19 Ecology and conservation

- **Ecology** is the study of organisms in relation to their environment.
- An **ecosystem**, such as a lake, woodland, or salt-marsh, is a stable, settled unit of nature. A **habitat** is the surroundings in which an organism lives.
- A **population** consists of all the living things of the same species in a habitat. A population may initially grow exponentially, but it is prevented from doing so indefinitely by environmental constraints.
- A **community** consists of all the populations of organisms interacting with each other and with their surrounding physical and chemical environment within a habitat.
- A **food chain** is a sequence of organisms within a habitat in which each is the food for the next, starting with **producers** (photosynthetic green plants – **autotrophs**), to primary **consumers** (herbivores), to secondary and tertiary consumers (carnivores). Each level of the food chain is called a **trophic level**.
- While energy flows through food chains, from sunlight to becoming heat energy lost into space, **nutrients** (particularly minerals, but also carbon dioxide) are endlessly recycled. These are released from dead organisms and their waste matter by the actions of **saprotrophic** bacteria and fungi (**decomposers**).
- This chapter extends study of aspects of ecology and of the **impact of humans on the environment** begun in Chapter 6 (pages 137–77).

About 150 years ago, the common approach to biology was to study a range of different species, each in isolation, as examples of different levels of biological organisation. This work established a great deal of information about the structure (morphology and anatomy) and function (physiology) of individual organisms. It largely ignored the ways in which **organisms interact with each other**.

Environmental biology or **ecology** is the study of relationships between living things and their environment, and of the impact of human actions on them. Humans have brought about change everywhere. One outcome may be the enhanced rate of **extinctions of species**. However, attempts at conservation often clash with the needs of productive industries. Conservation initiatives have international dimensions, and are the subject of national government policies and international action.

In this chapter, the **distribution of organisms in a community**, and the ways this may be **studied experimentally** are discussed. **Productivity of ecosystems** and the **successions** of organisms in the world's biomes (major life zones) are then investigated. Then, in these contexts, **the impacts of humans** on ecosystems are examined.

In the Additional Higher Level extension, issues in the **conservation** of biodiversity are explored further, and an experimental approach to **population ecology** is established.
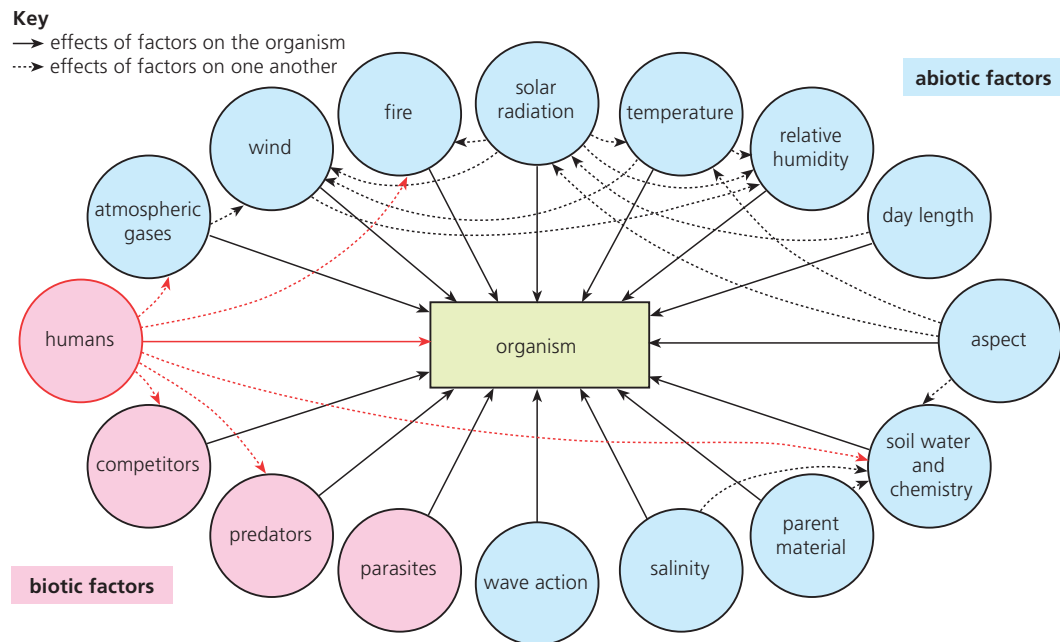
■ Community ecology

Ecology is the study of the relationships of living things with their non-living surroundings – their environment. Factors which have an effect on the life of organisms are called **environmental factors**.

Environmental factors, and there are many of them, divide naturally into those due to the living (**biotic**) components, and those due to the non-living (**abiotic**) components. At any one moment, one particular environmental factor may appear more influential than others. In practice, however, environmental factors are interrelated, and it is usually difficult to isolate the influence of any one (Figure 19.1). We can illustrate this interaction of factors first.

Figure 19.1 Abiotic and biotic factors and their interactions – a summary

Key
→ effects of factors on the organism
⇢ effects of factors on one another

abiotic factors: fire, solar radiation, temperature, relative humidity, wind, day length, atmospheric gases, aspect, soil water and chemistry, parent material, salinity, wave action

organism

biotic factors: humans, competitors, predators, parasites

Introducing factors that affect the distribution of plants

The individuals of a species are not distributed at random in the environment; each species is restricted to certain geographical areas, and there, in particular habitats. Some of the more important environmental factors that determine the distribution of green plants are the light regime (length of day, seasonality), temperature range, water availability, soil pH, salinity and mineral nutrition.

Light is the ultimate source of energy in ecosystems; plants grow where there is sufficient light for their **autotrophic nutrition**. This need for light has an effect on the structure of plant communities. For example, woodlands and forests are stratified into layers, from the canopy above, to the shrub layer below, the field layer (herbaceous plants) and ground layer (mosses). Each layer has a different degree of exposure to light, and it has plant life adapted to that light regime.

Also, the length of day is the dependable environmental clue for many plants (and animals) for the setting of their daily and seasonal rhythms; the duration of illumination is the environmental trigger for inducing flowering of many plants, for example. Sunlight is the major source of heat, too. Through its effects on temperature, light intensity also influences humidity.

Temperature determines the rate of biochemical reactions in organisms. Most eukaryotic green plants function within a temperature range of 0–50 °C. Within this range, individual plant species may have an optimum temperature, together with minimum and maximum temperatures they normally tolerate. Remember, higher plants are not mobile, and the plant body has a temperature approximately the same as that of the environment. In fact, temperature acts in conjunction with light and water in most habitats as determining factors. For example,

temperature determines the rate of evaporation from plants (transpiration), given they have an adequate water supply, and their stomata are open (page 312) in the light.

Water is vital to life; the unique properties of water (page 43) make life possible. Water availability in association with light and temperature largely determines the distribution of plants in terrestrial habitats. Where water is plentiful, vegetation tends to grow densely, and where water is in short supply, vegetation is sparse. Most of the water that enters plants is lost by evaporation, and death from dehydration is a major threat to the rooted plant. Land plants have extensive external surfaces (due to their mode of nutrition) over which evaporation may occur, so the plant body shows adaptations to reduce water loss, including a waxy cuticle covering the surface of leaves and stems. The plant attempts to replace all water lost via an extensive root system that is in intimate contact with the soil solution that occurs as a film surrounding individual soil particles.

Soil pH also exerts a strong influence on plant distribution, chiefly through its effect on the availability of essential ions, taken up by roots. The pH of soil also influences the population and activity of soil bacteria that decompose organic matter. So, the pH of the soil affects the release of ions from dead organic remains and waste matter in and on the soil. Generally, soils at or near pH 7 support a greater diversity of plants (and animals) than soils at or near pH 4 and pH 9. However, some plant species have adapted to particular soil environments, and many species are restricted to acid or alkaline soils.

Salinity is a factor in the distribution of water plants where salts and ions have accumulated to high levels. In natural fresh water, derived mainly from rainfall, the salt concentration is low (typically 0.02% dissolved salts), whereas in sea waters the salinity is relatively high, at about 35 parts per thousand (3.5%) dissolved salts.

In some low-lying coastal regions, salt marshes occur. In a salt marsh the salinity is variable. At high tides, salinity is at or close to that of the sea water that floods in. Once the tide turns, the salt concentration may change quickly. For example, salinity may exceed that of sea water when high temperatures and winds cause evaporation, and the remaining sea water is concentrated. Alternatively, when there is heavy rainfall, or when the flow of river water dilutes the sea water, the concentration of salts will fall well below that of sea water.

Plants that can survive in conditions of high salinity are known as **halophytes**. These generally survive by retaining enhanced levels of ions in their cells, thereby resisting loss of water to their environment, by osmosis. Such plants are typical of the salt marsh flora.

Mineral nutrients occur dissolved in water of the soil solution – generally at low concentrations. Essential elements for plants (and animals) are released by decay of dead organisms and their waste matter. For plant growth, the mineral salts required in substantial quantities – the macronutrients – include metal ions such as potassium and calcium, and the non-metal ions nitrate and phosphate. Other inorganic nutrients, required in much smaller amounts, are the micronutrients or trace elements (page 38).

As ions, micronutrients and macronutrients are absorbed and re-used by the plant. Nutrients are endlessly cycled, but some are lost from the system from time to time, for example, by leaching from the soils. Stocks of ions may be added to by weathering of parent rocks, but nitrates are generated from atmospheric nitrogen gas by the actions of nitrogen-fixing microorganisms, and as an outcome of lightning.

Introducing factors that affect the distribution of animals

The nutrition of animals is heterozoic, and many show **holozoic nutrition**, as humans do. Actually, the **study of food chains** (page 139) established the dependence of animals on plant life, either directly or indirectly, for their sources of energy and carbon. So very often it is the dominant plants in ecosystems that determine – or at the very least, strongly influence – animal distribution. In addition to being the principal source of nutrients, the dominant plant community typically determines the sorts of habitat that exist and the critical abiotic conditions.

As a consequence, the factors that affect the distribution of plant species are indirectly highly influential on animal distribution, and need to be kept in mind when investigating animal distribution.

Some of the more important environmental factors that determine the distribution of animals are temperature, water, food supply, territory and breeding sites. However, these factors seldom exert their effects alone.

Temperature variations both govern the rate of animal metabolism and growth, and also influence animal behaviour. Temperature changes may also be correlated with other physical factors, particularly light.

Animals may be divided into the **homeotherms** that regulate their body temperature, and the **poikilotherms** which maintain less control over their internal temperature. The latter have activities more determined by external temperatures, whereas the former remain active despite quite wide variation in environmental temperature.

Water is required by animals for use in ways similar to those of plants – simply because for them, too, water makes up the bulk of their bodies. In the processes of gaseous exchange and in regulation of body temperature, a great deal of water is lost by evaporation. Water is also lost in the disposal of waste matter. Terrestrial animals that possess adaptations to reduce water loss, such as an impervious body covering (like that of insects, reptiles, birds and mammals) occupy a wider range of habitats than animals with a body surface that permits a great deal of water loss by evaporation (like that of earthworms, woodlice and amphibians). However, so great is the need for water that no animals stray far from a source of fresh water for long. Reliable water sources (water holes, springs, and stream banks) are consequently places where carnivorous, hunting animals often concentrate their feeding activities.

Food supply is a factor influencing the existence and size of a local population. Some animals are dependent on plant matter (herbivores), some on animals (carnivores), and others eat both plant and animal matter (omnivores). Whatever the diet, when food supplies are short, individuals compete.

Competition is the term for interactions between individuals arising from their shared need for any limited resource. Either individuals of the same species compete (**intraspecific competition**), or individuals of different species do (**interspecific competition**). Competition for food is a major factor regulating population size. No population can be sustained for any length of time if it predates its prey population so severely that the organisms are threatened. (The same applies to herbivores that browse on particular plants.) Generally populations are regulated well below that level, because any food source that is over-grazed or over-predated, would itself crash. The result would be that the predator or browser population would then also crash – and so on, up the food chain.

Along with competition for food goes competition for space. **Territory** is a defended area of a habitat. Territoriality is a feature of the life style of many species of birds, mammals and a few non-vertebrates. A territory may be established by an individual, by breeding pairs, or by family groups. Many territories are established for a breeding period, but the same individuals then form into co-operative flocks at other times. Typically, we think of territory as a permanently held space, but some nomadic herds effectively mark out their territory in time, using scent markings as they travel, letting competitors know how recently they passed through the area.
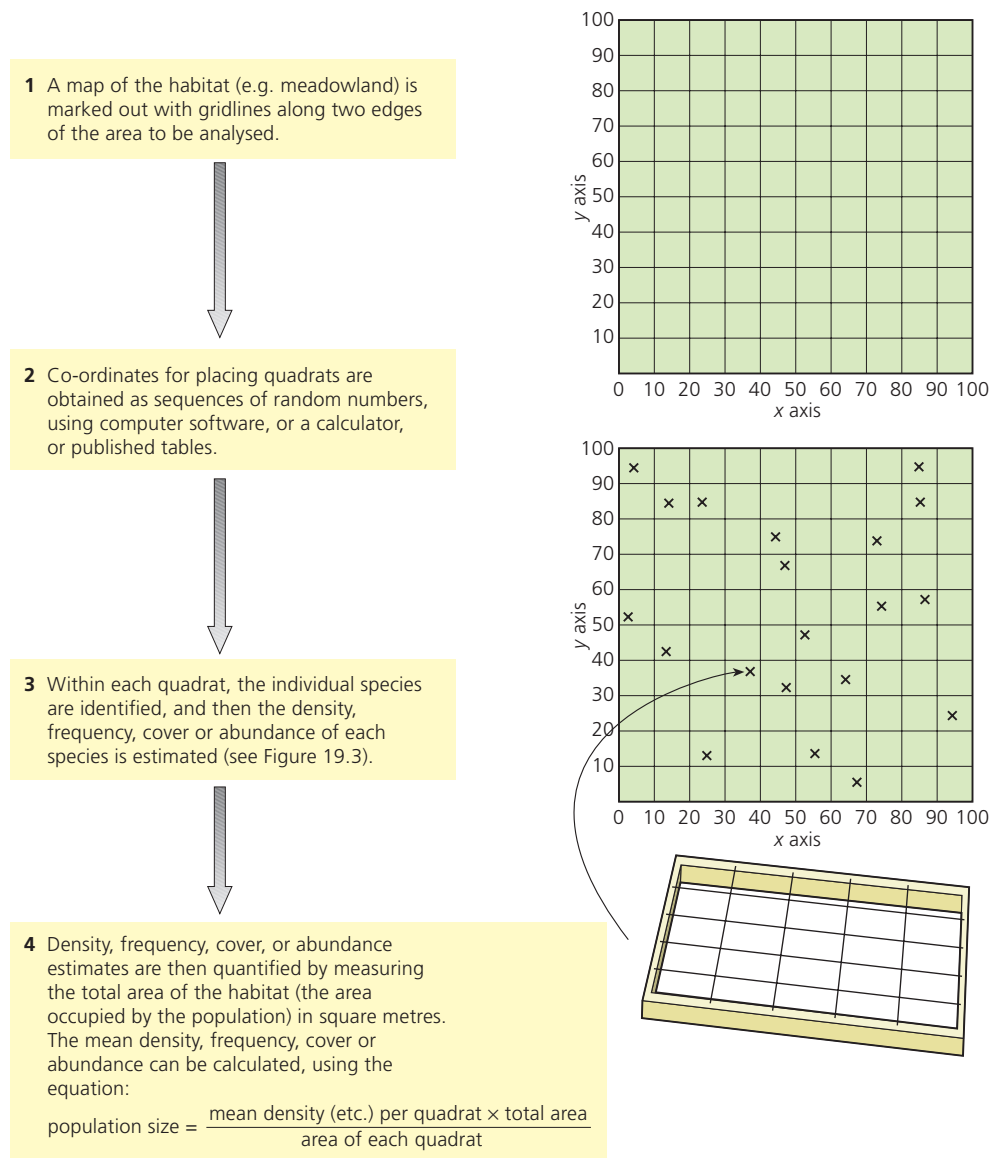
Defence of a territory, particularly by higher animals, is through active behaviour, but fighting may be kept to a minimum. Territory owners assert their ownership by conspicuous display or song. Aggression, when it arises, is most often ritualised, with body language positively displayed to declare displeasure, threat, and (eventually) submission on the part of one party to the dispute.

Breeding sites include the areas – nests or homes – in which the young are fed and reared. Typically they are placed at the heart of a territory. The amount of protection a site affords, and the accessibility of food resources, affect the survival chances of the young.

Estimating population size and distribution in a habitat

An important step in the study of a habitat is to collect accurate information on the size of populations present. For practical reasons, a random sample is selected for this, involving either a part of the area of the habitat, or a restricted number of the whole population (Figure 19.2). By means of random sampling, every individual of the population has an equal chance of being selected, and so a representative sample is assured.

Figure 19.2 Random locating of quadrats

1 A map of the habitat (e.g. meadowland) is marked out with gridlines along two edges of the area to be analysed.

2 Co-ordinates for placing quadrats are obtained as sequences of random numbers, using computer software, or a calculator, or published tables.

3 Within each quadrat, the individual species are identified, and then the density, frequency, cover or abundance of each species is estimated (see Figure 19.3).

4 Density, frequency, cover, or abundance estimates are then quantified by measuring the total area of the habitat (the area occupied by the population) in square metres. The mean density, frequency, cover or abundance can be calculated, using the equation:

$$\text{population size} = \frac{\text{mean density (etc.) per quadrat} \times \text{total area}}{\text{area of each quadrat}}$$

Random sampling of plant populations, using quadrats

Quadrats are commonly used to estimate plant populations (Figure 19.3). A quadrat is a square frame which outlines a known area for the purpose of sampling. The choice of size of quadrat varies depending on the size of the individuals of the population being analysed. For example, a 10 cm^2 quadrat is ideal for assessing epiphytic *Pleurococcus*, a single-celled alga, commonly found growing on damp walls and tree trunks. Alternatively, a 1 m^2 quadrat is far more useful for analysing the size of two herbaceous plant populations observed in grassland, or of the earthworms and the slugs that can be extracted from between the plants or from the soil below.

Quadrats are **placed according to random numbers** after the area has been divided into a grid of numbered sampling squares (Figure 19.2). The different plant species present in the quadrat may be identified. Then, using the quadrat, an observer may estimate the **density, frequency, abundance** or **cover** of plant species in a habitat. The steps are outlined in Figure 19.3, including the issue of how many quadrats may need to be placed for an accurate assessment of population size. An area of chalk grassland is illustrated in which the use of quadrats would give estimates of the population sizes of two species of flowering plants (Figure 19.4).

Figure 19.3 Estimating plant population size using a quadrat

Use of the quadrat:
- positioned at random within habitat being investigated
- different species present are then identified
- without destroying the plants present and the microhabitats beneath them, plant species' density, frequency, abundance or cover can be estimated.

