

Key fact

The percentage of ingested energy converted to biomass is dependent on the respiration rate.

Expert tip

The diet of an animal is also important in determining how much energy is passed on in the food chain. Herbivores are less efficient at digesting plant material (because more faecal matter produced) than carnivores are at digesting meat.

APPLICATIONS

Conversion ratio in sustainable food production practices

Most meat consumed in the human diet comes from farmed animals. These animals need to be fed, and the efficiency of food eaten compared to food produced (i.e. meat) can be calculated using feed conversion ratios (Table 14.2).

- The ratio is the amount of dietary input needed to produce a certain quantity of biomass in livestock or fish.
- The ratio is a measure of an animal's efficiency in converting feed mass into new protein biomass.
- Quantities are generally measured in kilograms
- A feed conversion ratio of 1.5 means that 1.5 kg of feed are required to produce 1 kg of body mass.

Animal	Feed conversion ratio
salmon	1.20
chicken	1.69
duck	2.41
turkey	2.46
pork	2.99
sheep	10.4
cow (beef)	10.4

Table 14.2 Feed conversion ratios for a range of different meat products

The ratios shown in Table 14.2 can be analysed as follows:

- A lower ratio means that there have been lower feed inputs per kilogram of meat produced.
- Lower grain inputs mean that there has been a lower energy input in food production.
- Lower amounts of feed means that less land is required to grow crops to produce the feed.

Expert tip

Not eating meat at all would be the most efficient form of feed conversion, as more of the energy from the crops would go into us (the consumer) rather than being lost in the farmed animals.

Pyramids of energy

NATURE OF SCIENCE

Use models as representations of the real world – pyramids of energy model the energy flow through ecosystems.

Pyramids are graphical models. They show quantitative differences between the trophic levels in an ecosystem. Pyramids of energy:

- model the energy flow through ecosystems
- represent the flow of energy through trophic levels (Figure 14.17).

Because energy is lost at each trophic level and is gradually diminishing throughout the food chain, these diagrams are always pyramid shaped.

Pyramids of energy represent the productivity of each trophic level, i.e. how much new biomass is being made and energy therefore stored) in a particular period of time in a specific area.

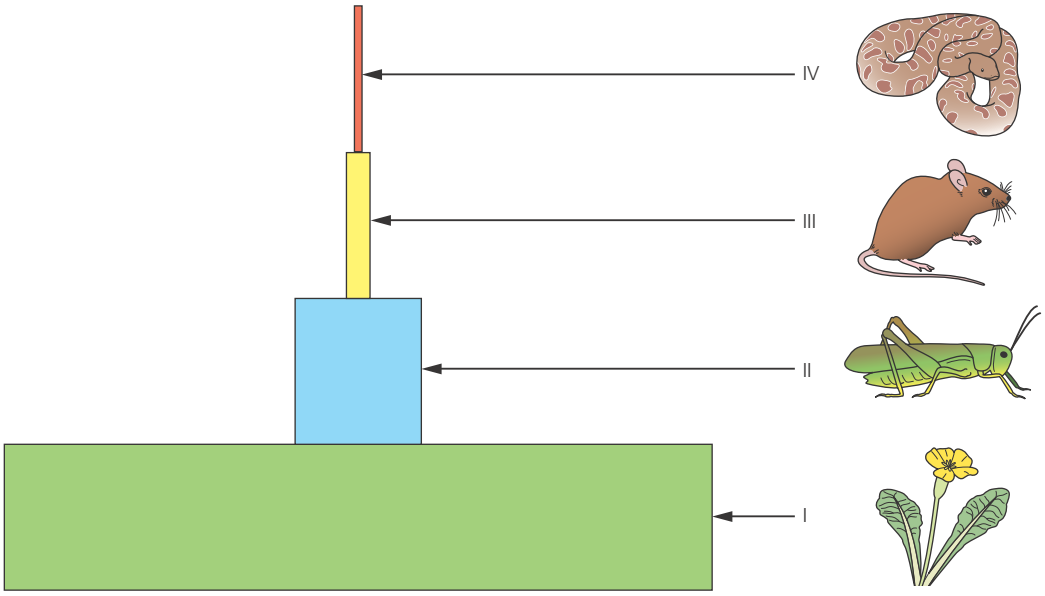


Figure 14.17 A pyramid of energy. I–IV indicate the different trophic levels: I = producer, II = primary consumer, III = secondary consumer, IV = tertiary consumer

The advantages of using pyramids of energy to represent ecosystems as graphical models, compared to other methods, can be summarized as follows:

- Pyramids of numbers and biomass show the storage in the food chain at a given point in time (they are a 'snap-shot' of the ecosystem), whereas pyramids of energy show the rate at which those stores are being generated.
- Pyramids of energy take into account seasonal fluctuations, as data are recorded over a period of time, rather than at one point in time.
- Pyramids of numbers and biomass can be inverted (i.e. the producer trophic level is narrower than the primary consumer trophic level). For example, grass in a field may have a lower biomass than the herbivores that feed on it because the herbivores have been eating the grass over time. As the grass grows and gets longer, the productivity of the grass will be higher than the productivity of the herbivores that feed on it.
- Because productivity, recorded over a period of time, is always higher in producers than subsequent trophic levels, pyramids of energy are never inverted.

Expert tip

Pyramids of energy are measured in units of flow (e.g. $kg\,m^{-2}\,yr^{-1}$ or $kJ\,m^{-2}\,yr^{-1}$).

Pyramids of energy from different ecosystems

Expert tip

Pyramids of energy are created by plotting each trophic level with equal thickness on the vertical scale, with the horizontal scale indicating the size of each bar. The vertical axis is in the centre of the horizontal one, with data distributed equally to each side of the *y*-axis, creating a pyramid.

Expert tip

You need to be able to compare pyramids of energy from different ecosystems.

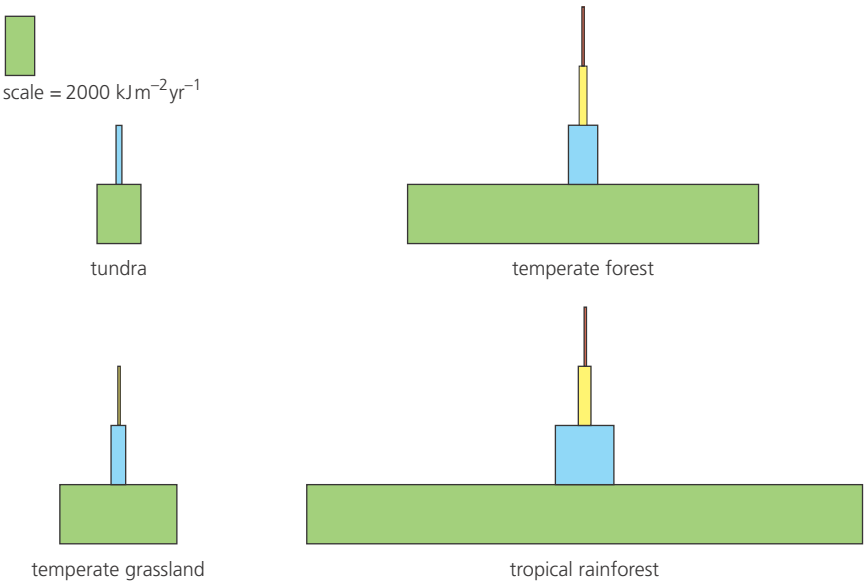


Figure 14.18 Pyramids of energy for different ecosystems

NPP values vary greatly for different ecosystems.

- NPP is affected by factors that influence the rate of photosynthesis, e.g. the amount of insolation (sunlight), the amount of rainfall (precipitation), and the temperature.
- Warmer temperatures speed up enzyme reactions that drive photosynthesis.
- Water and sunlight are needed for photosynthesis, so higher levels of light intensity and rainfall lead to greater rates of productivity.

Rainforests have the highest NPP:

- This is because they are found between the Tropics of Cancer and Capricorn (23.5°N and S of equator) where rainfall is high (over 2500 mm yr^{-1}), insolation is constant throughout the year, and temperatures are warm.
- Because so much energy is stored at the producer level, rainforests can support a number of trophic levels, as even at the tertiary (and even the quaternary) consumer level there is sufficient energy to support a wide diversity of animals (Figure 14.18).

Temperate ecosystems include deciduous and evergreen forests:

- NPP is still relatively high, although rainfall, temperature and sunlight are seasonal, which reduces overall NPP compared to tropical rainforests.
- Lower levels of NPP mean less stored chemical energy at the producer level and, therefore, less biomass at each trophic level, leading potentially to shorter food chains.
- Rainfall is sufficient in temperate forest areas to establish forest (500–1500 mm yr^{-1}) rather than grassland.

In colder ecosystems found in the northern hemisphere, such as tundra:

- There are slower nutrient cycles, a lack of soil fauna, and acidic leaf litter.
- Tree and shrub growth can be stunted.
- The low productivity of tundra means that large areas are needed to support grazing animals such as reindeer, and these animals need to migrate large distances to support their herds.
- In highly stressful environments, with very low temperature or rainfall, only mosses and lichens may be able to survive.
- Lower productivity in such ecosystems and harsher conditions means that food chains tend to be shorter (Figure 14.18), with limited energy available in biomass to support much more than the primary consumer trophic level.

The role of climate in determining ecosystem type

Insolation, temperature, and precipitation affect the type of ecosystem that develops in a given area:

- Temperature affects the rate of enzyme reactions in the cells of all organisms, affecting the rate of primary productivity through photosynthesis and decomposition.
- Temperature affects the rate of transpiration.
- Precipitation affects the rate of photosynthesis and primary productivity.
- Insolation also affects the rate of photosynthesis and primary productivity.

Other elements of the climate that can affect ecosystems are air pressure, humidity, cloudiness and winds.

Key fact

The type of stable ecosystem that will emerge in an area is predictable based on climate.

Predicting ecosystem distribution using a climograph

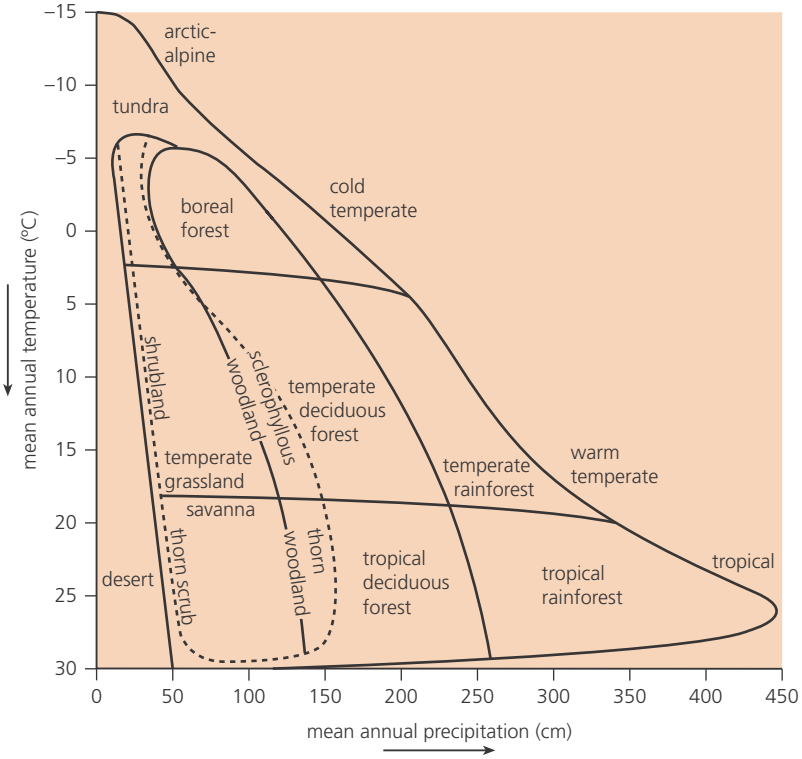
Key definition

Climograph – a graphical model that shows the relationship between temperature, precipitation, and ecosystem type.

Expert tip

You need to be able to analyse a climograph showing the relationship between temperature, rainfall, and the type of ecosystem.

Information about the relative contributions of two climatic factors, precipitation and temperature, can be used to predict the type of stable ecosystem that can be expected in a given area. These two variables can be plotted on a graph and the different ecosystems plotted within it (Figure 14.19).



The dashed line in Figure 14.19 delineates ecosystems where factors other than rainfall and temperature strongly influence ecosystem structure, such as soil type, the occurrence of fire, animal grazing and seasonal drought.

Figure 14.19 A climograph, showing the distribution of major terrestrial ecosystems with respect to mean annual precipitation and temperature

Each ecosystem may not in fact have a distinct boundary, with steady gradation existing from one ecosystem to another. Tropical ecosystems, for example, graduate from highly productive rainforest to low-productive desert.

Gersmehl diagrams: showing nutrient stores and transfers in ecosystems

Nutrients are required in all ecosystems for plant growth, and are recycled between soil, leaf litter and biomass.

- Plants take in nutrients which they build into new organic matter.
- Nutrients are taken up when animals eat plants, and are returned to the soil when animals die and the body is broken down by decomposers.
- Nutrients can be kept in stores within ecosystems (in biomass, soil, or leaf litter), moving between different storages as transfers. For example, leaf-fall from trees decomposes and returns nutrients to the soil.

Movement of nutrients can be shown in Gersmehl diagrams (Figure 14.20).

- Stores and transfers are drawn in proportion (to scale).
- The size of the nutrient stores (biomass, litter, and soil) is proportional to the quantity of the nutrients stored.
- The thickness of the transfer arrows is proportional to the amount of nutrients transferred.
- This quantitative way of showing information about the ecosystem gives extra information and adds value to the diagram.

Nutrient cycles vary greatly between different ecosystems. Factors that affect the store of nutrients and their transfer include:

- the amount of rainfall
- rates of decomposition of litter
- temperature
- type of vegetation, size of plants, and number of layers in the ecosystem
- length of growing season
- the amount of weathering of rock
- the amount of overland flow and soil erosion.

The efficiency of nutrient cycles varies between ecosystems. Figure 14.21 shows the nutrient flows for three different ecosystems (taiga, tropical rainforest, and desert) showing the interrelationships between nutrient stores and flows.

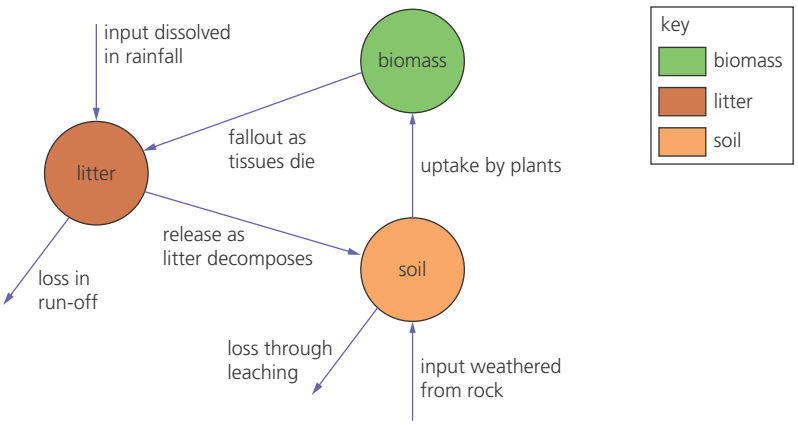


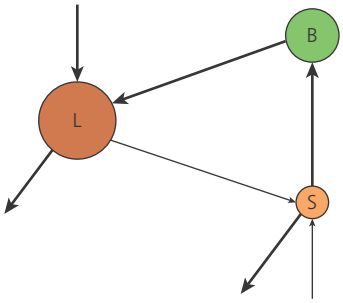
Figure 14.20 A model of the nutrient cycles in ecosystems; circles represent nutrient stores and arrows nutrient transfers

Expert tip

You need to be able to construct Gersmehl diagrams to show the inter-relationships between nutrient stores and flows between taiga, desert, and tropical rainforest.

