Option C Ecology and conservation

Understanding ecology and conservation enables us to appreciate the delicate web of interactions between organisms in different ecosystems and different parts of the world. Climate and other abiotic conditions influence where organisms can live. In addition, it is almost impossible for organisms to live in isolation – species interact to provide one another with food and shelter and each one influences the distribution of others. As human populations increase and encroach further into almost every part of the world, organisms are being lost and the Earth's biodiversity is decreasing. Conservation of threatened species and protection of important ecosystems can be achieved if there is international cooperation and understanding.

C1 Species and communities

Learning objectives

You should understand that:

- Certain factors limit the distribution of species.
- Keystone species can strongly affect the structure of a community.
- Owing to its particular spatial habitat and interactions with other species, every species plays a unique role within a community.
- Interactions between species in a community are classified according to their effect.
- Two different species cannot survive together in a habitat in the long term if they have identical niches.

Factors affecting the distribution of plant species

Organisms are said to live in communities. A **community** may be described by the geographical area it occupies (a lake community, for example), or by the dominant plant species present (coniferous forest, for instance). The organisms present in a community depend on the other organisms living there, as well as on the non-living, **abiotic** aspects, such as soil or climate. The distribution of plants in communities depends on a number of these abiotic factors. Any of the factors described below can limit the chances of survival of an individual or a species. If there is insufficient light or if the temperature is too low, for example, plants will die so these conditions are known as **limiting factors** for the distribution of plant species.

Temperature

No plant can survive freezing conditions for very long because to grow and reproduce plants must carry out chemical reactions within their cells that require enzymes. In arctic climates, plant growth is often very slow because enzymes work slowly at the low temperatures, but it shows seasonal variation as the rate of growth picks up during the relatively short summer. In tropical areas, like rainforests, growth is usually rapid and continuous because temperatures are warm and there is little seasonal variation in temperature.

Water

All plants require water. It is the universal solvent in their cells, the substrate for photosynthesis, and their transport medium. However, plants have evolved a variety of mechanisms to survive periods of drought. Some species remain dormant, some (such as cacti and succulent plants) store water, and others complete their life cycle in a brief rainy season.

Figure C.1 The spines and hairs on a cactus help to deflect harmful ultraviolet rays in sunlight.

Light

Plants need light for photosynthesis. Many use the changing day lengths of the different seasons to trigger flowering. Where light intensity is high, as in a desert, plants have evolved mechanisms to prevent damage to their chlorophyll, such as dense spines or white hair that reflects light (Figure **C.1**).

Where light levels are low, as they are at ground level in a deciduous forest in the northern hemisphere, some plants grow and complete their annual life cycle in the early part of the year, before overshadowing trees have come into leaf.

Soil pH

Most plants prefer a pH of 6.5–7.0 because nutrients are easily available in this range. Some soils are slightly alkaline because they are based on chalk. Chrysanthemum and lavender are two examples of plants that tolerate alkaline soils well and are found in chalky areas. Other soils are acidic; beech, spruce and camellia can grow here. Peat bogs are very acidic because they are composed of decomposing organic material. Very few plants can grow here, although heathers can survive in acid soils.

Salinity

Saline (salty) soils present a particular problem to plants because they make it difficult for them to take up water and minerals. Some plants absorb salt in the soil, secrete it in their leaves and then drop these leaves to remove the salt. A few plants, such as marram grass and lyme grass, can survive in saline conditions.

Mineral nutrients

Soils that are rich in minerals can support a diverse community of plant species, including trees and shrubs. Plants that survive in mineral-poor soils often have special adaptations to supplement their needs. Carnivorous plants such as sundew and Venus flytraps live in very peaty soils that are deficient in nitrogen (Figure **C.2**).

Figure C.2 The sundew (*Drosera rotundifolia*) is a carnivorous plant that attracts, kills and breaks down insects, for their protein. In this way, it can absorb amino acids and use these to make plant protein and other nitrogenous compounds.

Factors affecting the distribution of animal species

Just as for plants, the distribution of animals is affected by the abiotic factors in their environment. If any factor required by an animal is in short supply or is unsuitable for survival, the distribution of the species will be limited by that factor.

Temperature

Animal enzymes are influenced by temperature in much the same way as those of plants. However, animals have the advantage that they can move to avoid the harshest of conditions. In hot, arid areas like deserts, many animals avoid the heat of the day and burrow underground. The jerboa (*Jaculus jaculus*) has long legs that keep its body off the hot sand and its ears have a large surface area, enabling the animal to lose heat efficiently (Figure **C.3**). Birds and mammals can control their internal temperatures but other species use behaviour and other adaptations to maintain theirs.

Some animals, such as the hedgehog, hibernate to overcome the stress of cold winters. Many bird species migrate to warmer climates during wintry seasons.

Figure C.3 The jerboa is a desert rodent with both behavioural and physical adaptations that help modify its temperature in the fierce heat of its habitat.

Water

Most animals need to drink water to survive – very few have evolved to be independent of liquid water. Some desert animals like the jerboa (Figure **C.3**) have done this, however. Jerboas eat seeds and, as the stored carbohydrate is respired in their cells, it produces all the water these animals need – they do not actually drink any liquid water.

Lack of water in certain seasons may change the distribution of animals. Herds of wildebeest and zebra in Africa undertake huge migrations to find new supplies of water and, therefore, vegetation. Carnivorous species often follow these herds, which are their source of food.

Breeding sites

Animals need to find appropriate sites to express mating behaviour and then rear young. These sites may be chosen for safety away from predators, or because they provide rich feeding grounds so the young may benefit. Different species have their own requirements. Many frogs and toads live almost entirely on land but their distribution is limited because they must return to water to breed.

Food supply

Unlike plants, which are autotrophic, animals need a source of food. Herbivores need plants and carnivores need other animals to feed on. The availability of food will determine the distribution of different types of animal. Some animals are restricted to a particular area because it supplies their food – so, for example, rabbits are usually found on grasslands. Others, such as lions, have huge territories and may cover many kilometres searching for food. Animals that have a varied diet are generally more successful and have a wider choice of habitats. If one source of food becomes scarce, they can move on to another.

Territory

Herbivores, such as wildebeest, that live in herds, graze on large areas of grassland and, when the dry season arrives, migrate to find fresh grass. Some birds, such as the European robin, live in smaller numbers and have less need for space but males defend their territories vigorously because they contain food and a nesting area. Carnivores, such as wolves, that live in packs require a large area in which to hunt. They may mark their territory with scent and defend it from other packs. Others, like eagles and buzzards, live solitary lives and have a large hunting territory because their prey is hard to find.

Investigating distribution of species – random sampling

When ecologists want to understand the distribution of a species, or to compare the distribution of one species with another in a different location, it is usually impossible to do so by a direct counting method. In most cases, ecologists take a **sample** of the population and, if the sample is chosen at random, it should provide a good representation of the whole population. Random sampling is used if the area under investigation is large or if time is limited, and it assumes that every organism has an equal chance of being sampled (that is, of being selected as part of the sample).

There are a number of sampling methods used by ecologists to collect data on the distribution of species in relation to one another and to abiotic factors in their environment. Two common methods used are quadrats and transects. They can show not only which species are present, but also how many individuals of each species there are.

Quadrats

One of the simplest and easiest sampling techniques involves using a quadrat (Figure **C.5**). A **quadrat** is a square made of metal or wood that is placed on the ground so that the organisms present inside the square can be counted.

The size of the quadrat will largely be determined by what is being measured. To estimate the number of different trees in a wood may require quadrats of 10 m by 10 m, but a 1 m quadrat would be the best size for studying wild flowers in grassland. Very small 10 cm quadrats might be used for sampling lichens on walls or tree trunks.

Sampling bias

Placing quadrats in order to collect data on the distribution of species may not always be a truly random process. Researchers can introduce personal bias, even without meaning to, by placing a quadrat in a spot that they think will be more interesting or easier to work in. To ensure that the samples within a survey area are made completely randomly, a numbered grid of the area may be drawn up, and random number tables or generators used to select squares on the grid where a quadrat should be placed (Figure **C.4**). Random number tables and random number generators are lists of numbers selected by a computer without any human bias.

Questions to consider

- Is random sampling a useful tool for scientists?
- How significant is the potential for sampling bias and can this ever be completely avoided?

Figure C.5 Using a quadrat to sample a area of grassland.

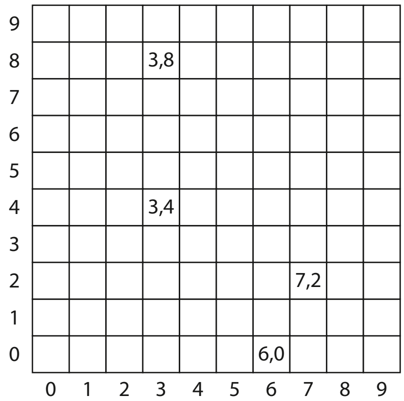


Figure C.4 To select a part of an area to sample with a quadrat, divide the area into a grid of squares, and then select a row and a column number using numbers generated randomly.

Transects

Another commonly used sampling method in ecology is a transect. A **transect** can show the distribution of a species in relation to a particular abiotic factor or it can give an idea of successions or changes in communities of organisms across a habitat (Figure **C.6**). Transects can be used to sample the distributions of plants along a beach or through a field, or to study the changing vegetation as soil or moisture varies. Transects provide a method of systematic, rather than random, sampling.

To take samples along a transect, follow these steps.

1 Stretch a tape or rope from a fixed point for a selected distance across the changing habitat you are interested in. If you are studying a salt marsh or sand dunes above a beach, a distance of 100 m would be appropriate.
2 At intervals of 10 m, or another suitable distance, along the tape put down a quadrat and count the organisms inside it. A series of samples like this provides information about the changes in density and community composition along the transect.
3 Measure the abiotic factor of interest – such as temperature, salinity, soil pH or light intensity – at each quadrat location.

The best type of transect to carry out depends on the terrain and on the organisms present. It may be better to carry out a point transect, where organisms are recorded at specific sampling points along the tape. On the other hand, a continuous 'belt' transect where all species in a 1 m zone along the transect are recorded, might be more helpful in providing a detailed picture of the area.

Figure C.6 These students are using a transect line to survey the plants in a grassy area. A quadrat is placed at measured intervals along the transect line and the plants at each location are counted and recorded. In this way, the plant population can be estimated from a series of samples in a few areas.

Stress zones and limits of tolerance

The distribution of a species is affected by limiting factors, and in the 'zones of stress' at the very edges of their ranges all species struggle to survive and thrive. Various environmental factors can be important in different cases and species are also affected by competition in their habitat. Two examples of the ways in which species survive at the very limits of tolerance are examined here.

Distribution of bristle cone pines in Colorado

Figure C.7 The bristlecone pine (*Pinus aristata*).

Tree lines at high elevations on mountainsides are easily seen from aerial photographs. For most tree species, distribution is limited by factors that occur as altitude increases. The bristlecone pine (*Pinus aristata*) is a conifer native to the USA, which grows in Colorado and other states at altitudes of between 2100 and 4000 m (7000–13 000 feet) (Figure **C.7**). It is able to live on exposed, cold, dry rocky slopes and high mountain ridges but its limit of tolerance is 4000 m, above which environmental conditions are too extreme for it to survive (Figure **C.8**).

The trees' appearance is determined by climate; at highest altitudes close to the alpine zone it grows as a small tree, while at slightly lower altitudes it grows in a Krumholtz formation with stunted growth caused by exposure to freezing winds. Below the timberline trees can reach a height of 12 m. The growth of the trees is particularly affected by the weather conditions of the previous year. Scientists have identified several key factors that explain how the pattern of the tree line indicates the **limits of tolerance** of the trees to key environmental conditions.

Low temperature and desiccation

In the coldest part of the winter, frost can damage cells by freezing them. This is a particular problem for tall trees, which are more exposed to the atmosphere, and partly explains why the height of trees decreases with altitude. Another reason for this pattern is that when the soil is frozen, water cannot be taken in and tissue becomes desiccated so that trees are unable to reach great heights at high elevations.

High winds and weight of snow

At high elevations, the weight of snow and ice can break tree branches, and in addition high winds above the tree line cause damage to the trees' needles. Wind damage is more of a problem for tall trees than for shorter alpine vegetation, which can survive beyond the tree line.

Insufficient light

Although trees may be adapted to survive at cold temperatures, beyond a certain altitude the combination of low temperature and short growing season means that a tree cannot undergo photosynthesis for long enough during the year to survive. When photosynthesis is limited, the supply of sugars and amino acids needed to make new cells and tissues is low and growth and development cannot take place.

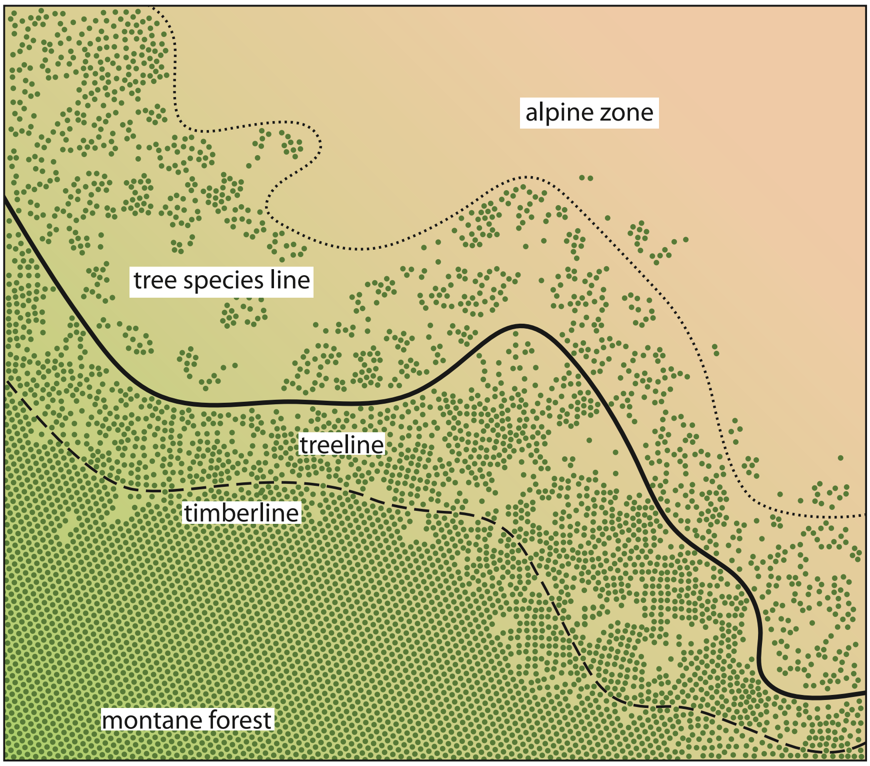


Figure C.8 The different zones of growth in Colorado mountains. The timberline is the limit of tall forest, the treeline is the limit of groups of trees over 3 m high, and the tree species line is the limit of all individual trees.

Distribution of the common limpet on European shores

Common limpets (*Patella vulgata*) are a feature of temperate rocky shores and are found throughout Europe, from Norway to Portugal. Limpets live clinging to rock surfaces where their shells grow to perfectly match their habitat (Figure **C.9**). Limpets are considered to be a **keystone species** of rocky shores because they keep levels of the small fucoid algae (*Fucus* spp.) on which they feed, under control.

Common limpets live in the mid-littoral or **intertidal zone**, an area of the seashore that is covered and uncovered twice a day by the tides. Limpets are adapted to being exposed to air and immersed in sea water but their range is limited by their tolerance of several of the conditions on the seashore, including those described below.

Keystone species a species that is important in maintaining community structure; keystone species may be either herbivores or carnivores that reduce competition in other trophic levels, so that community diversity is sustained

Exposure

In order to live in the intertidal zone, limpets must tolerate extremes of temperature and desiccation. As the tide recedes, limpets are exposed to the sun and their bodies may reach very high temperatures without a cooling covering of water. Limpets also absorb oxygen for respiration from sea water. If they are uncovered for too long they will not be able to survive the heat stress and lack of oxygen.

Limpets have adaptations that help them to tolerate and survive extremes of exposure. Individuals living higher up on the shore, where they are further from the sea and therefore exposed for longer periods between high tides, tend to have higher domes to their shells than those closer to the sea. This shape reduces the ratio of shell aperture (opening) to body size, so the limpet can grow larger without losing more water from the aperture. As well as their primary gills, limpets have a line of secondary gills around the edge of their shell so that they can use water that is trapped on the rock surface under their shells for respiration. They are also able to respire anaerobically while the tide is out and can tolerate an oxygen debt until they are covered with water again.

Figure C.9 Adult limpets usually return to the same area of rock after feeding. They form a small depression, known as a scar, by rubbing against the rock. This scar makes a tight fit for the shell so that the limpet can avoid water loss.