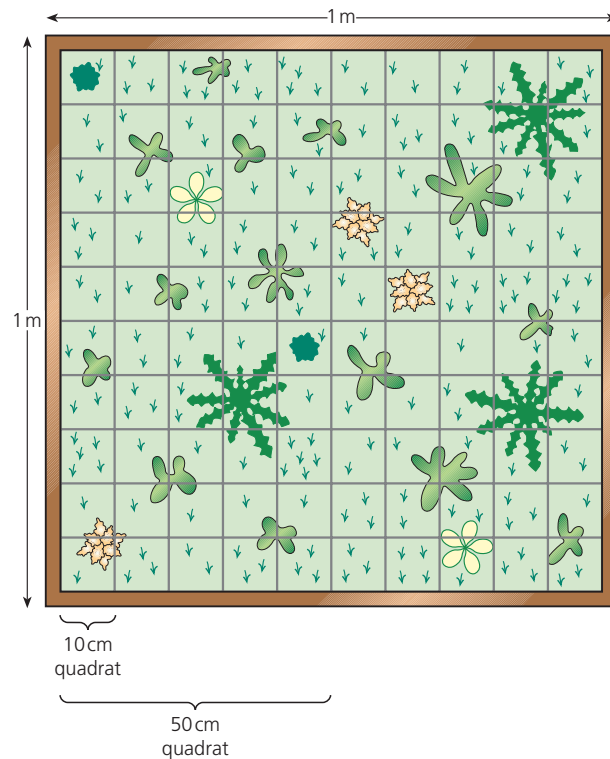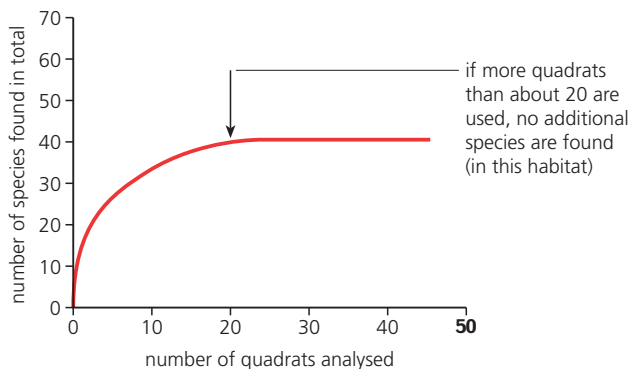**density** = mean numbers of individuals of each species per unit area (time-consuming and may be hard to assess separate individuals)

frequency = number of quadrats in which a species occurs, expressed as % (rapid and useful for comparing two habitats)

cover = the % of ground covered by a species (useful where it is not possible to identify separate individuals)

abundance = subjective assessment of species present, using the DAFOR scale: D = dominant, A = abundant, F = frequent, O = occasional, R = rare (same observer must make 'abundance' judgements, which may be useful as comparisons of two or more habitats, rather than objective scores)

What is the optimum size of quadrat? This varies with the habitat, and the size of plants found. Look at the example here. In the 1 m quadrat there are six species present. How many different species are counted in the quadrat of sides 10, 20, 30, 40, 50, 60, 70, 80 and 90 cm? The optimum quadrat size is reached when a further increase in size adds no or very few further species as present.

How many quadrats? When there is no further increase in the number of species found, sufficient quadrats have been analysed in that habitat.

if more quadrats than about 20 are used, no additional species are found (in this habitat)

10 cm quadrat

50 cm quadrat

Estimating species distribution by means of a transect

Whereas some communities are relatively uniform over a given area and are suitable for random analysis (such as the grassland habitat shown in Figure 19.4), others show a trend in **variation in a particular direction**. Examples include seashore, pond or lake margin, salt marsh or even an area where there is a change from dry soil to wet land. The appropriate technique to study such a trend of variation is the **transect**.

Figure 19.4 An area of chalk grassland with a rich flora

Transects are a means of sampling biotic (and abiotic) data at right angles to the impact of unidirectional physical forces. Although there may only be time to study one transect in detail (and this may be sufficient as a demonstration of the zonation of communities), a single transect may not provide an adequate sample or give an indication of differences from place to place. Transects should, therefore, preferably be replicated several times.

Where transects are carried out across a habitat where the land changes in height and where level is an important factor (such as a seashore, salt marsh or pond margin), then the changes in level along the transect line can be measured and recorded as a **profile transect**. The surveying for this requires the use of survey poles and a field level device (Figure 19.5).

Figure 19.5 Profile and belt transect analysis of a rocky shore community

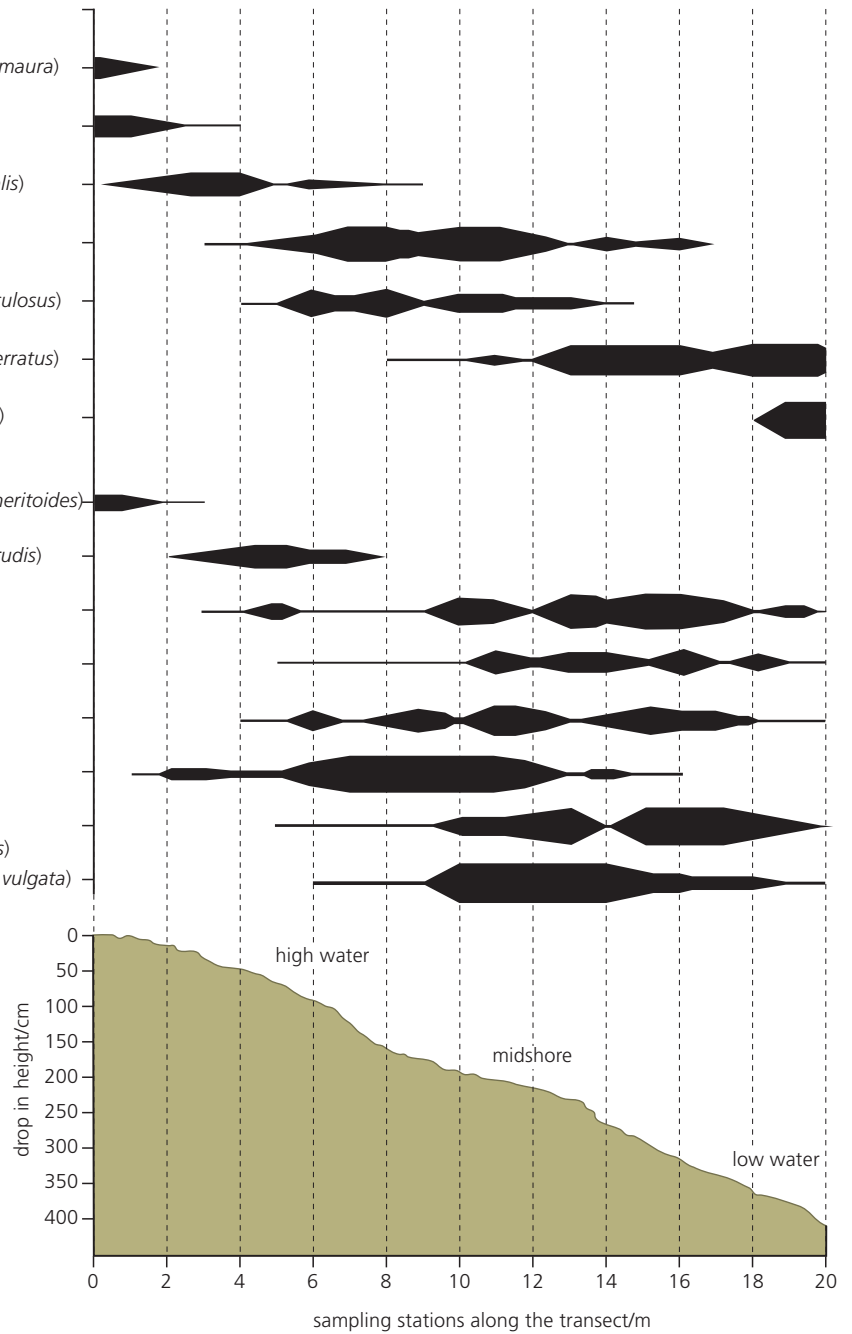**belt transect study of a rocky shore**

plants
black lichen (*Verrucaria maura*)

channelled wrack (*Pelvetia canaliculata*)

spiral wrack (*Fucus spiralis*)

knotted wrack (*Ascophyllum nodosum*)

black wrack (*Fucus vesiculosus*)

serrated wrack (*Fucus serratus*)

oar weed (*Laminaria* sp.)

animals
nerite winkle (*Littorina neritoides*)

rough winkle (*Littorina rudis*)

edible winkle (*Littorina littorea*)

smooth winkle (*Littorina obtusata*)

dog whelk (*Nucella lapillus*)

barnacle (*Chthamalus montagu*)

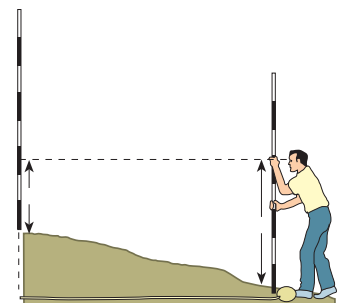acorn barnacle (*Semibalanus balanoides*)

common limpet (*Patella vulgata*)

high water

midshore

low water

Key

— rare

occasional

frequent

abundant

dominant

drop in height/cm

sampling stations along the transect/m

profile transect
data obtained by surveying using survey poles and a levelling device

The community present along a transect can be analysed from a straight line such as a measuring tape, laid down across an apparently representative part of the habitat. The positions of every organism present that touches the line are recorded either all the way along the line or else at regular intervals. The result is a **line transect**.

A **belt transect** is a broad transect, usually half a metre wide. To produce it, a tape measure or rope is laid as for a line transect, but this time the organisms in a series of quadrats of half-metre width are sampled at (say) metre intervals. If the community changes little along the transect, then quadrats can be placed less frequently. Along with data on the biota, data on abiotic variables can be measured and recorded along the transect. For example, along a terrestrial transect the pH of the soil might be measured.

The results of a belt transect study of a seashore community are shown in Figure 19.5. The seashore (known as the littoral zone) is a part of the extreme margins of continents and marine islands periodically submerged below sea water, and so affected by tides. Tides are the periodic rise and fall of the sea level due to the attractions (gravitational pull) of the Moon and Sun. The shore is an area very rich in living things, and almost all are of marine origin.

The higher an organism occurs on the shore, the longer the daily exposure to the air. Exposure brings the threat of desiccation and wider extremes of temperature than those experienced during submersion. Exposure is an abiotic factor that influences distribution of organisms on the seashore.

1 From the data in Figure 19.5, **deduce** a plant and an animal species that appear to be well adapted to the degree of exposure experienced at:

a a high water location of the shore

b a low water location of the shore.

The niche and competitive exclusion

The **niche** is an ecological term that defines just how an organism **feeds**, where it lives, and how it **behaves** in relation to other organisms in its habitat. The niche concept is useful because it identifies precise conditions which a species needs.

Figure 19.6 Different niches of the cormorant and the shag

shag (*Phalacrocorax canbo*)   cormorant (*P. aristotelis*)
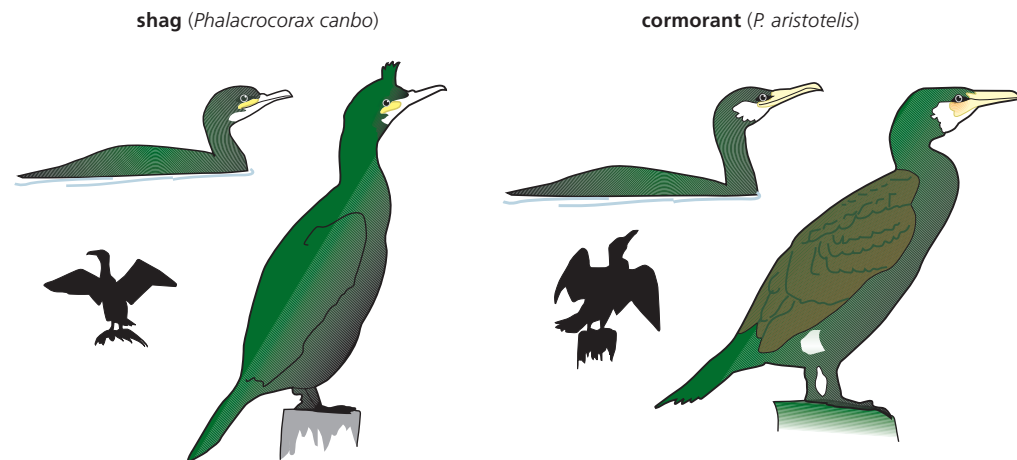
diet is a key difference in the niches of these otherwise similar birds

| prey		% of prey taken by	
		shag	cormorant
surface-swimming prey	sand eels	33	0
	herring	49	1
bottom-feeding prey	flatfish	1	26
	shrimps, prawns	2	33

The principle of distinct niches can be illustrated by two common and rather similar seabirds, the cormorant and the shag (Figure 19.6). These birds live and feed along the coast line, and they rear their young on similar cliffs and rock systems. We can say that they apparently share the same habitat. However, their diet and behaviour differ. The cormorant feeds close to the shore on seabed fish, such as flatfish. The shag builds its nest on much narrower cliff ledges. It also feeds further out to sea, and captures fish and eels from the upper layers of the waters. Since these birds feed differently and have different behaviour patterns, although they occur in close proximity, they avoid competition. They have different niches.

Competition refers to the interaction between two organisms striving for the same resource. For competing organisms, the more their niches overlap, the more both will strive to secure a finite resource. Hence, potential competitors have evolved different niches.

However, another possible outcome may be an equilibrium situation in which neither competitor succeeds as it might, yet both survive. This was found to be the case with two species of clover (*Trifolium* spp.) in an experiment in which they were grown together and separately, and the resulting growth rates compared (Figure 19.7).

2 **Suggest** the most likely finite resources that the two species of *Trifolium* (Figure 19.7) were competing for.

**Figure 19.7** Competing organisms in equilibrium
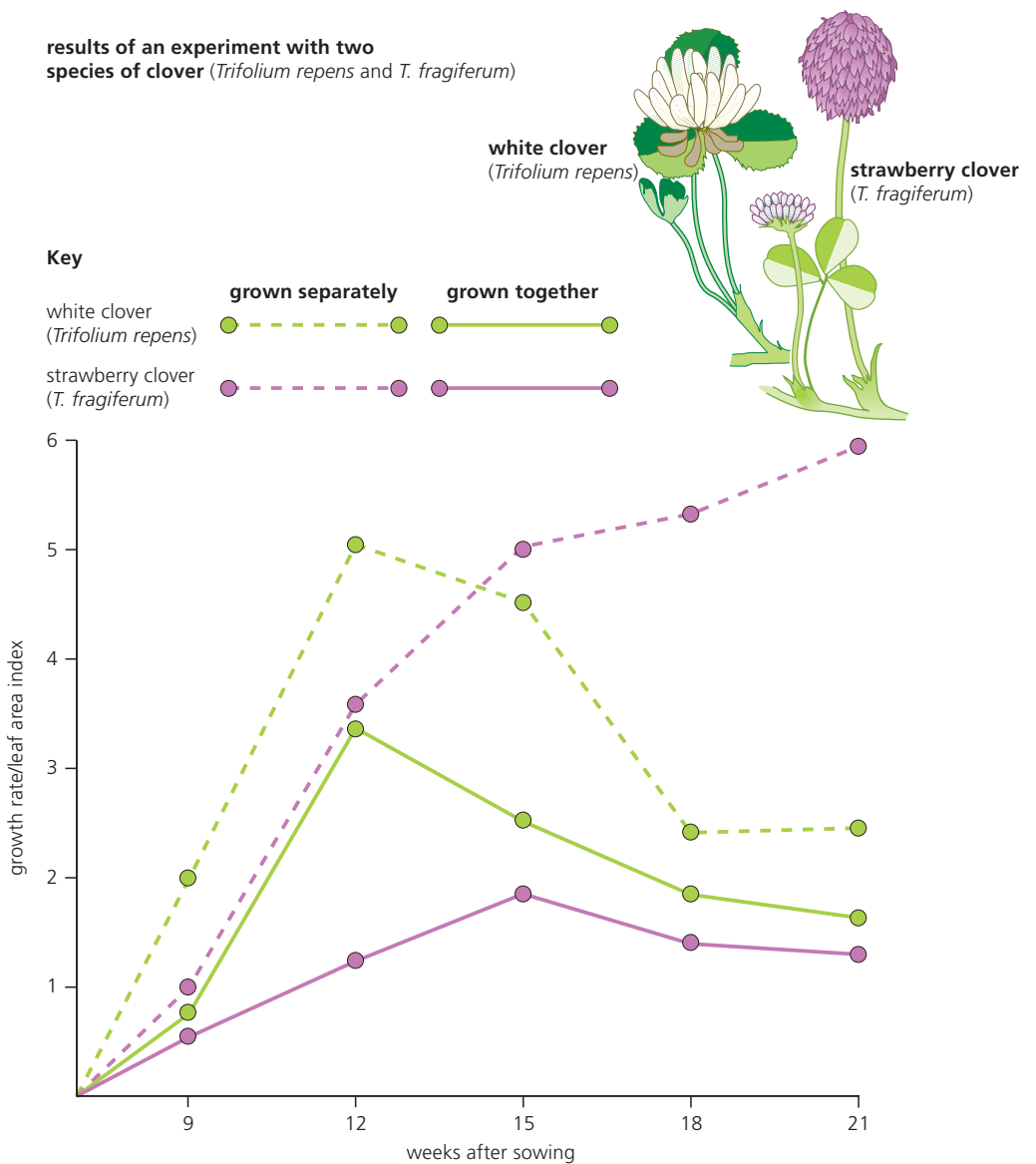
Fundamental and realised niches

Most species of plants and animals can survive in a range of conditions – in effect, their niches are fairly unrestricted ones. For example, animals can mostly eat a wide range and variety of food sources. This range of conditions an organism can tolerate is defined as its **fundamental niche**.

The fundamental niche of a species is the potential mode of existence, given the adaptations of the species.

Figure 19.8 Population growth curves for two species of *Paramecium*

An experiment carried out by G. C. Gause in 1934 using species of *Paramecium*, a large protozoan common in fresh water. It feeds on plankton, the food source used in these experiments.
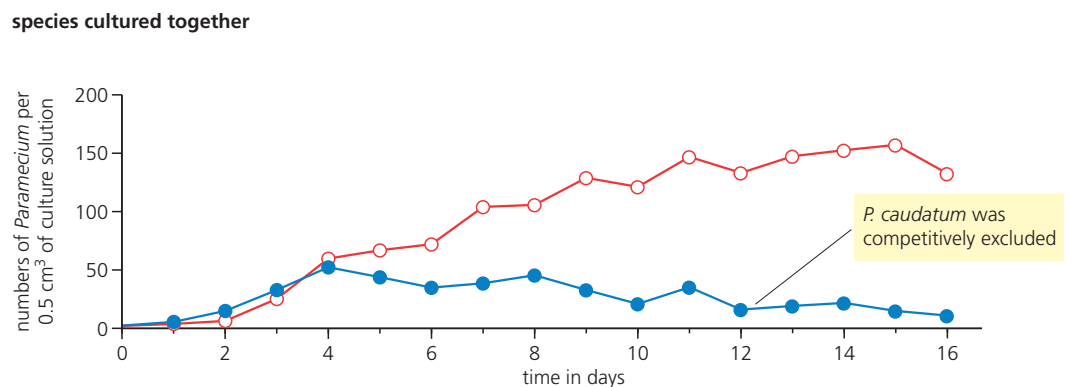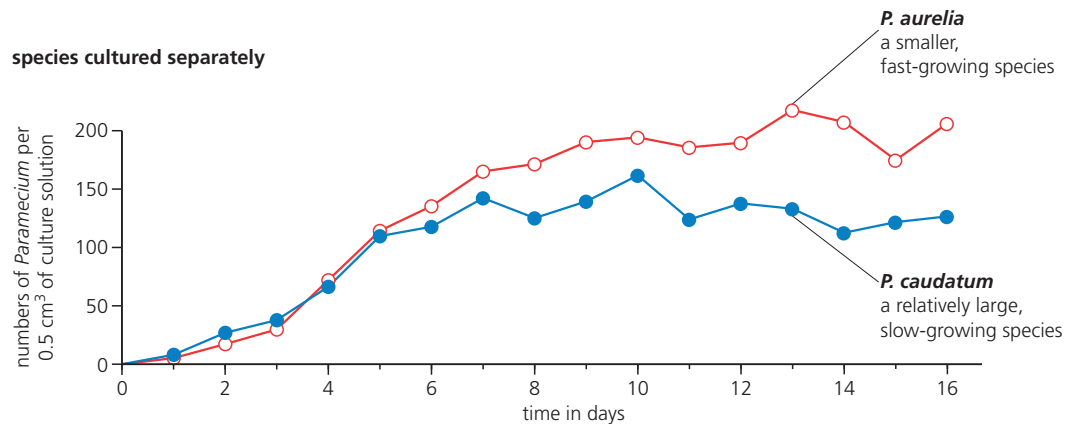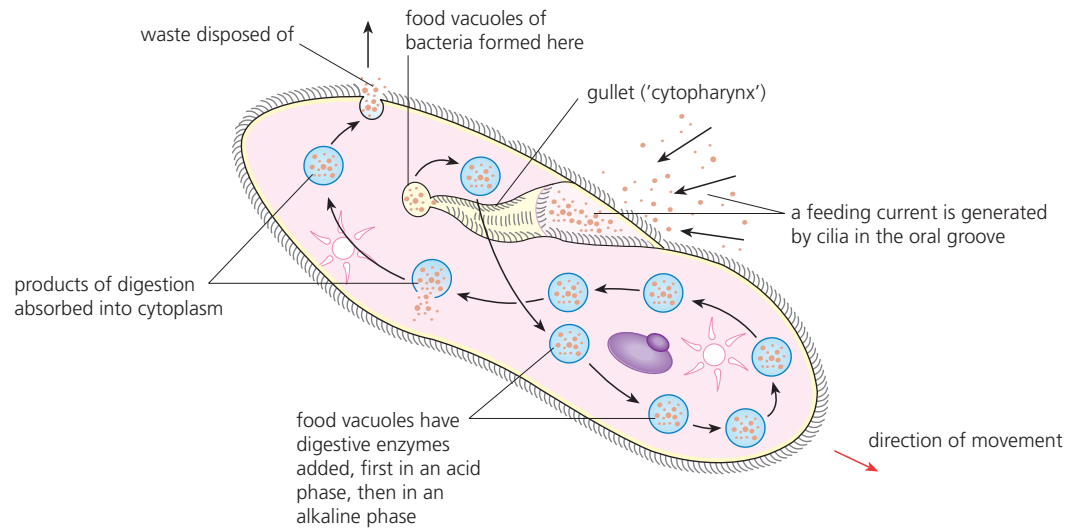
Only when organisms experience resources and conditions completely outside this range are they fatally threatened by their environment, and so die out. In practice, it is the experience of most organisms that only part of their fundamental niche is available to them because of a degree of competition with other organisms. The portion of the niche that is occupied in these cases is the **realised niche**.