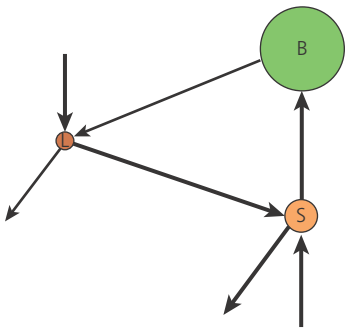
Expert tip

Gersmehl diagrams consist of transfers in (nutrients such as carbon and nitrogen dissolved in precipitation and minerals from weathered parent rock, for example), transfers out (loss of nutrients from the soil, such as by leaching and by surface run-off), and stores (e.g. trees).



taiga (northern coniferous forest) environment

Figure 14.21a Taiga (northern coniferous forest) – litter is the main store, with little transfer between stores



selva (equatorial rainforest) environment

Figure 14.21b Tropical rainforest – biomass is the main store, with rapid transfers between stores and the environment

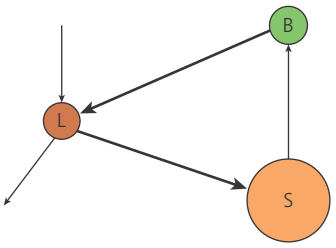


Figure 14.21c Desert – soil is the main store, with little movement between stores

Explanation of Figures 14.21a–c:

	Taiga	Tropical rainforest	Desert
input dissolved in rainfall	little precipitation; falls as snow and so remains on surface of ground	high precipitation all year round	very little rainfall – what does occur is very irregular
input from weathered rock	slow weathering due to cold conditions and lack of rainfall	rapid weathering due to humidity, temperature, and high levels of precipitation	negligible chemical weathering due to lack of rain
biomass	relatively low: conifer trees only; there is little undergrowth and few species	tall, dense vegetation with rapid growth, several layers, and many species	low biomass due to harsh conditions; only desert-adapted (xerophytic) plants can survive
soil	small store due to soils being formed from glacial deposits that are low in nutrients	small store due to leaching and soil infertility	the biggest store as low productivity leads to nutrients remaining in soil
litter	large store because cold limits the rate of decomposition	small store because of high decomposition rate	some litter formed from the plants present
release as litter decomposes	slow, due to cold conditions; conifer needles have a thick cuticle and are slow to decay	rapid decay due to warm temperatures and high humidity (ideal conditions for bacteria)	very little due to very hot conditions in the day and cold at night
fallout as tissues die	continual supply of litter	continual supply of litter	continual supply of litter
uptake by plants	trees take up nutrients	vast amounts of plant roots take up large quantities of nutrients	few plants and so low uptake of nutrients
loss through leaching	some limited leaching due to precipitation	rapid due to high levels of precipitation	not enough rainfall for leaching to occur
loss in run-off	can be high after snowmelt and with ground still frozen	large because of high precipitation – soil cannot absorb it all	little run-off as precipitation is very low

Table 14.3 Comparing the inputs, outputs, transfers, and stores of three different ecosystems

Succession

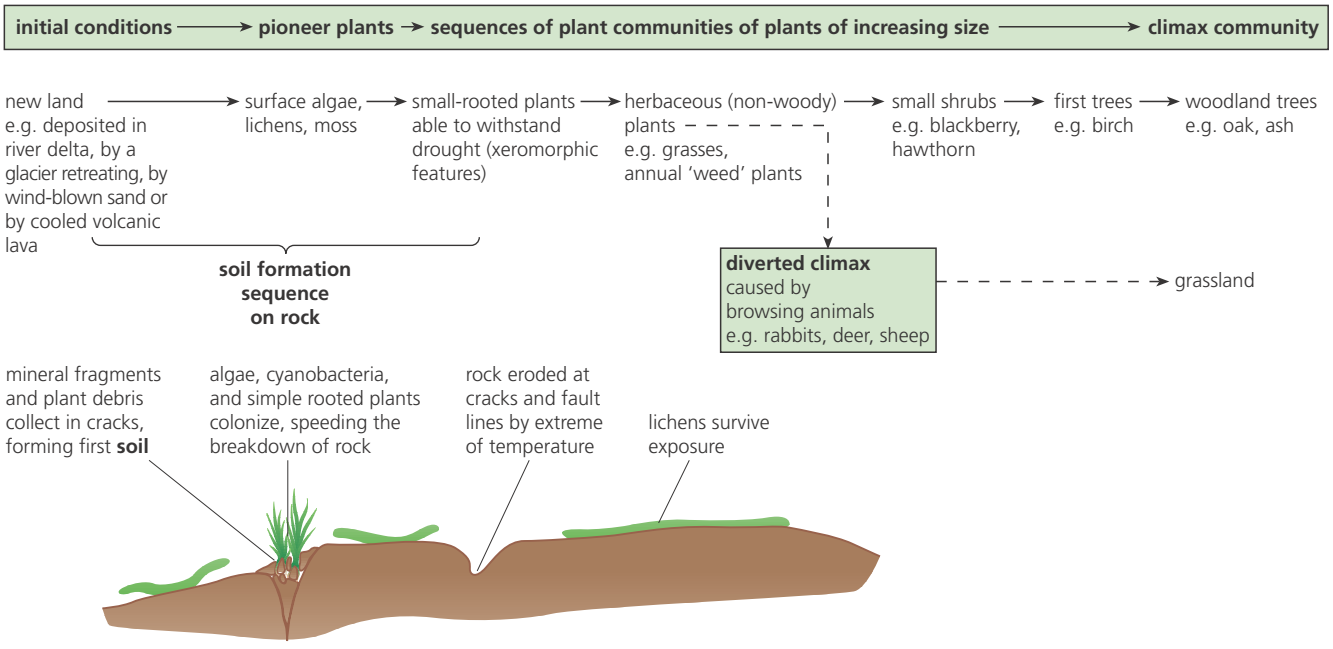
Changes in the community of organisms frequently cause changes in the physical environment:

- Changes in the environment allow another community to become established and replacing the former through competition.
- Often, but not inevitably, the later communities in such a sequence, or sere, are more complex than those that appear earlier.
- The first communities are called pioneer communities.
- The final stage of the **succession** the climax community (Figure 14.22).
- Nutrient availability changes from poor initial stores through to gradual accumulation of nutrients as biomass develops and soil fertility increases.

Key definition

Succession – the process of change over time in a community.

A **xerosere** = succession under dry, exposed conditions where water supply is an abiotic factor limiting growth of plants, at least initially.



This succession sequence is not a rigid ecological process, but an example of what may happen. It is influenced by factors such as:
a how quickly humus builds up and soil forms
b rainfall or drought, and the natural drainage that occurs
c invasions of the habitat by animals and seeds of plants.

Figure 14.22 A primary succession on dry land – a xerosere

Primary succession

The formation of an ecosystem in an environment devoid of vegetation and lacking soil, for example bare rock, is called primary succession:

- Pioneer species arrive (for example, lichens, mosses, and bacteria).
- As pioneers die, soil is created.
- New species of plants arrive that need soil to survive – these displace pioneer species.
- Growth of plants causes changes in the environment (factors such as light, wind, moisture).
- Growth of roots enables soil to be retained; nutrients and water in the soil increase.
- Nitrogen-fixing plants arrive, adding nitrates to soil (see pages 133–134, this chapter).
- Soil depth increases further, allowing shrubs and other taller plants to arrive.
- Animal species arrive as species of plant they rely on become established.
- A climax community is established.

Secondary succession

A secondary succession occurs in an environment after an ecosystem has been disrupted or destroyed due to a disturbance that reduces the population of the original inhabitants. Soil already exists in this type of succession.

Expert tips

You need to be able to analyse data showing primary succession.

Disturbance influences the structure and rate of change within ecosystems

CASE STUDY: LOGGING AND SUCCESSION IN TROPICAL RAINFORESTS

Tropical rainforests are found in South America, Africa, and Southeast Asia. The climate is warm and stable, with temperatures varying from 20°C at night to 35°C at midday; rainfall is high, with up to 2500 mm per year (see also pages 99–100, this chapter).

- The constant warm temperatures, high insolation, and high rainfall lead to high levels of photosynthesis and high productivity (page 97 earlier in this chapter).
- High productivity leads to high biomass, which in turn leads to ecosystem complexity, abundant resources (such as food), and niche diversity.
- Abundant niches lead to high species richness and high biodiversity.

Tropical rainforests are vulnerable to disturbance:

- Because they have high biodiversity, many species are affected when they are disturbed.
- Deforestation and forest disturbance are caused mainly by demands for timber, for land for cattle to provide beef and for plantation crops such as soya and biofuels (such as oil palm in Southeast Asia).
- Tropical rainforests are found on nutrient-poor soils that are thin and easily eroded once forest is cleared.

Rainforests illustrate how disturbance influences the structure and rate of change within ecosystems. The time taken for rainforest to regenerate depends on the level of disturbance:

- Small-scale disturbance, for example from shifting cultivation, can recover in around 50 years.
- Large areas of cleared land will take longer to grow back (around 4000 years), if at all.
- Areas subject to selective logging methods will regenerate more quickly than areas logged using conventional methods.

Following logging and disturbance:

- The canopy of the rainforest is opened up, letting more light reach the forest floor.
- Fast growing species, such as Macaranga, benefit from this and rapidly fill in the gaps left by the hardwood species that have been removed.
- Secondary succession occurs, although if high densities of timber have been removed then the forest is unlikely to be return to its original structure because the fast-growing species begin to dominate and block light from other slower growing species.

It is possible to reduce the effects of disturbance:

- Logging operations where lower densities of timber are removed better maintain the structural integrity of the forest.
- Lower intensity, or reduced-impact, logging activities are more likely to allow secondary succession to return the forest to nearer its original state of equilibrium than more damaging methods.

APPLICATIONS

The effect of deforestation on nutrient cycling

When humans log forests they interfere with nutrient cycling. This is especially true in tropical rainforests, where soils have low fertility and nutrients cycle between the leaf litter and tree biomass.

- Once trees have been removed, the canopy no longer intercepts rainfall, and the soil and leaf litter is washed away (and with it much of the available nutrients).

Expert tip

You need to understand one example of how humans interfere with nutrient cycling.

- The store of nutrients in trees is reduced, as well as in the soil.
- Fewer trees means less litter fall and fewer nutrients reaching the forest floor.
- There are fewer plants to take up the remaining nutrients, which again affects nutrient cycling.

In Southeast Asia, large areas have been cleared to grow oil palm (*Elaeis guineensis*).

- Oil palm is used in food production, domestic products and to provide biofuel.
- Once the original forest has been removed, natural nutrient recycling is also lost.
- Because the soils are generally nutrient poor, oil-palm trees require fertilizer to be applied to produce yields that return a reasonable profit.
- Fertilizers can have negative environmental impacts (pages 138–139, this chapter).
- Fertilizer application in oil-palm plantations has also been linked to increases in ground-level ozone, which can have detrimental effects on humans and wildlife alike, and reduce plant productivity.

Expert tip

In tropical rainforest, warm temperature, high humidity and rainfall provide ideal conditions for decomposition – this rapidly leads to the breakdown of the rich leaf litter throughout the year.

Expert tip

You need to know how to investigate the effect of an environmental disturbance on an ecosystem.

Studying the effects of an environmental disturbance on an ecosystem

In your local area there will be locations where you can investigate the effect that human disturbance has had on natural ecosystems. These may be areas of forest that have been harvested for timber, grassland habitats that are regularly trampled by walkers, ecosystems where fire has damaged natural habitats, and so on. There are a variety of methods you can use to study derived ecosystems:

- carry out capture–mark–release–recapture methods on invertebrate species in disturbed and undisturbed sites (page 125, this chapter)
- measure species diversity using the Simpson's reciprocal index (pages 116–117, later in this chapter)
- use indicator species (pages 113–115 later in this chapter)
- measure variables such as leaf area index, above ground biomass, average width of tree stems at breast height (DBH), degree of canopy openness, volume of leaf litter, water cycle variables including run-off and infiltration rates, light levels, temperature, and wind speed
- measure soil erosion – in areas with high precipitation this can be simply calculated by measuring the depth of soil remaining under free-standing rocks and stones, where soil around these solid objects has been eroded
- measure soil variables such as soil structure, nutrient content, pH, compaction levels, and soil moisture.

Expert tip

Examples of aspects to investigate in an ecosystem could be species diversity, nutrient cycling, water movement, erosion, leaf area index, among others.

Closed ecosystems

There are three different types of system – open, closed, and isolated (Figure 14.23). Differences depend on how matter and energy move into and out of the system:

- Open systems exchange both matter and energy with their surroundings (a natural ecosystem).
- Closed systems exchange only energy but not matter with their surroundings (for example the Earth).
- Isolated systems do not exchange either matter or energy with their surroundings (the Universe).

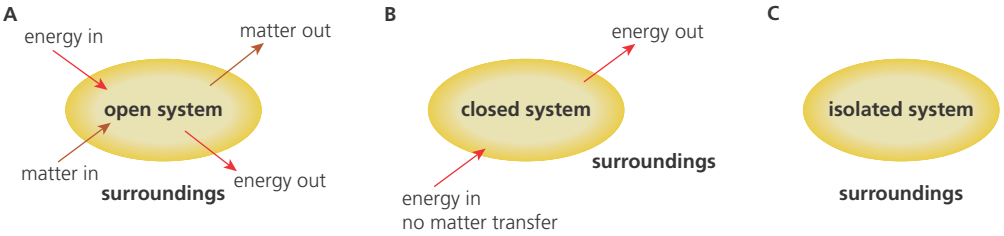


Figure 14.23 The exchange of matter and energy across the boundaries of different systems. Open systems (A) exchange both energy and matter; closed systems (B) exchange only energy; and isolated systems (C) exchange neither

Key fact

In closed ecosystems energy but not matter is exchanged with the surroundings.

In closed ecosystems energy but not matter is exchanged with the surroundings. Such ecosystems include the mesocosm discussed in Topic 4 (page 118). In nature, ecosystems are open systems, because both energy and matter are exchanged with their surroundings.

QUICK CHECK QUESTIONS

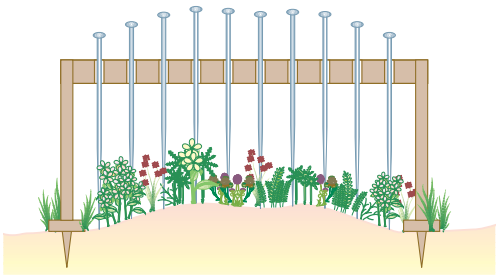
1 Using Figure 14.19 (page 98):
   - **a** explain which factor is most important in determining whether an area will be a broadleaf forest or a coniferous forest
   - **b** explain which factor is most important in determining whether an area will be a grassland or a forest.

2 Describe the ways in which secondary succession on burnt forest land differs from primary succession on a barren, rocky shore.

3 Figure 14.24 shows a study of the vegetation of a system of developing sand dunes. Both the species diversity and physical parameters change as the dunes age. Calculate the diversity indices of the fore dune and semi-fixed dune. Comment on the results.

Sand deposited by the sea and blown by the wind, builds into small heaps around pioneer xerophytic plants, such as marram and couch grass, at coasts where the prevailing wind is on-shore. The tufts of leaves growing through the sand accelerate deposition, and gradually drifting sands gather a dense cover of vegetation. Fixed sand dunes are formed.

point frame quadrat in use



The frame is randomly placed a large number of times, the 10 pins lowered in turn onto vegetation and the species (or bare ground) recorded.



Behind the fore dune the fixed dunes can be seen.

Figure 14.24 Sand dune community development – a student field study exercise

4 State which species are pioneers and which form the climax community.

Study of a sand dune succession from embryo state to fixed dune

	Site 1	Site 2	Site 3	Site 4
Stage in succession	Embryo dune	Fore dune	Semi-fixed dune	Fixed dune
Number of pins dropped	220	220	220	220
sea couch grass	169	9	0	0
marram grass	1	123	19	0
fescue grass	0	0	126	182
spear-leaved orache	4	0	0	0
prickly saltwort	2	0	0	0
bindweed	1	44	0	0
bird's foot trefoil	0	0	0	6
biting stonecrop	0	0	0	1
buttercup	0	0	0	1
cat's ear	0	0	5	2
clover	0	0	0	68
common stork's bill	0	0	0	11
daisy	0	0	2	8
dandelion (common)	0	0	5	1
eyebright	0	0	0	4
hawkbit	0	0	20	1
ladies bedstraw	0	0	86	35
medick	0	0	0	62
mouse-ear chickweed	0	0	0	2
ragwort	0	0	8	1
restharrow	0	0	25	15
ribwort plantain	0	0	0	37
sand sedge	0	0	32	17
stagshorn plantain	0	0	0	36
tufted moss	0	0	0	119
yellow clover	0	0	0	5
Yorkshire fog	0	0	2	0
wild thyme	0	0	0	82
Total live hits	**177**	**176**	**330**	**706**
Bare ground hits	**48**	**68**	**6**	**0**
% bare ground	27	38	3	0
soil moisture (%)	5.0	8.5	16.0	14.3
soil density (g cm^{-3})	1.6	0.9	0.6	0.5
soil pH	8.0	7.5	7.0	7.0
wind speed (m s^{-1})	10.0	9.3	2.4	1.3

14.3 Impacts of humans on ecosystems

Essential idea: Human activities impact on ecosystem function.

The spread of alien species

Once introduced into a new area, **alien species** can occupy local ecosystems, increase rapidly in number, and have such a large impact that they lead to the decline of **native species**, and become **invasive**.

- Both the introduced species and the native species end up occupying smaller realized niches, as a result of interspecific competition.
- If the alien species lacks natural predators, it may be able to out-compete the native species and become invasive.

Key definitions

Alien species – species that are introduced into an area by human activity.

Native species – a species found in an area where it originated, i.e. occurs naturally within a particular ecosystem.

Invasive species – an alien species that has increased rapidly in number, having a negative effect on the environment and on native species.

Endemic species – species restricted to a particular region.

- Understanding the fundamental niche of invasive species can help predict their dispersal patterns and invasion success, and provide the basis for better-informed conservation and management policies.

Key fact

Introduced alien species can escape into local ecosystems and become invasive.

APPLICATIONS

CASE STUDY 1: THE GREY SQUIRREL

The success of the grey squirrel at the expense of the red squirrel (Figure 14.25) is a very good example of an alien species becoming an invasive one.