Danger of physical damage

If the sea is rough and waves are pounding the shore, animals can be dislodged from their positions and damaged or killed. Limpets produce sticky mucus, which binds their bodies to the rock surface – they are more tightly bound when the tide is in and conditions are rough. They also have a form of suction, which helps them to hold fast. Nevertheless, they cannot survive in areas where there is excessive disturbance.

Availability of food

Limpets are herbivores and graze on the small, thin fucoid algae that cover rocks. They are active foragers and travel across rocks when the tide is in, using chemical cues to return to their home spot. They sometimes use the edge of their shell to scrape away at rocks and remove the algae.

The distribution of limpets is limited by the availability of small algae for food. These algae cannot survive too far from the sea because they require water to respire and photosynthesise. In areas further down the shore, which are covered by the sea for most of the day, small algae are out-competed by larger species. So limpets do not have a suitable source of food high up the shore or much lower down by the sea – they are limited to an intermediate zone.

Maintaining community structure

A rocky shore contains many different species and limited space. Environmental gradients of temperature, water availability and food allow some species to survive in places where their competitors cannot.

Another factor affecting community structure is the presence of specific predators or grazers, which act as keystone species. For example, limpets are a keystone species, controlling the level of algae on the seashore as they graze and lobsters are a predatory keystone species. Lobsters in the North Atlantic Ocean used to be important predators of sea urchins. When the lobsters were subjected to overfishing, so that their numbers declined significantly, there were not enough lobsters to control the numbers of sea urchins. Sea urchin populations increased significantly and destroyed large areas of kelp, a species of seaweed (*Laminaria* sp.), which they grazed on and was their main source of food. As the kelp was removed, the complex community of molluscs and other small organisms that had lived on it and under it was also destroyed so that overall the diversity of species and the complexity of the food webs that existed in the area were much reduced. Control by predators like the lobster that reduce competition in lower trophic levels is known as **top-down control**. You can read more about this in Subtopic **C5**.

Community structure is also maintained by other interactions between species, including competition, as described in the next sections.

Habitats and niches

In all communities each species plays a unique role. This role is determined by its place in the habitat and the interactions that it has with other species.

A **habitat** is an area offering living space to a number of different types of organism, and includes all the physical and abiotic factors in the environment. An example might be a woodland habitat, whose community includes a huge variety of species, from burrowing invertebrates at ground level to nesting birds in the tree canopy.

Every organism occupies its own space in an ecosystem, which is known as its **spatial habitat**. The surroundings are changed by the presence of the organism – for example, a woodpecker lives inside hollow trees, adapting them to provide nesting places and shelter, while a rabbit burrowing underground affects the soil and plant species growing there.

A **niche** is the particular environment and 'lifestyle' that is adopted by a species. It includes the place where the organism lives and breeds – its spatial habitat – as well as its food and feeding method, and its interactions with other species. As an organism feeds within its niche, it affects the other organisms that are present. For example, an owl feeding on mice in woodland helps to keep the population of mice at a stable level, and rock limpets grazing on small algae control the degree of algal cover. A habitat comprises a number of niches, each of which is unique to its particular species because it offers the exact conditions that the species needs or has become adapted to.

Interactions between organisms

Organisms interact with other organisms living in the same community. The interactions include competition, herbivory, predation, parasitism and mutualism. Almost all organisms influence the lives of others and their interactions can be classified according to their effect.

Competition

Competition occurs when two organisms require the same limited resource. For example, if a pride of lions kills an antelope, they must protect this source of food from scavenging hyenas and vultures that will compete with them for the prey. In most cases, competition will lead to the exclusion of one species by another – as one uses the resource, less is available to the other, so that the less successful species may have to adapt to use some other resource if it is going to survive.

Plants also compete for resources such as light and space. Fast-growing birch trees quickly become established in areas of cleared land, but they require high light levels. Slower-growing species such as oak begin to grow up around them and for a while, they form a mixed woodland. Eventually the birch trees are over-shadowed and out-competed by the more dominant oaks.

Competitive exclusion

Loss of habitat, often caused by human activities such as farming or deforestation, severely limits vital resources such as food, water and breeding sites for the species that live there. When two different species require the same limited resources in the same area, they may find themselves in competition for the same niche. If they are prey species, they may become susceptible to the same predators as well. The principle of **competitive exclusion** states that no two species can occupy the same niche. The species cannot exist together because one will come to dominate and exclude the other. The oak and birch trees described above are an example of competitive exclusion. Both compete for soil resources and light but eventually the oak shades out the light and the birches die off.

In 1934, a classical study on competition was conducted by G. F. Gause (1910–86), a Russian ecologist. He experimented with two species of *Paramecium*, a large protozoan that is common in fresh water – *P. aurelia* and *P. caudatum*. If the two species were allowed to grow in separate cultures on a food source of bacteria, both species grew well. When the two species were cultured together with an identical food source, *P. aurelia* survived while *P. caudatum* died out (Figure **C.10**). Both species had similar needs in the culture but *P. aurelia* had an advantage that enabled it to outgrow *P. caudatum*.

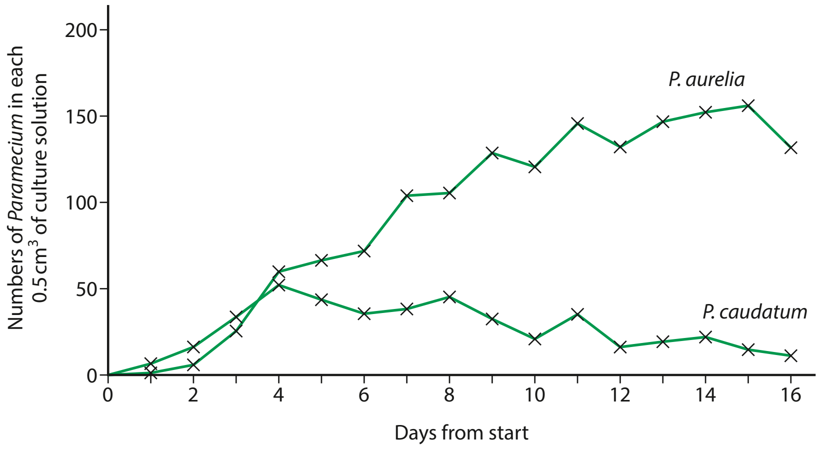


Figure C.10 Over the 16-day culture period, the population of *P. aurelia* increased while *P. caudatum* declined. *P. caudatum* was competitively excluded by *P. aurelia*.

Fundamental and realised niches

We have described a niche as the special space and 'lifestyle' inhabited by a particular species. This is the **fundamental niche** for that species. It is the *potential* mode of existence of the species, given its adaptations.

Often the environment will change through natural phenomena, competition or human intervention. So a species may find that its niche becomes more restricted or begins to overlap with that of another species. This more restricted life pattern is known as the **realised niche**. The realised niche is the *actual* mode of existence of a species resulting from its adaptations as well as from competition with other species. A realised niche can only be the same size as or smaller than the fundamental niche.

In Gausses' study with *Paramecium*, the fundamental niche of both *P. aurelia* and *P. caudatum* was the tank in which they grew alone. However, in a tank together each occupied a more restricted, realised niche where *P. caudatum* was outcompeted and failed to thrive as it became limited by *P. aurelia*. In an urban situation, normally wild animals like raccoons and foxes, whose fundamental niche is living in open countryside and hunting as predators, instead occupy a realised niche in which they scavenge on the waste left by humans.

Herbivory

Herbivory affects both the plants that are food providers and lose parts of their structure, as well as the herbivores that are able to grow and thrive as a result of the food they gain.

A single plant may provide leaves for browsing animals, fruits and seeds for birds, and roots for burrowing animals. The horse chestnut leafminer (*Cameraria ohridella*) is a moth that lays its eggs on horse chestnut leaves. As the larvae hatch, they burrow inside to feed on the tissues of the leaf. The nuts from the horse chestnut tree also provide food for squirrels and deer.

Other leafminer species feed on different tree species around the world, such as oak, birch and holly.

Predation

A well-studied example of the effects of **predation** is that of the Canadian lynx, which feeds on the arctic hare. The numbers of predator and prey fluctuate over the years with changes in the hare population being followed by corresponding changes in the numbers of lynx (Figure **C.11**).

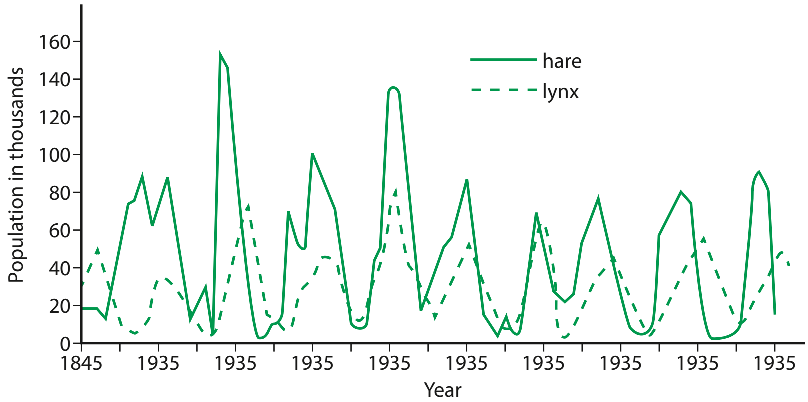


Figure C.11 Changes in the populations of the Canadian lynx and the arctic hare over time.

Parasitism

Parasites are organisms that live entirely on or in a **host** species and cannot survive without it.

Exoparasites, such as fleas and ticks, live on the outside of a host. One economically important example is the southern cattle tick (*Boophilus microplus*), which lives on cattle, feeding on their blood and weakening the animals. It causes significant losses to farmers all over the world.

Endoparasites, such as tapeworms, roundworms and malarial parasites, live inside their host. One example, the barber's pole worm (*Haemonchus contortus*) is a roundworm that lives in the stomachs of sheep in warm, humid climates. It causes anemia and progressive weakness as it feeds on blood in the sheep's stomach. If present in large numbers, this parasite can kill young animals.

Mutualism

Sometimes two organisms coexist and benefit each other, forming what is known as a **mutualistic** relationship.

Lichens such as common orange lichen (*Xanthoria parietina*), which grows on twigs and branches, are the result of a union between a fungus and an alga. The alga carries out photosynthesis and provides sugars for both organisms. The fungus protects the alga from intense sunlight and drying out and absorbs minerals for the benefit of both organisms.

Another mutualistic relationship occurs between the Egyptian plover (*Pluvianus aegyptius*) and the Nile crocodile. The bird feeds on parasites and food particles left around the crocodile's mouth, keeping its teeth clean and healthy. The crocodile openly invites the birds to hunt on its body, even allowing them to enter its mouth.

The relationship between zooxanthellae and reef-building corals

Most reef-building corals contain photosynthetic algae, called zooxanthellae, which live within their tissues. The corals and algae have a symbiotic, mutualistic relationship, in which both the coral and algae benefit from their association. The coral provides the algae with a protected environment and inorganic nutrients, while the algae produce oxygen and help the coral to remove waste products. Zooxanthellae also supply the coral with essential compounds such as glycerol, amino acids and glucose, produced from photosynthesis. The coral uses these products to make fats, proteins and carbohydrates, and to produce calcium carbonate. It has been estimated that up to 90% of the organic material produced by photosynthesis in zooxanthellae is transferred to the coral's tissues, enabling it to grow.

Zooxanthellae also produce the wide range of colours that are seen in corals. If corals are stressed by environmental factors, such as changes in pH or salinity of the water, they may expel the algae so that the colony becomes white. This phenomenon is known as 'coral bleaching' and can result in the corals' death.

Because of their relationship with zooxanthellae, reef-building corals must live in clear water so that their algae can receive sufficient light to photosynthesise, and so coral is usually found in quite shallow water with small amounts of suspended material. Such waters in the tropics are poor in nutrients, but the relationship between the algae and coral allows nutrient recycling, and so provides another mutual benefit to both organisms.

Mutualism and symbiosis – the importance of definitions and communication in science

In order for scientists to be able to communicate ideas and discoveries effectively, it is vital that agreed definitions for important terms are used. However, in practice definitions sometimes slide, diverge or even overlap, which can cause confusion. For example, **symbiosis** is usually defined as a close, long-term interaction between two species. But this definition is the subject of debate among scientists. Some believe symbiosis should only refer to 'persistent mutualisms', such as the interaction between reef-building corals and zooxanthellae, in which both organisms benefit. In this case, **mutualism** and **symbiosis** would mean the same thing. Others believe the term symbiosis should apply to any type of close interaction between two species from which one benefits, but not necessarily both. Under this broader definition, symbiosis would include not only mutualistic relationships, but also **commensalism**, in which the host organism is not affected by the presence of the 'guest', and even **parasitism**, in which the host is harmed while the parasite benefits. Mutualism would be just one type of symbiosis.

Questions to consider

- Do you think it matters if scientists define terms differently, as long as they state clearly the definitions they have used in their writing?
- To what extent is it more important for scientists to use agreed, precise definitions for terms than it is for poets, novelists or journalists?

Nature of science

Using models to study the real world – limits of tolerance graphs

Ecologists often use models to predict events in the natural world. Graphs such as the one shown in Figure **C.12** can be drawn to indicate the likely ranges of different species in different situations. Consider the graph and try to identify the environmental conditions that apply in the case of the limpet and the bristle cone pine. For each species, try to describe what conditions might be like in the 'zone of intolerance' where species are absent.

Knowledge of the stresses that apply to different species can enable ecologists to predict whether another species might be able to survive in a habitat or whether the species being studied could survive in a different location with different pressures.

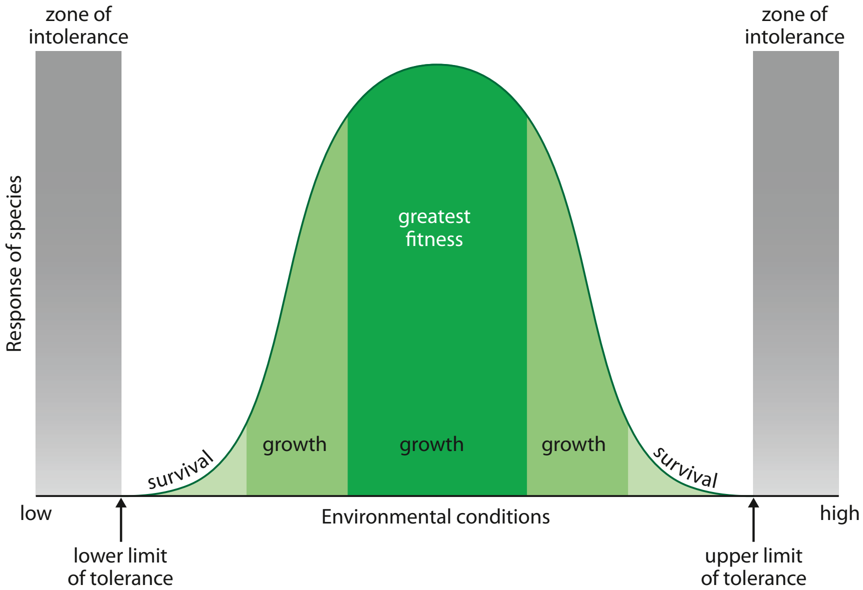


Figure C.12 The graph shows how the range of a species is limited at the upper and lower environmental extremes by zones of intolerance in which the organism cannot survive.

Test yourself

1 Outline **three** factors that affect the distribution of animals and why they are important.

2 Define the term 'competitive exclusion'.

3 Outline the difference between a fundamental and realised niche.

Learning objectives

You should understand that:

- Most species occupy different trophic levels in a number of food chains.
- A food web is a diagram showing many possible food chains in a community.
- The respiration rate of an animal determines the percentage of its ingested food that is converted to biomass.
- The type of stable ecosystem that forms in an area depends upon the climate.
- In closed ecosystems, energy is exchanged with the surroundings, but matter is not.
- The structure of an ecosystem, and rate of change within it, is influenced by disturbance.

C2 Communities and ecosystems

The difficulty of defining a trophic level

grass → rabbit → fox

In a simple food chain, such as the one shown above, grass is the primary producer, the rabbit is the primary consumer and the fox is the secondary consumer, so each organism is said to occupy a separate trophic level. In practice, simple food chains rarely exist – foxes do not feed exclusively on rabbits – so more complicated food webs must be constructed.

In the example of a woodland food web shown in Figure **C.13**, several of the organisms do not occupy a single trophic level because they have a varied diet. The fox could be said to be a primary consumer because it eats fruit, from the crab apple tree, it could also be classed as a secondary or tertiary consumer because it eats both rabbits (primary consumers) and great tits (secondary consumers). In addition, food chains and webs usually contain organisms that feed on dead material. These are the detritivores and saprotrophs, which do not fit into a particular trophic level. A food web shows many possible food chains in a community, and if analysed most show that most species occupy more than one trophic level in many different food chains.