> **The realised niche of a species is the actual mode of existence, which results from its adaptations and competition with other species.**

Competitive exclusion principle

Competition between two organisms of different species (interspecific competition) which results in one competitor taking the resource exclusively, and the other being driven out and away, or even dying out, is another possible outcome wherever two species compete intensively. When two species cannot co-exist, this is known as **competitive exclusion**.

The **competitive exclusion principle** is the idea that ecological separation of closely related or otherwise similar species is the inevitable outcome. So, if two species share the same resource at the same place and the same time, then the dominant species will out-compete the other, which will either die out or move away to avoid the competition. This principle was first suggested by a Russian biologist, G. F. Gause in 1934, based on his experiments culturing different species of *Paramecium* in the laboratory (Figure 19.8).

We can see that competitive exclusion could be the pressure that causes closely related species living in close proximity to have evolved clearly defined but separate niches in which competition between them is at an end. This would occur over an extended period of time. For example, the competitive exclusion principle would account for the difference in niches between the cormorant and the shag that we noted above.

Since it was first proposed, the competitive exclusion principle has been experimentally tested in many laboratory studies in which pairs of species have been reared together under constant conditions. Much convincing evidence has been obtained.

Figure 19.9 The growth of two species of barnacle on the seashore. Barnacles have a free-swimming larval stage and tend to settle and colonise all surfaces of intertidal zones of rocky shores. Where they are subsequently found in large numbers depends on their ability to survive periods of exposure (between high tides)

Chthamalus **sp.** is a barnacle able to withstand prolonged exposure – it survives higher on rocky shore lines, where other species of barnacle cannot compete.
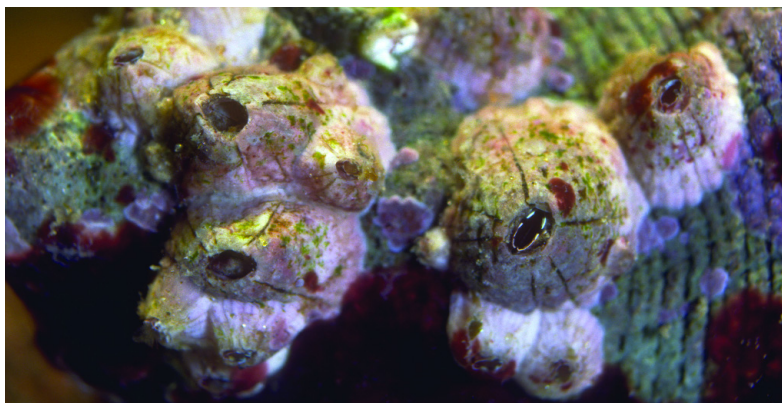
Semibalanus **sp.** is a barnacle easily crowded out from more exposed positions on the shore. It is mostly found lower down, in the mid to lower shore region.

However, the demonstration of its operation in the environment is more difficult. Two species of barnacle that occur on the seashore do appear to be a case in point (Figure 19.9). One species (*Chthamalus*) is able to withstand prolonged exposure when the tides recede, conditions that kill off the other species (*Semibalanus*). But before the sedentary adult stage, the free-swimming larval stages of these crustaceans colonise any surface in the intertidal zone on which they happen to settle. Only later, as the degree of exposure is experienced by the growing barnacles, are *Chthamalus* barnacles crowded out from lower zones, and *Semibalanus* barnacles crowded out from exposed zones. We see here that it is a difference in resistance to periodic desiccation that has determined where each species survives best.

> **3 Illustrate** and **explain** the competitive exclusion principle by reference to a species in a habitat you have studied in your locality.

The range of interactions between species within a community

Resources of many sorts are often in limited supply in the environment, and so organisms must compete for them. For example, plants may compete for space, light and mineral ions. Animals may compete for food, shelter and a mate. Whenever resources are in short supply, they become a limiting factor.

Competition between individuals of the same species, **intraspecific competition**, occurs when individuals compete for a mate, for example.

Competition between individuals of different species, **interspecific competition**, may be so intense as to cause the exclusion of one species by another. Examples of interspecific competition are species of *Paramecium* competing for plankton, and species of clover (*Trifolium*) competing for mineral ions, as already noted.

What other forms of interactions between species occur?

Herbivory is the feeding on plant matter (browsing, in effect) by animal species (Figure 19.10). Herbivorous mammals include the ruminant species, some of which like cattle and sheep have been domesticated, while others are wild animals of grasslands and savannah, such as the wildebeest. Non-vertebrate herbivores include the leaf-eating caterpillars (the larval stage of a butterfly) such as that of the monarch butterfly, feeding on the leaves of milkweed plants. The monarch is a migratory insect of the American continent.

Predation is preying of one animal on another for food (Figure 19.10). Predation frequently requires patient stalking of prey and a determined final attack because most prey species invest time and care in their own or the whole herd's defence. We see this, for example, in the hunting of a juvenile or an isolated or ailing wildebeest, part of a large herd, by a pride of lions living beside their prey among the long grass of the African savannah. Not all cases of predation are so dramatic. A ladybird insect alights on a plant stem where aphids are feeding, their probosces inserted deep into the plant stem tissues, and systematically eats its fill of the defenceless aphids.

Parasitism involves two organisms living together for all or most of the parasite's life cycle, and feeding at the expense of the host's living tissues (Figure 19.10). The relationship is, at the very least, unhelpful or possibly very **harmful to the host**. The parasite has a supply of nutrients on hand, but may experience resistance by the host which has to be overcome. Movement between hosts is another period of danger to parasites. Both plant and animal parasites exist.

One example of an animal parasite is the protozoan *Plasmodium*, which lives in blood and liver cells of humans and causes malaria (see Figure 18.38, page 595). Chance transfer of *Plasmodium* between hosts may be achieved when a female mosquito takes a blood meal from an infected human, and later feeds on another human, not yet infected with malaria. *Plasmodium* is an **endoparasite** as it resides within its host.

Ticks are small arachnids (related to spiders) that attach themselves to the skin of endothermic (warm-blooded), furry mammals. They are **ectoparasites**. They bite into the skin sufficiently to draw out blood meals. Ticks on dogs, rabbits, hedgehogs, and many similar hosts tend to drop off when satiated with blood, often where the mammal rests. They re-attach later, and they continue to feed and breed in the vicinity of their hosts.

Mutualism is a form of symbiosis in which the two organisms of different species, living in intimate association, do so to **mutual advantage** (Figure 19.10). Mutualism is an example of favourable interaction between organisms. Simple examples are the egrets that pick ticks off the backs of water buffalo, or cleaner fish that remove sea lice from big fish.

One good example of mutualism is the huge community of microorganisms, mainly bacteria and fungi, that live in the rumen of ruminant mammals. The rumen is a large, stomach-like fermentation vessel. Here the vegetation the herbivore has eaten and begun to chew up is received. The microorganisms break down the cellulose and other polymers in the plant matter, producing organic acids (and a great deal of methane). The ruminant is dependent on this enzymic digestion in order to gain nutritional benefit from its diet. For the microorganisms, the rumen is their habitat (until digested by ruminant enzymes as they pass further down the gut of the herbivore host).

Another example of mutualism is the **mycorrhizal association** between the roots of plants, particularly trees, and the hyphae of particular species of soil fungi. The fungus benefits from sugar supplied by the plant, and in turn, feeds back to the tree's roots the excess mineral ions, like phosphate, potassium and nitrate, that the fungus absorbs from the soil immediately they are released there (often at times of the year when the tree's growth is minimal). Given the importance of trees as a resource for human activities, the mycorrhizal relationship is of great ecological and economic significance.

Figure 19.10 Interactions between species

Top left: Herbivory – caterpillars of the monarch butterfly feeding on milkweed leaves

Top right: Predation – African lion at the moment of capture of prey (kudo – a savannah herbivore)

Bottom left: Parasitism – sheep tick (an ectoparasite) attached to the skin of a cat where it has fed on a blood meal

Bottom right: Mutualism – mushroom of fly agaric fungus takes sugars and amino acids from a tree's roots in return for essential ions, via its hyphae attached below ground
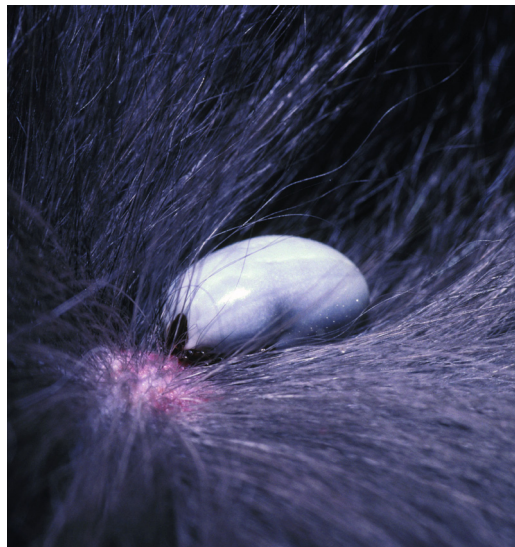
Ecosystems and biomes

Ecosystems are stable, settled units of nature consisting of a community of organisms, interacting with each other and with their surrounding physical and chemical environment. Examples of ecosystems are ponds or lakes, woods or forests, seashores or salt marshes, grassland, savannah or tundra. From this list you can see that any particular ecosystem is variable in size, but each represents a space favourable for the growth of a community of organisms, all of which constitute the biomass of the ecosystem.

> **Biomass is the total weight (or volume, or energy equivalent) of living organisms in a given area (e.g. a quadrat).**

The rate at which biomass is produced by an ecosystem is an expression of the productivity of the ecosystem. Biomass is commonly expressed as mass or energy per unit area; for example, kilojoules per square metre per year ($kJ\,m^{-2}\,yr^{-1}$).

Productivity within an ecosystem

Productivity has two components: **primary productivity**, the production of new organic matter by green plants (autotrophs), and **secondary productivity**, the production of new organic matter by consumers (heterotrophs). Both of these can be divided into gross productivity and net productivity.

> **Gross productivity is the total amount of organic matter produced.**
> **Net productivity is the organic matter of organisms less the amount needed to fuel respiration.**
> **Gross production – respiration = net production.**

Measuring the biomass of different trophic levels in a community

The level at which an organism feeds in a food chain is called its **trophic level** (page 142). Producers (green plants) are designated as trophic level 1, because their energy has been transferred once, from Sun to plant. Herbivores constitute level 2, because here energy has been transferred twice, and so on. The different trophic levels in a community are:

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

How can we measure the biomass at different trophic levels?

To do this in the field first involves estimating the numbers of organisms of each type at each trophic level in a representative part of the community. Then, if the mass at each trophic level is to be expressed (as it commonly is) as grams dry mass, then it is necessary to find the **dry mass** of a representative sample (at least) of each type of organism.

The dry mass is found by heating a weighed sample to a temperature of about 80 °C. This drives off the water, but is not hot enough to burn away any organic matter. Cooled samples are weighed and heated, cooled and re-weighed. This is repeated until two consecutive readings give the same mass, showing that all the water has been driven off.

Of course, to obtain dry mass measurements the representative samples of organisms have first to be killed. Consequently, communities of organisms are destroyed by this technique, and the area of the habitat they occupied is reduced to being a 'desert' – at least until it is repopulated from surrounding communities.

This destructive technique raises challenging ethical issues, and these are of increased pertinence at a time that biodiversity is under threat. A less destructive approach would involve finding the **fresh mass** of a small representative sample of organisms all or most of which can then be returned to the environment. However, it is less accurate.

4 Identify the reasons why fresh mass is a much less reliable measure of biomass than dry mass.

Calculating productivity

A study of the ecological productivity of a fresh-water site in Florida was published in 1957 by Professor Eugene Odum of the University of Georgia, USA (Table 19.1). In this painstaking work, species present were divided into their four trophic levels. Data were obtained on the biomass organisms at each level acquired by feeding (herbivory or predation). Losses by primary, secondary and tertiary consumers due to respiration were calculated. Results were expressed in energy values (kJ m^{-2} yr^{-1}).

Trophic level	Biomass expressed in terms of energy content (kJ m^{-2} yr^{-1})		
	Matter retained	Lost in respiration	Exported due to herbivory or predation by organisms of next trophic level
producers (energy input in the form of sunlight)	1 695	50 112	35 263
primary consumers	6 506	27 154	1 602
secondary consumers	192	1 322	88
tertiary consumers	33	54	

Table 19.1 Ecological productivity by the fresh-water community at Silver Springs, Florida

We can use these data to calculate values for gross productivity and net productivity by the consumers present.

The gross production by the primary consumers (herbivores that browsed on the producers – the green plants) was the biomass that is recorded as exported by the primary producers, that is 35 263 kJ m^{-2} yr^{-1}.

The respiratory loss by the primary consumers was 27 154 kJ m^{-2} yr^{-1}.

So the net production by the primary consumers was:

$$35\ 263 - 27\ 154 = 8109 \text{ kJ m}^{-2}\text{ yr}^{-1}.$$

5 Calculate net production by the secondary and the tertiary consumers of the fresh-water community at Silver Springs (Table 19.1).

common blenny (*Blennius pholis*) ×2

Figure 19.11 Simplified food web for a community of a rocky shore

Issues of trophic levels

The **trophic level** is a level in a food chain defined by the method of obtaining food, and in which all organisms are the same number of energy transfers away from the original source of energy (the Sun and photosynthesis).

For studies of the productivity of whole communities, it is first necessary to designate to each organism identified, a trophic level. This is clearly a straightforward task in the case of the producers (they are level 1), but after that, problems may arise.

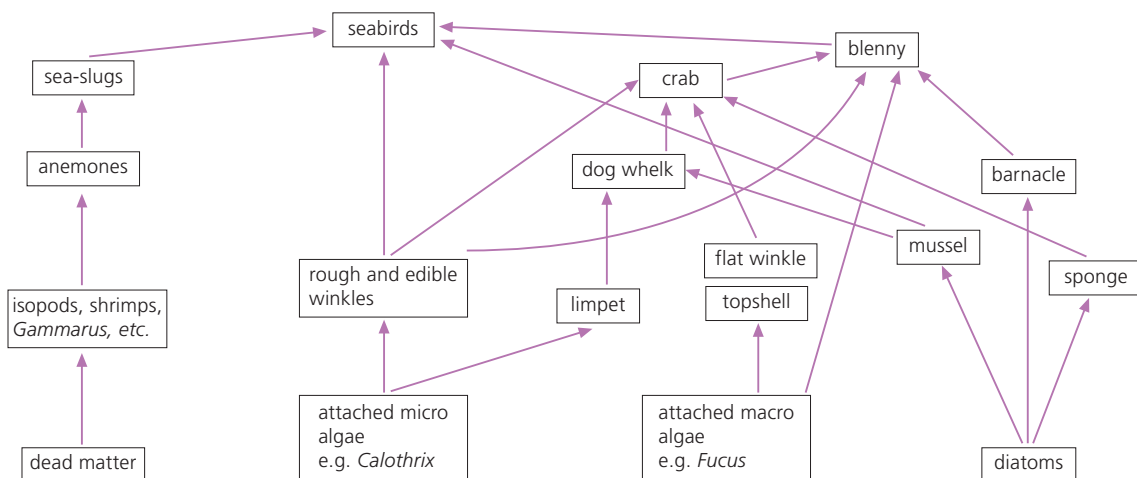For example, for many organisms, **the trophic level may vary with each item of the diet**. In the simplified food web for a rocky shore (Figure 19.11) the blenny (a small marine fish of inshore waters) feeds as a primary consumer (of *Fucus*, brown seaweed), as a secondary consumer (of winkles), and as a tertiary consumer (of crabs). In terrestrial food webs, too, it is common to find the top carnivores feed at trophic levels between 2 and 5, at any one time.

6 Analyse the number of trophic levels occupied by seabirds in the food web in Figure 19.11.

A similar difficulty arises with **omnivores** in all food webs. Omnivores necessarily feed at two trophic levels, at the very least. By definition, they are primary consumers and secondary consumers.

Another pertinent factor in the collection of data over days, weeks or months is that the **diets of many animals change** dramatically at different stages in their growth and development.

Again, the consumers of dead organic matter, the **detritivores and decomposers** that break up dead organisms and decay complex organic matter to simple, inorganic nutrients, are not featured in food webs. Yet up to 80% of plant matter produced may be consumed in this way.

So, for experimental ecologists, the quantification of food webs has many unresolved difficulties.

TOK Link

It is said that 'observations provide a secure basis from which knowledge may be derived'. Does this apply to the apparently simple task of classifying organisms into trophic levels?

Constructing a pyramid of energy

Pyramids of numbers of organisms present, or of biomass, or of energy, give a proportional representation of the organisms present at successive trophic levels. Quantitative measurements are required, and are then represented on graph paper by areas proportional to the data being used – basically, numbers, biomass or energy of the organisms sampled in a defined area.

We can use the data assembled in Table 19.1 to draw up a pyramid of energy for the Silver Springs fresh-water community (Table 19.2 and Figure 19.12). Note that the energy acquired at each of the four trophic levels is the total of energy recorded in the table as matter retained, lost in respiration, and exported.

Table 19.2 Trophic level and total energy (from Table 19.1)

Trophic level	Energy (kJ m^{-2} yr^{-1})
1	87 070
2	35 262
3	1 602
4	87
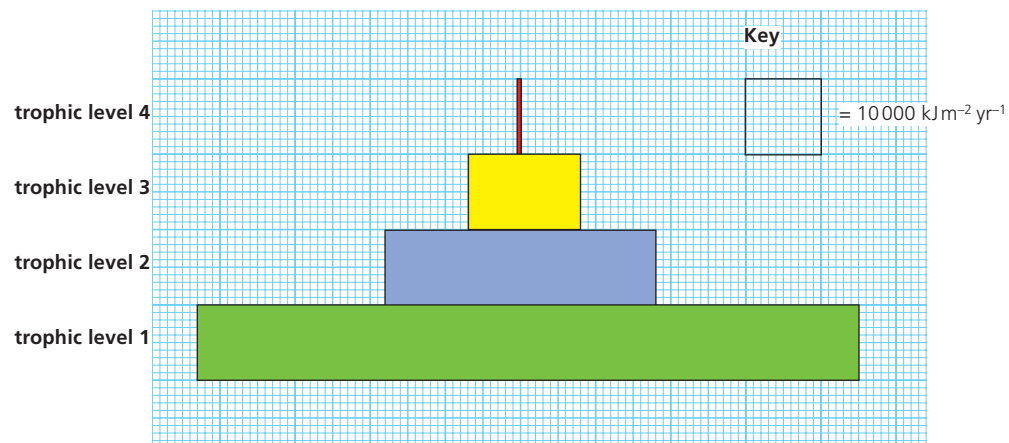
Figure 19.12 Pyramid of energy for the Silver Springs fresh-water community

Key: = 10 000 kJ m^{-2} yr^{-1}

trophic level 4
trophic level 3
trophic level 2
trophic level 1

Ecological pyramids, such as the pyramid of energy for the Silver Springs community (Figure 19.12), convey a visual impression of the relative importance of the trophic levels in the ecosystem. Particularly evident are the low energy levels at the higher trophic levels – reflecting the relatively small biomass and low numbers of organisms at these levels.