Figure 14.25 Red and grey squirrels

- The red squirrel is native to the UK and the grey squirrel has been introduced.
- The grey squirrel has spread rapidly, by being able to consume a wide range of locally growing nuts (including the oak tree's acorn, which the grey squirrel can digest, but which the red squirrel cannot).
- The red squirrel is now restricted to just a few locations in the UK, having once been widespread over much of the country.
- Although they have similar niches, with its wider diet, the grey has outbred the red and multiplied much faster.
- The grey squirrel is an example of an alien species that has a similar niche to an **endemic species** – because the niches of the grey and red squirrel overlap, competitive exclusion can take place (pages 85–86, this chapter).

Key fact

Competitive exclusion and the absence of predators can lead to a reduction in the numbers of endemic species when alien species become invasive.

APPLICATIONS

CASE STUDY 2: THE INTRODUCTION OF CANE TOADS IN AUSTRALIA

In the early 1930s, two species of beetle, French's cane beetle and the Greyback cane beetle, were abundant in North Queensland, feeding on and destroying valuable sugar cane crops.

- In 1935, cane toads (*Rhinella marina*) were released in Queensland to eat and remove the cane beetles.
- The native habitat of the cane toad is sand dunes, coastal heath, mangroves, and around rainforests in Central and South America.
- Large-scale releases occurred; by March 1937, 62 000 toads had been released.
- In the Americas, the toads have natural predators that restrict their population size, but in Australia these predators are absent and so the toads can rapidly increase in number.
- The cane toad secretes a toxic liquid – the venom causes excessive salivation, rapid heartbeat, convulsions, and, in severe cases, paralysis. This makes them a danger to native animals, pets and humans.



Figure 14.26 Cane toads mating

Expert tip

Cane toads have a rapid reproductive cycle. Females lay between 8000 and 35 000 eggs at a time, and usually breed twice a year. Tadpoles develop into small toads within 6 months, and then require between 6 and 18 months to reach sexual maturity.

The toad proved to be ineffectual against the sugar cane beetle – the beetles live at the tops of sugar cane and cane toads are not good climbers. The toads did prove to be effective at eating the native fauna of Australia.

- Cane toads mainly eat insects, but will also eat any small creature that fits in their mouth, including many native species.
- They eat honey bees and compete for food with native animals.
- They may carry diseases that are transmitted to native frogs and fishes.
- Their effects have included the depletion of native species that die from eating cane toads, such as freshwater crocodiles, tiger snakes, dingos, and western quolls.
- Cane toads now number well into the millions, and their still expanding range covers thousands of square miles.

Cane toads have proven difficult to eradicate.

- Between 2000 and 2008 a research programme was launched with the aim of developing a solution for long-term biological control of cane toads.
- The programme involved research into engineering a virus that would infect young toads and stop them developing into adults.
- The research was ultimately not pursued due to regulations on the use of genetically modified organisms in the environment.

Expert tip

Scientists at the University of Adelaide have investigated whether a sex pheromone in cane toads can be used to disrupt the toad's breeding cycle.

The conclusions of the eradication programmes has been that managing the local impacts of cane toads, rather than attempting to eradicate the species, is a more effective long-term approach. Communities are encouraged to remove the toad from local habitats, and exclusion zones have been set up across Australia to ensure that the cane toad is restricted to its current distribution.

Expert tip

You need to have studied the introduction of cane toads in Australia and one other local example of the introduction of an alien species.

Biocontrol

NATURE OF SCIENCE

Assessing risks and benefits associated with scientific research – the use of biological control has associated risk and requires verification by tightly controlled experiments before it is approved.

Invasive species can be controlled by introducing natural predators or other enemies of the alien species into the environment where they are found. This method is called biological control or biocontrol.

- The release of natural enemies should lead to the establishment of permanent populations of the biocontrol agent, although further releases may be needed to 'top up' the predator numbers.

- Biocontrol is effective as it has a high degree of host-specificity, i.e. one predator targets one invasive species and the effects on non-target species are minimized.
- Less effective biocontrol, which can have occasionally disastrous outcomes, occurs when the biocontrol agent is not specific to one prey (see the example of the cane toads in Australia, page 107).

The use of biological control has associated risk and requires verification by tightly controlled experiments before it is approved.

Biological control is implemented in the following way:

1. The alien species is identified as a target for biological control.
2. Natural predators of the alien species are sought by surveying the natural habitat of the alien.
3. The control organism is examined to assess the potential impact on the alien species and non-target species, as well as possible environmental impacts.
4. Following approval from federal and state regulatory officials, biological control agents are brought to the country and quarantined. They are examined to confirm species identity and to determine whether they are free of parasites and diseases.
5. Biocontrol agents are tested in field plots. These trials determine whether the agents reduce the density of the target species, and do not have negative effects on non-target species.
6. Following small-scale testing, biocontrol agents are mass-reared to high numbers and released at field sites established by local biologists.
7. Once released, each biological control agent is evaluated for establishment, spread, impact on the target species and impact on non-target species.
8. Careful, long-term evaluation studies provide scientific data that is used to improve current and future programmes. Additional releases may be made when and as needed.

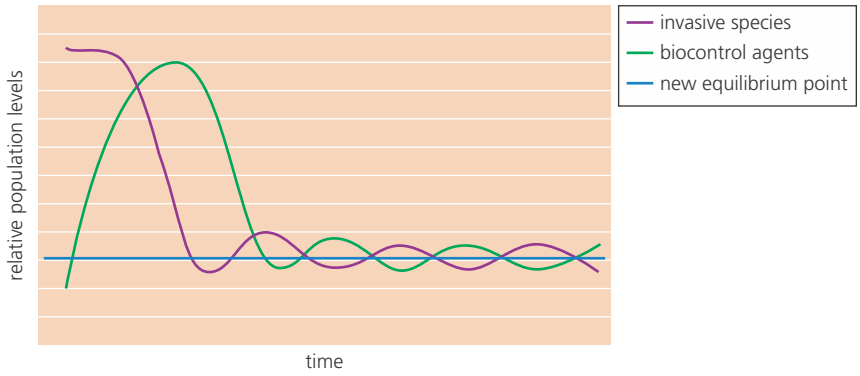


Figure 14.27 Graph showing how biocontrol agents and invasive species reach a new equilibrium following introduction

Figure 14.27 shows the impact of biocontrol agents on invasive species.

- Invasive species numbers fluctuate around a new, much lower, equilibrium point after control is implemented.
- Because the invasive species are never completely eradicated, a small population of the biocontrol agent remains: if the numbers of invasive species increase for some reason, the number of biocontrol agents will also increase.

Expert tip

You need to be able to evaluate eradication programmes and biological control as measures to reduce the impact of alien species.

Pesticide pollution and food chains

Wild plants and animals have evolved alongside their predators and parasites, and most live in balance with them. In contrast, cultivated crops and herds have been artificially selected to be especially productive and high-yielding, but typically have limited resistance to local parasites and predators. Crops grown as monocultures are especially prone to local predators.

- **Pesticides** are used to kill unwanted pests of crops.
- Pesticides have enormously improved productivity in agriculture, but their use has generated problems in the environment.

Dichlorodiphenyltrichloroethane (DDT) is a nerve poison to insects, causing rapid death even when applied in low concentrations. DDT was economic to use because

- the molecule was stable when dispersed in the biosphere
- it remained lethal for a very long time
- it was effective against a very wide range of insect pests (a broad-spectrum insecticide)
- it did not do any harm to vertebrates in concentrations needed to kill insects, and so it was liberally used.

DDT has been used to control the lice that spread typhus and the mosquitos that spread malaria.

- DDT is fat soluble and is selectively retained in fatty tissues of animals, rather than circulating in their blood to be excreted by the kidneys.
- DDT gets stored in fat tissues because it is not recognized as a toxin and is not excreted. **Bioaccumulation** takes place.
- At each stage of the food chain, DDT becomes concentrated. **Biomagnification** takes place (Figure 14.28).
- The result of biomagnification can be that a top predator may have a concentration of the pesticide that is several thousand times greater than that of a primary producer.
- In non-vertebrates, fish, and birds, DDT concentrations sometimes reach toxic levels.
- DDT has been concentrated in top carnivores, with devastating consequences.

Key definitions

Pesticide – chemical that is used to control harmful organisms which are a danger to crops or herds.

Bioaccumulation – the build-up of non-biodegradable or slowly biodegradable chemicals in the body.

Biomagnification – the process by which chemical substances become concentrated in the tissues of organisms at higher trophic levels.

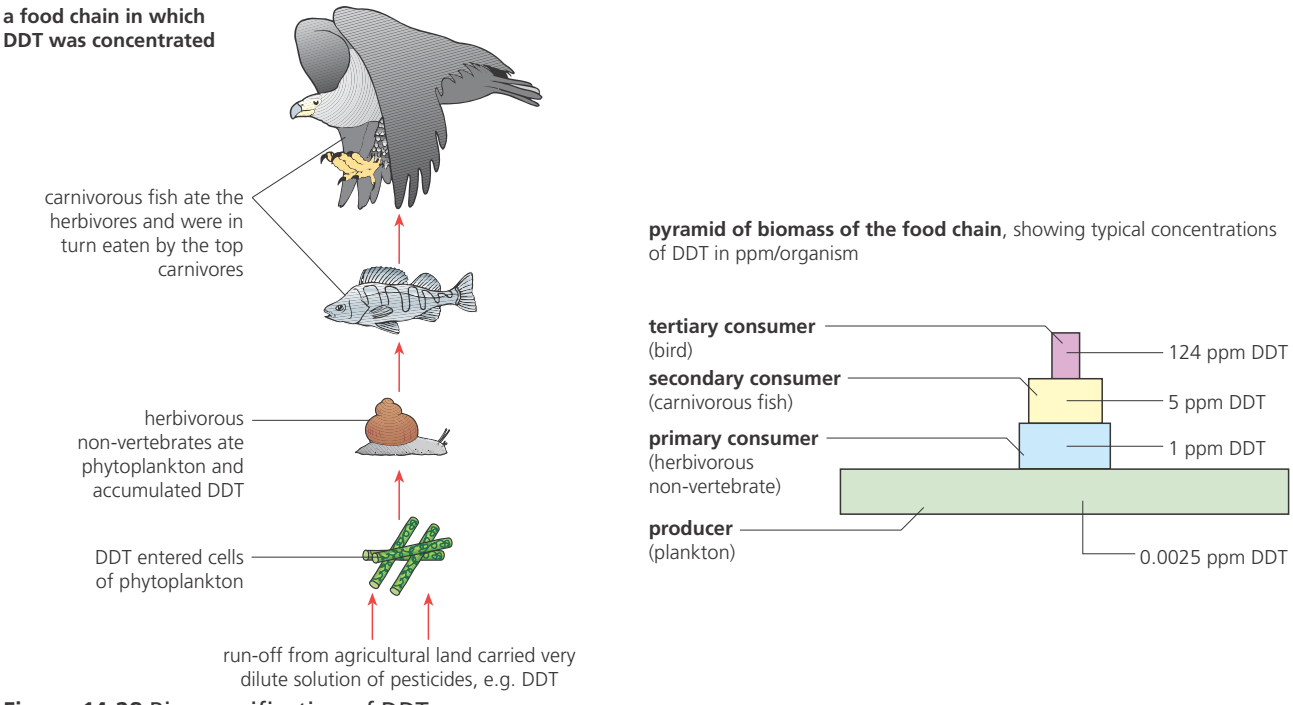


Figure 14.28 Biomagnification of DDT

APPLICATIONS

The trade-off between control of the malarial parasite and DDT pollution

In 2001 the Stockholm Convention on persistent organic pollutants regulated the use of DDT – it was banned for use in farming but was permitted for disease control.

- The plan is to find alternatives for disease control by 2020.
- In 2006, The World Health Organization (WHO) recommended the use of DDT for regular treatment in buildings in areas with a high incidence of malaria, using a method known as indoor (residual) spraying (IRS). WHO still aims for a total phase-out of the use of DDT.

Alternatives to chemicals such as DDT include insecticides that are biodegradable in the biosphere (not persistent) and which are more specific in their actions.

- Initially, following the DDT ban, organophosphate insecticides were favoured because they break down in the soil.
  - Organophosphates work by blocking the synapses of the insect nervous system, but are now suspected of being harmful to humans.
  - If tiny quantities of pesticide persist in the food chain, these residues may accumulate in humans.
- Subsequently, other substances, synthetic derivatives of pyrethrum, have been developed.
  - These are much less toxic to mammals and also biodegradable.
  - However, they are lethal to fish and must not be used near streams, rivers, or lakes.

The World Bank estimates that there are about 250 million cases of malaria each year.

- In South America, cases of malaria increased after countries stopped spraying DDT.
- IRS appears to limit the growth of malarial incidence and many countries that had banned the use of DDT reapproved its use in IRS.
- Despite the use of IRS, malaria is still on the rise and many people believe that this increase in the disease is unacceptable.
- The application of DDT provides the least economically developed countries with a quick and effective means of eradicating malaria.
- Other methods, such as the use of mosquito-nets at night, rely on community participation and often this can be problematic when people are not used to these methods of control.

Chemicals such as DDT can harm many species and, even with the use of IRS, DDT can spread into the local environment by dispersing from houses.

- There is evidence that DDT can harm human health, by accumulating in body fat and leading to problems such as infertility, cancer, and brain damage during developmental stages.
- People who are against the use of DDT argue that alternative (less objectionable) strategies exist, such as lowering population density, using bed-nets, removing standing water, using natural repellents, and encouraging natural predators.
- Pressure is mounting for governments to develop alternative methods of malaria vector control, and use DDT only as a last resort.

Key fact

Pollutants become concentrated in the tissues of organisms at higher trophic levels by biomagnification.

Pollution from marine plastics

Plastics are used in an increasing number of disposable consumer products. Figure 14.29 shows how **macroplastic** enters the marine environment, and what happens to it subsequently.

Key definition

Macroplastic – large debris that is easily visible, such as bottles, plastic bags, rubbish, and other material that have not degraded.

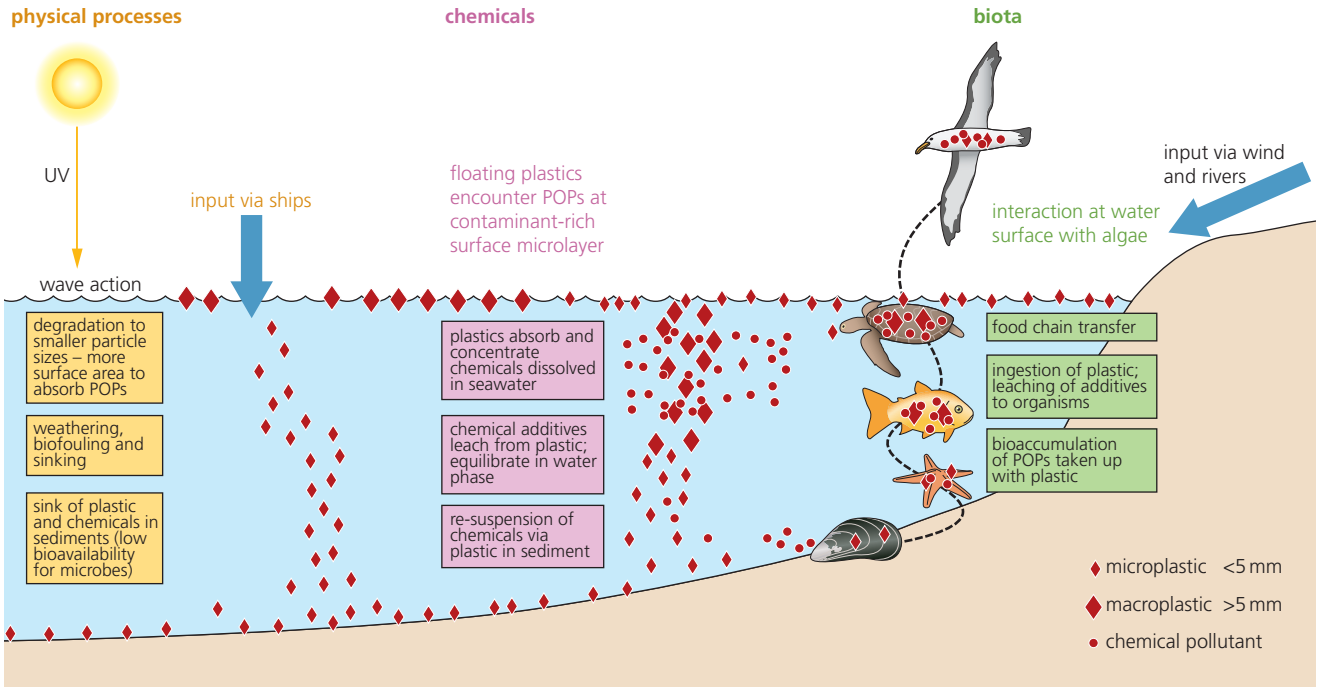


Figure 14.29 Sources of marine macroplastics and the various abiotic (physical and chemical) and biotic processes affecting microplastics in the marine environment. POPs are persistent organic pollutants that are resistant to environmental degradation: they can therefore accumulate through food chains.

Macroplastic and **microplastic** debris has accumulated in marine environments.