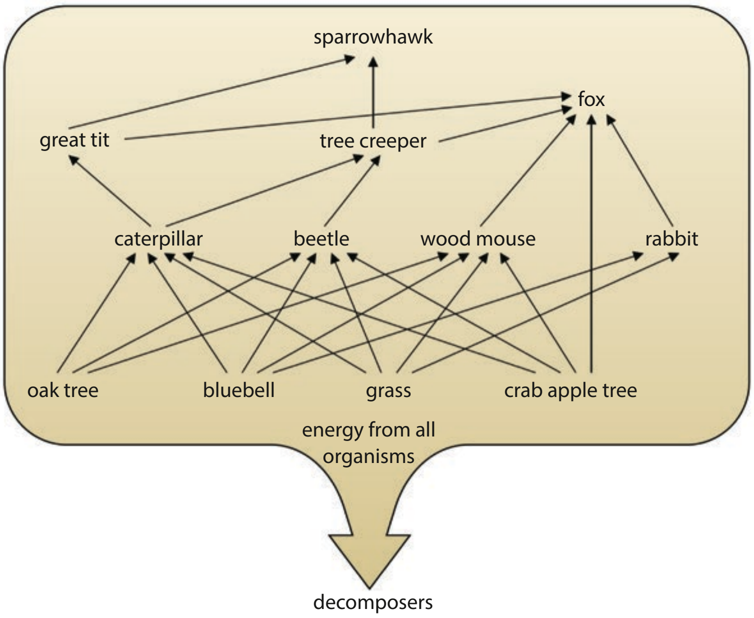


Figure C.13 In a food web such as this, species may feed at different trophic levels depending on what they eat.

Energy in ecosystems

Plants are the primary source of energy in nearly all ecosystems. They carry out photosynthesis and use energy in sunlight to build carbohydrates. They use these carbohydrates, and minerals from the soil, to make all the proteins, lipids and nucleic acids they need to grow. These processes are not 100% efficient and not all of the energy of the sunlight is used. Some is reflected at the leaf surface, some goes right through leaves without being used, and some is lost when plants respire carbohydrate for energy.

When herbivores feed, the energy transferred from plant to herbivore is also not 100% efficient. Not all of the plant material is eaten, not all the material is absorbed in the gut, and some energy is lost in movement and respiration. The same is true for carnivores eating prey animals. Only about 10% of the energy in producers is passed to herbivores and a similar low percentage of energy is passed from herbivores to carnivores (Figure **C.14**).

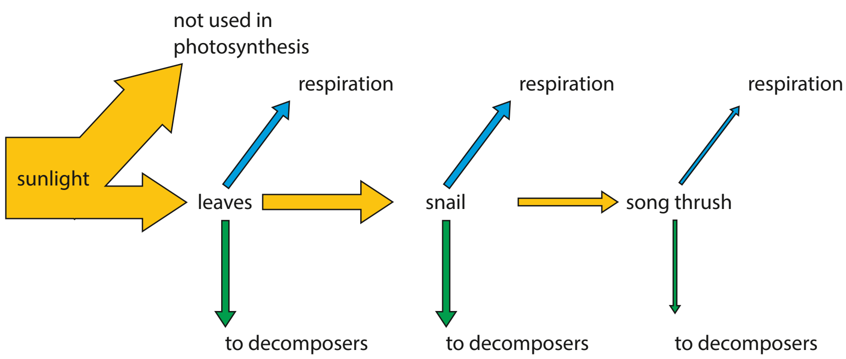


Figure C.14 Energy losses in a food chain (not to scale).

Ecologists show the availability of energy in an ecosystem in diagrams known as **energy pyramids**. Each layer of the pyramid represents the organisms at each trophic level, so layer 1 includes all the primary producers, layer 2 all the primary consumers and so on (Figure **C.15**). It is also possible to construct pyramids of numbers and biomass.

Pyramids of energy

To overcome the difficulty of categorising organisms which occupy multiple trophic levels, animals are often classified according to their main food source.

As one moves up a food chain or food web, energy is lost at each trophic level through respiration and waste. The efficiency of transfer from one level to the next is only about 10%. This is why ecosystems rarely contain more than four or five trophic levels. There is simply not enough energy to support another level. This is true in all ecosystems. The percentage of ingested energy which is converted to biomass in the bodies of animals in the food chain varies in different ecosystems. Pyramids of energy can be compared to demonstrate this (Figure **C.15**).

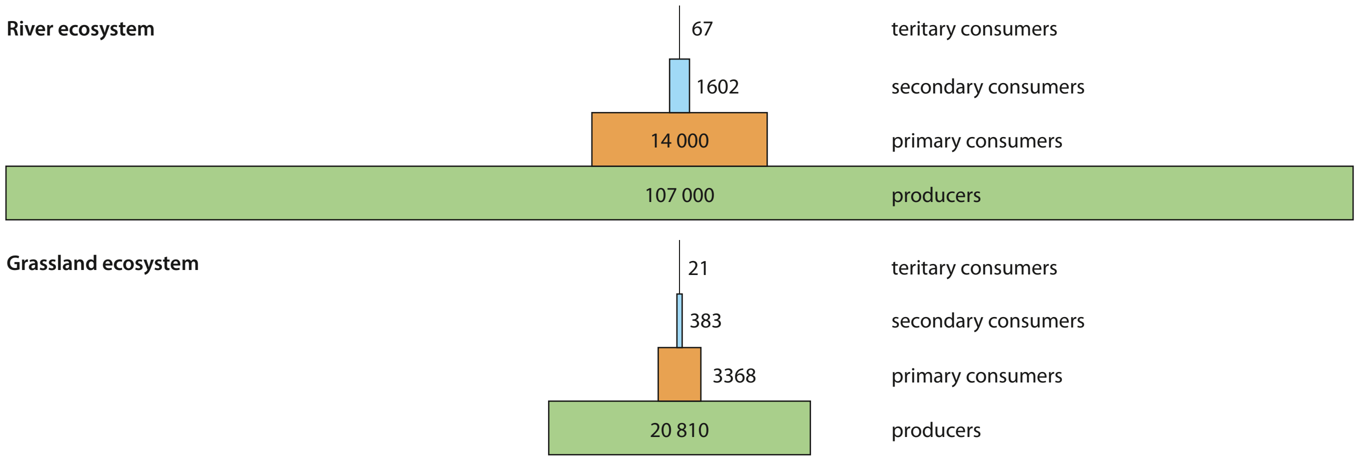


Figure C.15 Pyramids of energy for a river ecosystem and a grassland ecosystem. Each bar represents a trophic level and the width of the bar indicates how much energy it contains. Energy is measured in kJ m^{-2} y^{-1}. Only a small percentage of the energy in each level is transferred to the next.

Biomass

Biomass is biological material, living or dead, that can be used as an energy source. Since living material also contains water, which is not organic and does not contain energy, the biomass in a habitat or sample is usually measured as dry mass of organic matter in organisms, per unit area of land or unit volume of water.

Biomass does not include biological material that has been changed over time into coal or oil. There is much interest currently in using biomass as fuel in place of fossil fuels, because it is a renewable resource. Plants such as perennial grasses, hemp and sugar cane are undergoing trials as sources of industrial biomass.

Gross primary production the total amount of energy used by plants to make carbohydrates during photosynthesis

Net primary production the amount of energy in plants that is available to herbivores, per square metre, per year, after some energy has been lost through respiration

Gross production and net production

A pyramid of energy shows energy flow in an ecosystem. The lowest bar of the pyramid represents **gross primary production**, the total amount of energy that flows through the producers. It is measured in kilojoules of energy per square metre per year (kJ m^{-2} y^{-1}).

Net primary production is the amount of energy available to herbivores from producers after subtracting the energy used by the plants for respiration. This can be represented as:

net production = gross production − energy lost in respiration

Similar calculations can be carried out for each successive trophic level and the data used to construct a pyramid of energy like those shown in Figure **C.15**.

The percentage of ingested energy that can be converted to biomass depends on the respiration rate of the ingesting organism – the greater the amount of energy the animal uses for its own needs, the less there is available to convert to biomass. Animals that are poikilotherms (and have a variable body temperature) are more efficient producers of body mass than homeotherms, which use a lot of energy to maintain a regulated body temperature.

Food conversion ratios

In commercial food production, farmers measure the food conversion ratio (FCR) of their animals. The FCR is a measure of an animal's efficiency in converting food mass into increased body mass (biomass). It is calculated by dividing the mass of food eaten by the gain in body mass over a period of time.

Animals that have a low FCR are considered efficient users of the feed they are given. Pigs have an FCR of about 3.5 while farmed salmon have an FCR of 1.2. It is not possible to compare animals directly because there are differences in the composition and energy content of their foods, but approximate values for other livestock are shown in Table **C.1**.

Animal	Approximate FCR
farmed salmon	1.2
poultry	2
pigs	3.5
sheep	8
cattle	8

Table C.1 The food conversion ratios of some farmed animals.

The low FCR for farmed salmon is due to a number of factors:

- Their (commercially produced) food has a high energy content.
- Salmon use and retain the protein in their food very much more efficiently than other farmed animals.
- Salmon live in water and use very little energy to support their bodies compared with land animals.
- Salmon are poikilotherms (that is, they have a variable body temperature) and need less energy than homeotherms (which maintain a regulated body temperature) to sustain body temperature and functions; their respiration rate is lower.

In natural systems too, energy conversion along aquatic food chains tends to be more efficient than in terrestrial food chains. But because the absorption of light in water is less efficient than on land, the initial capture of light energy by aquatic primary producers tends to be lower than for land plants.

Succession and stability

The processes of succession

Succession is the process of change to communities in a particular area over a period of time so that the appearance of the whole area evolves and changes. Succession involves interactions between both the biotic and abiotic components of the area. If an area of land is left bare as a result of an event such as a fire or land clearance, early 'pioneer' communities modify the physical environment, which, in turn, modifies the biotic community. This enables more species to move in and modify the physical environment still more, and so on until a stable situation is reached.

The different stages of succession are known as **seral stages** and the final stable community, which remains unless there is further disturbance, is called a **climax community**.

A **primary succession** begins when an area of bare ground or rock, with no existing soil, is colonised for the first time. Two well-studied examples are the area on the Indonesian island of Krakatau, which was left bare when the volcano Krakatoa erupted in 1883, and the newly formed volcanic island of Surtsey off the coast of Iceland, which formed in 1993.

The first organisms to colonise bare rock are lichens and mosses, which can settle on the rock surface. Lichens gradually break up the rocks and use dissolved minerals for growth. As lichens die they decompose, leaving debris, which begins the formation of humus and soil. Low-growing lichens and mosses modify the environment sufficiently for seeds of grasses and small shrubs to start growing and these plants modify the land still further. A deeper layer of soil develops as plants die and decompose, and this soil can hold more moisture and contains more organic matter. Later, fast-growing trees such as rowan and birch begin to grow and, as they extend their roots, the soil is bound together and protected from erosion. Eventually these trees will be replaced by slower-growing species, which form a climax community, usually after a period of about 100–200 years.

A typical succession in the northern hemisphere might be:

	bare rock →	lichens →	mosses →	grass and small shrubs →	fast-growing trees →	slow-growing trees
Approx. years:	2–3	3–10	10	15–20	25–50	100–200

Each stage is known as a **sere** or **seral stage**. Seres of particular environments tend to follow similar succession and can be classified according to the environment. For example, a hydrosere develops in water and a halosere in a salt marsh.

Secondary succession occurs where there has been a land clearance, perhaps by fire or landslip. An ecosystem has been established but is replaced as conditions have changed. Soil is already present so secondary succession is usually much quicker than primary succession and a variety of plants such as annual grasses and low-growing perennials can colonise rapidly.

Energy flow and productivity at different stages of a succession

As a succession develops in an ecosystem, it is not only the species present that change. The productivity of the system also changes.

In the first stages of a succession when there are few producers present, gross primary productivity is low but the proportion of energy lost in respiration by these organisms is also low. This means that net primary productivity is relatively high, and the ecosystem grows and accumulates biomass.

In the later stages of succession, there are more consumers present and gross productivity may be high. With more consumers there are more complex feeding interactions and food webs so that net productivity also increases.

Stability

The type of stable ecosystem, known as a climax community, that emerges following a succession depends on the local climate and, to a certain extent, this can be predicted. Rainfall and temperature are the two most important factors that determine the appearance of a stable ecosystem. Figure **C.16** shows a climograph – a diagram relating the prevailing type of ecosystem to conditions of temperature and rainfall. A climograph can be used to predict the type of stable ecosystem that will emerge in an area, from information about the mean annual temperature and mean annual precipitation in the region.

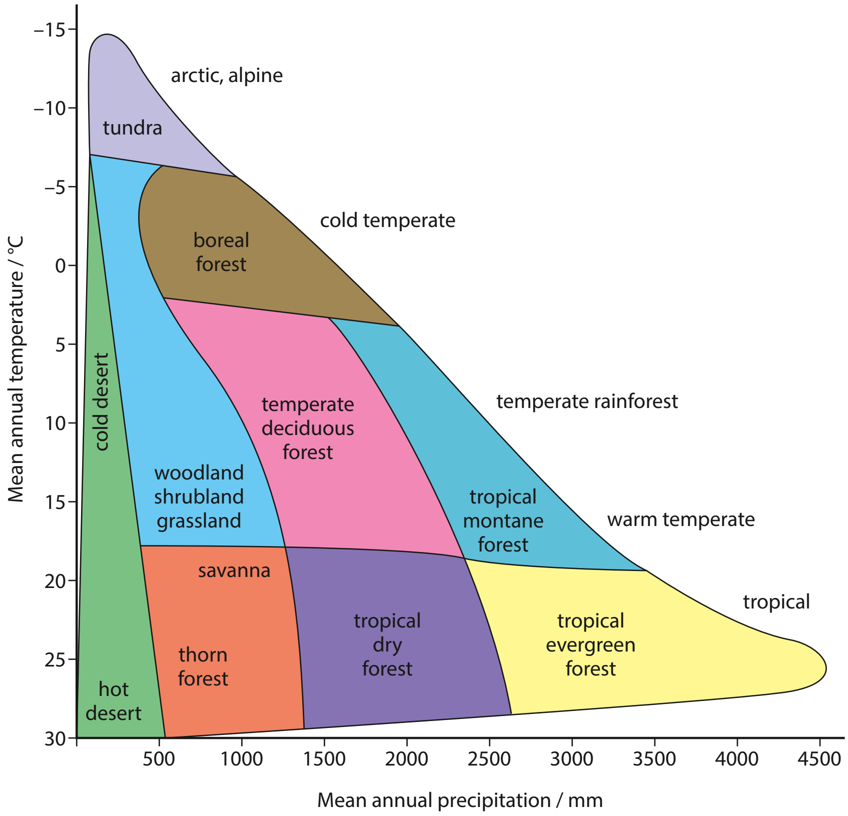


Figure C.16 A climograph shows the differences in vegetation, and therefore in the type of ecosystem, in different climatic regions.

The systems approach

Many ecologists now study ecosystems using the **systems approach**. A system is defined as an assemblage of parts and the relations between them that enable them to work together to form a functioning whole (Subtopic **1.1**). The systems approach studies an ecosystem as a whole, rather than examining individual parts such as a food chain within it. Systems are divided into three types: open, closed and isolated. Living systems may be either open or closed.

An **open system** exchanges both matter and energy with its surroundings across the boundaries of the system. Most living systems and all ecosystems are open systems, which exchange energy and matter with their environment. These open systems and the exchanges that take place can be seen in any living environment.

In a woodland ecosystem, the main inputs include light and carbon dioxide, which plants convert during photosynthesis. Further inputs come from woodland herbivores, which return mineral nutrients to the soil, and bacteria in the soil, which fix nitrogen from the air. Outputs may include water, which is lost during respiration and transpiration, nutrients, which flow away in waterways, and heat, which is exchanged with the environment around the woodland.

In a **closed system** energy, but not matter, is exchanged across the boundaries of the system. These systems are very rare in nature. Most examples are set up for experiments and are artificial. A bottle garden or an aquarium can be set up so that light and heat are exchanged across their boundaries but matter cannot be exchanged or leave the system. In most cases these systems do not survive because they become unbalanced.

Sometimes organisms die as oxygen is depleted or food runs out, or waste matter builds up to toxic levels. Figure **C.17** shows how open and closed systems are represented as diagrams.

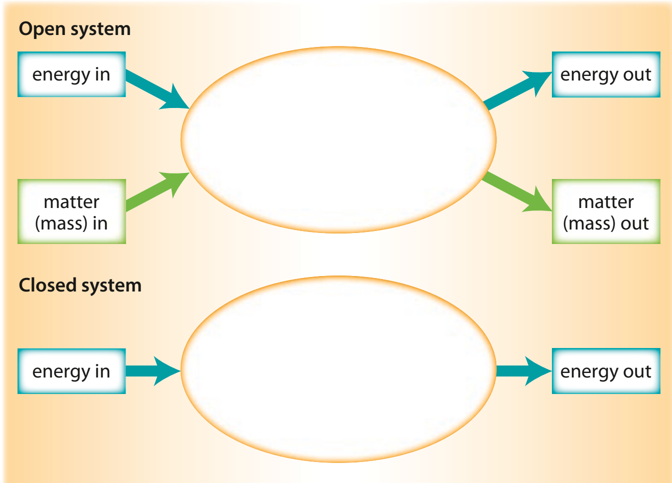


Figure C.17 Open and closed systems.