Why are the numbers of organisms low at higher trophic levels?

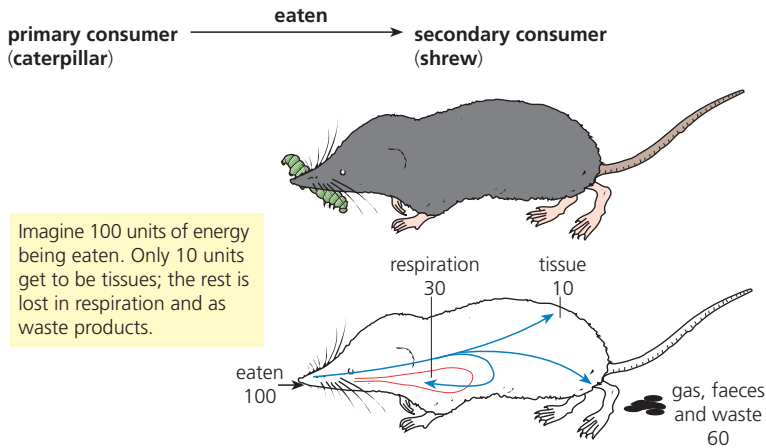Largely, this occurs because there are significant losses of energy in each trophic level. This occurs as a result of respiration – animals invest efforts into finding food, digesting food, and in processes like reproduction and the caring of their young. All these activities require a supply of energy. Also, a proportion of the biomass at each level is not eaten by the next trophic level for various reasons (e.g. deep roots of producers are rarely available to primary consumers). In addition, losses in the form of the faeces (including undigested food matter) and urine have to be taken into account. Deep roots and faeces mostly pass directly to decomposers. Consequently, typically only 10% of the matter and energy at any one level becomes matter in the organisms of the next level (Figure 19.13).

Additionally, the top carnivores may hunt for their food, which often has to be killed. In the chase, more energy is transferred, prey are sometimes injured but escape to die elsewhere, and perhaps become food for other organisms, at a lower trophic level. So, at each boundary in a food chain, the principal feature is that 90% of what is eaten at one trophic level is not available to the next level in the chain.

Figure 19.13 Loss of energy between trophic levels

primary consumer → **eaten** → secondary consumer
(**caterpillar**)   (**shrew**)

Imagine 100 units of energy being eaten. Only 10 units get to be tissues; the rest is lost in respiration and as waste products.

respiration 30   tissue 10

eaten 100

gas, faeces and waste 60

Ecological successions

When new land is exposed it is quickly invaded and colonised by organisms. In fact, a sequence of communities develops with time by a process known as **ecological succession**. The stages in a succession are a series of plant and animal communities of increasing complexity, that develop with time. These stages are called **seral stages**, and the whole process is termed a **sere**. A **climax community** finally results (if the site remains undisturbed) which is characteristic of the area. We illustrate this in typical primary and secondary successions.

Primary and secondary successions

When the succession sequence starts on entirely new land **without established soil**, then the process is known as a **primary succession**.

New land is formed on the Earth's surface at river deltas, at sand dunes, and from cooled volcanic lava, for example. Primary successions also develop in aquatic habitats, such as in a pond formed and fed by a spring. In all cases, the first significant development in a primary succession is the formation of soil.

Alternatively, sometimes established communities are suddenly disrupted and totally destroyed. This occurs, for example, when fire destroys a large area of vegetation; occasionally it occurs as a result of human activities. In these situations, soil is already formed and present – it is the existing biota that has been abruptly removed. A succession that starts from **existing soil** is known as a **secondary succession**.

Successions and seral stages

At the initial site of a primary succession, all that may be present is **parent rock**, from which the bulk of the **soil** is formed by erosion. Erosion is the breaking of solid rock into smaller particles by the effects of extremes of temperature, by the action of wind and water, and by chemical reactions that occur, such as when slightly acid rain falls. Mineral particles may also be blown or washed in from elsewhere. The resulting **mineral skeleton** is of particles of a wide range of sizes from small stones and coarse sand to the finest clay particles.

Soil, when fully formed, has organic matter called **humus** wrapped around the particles of the mineral skeleton. Humus is a substance derived from dead plant and animal remains, together with animal faeces, that have been decomposed by the actions of microorganisms. Humus is a dark-coloured, sticky substance, that continues to be decayed, releasing mineral nutrients. Humus also helps the soil to hold **water**. Between mineral particles and humus linings are innumerable pockets of **air**. Also present in a developed soil is a huge community of **microorganisms** and small animals, including **earthworms**, all adapted to life in this habitat.

Humus is first added by plant invaders of the primary succession, known as **pioneer plants**. These are typically lichens and cushions of moss, and after them, tiny herbaceous plants, many with features that help them survive where water is scarce.

Until the soil is fully formed it retains little water, even when water is freely available. Plants able to survive drought are called xerophytes, and their special features are called xeromorphic features (page 316). When a sere starts from dry conditions, then the sere is called a **xerosere** (Figure 19.14).
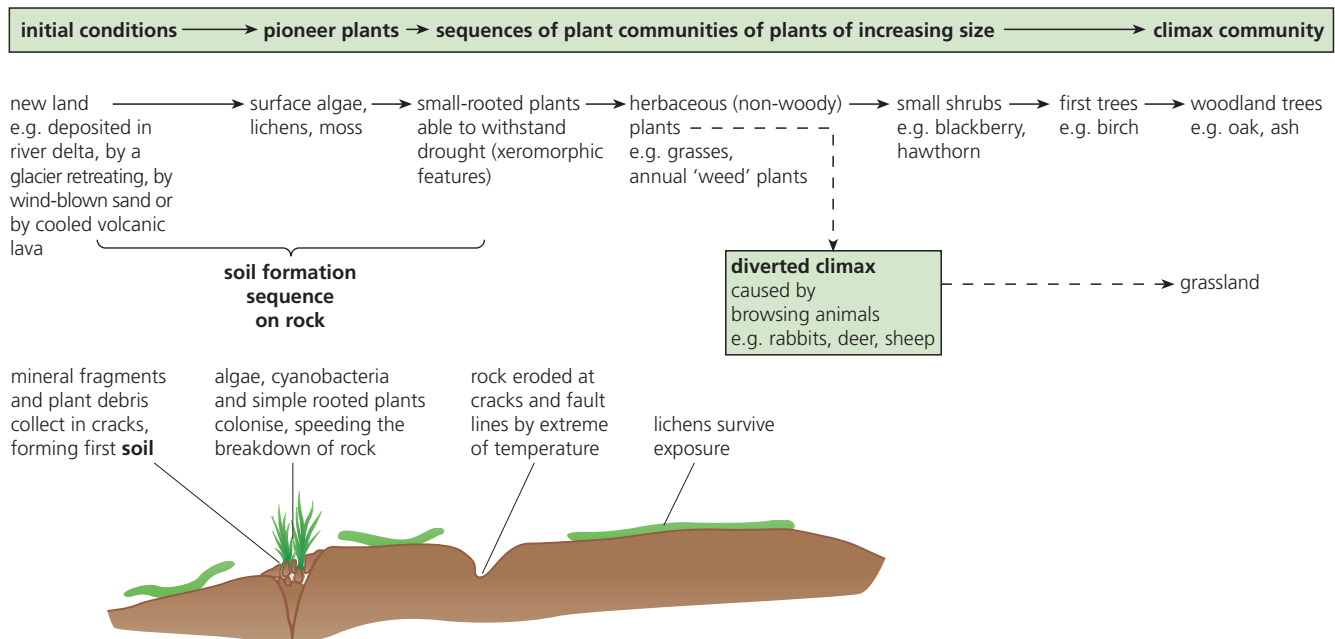
The growth and death of the early plant communities continue to add humus, and so more soil water is retained. Nutrients are added to the soil when organisms die, and the range of nutrients available to plants increases steadily. Nutrients are the **ions essential for plant growth**, such as nitrates, phosphates, and a range of micronutrients. Different plants now grow – various herbaceous weeds, for example, may start to shade out the pioneers. The conditions in the soil are increasingly favourable to microorganisms and soil animals, which continue to invade the habitat from the surroundings. Herbaceous plants are followed by shrubs and small trees, all growing from seeds that are carried in by wind, water or the activities of animals.

The first-formed soil accumulates relatively slowly, because much is vulnerable to erosion and dissipation by wind and heavy rains. Increasingly, as plant life becomes established, the growth of plant roots and the cover provided by plant vegetation prevent or reduce **loss of soil by erosion**.

Figure 19.14 A primary succession on dry land – a xerosere

So, succession can be seen as a directional change in a community with time. Initially, **abiotic factors** have the greater influence on the survival and growth of organisms. Later, as the numbers of living organisms build up, **biotic factors** increasingly affect survival too.

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

initial conditions ⟶	pioneer plants →	sequences of plant communities of plants of increasing size ⟶			climax community
new land e.g. deposited in river delta, by a glacier retreating, by wind-blown sand or by cooled volcanic lava	surface algae, lichens, moss	small-rooted plants able to withstand drought (xeromorphic features)	herbaceous (non-woody) plants e.g. grasses, annual 'weed' plants	small shrubs e.g. blackberry, hawthorn	first trees e.g. birch	woodland trees e.g. oak, ash

soil formation sequence on rock

diverted climax caused by browsing animals e.g. rabbits, deer, sheep ⟶ grassland

mineral fragments and plant debris collect in cracks, forming first **soil**

algae, cyanobacteria and simple rooted plants colonise, speeding the breakdown of rock

rock eroded at cracks and fault lines by extreme of temperature
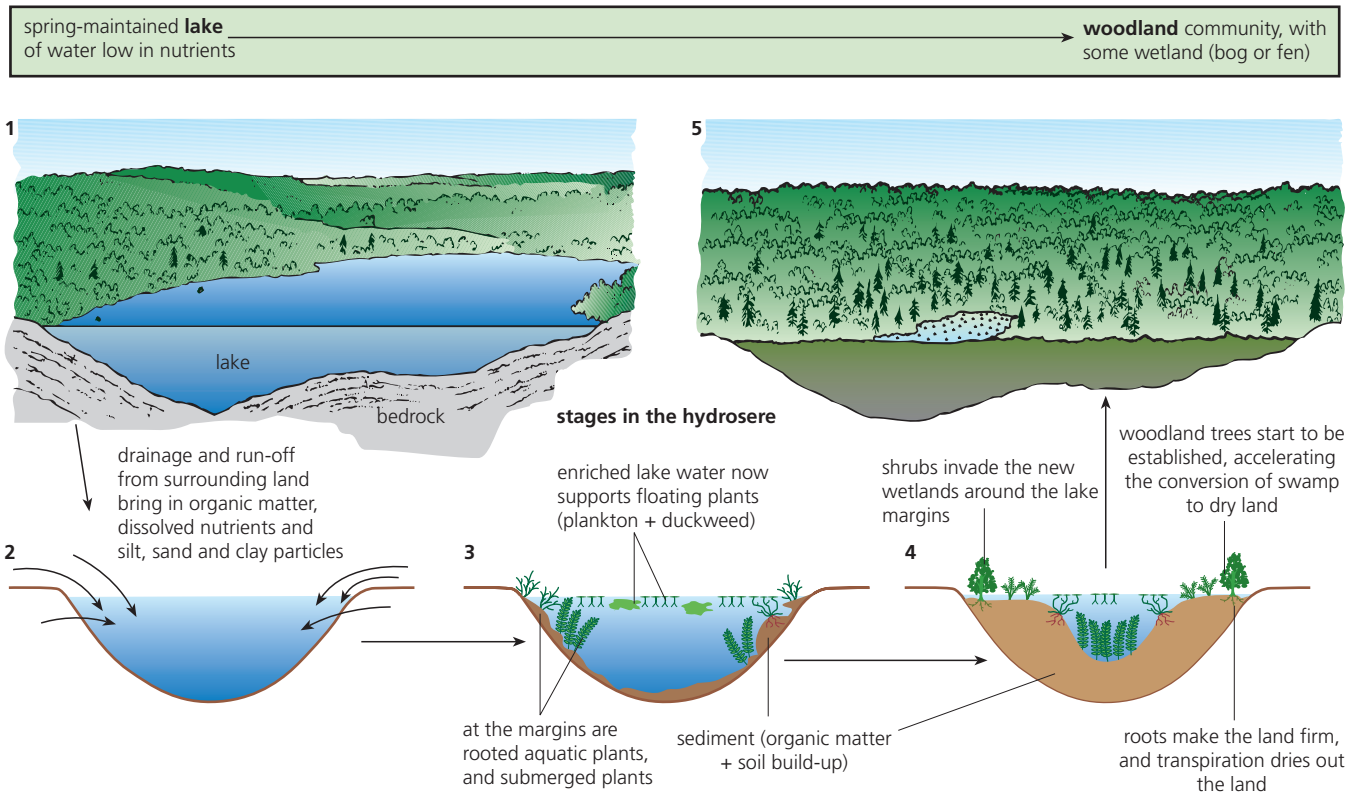
lichens survive exposure

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

The eventual outcome of the succession is perhaps a stable woodland community (an example of a **climax community**) where once bare rock or dry sand stood. Whether or not this specific community is the outcome, an important feature of a succession is the **progressive increase in the number of species present**. As more and more species occur in a habitat, the food webs are likely to be more diverse and complex. If so, in the event that one population crashed, such as when a disease sweeps through the members (or predators of a population have a temporary population explosion), then alternative food chains may be sufficient to supply the higher trophic levels.

If the primary successions develop in aquatic habitats, then the sequence of pioneer plants differs from a dry land primary succession, but the result may well be a woodland climax community, too (Figure 19.15). The succession is called a **hydrosere**. Plants adapted to aquatic or permanent swamp conditions are known as hydrophytes.

Figure 19.15 A primary succession from open water – a hydrosere

spring-maintained **lake** of water low in nutrients ⟶ **woodland** community, with some wetland (bog or fen)

1

lake

bedrock

stages in the hydrosere

5

2

drainage and run-off from surrounding land bring in organic matter, dissolved nutrients and silt, sand and clay particles

3

enriched lake water now supports floating plants (plankton + duckweed)

at the margins are rooted aquatic plants, and submerged plants

sediment (organic matter + soil build-up)

4

shrubs invade the new wetlands around the lake margins

woodland trees start to be established, accelerating the conversion of swamp to dry land

roots make the land firm, and transpiration dries out the land

Figure 19.16 An example of a secondary succession – recolonisation of woodland after fire
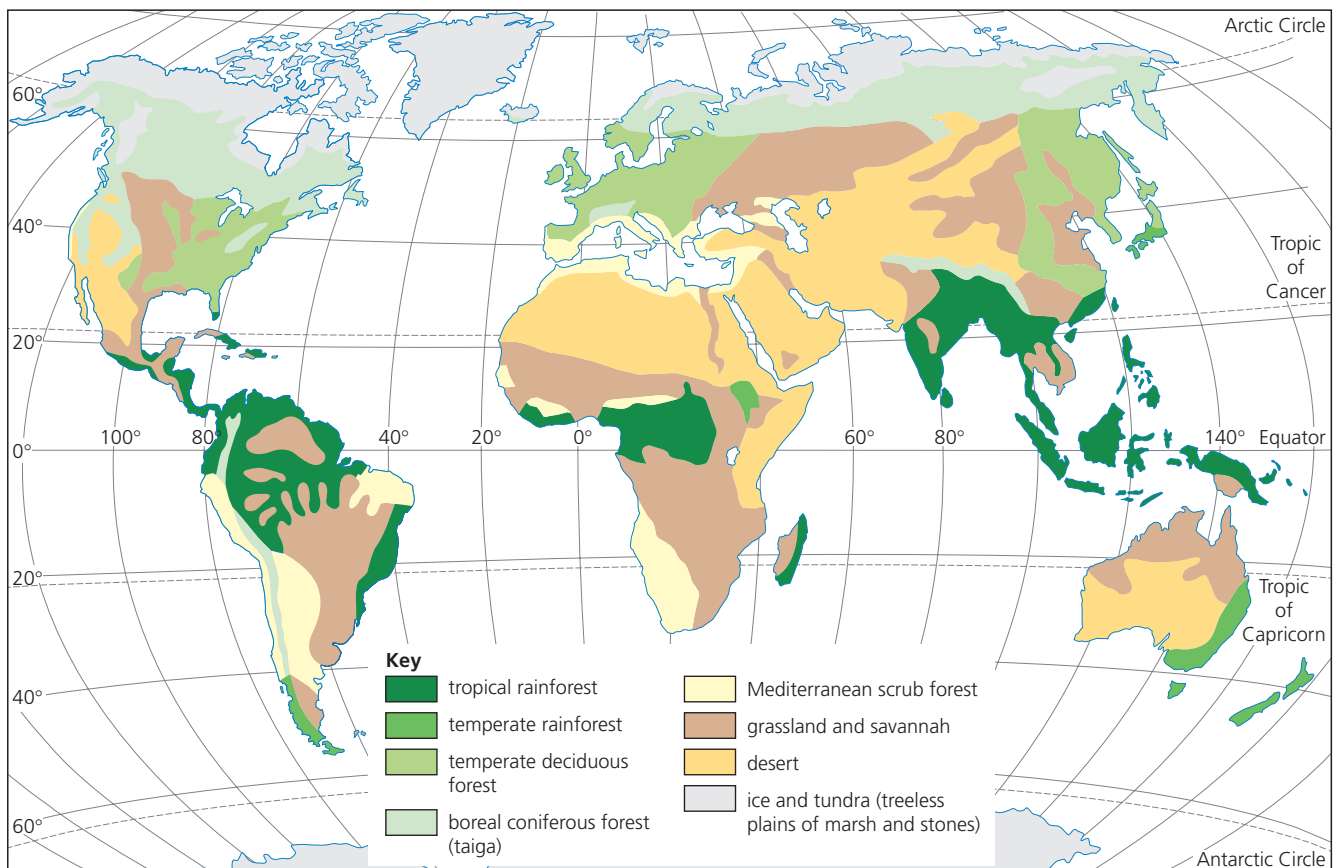
Secondary successions normally happen quite quickly, since the necessary soil for plant life is already present. Plant communities are established in succession, as spores and seeds are blown in, or carried in by visiting animal life, or as they grow in from the surrounding, unharmed climax communities. After forest fires, for example, the soil is quickly covered by moss species that favour scorched soil habitats. The carpet of moss reduces soil erosion, starts to contribute to the supply of humus, and provides conditions favourable to the lodging and germination of seeds of higher plants (Figure 19.16).

Introducing biomes

Only a part of planet Earth, its land, oceans and atmosphere, is inhabited. In fact, the majority of organisms occur in a narrow belt from upper soil to the lower atmosphere; if marine, many – perhaps most – occur near the ocean surface.

This restricted zone which living things inhabit is called the **biosphere**. Ecology sets out to explain, among other things, the distribution patterns of living things within the biosphere. Important patterns, often visible on a global scale, are the large, stable vegetation zones on the Earth (Figure 19.17). The zones are called biomes. A **biome** is a major life zone characterised by the dominant plant life present. Examples include tropical rainforest and grassland. Here the climax community typically extends unbroken over thousands of square kilometres.

Figure 19.17 The biomes of the world

Key

- tropical rainforest
- temperate rainforest
- temperate deciduous forest
- boreal coniferous forest (taiga)
- Mediterranean scrub forest
- grassland and savannah
- desert
- ice and tundra (treeless plains of marsh and stones)

Why are particular biomes found where they are?

The abiotic factors which appear to determine the occurrence and distribution of the biomes are **rainfall** and **temperature** (Figure 19.18). The interaction of these two factors, which vary with latitude, longitude, position within land masses and proximity to the sea, are critical.

The reason why temperature is influential on distribution of organisms is mainly because of its effects on their metabolism. Many plants (and animals too) have phases in their life cycles that require particular temperature conditions for success. Seed germination is a case in point.