- Macroplastics can be confused with food by marine predators (see below and next page).
- Degradation of marine plastics releases non-biodegradable contaminants that can bioaccumulate in the food chain.
- Once chemicals enter food chains, the top predators are often at extra risk because of the biomagnification effects of some chemicals.

Food chain transfer is of concern particularly in convergence zones (hotspots), where microplastics can be consumed in large amounts due to their high concentration. These hot spots, or 'gyres', are created by ocean currents, which transport garbage to five concentrated areas or 'patches' – North Pacific gyre, South Pacific gyre, North Atlantic gyre, South Atlantic gyre, and the Indian Ocean gyre.

- Microplastics are more prevalent than plankton in some South Pacific gyre sea surface samples.
- The presence of microplastics at such low levels of the food chain can have serious consequences, since plankton and small swimming organisms, such as fish larvae, support the transfer of energy to higher trophic levels.

APPLICATIONS

The impact of marine plastic debris on Laysan albatrosses

The Laysan albatross (*Phoebastria immutabilis*) ranges across the North Pacific, with 99.7% of the population breeding on the Northwestern Hawaiian Islands. The albatrosses require large quantities of fish to survive. One island on which they nest, Midway Atoll, is in the North Pacific gyre, and large volumes of plastic are found in the water.

- The Laysan albatrosses catch squid and other seafood by skimming the surface of the water with their beak.

Key definition

Microplastics – tiny plastic particles up to 5 mm in diameter.

Expert tip

Studies of southern fur seals have shown that seal scats (faeces) can contain plastic particles from the night-feeding myctophids (lanternfish), which are active near the sea surface and which are consumed by the seals

Key fact

Macroplastic and microplastic debris has accumulated in marine environments.

Expert tip

You need to know the impact of marine plastic debris on Laysan albatrosses and one other named species.

- By catching food in this way they also accidentally pick up a lot of floating plastic, which they then feed to their chicks.
- Chicks, unlike adults, cannot regurgitate plastic that they have swallowed, and so the plastic can fill their stomachs, potentially leading to starvation.

APPLICATIONS

The impact of marine plastics on sea turtles

Macroplastic garbage harms and kills approximately 100 000 sea turtles and other marine animals each year.

- Sea turtles mistake plastic bags for jellyfish (one of their favourite foods) and so eat them.
- The consequences of ingesting plastic can be fatal; if the plastic debris gets lodged in the mouth, the turtle can have problems feeding, leading to eventual starvation.

Key fact

Many Laysan albatrosses accidentally eat plastic and other marine debris floating in the ocean, mistaking it for food.

QUICK CHECK QUESTIONS

1 The European wild rabbit was introduced to Australia in 1859. There were no natural predators in Australia for the rabbit and so they quickly became invasive. As a biological control measure, a myxoma virus that had been discovered in South American rabbits was introduced to Australia in 1950.

Myxoma virus causes a parasitic disease of rabbits, myxomatosis, but on its original continent, the effects were mild. The changing effects of this virus on rabbit mortality (1950–56) in Australia are shown in Figure 14.30, and also the resulting change in virulence of the virus.

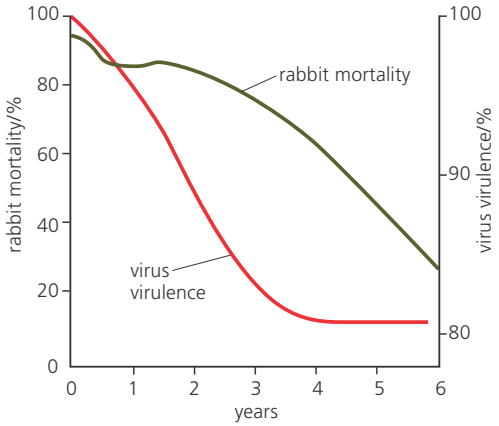


Figure 14.30 Changing rabbit mortality and virus virulence, following introduction of the myxoma virus as a biological control measure

Evaluate the rabbit eradication programme and the use of myxomatosis as a biological control method.

2 Explain how a pesticide, applied at safe concentrations to crops or herds, may cause the death of unrelated organisms.

3 Figure 14.31 shows the food web for a sparrowhawk, and the effect of the pesticide DDT on the thickness of its eggshells.

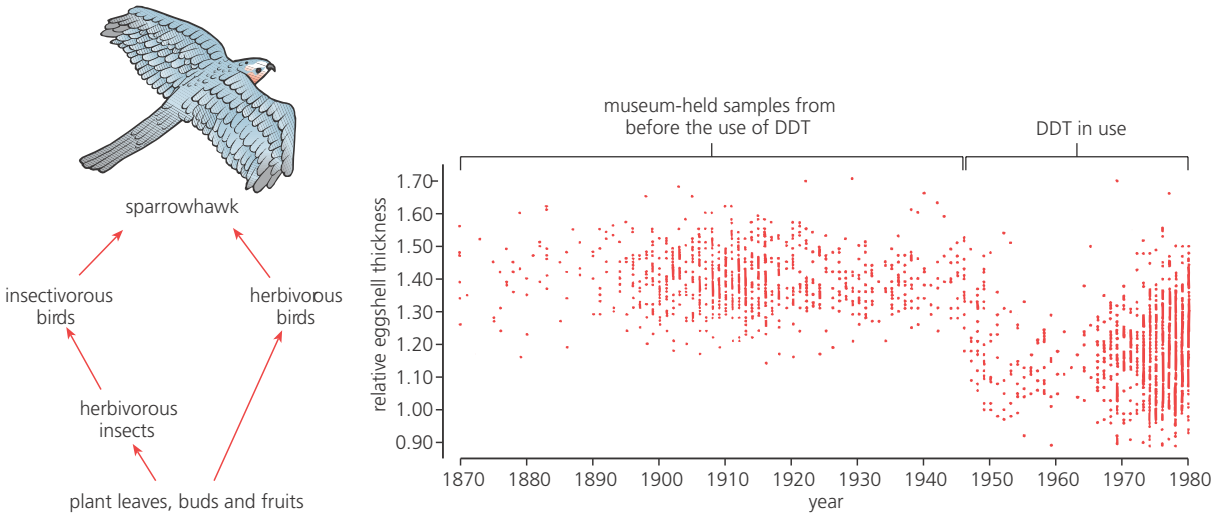


Figure 14.31 Eggshell thickness studies in sparrowhawks

Analyse the data shown in Figure 14.31. Explain the observed results.

14.4 Conservation of biodiversity

Essential idea: Entire communities need to be conserved in order to preserve biodiversity.

Indicator species

Changes to **indicator species** may show effects of disturbance to an ecosystem. These species are ones whose presence, absence, or abundance can be used as an indication of pollution or other habitat disturbance.

Key definition

Indicator species – an organism used to assess a specific environmental condition.

- Species have different levels of tolerance to environmental conditions.
- If change occurs to a habitat, some species can survive and others cannot.
- The presence or absence of indicator species can be used to indicate changing conditions in the environment.
- Indicator species can be used as an indirect measure of pollution, or to indicate environmental degradation due to habitat disturbance.

Examples of indicator species, and the conditions they indicate, include:

- nettles (*Ullica dioica*) indicate high phosphate levels in the soil.
- the red algae (*Corauina officinalis*) inhabit saline rock pools and are absent from brackish pools.
- certain lichen species (such as *Usnea alliculata*) indicate very low levels of sulfur dioxide in the atmosphere.

The Trent Biotic Index

Freshwater invertebrates such as *Tubifex* worms, bloodworms and mayfly nymphs can be used as indicators (Figure 14.32). These form part of the Trent Biotic Index that indicates the quality of fresh water streams and rivers.

Key fact

An indicator species is an organism used to assess a specific environmental condition.

Relative numbers of indicator species are used to calculate the value of the Trent Biotic Index:

- The Index is based on the disappearance of certain indicator species as levels of pollution increase (Table 14.4).
- It uses the presence or absence of six key organisms (stonefly larvae, mayfly larvae, caddis fly larvae, *Gammarus* shrimp, water hoglouse (*Asellus*), *Tubifex* worms and non-biting midge larvae) to indicate the relative level of pollution in fresh water (Figure 14.33 and Table 14.4).
- Changes in the amount of light and dissolved oxygen cause less tolerant species to die out.
- Certain species are tolerant of organic pollution and the low oxygen levels associated with it: they are found in high population densities where an organic pollution incident occurs.
- Other species cannot tolerate low oxygen levels and, if organic pollution enters the river where they live, they move away or do not survive.
- As pollution increases, diversity decreases.

Key fact

Relative numbers of indicator species can be used to calculate the value of a biotic index.

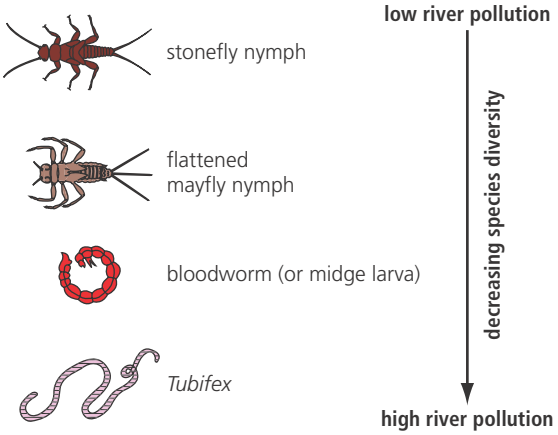


Figure 14.32 Invertebrate indicators of freshwater pollution

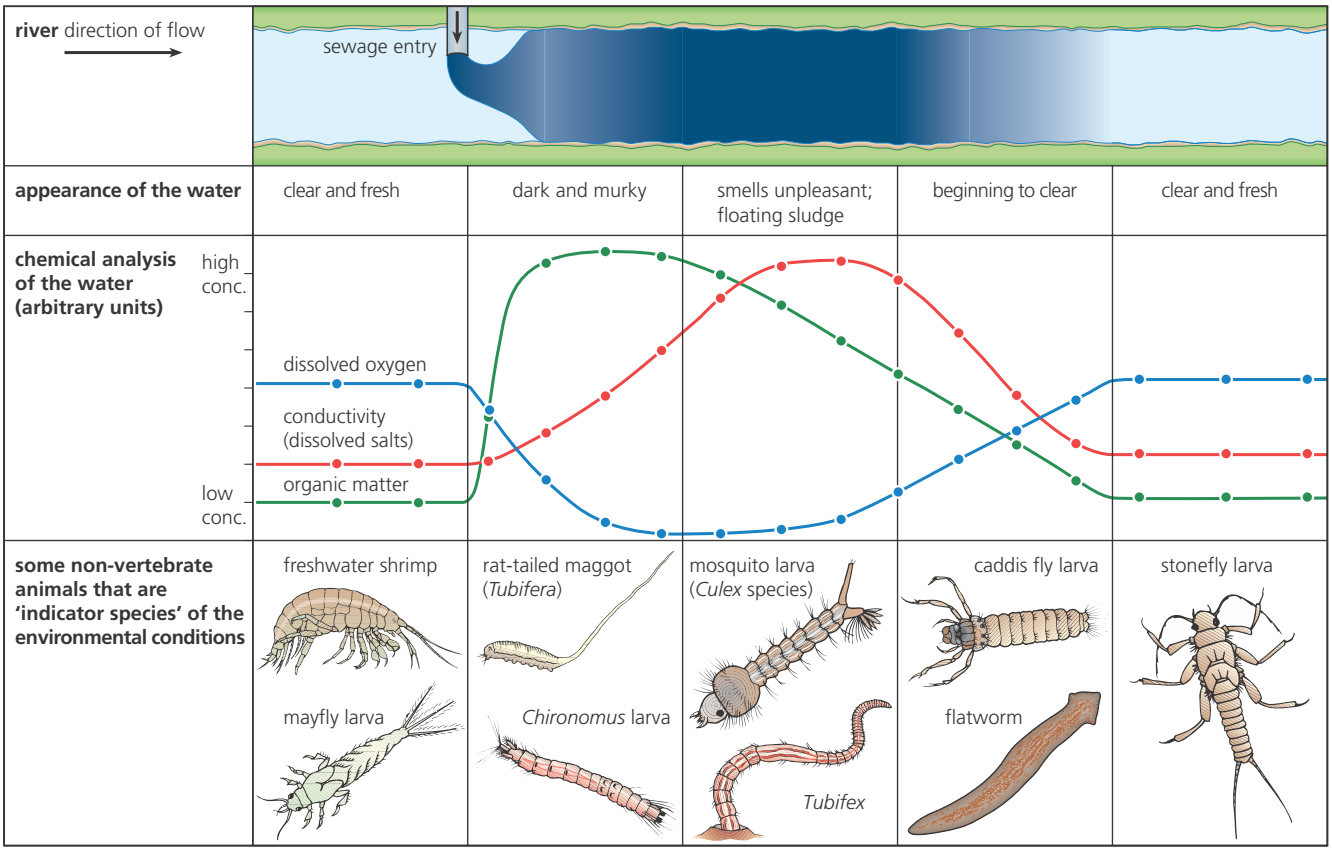


Figure 14.33 The effect of pollution on a river with untreated sewage can be observed by eye, measured by chemical analysis, and analysed using indicator species

Calculating the Trent Biotic Index

The maximum value for the Trent Biotic Index is 10. The index value corresponds to one of four basic water quality descriptions (excellent, good, fair, or poor). A score of 10 is considered to be clean water – excellent.

Indicator species	Total number of groups present					
		0–1	2–5	6–10	11–15	16+
	Trent Biotic Index					
stonefly (Plecoptera nymph) present	more than one species	–	7	8	9	10
	one species only	–	6	7	8	9
mayfly (Ephemeroptera) nymph present	more than one species	–	6	7	8	9
	one species only	–	5	6	7	8
caddis fly (Trichoptera) larvae present	more than one species	–	5	6	7	8
	one species only	4	4	5	6	7
Gammarus present	all above species absent	3	4	5	6	7
water hoglouse (*Asellus*) present	all above species absent	2	3	4	5	6
tubificid worms and/or red blood worm (chironomid) larvae present	all above species absent	1	2	3	4	–
all above types absent	some organisms, such as *Eristalis tenax*, not requiring dissolved oxygen, may be present	0	1	2	–	–

Table 14.4 Indicator species for the Trent Biotic Index

The Trent Biotic Index is calculated as follows:

1. Samples are taken from the river by disturbing the stream bed with a boot and collecting dislodged animals downstream in a net. A fixed time is set for this 'kick sample'.
2. The catch is put in a shallow white tray with at least 2 cm depth of fresh water from the river.
3. An identification key is used to sort the catch into different groups. The number of different groups is counted.
4. The presence of the indicator species is recorded (Table 14.4), starting from the top of the list. (*Note: some groups are not indicator species – these should still be counted.*)
5. The highest indicator species is taken. The Trent Biotic Index is calculated by going along the line from this indicator species until the number of groups present in the sample (top line of table) is reached.

For example, if the highest indicator animal is a Trichoptera, there is more than one of this indicator species (i.e. more than one species of Trichoptera), and the total number of groups is seven, then the Trent Biotic Index is 6.

Biodiversity

Biodiversity is the amount of biological or living diversity per unit area. It includes the concepts of species diversity, habitat diversity, and genetic diversity:

- Species diversity is the variety of species per unit area. This includes both the number of species present and their relative abundance.
- Habitat diversity is the range of different habitats or number of ecological niches per unit area in an ecosystem.
- Genetic diversity is the range of genetic material present in a gene pool or population of a species.

Expert tip

Conservation of habitat diversity usually leads to the conservation of species and genetic diversity.

Richness and evenness

Richness and evenness are components of biodiversity. Richness is a term that refers to the number of a species in an area, and evenness refers to the relative abundance of each species.

Species richness in an area can be high, but diversity low (Figure 14.34). Species diversity is a better measure of ecosystem quality and health than species richness.

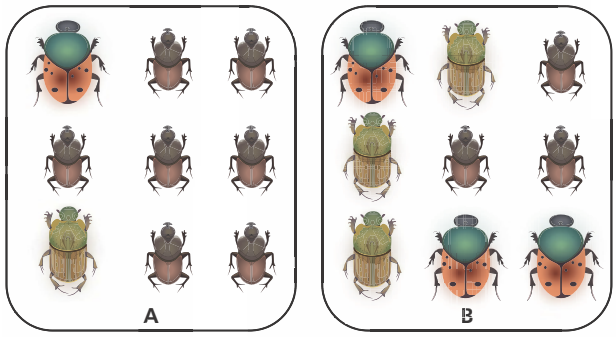


Figure 14.34 Species richness vs. species diversity. The species richness is the same in both ecosystems (ecosystem A and ecosystem B – 3 species of beetle in each). In ecosystem B, diversity is higher than ecosystem A because evenness is higher. One species dominates in ecosystem A, indicating a less complex ecosystem

Diversity indices, such as the Simpson's reciprocal index (see below), can be used to describe and compare communities. Diversity indices can be used to assess whether the impact of human development on ecosystems is sustainable or not. When comparing communities that are similar:

- Low diversity could indicate pollution, eutrophication, or recent colonization of a site.
- The number of species present in an area is often indicative of general patterns of biodiversity, although disturbed sites often have artificially increased species richness due to the mixing of habitats that are usually spatially separate in undisturbed sites.