Ecosystems and disturbance

Disturbance in an ecosystem influences both its structure and the rate of change within it. If there is a disturbance, either a natural event such as a flood or drought, or an event caused by human interference, a decline in the numbers of top carnivores may be one of the first observable signs that something has changed. Extreme climatic events can destroy all or part of a food web. If plants die in a drought, all the consumers in the food chain, right up to the top carnivores, will be affected and the system may take time to recover. The nutrient cycles within the system (Subtopic **C6**) will also be disrupted.

As the human population grows and disturbs or destroys natural ecosystems, many large carnivores have come under severe threat. Carnivores require territories with enough space to hunt and their numbers fall significantly if human populations expand and take over their habitats. In Borneo, large areas of tropical rainforest have been cleared for palm oil plantations and the areas that remain are often separated from one another by roads or housing. This fragmentation of the natural forest has interrupted food chains and led to significant changes. Numbers of clouded leopards (*Neofelis nebulosa*) in north-eastern Borneo (Sabah) have fallen rapidly as their territories and prey have been destroyed so that now the leopard is classified as a 'vulnerable' species. Natural cycling of nutrients is also interrupted when land is cleared and to maintain soil fertility and crop yields more artificial fertilisers must be used.

Pesticides can also disrupt ecosystems. They are used to improve human food production but they also affect the way ecosystems function. The first pesticides made in the 1940s and 1950s were non-specific and so killed many different species indiscriminately, including both pests and useful pollinating insects. One well-documented case is that of DDT, an insecticide that was used by farmers to reduce losses and maximise crop yields. When it was first used, no one understood that DDT was not biodegradeable and remained poisonous in the environment for a long time. Although only low concentrations of DDT were used each time, small amounts soon accumulated in the environment and in organisms' bodies, leading to their deaths and to disruption of ecosystems. This process is known as

biomagnification (Subtopic **C.3**). Once again, humans were first alerted to the problem by the deaths of predatory birds, the top carnivores in the ecosystems.

Nature of science

Using models to study the real world – modelling energy flow in ecosystems

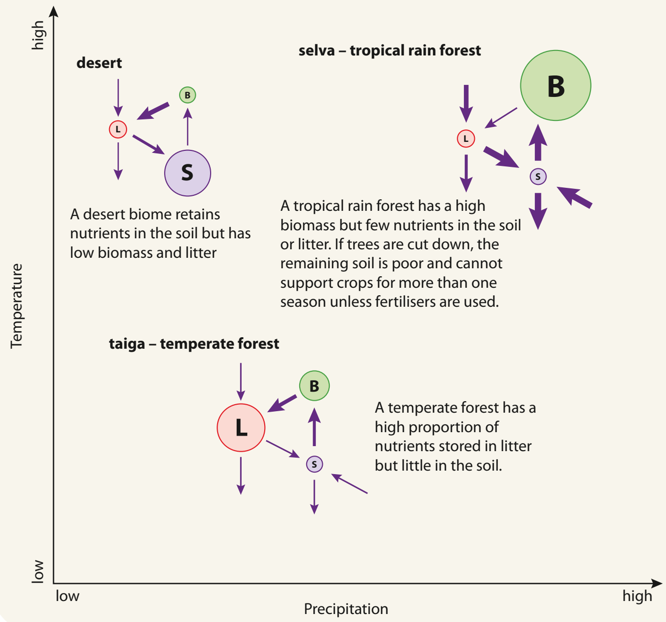
Gershmehl diagrams and pyramids of energy model the flow of energy through ecosystems. Although both have inaccuracies, the models and others like them provide a useful representation of the natural world that can be used to promote discussion between scientists. Models are also very useful in making hypotheses and predictions about future events. Understanding energy flow can enable computer models to be built to predict the effect of a disturbance to an ecosystem or the possible consequences of climate change.

Gersmehl diagrams – do the entities in scientists' models actually exist?

In 1976, the geographer and scientist P. F. Gersmehl developed a model of **nutrient cycling** to highlight differences between ecosystems. His diagrams (Figure **C.18**) show how nutrients are transferred and stored between three different parts of an ecosystem: the litter, biomass of organisms and the soil. As nutrients cycle in an ecosystem, there are interactions between the atmosphere and soil, and many food chains are involved. Nutrient cycles are different in different ecosystems and the rate of nutrient transfer is dependent on the amount of moisture, heat, vegetation and the length of the growing season. Diagrams can be drawn for different ecosystems and provide insights into systems that have high levels of nutrients in the soil or a large biomass of organisms.

Questions to consider

- Are Gersmehl's diagrams real representations of the world or are they useful inventions to explain the natural world?
- Do trophic levels actually exist or are they simply a human strategy to predict and explain feeding relationships?



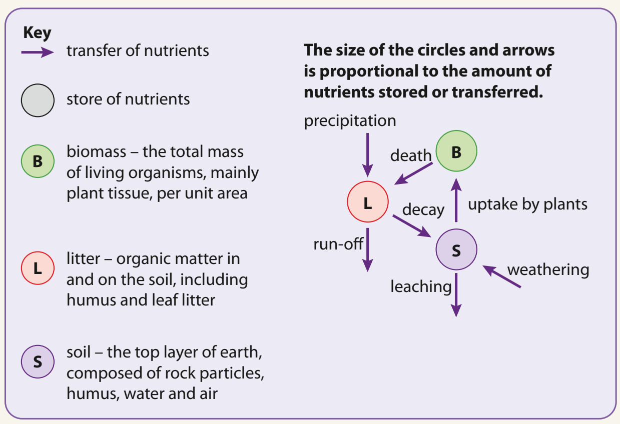


Figure C.18 The model of nutrient cycling developed by Gersmehl.

Test yourself

4 Outline the difference between a closed and open ecosystem.
5 State what is meant by the term 'conversion ratio'.
6 State **two** factors that influence the type of stable ecosystem that develops in a given area.

Learning objectives

You should understand that:

- Introduced alien species can become invasive if they escape into local ecosystems.
- The numbers of endemic species can be reduced by invasive alien species, which can cause competitive exclusion, especially if they have no natural predators.
- Biomagnification can lead to the accumulation of pollutants in the tissues of organisms at higher trophic levels.
- Both macroplastic and microplastic debris has accumulated in marine ecosystems.

C3 Impacts of humans on ecosystems

Interfering with ecosystems – introducing alien species

An **alien** species is one that is not native to the region in which it is found. There have been many occasions throughout history when an organism has been introduced from one ecosystem to another, either:

- accidentally
- deliberately
- or for biological control of a pest organism.

Accidental introduction

The zebra mussel (*Dreissena polymorpha*) is a small freshwater species, originally native to lakes in southeast Russia. It has been accidentally released in many other areas, probably carried in ballast water of cargo ships. It has become an invasive species in many different countries. Zebra mussels are now found in the Great Lakes of the USA where they grow on docks and boats. They have spread into streams and rivers and block water pipes and interfere with water supplies (Figure **C.19**). In some areas, they have out-competed all other freshwater mussels because they grow in dense clumps. Zebra mussels are also believed to be the source of deadly avian botulism poisoning that has killed tens of thousands of birds in the Great Lakes since the late 1990s. On the other hand, zebra mussels are thought to be partly responsible for the increase in the population of bass and yellow perch in the lakes. Zebra mussels are filter feeders and remove pollutants from lake water, which becomes clearer as a result. Algae deep under the water receive more light and grow more vigorously, providing habitats and food for the fish.

Figure C.19 Masked workers use a water jet to clear zebra mussels clogging the walls of the pump room of Detroit Edison's power station in Michigan, USA. Not only do zebra mussels encrust water pipes and pump rooms, but they also excrete a corrosive substance.

Deliberate introduction

Many plants, collected in distant regions, have been deliberately introduced to domestic gardens because of their attractive flowers or exotic foliage. Orchids, bamboos and rhododendrons are now seen all over the world but most were introduced following plant-collecting expeditions in the 19th and 20th centuries.

Much of the time, introduced species create no problems. However, in some cases, an introduced species finds the new conditions so advantageous that it becomes **invasive**. It grows rapidly and becomes a threat to **endemic** (native) species, which it out-competes and eventually eliminates. One such example is Japanese knotweed (*Fallopia japonica*), which was deliberately introduced into European gardens in the 19th century for its attractive flowers. It reproduces vegetatively and even short sections of root can re-grow to become whole new plants. This plant now covers huge areas of land in Europe. It can be controlled with herbicides, but there is a problem using these chemicals near rivers, as the herbicide gets into the waterway and upsets its ecological balance, harming plant and animal life.

The principle of **competitive exclusion** states that no two species can occupy the same niche indefinitely. The species cannot exist together because one will come to dominate and exclude the other. Both rhododendron and Japanese knotweed have competitively excluded native species.

Introduction for biological control

Another example of a deliberately introduced species is the prickly pear cactus (*Opuntia* sp), which was introduced to Australia as a source of cattle feed. The prickly pear rapidly grew out of control. At its height, it was spreading at a rate of 400 000 hectares per year. The dry, hot climate of Australia was ideal for this plant and there were no native animals that would eat it. Scientists conducted research to find a natural consumer for the prickly pear – they found that in its homelands of the USA and Mexico the prickly pear is eaten by the caterpillar of the cactus moth (*Cactoblastis cactorum*). This caterpillar was therefore also deliberately introduced into Australia and now keeps the plant under control. This is an example of successful **biological control**.

A far less successful attempt at biological control has proved disastrous for much of the wildlife of Australia. The Puerto Rican cane toad (Figure **C.20**) was introduced into Queensland in 1935 in an attempt to control sugar cane beetles, which were causing huge losses to cane growers in the north of Australia. In their native regions of Central and South America, cane toads are controlled by a number of predators, particularly snakes. In Australia, potential predators were not adapted to deal with the cane toad's skin, which produces dangerous toxins, so the toad population has grown out of control – so much so that they have spread from Queensland to Northern Territory and New South Wales, wiping out the endemic amphibians, which can live for an average of more than ten years, and who breed more slowly and later in the season than the cane toad. The toads also failed to control the sugar cane beetle, preferring to eat small rodents, insects and even dog food.

The introductions of alien species described above are summarised in Table **C.2**.

Figure C.20 The cane toad's (*Bufo marinus*) large size (up to 15cm in length) and mating behaviour have enabled it to out-compete native amphibians.

Species	Reason for introduction
Japanese knotweed	deliberately planted in European gardens
zebra mussels	accidentally introduced into USA
cane toad	deliberately introduced to control sugar cane beetles in Australia (unsuccessful)
cactus moth	deliberately introduced to control prickly pear cactus in Australia (successful)

Table C.2 Examples of species that have been introduced into new ecosystems.

Restoration of invaded areas

Restoring an area of land invaded by an alien species to its natural state may be extremely time-consuming and expensive. In 2004, a 6-year restoration programme was started on Montague Island in New South Wales, Australia. The island had become covered with kikuyu grass (*Pennisetum clandestinum*) and other non-endemic plants that had been planted in the 1900s to help stabilise the sandy soil and provide food for grazing animals. The kikuyu grass had spread to such an extent that it had displaced seabird nesting areas and was responsible for the death of significant numbers of the native little penguins, which became trapped or strangled in the grass. The grass was also a significant threat to other bird species, such as the shearwaters and crested terns that nest on the island. Management techniques included clearing the grass by controlled burning and spraying with herbicide, followed by re-vegetation of the island with endemic plant species.

In the 20th century, large areas of Snowdonia National Park in North Wales, UK, had become overgrown with rhododendron, which flourished in the wet climate. This plant, which is native to China, had been introduced widely in Britain in the 19th century as a garden shrub because of its very showy flowers. To restore the land, the thick branches had to be cut and the roots pulled out to prevent re-growth. Rhododendron forms an association with certain soil fungi, which prevent the germination of seeds of many other plants. So, even when the ground had been cleared, it had to be left for some time until these fungi died.

DDT and biomagnification

Biomagnification the process that leads to accumulation of chemical substances in food chains; the chemical substances become more concentrated at each trophic level

Some chemicals used in the environment as pesticides are taken into living organisms but then accumulate in their body tissues because the organism cannot break them down and excrete them very well. Insecticides such as DDT and dieldrin are well-studied examples of the way toxic chemicals can accumulate in the environment – in a process called **biomagnification**.

Small quantities of these substances, used to control insect pests, may be taken up by plants, or deposited on the surface of their leaves. The plants may be unaffected, but when primary consumers feed on the sprayed plants they take in a far greater quantity of the toxin. The chemical remains in the bodies of the primary consumers and if a secondary consumer feeds on a number of these animals, it accumulates an even greater amount of the chemical.

Rachel Louise Carson (1907–1964)

Rachel Carson was a writer and ecologist, born in the rural town of Springdale in Pennsylvania, USA. Having graduated from Pennsylvania College for Women in 1929, she went on to receive an MA in zoology from Johns Hopkins University in 1932, and then began a career as a writer and scientist working for the government.

Carson was concerned about the over-use of synthetic chemical pesticides and in her book *Silent Spring*, published in 1962, she challenged modern agricultural practices and called for a change in the way we view the natural world. She was one of the earliest writers to highlight the effects of the biomagnification of pesticides on the populations of predatory birds, such as the American bald eagle.

Some dismissed Carson as an alarmist, but she continued to speak out, reminding us that we too are part of the natural world and potentially subject to the same damage as the rest of the ecosystem. She called for new policies to protect human health and the environment.

DDT is an organochlorine (OC) insecticide that was widely used to kill mosquitoes that carry the malarial parasite. It is stored in the fatty tissues of animals that have ingested it. It is now known that it is not readily biodegradable and can remain in the environment for up to 15 years.

A survey of numbers of peregrine falcons in Europe in the early 1960s showed that they were in decline. Their bodies contained high levels of DDT, which was causing the shells of the bird's eggs to be thinner than normal. As a female tried to incubate the eggs, they broke under her body. This effect was also reported in many other parts of the world in a variety of wild bird populations. Even penguins in Antarctic regions were found to have the chemical in their bodies.

Although the original concentration of DDT used in insecticide sprays was low, at about 3×10^{-6} ppm (parts per million), the chemical was running into waterways and being taken up by microscopic plants in rivers and lakes. As these plants were eaten by microscopic animals, the DDT became more concentrated. It was found that small fish feeding on the microscopic animals had accumulated about 0.5 ppm in their body fat and fish-eating water birds, such as the osprey, had about 25 ppm of DDT in their bodies (Figure **C.21**).

DDT was a successful insecticide because it remained effective for a long time without breaking down, but its damage to the environment was considerable. Since the 1970s, it has been banned in many countries and wild bird populations are recovering. Heavy metals and industrial chemicals such as PCBs (polychlorinated biphenyls) that are also released into the environment remain a problem for living organisms as these accumulate in a similar way.

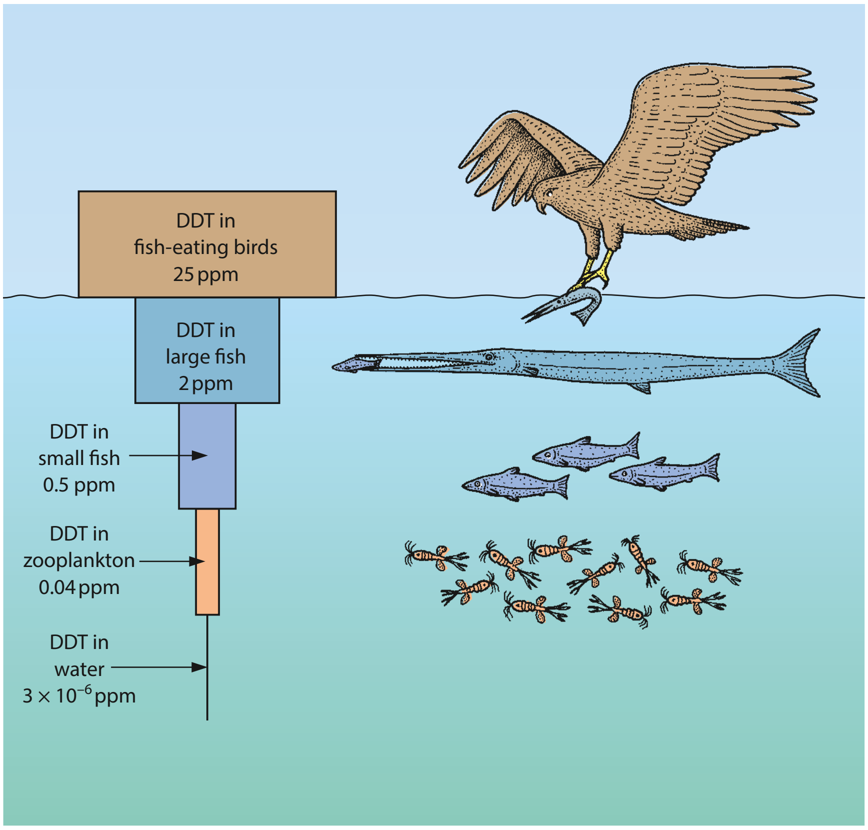


Figure C.21 An example of how DDT concentrations increase up the trophic levels of an estuarine food chain.