Figure 19.18 The relationship of biome type to climate (mean annual temperatures and precipitation levels)
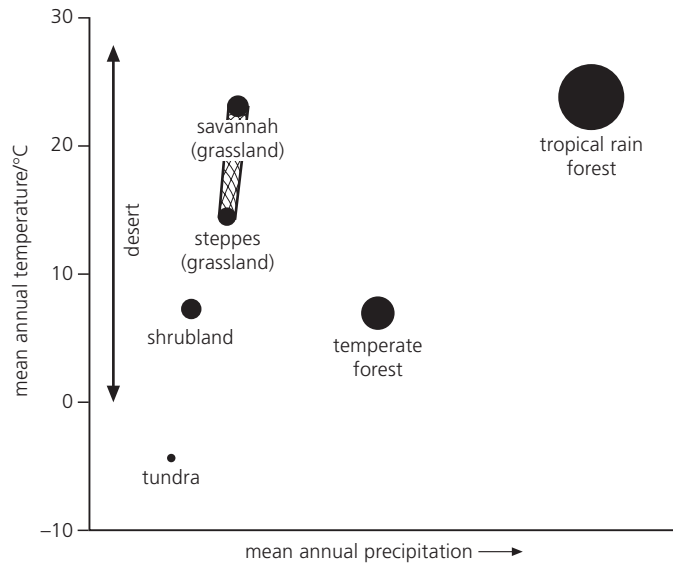
Similarly, the availability of water in the soil is critical for both the growth of the plant and its nutrition. The availability of water varies greatly, and the adaptations of plants to growth under differing water-level regimes (in relation to various ambient temperatures) influence where different species grow successfully.

The biomes

Examine the map in Figure 19.17 to note the various locations where each of the following biomes is found.

1 **Tundra**, particularly **Arctic tundra**, is a biome found where temperatures are low and the ground is typically continuously frozen, a condition known as permafrost. Plant roots cannot penetrate the soils, which are described as poor. The soils are saturated with water that is unable to evaporate away, and so soil air is limited. The growing season is short – winters are long, dark (and dry). In the brief summer period, conditions improve sufficiently for plant growth and flowering to be spectacular. Growth of the flora is immediately accompanied by the equally brief appearance of vast numbers of insects.

   Alpine tundra occurs on the highest mountains, well above the tree-line. Night-time temperatures here are below freezing, but daylight typically varies little around the year. Day-time temperatures typically rise above freezing, sufficient for the plant life here to show steady, very slow growth, more or less throughout the year.

2 **Grassland** (also called temperate grassland) occurs as **steppe, prairie** and **pampas** around the world where climates are moderately dry, summers are hot and winters cold. The principal plants are perennial grasses, together with some broad-leaved flowering plants that flower either at the start or the end of the growing season when the grasses are less dominant and over-shadowing. Grassland provides natural pasture for grazing animals, and these areas have often been converted into grain-crop grassland, where rainfall is sufficient, as human populations have expanded and their agriculture has become mechanised.
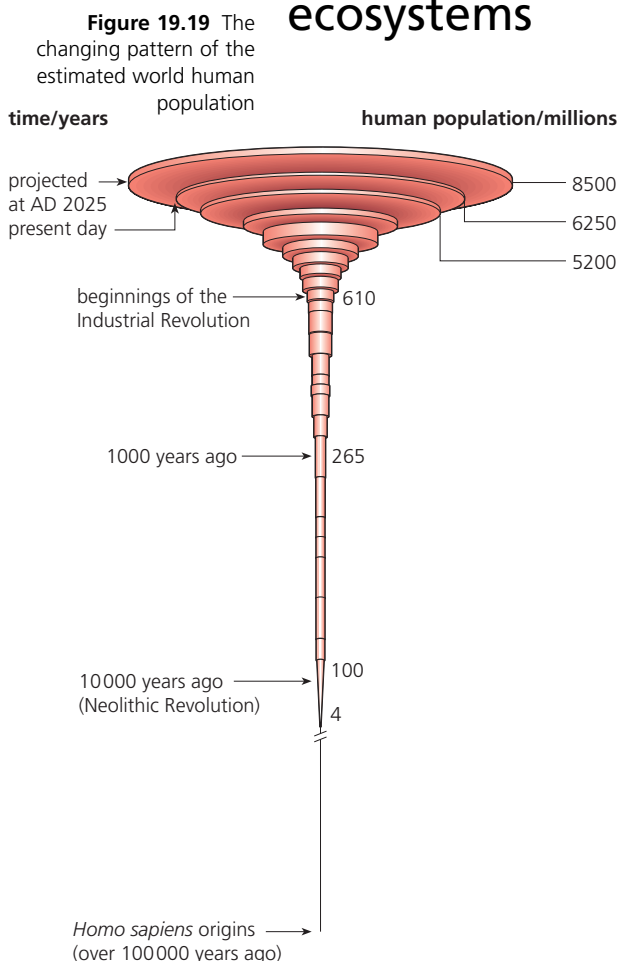
   Savannah is tropical grassland with scattered, individual trees. Typically, here there are three distinct seasons: cool and dry, hot and dry, and warm and wet. This environment typically supports an abundance of wildlife, including large herds of herbivores and their predators, many from the cat family. Frequent fires triggered by electric storms, and the presence of large, destructive herbivores like the elephant, are important factors limiting the growth and spread of trees.

3 **Desert** occurs in the sub-tropical zones where the land receives **very limited** and **unpredictable rain**. The limited plant life is either of ephemerals (dormant until rain, then completing their life cycle in days or weeks) or succulents that survive above ground all the year round. The limited animal life responds to the danger of desiccation in various ways. Camels are large mammals that have adapted to this terrain. Their many adaptations include the ability to allow body temperature to vary by up to 7 °C, allowing conservation of water in daylight hours.

4 **Tropical rainforest** grows in areas of heavy rainfall near the equator. Despite the more or less continuous growth of the dominant plants (trees 30–50 metres high) which the continuous moisture and warmth make possible, the resulting forest is not impenetrable. The height of the trees, their substantial canopies, and the dense growth of epiphytes along the branches, all reduce the light that can reach the forest floor. The flora and fauna is extremely rich – many species present are unknown to science, because it is here that the greatest diversity of any biome is to be found. Much of the animal life is confined to the canopy, specialising on a diet of the abundant fruits present, or else on the leaves. The soil below and the canopy above support a huge fauna of non-vertebrates.

5 **Temperate deciduous forests** are dominated by broad-leaved deciduous trees growing in conditions of adequate moisture. Typically these forests have several layers, with sufficient light penetrating to the lowest layer, the herbaceous plants of the ground level. Between the tree canopy and the ground layer are found a shrub layer, and sometimes an understorey of lower trees. All this vegetation supports a diversity of animal life at all levels. These forests have an annual rhythm to their growth, in which buds break in spring leading to growth of new foliage. The leaves fall at the end of summer, and the trees are, in effect, dormant during the winter. Leaf-loss like this is only possible in temperate zones where the soil holds the essential nutrients that will be required for fresh growth, when it comes in spring.

6 **Scrubland** includes chaparral and heathland. They occur in mild temperate regions with abundant winter rainfall but dry summers. Typical climax vegetation here consists of evergreen shrubs. The origins of this biome are disputed, some ecologists holding that it forms from temperate forest ravaged by fire or the effects of over-grazing, others that it is a diverted climax community.

Biodiversity, and the impact of humans on ecosystems

G3.1–3.11

Figure 19.19 The changing pattern of the estimated world human population

time/years

human population/millions

projected at AD 2025
present day

8500

6250

5200

beginnings of the Industrial Revolution — 610

1000 years ago — 265

10 000 years ago (Neolithic Revolution) — 100

4

Homo sapiens origins (over 100 000 years ago)

There are vast numbers of living things in the world. The word **biodiversity** is a contraction of 'biological diversity', and is the term we use for this abundance of different types or species. Today, the issue of **human influence on biodiversity** is of major concern.

Why?

In the long history of life on Earth, humans are very recent arrivals. Life originated about 3500 million years ago, but our own species arose only a little over 100 000 years ago. Initially, human activities had little impact on the environment. For one thing, during early human prehistory, population numbers were low. *Homo sapiens* was a rather struggling species, living among many very successful ones. At this stage, survival must have been a very chancy affair.

The first significant increase in the human population occurred with the development of settled agriculture – a change began in the fertile crescent in the Middle East about 10 000 years ago. It is known as the **Neolithic (new stone age) Revolution**. After that time, the human population started to increase in numbers, but only at a very slow rate. The current human population explosion began around the beginning of the **Industrial Revolution**, some 200 years ago. The human population explosion continues still, and no-one is certain when the rate of population growth will slow down, as it surely must. When we plot world human population against time we see a steeply rising J-shaped curve (Figure 19.19). This curve can be compared to the first half of the sigmoid curve of growth of microorganisms, shown in Figure 6.17 (page 155).

Human population growth appears to be in an **exponential** (log) **phase of growth**, due to high birth rates and lower death rates, leading to rising life expectancy (people are living very much longer).

Today, the impact of humans on the environment is very great indeed – there is virtually no part of the biosphere which has not come under human influence and been changed to some extent. It continues to be changed now, both the physical and chemical (abiotic) environment, and the living organisms (the biota). Many of these changes threaten biodiversity.

Next we look at how biodiversity can be studied in a local habitat, and then consider some of the ways biodiversity is threatened by us.

Simpson diversity index

Early on in the development of a succession – for example, at the pioneer plants stage on new land (Figure 19.14, page 615) – the number and diversity of species are low. At this stage, the populations of organisms present are usually dominated by abiotic factors. For example, if extreme, unfavourable abiotic conditions occur (prolonged, very low temperatures, perhaps), the number of organisms may be severely reduced.

On the other hand, in a stable climax community many different species are present, many in quite large numbers. In this situation, adverse abiotic conditions are less likely to have a dramatic effect on the numbers of organisms present. In fact, in a well-established community the dominant plants set the way of life for many other inhabitants. They provide the nutrients, determine the habitats that exist, and influence the environmental conditions. These plants are likely to modify and reduce the effects of extreme abiotic conditions, too.

Thus the **diversity of species** present in a habitat is also an indicator of the **stability** of the community. Species diversity of a community may be measured by applying the formula known as the **Simpson diversity index**:

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

where N = the total number of organisms of all species found
n = the number of individuals of each species

8 In a vegetable plot left fallow (left unsown for a year) three weed species appeared. Individual plants were counted:

| Species	n – number of individuals
Groundsel (*Senecio vulgaris*)	45
Shepherd's purse (*Capsella bursa-pastoris*)	40
Dandelion (*Taraxacum officinale*)	10
Total (*N*)	95

Calculate the Simpson diversity index for this habitat.

9 Figure 19.20 is a study of the vegetation of a system of developing sand dunes. Note how both the species diversity and physical parameters change as the dunes age. **Calculate** the diversity indices of the fore dune and semi-fixed dune (using a spreadsheet). **Comment** on the results.

The case for conservation of biodiversity – rainforests as a special case

Rainforests cover almost 2% of the Earth's land surface, but they provide the habitats for almost 50% of all living species. It has been predicted that if all non-vertebrates occurring in a single cubic metre of tropical rainforest soil were collected for identification, there would be present at least one completely previously unknown species. It is the case that tropical rainforests contain the greatest diversity of life of any of the world's biomes.

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

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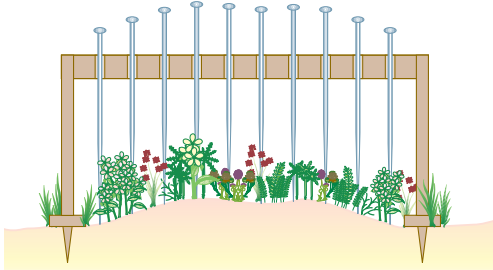
The frame is randomly placed a large number of times, the 10 pins lowered in turn onto vegetation and the species (or bare ground) recorded.

Behind the fore dune the fixed dunes can be seen.

Figure 19.20 Sand dune community development – a student field study exercise

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

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

Sadly, tropical rainforests are being rapidly destroyed. Satellite imaging of the Earth's surface provides the evidence that this is so – even where no other reliable sources of information are available. The world's three remaining tropical rainforests of real size are in **South America** (around the Amazon Basin), in **West Africa** (around the Congo Basin) and in the **Far East** (particularly but not exclusively on the islands of Indonesia).

The current rate of destruction is estimated to be about one hectare (100 m × 100 m – a little larger than a football pitch) every second. This means that each year an area larger than the British Isles (31 million hectares) is cleared. While extinction is a natural process, the current rate is on a scale equivalent to that at the time of the extinction of the dinosaurs (an event 65 million years ago, at the boundary of the Cretaceous and Tertiary periods – Figure 16.17, page 474).

Extinctions have been a feature of the history of life. Why should we strive to conserve biodiversity?

Conservation involves applying the principles of ecology to manage the environment. The reasons for conservation of rainforest are outlined below.

Figure 19.21 Most species have small ranges and these are concentrated unevenly
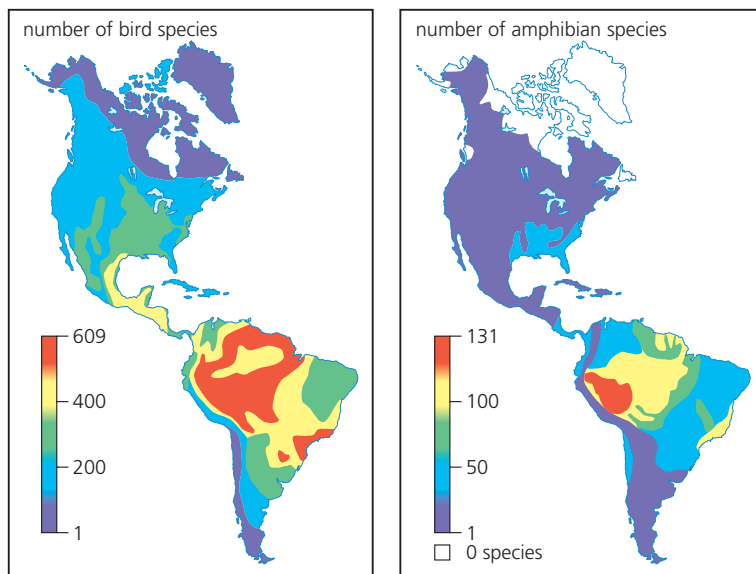
1 **Ecological**

a Most species of living things are not distributed widely, but instead, are restricted to a narrow range of the Earth's surface. In fact, the majority of species living today occur in the tropics (Figure 19.21). So when tropical rainforests are destroyed, the only habitat of a huge range of plants is lost, and with them very many of the vertebrates and non-vertebrates dependent on them.

b In effect, the rainforests are critically important 'outdoor laboratories' where we learn about the range of life that has evolved, the majority of which consists of organisms as-yet unknown.

c The soils under rainforest are mostly poor soils that cannot long support an alternative biota. To destroy rainforest is to remove the most productive biome on the Earth's surface – in terms of converting the Sun's energy to biomass.

d If destroyed but later left to regenerate, only species that have not become extinct may return. Re-grown rainforest will be deprived of its variety of life.

2 **Economic**

a The whole range of living things is functionally a gene pool resource, and when a species becomes extinct its genes are permanently lost. The destruction of rainforests decreases our genetic heritage more dramatically that the destruction of any other biome. As a consequence, future genetic engineers and plant and animal breeders are deprived of a potential source of genes. Many new drugs and other natural products, in some form or another, are manufactured by plants. The discovery of new, useful substances often starts with rare, exotic or recently discovered species.

b About half of the original rainforest present before clearance programmes started has been cleared – 7 million km^2 of humid tropical forest. Much is cleared to make way for the production of crops for food (Figure 19.22). Yet only 2 million km^2 have remained in agricultural production. Mostly, the soil does not sustain continued cropping.

c Rainforest is a continuing resource of hardwood timber, which if selectively logged can be productive, but when cleared as forest, is lost as a source of timber for the future.

d Trees help stabilise land and prevent disastrous flooding downriver. Huge areas of productive land are washed away once mountain rainforest has been removed.

e Trees in general are carbon dioxide sinks that help reduce global warming. Without these trees, other ways of reducing atmospheric carbon dioxide must be found.

Figure 19.22 Rainforest land for agriculture

Adapted from: *THE TIMES* Thursday February 2 2006

Rainforest Eden faces death by chainsaw – to make margarine

A £4.4bn plantation could destroy an ecological treasure, reports **Nick Meo** from Borneo.

IN THE cool of dawn Betung Kerihun could almost be an English wood until the honks of a rhinoceros hornbill echo around the great creeper-festooned trees.

The forest is an almost untouched Eden. Orang-utans and gibbons live high in the canopy. On the forest floor clouded leopards and eight-metre pythons hunt wild boar and deer and are themselves hunted by one of the last truly nomadic forest peoples, the Penan. But this rainforest, which has survived for millions of years, may now be doomed.

A £4.2 billion plan proposed by a Chinese bank and backed by Jakarta politicians would clear 1.8 million hectares of this wilderness over the next six years to grow oil palms to feed the world's growing appetite for margarine, ice-cream, biscuits and biodiesel fuel.

Until now Betung Kerihun, technically a protected national park, has been saved by its remoteness despite the network of roads that illegal loggers have begun to push inside its boundaries.

What survives is a biological treasure that staggers scientists newly arrived from Europe. It is home to thousands of tree frogs, bats and orchids. More than 1,000 insects have been identified in a single tree. In one ten-year period 361 new plant, animal and insect species were discovered in Borneo.

Charles Darwin, who explored the giant island before writing *The Origin of Species*, called it "one great untidy luxuriant hothouse made by nature for herself".

Reaching the virgin jungle from the coast takes days by river or logging road across a landscape of tree stumps, and the most common sound is that of the chainsaw. Only half of the island is now covered with forest, compared with three quarters in the 1980s.

Conservationists believe that the real motive for the oil palm scheme is to gain access to the valuable timber along a great swath of the Indonesian-Malaysian border.

"It's a scam," said Stuart Chapman, of the WWF conservation group. "Palm oil is a lowland equatorial crop and not suited to steep upland soils. There are two million hectares of idle land, already cleared of forest, in lowland Borneo which is suitable for planting. but putting this plantation in the island's centre would give logging interests the excuse they need to cut down trees."

10 There are other reasons for conservation of diversity, besides those listed above. **Suggest** at least one more reason under one or more of the categories listed here.

3 Aesthetic
  a These habitats are beautiful and exhilarating venues to visit and be inspired by.
  b They are part of the inheritance of future generations which should be secured for future people's enjoyment, too.

4 Ethical
  a This biome is often home to forest people who have a right to their traditional ways of life.
  b Similarly, many higher mammals, including relatively close relatives of *Homo*, live exclusively in these habitats. The needs of all primates must be respected.

The impacts of alien species and of invasive species on ecosystems

Alien species are introduced plants and animals that have been accidentally or deliberately transferred from habitats where they live, to new environments where the abiotic conditions are also suitable for them. If the alien takes over in an apparently aggressive way, detrimental to the food chains of their new habitat, then they are described an **invasive species**.

Examples of alien species that have become invasive are:

- the **rabbit** (*Oryctolagus* sp.) deliberately introduced from Europe, into Australia, and the **myxoma virus** disease of rabbits, from South America, introduced as a biological control;
- **Japanese knotweed** (*Fallopia japonica*) deliberately introduced into northern Europe in the early nineteenth century as an ornamental plant for garden ponds and lakes;
- **American grey squirrel** (*Sciurus carolinensis*) accidentally introduced into Britain in the nineteenth century.

The profile of the impact of an alien species can be illustrated by the introduction of the European wild rabbit to Australia in 1859. This voracious herbivore spread rapidly. Clearly, no

natural predators in Australia were threats to numbers (**interspecific competition** failed) because rabbits quickly over-ran large parts of that continent. Grassland, available to herds of herbivores, principally cows and sheep, was seriously damaged. In desperation, and as a **biological control measure**, myxoma virus that had been discovered in South American rabbits (a different species from the European rabbit), was introduced in 1950.