Expert tip

Diverse communities are ones that have high evenness – each species is approximately equally abundant, indicating a complex ecosystem with lots of niches.

Calculating species diversity

Species diversity refers to the number of species and their relative abundance. It can be calculated using diversity indices.

Species diversity can be calculated with Simpson's reciprocal index, using the equation:

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

where: D = diversity index, N = total number of organisms of all species found and n = number of individuals of a particular species.

- Index values are relative to each other and not absolute, unlike measures of, for example, temperature, which are on a fixed scale. This means that two different areas can be compared to each other using the index, but a value on its own is not useful.
- Comparisons can be made between areas containing the same type of organism in the same ecosystem.

Expert tip

You need to be able to analyse the biodiversity of two local communities using Simpson's reciprocal index of diversity.

- A high value of *D* suggests a stable and ancient site, where all species have similar abundance (or 'evenness', see above).
- A low value of *D* could suggest disturbance through, say, logging, pollution, recent colonization or agricultural management, where one species may dominate.

Analysis of the biodiversity of two communities

Table 14.5 contains data from two different habitats. Total number of species ('species richness') and total number of individuals is the same in each case.

Species found	Number found in habitat X	Number found in habitat Y
A	10	3
B	10	5
C	10	2
D	10	36
E	10	4
number of species =	5	5
number of individuals =	50	50

Table 14.5 The number of species and their abundance in two habitats

The Simpson's reciprocal index is calculated for each habitat. This is done using a table to calculate components of the index:

Species	Number (*n*) found in habitat X	$n(n-1)$	Number (*n*) found in habitat Y	$n(n-1)$
A	10	10(9) = 90	3	3(2) = 6
B	10	10(9) = 90	5	5(4) = 20
C	10	10(9) = 90	2	2(1) = 2
D	10	10(9) = 90	36	36(35) =1260
E	10	10(9) = 90	4	4(3) = 12
	$\Sigma n(n-1)$	= 450	$\Sigma n(n-1)$	= 1300

Table 14.6 Calculating the Simpson's reciprocal index for two habitats

Species diversity for each habitat:

Habitat X:

$$D = \frac{50(49)}{450} = \frac{2450}{450} = \mathbf{5.44}$$

Habitat Y:

$$D = \frac{50(49)}{1300} = \frac{2450}{1300} = \mathbf{1.88}$$

These values reveal the following about each habitat:

- There is greater 'evenness' between species in habitat X. This implies more opportunity for niches in this habitat, due to greater resources and space.
- There is less competition due to non-overlapping niches in habitat X.
- One species does not dominate in X, reflecting greater habitat complexity.
- Habitat Y is less complex with fewer, or overlapping, niches. One species can dominate, leading to lower diversity.

CASE STUDY: SPECIES DIVERSITY AND RICHNESS IN BEETLE COMMUNITIES IN BORNEO

Pitfall traps were used to sample dung beetle communities in the tropical rainforest of Borneo.

- Pitfalls were made from pots buried in the soil, baited with primate dung to attract beetles.
- Pitfalls were used to collect beetles in primary (undisturbed) forest by a large river (riverine forest), primary forest further in the interior, logged forest (areas harvested for timber) and plantation (one species of tree used to grow a local crop).

Location	Species richness	Diversity	Dominance index
Riverine primary forest	48	1.92	0.54
Primary interior forest	42	2.63	0.24
Logged forest	46	1.59	0.66
Plantation	29	1.78	0.52

Table 14.7 Results from pitfall trapping of dung beetles in the rainforest of Sabah, Malaysian Borneo

Species richness is the total number of species collected in each forest type. Diversity was calculated for each location, and also a dominance index. The dominance index is a measure of the degree to which a few species dominate the community – high dominance indicates low evenness.

- Riverine forest had the highest species richness – this is because it is an area where several habitats meet (it is 'edge' habitat – see page 121, this chapter), increasing the number of species sampled. This forest had a lower diversity than interior primary forest, due the dominance of one species and the corresponding lower evenness.
- Logged forest had high species richness but lower diversity compared with undisturbed forest. Logged forest contains a mixture of species usually separated along environmental gradients in primary forest: riverine species and those found in the canopy move into logged areas, increasing species richness artificially.
- The lower species diversity in logged forest indicates a simplified ecosystem where some species dominate (indicated by a high dominance measure).
- Plantation forest has the lowest species richness and also a low diversity, indicating a loss of primary forest species and a much simpler ecosystem compared to primary rainforest.

This study indicates that species richness is a poor indicator of habitat disturbance when used on its own. Diversity indices, and measures of evenness, more clearly show changes to community structure as a result of human impact.

Expert tip

A community with high evenness is one that has a similar abundance of all species – this implies a complex ecosystem where there are lots of different niches that support a wide range of different species. In contrast, low evenness refers to a community where one or a handful of species dominate – this suggests lower complexity and a smaller number of potential niches, where a few species can dominate.

Common mistake

Some think that biodiversity is only seen in animals. This is incorrect – it is a term that can be applied to all living organisms.

In situ conservation

- ***In situ* conservation** leads to endangered species being conserved in their native habitat.
- Not only are endangered animals protected, but also the habitat and ecosystem in which they live, leading to the preservation of many other species.
- *In situ* conservation works within the boundaries of conservation areas or nature reserves.

In situ conservation may require active management of nature reserves or national parks. This involves

- active clearing of overgrowth
- limiting predators
- controlling poaching
- controlling access
- reintroducing species that have become locally extinct and removing alien species.

Successfully protected areas:

- provide vital habitat for indigenous species; this can include habitat and food for migrating species such as birds
- create community support for the area

Key fact

Richness and evenness are components of biodiversity.

Key definition

***In situ* conservation** – the conservation of species in their natural habitat.

Key fact

In situ conservation may require active management of nature reserves or national parks.

- receive adequate funding and resources
- carry out relevant ecological research and monitoring
- play an important role in education
- are protected by legislation
- have policing and guarding policies
- give the site economic value.

The effect of biogeographic factors

Biogeographic factors affect species diversity and so must be taken into account when planning nature reserves.

Island biogeography theory predicts that smaller islands of habitat will contain fewer species than larger islands. It is, therefore, inevitable that protected areas will have lost some of the diversity seen in the original undisturbed ecosystem. The principles of island biogeography can be applied to the design of reserves (Figure 14.35).

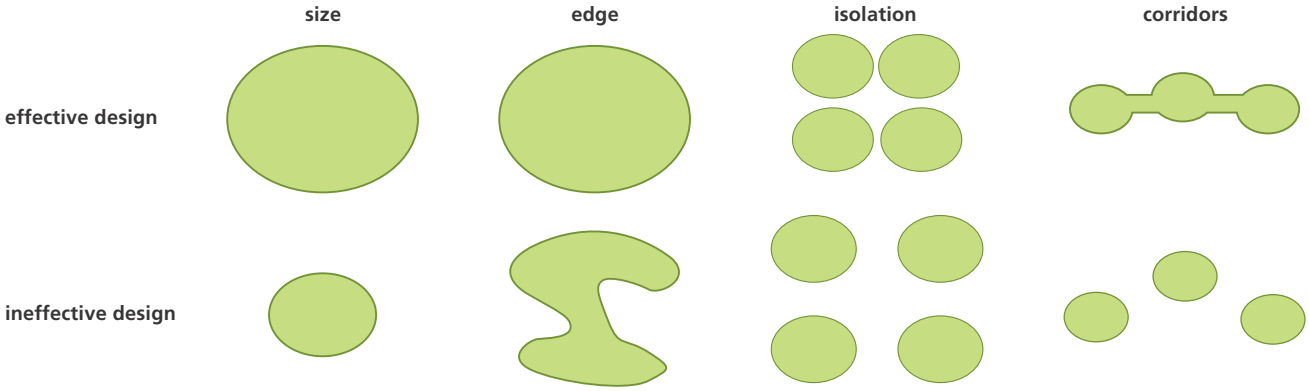


Figure 14.35 Features of effective nature reserves

Better	Worse
single large area	single small area
single large area	several small areas of the same total size
intact habitat	fragmented and disturbed habitat
areas connected by corridors	separated areas
round (= fewer edge effects)	not round (= more edge effects)

Table 14.8 Features of protected areas that are better or worse for conservation (see Figure 14.35)

Nature reserves that are better for conservation have the following features.

- They are large, so that they:
  - support a greater range of habitats and, therefore, greater species diversity
  - have higher population numbers of each species
  - have greater productivity at each trophic level, leading to longer food chains and greater stability.
- They have reduced edge effects (see below).
  - Fewer edge effects mean more of the area is undisturbed.
  - Edge conditions are very different from those of the interior habitat (hotter, less humid, and windier), and so flora and fauna that are interior specialists cannot survive in edge conditions.
  - The best shape for a reserve is a circle as this has the lowest edge to area ratio – it is better than an extended strip of land, or one that has an undulating edge, even if total area is the same.

- If areas are divided, then fragmented areas need to be close together to allow animals to move between fragments, or corridors are needed to join fragments.
  - Gene flow between fragmented reserves is maintained by allowing movement along corridors.
  - Movement of large mammals and top carnivores between fragments is maintained by corridors.
  - Top carnivores and large mammals are maintained and conserved.

Key fact

Biogeographic factors affect species diversity.

Expert tip

You need to understand the effects of island size and edge effects on diversity.

APPLICATIONS

Analysis of the impact of biogeographic factors on diversity

Figure 14.36 shows how variables associated with island biogeography theory correlate with species richness.

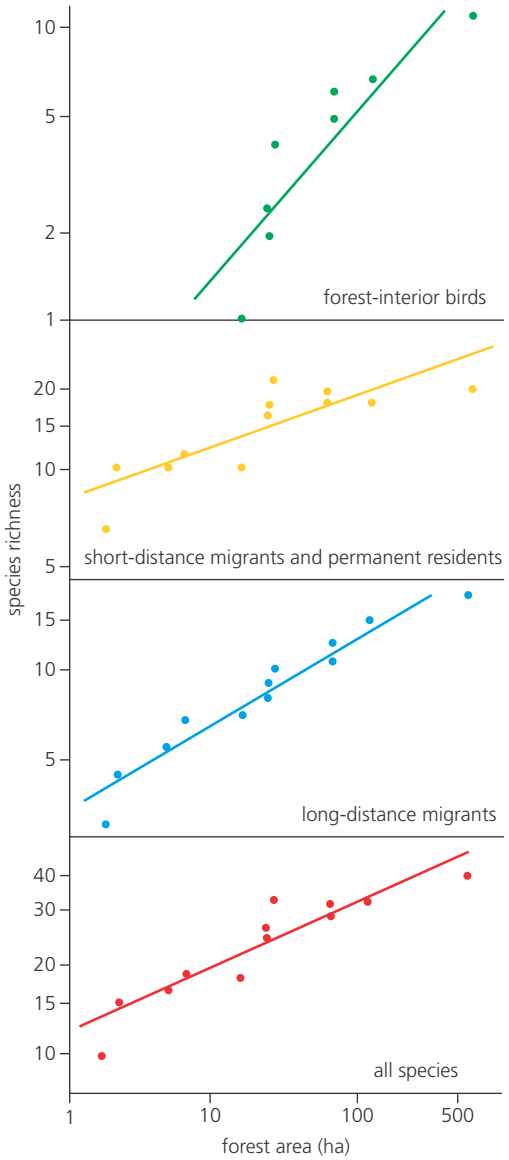


Figure 14.36 The theory of island biogeography explains species diversity

In each case, increasing island size increases species richness and also diversity. Diversity increases because:

- the range and diversity of niches increases as forest area increases
- the greater range of niches means that a larger number of species can co-exist
- both evenness and richness increase, leading to greater diversity.

Human disturbance can lead to the creation of habitat islands within areas of cleared land (Figure 14.35). Such habitat islands may form important nature reserves where surviving undisturbed ecosystems can be conserved. Edge effects, as well as island size, have an effect on diversity of these habitat islands (Figure 14.37).

- Edge effects exist at the boundary between two different habitats or ecosystems, e.g. where forest and land cleared for agriculture meet.
- As the total area becomes smaller, the edge becomes proportionally larger.
- Larger islands have a smaller perimeter: area ratio than smaller islands, and so have fewer edge effects:
  - In Figure 14.37, island A is larger than B or C and so has fewer edge effects.
  - Island B is larger than C, and so has a larger area of undisturbed forest than island C.
  - Island C is almost entirely edge habitat – this will have a very different species composition to undisturbed forest, with lower conservation value.
- The shape of the habitat area is important – elongated areas (island D, Figure 14.37) have a proportionally large edge effect than rounder areas.
- Edge areas can benefit some species that enjoy edge conditions, although these may be species from outside the habitat island.
  - Edge habitat will have a different species composition to interior forest.
  - Edge effects should be minimized if the largest area of undisturbed habitat is to be conserved.
- Species richness may increase in edge habitat (see Case study, page 118) because it represents the intersection of different habitats where species from these habitats can mix, although species diversity can decrease due to decreased evenness (see Case study).
- Fewer interior species will be found in edge habitat, and so edge habitat has lower conservation value.

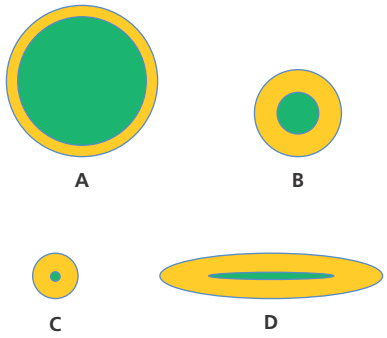


Figure 14.37 The effect of edge effects on habitat islands of different sizes and shapes. Yellow areas indicate edge habitat; green areas indicate interior undisturbed habitat

Ex situ conservation

***Ex situ* conservation** usually takes place in zoos, which carry out captive breeding and reintroduction programmes:

- A small population is obtained from the wild or from other zoos.
- Enclosures for animals are made as similar to the natural habitat as possible.
- Breeding can be assisted through artificial insemination.

Botanic gardens also have a role in plant *ex situ* conservation, where both living collections and seed banks are used to store genetic diversity.

The relative strengths and limitations of *ex situ* conservation are outlined in Table 14.9.

Key definition

***Ex situ* conservation** – the preservation of species outside their natural habitats.

Key fact

Ex situ conservation is the preservation of species outside their natural habitats.

Strengths	Limitations
populations can build up quickly as habitat and food are abundant	does not directly conserve natural habitat diversity of the species (conservation of habitat should lead to conservation of species)
abundant food and habitat reduce competition	not all species breed easily in captivity (for example, the giant panda)
allows predators and diseases to be controlled	difficult to maintain genetic diversity and so the gene pool of a species may be small
individual animals can be exchanged between collections to prevent inbreeding and to maintain genetic diversity	released animals may be easy targets for predators
successful examples are Arabian oryx and golden lion tamarin (see below)	aesthetic values can lead to an imbalance in conservation activity, so that popular and charismatic species are conserved (such as Madagascan lemurs) but small and less popular animals may not be part of a conservation programme (for example, endemic Madagascan hissing cockroaches)
	some countries may have technical or economic difficulties in establishing programmes

Table 14.9 The strengths and limitations of *ex situ* conservation

APPLICATIONS

CASE STUDY: THE GOLDEN LION TAMARIN

Expert tip

You need to know an example of the captive breeding and reintroduction of an endangered animal species.



Figure 14.38 A golden lion tamarin monkey

Species	Golden lion tamarin
Conservation status	critically endangered, but conservation status has been improved by intervention
Threats to species	90% of their original forest habitat (tropical rainforest) in Brazil has been cut down remaining habitat is small and fragmented the species is found in only one small area of Brazil and so is especially prone to extinction thought by some people to be carriers of human diseases, such as yellow fever and malaria, and were killed for this reason kept as pets as part of exotic pet trade
Ecological role	omnivore
Possible effects on ecosystem if the species disappeared	the species eats fruits, insects, and small lizards. Loss of the species would affect: • seed dispersal of plants that have fruits eaten by the monkey • species at lower trophic levels, e.g. insects and small lizards, which would become more numerous • species at higher trophic levels, which would become less numerous • food chains become shorter, giving changes in other trophic levels and producing imbalances in the forest food web
How are they being restored?	numbers in the wild have increased from a low of 400 in the 1970s to about 1000 today captive breeding programmes in zoos (*ex situ* conservation) have increased numbers that allow release into the wild

Table 14.10 Conserving the golden lion tamarin

Captive breeding has been carried out at institutions such as Bristol Zoo in the UK. There are also efforts to preserve the native forests of the monkey in Brazil (*in situ* conservation), for example at the Reserva Biologica de Poyo Antas, near Rio de Janeiro.

International cooperation to conserve biodiversity

NATURE OF SCIENCE

Scientists collaborate with other agencies – the preservation of species involves international cooperation through intergovernmental and non-governmental organizations.

Scientific research shows the impact that humans are having on the planet and indicate necessary conservation measures. Organizations then have a role in seeing that the necessary changes are brought about to preserve species.

- Governments and **intergovernmental organizations (IGOs)** have the ability to make the change that is necessary.
- Organizations not linked to government (**non-governmental organizations – NGOs**) also have a role in raising awareness of environmental issues and campaigning for change.