The control of malaria versus the use of DDT

DDT was banned for use in agriculture under the Stockholm Convention in 2004, an international agreement that was signed by 170 countries. But DDT is still used today in countries that have high levels of malaria to control mosquitoes, the vectors that transmit malaria to humans. At present there are few effective alternatives, so DDT is used for spraying internal surfaces of homes to kill mosquitoes.

There is considerable debate about the use of DDT in malaria prevention. Consider the following points in favour and against the use of the insecticide:

- Health of individuals is greatly improved if they do not suffer from malaria.
- There are few affordable or effective alternatives to DDT for killing mosquitoes.
- DDT remains active so that it can kill mosquitoes.
- People who live in sprayed homes and the workers who spray the homes are exposed to DDT for long periods of time.
- All the members of a household are exposed, including babies, pregnant women and old people.
- The evidence of human health problems due to DDT is increasing.

Taking into account these points, should the use of DDT be reduced as a precaution?

Those against the use of DDT say that its use and production should be halted because of potential health concerns and damage to the environment.

Those in favour of DDT say that it is safe to use if it is applied correctly. They argue that even if human health is found to be affected by the insecticide, the harm caused would be far less than that caused by malaria.

Others take a pragmatic approach and argue that there is still a need for DDT to fight the transmission of malaria but recognise that there are risks involved in spraying the homes of millions of people.

Material	Time to dissolve
paper	2–4 weeks
cotton cloth	1–5 months
woollen cloth	1 year
tin can	100 years
aluminium can	200 years
plastic bottle	450 years

Table C.3 Time taken for objects to dissolve at sea (Hellenic Marine Environment Protection Association, 2009).

Plastic debris in marine environments

Over recent years the production and use of plastics has increased enormously. It is estimated that over 250 million tonnes of plastic are used annually and that its production requires approximately 8% of the world's annual oil production. Plastic litter degrades very slowly (Table **C.3**), so it builds up in landfill and has serious implications in ocean environments, where it makes up between 60 and 80% of marine debris and as much as 90% of floating debris.

Macroplastic debris is defined as plastic fragments which are greater than 1 mm across, and **microplastic debris** is defined as fragments that are less than 1 mm. Macroplastics include items such as plastic bottles and bags, detergent containers and food wrapping. These items accumulate in marine habitats worldwide and may persist for centuries. Microplastics account for more than 65% of marine debris and mainly comprise PVC, polyester, acrylic and polyamide particles. Researchers have traced much of the microplastic back to synthetic clothes, which can release up to 2000 tiny fibres per garment every time they are washed.

Both types of plastic are ingested by many marine organisms, which mistake them for food. This plastic may enter the food chain or cause blockages of the intestine. Residues of the plastic can also accumulate in organisms' cells. Other problems include entanglement of organisms in plastic, suffocation and general health problems. Some scientists have suggested that an animal whose stomach is full of plastic fragments feels full and stops feeding which may lead to starvation and death.

The Laysan albatross, which lives on Midway Atoll in the North Pacific Ocean, thousands of kilometres from both mainland Asia and North America, is one tragic example of this (Figure **C.22**). Albatrosses skim the water surface to feed and pick up plastic as they do so. Adults feed the plastic to their chicks and while adults are able to regurgitate some plastic, the chicks cannot and can be killed by its effects. As well as making the chick feel falsely full, sharp plastic pieces can cut through the stomach and cause infections and death.

Figure C.22 Laysan albatross chick which died with a stomach full of plastic debris on Midway Atoll.

Harbour seals (*Phoca vitulina*) in the Netherlands and in the Wadden Sea in Germany have also been shown to be affected by plastics. Samples taken from more than 100 seals revealed that more than 11% had plastic in their stomachs and 1% had plastic fragments in their intestines. Animals younger than 3 years were most affected. Researchers have also analysed fecal samples from both harbour and grey seals and found that all of them contained between a few milligrams and a few grams of granular or fibrous microplastics per sample.

The death of another mammal, a sperm whale, which was found in the Mediterranean Sea in 2013, has also been attributed to the ingestion of large amounts of plastic debris. The debris included several metres of plastic sheeting. The plastic is used as a cover in greenhouses and may have been torn off by the wind or not disposed of properly.

As well as the direct physical effects of plastic debris, researchers are also investigating the importance of so called 'hitch hikers' – species that attach to floating debris, which is then dispersed to other areas or sinks to the sea floor. It is possible that aggressive alien and invasive species could be dispersed in this way and travel to sensitive areas or coastal environments far away from their native habitats. Here they could compete with or endanger sensitive or at-risk species.

Nature of science

Assessing risk in science – biological control

Any programme to introduce an alien species as a means of biological control must weigh very carefully the risks involved in the introduction against the benefits. In the light of past experience, tightly controlled experiments should be carried out before a species is approved for release.

Risks associated with the introduction of an alien species include the following.

- The new species may compete with endemic (native) organisms and reduce their populations.
- This in turn may affect other species within the ecosystem.
- The introduced species may feed on endemic organisms, affecting local food chains and webs.
- The combined effect may be that an endemic species becomes extinct.

Consider the example of the cane toad, described above. What experiments should have been carried out before the species was introduced into Australia?

Test yourself

7 Outline what is meant by the term 'alien species'.

8 Define the term 'biomagnification'.

9 List **three** ways in which plastic debris can harm marine organisms.

C4 Conservation of biodiversity

Learning objectives

You should understand that:

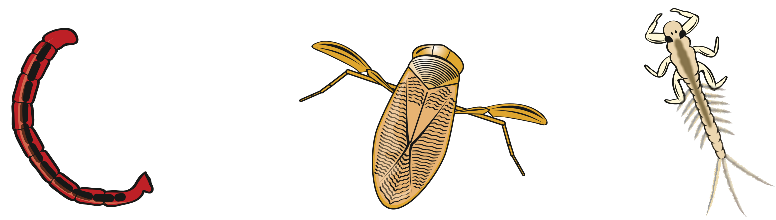
- An indicator species is one whose abundance can be used to assess a specific environmental condition.
- The value of a biotic index can be calculated using relative numbers of indicator species.
- *In situ* conservation involves active management of nature reserves or national parks.
- *Ex situ* conservation involves the preservation of species away from their natural habitat.
- Biogeographic factors affect the diversity of species.
- Richness and evenness are two components of biodiversity.

Biotic indices and indicator species

Certain species are very sensitive to environmental changes such as pollution from toxic gases in the atmosphere or chemicals in water. These organisms are called **indicator species** because their presence or absence tells us about environmental conditions in a way that direct measurements of abiotic factors cannot.

Lichens and bryophytes (mosses) are very sensitive to air pollution. Leafy species of lichen can only survive in areas with the highest quality of clean air, so by studying the lichens present in an area we can obtain a measure of air quality. Lichens vary considerably in their ability to tolerate pollutants such as sulfur dioxide in their environment because they have no waxy cuticle as the majority of terrestrial plants do. Without this protection, lichens absorb and accumulate various pollutants, including metal ions in airborne dust. Large, branching lichens grow in clean air, but in polluted air only small flat lichens can survive.

Water quality in rivers and lakes can be measured in a similar way. Some invertebrates can survive in polluted water, while others cannot (Figure **C.23**). Water that is polluted by sewage effluent is usually low in oxygen because bacteria in the water feed on the organic material and respire aerobically, using up the oxygen. Active invertebrates such as stonefly nymphs, mayfly larvae and flatworms are very sensitive to this kind of pollution because they require a lot of oxygen. So if these organisms are abundant, it is a good indication that water is clean. On the other hand, bloodworms (midge larvae of *Chironimus* sp.), sludge worms and leeches are more tolerant of low oxygen levels, and the presence of these organisms in large numbers is an indication of polluted water.



Chironimus larvae can tolerate low levels of oxygen and so indicate high levels of pollution.

The presence of water boatmen indicates moderately polluted water.

Mayfly nymphs are an indicator of clean, unpolluted water.

Figure C.23 The presence of particular organisms can indicate how polluted a body of water is.

Using a biotic index for a freshwater habitat

To gather data for a **biotic index** of a river or lake, the habitat is surveyed and samples of the organisms present are collected. Different indices use slightly different methods of calculation but the species present are recorded and usually counted. The number of each organism found, or simply the presence ('1') or absence ('0') of them, is multiplied by a 'sensitivity factor', which indicates that species' ability to tolerate pollution. A greater value is given to intolerant species, which require clean water, and a calculation is performed resulting in a figure for the overall cleanliness of the water. A high number of sensitive species gives a high biotic index score but if many species that are very tolerant to pollution are found the index will be low. For example, one index, the Trent Biotic Index for the River Trent in the UK, gives values between 0 and 15 at different points along its length. Zero indicates very polluted water, whereas 15 indicates very clean water.

The Trent Biotic Index was developed for the River Trent in the UK, and most modern systems have evolved from this. Two such systems that are commonly used are the Biological Monitoring Working Party (BMWP) system (described here), used in many countries, and the Belgian Biotic Index Method.

The Biological Monitoring Working Party system

The advantages of this system are that the invertebrate organisms need to be identified only to family level, and that it can be used internationally. Each family is assigned a score from 1 to 10 depending on their pollution tolerance, 10 being the most intolerant. Some example organisms are listed in Table **C.4**.

Example organisms	Score
caddis flies	10
freshwater crayfish, stoneflies	9
dragonflies, damselflies	8
mayfly, tube-making caddis flies	7
small air-breathing snails, amphipod crustaceans	6
pondskaters, water striders, creeping water bugs	5
small mayflies, freshwater leeches, alderflies	4
valve snails, bladder snails	3
non-biting midges	2
segmented worms	1

Table C.4 Some of the families in the ten different classes of pollution tolerance (scores are approximate and common names have been used for simplicity).

All parts of the stream, river or lake are sampled. The sides, centre and areas among vegetation are all included and the invertebrates are collected and sorted into their families. Each is assigned a score from the table. The number of individuals in each family is not important. The results are added together to give a BMWP score.

The efficiency of sampling and sample size are taken into account using the Average Score Per Taxon (ASPT). ASPT is the BMWP score divided by the number of families (taxa) in the sample, which gives an idea of the diversity of the community. The overall water quality is assessed by looking at the BWMP and ASPT scores, as summarised in Table **C.5**.

BMWP	
Score	**Water quality**
>150	very good biological quality
101–150	good biological quality
51–100	fair biological quality
16–50	poor biological quality
0–15	very poor biological quality

ASPT	
Score	**Water quality**
>4.4	very good
4.81–4.4	good
4.21–4.8	fair
3.61–4.2	poor
<3.61	very poor

Table C.5 BMWP and ASPT scores related to water quality.

Worked example

Samples taken from two streams are recorded and given scores as shown in Table **C.6**.

Stream 1		Stream 2	
Families present	**Score**	**Families present**	**Score**
pondskaters	5	bladder snails	3
pulmonate snails	6	midge larvae	2
water striders	5	marsh snails	3
creeping water bugs	5	valve snails	3
leeches	4		
air-breathing snails	3		
alder flies	4		
midge larvae	2		

Table C.6 Species recorded in two streams.

The total BMWP scores are 34 for stream 1 and 11 for stream 2. The ASPT scores are calculated using:

$$\text{ASPT} = \frac{\text{BMWP}}{\text{number of families}}$$

So for stream 1:

$$\text{ASPT} = \frac{34}{8} = 4.3$$

And for stream 2:

$$\text{ASPT} = \frac{11}{4} = 2.8$$

Looking up these scores in Table **C.5**, we can see that the water quality of stream 1 is poor by the BMWP score, but fair by the ASPT. Stream 2 scores very poor on both scales.

Exam tip
Always include your working out when you are calculating numerical answers. It helps you to find any mistakes when you are checking your results.

Conserving threatened species

Conserving and protecting a natural habitat as a nature reserve should benefit all species. However, if population numbers are very low and a species is at risk, more active intervention may be required. Each nature reserve will have its own unique solutions to conservation problems. At Belsize Wood Nature Reserve, a small woodland reserve near the centre of London in the UK, nesting boxes for birds and bats have been put in place, because the number of mature trees providing suitable natural nesting sites is low. In a wetland nature reserve, nesting platforms that float on lakes can be beneficial and offer some protection against predators for nesting birds. At Sungei Buloh Wetland Reserve in Singapore, sluice management allows the control of water levels in the ponds. At any one time, the water level in at least one pond is kept low to expose the mudflats for shorebirds to feed and roost (Figure **C.24**).

Members of the public may question the funding and existence of a nature reserve if access is denied to them. This is a difficult issue, as the more people that visit a nature reserve, the more chance there is of habitats being damaged or destroyed. On the other hand, visitor access can have positive outcomes, if public awareness and knowledge of wildlife is improved. Usually, special trails or walkways are built at reserves to ensure that observers can visit safely without compromising the surrounding habitats (Figure **C.24**). Legislation can also protect nature reserves from development and industrial activities.

Figure C.24 The habitat is carefully managed at Sungei Buloh Wetland Reserve in Singapore. There are a number of trails through the wetland, but the highlight is this 500 m boardwalk that takes visitors right to the centre of the reserve.

In situ conservation

***In situ* conservation** protects species within their normal habitat. This makes sense because each species has evolved to adapt to a particular environment. *In situ* conservation protects species in their own habitats by maintaining the environment, often within nature reserves or national parks. In situ conservation work can involve removal of invasive species, such as the kikuyu grass on Montague Island or rhododendron plants in North Wales (described in Subtopic **C3** earlier), or protecting certain species from predators. Provided there are sufficient numbers in the population, *in situ* conservation should provide sufficient genetic diversity for a population to be sustained.

Ex situ conservation

***Ex situ* conservation** involves preserving a species whose numbers are very low in a **captive-breeding programme** in a zoo or botanic garden to prevent it dying out.

In situations where *in situ* conservation is difficult or inadequate, *ex situ* conservation must be used. This is not ideal, because an organism behaves differently outside its natural habitat. However, it does give rise to the opportunity for captive breeding using scientific knowledge and modern technology. Techniques such as artificial insemination and embryo transfer may be used if animals fail to breed normally, and embryos can be preserved for later use. Difficult pregnancies can be monitored and the young cared for by staff.

An *ex situ* breeding programme has proved invaluable for the Arabian oryx. This animal, once almost extinct in the wild, has been successfully bred in a number of zoos in the USA and Europe. The DNA from the few remaining animals was compared and animals specially selected for breeding so that genetic diversity was maintained as far as possible. Studying the behaviour of captive animals is key to breeding programmes. Some species with complex behaviours such as the giant panda from China are highly challenging to breed in captivity, but the centre at Chengdu in China has been very successful.

Plants are more straightforward to maintain in an *ex situ* situation. Botanic gardens can supply the correct environmental conditions for different plants and computer-controlled glasshouses can maintain the temperature and humidity that each requires. Many countries maintain 'national collections' of a variety of species including endemic plants, exotic genera and important food plants.

There are also **seed banks** for many of the world's staple crops such as rice and maize. These preserve varieties of important crops, called **landraces**, which may be useful in the future to produce new varieties of food plants. At the Millennium Seed Bank at Wakehurst Place in England, seeds are kept in cool, dark conditions, which prevent germination, and can be stored for many decades. The Svalbard Global Seed Vault, on the Norwegian island of Spitsbergen, holds duplicate samples of seeds held in gene banks worldwide, in an underground cavern.

Case study – the Arabian oryx

In 1986, the Arabian oryx (*Oryx leucoryx*) was classified as 'endangered' on the IUCN (International Union for Conservation of Nature) Red List and in 2011 it was the first animal to receive 'vulnerable' status again after having been listed as 'extinct in the wild'.

The oryx is a grazing antelope which is adapted to survive in the extreme conditions of hot, dry deserts. The animals live in small herds of 10–30 animals with a hierarchy of dominance amongst both males and females. They defend their territories using their horns and have keen eyesight to maintain the group. They also use their horns to dig shallow pits to rest from the heat of the day. The oryx lives across the Arabian and Sinai peninsulas and has been reintroduced into Oman, Israel, Saudi Arabia and Jordan (Figure **C.25**).

By the early 1970s, the Arabian oryx was extinct in the wild as a result of hunting by poachers who chased them across the desert in four-wheel drive vehicles. A new population was established by breeding animals that were held in zoos in different parts of the world. A captive-breeding programme began in 1962 at the Phoenix Zoo and was supported by the Fauna and Flora Preservation Society of London and the World Wildlife Fund. It began with nine animals and soon oryx were sent to other zoos and parks to start new herds. The pedigree of the captive-bred animals was monitored to ensure that a sufficiently large gene pool was maintained. Animals were reintroduced into the wild in 1982 and the population thrived for about 15 years. But poaching began again in 1996. However, this time laws were changed to put a stop to the practice and a second reintroduction took place in Saudi Arabia. So far this population has survived successfully. The total reintroduced population now stands at about 1000 animals and is well over the threshold number of 250 mature individuals, below which a species qualifies for 'endangered' status.