Figure 19.23 Changing rabbit mortality and virus virulence, following introduction of the myxoma virus as a biological control measure
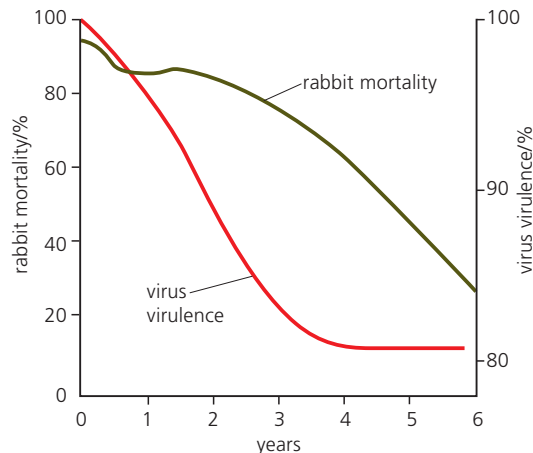
Myxoma virus causes a parasitic disease of rabbits, **myxomatosis**, but on its original continent, the effects were mild. The changing effects of this virus on rabbit mortality (1950–56) are shown in Figure 19.23, as is the resulting change in virulence of the virus. We may assume that initially, a small number of the huge population of rabbits had immunity. As their vulnerable relatives were killed off the immune rabbits prospered from the diminished competition for grass. Rapidly, the bulk of the population were immune, and any that failed to develop immunity were quickly taken out.

11 Describe how the rabbits' immune system confers immunity to the effects of a virus.

In its original habitat, an alien species will have evolved in the company of **natural parasites** and **predators** – and come to exist in balance with other organisms of the community. In a new habitat, the aliens' natural enemies may be absent, so they may grow at the expense of native species, crowding them out.

This is the case with **knotweed**, which in Britain is not browsed by natural herbivores as it escapes into natural waterways. Similarly, plant parasites here do not attack the plant.

Knotweed plants grow into dense, submerged thickets that over-shadow and crowd out native water plants, block waterways, and block public access to stream banks. Yet back in its native Japan, the plant grows in a balanced relationship with other water plants and causes no significant problems. The reason for the difference is that knotweed was introduced in Britain without its natural populations of predators. The chemicals in its leaves and roots discourage predation by leaf browsers or root parasites. In Japan, there are natural populations that browse on knotweed and keep its growth in check. The **invasive pattern** of this alien's growth is shown in Figure 19.24.

The invasive pattern of the spread of the grey squirrel in Britain is proving a serious threat to the indigenous **red squirrel**, which is **now threatened with extinction** if its current rate of decline is maintained (Figure 19.25). Since it arrived, the grey squirrel has spread rapidly and it appears to be driving out the red squirrel, chiefly by being able to consume a wide range of locally growing nuts (including the very common woodland oak tree's acorn – this contains polyphenolic substances that the new arrival can digest, but which the red squirrel cannot). With its wider diet, the grey has out-bred the red, and multiplied much faster. This enlarged population has successfully competed for hazel nuts and pine cones too (the limited diet of the red squirrel).

Pesticide pollution and food chains

Wild plants and animals have evolved alongside their predators and parasites and most live in balance with them. Meanwhile our cultivated crops and herds have been selected to be especially productive and high-yielding, but typically have limited resistance to local parasites and predators, especially given the way they are grown – in intensive monocultures.

Pesticides are substances used to control harmful organisms that are a danger to crops or herds. Pesticides have enormously improved productivity in agriculture, but their use has generated problems in the environment.

Figure 19.24
Distribution of knotweed
in the UK, 1900–94
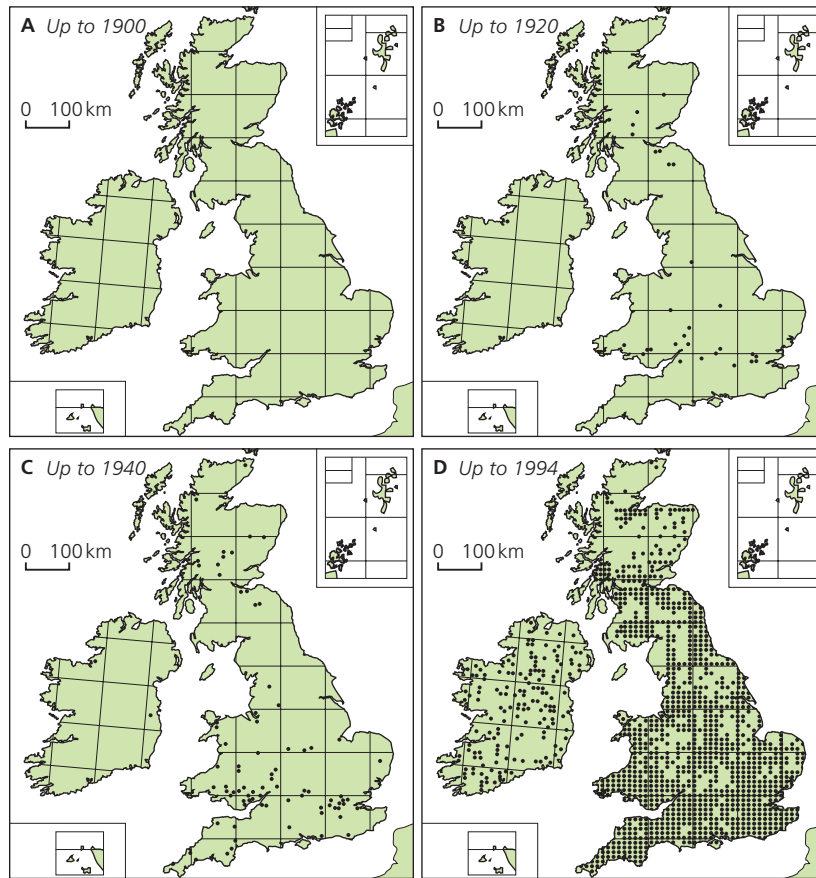
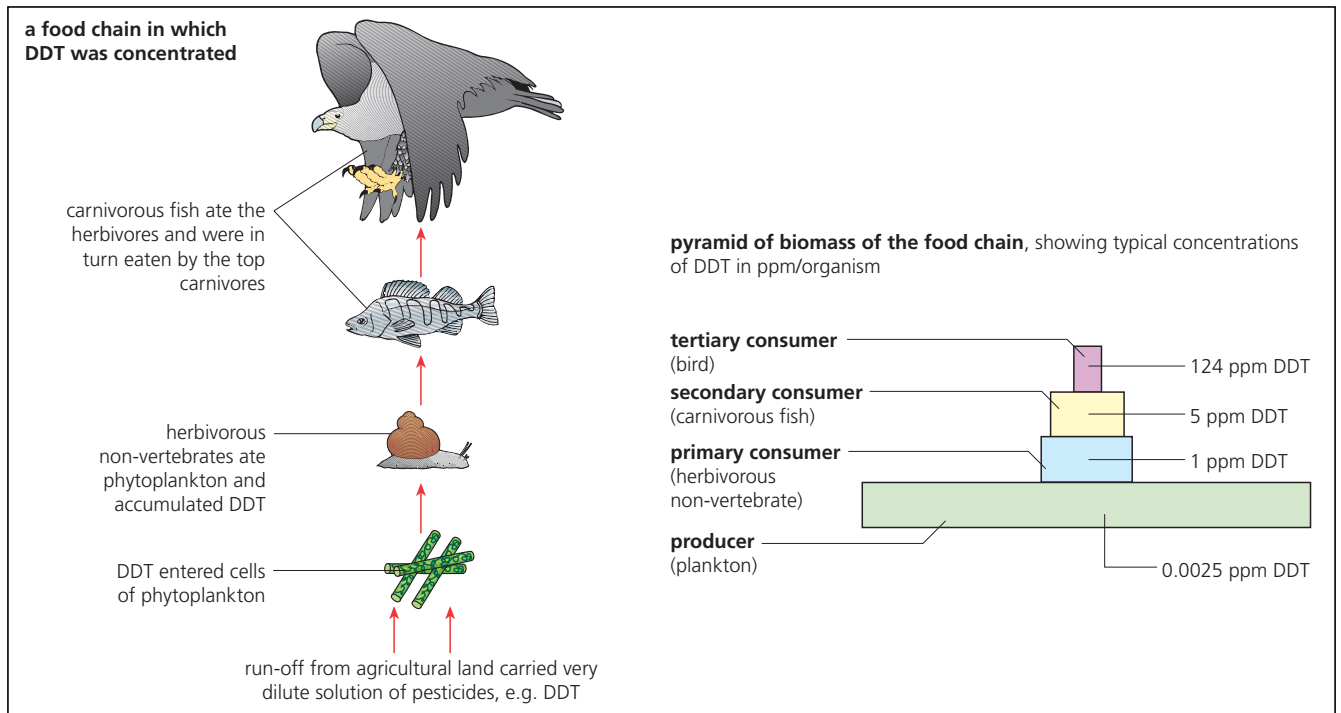**Figure 19.25** Red and
grey squirrels

The revolution in the chemical control of insect pests came when a particular substance known as dichlorodiphenyltrichloroethane (**DDT**) was found to be a very effective insecticide.
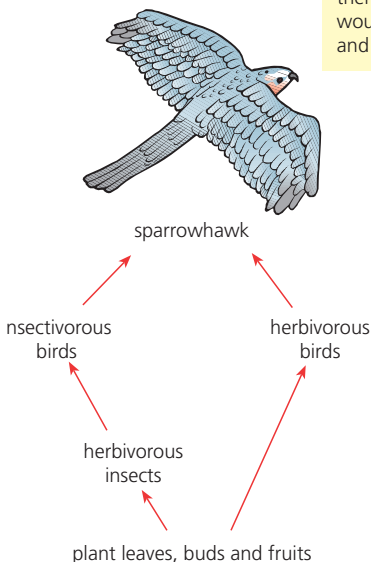
The DDT molecule has chlorine atoms attached to hydrocarbon rings, and was the first of a family of **organochlorine insecticides**. DDT is a nerve poison to insects, causing rapid death even when applied in low concentrations. DDT was economical to use because the molecule was **stable** when dispersed in the biosphere, remained **lethal for a very long time**, and was effective against a very wide range of insect pests (broad-spectrum insecticide). It did not do any harm to vertebrates in concentrations needed to kill insects, and so it was liberally used.

During the 1939–45 war and subsequently, DDT was especially effective against the mosquito, the vector for malaria (page 595). Of course, very many insect predators of pest species were also killed by DDT.

Figure 19.26
Biomagnification of DDT

a food chain in which DDT was concentrated

carnivorous fish ate the herbivores and were in turn eaten by the top carnivores

herbivorous non-vertebrates ate phytoplankton and accumulated DDT

DDT entered cells of phytoplankton

run-off from agricultural land carried very dilute solution of pesticides, e.g. DDT

pyramid of biomass of the food chain, showing typical concentrations of DDT in ppm/organism

tertiary consumer (bird) — 124 ppm DDT
secondary consumer (carnivorous fish) — 5 ppm DDT
primary consumer (herbivorous non-vertebrate) — 1 ppm DDT
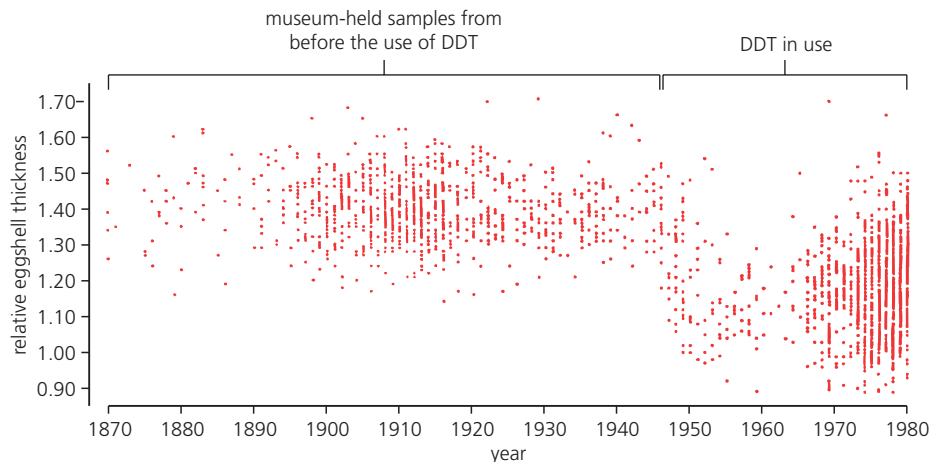**producer** (plankton) — 0.0025 ppm DDT

Figure 19.27 Eggshell thickness studies in sparrowhawks

Food web of the sparrowhawk
When DDT was used as an insecticide, there was a likelihood this pesticide would bioaccumulate at each step, and biomagnify in the top carnivore.

In the eggshell thickness study of British sparrowhawks 1870–1970, more than 2000 clutches of eggs were measured; each dot represents the mean shell thickness of a clutch (typically five eggs).

sparrowhawk

nsectivorous birds

herbivorous birds

herbivorous insects

plant leaves, buds and fruits

museum-held samples from before the use of DDT

DDT in use

relative eggshell thickness

DDT is fat soluble and is **selectively retained in fatty tissues** of animals, rather than circulating in their blood to be excreted by the kidneys. As a result, at each stage of the food chain, DDT becomes concentrated, a process known as biomagnification.

> **Biomagnification is a process in which chemical substances become more concentrated at each trophic level.**

In fact, in non-vertebrates, fish and birds, for example, DDT concentrations sometimes reached toxic levels (Figure 19.26). It began to be concentrated in top carnivores with devastating consequences (Figure 19.27). Although DDT is not a nerve poison in birds and mammals, in breeding birds it does inhibit the deposition of calcium in the egg shell. Affected birds lay thin-shelled eggs that easily crack. There was a rapid decline in numbers of birds of prey, in areas where DDT had become widely used in agriculture.

With this harmful effect of DDT discovered, the quality of 'stability' was renamed 'persistence'. Once the wider effects of organochlorine pesticides on wildlife were recognised, a ban was imposed, at least in the developed countries.

Instead, insecticides that are **biodegradable** in the biosphere (not persistent) and which are more specific in their actions were sought. Initially, organophosphate insecticides were favoured because they break down in the soil. They work by blocking the synapses of the insect nervous system, but are now suspected of being harmful to humans. If tiny quantities of pesticide persist in the food chain, these residues may accumulate in humans.

Subsequently, other substances, synthetic derivatives of pyrethrum, have been developed. These are much less toxic to mammals and also biodegradable. However, they are lethal to fish and must not be used near streams, rivers or lakes.

> **12 Analyse** the steps by which pesticides, applied at apparently safe concentrations, may cause death of organisms seemingly unrelated to the crops or herds for which the pesticides are designed.

# Atmospheric pollution and the ozone of the stratosphere

Ozone is a form of oxygen that contains three atoms of oxygen combined together. Today it occurs naturally in the Earth's atmosphere as an **ozone layer** found in the region of the atmosphere called the **stratosphere**. This is at a height of 15–40 km above the Earth's surface, so it is described as **high-level ozone**.

Ozone (O_3) is formed in the upper atmosphere by the action of ultra-violet (UV) radiation on molecular oxygen (O_2), which is split into two highly reactive atoms of oxygen. Each highly reactive oxygen atom reacts with a molecule of oxygen to form ozone:

$$O_2 \xrightarrow{+ \ UV \ light} O\cdot + O\cdot \qquad O\cdot + O_2 \xrightarrow{+ \ UV \ light} O_3$$
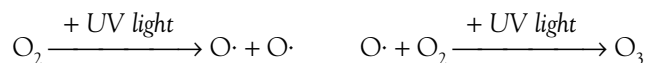
At the top of the stratosphere there is much incoming UV radiation but little oxygen. Closer to the Earth's surface there is much oxygen but little UV radiation. Consequently, the highest concentration of ozone is at a midpoint of the stratosphere.

Ozone of the stratosphere is maintained by the action of UV light, and this ceaseless cycle of changes leaves the composition of the atmosphere unchanged, *and most of the incoming UV light absorbed*. The stratosphere is slightly warmed by the reactions, but the heat is lost to space:

$$O_3 \overset{+ \ UV \ light}{\underset{+ \ UV \ light}{\rightleftharpoons}} O\cdot + O_2$$
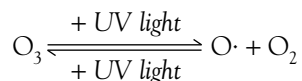
UV radiation that reaches the Earth's surface is harmful to living things because it is absorbed by the organic bases (adenine, guanine, thymine, cytosine and uracil) of nucleic acids (DNA and RNA) and causes them to be modified (mutation, page 100).

Consequently, the maintenance of the high-level ozone layer is important to the survival of life.

Atmospheric pollution destroys high-level ozone

Gaseous pollutants are threatening the ozone layer. These pollutants are chemicals made by industry – substances such as chlorofluorocarbons (**CFCs**). CFCs are very unreactive, stable molecules, deliberately manufactured to use as propellants in aerosol cans and as the coolant in refrigerators. However, gases escape into the atmosphere from these sources from time to time, and are slowly carried up to the stratosphere. It takes as long as five years for this to happen.

In the stratosphere, CFCs are exposed to high levels of UV light, and are broken down. Highly reactive chlorine atoms are then released, and these break down ozone molecules in a cyclic reaction:

$$O_3 + Cl\cdot \longrightarrow ClO + O_2$$

$$ClO + O\cdot \longrightarrow Cl\cdot + O_2$$
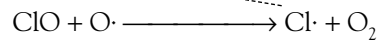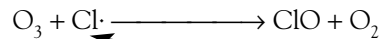
The outcome is that in the presence of CFCs, ozone molecules are broken down **faster than they can be reformed** by the natural reaction between molecular oxygen and UV light that we noted above.

Large quantities of CFCs were released into the atmosphere before this danger was realised. Because of the time taken for CFCs to reach the upper atmosphere, ozone depletion continues, despite the current steps to replace CFCs by safer chemicals.

The thinning of the ozone layer is greater over some countries than others, but for all organisms exposed to sunlight on land, the thinning ozone layer (called an **ozone hole**) is a potential problem. Protective clothing and UV blocking creams are necessary to avoid the danger of skin cancer, for people exposed to sunlight. This is potentially a major danger for people in Chile, South Africa, New Zealand and Australia, for example.

■ Conservation of biodiversity

G4.1–4.6

The destruction of tropical rainforest has already been noted as an existing major threat to biodiversity (page 619). In fact, human activities are changing many biomes worldwide, and in far-reaching ways, although it is not always as self-evident as the process and outcomes of deforestation are. The first step to effective conservation of natural and semi-natural environments is the early detection of environmental change.

Figure 19.28 The physiology of lichen mutualism

lichen (*Evernia prunastri*) common on trees, fences, rocks and walls

The presence and metabolism of lichen may speed rock erosion.

lichen thallus in section

rain water and condensation (with dissolved chemicals) are absorbed

LIGHT

many lichens produce organic acids (some highly coloured) which are deposited on the outer surface – may provide some protection from desiccation and predation

water evaporates from thallus in hot water

fungus shares water and ions; green 'plant' component shares glucose (and amino acids, perhaps) with fungus

when the thallus is hydrated the lichen can photosynthesise and grow – at other times metabolism is minimal

Fungal hyphae retain water and ions as and when they are available.

When the green 'plant' component is a cyanobacterium, atmospheric nitrogen may be fixed to form amino acids.

How can environmental change be detected and monitored?

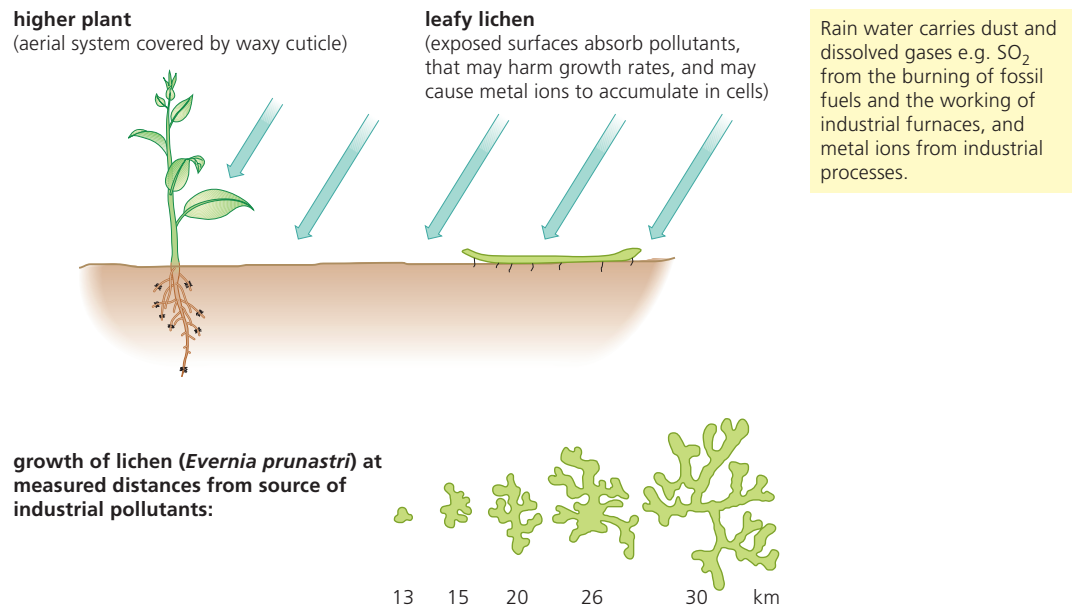Some organisms are particularly sensitive or vulnerable to change in their environment. If the numbers and condition of such species in threatened habitats can be monitored, their predicament (their health and well-being) can function as biological indicators (**biotic indices**) of impending environmental damage. For example, lichens (and mosses) are ideal organisms for the early detection of atmospheric pollution – in effect, they are potential **indicator species** of environmental change.