Examples of NGOs include Greenpeace and the World Wide Fund for Nature (WWF). IGOs such as the United Nations Environment Programme (UNEP) bring governments together to work to protect the Earth's natural resources. Each type of organization has contrasting roles and activities (Table 14.11).

Key definitions

Intergovernmental organizations (IGOs) – organizations established through international agreements.

Non-governmental organizations (NGOs) – organizations not run by, funded by, or influenced by governments of any country.

Key fact

The preservation of species involves international cooperation through intergovernmental and non-governmental organizations.

	NGO	IGO
speed of response	rapid: organizations can make their own decisions	slow: there must be agreement between governments
use of media	use films of activities (for example, chasing whaling boats) to gain media attention	professional: media liaison officers prepare and read written statements
diplomatic constraints	unaffected by political considerations activities may be illegal, although this is officially discouraged	many constraints: cannot make decision without agreement from all parties disagreements can cause serious constraints
political influence	green politics can establish environmental issues as part of the political process	direct access to the governments of many countries
enforceability	no direct power: must use public opinion to persuade governments to act	use international treaties and national or state laws to protect the environment, ecosystems and biodiversity

Table 14.11 The contrasting roles of NGOs and IGOs

Both IGOs and NGOs work together to preserve and restore ecosystems and biodiversity, and ensure that human activities are run on a more sustainable basis.

NGOs, because of the responsible and constructive role they play in society, are essential in implementing conservation measures within individual countries, such as:

- collecting data on conservation needs within a country
- monitoring and evaluating action from governments
- lobbying political parties and politicians to help implement sustainable development
- raising environmental awareness through publications, local activities, education, TV, and radio
- liaising with other NGOs; sharing information and best practice; creating networks; sharing resources.

QUICK CHECK QUESTIONS

1 Below is a comparison of species diversity in five habitats. Details of the Simpson indices of these habitats are incomplete.

	Number of individuals found in each habitat				
Species found	Habitat A	Habitat B	Habitat C	Habitat D	Habitat E
species 1	25	50	80	97	100
species 2	25	30	10	1	0
species 3	25	15	5	1	0
species 4	25	5	5	1	0
Simpson's index (*D*)	4.13		1.37	1.04	1.00

Table 14.12 Comparing the species diversity of five habitats

   a Calculate the Simpson's diversity index for habitat B using data from the table above.
   b Describe and explain the differences between the habitats shown in the table.
   c Suggest reasons for the different values of Simpson's reciprocal index recorded in different habitats.

2 Using Table 14.4, state the minimum Trent Biotic Index for a sample of water containing stonefly nymphs.

3 Using Table 14.4, state the maximum Trent Biotic Index for a water sample containing *Tubifex*.

4 Evaluate the particular challenges in management of a nature reserve that is maintained near your home, school, or college.

14.5 Population ecology (*AHL*)

Essential idea: Dynamic biological processes impact population density and population growth.

Estimating population size

Sampling techniques are used to estimate population size. The type of sampling method will depend on the nature of the organism being studied.

- For non-mobile species, quadrats and transects are suitable techniques, because the organisms do not move away from the sample area.
- For mobile species, other methods are needed. For animals, a common technique is known as the 'capture–mark–release–recapture' method (usually abbreviated to mark, release, recapture, or MRR).
  - In this method, animals are sampled, marked in some way, released back into the wild, and then resampled.
  - The MRR method allows ecologists to estimate population size by using the ratio of animals marked in the first sample to the number of marked animals resampled to estimate the total population size (see page 125, this chapter).

Random sampling

NATURE OF SCIENCE

Avoiding bias – a random number generator helps to ensure population sampling is free from bias.

Samples are used to obtain a representative sample of populations from the area being studied.

- Samples are taken because it is not possible to study the entire ecosystem.
- Samples must be located at random, so that accurate representative data can be acquired.
- A random number generator helps to ensure population sampling is free from bias.

Expert tip

Random number generators can be found on most modern calculators. In addition, sites on the Internet offer random number generators, such as **www.random.org/** as do apps for smart phones (sometimes advertised as 'integer generators').

Sampling plant populations using quadrats

Quadrats are commonly used to estimate plant populations (Topic 4, page 119).

Key definition

Quadrat – a square frame which outlines a known area for the purpose of sampling.

- The choice of size of quadrat varies depending on the size of the individuals of the population being analysed:
  - 10 cm^2 quadrat is ideal for assessing epiphytic *Pleurococcus*, a single-celled alga, found growing on damp walls and tree trunks.
  - 1 m^2 quadrat is far more useful for analysing the size of two herbaceous plant populations in grassland.
- Quadrats are placed according to random numbers, after the area has been divided into a grid of numbered sampling squares (Figure 4.12, page 119).

The different plant species present in the quadrat are then identified and various measurements can be taken:

- Density – mean number of individuals of each species per unit area.
- Frequency – number of quadrats in which a species occurs, expressed as percentage
- Percent cover – the percentage of ground covered by a species
- Abundance – subjective assessment of species present, using the DAFOR scale (D = dominant, A = abundant, F = frequent, O = occasional, R = rare).

APPLICATIONS

Lincoln index

The capture–mark–release–recapture method is used to estimate the population size of a mobile animal species. This method is also known as the Lincoln index.

- Organisms are captured, marked, released, and then recaptured.
- Marking varies according to the type of organism.
  - Wing cases of insects can be marked with pen.
  - Snails can be marked with paint.
  - Small areas of clipped fur can be used for mammals.
- Markings must be difficult to see – high visibility increases predation risk.
- The number of individuals of a species is recorded at each stage.

The total population size is estimated using the following equation:

$$N = \frac{n_1 \times n_2}{m}$$

where N = total population of animals in the study site, n_1 = number of animals captured (marked and released) on first day, n_2 = number of animals recaptured on second day, and m = number of marked animals recaptured on second day.

The steps of the MRR technique are outlined in Figure 14.39.

Assumptions made when using the index on wild animal populations are that:

- mixing is complete, so that the marked individuals have spread evenly throughout the population
- marks do not disappear
- marks are not harmful nor do they increase predation by making marked individuals more visible
- it is equally easy to catch each individual
- there is no immigration or emigration, or births or deaths in the population between the times of sampling.

Expert tip

You need to know how to use the capture–mark–release–recapture method to estimate the population size of an animal species.

Population growth

Populations are affected by four main factors:

- natality – the rate at which individuals are born (the birth rate)
- mortality – the rate at which individuals die (the death rate)
- immigration – movement of new individuals into a population from outside a given area
- emigration – the departure of individuals from a population in a given area.

Population growth can be calculated in this way:

Population growth = (I + N) – (E + M)

where I = immigration, N = natality, E = emigration and M = mortality.

Expert tip

Natality and immigration add individuals to a population. Mortality and emigration remove individuals from a population.

In 'mark, release, recapture' the size of the animal population is estimated by the formula:

$$N = \frac{n_1 \times n_2}{m}$$

where

N = the population being estimated

n_1 = number captured, marked and released

n_2 = total number captured on the second occasion

m = number of marked individuals recaptured

Here: $N = 5 \times 8 / 1 = 40$

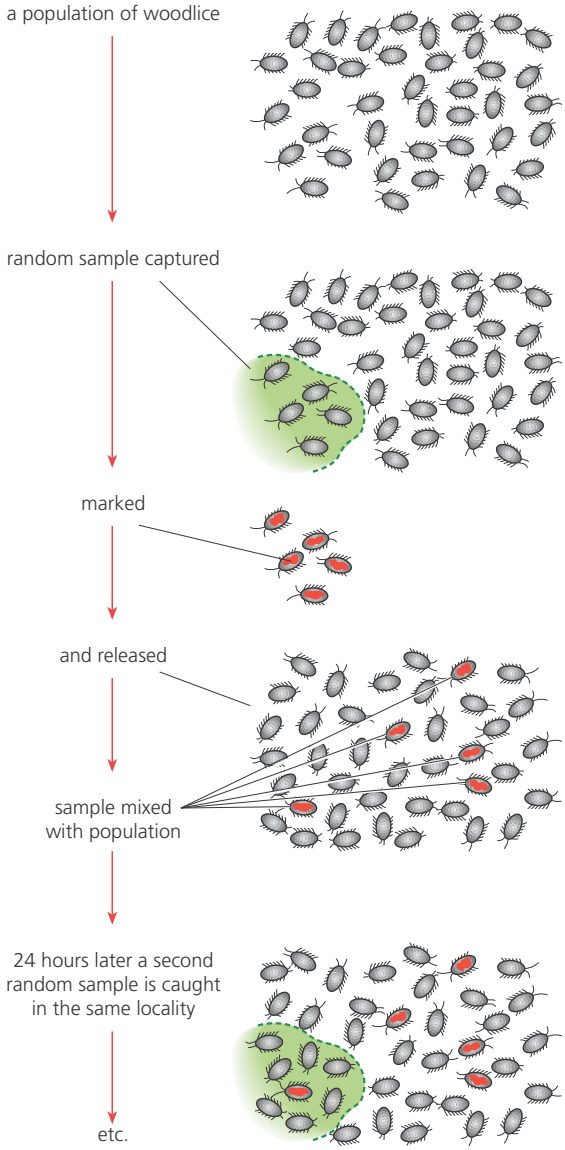


Figure 14.39 Estimating animal populations using mark, release, and recapture

If the growth is calculated over a year, this gives the growth rate. For example, if the input and output of individuals into a population are as follows:

- annual birth rate = 15 per 1000
- annual death rate = 9 per 1000
- annual immigration rate = 4 per 1000
- emigration rate = 6 per 1000

then the population growth rate will be:

$(15 + 4) – (9 + 6) = 4$

This population, growing at this rate over a year, will increase by four individuals for every 1000 in the population.

APPLICATIONS

The effect of natality, mortality, immigration, and emigration on population size

A population faces one of three possible situations:

1 Immigration and natality are, when combined, higher than emigration and mortality combined. This leads to population *growth*.

This can be represented by the equation:

I + N > E + M

2 Immigration and natality are, when combined, the same as emigration and mortality combined. This leads to population *stability*.

This can be represented by the equation:

I + N = E + M

3 Immigration and natality are, when combined, lower than emigration and mortality combined. This leads to population *decline*.

This can be represented by the equation:

I + N < E + M

Exponential growth

Exponential growth is sometimes referred to as a J-shaped or J-population curve (Figure 14.40). The exponential growth pattern occurs in an ideal and unlimited environment.

Key definition

Exponential growth – an increasing or accelerating rate of growth.

CASE STUDY: GROWTH IN RABBIT POPULATIONS

A small number of rabbits are allowed to enter a meadow where other rabbits have been excluded.

- The rabbits initially get used to the new territory and establish burrows.
- There are few reproducing individuals, so initially population growth is small.
- Once established, the rabbits benefit from unrestricted access to rich food supplies and an absence of limiting factors – they begin to reproduce.
- Once numbers start to build up there is a rapid increase in the population: such rapid increase is called exponential growth.

Key fact

The exponential growth pattern occurs in an ideal, unlimited environment.

Exponential growth occurs when:

- limiting factors are not restricting the growth of the population
- there are plentiful resources such as light, space and food, and a lack of competition with other species
- there are favourable abiotic components, such as temperature and rainfall, and a lack of predators or disease.

Growth is initially slow but becomes increasingly rapid, and does not slow down as population increases.

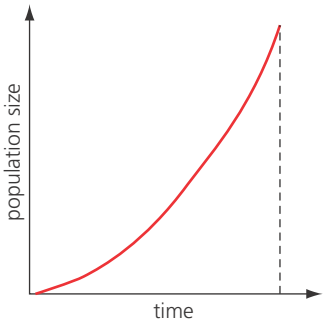


Figure 14.40 A J-shaped (exponential) growth curve

Carrying capacity and the S-shaped population curve

In most ecosystems, limiting factors restrict the growth of a population or prevent it from increasing further:

- Limiting factors in plants include light, nutrients, water, carbon dioxide, and temperature.
- Limiting factors in animals include space, food, mates, nesting sites, and water.

CASE STUDY: CARRYING CAPACITY IN RABBIT POPULATIONS

Returning to the example of the rabbits introduced into a new meadow:

- After the initial exponential growth, eventually the vegetation would be used up faster than it grew, because of the large numbers of rabbits.
- Further increases in population would stop: in this situation the food has become a limiting factor in the growth of the rabbit population.
- Eventually, the rabbits would reach their carrying capacity.

The **carrying capacity** of a population is affected by various limiting factors, such as:

- the availability of food and water
- territorial space
- sites for nesting
- predation
- disease
- the availability of mates.

The carrying capacity represents the population size at which **environmental resistance** limits further population growth, leading to a decrease in natality, an increase in mortality, or both. When a graph of population growth is plotted against time, an S-population curve is produced, showing an initial rapid growth (exponential growth) and then slows down as the carrying capacity is reached (Figure 14.41).

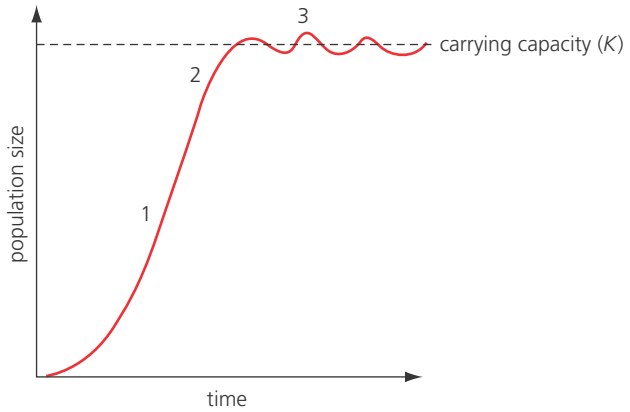


Figure 14.41 An S-shaped or sigmoid growth curve. The curve shows the establishment of a population following introduction into a new environment

There are three stages:

1 Exponential growth stage
   - Limiting factors are not restricting the growth of a population.
   - The population expands exponentially into the habitat.
   - Both the number of individuals and the rate of growth increase rapidly.

2 Transition phase
   - The increase in number begins to slow, as does the rate of growth.
   - The slowdown occurs because limiting factors begin to affect the population and restrict its growth.
   - In a larger population there will be increased competition between the individuals of that population for the same limiting factors, such as resources.
   - An increase in predators, attracted by the large population, and an increase in rate of disease and mortality due to increased numbers of individuals living in a small area, also cause a slowdown in growth.

3 Plateau phase
   - Limiting factors restrict the population to its carrying capacity.
   - The population reaches its carrying capacity (see below).
   - Changes in limiting factors, predation, disease, and abiotic factors cause populations to fluctuate (increase and decrease) around the carrying capacity (*K*).

Key definitions

Carrying capacity – the maximum number of a species or the 'load' that can be sustainably supported by a given environment. The population size at which environmental resistance limits further population growth.

Environmental resistance – when limiting factors affect population growth.

Key fact

Population growth slows as a population reaches the carrying capacity of the environment.

Key fact

The phases shown in the sigmoid curve can be explained by relative rates of natality, mortality, immigration, and emigration.

The phases of the S-curve can be summarized as equations using natality, immigration, emigration and mortality:

Phase	Equation	Relative effects	What is happening?
exponential	I + N > E + M	initially, natality exceeds mortality; as population rapidly increases, mortality rates begin to increase	no limiting factors; abundant resources
transition	I + N > E + M	natality rate approaches mortality rate	resources are more scarce; competition increases; low competition; high reproduction
plateau	I + N = E + M	fluctuation around a set point; where the curve slopes downwards, M > N; where it slopes upwards, N > M	population stabilizes around the carrying capacity

Table 14.13 The phases shown in the sigmoid curve can be explained by relative rates of natality, mortality, immigration and emigration

Comparing exponential and sigmoid growth curves

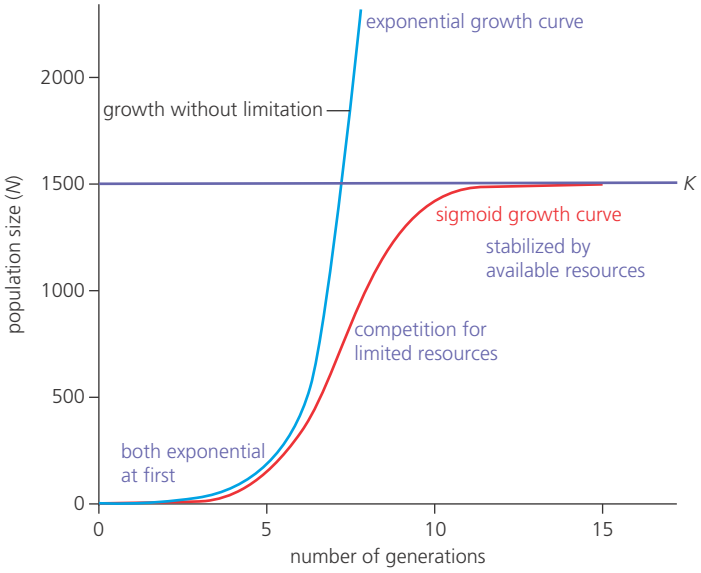


Figure 14.42 Comparing exponential and sigmoid growth curves

Modelling the growth curve using duckweed

Duckweed (*Lemna*) is a free-floating aquatic plant (Figure 14.43). These rapidly growing plants are used as a model system for studies in **population ecology**. They follow the classic growth curve and can therefore be used effectively to model the changes in population size.