Figure C.25 Arabian oryx.

Biogeographic features and species diversity

The study of spatial distribution of organisms, species and ecosystems is known as **biogeography**. Biogeographic regions are distinguished by virtue of their particular climatic conditions, physical characteristics such as altitude and soil type, and the presence of particular species of organisms – areas with similar biogeography have similar distributions of organisms. This means that species with similar lifestyles and adaptations can survive in different parts of the world, if the biogeographic conditions are comparable. For example, tropical rain forests are found at various places on Earth where the climate and terrain is similar. Each area of forest contains similar communities of organisms, even though the actual species may be different in different parts of the world. Biodiversity varies across the world and in different biogeographic regions – it is much greater in rain forests, for example, than in desert ecosystems.

As people have become more aware of the need to conserve species, many governments have set aside land or protected areas of the country to provide regions where organisms are safeguarded. When new reserves of this kind are planned, many factors need to be taken into account to ensure they are successful in promoting conservation of diversity. The chosen areas must have the correct climate and terrain – that is, the correct biogeography – to support the species that are to be conserved. In addition, both the size of the area and the total length of its boundary are important (Figure **C.26**).

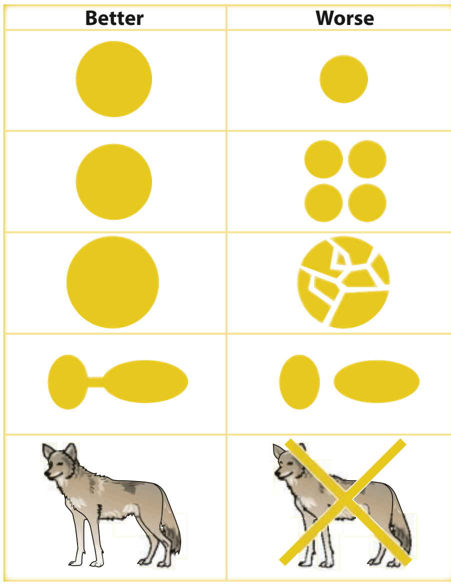


Figure C.26 When designing a conservation area, a large area is better than a small one; a single large area is better than several small areas of the same total size; an intact area is better than a fragmented or disturbed one; areas connected by corridors are better than separate, isolated areas and it is better to have large native carnivores present in the area than not.

Size

Large areas reserved for conservation of biodiversity work better than small ones. Small reserves can only support small population numbers, so there is a risk that inbreeding will occur and the genetic diversity of species will diminish. In a small reserve, there is always a risk that a natural disaster such as flooding or a forest fire will wipe out all the organisms of a species. This is less likely to happen in a large reserve. Edge effects are also less significant in large reserves than in small ones.

Edge effects

The centre of a nature reserve is likely to have different features from the areas at the edge. A woodland reserve has more light, more wind and less moisture at the edge than at the centre. Organisms that live in the centre of the wood will be protected from the influence of other organisms, such as farm animals or human activity, outside the reserve. This is not so for organisms living close to the edge, which may be disturbed by or even compete with organisms outside the reserve. Small reserves have more edge per hectare than large ones, so edge effects have a greater impact on the overall ecosystem in smaller reserves.

One well-studied example of an edge effect involves the brown-headed cowbird of northern and western USA. This bird is a brood parasite, laying its eggs in the nests of other birds at the edge of forests. It feeds in open areas where insects are abundant. As forests have become fragmented, due to urbanisation and farming, more forest edges have become available. The brown-headed cowbird population has increased so much that, in recent decades, many land managers and conservationists have argued that brown-headed cowbirds are a major threat to North American songbird populations.

Wildlife corridors

If it is impossible to create a large nature reserve, good planning may make it possible to link two smaller areas through a corridor. These are often built under busy roads or railway lines, so that organisms have a larger area to move about in and colonise. A corridor is not ideal because animals using it may be exposed to dangers from outside the reserve and corridors can act as conduits for the spread of disease or make certain species easy targets for poachers. On the other hand, the benefits of corridors include the fact that gene flow between two otherwise isolated areas can take place and promote diversity.

Simpson's diversity index gives us a measure of both richness and evenness. It is calculated using the formula:

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

where

D is the diversity index
N is the total number of organisms in the habitat
n is the number of individuals of each species

Measuring biodiversity – the Simpson diversity index

Biodiversity is a relatively modern term that simply means 'the variety of life on Earth'. One of the best ways to assess the health of an ecosystem is to measure the variety of species living there. The Simpson diversity index allows us to quantify the biodiversity of a habitat. It takes into account both the number of different species present (the species '**richness**' of the habitat) and the abundance of each species. If a habitat has similar population sizes for each species present, the habitat is said to have '**evenness**'.

The value of the Simpson diversity index is best illustrated by comparing two habitats. Two ponds might contain species of invertebrates in the numbers shown in Table **C.7**.

	Species					Total number of organisms
	Water boatmen	Water measurers	Pond skaters	Whirligig beetles	Water spiders	
Number of organisms in pond A	43	18	38	3	1	103
Number of organisms in pond B	26	18	29	11	5	89

Table C.7 Numbers of different invertebrate species found in two separate ponds.

Using the formula, we can calculate that for pond A:

$$\text{Simpson diversity index } D = \frac{(103 \times 102)}{43(43-1) + 18(18-1) + 38(38-1) + 3(3-1) + 1(1-1)}$$

$$= \frac{10506}{3524}$$

$$= 2.98$$

For pond B:

$$\text{Simpson diversity index } D = \frac{(89 \times 88)}{26(26-1) + 18(18-1) + 29(29-1) + 11(11-1) + 5(5-1)}$$

$$= \frac{7832}{1898}$$

$$= 4.13$$

Although there are fewer organisms in pond B, the individual populations are more even, so the community is not dominated by one or two species. We conclude that pond B is more biodiverse. It is instructive to alter some of the figures and see what effect this has on the value of D. An advantage of the index is that you do not need to know the name of every different species – it must simply be distinguished as a separate species. Calculating the Simpson diversity index at intervals over time can give a good indication of the health of an ecosystem and whether conservation measures might be valuable.

Nature of science

Cooperation and collaboration – conserving biodiversity requires international cooperation between scientists, organisations and politicians

In the last 50 years, the importance of biodiversity has come to the forefront of science. Species are not evenly distributed on Earth – biodiversity is far richer around the tropics, and areas containing rainforest are among the most diverse on the planet. People have come to realise that there are many compelling reasons for conserving the biodiversity of habitats such as the rainforests where as yet undiscovered species may provide valuable medicines and other resources for future generations. Conservation in one part of the world may depend on cooperation and collaboration in another and international organisations such as World Wide Fund for Nature (WWF) and the United Nations Environment Programme (UNEP) coordinate such work in many countries. The key objective of all conservation organisations is to preserve species and their habitats. Some work at a local level while others are global. Some organisations, such as UNEP, are funded by governments while others, such as WWF, are non-governmental organisations (NGOs), which are funded by individuals or groups. Organisations such as WWF work with businesses, governments and local communities to create solutions that take account of the needs of both people and nature.

Conservation programmes must select which species are to be protected, but it is often difficult to decide which species most merit conservation efforts. On what basis should one species be chosen over another? For example, is a large mammal such as a tiger or panda more important than a small, seemingly insignificant mollusc? A striking or endearing mammal may encourage people to support a conservation programme but smaller, less appealing species may, in fact, be more important and play a pivotal role in an ecosystem. Should endangered animals be given priority over other species whose numbers are not yet so low?

The choice of species for *ex situ* conservation can also be difficult, and many factors must be taken into account. For example, when zoos select animals for captive breeding programmes, certain animals with aesthetic appeal are likely to increase visitor numbers and therefore raise public awareness and attract greater financial support for conservation. If these animals are returned to the wild, they may engage local people who could benefit from ecotourism. On the other hand, choosing a species for ecological reasons is more likely to benefit a whole ecosystem – assuming the programme does not fail through lack of funding and support.

Ecotourism involves developing a conservation area to make it suitable and attractive for visitors, who pay for local goods and services thus providing economic support for the area and its people.

Science can support conservation efforts by providing the expertise needed to ensure breeding programmes are successful. Different zoos have different areas of expertise and are likely to be more successful at *ex situ* conservation with some species than with others, so this factor too will influence the organisms whose preservation is prioritised.

Test yourself

10 Outline the differences between *in situ* and *ex situ* conservation programmes.

11 Define the term 'indicator species' and give one example.

12 Compare the terms 'richness' and 'evenness' as components of biodiversity.

C5 Population ecology (HL)

Learning objectives

You should understand that:

- Population size is estimated using sampling techniques.
- In an ideal, unlimited environment, exponential population growth can take place.
- As the carrying capacity of the environment is reached, population growth slows.
- The shape of a sigmoid growth curve can be explained by relative rates of natality, mortality, immigration and emigration.
- Limiting factors can act on population size from the top down or from the bottom up.

Estimating numbers in populations

A **population** is a group of individuals of the same species that live in the same area. Population numbers can and do change over time and are affected by a number of factors in the environment. In order to assess the size of a population, **sampling** techniques are used (Subtopic **C1**).

The most common method of estimating population size of animals is the 'capture–mark–release–recapture' technique (Figure **C.27**). It is used for populations where individuals are mobile and move freely in their habitat.

1 A sample of the population is collected by netting or trapping or another suitable method. The sample must be as large as possible and the trapping method must not harm the animals.
2 The number of organisms in the sample is counted and recorded.
3 Each of the captured animals is inconspicuously marked in some way – for example, with non-toxic paint for invertebrates or by trimming a concealed area of fur for small mammals.
4 The animals are returned to the wild and left for long enough to mix with the rest of the population.
5 A second sample of the population is collected after this time.
6 The number of marked and unmarked individuals in the second sample is counted.

The population size is calculated using the Lincoln Index formula:

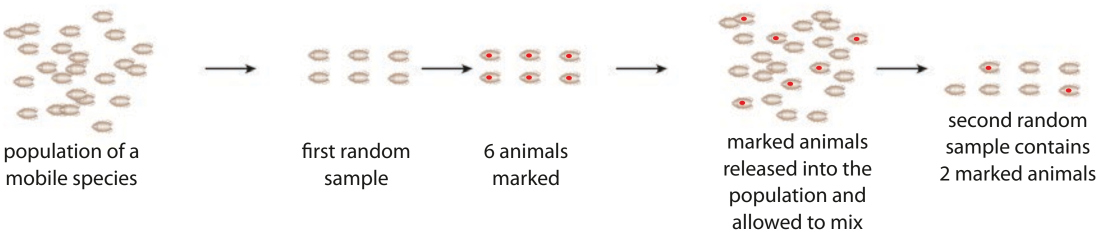
$$\text{total population } p = \frac{\text{number of animals in first sample} \times \text{number of animals in second sample}}{\text{number of marked animals in second sample}}$$

or

$$p = \frac{(n_1 \times n_2)}{n_3}$$

where

P is the total population
n_1 is the number of organisms caught originally
n_2 is the number caught in the second sample
n_3 is the number of marked individuals in the second sample



estimated population size = $\frac{\text{number in first sample} \times \text{number in second sample}}{\text{number of marked animals in second sample}}$

estimated population size = $\frac{6 \times 7}{2}$

estimated population size = 21

Note: This method only produces results of acceptable accuracy if the numbers in the samples are larger than shown here. At least 20 animals should be sampled.

Figure C.27 Capture–mark–release–recapture technique for estimating population size.

This method depends on a number of factors, which need to be taken into account.

- Marking the organisms must not harm them or cause them to be conspicuous to predators. That is, the marking itself must have no effect on the population size.
- There should be minimal **immigration** into or **emigration** from the population.
- The measurements must be conducted within a single life cycle, so there are no changes to the population through births or deaths.

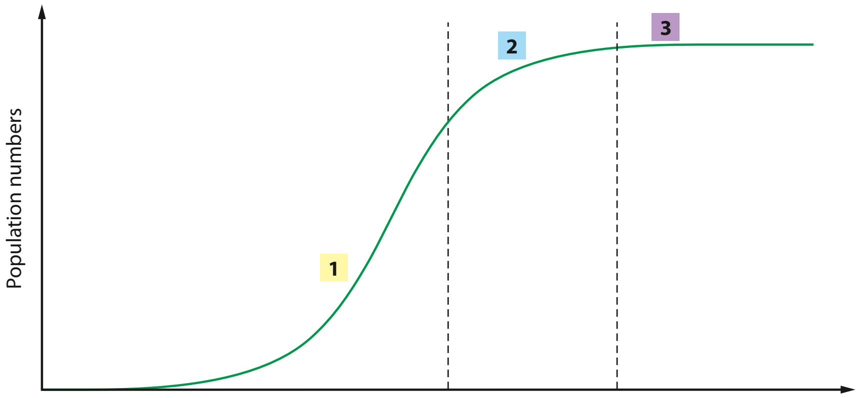
The capture–mark–release–recapture technique is most appropriate for invertebrates such as woodlice, snails and ladybirds or small mammals, such as mice, with a limited territory. Sampling organisms with a large territory, or those where the population is small, is not accurate using this method.

Population size and growth

Consider what happens if a few individuals of a species enter an unoccupied area. Perhaps a few rabbits arrive on an uninhabited island covered by lush grassland or some fish are washed into a newly established pond. Assuming there is enough food and there are few predators, the newcomers will reproduce and the population will increase rapidly. After a time, when there are large numbers of individuals, the food supply will start to be used up faster than it can be replaced. The population will be unable to increase any further and the population numbers will stabilise.

This typical pattern of population growth can be represented on a graph, like that shown in Figure **C.28**.

1. As reproduction gets underway, the population shows exponential growth (the steepest part of the curve). At this time, the population inhabits an ideal, unlimited environment – there is abundant food, little competition for space and the effects of predation and disease are minimal.
2. After a time, the exponential phase ceases and one or more of the resources individuals need become limited. The shape of the curve shows that the rate of population growth is declining at this point and the population is said to be in the transitional phase. Individuals must compete with one another for the resources they need, which may include space, light, food, nutrients and water. Competition for resources between members of the same species is known as **intraspecific competition**. This increases as population numbers increase. When the rate of demand for a particular resource is greater than the rate of supply we say that the resource has become a **limiting factor**. Predation, disease, and in some cases the accumulation of toxic wastes, such as carbon dioxide, can also limit a population.
3. Eventually population numbers become more or less constant and the curve levels off, in the plateau phase. The ecosystem has reached its **carrying capacity**, which is the number of individuals in a population that the resources in the environment can support for an extended period of time. Once the carrying capacity is reached, the population growth rate will slow down either because organisms die through lack of an essential resource, or because they fail to breed and their birth rate falls. In the plateau phase, the population remains more or less stable because rates of natality and mortality are balanced, as are rates of emigration and immigration.



1 Exponential phase

Population increases with no restraint on growth. Nutrients are abundant and there is little accumulation of waste.

2 Transitional phase

One or more factors in the environment are limiting the rate of reproduction. These might be competition for resources such as food, space or mates, increased predation and disease, or an abiotic factor such as oxygen might be in short supply.

3 Plateau phase

In this phase the number of births plus immigration is equal to the number of deaths plus emigration.

Figure C.28 The sigmoid population growth curve for a model species such as duckweed (*Lemna* spp.), growing in a stable environment.

The human population

The human population growth graph has not followed the sigmoid pattern shown in Figure **C.28**. Since the evolution of humans, no plateau has been reached, and instead the global population continues to rise exponentially. The natural carrying capacity of Earth has been manipulated as humans have found ever more technologically advanced ways to produce food and extract resources from the environment. Humans have also overcome other limiting factors like disease through improved medicine, and colonised almost every part of the planet. But over-population has led to poor living conditions and environmental degradation in many parts of the world.

Why do population sizes vary?

There are a number of important reasons why a population may change in size:

- **natality** – the birth rate may change (the number of new individuals joining the population due to reproduction)
- **mortality** – the number of deaths may change
- **emigration** – members of the population may move away to new habitats
- **immigration** – new members of the species may arrive from elsewhere.

Factors that limit population increases

There are certain key factors that affect a population, no matter what species is considered. These include:

- availability of key resources such as food, water, oxygen, light, space, mates and shelter

- levels of waste products, such as carbon dioxide or nitrogenous waste
- disease
- predation or herbivory.

Ecologists divide limiting factors into two categories: 'top down' or 'bottom up'.