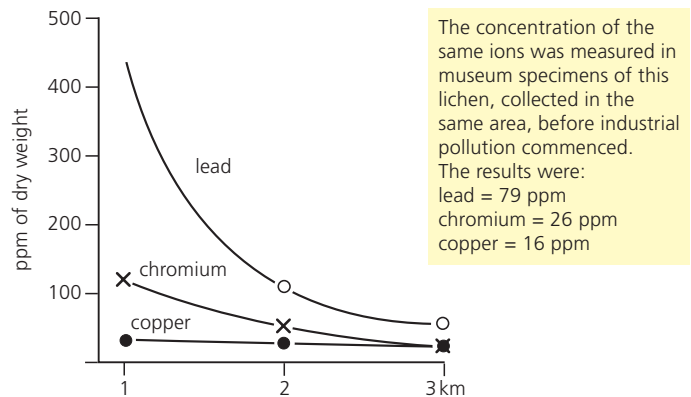## Lichens as pollution monitors

Lichens are dual organisms; their body (called a thallus) is made of a fungal component and an algal (or photosynthetic bacterium, cyanobacterium) component living together for mutual benefit (Figure 19.28). Some lichens are leaf-like, some crust-like, and others are described as shrubby or beard-like. There are several thousand different species of lichen, often occurring in quite hostile habitats. Compact fungal hyphae make up the bulk of the lichen, and this component absorbs and retains water and ions. The algal component carries out photosynthesis.

Lichens (and mosses) are especially susceptible to air-borne pollutants dissolved in rain water because their surfaces are not protected by a waxy cuticle. The lichen thallus absorbs and accumulates various pollutants, and samples of lichens may be analysed for contamination by heavy metal ions. The effects of pollution on the extent of their growth may also be a valuable indicator (Figure 19.29).

Figure 19.29 Lichens as pollution indicators

higher plant
(aerial system covered by waxy cuticle)

leafy lichen
(exposed surfaces absorb pollutants, that may harm growth rates, and may cause metal ions to accumulate in cells)

Rain water carries dust and dissolved gases e.g. SO_2 from the burning of fossil fuels and the working of industrial furnaces, and metal ions from industrial processes.

growth of lichen (*Evernia prunastri*) at measured distances from source of industrial pollutants:

13   15   20   26   30   km

graph of the concentration of various metals in lichen (*Peltigera rufescens*) in parts per millions (ppm) from sites up to 3 km from a steel works

The concentration of the same ions was measured in museum specimens of this lichen, collected in the same area, before industrial pollution commenced. The results were:
lead = 79 ppm
chromium = 26 ppm
copper = 16 ppm

Monitoring fresh water pollution

In water enriched with inorganic ions, aquatic plant growth becomes abnormally luxuriant. Ion enrichment may be due to accidental pollution by raw sewage, or from stockyard effluent (manure or silage liquors). Alternatively, an excessive or incorrect use of fertilisers on farm crops results in excess soluble fertiliser being leached from the soil by rain. Of the many ions beneficial to plants, an increased concentration of ammonium, nitrate and phosphate ions particularly increases plant growth.

In summer, in waters that are ion-enriched, with raised water temperatures, there occurs a phenomenal plant population explosion, often referred to as an **algal bloom** (because algae are involved, too, and as many are unicellular, their growth rates are spectacular). An excess of aquatic plant life in polluted waters is an example of **eutrophication**.

Figure 19.30 Detection of aquatic pollution following eutrophication
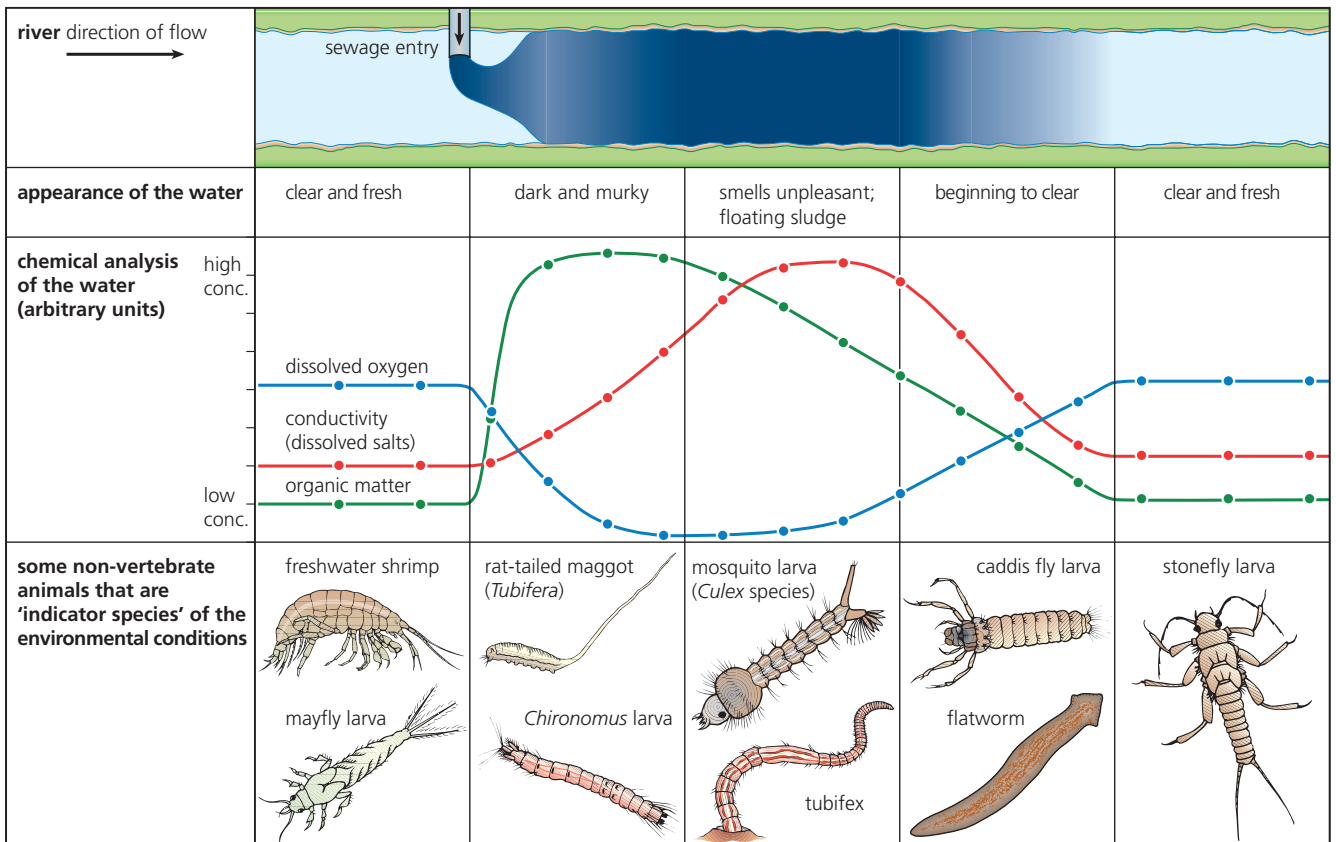
In marine habitats

Extensive seasonal algal blooms of the oceans can be observed in satellite images.

This 'false colour' photograph of the Earth's surface, taken from a satellite, shows where **algal blooms** (orange) are most common, and where algal growth is least (purple areas).
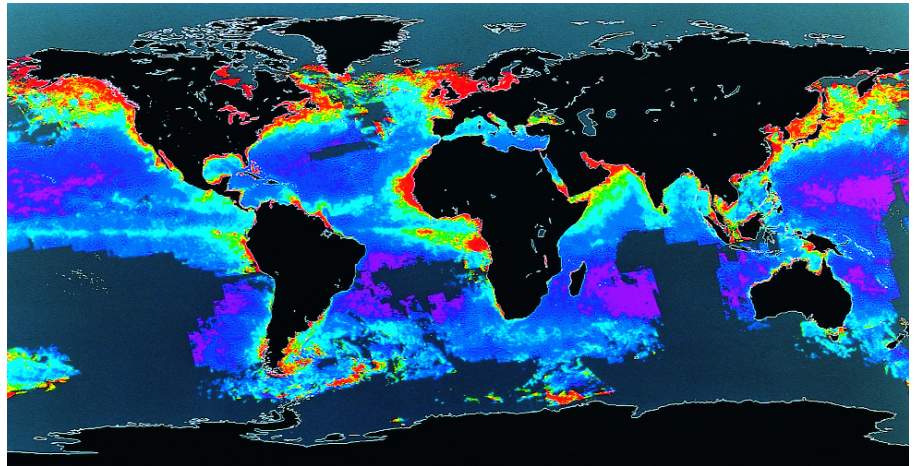
In fresh-water habitats

The effect of pollution of a river with untreated sewage can be observed by eye and measured by chemical analysis.

river direction of flow →	sewage entry ↓				
appearance of the water	clear and fresh	dark and murky	smells unpleasant; floating sludge	beginning to clear	clear and fresh
chemical analysis of the water (arbitrary units)	dissolved oxygen; conductivity (dissolved salts); organic matter				
some non-vertebrate animals that are 'indicator species' of the environmental conditions	freshwater shrimp; mayfly larva	rat-tailed maggot (*Tubifera*); *Chironomus* larva	mosquito larva (*Culex* species); tubifex	caddis fly larva; flatworm	stonefly larva

Later, after the algal bloom has died back, the organic remains of the plants are rapidly decayed by saprotrophic, aerobic bacteria. As a result, the water becomes deoxygenated, causing anaerobic decay and then, hydrogen sulphide formation. The few organisms that can survive in these conditions prosper, but the death of many aquatic organisms occurs, including fish, due to the total absence of dissolved oxygen and the presence of hydrogen sulphide. The sequence of events when a river is polluted in this way is summarised in Figure 19.30. Note that the changing populations of non-vertebrate aquatic animals are indicators of the degree of pollution and recovery.

Much of the waters from the land eventually drain into the seas, where the phenomenon of algal blooms is repeated. **Satellite photography** is a way of monitoring pollution in marine habitats as well as rainforest destruction.

Red Data Books as listings of indicator species

Currently, the rate of extinctions is exceptionally high. Environmentalists seek the survival of endangered species by initiating and maintaining local, national and international action. The International Union for the Conservation of Nature and Nature Reserves co-ordinates the updating of **Red Data Books**. These list endangered species, identifying those for which special conservation efforts are needed. The health and general well-being of populations of these organisms are indicators of environmental changes.

Practical conservation steps include the designation and maintenance of nature reserves, botanical and zoological gardens (with their captive breeding programmes), and the establishment of viable seed banks; all are measures to combat loss of endangered species and of the habitats that support them. We look into this issue next.

Extinctions and conservation of species

New species evolve, but other species, less suited to their environment become extinct, as much of the fossil record throughout geological time records. One example of a well documented extinction is the dodo.

Figure 19.31 A reconstruction of the dodo

The dodo

The dodo (*Raphus cucullatus*) was an inhabitant of the island of Mauritius in the Indian Ocean (Figure 19.31). It was a bird related to modern pigeons. Over geological time, it had evolved to master a terrestrial habit. In the process it became large bird (about a metre long, with a mass of approximately 20 kg).

The dodo nested on the ground, and reared its young there. The diet was one of seeds and fruits that had fallen from the forest trees. It was one of many forest-dwelling birds on the island – one of the 45 species for which there are early records, of which only 21 species have survived to this day.

What factors contributed to the extinction of the dodos?

Mauritius is a medium-sized island, extremely far from any mainland. The dodo's misfortune was that Mauritius got involved in developments in what we know as the **spice trade**.

Spices have been brought from the East, where they are grown and produced, to European centres since ancient times. The rarity of spices in the West and their importance at times when food was difficult to preserve fresh gave them great value. In order to break the monopoly in spice trading held by the people of Venice from 1200 to 1500, other European explorers (first from Portugal, and then from other west European sea-going countries) sailed the sea-routes from early in the sixteenth century. They made stop-over visits to ports and islands to restock (fresh water and fresh meat were required). Visits led to population migrations, and people brought their farm stock with them. Mauritius was a popular location for this, and later was also used secretly to grow imported spice plants. Seeds and plants were smuggled in from previous supply centres, in order to further break monopolies. The aim was to reduce prices set by traditional suppliers.

Records show that the dodo became extinct on Mauritius by 1681. The specific factors that contributed to this were:

1 Visiting **sailors killed the dodo** as a source of fresh meat to restock their ships. The dodo proved an easy victim, unfamiliar with humans (or other mammals). In fact, it had previously lacked significant natural enemies.
2 Later, **settlers brought cats, dogs and pigs**, and inadvertently, rats – all alien species which fed on the occupant of the dodo's nest: the eggs and growing chicks. The dodo population numbers were no longer maintained.
3 **Natural habitats on the island were deliberately destroyed** as land was cleared for agriculture and the growth of introduced spice plant species. The forests with their fruit and seed-yielding trees were removed, so the remaining dodos lost their source of food. Indeed, many other species are likely to have become extinct with the forest clearance.

Conservation by promotion of nature reserves

Biological conservation can be attempted by setting aside land for restricted access and controlled use, to allow the maintenance of biodiversity, locally. This is not a new idea; the New Forest in southern Britain was set aside for hunting by royalty over 900 years ago. An incidental effect was a sanctuary for many forms of wildlife.

Today, this solution to extinction pressures on wildlife includes the setting up of nature reserves (such as areas of chalk downland in northern European countries) and National Parks (such as Yellowstone, one of the original National Parks, set up in North America in 1872; and African game parks, more recently established). In total, these sites represent habitats of many different descriptions, in many countries around the world. Some of the conservation work they achieve may be carried out by volunteers.

*What biogeographical features of a reserve best promote conservation?*

In a nature reserve, the area enclosed is important (Figure 19.32). In fact, there is an area of reserve too small to be effective, but as size increases there comes a point where further increase secures no greater diversity. The actual dimensions of an effective reserve vary with species, size, and life style of the majority of the threatened species it is designed to protect.

Also, for a given reserve there is an **edge effect** (Figure 19.32). A compact reserve with minimal perimeter is more effective than one with an extensive interface between its perimeter and the surroundings. But whatever the size, the uses of the surrounding area are important, too. If it is managed sympathetically it may indirectly support the reserve's wildlife.

Another feature is **geographical isolation** (Figure 19.32). Reserves positioned at great distances from other protected areas are less effective than reserves in closer proximity. Where reserves are small, and a larger provision would help, it has been found that connecting corridors of land may overcome the disadvantage. In agricultural areas, these may simply take the form of hedgerows protected from contact with pesticide treatments that nearby crops receive.

Active management of nature reserves

Conservation involves using knowledge of the ecology of habitats, including of both the biota and the abiotic factors operating, in order to manage the environment of the nature reserve, and so maintain biodiversity. Conservation is an active process, not simply a case of preservation.

Figure 19.32 Features of effective nature reserves
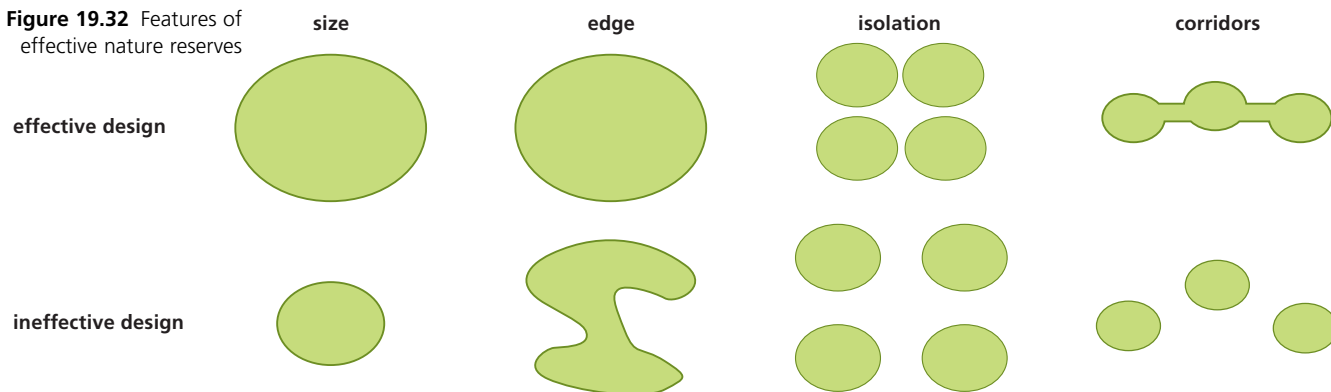
There are five key steps to active management of a nature reserve:

1 **Continuous monitoring** of the reserve so that causes of change are understood, change may be anticipated, and measures taken early enough to adjust conditions without disruption, should this be necessary. Changes particularly arise from natural succession tendencies in habitats that are not climax communities. Alternatively, changes in human industries and land use in surrounding areas, or devastating natural disasters due to unseasonal weather conditions might all cause havoc. Information is essential to keep the reserve from changing.

2 **Habitat conservation** to maintain stable habitats essential for threatened species. For example, diverted climax communities such as grassland may be quickly displaced by the growth of scrub followed by wood, if the natural invading plants are not checked. A diverted climax has often arisen by particular human farming practices (such as land grazing by ruminant herds), and this may need to be re-introduced and periodically maintained.

3 **Maintenance of effective boundaries**, and the limiting of unhelpful human interference. The enthusiastic involvement of the local human community should be facilitated, at the same time. This often involves the provision of vantage points for over-viewing the reserve, hides for observation of shy animals, and seasonal information on the life of the community – all encourage understanding of the ecology that underpins the purpose of the reserve. Opportunities for local volunteers communicate the message that everyone has a part to play in conservation.

4 **Measures to facilitate the successful completion of life cycles** of any endangered species for which the reserve is home, together with supportive conditions for vulnerable and rare species, too. These may involve the supply and maintenance of nesting boxes, access to ponds or flowing water, and the planting of essential food plants to sustain critical food chains.

5 **Restockings and re-introductions of once-common species** from stocks produced by captive breeding programmes of zoological and botanical gardens. Introduced organisms from these sources do not necessarily make a successful transition, so their initial progress requires monitoring carefully.

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

Active management measures vary greatly with individual reserves. Local reserves need to be consulted to appreciate the significance of the challenges of conservation in your locality.

Endangered species – an appraisal of *in-situ* conservation *versus ex-situ* conservation

Endangered species typically have very low population numbers and are in serious danger of becoming extinct. Our own self-interest requires the preservation of endangered species. The reasons are numerous.

When a particular species becomes extinct, its genes are permanently lost, and the total pool of genes on which life operates is diminished. Wild organisms contribute to a pool of genetic diversity useful to genetic engineers.

Many wild plants are sources of compounds with medicinal value. Some wild organisms are more efficient energy converters than existing crops and herbs in particular ecosystems.

It is also essential to maintain a diverse flora and fauna to ensure the continuation of the processes of evolution of new species in response to the changing environments of the Earth.

International action

As noted above, the International Union for the Conservation of Nature and Nature Reserves coordinates the updating of the Red Data Books which list endangered species, identifying those for which special conservation efforts are needed. Problems are well documented.

How may endangered species best be preserved?

In effect, the alternative practical approaches (as immediate responses) to the problem are:

■ **habitat preservation** (*in-situ* conservation) – this involves the setting up and maintenance of nature reserves, national parks of representative habitats, and conservation areas all over the world;

■ **captive breeding programmes** (*ex-situ* conservation) in zoological and botanical gardens, and the building up of seed banks.