An experiment on population growth in *Lemna* can be carried out in the lab:

1. A small number (e.g. 15) of duckweed thalli (leaf units that are over 1.5 mm in diameter) are put in a cup or beaker containing pond water (200–300 cm^3).
2. Replicates (at least five) of the experiment are set up.
3. The number of thalli is counted twice a week, for at least 6 weeks.
4. The mean number of thalli is calculated and plotted against time.
5. The graph should show the S-shaped/sigmoid population growth curve. Carrying capacity is reached when there is no room for further thalli, and competition for space limits further growth.

Expert tip

You need to know how to model the growth curve using a simple organism such as yeast or species of *Lemna*.

Key definition

Population ecology – concerned with the study of factors that influence the numbers and structure of a population.



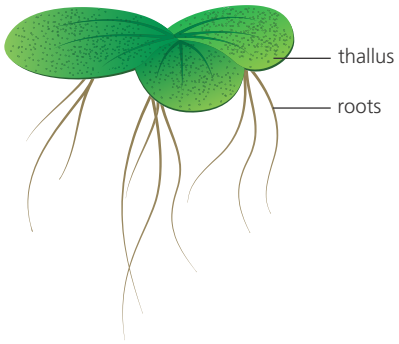


Figure 14.43 Duckweed of the genus *Lemna*, covering the surface of a pond and diagram of duckweed thallus

The effect of different environmental conditions on growth rate can be studied, such as salinity, pH, concentration of nitrates, and phosphate level. Of course, one environmental condition should be changed at a time.

Expert tip

Yeast is another simple organism that is used in population ecology studies.

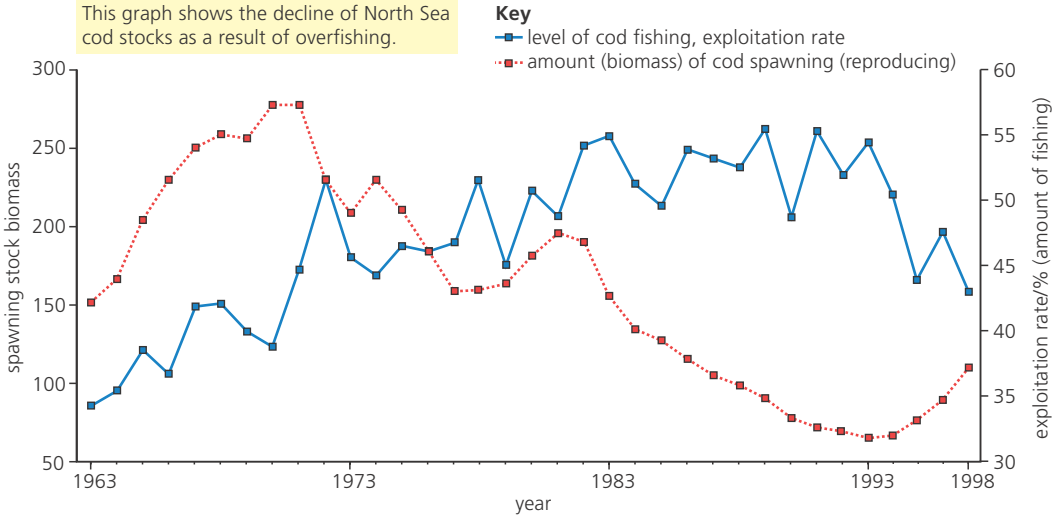
APPLICATIONS

Sustainable fishing practices

Fish are an important source of food for many human populations. The majority of fish populations that are exploited commercially as food sources are marine species, and it is commonly the case that the populations are shared among a number of harvesting countries.

- Fishing vessels from many nations take their harvest from common waters and overfishing is now a global issue (Figure 14.44).
- Conflict between economic and conservation interests arises.
  - Demand for the harvest of the seas and the need for economic returns for fishermen have to be balanced with our obvious need to sustain the resources themselves.
  - In fact, the scale of commercial fishing has seriously depleted many stocks in recent years.

This graph shows the decline of North Sea cod stocks as a result of overfishing.



As the amount of fishing has been reduced (since about 1990), the decline in spawning fish has been reversed. With time, this trend may allow stocks to recover completely.

Figure 14.44 Overfishing in European waters

If populations of fish are persistently overfished, stocks will be rapidly depleted to the point where they collapse and can no longer support a commercial fishery. The extent to which species are fished should be based on population dynamics that take into account their reproductive and growth rates (see below).

The effect of population size, age, and reproductive status on sustainable fishing practices

Sustainable fishing practices mean using methods of catching fish that do not diminish the fish stock.

- The **maximum sustainable yield (MSY)** corresponds to optimum balance between
  - the reproductive rate and growth rate of the stock
  - deaths due to harvesting and natural mortality.
- Harvesting at MSY requires much lower fishing rates than occur in many fisheries.
- If fish were harvested at the MSY then fishing would be able to continue in a sustainable way.

Key definition

Maximum sustainable yield (MSY) – the maximum average catch that a stock can sustain over a long period of time.

A growing and healthy fish population is indicated by:

- a relatively larger number of younger fish (a declining population would have a larger number of older fish relative to younger fish)
- high numbers of young fish, showing good spawning potential for the population
- the presence of older fish in the population, showing that fish have had a long time to reproduce successfully.

Population size and age structure can be used to inform practices associated with sustainable fishing. Most practices depend on international cooperation, as fish stocks are spread over large areas that cover many national boundaries. Practices include:

- putting restrictions on catching younger fish (mesh size restrictions on nets help to achieve this)
- exclusion zones and periods when fishing is not permitted to allow stocks to recover
- quotas are set for fish species that have low population sizes
- suspensions are put on the fishing of endangered species
- damaging methods of fishing are often banned.

Expert tip

Population age structures can, along with population size, indicate whether fishing methods are sustainable or not.

Evaluating the methods used to estimate the size of commercial stock of marine resources

To enable effective conservation of fish stocks and to create sustainable fishing policies, accurate measurements of existing fish stocks are essential. Methods used to estimate the population size of marine animals have limitations:

- Species are highly mobile and using techniques such as capture–mark–release–recapture (page 125, this chapter) is ineffective because very few marked individuals are recaptured.
- Echo-sounders can be used to locate shoals of fish, but not all species form shoals. In rivers and streams, electric-shock capture methods can be used (an electric charge is discharged into the water from a small generator and stunned fish are caught with a net) – something that is not possible in the open ocean.
- Electric-shock capture methods can be used (an electric charge is discharged into the water from a small generator and stunned fish are caught with a net) – this is not possible in the open ocean.

Data gathered from fish catches can, however, be used to estimate population size. Information on the state of fish stocks is based on four parameters which are measured or assessed by the fishery research services of national governments.

These are:

- fishing mortality – the proportion of fish stocks taken each year during commercial fishing
- spawning stock biomass (SSB) – the total mass of mature fish in the population
- recruitment – the number of young fish produced each year which survive to enter the spawning stock
- landings – the total annual tonnage of fish landed by the fishing fleet.

These methods rely on the cooperation of the fishing community, because estimates of fish stocks rely on accurate measurement of age structure.

- Operators who work outside the regulations and discard restricted fish at sea before returning to port create skewed data that can lead to miscalculation of stock size.
- Calculation of MSY requires good knowledge of the relationship between the size of the stock and the number of juveniles produced each year. The natural variation in the number of juveniles produced annually makes establishing this relationship difficult. It usually requires a very long series of data – at least 20 years' worth.

APPLICATIONS

Controlling the effects of pollution

- Pollution can be caused by pesticide use, such as DDT (pages 109–110, this chapter).
- Indicator species can be used to investigate specific environmental conditions resulting from pollution (pages 113–115, this chapter)
- Pollution from plastics is a global problem (pages 110–112, this chapter).

In the next section, fertilizer use in agriculture will be examined and how it can lead to pollution, specifically a phenomenon known as eutrophication, whereby excessive algal growth in bodies of water causes a reduction in dissolved oxygen.

Controlling algal growth using limiting factors

Algal growth can be controlled in two contrasting ways. Both examples limit algal growth by utilizing limiting factors.

- Bottom-up control:
  - reduction in fertilizer use and use of slow-release sources of nutrients such as manure
  - reduction in the supply of nutrients will reduce algal growth, as there will be less raw material to construct proteins
  - water quality is improved by reducing nitrogen and/or phosphorus inputs into aquatic systems
  - nutrient reduction can, however, be difficult and expensive, especially in agricultural areas where the nutrients washing into the rivers and lakes come from a variety of different sources (such as from different farms).
- Top-down control:
  - use of herbivores to consume the excessive algal growth
  - can involve the alteration of a food web to restore ecosystem health (Figure 14.45)
  - such control is known as biomanipulation.

Expert tip

You need to know how algal blooms can be controlled using bottom-up and top-down methods.

Expert tip

Bottom-up control of algal blooms uses shortage of nutrients and top-down control uses herbivory.

Key fact

Limiting factors can be top down or bottom up.

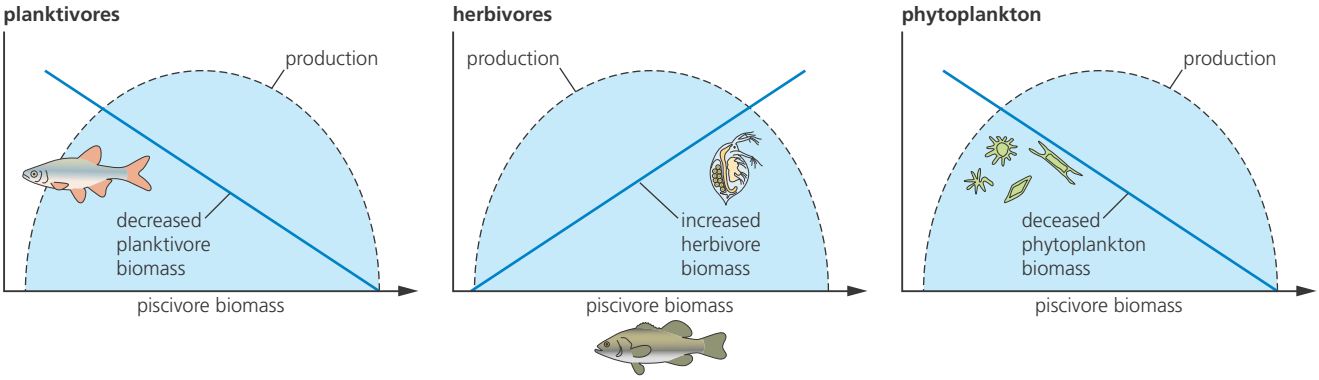


Figure 14.45 Top-down control of eutrophication. Biomanipulation of fish-eaters (piscivores) leads to a reduction in planktivores and a corresponding increase in herbivore biomass. The result is an overall reduction in phytoplankton (algal) biomass

The biomanipulation shown in Figure 14.45 encourages the population growth of *Daphnia*, a generalist herbivore that plays a significant role in controlling the abundance of algae in normal lake ecosystems.

- Fish-eating fish (piscivores) are added to the water to reduce the number of plankton-eating fish (zooplanktivores), which in turn leads to an increase in the number of *Daphnia* and the rate of herbivory on the algae, reducing the algal bloom.

Biomanipulation has been shown to have typically short-lived effects on water quality (lasting weeks to months) and is only applicable in small, easily-managed systems such as ponds.

QUICK CHECK QUESTIONS

1 Calculate the population growth rate when:

annual birth rate = 14 per 1000, annual death rate =11 per 1000, annual immigration rate = 5 per 1000, and emigration rate = 7 per 1000.

2 Discuss the effect of natality, mortality, immigration, and emigration on population size.

3 Describe a sampling technique that can be used to estimate the population size of a motile species.

4 Explain how limiting factors can be used to control algal growth following nutrient enrichment. Explain the difference between bottom-up and top-down approaches.

14.6 Nitrogen and phosphorus cycles (*AHL*)

Essential idea: Soil cycles are subject to disruption.

The nitrogen cycle

Nitrogen is needed to synthesize amino acids and proteins, and so a regular supply of nitrogen needs to be made available to food chains:

- The majority of nitrogen on the planet is found in the atmosphere – 78% of the air is nitrogen (N_2).
- Eukaryotic organisms cannot use nitrogen gas directly as it is inert (the two nitrogen atoms are triple bonded and so are very difficult to separate).
- To separate the nitrogen atoms, a great deal of energy is needed.
  - Lightning can split N_2 to form an oxide of nitrogen (NO_3^-)
  - Nitrogen-fixing bacteria can convert nitrogen gas into a usable form (see below).

Nitrogen is taken into plants as nitrate. Once nitrogen is contained within organisms it can be used in growth and metabolic reactions. To complete the cycle, nitrogen is returned to the atmosphere or back into the soil, where it can be taken up once again by plants.

Nitrogen-fixing bacteria

Nitrogen-fixing bacteria convert N_2 into ammonia (NH_3), which dissolves in water to form NH_4.

- Some of these bacteria live in the soil (genus *Azotobacter*).
- Other nitrogen-fixing bacteria (genus *Rhizobium*) live in the roots of leguminous plants.
- Ammonium can be absorbed by plants, although if it is in too high a concentration it can prove toxic.
- Ammonium is converted by other bacteria into nitrates, which can be safely absorbed by plant roots.

Rhizobium is a bacterium that lives in the root nodules of clover plants (Figure 14.46) and other legumes. *Rhizobium* associates with roots in a mutualistic relationship.

Key fact

Nitrogen-fixing bacteria convert atmospheric nitrogen to ammonia. Other bacteria then convert ammonium ions to nitrates.

- The plant benefits from the nitrates (formed after other bacteria convert ammonium).
- The plant supplies carbohydrates to the bacteria in the root nodule.
  - This is very nutritionally expensive for the plant (it loses a source of glucose) but it does enable it to live in nitrate-deficient soils.
  - The bacteria need a ready supply of glucose for respiration that supplies the energy to split the triple-bonded nitrogen.

Nitrogen fixing takes place as follows:

  - *Rhizobium* are aerobic.
  - Nitrogen fixation needs lots of energy, which requires large amounts of ATP.
  - The most ATP is generated by aerobic respirations.
- The *Rhizobium* contain an enzyme, nitrogenase, which catalyses nitrogen fixation. This reaction is blocked by exposure to oxygen (by competitive inhibition) because N_2 and O_2 are approximately the same size and shape.
- Oxygen exclusion is therefore necessary for nitrogen fixation. This problem is solved in *Rhizobium*:
  - *Rhizobium* has an exceptionally fast and efficient aerobic metabolism meaning very little oxygen builds up in the root nodules.
  - The root nodule has a chemical called leghemoglobin which, like hemoglobin in blood, has a high affinity for oxygen.
  - Leghemoglobin removes oxygen from the nodule, allowing nitrogen fixation to occur catalysed by nitrogenase.



Figure 14.46 Root nodules on the roots of clover. The nodules are created by the nitrogen-fixing bacterium *Rhizobium trifolii*. The bacteria convert atmospheric nitrogen into a usable organic form, something the clover cannot do itself

Key fact

Rhizobium associates with roots in a mutualistic relationship.

The role of decomposers

Other bacteria that are vital to the nitrogen cycle are the decomposers.

- These bacteria break down dead organic matter and manure into ammonia. They feed on protein and break it down saprophytically – a process called ammonification or putrefaction.
- Once the ammonia is in the soil in the form of ammonium ions, other bacteria can convert the ammonium ions into different inorganic forms (nitrites and nitrates) – see below.

Expert tip

Farmers plant clover to increase the nitrate content of the soil and plough the crop into the ground rather than harvest it. Regular ploughing and good drainage keep conditions in the soil aerobic for the *Rhizobium*.

Nitrifying bacteria

Other bacteria convert ammonium ions into nitrite (genus *Nitrosomonas*) and then nitrate (genus *Nitrobacter*) – a process called nitrification. Oxygen is needed for these processes.

- The bacteria oxidize ammonium ions into first nitrite and then nitrite.
- They release energy which they can use to convert inorganic molecules (water and carbon dioxide) into organic molecules (glucose).
- Because these bacteria can make their own sugars, they are autotrophic: because they do this by utilizing the energy from chemical reactions, they are known as chemoautotrophs.

The bacteria get a source of food and plants get a usable form of nitrogen.

Because oxygen is vital to these nitrifying bacteria, soil must be well aerated:

- Farmers achieve this by ploughing the soil.
- This ensures that soils have a good supply of functioning nitrifying bacteria and, hence, nitrates.
- Nitrates in the soil are essential for healthy plant growth.

Expert tip

It is not correct to say that all energy in food chains comes from the Sun – some is generated by chemoautotrophs.

Denitrifying bacteria

- In the absence of oxygen, denitrifying bacteria reduce nitrate (NO_3^-) in the soil to N_2.
- This process is called denitrification.
- Denitrifying bacteria, such as *Pseudomonas denitrificans*, can survive in low-oxygen conditions because they can use nitrate as an electron acceptor in respiration, leaving the nitrogen to return to the atmosphere in the form of nitrogen gas (N_2).