Top-down limiting factors

Top-down limiting factors are those that involve an organism higher up the food chain limiting the numbers of a species at a lower trophic level, usually through predation or herbivory. One example of this is the control of the small algae (*Fucus* spp.) on a rocky shore by grazing limpets (Subtopic **C1**). Another example is the control of kelp forests due to the impact of sea otters. Otters feed on sea urchins, which use kelp as a source of food so if sea otter numbers fall, the sea urchin populations expand and reduce the kelp forest. Ecosystems such as those where sea otters and limpets are found are not controlled by the productivity of the primary producer but rather by a top predator or major herbivore acting as a **keystone species**.

Bottom-up limiting factors

Bottom-up control by limiting factors occurs where the nutrient supply and productivity of primary producers (plants and phytoplankton) control the structure of the ecosystem. In marine coastal ecosystems, plankton populations depend on and are controlled by the availability of nutrients.

Phytoplankton populations increase so that large growths known as **algal blooms** appear when nutrients are abundant. This happens when sea currents cause upwelling, which brings nutrients to the surface where they are accessible to phytoplankton. The abundant growth of phytoplankton is then controlled by top-down control by herbivores, which use it as food. Algal blooms are also controlled by bottom-up control at times when nutrients are in short supply or in places where currents do not bring nutrients to the surface.

Limiting factors and ecosystem stability

Bottom-up and top-down control tends to keep a stable population at the carrying capacity of the ecosystem. The bottom-up resources set the limit for the maximum sustainable population, while top-down control removes individuals from a large population, with the result that resources are not over-exploited. The concept of internal control of populations by interactions between them is a key argument for the conservation of ecosystems.

? Test yourself

13 Suggest factors that might lead to an increase in a bird population in a woodland.

14 Complete this equation for the plateau phase of a growth curve:

natality + __________ = __________ + __________

Estimating the size of commercial fish stocks

The commercial fishing industry is of enormous importance worldwide. Fish provide what should be a renewable source of food, but catching fish has become an industrial process, involving technology, such as the use of sound waves to track shoals of fish, and large-scale machinery, including huge trawling nets. Many species are in danger of being over-fished, as their populations are reduced to unsustainable levels. In some species, the numbers of adult fish available to breed is too low to replace the animals removed by fishing. There is a pressing need to monitor populations so that fish species, and the fishing industry as a whole, can survive.

The International Council for Exploration of the Sea (ICES) is an organisation that monitors harvests in the North Atlantic. Fish are not easy to count because they move over long distances. The usual method of estimating a population involves collecting data from landings at fish markets, from the numbers of fish discarded from fishing boats, and from targeted surveys with research vessels.

- The numbers of fish of different ages are recorded to give an idea of the age distribution in the population. The ages of individual fish are a useful indicator of fish stocks. Too few young ones indicate that the fish are not spawning sufficiently to replace caught fish, and too few older, larger fish indicates that over-fishing is occurring.
- Fish age can be estimated by the length and weight of individuals. A more accurate method is to measure the rings in the ear bones. As fish grow, the number of rings increases and these can be measured using a microscope.
- The data collected from catches and age estimation can be used to deduce spawning rates and survival of different species.
- Research vessels can use echo sounding to estimate the sizes of fish shoals in some locations.

ICES offers advice on over 130 species of fish and shellfish. Using the advice from this and other similar organisations, scientists can work out the health of a particular fish population and whether it is being over-fished.

Maximum sustainable yield

The **maximum sustainable yield** is the largest proportion of fish that can be caught without endangering the population. Setting this figure is hotly debated and countries have different views on the issue, often influenced by local interests. At extremes, if the fish population is very small, there will be few adults to produce young, and if the population is large, competition for food will slow growth. The ideal, then, is to fish at a level that maintains the maximum yield by allowing fish stocks to replenish at the optimum rate. Fish are a renewable resource and can always be available for food if they are only taken in a way that allows them to survive and replenish their numbers.

International measures to conserve fish

In recent years, there have been several alarming reports on declining fish populations worldwide. In 2003, 29% of open-sea fisheries were in a state of collapse, defined as a decline to less than 10% of their original yield.

Populations of fish must be monitored and quotas or closed seasons put in place to reduce fishing during the breeding seasons. If net sizes are monitored and controlled, smaller fish can be left in the water to mature and breed. Today bigger vessels, bigger nets and new technology for locating fish are not improving catches, simply because there are fewer fish to catch. Where fishing is banned or regulated, biodiversity can improve and fish populations may be restored relatively rapidly. This means protecting not only fish populations but also other organisms within a marine ecosystem.

International cooperation is essential if measures like these are to be successful. In 1995, the United Nations Fish Stocks Agreement became one of the first international treaties to protect fish. It was the first attempt made to develop a long-term, sustainable fishing strategy and has already had an impact on the regulation of fishing since it came into force in 2001. Now 77 countries including most of the major fishing nations and the European Union have signed up to the Agreement. It has encouraged countries to adopt responsible fishing policies and manage fisheries with more care. In 2006, a Review Conference was held to strengthen the Agreement still further.

The ICES has noted that the situation in the North Sea has been gradually improving since 2006. It is estimated that there are now 21 million mature cod (65 000 tonnes) in the North Sea and fish have been found to be reproducing at a younger age – at 4 years of age, 60% of fish are mature and all are mature at 6 years old.

Cod discard rates have fallen from 62% in 2007 to 24% in 2011 so fewer fish are dying needlessly, but the situation is still precarious. As the graph in Figure **C.29** shows, fishing mortality was estimated at 0.67 in 2010, which means that 49% of all fish between the ages of 2 and 4 years were caught. Although the biomass of spawning fish has increased since its lowest point in 2006 (Figure **C.29**), it is still below the limit of what is healthy for a sustainable population.

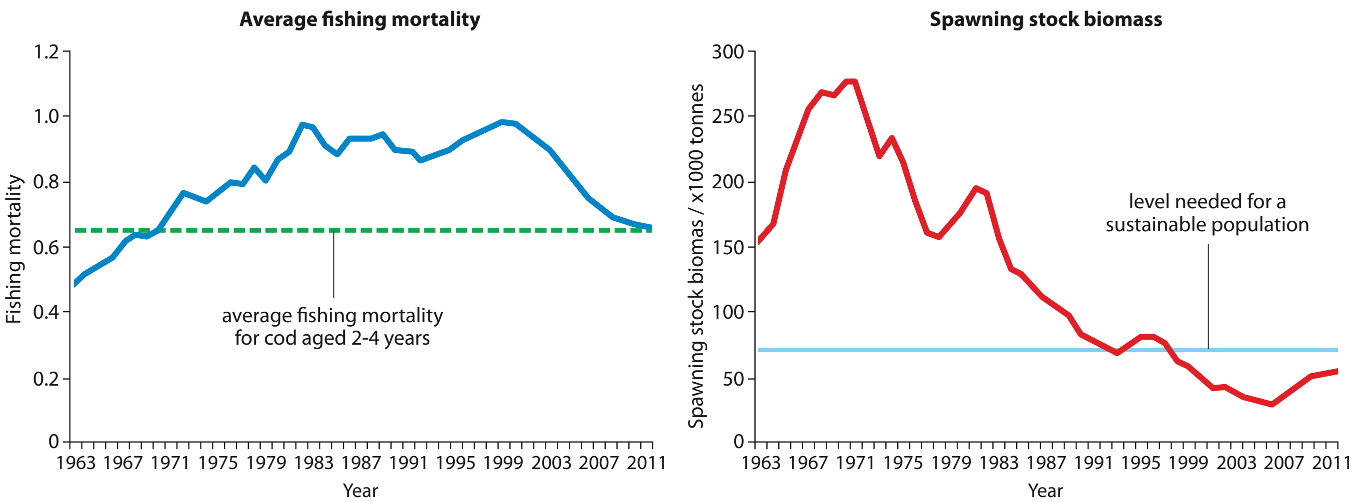


Figure C.29 Fishing mortality and spawning stock biomass for North Sea cod between 1963 and 2011. The population of North Sea cod has fallen greatly since the end of the 1960s, almost certainly as a direct result of over-fishing. The horizontal line in the right-hand graph shows the minimum stock size that has been calculated will allow the cod population to be maintained at a viable level.

Nature of science

Cooperation and collaboration – international efforts to conserve fish stocks

Why is it difficult to ensure that fishing is regulated to the benefit of fishermen, consumers and the environment? Consider the following statements and discuss the problems that arise as international negotiators attempt to interpret and apply scientific data.

- Data on fish stocks is difficult to obtain and there is no common view on what is a sustainable population.
- It is difficult to enforce fishing regulations. Authorities may be active in one region but unable to control actions of other countries that ignore the rules.
- Politicians are under pressure from fishing communities not to limit fish catches.
- As fisheries go out of business due to declining stocks, it is not easy to limit the activities of those that remain.
- Fish are mobile animals and can be caught thousands of miles from where they are bought. Can ethical consumers be sure that the fish they buy is from a sustainable stock?

Exam tip
Remember that if an examination question asks you to 'discuss', it is important to present alternative points of view.

Test yourself

15 a Describe how the 'capture–mark–release–recapture' method is used to estimate the size of a population of small invertebrates.

b Explain the limitations of this method.

16 Outline what is meant by 'maximum sustainable yield' of fish stocks.

Exam tip
If you are asked to 'explain' a concept or situation, remember to include the steps in the process and write about them in some detail.

Learning objectives

You should understand that:

- Nitrogen-fixing bacteria convert nitrogen from the atmosphere into ammonia.
- *Rhizobium* bacteria form a mutualistic relationship with roots.
- Denitrifying bacteria reduce soil nitrate levels in anaerobic conditions.
- Phosphorus can be added to the phosphorus cycle in the form of fertilisers or removed as crops are harvested.
- In the phosphorus cycle the rate of turnover is much slower than in the nitrogen cycle.
- Phosphate availability may limit agriculture in the future.
- Eutrophication is caused by the leaching of mineral nutrients from agricultural land into rivers. Increased levels of nutrients in the water lead to an increased biochemical oxygen demand (BOD).

C6 Nitrogen and phosphorus cycles (HL)

The nitrogen cycle

Nitrogen is a vital element for the formation of proteins and nucleic acids in the bodies of plants and animals. However, although almost 80% of the Earth's atmosphere is nitrogen gas, it is so stable that it cannot be used directly by living organisms, and nitrogen is often in short supply as a nutrient. It is recycled in ecosystems through the actions of many organisms (Figure **C.30**).

Nitrogen fixation

Nitrogen is made available to an ecosystem by bacteria that are crucial in transferring nitrogen compounds from the abiotic to the biotic environment. Two types of bacterium, *Azotobacter* and *Rhizobium*, are able to 'fix' nitrogen from the air and convert it into ammonia. Ammonia formed by both organisms reacts with organic acids to form amino acids.

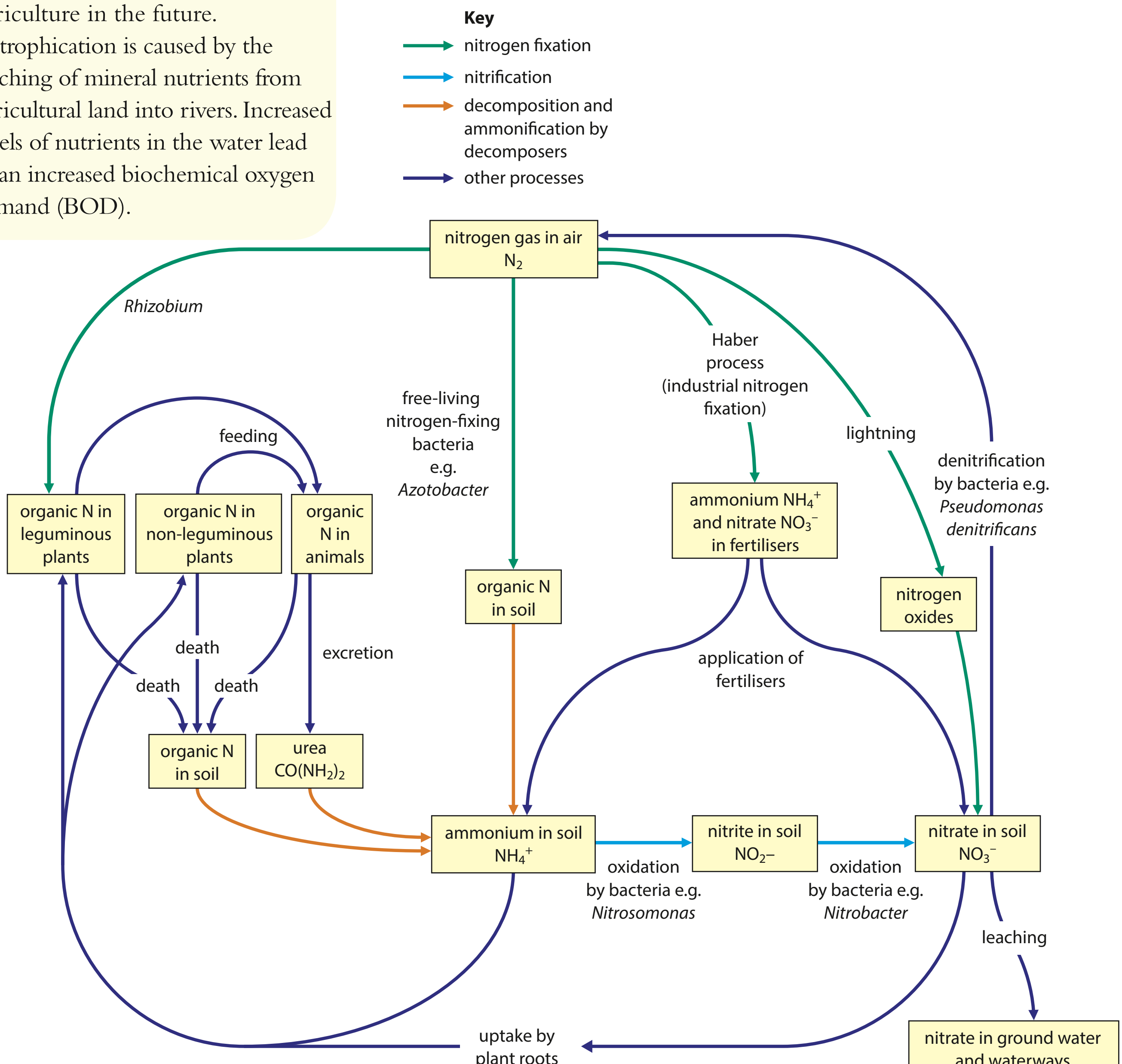


Figure C.30 The nitrogen cycle.

For example, pyruvate (pyruvic acid) reacts with ammonia to form the amino acids alanine, valine and leucine. *Rhizobium* invades the roots of leguminous plants such as peas, beans and clover to form nodules on the roots (Figure **C.31**). The bacteria and plants form a **mutualistic** relationship in which the bacteria receive sugars from the plant, and the plant in turn receives nitrates from the bacteria. The only other natural method of **nitrogen fixation** is the effect of lightning, which combines nitrogen gas in the air with oxygen, forming nitrates that enter the soil, where they are useful to living things. Humans also fix nitrogen in the Haber process, which is used to manufacture fertilisers.

Figure C.31 *Rhizobium* nodules on the roots of a bean plant.

Nitrification

Other important groups of bacteria in the nitrogen cycle are the nitrifying bacteria *Nitrosomas* spp., which use oxygen to convert ammonia from excretory material into nitrites, and *Nitrobacter* spp., which use oxygen to convert nitrites into nitrates. **Nitrification** is an important part of the nitrogen cycle because both ammonia and nitrite are toxic to plants. Nitrates are all soluble compounds that can be absorbed by plants through their roots and assimilated into their biomass. Nitrification is favoured by a neutral pH, warmth and well-aerated soil, as it is an oxidative process. Ammonium compounds and nitrites cannot be taken in directly by plants.

Although nitrogen gas (N_2) is inert and unreactive, many important compounds contain nitrogen. Ions of some of these compounds are:

NO^{2-} nitrite
NO^{3-} nitrate
NH^{4+} ammonium

Denitrification

Denitrification reduces the fertility of the soil, depleting it of nitrates so that it may not be useful for cultivation. Denitrifying bacteria (for example, *Pseudomonas denitrificans*) – which are found mainly in anaerobic conditions in compacted or waterlogged soils – convert nitrates to nitrogen gas. Waterlogging therefore has an impact on the cycling of nitrogen – it causes a lack of nitrifying and nitrogen-fixing bacteria, and favours the return of nitrogen to the atmosphere by denitrification.

The nitrogen cycle and soil fertility

Plants obtain the nitrogen they need to grow in the form of nitrates, which they absorb from fertile soil through their roots.

Good for plant growth are:

- nitrogen fixation, which converts nitrogen gas to useful nitrates
- nitrification, which converts ammonia to useful nitrates.

Bad for plant growth is:

- denitrification, which converts useful nitrates into nitrogen gas that plants cannot use.

Insectivorous plants

A few plants are able to survive in nitrogen-poor and phosphorous-poor environments such as bogs and acidic moorlands where waterlogging encourages the growth of denitrifying bacteria. Conditions like these limit the amount of nutrients that plants can extract from the soil.