Terrestrial and aquatic nature reserves (*in-situ* conservation)	Captive breeding programmes of zoological and botanical gardens and seed banks (*ex-situ* conservation)
Habitats that are already rare are especially vulnerable to natural disaster – rare habitats themselves are easily lost, if a range of examples are not preserved as nature reserves.	Originally, zoos were collections of unfamiliar animals kept for curiosity, with little concern for any stress caused to the animals. Today, captive breeding programmes make good use of these resources.
When a habitat disappears the whole community is lost, threatening to increase total numbers of endangered species.	Captive breeding maintains the genetic stock of rare and endangered species.
A refuge for endangered wildlife allows these species to lead natural lives in a familiar environment for which they are adapted. They are also able to fit into their normal food chains.	The genetic problems arising from individual zoos having very limited numbers to act as parents is overcome by cooperation between zoos (and artificial insemination in some cases).
The biota of a reserve may be monitored for early warning of any further deterioration in numbers of a threatened species, so that remedial steps can be taken.	Animals in zoos tend to have significantly longer life-expectancies, and are available to participate in breeding programmes for much longer than wild animals.
The offspring of endangered species are nurtured in their natural environment and gain all the experiences this normally brings, including the acquisition of skills from parents and peers around them.	Captive breeding programmes, for most species, have been highly successful. However, the young do not grow up in the wild, so there is less opportunity to observe and learn from parents and peers.
There is an established tradition of maintaining reserves and protected areas in various parts of the world, so there is much experience to share on how to manage them successfully.	Captive breeding programmes generate healthy individuals in good numbers for attempts at re-introduction to natural habitats, a particularly challenging process, given that natural predators abound in these locations.
Nature reserves are popular sites for the public to visit (in approved ways), thereby maintaining public awareness of the environmental crisis due to extinctions, and individual responsibilities that arise from it.	Zoos and botanical gardens are accessible sites for the public to visit (often sited in urban settings where many may have access), contributing effectively to public education on the environmental crisis.
Reserves are ideal venues to return endangered individuals to (the products of intensive breeding programmes) as they provide realistic conditions for re-adaptation to habitat, and progress can be monitored.	Seed banks are a convenient and efficient way of maintaining genetic material of endangered plants, with similarities to the ways seeds may survive long periods in nature.

Table 19.3 *In-situ* and *ex-situ* conservation of endangered species

■ Population ecology

Population ecology is concerned with the study of factors influencing the numbers and structure of a population. Three aspects are considered here: reproduction strategies in relation to habitat and environment; a method used by ecologists to estimate population size in mobile animal species in the wild; and finally an applied aspect of population in the issue of fish stock sizes in the face of commercial fishing practices.

Reproduction in an ecological context – r-strategies and K-strategies

Some species reproduce themselves **rapidly**, and they produce **large numbers of offspring**. We say they demonstrate high fertility, and they have a short generation time. Ecologists define these organisms as having an opportunistic way of life. Typically, such species are **pioneer organisms** – they move into new habitats, breed early, and often **achieve rapid colonisation**. Migration and dispersal are important to their survival, their mortality rates are high but their **lifespans are short**. Species adopting this distinctive reproductive strategy and life style are called **r-species**.

Can you identify an animal and a plant found in habitats near you, your home or school or college, that show many of the features of r-species?

On the other hand, there are many species that reproduce **slowly** and have a **long lifespan**. These species are seen to move into habitats that are settled and stable. Once established, they **compete successfully for the resources**. Population numbers of these organisms are more or less **constant** – ecologists say they occur at the **carrying capacity** for the habitat (where carrying capacity is defined as the maximum number of individuals of a particular species that can be supported indefinitely by a given part of the environment). Species with this type of life cycle are called **K-species**.

Perhaps these strategies (r-strategy and K-strategy) are two possible extremes of evolutionary strategy?

How representative are they of most organisms' life styles?

Before answering this question, look at Table 19.4, where the profiles of species employing r-strategy and K-strategy are compared in the context of the characteristics of the likely environments that favour each.

r-strategy species	Characteristic	K-strategy species
variable; frequently new or changed by environmental crisis (e.g. fire) in which they are 'pioneer' organisms	**favoured environment**	stable and settled habitats, typically with a fairly wide and varied range of established species
reproduce early and often, producing many offspring	**rate of reproduction**	reproduce slowly, producing few offspring
very variable, but often well below the maximum that a habitat will support	**size of population**	typically small; significant time and effort is invested in rearing young
emigration and recolonisation are common events	**tendencies for emigration and immigration**	typically settled, stable communities – individuals unlikely to move on
short	**lifespan**	long
typically poor competitors	**response to competition**	typically strong competitors
often high and variable	**mortality rate and survival qualities**	often low and typically regular

Table 19.4 r-strategies and K-strategies compared in context

r-strategy and K-strategy as extremes?

When biologists attempt to compare possible examples of organisms which display r- and K-strategies, agreements are not always easily achieved.

If we take the case of human populations, for example, it seems to depend on circumstances. In countries in developed parts of the world, many, if not most, humans conform as K-species. However, in less developed parts, many families exhibit several r-species characteristics. It seems that ecological disruption favours r-strategies.

Can you think of examples? Does this seem true to you?

There are some organisms that do conform to one or other of these strategies – after all, parasites and pests (and many weed species) certainly exhibit r-strategies.

However, it is probable that most organisms have life histories that are to varying degrees intermediate between these two extreme situations. And some organisms switch strategies depending on environmental conditions – for example, the vinegar fly, *Drosophila*, and perhaps also humans.

Techniques for estimating population size

We have already noted that an important step in the study of populations is the collection of accurate information on the size of populations present in a habitat.

A total count of all the members of a population is called a **census**, and would give us the most accurate data. However, the taking of a census is normally impractical. This may be because of the size of the habitat, or because of the quick movements of many animals, or because of species that are only active at dusk or after dark.

The capture, **mark, release and recapture (MRR)** technique, also known as the Lincoln index, is a practical method of estimating population size (N) of mobile animals, such as small mammals, woodlice, or insects that can be captured and marked with a ring, tag, or dab of coloured paint or nail varnish.

For the first sample caught for marking (n_1), it is essential to use a method of marking that is totally resistant to removal by moisture or the deliberate actions of the animals. It must also be a method that does no harm to the captured animals. For example, they must not be more visible and therefore more vulnerable to predation than normal. It is essential to trap relatively large samples if the results are to be significant.

The method then requires that marked individuals, on their release, are free to distribute themselves randomly in the whole population. After randomisation has occurred, a second sample is caught (n_2), some of which will be from the first sample (n_3), recognised by their marking. The size of the population is estimated by the formula:

$$N = n_1 \times n_2 / n_3$$

MRR may be demonstrated on populations of woodlice discovered sheltering under stones and flower pots, etc. in an area of a garden or woodland. Alternatively, it can be demonstrated on populations of night-flying moths caught with light traps, or on populations of small mammals trapped in Longworth small mammal traps (provided sufficient traps are available).

Prior to experimenting on natural populations, the technique can be learned and understood by application to non-living models. Possible models include beans dispersed in sawdust or a population of dried peas in a hessian bag. Here, samples are taken by hand, the sampler being effectively blindfolded as they cannot see the individual beans or peas. These trials enable the accuracy of the MRR method to be tested because the actual population size of beans or dried peas is easily known. It will quickly be evident that the sizes of samples captured determine the accuracy of the technique; small samples may give wildly inaccurate estimates. The steps of the MRR technique are outlined in Figure 19.33.

Figure 19.33 Estimating animal populations using mark, release and recapture

a population of woodlice

random sample captured

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

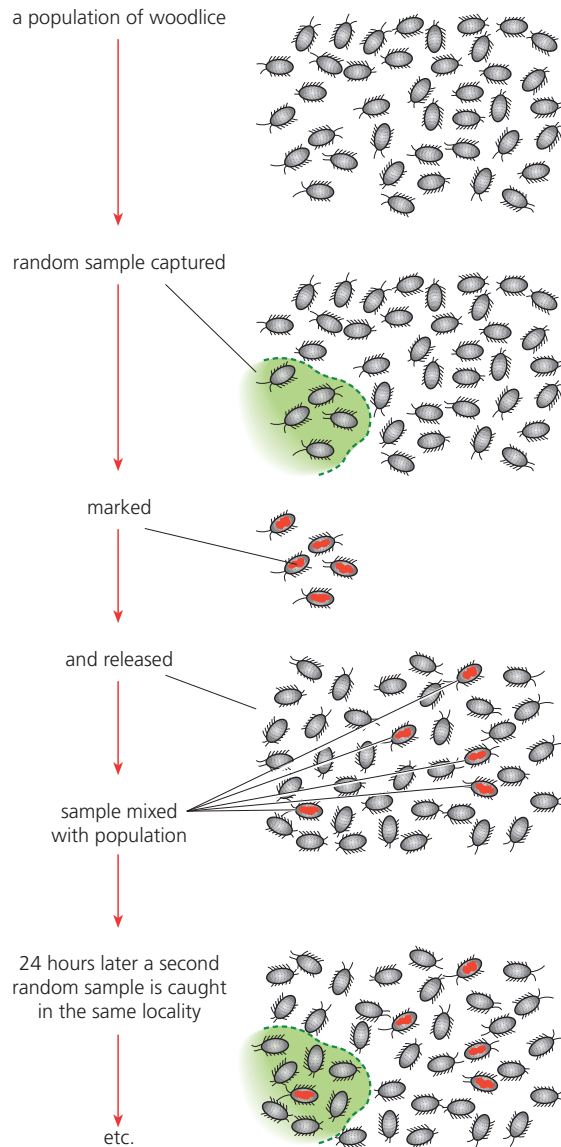$$N = n_1 \times n_2 / n_3$$

where

N = the population being estimated

n_1 = number captured, marked and released

n_2 = total number captured on the second occasion

n_3 = number of marked individuals recaptured

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

marked

and released

sample mixed with population

24 hours later a second random sample is caught in the same locality

etc.

14 Using MRR, relatively large samples must be caught for significant results. **Calculate** the estimated size of the population in Figure 19.33 if the second sample had included two marked woodlice, not one.

15 As a new habitat was colonised, the size of a population of the common rough woodlouse *Porcellio scaber* was investigated by mark, release and recapture, with the following result.

Day	1/2	15/16	30/31	45/46	60/61	75/76
Captured, marked and released (n_1)	7	14	25	19	15	19
Captured in the second sampling (n_2)	6	12	24	16	9	14
Marked individuals recaptured (n_3)	2	2	3	2	1	2

a **Calculate** the size of the population at days 2, 16, 31, 46, 61 and 76.

b **Plot** a graph of estimated population size against time.

c **Annotate** your graph as fully as you are able.

Fishing and commercial fish stocks

Fish are an important source of food for many human populations. The majority of fish populations that are exploited commercially as food sources are marine species, and it is commonly the case that the populations are shared among a number of harvesting countries. Fishery vessels from many nations take their harvest, and over-fishing is increasingly a problem (Figure 19.34). Conflict between economic and conservation interests arises – demand for the harvest of the seas and the need for economic returns for fishermen have to be balanced with our obvious need to sustain the resources themselves. In fact, the scale of commercial fishing in the seas around Western Europe in recent years has seriously depleted many stocks.

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

The **maximum sustainable yield (MSY)** of a stock represents the maximum average catch that a stock can sustain over a long period of time. This catch corresponds to optimum balance between the reproductive rate and growth rate of the stock and the deaths due to harvesting and natural mortality. Typically, harvesting at MSY requires much lower fishing rates than occur in many fisheries.
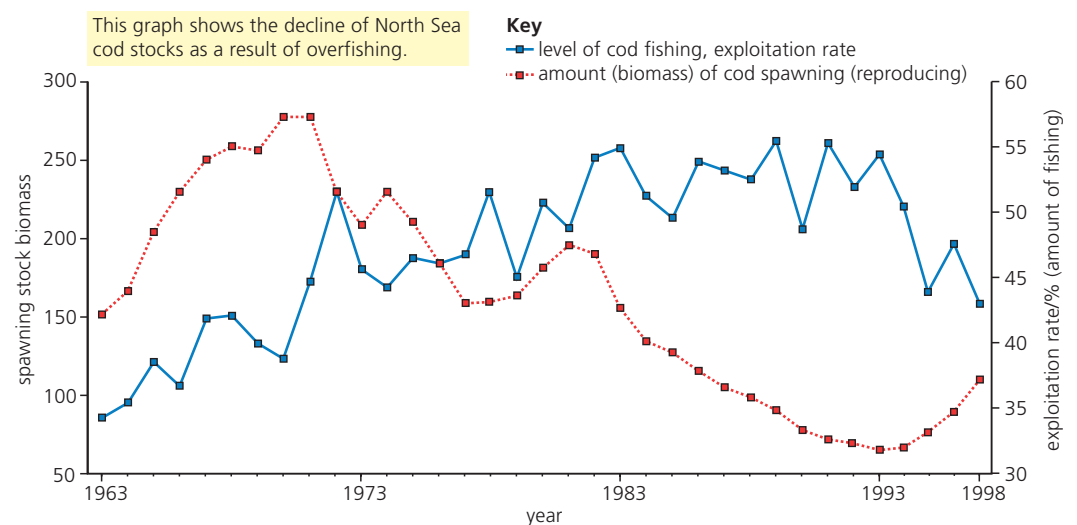
Calculation of MSY requires good knowledge of the relationship between the size of the stock and the number of juveniles produced each year. The natural variation in the number of juveniles produced annually makes establishing this relationship difficult. It usually requires a very long series of data – at least 20 years. Nevertheless, there are reliable methods that provide an adequate approximation to MSY.

Estimating the size of commercial fish stocks

Information on the state of fish stocks is based on four parameters which are measured or assessed by the fishery research services of national governments. These are:

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

Figure 19.34 Over-fishing in European waters

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

Key
- level of cod fishing, exploitation rate
- amount (biomass) of cod spawning (reproducing)

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

How do marine fishery research scientists obtain this information?
Every year, teams of marine scientists collect data via three routes:

1 **Market sampling**, in which the landings of fish are sampled to compile information on fish length and age. Fish are aged by examination of the ear otolith, taken from the head of the animal. These consist of layers of bone which are added annually, in light and dark bands. The age is obtained by counting the number of bands (like counting tree rings in the trunks of trees).

  Data from many samples allow the age structure of the whole population to be estimated. Year by year, a picture of how the population is changing in the face of the fishing demands emerges. For example, if there are very few old fish in the stock, then over-fishing is likely as the figures indicate that survival rate is very low and few fish mature to breed.

2 **Discard sampling**, in which the mass of fish caught and then discarded is measured. Many fish caught at sea are discarded, for example, because they have no commercial value, or because they are below the legal minimum landing size, or because quota limits have been exceeded.

  These data are combined with landings data to give a more complete picture of the total catch from the stocks.

3 **Research vessel surveys**, in which distribution and abundance of adult stocks and of recruits are investigated. Surface species (such as herrings) are assessed by acoustic surveys which use sonar equipment to detect fish and convert the signal into a biomass estimate.

  Bottom-dwelling species (such as cod and haddock) are monitored by trawling surveys where the number of fish caught per hour gives an index of abundance.

With these data to hand, ecological computer models are used to create a picture of the total biomass of living fish across the whole area studied, and of the trend in any changes detected, year by year.

International measures to promote the conservation of fish

Because the scale of fishing in the seas around Western Europe has been so intensive as to over-exploit the resource, fishing nations have implemented a wide variety of control measures, including bans on fishing of certain species. Where these measures are respected, breeding stocks have recovered.

  Currently, the European Union is regulating fishing around the shores of member states and in adjacent seas by a number of enforced measures.

1 **Total allowable catches (TACs) and quotas**
  TACs – figures for the overall weight of fish which fishing boats can land – are agreed by member states annually. This is based on advice from scientists in the International Council for the Exploitation of the Sea (ICES) on levels of catch if breeding stocks are to be sustained. The TACs for each type of fish harvested are then divided between member states. **Each state receives a quota for individual fish stocks**, reflecting levels of dependence on fishing.

2 **Technical conservation (TC)**
  TC measures provide a further line of protection for breeding stocks. These are rules that aim to make fishing itself more selective and so reduce the discarding of young fish. These measures:
 a set **minimum landing sizes** for different species of fish to discourage the catch of small fish;
  b require the use of **specific mesh sizes** in some circumstances so that small fish can escape;
  c require the use of **separator devices** as an integral part of the gear to prevent the catch of more vulnerable stocks;
  d restrict the type of fishing gear that may be used in certain localities;
  e close down some areas to certain types of fishing, either permanently, or for a part of the year.

Meanwhile, funding is maintained for national marine biology stations to carry out the necessary research to gain a clear picture of the ecology of the fishing grounds and of the key stages in life cycles of organisms that make up the relevant food chains.

■ *Examination questions – a selection*

Questions 1–4 are taken from past IB Diploma biology papers.

Q1 A study was conducted to investigate the growth factors affecting plants in urban areas compared to rural areas. Fast-growing clones of Eastern cottonwood trees (*Populus deltoides*) were grown in both urban and rural sites. The results of three successive growing seasons (X, Y and Z) are shown below.

Key
LI and HV are rural sites

NY is an urban site
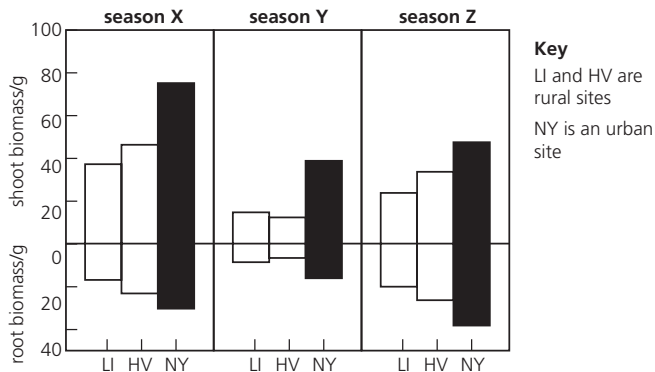
a Identify the site which most favours the growth of cottonwood trees. (1)

b Calculate the ratio of shoot biomass to root biomass in site L1 during season X. (1)

c Analyse the data for growth patterns over three years of the study. (3)

A further study showed that differences in light, temperature, water, CO_2 concentration, and the soil could not account for the differences in growth of the cottonwoods in the urban and rural areas.

d Suggest a reason which could account for the growth differences. (1)

Higher Level Paper 3, May 05, QG1

Q2 a Define the term *biomass*. (1)

b State **two** organisms that interact together by mutualism. (1)

c Explain why the biomass at higher trophic levels tends to be small. (3)

Standard Level Paper 3, November 05, QG2

Q3 a Describe the use of *ex situ* conservation measures. (3)

b i Define the term *niche*. (1)

ii Explain the niche concept using named organisms. (4)

Standard Level Paper 3, November 04, QG3

Q4 a Simpson's Index is given by the following equation:

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

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

i State what happens to this index if the number of all species found increases but the number of individuals in a species stays the same. (1)

ii State what a high value of D suggests about an ecosystem. (1)

b Explain the use of biotic indices in monitoring environmental changes. (3)

Standard Level Paper 3, November 03, QG3

Questions 5–10 cover other syllabus issues in this chapter.

Q5 a Outline the effects of **three** environmental factors that affect the distribution of plants. (6)

b Explain how:
i temperature   **ii** water supply
may effect animal distribution. (6)

c Discuss the special value of transects in analysing the distribution within a **named** community of organisms that continually experiences the impact of unidirectional abiotic factors. (8)

Q6 a Outline the difference between a *primary succession* and a *secondary succession*, using **named** examples. (6)

b Distinguish between the ecological concepts of *biosphere* and *biome*. (4)

c Compare the main features of a *tropical rainforest* and a *temperate deciduous forest*, by means of a table. (6)

Q7 Evaluate **three** reasons in support of our striving to maintain species diversity in the face of increasing extinctions, today. (9)

Q8 a Describe how the *ozone layer* in the stratosphere is created and maintained. (6)

b Explain the importance of the ozone layer for terrestrial organisms. (3)

Q9 a Discuss the ecological significance of r- and K-strategies in an ecological context. (6)

b Suggest how you might classify human communities in terms of r- and K-strategies. (4)

Q10 a Describe **one** technique used to estimate animal population size. (4)

b Outline the methods used to estimate the size of commercial fish stocks in marine waters. (4)

c Explain what international measures might best promote the conservation of marine fish stocks. (4)