Key fact

In the absence of oxygen denitrifying bacteria reduce nitrate in the soil.

Farmers aerate their soil by ploughing so as to increase the amount of nitrifying bacteria but limit the amount of denitrifying bacteria.

- Soils with lots of denitrifying bacteria will be low in nitrates.
- This affects plant growth and yield.

Diagram of the nitrogen cycle

Expert tip

You are expected to be able to draw and label a summary diagram of the nitrogen cycle. Your diagram should show the roles of *Rhizobium*, *Azotobacter*, decomposers, *Nitrosomonas*, *Nitrobacter*, and *Pseudomonas*.

Figure 14.47 shows the nitrogen cycle – this is a summary of the information outlined above, and shows how this vital element recycles between the atmosphere, soil and living biomass.

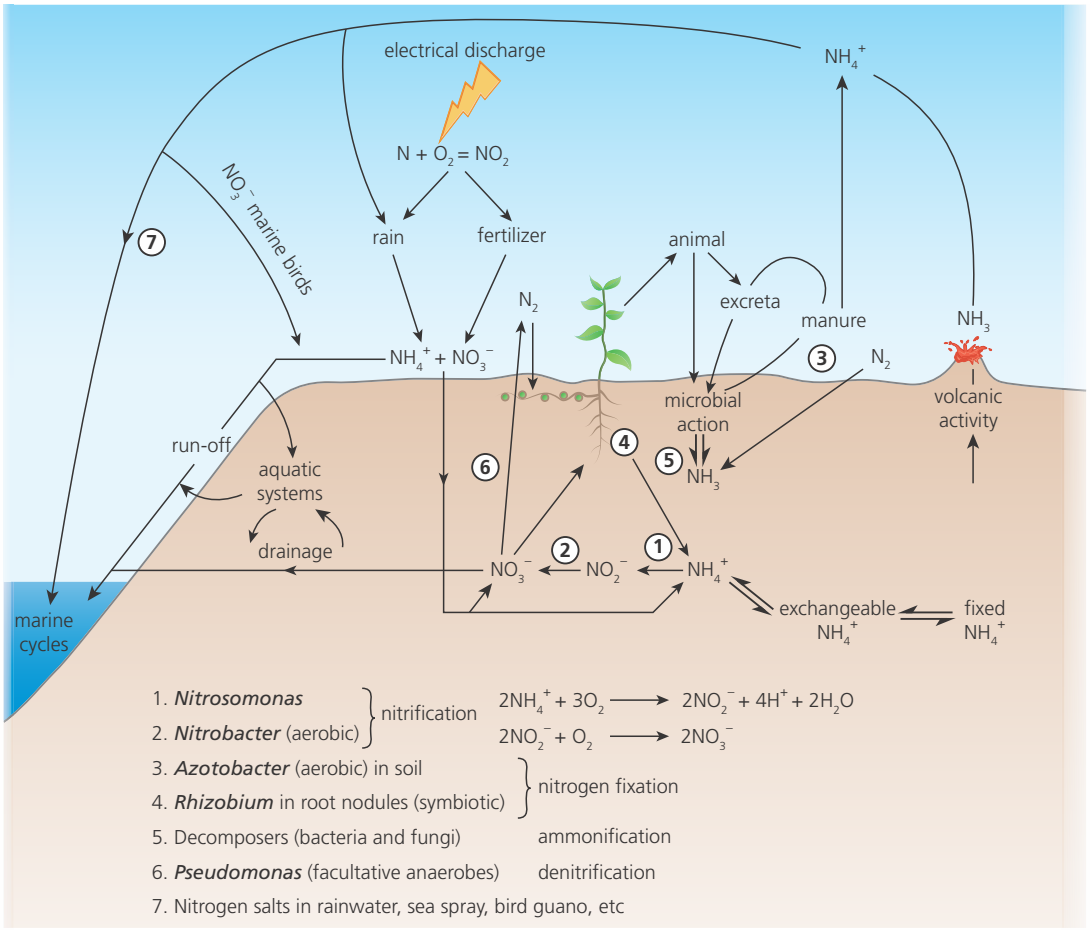


Figure 14.47 The nitrogen cycle

APPLICATIONS

The impact of waterlogging on the nitrogen cycle



Figure 14.48 A waterlogged field

Flooding or poor irrigation of fields can leave soil waterlogged (Figure 14.48).

- Because water fills air spaces in the soil, oxygen becomes limiting.
- These conditions favour the *Pseudomonas* bacteria and the process of denitrification.
- The denitrifying bacteria reduce nitrates to N_2, resulting in poor plant growth.

Excessive irrigation (watering) can be a problem for the same reason:

- This results in the proliferation of denitrifying bacteria.
- This leads to a reduction in soil nitrates.

APPLICATIONS

Insectivorous plants and the nitrogen cycle

Many habitats, such as swamps and bogs, have permanently waterlogged soils. These conditions are ideal for denitrifying bacteria, leading to nitrogen-deficient soils. Some plants are adapted to overcome low nitrogen availability.

- Adaptations enable these plants to obtain nitrogen in the form of protein from small invertebrates such as insects.
- These plants are therefore carnivorous (or, more specifically, insectivorous).
- Once the insect has been trapped, its amino acids and peptides are absorbed following extracellular digestion.

Key fact

Low nitrogen availability in waterlogged soils has led to the evolution of insectivorous plants, which obtain the nitrogen they need from insect protein rather than soil nitrates.

CASE STUDY: THE SUNDEW – AN EXAMPLE OF AN INSECTIVOROUS PLANT

The sundew (Figure 14.49) is an example of a carnivorous plant.

- The plant has tentacles that extend from the leaf surface.
- Sugary droplets at the tips of the tentacles attract insects to the plants. Insects stick to the longer tentacles, at which point the leaf curls over the insect.
- Digestive enzymes are secreted from the tentacles. These break the insect protein down into a form that can be absorbed by the modified leaf.



Figure 14.49 A sundew

Expert tip

Other examples of carnivorous plants include the pitcher plants and Venus fly trap.

The phosphorus cycle

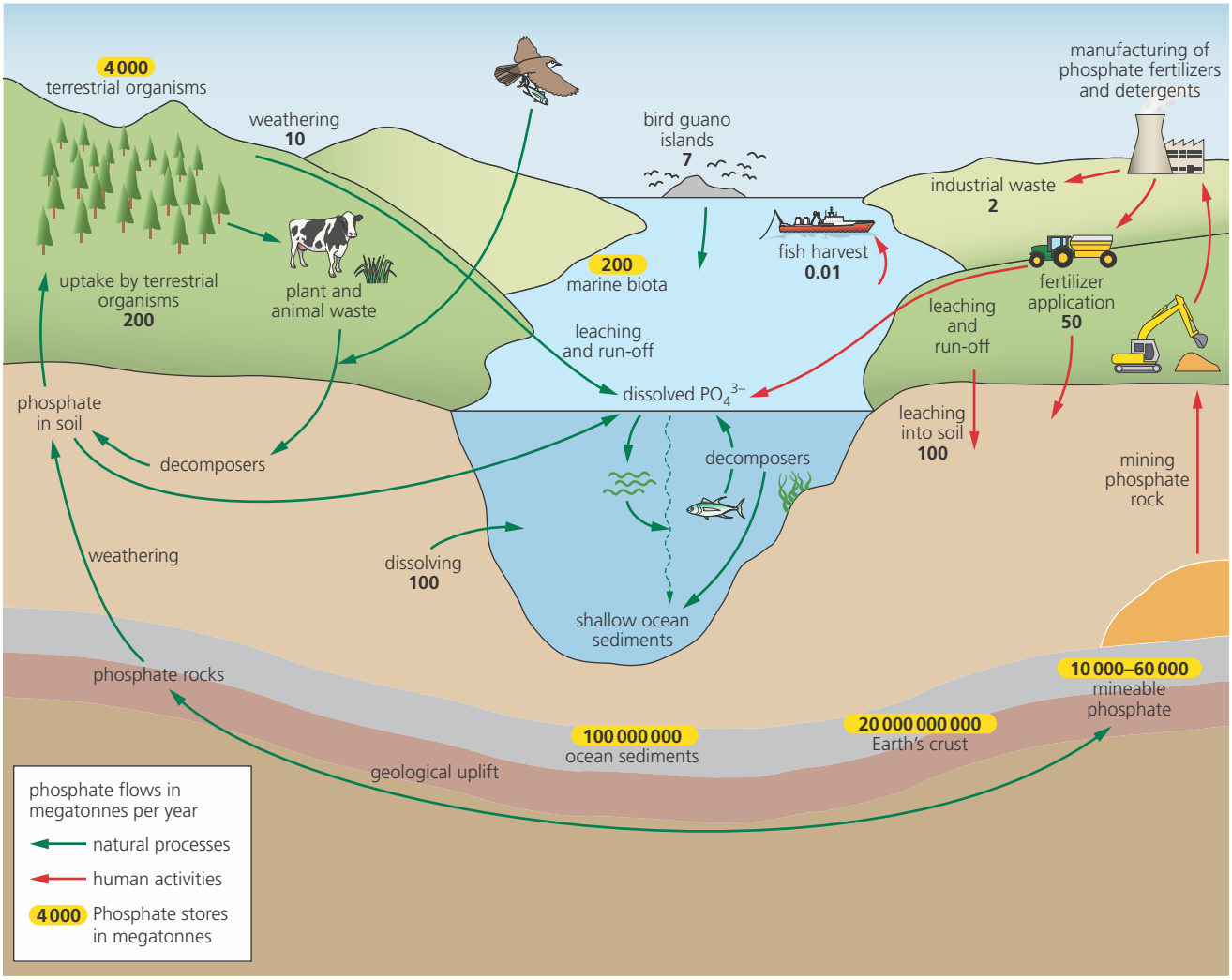


Figure 14.50 The phosphorus cycle

Living organisms need phosphorus for a range of structures:

- DNA and RNA
- ATP
- coenzymes in respiration and photosynthesis, NAD, FAD, and NADP
- phospholipids in cell membranes
- to maintain skeletons in vertebrates.

Turnover is the rate at which phosphorus moves from one store to another.

- Because phosphorus does not have a gaseous form, the rate of turnover in the phosphorus cycle is much lower than the nitrogen cycle.
- Much of the store of phosphorus is in the form of rock (Figure 14.50)
- Mining and erosion release phosphorus back into the cycle, ending up in the biotic environment.
- Phosphorus is only slowly released from rocks to ecosystems, making the rate of turnover low.

Key fact

The rate of turnover in the phosphorus cycle is much lower than the nitrogen cycle.

Fertilizers and their effects

NATURE OF SCIENCE

Assessing risks and benefits of scientific research – agricultural practices can disrupt the phosphorus cycle.



Figure 14.51 Tractor applying fertilizer to a field

The rapid growth of the human population has put increasing pressure on the land, as intensive agricultural methods attempt to extract as much food per unit of farmland as possible.

Phosphorus can be mined and converted to phosphate-based fertilizer. Fertilizer is added to soils to increase productivity (Figure 14.51). In this way, phosphorus can be added to the phosphorus cycle.

- Nutrients such as phosphate are taken up in the biomass of the crops.
- When agricultural crops are harvested, the phosphorus is moved from the place it was applied as fertilizer to the place the crops are sold.
- The phosphorus does not recycle as it would be in a natural ecosystem, and must be replaced through the use of fertilizer within the ecosystem.
- All these factors affect the phosphorus cycle.

Phosphate dissolves in water to form phosphate ions. In waterlogged soils, run-off containing phosphate ions can contribute to nutrient-enrichment in nearby rivers, streams and ponds (the process of eutrophication, see below).

Availability of phosphate may become limiting to agriculture in the future

Modern intensive farming practices rely on phosphate, much of which is mined from stores in rocks. Data suggest that the maximum rate of phosphate production from mining is approaching, after which supplies will start to decrease.

- Availability of phosphate may become limiting to agriculture in the future.
- The point at which phosphate production is at its highest is known as 'peak phosphorus'.
- Lack of availability of phosphorus is of concern to farmers because, with reduced phosphate supply, the cost of fertilizers will increase.
- The problem may become serious within 50 to 100 years.
- Without the addition of fertilizer, the productivity of fields will dramatically reduce and famine could result.
- Whereas ammonia can be created by industry, using the Haber process, there is no process that can make phosphate industrially.

Humanity needs to find alternative ways of conducting agriculture (ones that do not rely so heavily on fertilizer), and better ways to conserve nutrients, if the ever-expanding human population is to continue to be fed.

Key fact

Phosphorus can be added to the phosphorus cycle by application of fertilizer or removed by the harvesting of agricultural crops.

Key fact

Agricultural practices can disrupt the phosphorus cycle.

Eutrophication

Eutrophication is the natural or artificial enrichment of a body of water, particularly with respect to nitrates and phosphates. There are both natural and human causes of eutrophication.

- Natural effects include nutrients being added from decomposing biomass and run-off from areas surrounding the body of water.
- Human causes include:
  - run-off of fertilizers or manure from agricultural land
  - domestic waste water containing phosphates from detergents
  - non-treated sewage.

Leaching of mineral nutrients from agricultural land into rivers causes eutrophication:

- as more nutrients are added to rivers the biomass of algae increases due to the availability of nutrients
- the growth of algae (Figure 14.52) gives lower light penetration, causing underwater plants to die and release more nutrients as they decompose
- more nutrients leads to further growth of algae
- the increased death of algae and underwater plants leads to an increase in dead organic matter (DOM)
- the increase in DOM leads to an increase in bacteria that feed on the dead biomass, causing it to decompose
- bacterial respiration leads to increased **biological oxygen demand (BOD)** (see below), which causes a lowered oxygen content of water (hypoxia)
- oxygen-dependent organisms, such as fish, die due to a lack of oxygen.

Key definitions

Eutrophication – the natural or artificial nutrient enrichment of a body of water.

Biochemical oxygen demand (BOD) – a measure of the amount of dissolved oxygen required to break down the organic material in a given volume of water through aerobic biological activity.



Figure 14.52 Eutrophication in Slapton Ley – a freshwater lake in Devon, UK

BOD is affected by:

- the number of aerobic organisms
- their rate of respiration.

As the number of bacteria increase in eutrophic waters, BOD increases.

Expert tip

BOD can be measured directly:

1. Take a sample of water of measured volume.
2. Measure the oxygen level using an oxygen probe.
3. Place the sample in a dark place at 20°C for five days. (*Lack of light prevents photosynthesis which would release oxygen and give an artificially low BOD.*)
4. After five days, remeasure the oxygen level.
5. BOD is the difference between the two measurements.

Key fact

Leaching of mineral nutrients from agricultural land into rivers causes eutrophication and leads to increased biochemical oxygen demand.

Further effects of eutrophication include:

- net primary productivity is usually higher compared with unpolluted water, and may be indicated by extensive algal or bacterial blooms
- diversity of primary producers changes and finally decreases; the dominant species change
- the length of the food chain decreases as algae lock up the nutrients and block sunlight from reaching the riverbed
- with less sunlight penetrating the water, macrophytes (submerged aquatic plants) disappear because they are unable to photosynthesize
- as eutrophication proceeds, early algal blooms give way to cyanobacteria (blue-green algae) – these are toxic to wild animals and humans
- fish populations are adversely affected by reduced oxygen availability, and the fish community becomes dominated by surface-dwelling coarse fish, such as roach and rudd.

Assessing the nutrient content of a soil sample

The bulk of soil is made up of a mixture of organic matter, rock and mineral particles. The relative proportions of all these, along with pH, determine soil type.

- Soil testing kits are readily available on the Internet and from garden supply companies.
- Testing kits test for major nutrients and/or pH level.

Soil testing kits usually involve adding a chemical to soil samples to test for specific characteristics of the soil:

- pH testing: acidity or alkalinity is a vital factor in plant growth, as it affects enzyme activity.
  - Kits generally indicate pH using colour changes, with colours corresponding to numbers on a scale from 1 to 14.
- Testing for major nutrients: nitrogen (N), phosphorus (P), and potassium (K).
  - Tests use standard reagents to produce colour changes.
  - Results are compared to colour charts to give the concentration of each macronutrient.
- Soil texture: kits separate soil samples into their sand, silt and clay portions.
  - Sand particles are those less than 2 mm in diameter, silt less than 0.02 mm and clay less than 0.002 mm.
  - The relative proportion of different sized soil particles determines how well plants grow in the soil and how well it retains soil nutrients.
  - Loam soil is the best soil for cultivation as it has the optimum combination of sand, silt and clay: it is easily workable, drains well, retains moisture and nutrients, is well aerated and, as a result, has the highest plant productivity.
- Electrical meters measure pH, water content, and sometimes nutrient content of the soil.

Expert tip

You need to know techniques to assess the nutrients in a soil sample.

Expert tip

Gardeners use soil test kits to identify problems with pH in their soil and nutrient deficiency, so that fertilizers or other treatments can be made to adjust the soil so that conditions are improved for the plants they want to grow.

QUICK CHECK QUESTIONS

1 Draw and label a summary diagram of the nitrogen cycle.
2 Explain the relationship between BOD and eutrophication.
3 Explain why eutrophication reduces the length of an aquatic food chain.