Insectivorous plants, including the Venus fly trap (*Dionaea muscipula*) and the sundews (*Drosera* spp.), supplement their nutrition by trapping and digesting insects and other small arthropods, which provide the nitrogen they need to form proteins.

The Venus fly trap, which is endemic in the wetlands of the East Coast of the USA, has spines on the edges of its leaves (Figure **C.32**). When they are triggered, the leaves can fold to form a cage, which traps an insect inside. The closing of the trap is triggered when an insect comes into contact with hairs on the surface of the leaves. The leaves squeeze tightly together and release digestive enzymes on to the prey inside.

Figure C.32 Venus fly trap.

Sundews, which can be found growing in bogs and moorland on every continent except Antarctica, use a sticky mucilage to trap their prey. Insects are attracted to the plant by sweet, sticky secretions from their 'tentacles' (Figure **C.2**). If an insect touches the tentacles it becomes trapped in the sticky fluid and is unable to escape – it will either die of exhaustion or of suffocation if the mucilage fills its spiracles. Tentacles bend towards the centre of the leaf and secrete digestive enzymes, which dissolve the prey. Nutrients are absorbed through the surface of the leaves.

The phosphorus cycle

Phosphorus is an essential nutrient for life and is vital to many physiological and biochemical processes. It is an essential raw material needed for the formation of DNA. Most of the phosphorus on Earth is found stored in soil and rocks as inorganic phosphate (PO_4^{3-}). Phosphates are released naturally through the weathering and dissolution of rocks and minerals. Phosphorus is usually the limiting element for animal and plant production and throughout history phosphate has often been in short supply in agriculture.

The phosphate that dissolves in the soil as rocks are weathered and eroded is absorbed by plants through their roots and flows through food chains and webs, eventually being returned to the ground when organisms die and decompose (Figure **C.33**).

The rate of turnover in the phosphorus cycle is much lower than in the nitrogen cycle. Weathering and erosion are slow, long-term processes so that phosphates remain locked up in the abiotic part of the cycle for long periods of time.

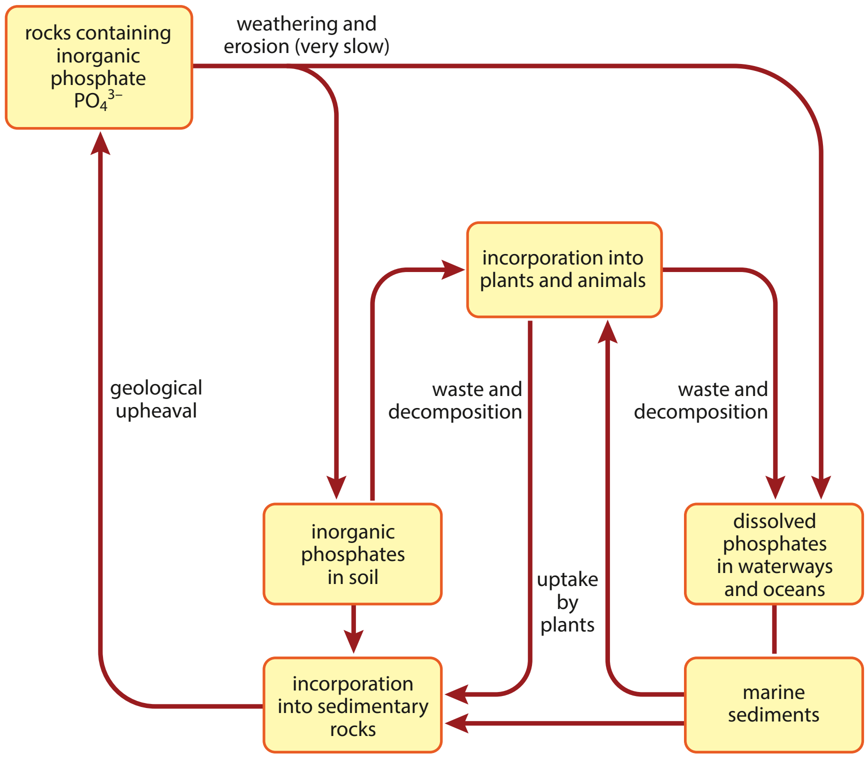


Figure C.33 The phosphorus cycle.

Agricultural demands for phosphate

Farmers have known about the importance of organic manure, which contains phosphate, for thousands of years and animal manure, compost and sewage sludge are still important sources of both phosphate and nitrates. But with the increasing world population and demand for food, the natural recycling of phosphorus has been interrupted and phosphate fertilisers have become more important. Where fertilisers are available the quantity and quality of agricultural output has been increased.

Phosphate is mined on a large scale to make fertilisers. Today plant and animal health problems caused by lack of phosphate have been eliminated in developed countries and more than 30 countries extract phosphate rock for use in fertilisers. The three major producing countries are the USA, China and Morocco, who together produce approximately two thirds of the world's phosphate. Moroccan reserves account for around 50% of the world total. But phosphate remains in short supply in many countries due to economic or political limitations.

Increased life expectancy, lower child mortality and improved farming methods allowing increased food production have led to exponential global human population growth over the last 150 years. Rising populations and increased wealth have also increased the demand for higher-grade foods – for example, the proportion of meat and dairy products in the world diet is rising. Increasing meat consumption leads to an increase in the need for cereals to feed farmed animals and thus a greater demand for phosphate fertilisers. It is possible that availability of phosphate may one day limit the expansion of agriculture worldwide.

Crop rotation

Crop rotation is a traditional method of farming which involves changing the type of crop grown in a field on an annual or regular basis. Farmers alternate different types of plants to increase soil fertility and prevent pests and diseases becoming established. A typical rotation might be a root crop, followed by cereals, then brassicas (cabbages) and finally legumes (Figure **C.34**). Legumes, such as clover, add nitrogen to the soil, while wheat and potatoes use up nutrients. A crop rotation will often include a 'rest' period for an individual field. In a resting field, grass or clover can be planted for a season or longer, and then grazed or ploughed into the soil to add fertility.

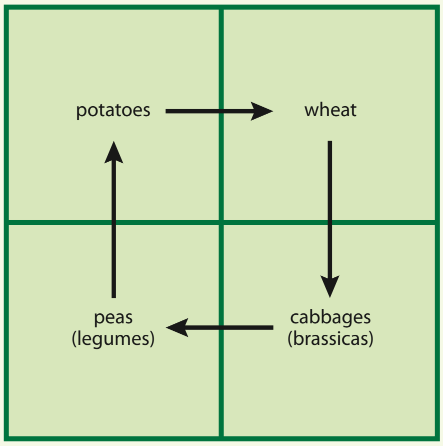


Figure C.34 Crop rotation.

Eutrophication

Eutrophication is defined as the natural or artificial addition of nutrients (especially nitrates and phosphates) to water, which leads to a reduction or depletion of the oxygen content of the water.

Phosphorus is present in agricultural fertilisers, animal manure and sewage, and household detergents have also been a major source. Nitrates from fertilisers and animal manure also contribute to eutrophication. Excess fertiliser can run off the land, particularly in areas where large numbers of livestock are kept or where slurry is used as a fertiliser. Soil erosion also deposits both manure and artificial fertilisers in waterways, especially where forests have been cut down and **leaching** of minerals from the soil by rainwater is therefore increased. Nitrate and phosphate flowing into rivers and streams can cause ecological problems and eventually lead to eutrophication.

If manure or sewage enters a river, the following processes occur:

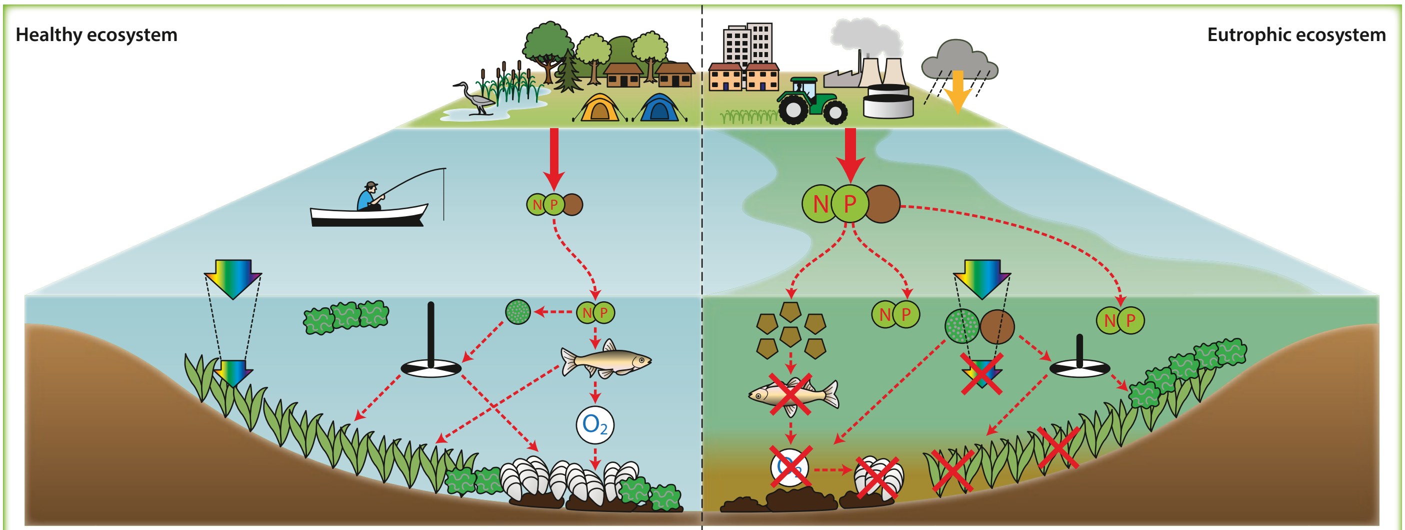
1 Saprotrophic bacteria and fungi feed on the organic material in the raw sewage as a source of nutrients, and multiply. These aerobic organisms use up a large amount of oxygen and reduce its concentration in the water. They are said to cause an increased **biochemical oxygen demand** (BOD).

2 When the oxygen level drops, river organisms, including fish and many invertebrates that are highly dependent on high oxygen levels, die or move to other unpolluted areas if they can.

3 Death and decay of the sensitive organisms leads to a build-up of ammonia, phosphate and minerals.
4 Ammonia is converted to nitrate and with this increased concentration of nutrients, algae reproduce rapidly. This is known as **eutrophication** (Figure **C.35**).
5 In time, the increased photosynthesis by the large amounts of algae that use the nitrate to grow can restore the levels of oxygen, so the river returns to normal.
6 But if the algae produce an **algal bloom** and then die and decay, this may cause a cycle of events that reduce oxygen concentration again and lead to the death of other organisms. In this case river, the takes longer to recover. If the algae do not die, then the river can recover from sewage pollution, although this may be several kilometres downstream from where the pollution entered the river.

Biochemical oxygen demand (BOD) the amount of dissolved oxygen that aerobic organisms need to break down organic material present in a body of water, at a certain temperature, over a certain period of time.

In many countries, fertiliser use is controlled, and in modern farming the requirements of crop plants are closely monitored. Farmers are sometimes blamed for causing eutrophication through inappropriate use of fertilisers that are high in nitrates and phosphates. However, farmers cannot always be held responsible, for example, if it rains heavily after fertiliser is applied, much of it will pass through the soil to ground water, before crop plants have had a chance to absorb it.



In healthy ecosystems nutrient inputs, specifically nitrogen and phosphorus (N P), occur at a rate that stimulates a level of macroalgal and phytoplankton ( ) growth in balance with its consumption. A low level of phytoplankton in the water column helps keep water clarity high, allowing light to penetrate deep enough to reach submerged aquatic vegetation. Low levels of phytoplankton and macroalgae result in dissolved oxygen (O_2) levels most suitable for healthy fish and shellfish, so that humans can enjoy the benefits that the environment provides.

In a eutrophic ecosystem, increased sediment and nutrient loads (N P) from farming, urban development, water treatment plants and industry, in combination with atmospheric nitrogen, help trigger both macroalgae and phytoplankton ( ) blooms, exceeding the capacity of control by consumers. These blooms can result in decreased water clarity, decreased light penetration, decreased dissolved oxygen, loss of submerged aquatic vegetation, nuisance/toxic algal blooms and the contamination or die off of fish and shellfish.

Figure C.35 Comparing healthy and eutrophic systems.

Nature of science

Assessing risk in science – use of phosphate fertilisers

Research has revealed that 'phosphate efficiency' is low in agricultural systems. One year after it has been applied, only about 15–25% of the phosphate in a fertiliser is taken up by crops. Much of it remains in the soil, bound to soil particles or other elements, and unavailable to crops for a long period of time. This may increase phosphate reserves in the soil – indeed, in many western countries the soil fertility has been improved by year-on-year application of phosphate fertilisers so that it may now be possible to reduce the level of phosphate in fertilisers and still maintain yields – but up to 25% will never be available to crops because it is in form they cannot use. Increased phosphate reserves in the soil are at risk of being leached out by rain and polluting waterways and thus causing an imbalance in the natural cycling of phosphorus.

The benefits of using phosphate and nitrate fertilisers must therefore be balanced against the potential damage that can be caused to ecosystems such as rivers and streams. Monitoring of these systems by environmental agencies produces data about risks to their structure, which must be weighed against the value of the sustained increases in food production that the burgeoning human population requires.

Test yourself

17 Name **one** species of nitrogen-fixing bacterium.

18 State what is meant by the term 'eutrophication'.

19 Outline the reasons why some plant species have evolved to be insectivorous.

Exam-style questions

1 Explain **three** factors that affect the distribution of plant animal species. **[4]**

2 a Discuss the strengths and weaknesses of an approach to conservation that favours a high-profile mammal. **[3]**

b Explain the importance of shape and size in the design of a nature reserves. **[4]**

c Outline **two** advantages of wildlife corridors. **[2]**

3 The Simpson's diversity index is used to calculate the diversity of an ecosystem.

a Calculate the diversity index (D) of this area of sand dune (using the formula in Subtopic **C4**). **[2]**

Species	Number (n)
sea holly	20
sedge	80
sea bindweed	10
Portland spurge	30
sea spurge	10
Total	150

b A similar area of sand dune at a different location was sampled and found to have a higher diversity index. What does this tell you about the second sand dune? **[1]**

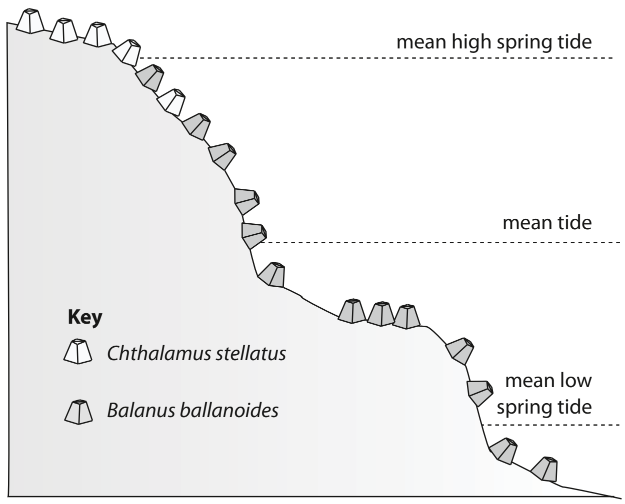
4 a Bacteria in a culture vessel divide so that the population doubles every 20 minutes. Complete this table to show the number of bacteria present over a period of 160 minutes. **[4]**

Time / mins	Population / 1000s
0	1
20	2
40	4
60	8
80	16
100	
120	
140	
160	

b Construct a graph of these data and describe the shape of the curve. **[2]**

c If no additional nutrients were added to the culture of bacteria, predict what would happen to the shape of the curve and explain your answer. **[3]**

5 Two species of barnacle *C. stellatus* and *B. balanoides* live on rocky shores of Europe. The distributions of the two species are shown in the diagram. Below the tide line there is abundant growth of seaweed on the rocks and large numbers of a predatory whelk that feeds on barnacles.



a Suggest **two** factors that may be limiting the distributions of each of the two species at the upper and lower limits of their ranges. **[4]**

b If a rock on which *C. stellatus* is found is placed lower down the shore the barnacles can survive very well. Suggest a reason why they are not normally found on the lower shore at this location. **[1]**

6 Calculate the species frequency of an organism if 200 quadrats are used to sample an area and the species is present in 86 of them. **[2]**

7 Outline **four** ways in which macroplastic debris accumulating in the oceans has harmed marine species. For each suggestion outline how the animal is harmed. **[4]**

8 The cane toad is an example of an alien species that was introduced into Australia and has become invasive. Outline **three** reasons why this species has caused the reduction of the number of endemic and other species. **[3]**

9 Explain the use of indicator species and biotic indices in monitoring pollution in a stream environment. **[4]**

10 Discuss the advantages of *ex situ* conservation of endangered species. **[5]**

11 **a** Outline the technique of capture–mark–release–recapture to estimate a population. **[3]**

b List **three** limitations of this method. **[3]**