11

Biogeography

'The Earth's green cover is a prerequisite for the rest of life. Plants alone, through the alchemy of photosynthesis, can use sunlight energy, and convert it to the chemical energy animals need for survival.'

James Lovelock, *The Gaia Atlas of Planet Management*, 1985

Biogeography may be defined as the study of the distribution of plants and animals over the Earth's surface. The biogeographer is interested in describing and explaining meaningful patterns of plant and animal distributions in a given area, either at a particular time or through a time-period.

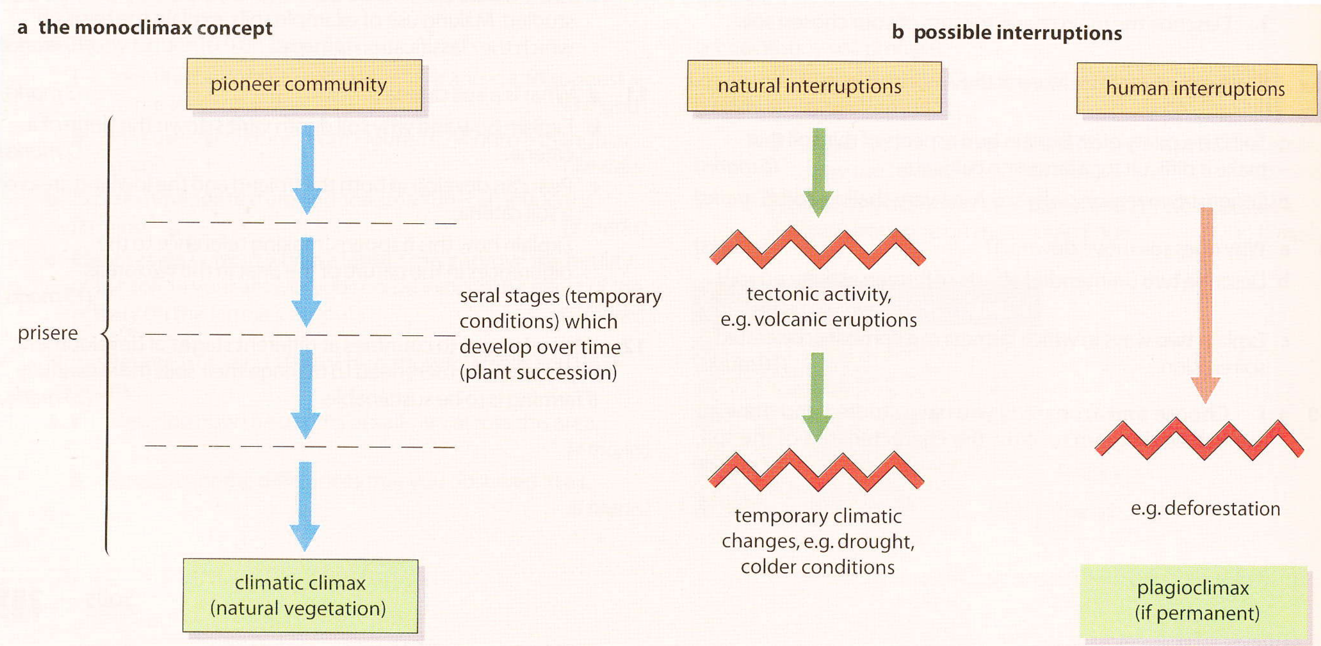
Seres and climax vegetation

A **sere** is a stage in a sequence of events by which the vegetation of an area develops over a period of time. The first plants to colonise an area and develop in it are called the **pioneer community** (or **species**). A **prisere** is the complete chain of successive seres beginning with a pioneer community and ending with a **climax vegetation** (Figure 11.1a). F.E. Clements suggested, in 1916, that for each climatic zone only one type of climax vegetation could evolve. He referred to this as the **climatic climax vegetation**, now known as the **monoclimax concept**. The climatic climax occurs when the vegetation is in harmony or equilibrium with the local environment, i.e. when the natural vegetation has reached a delicate but stable balance with the climate and soils of an area (Chapter 12). Each successive seral community usually shows an increase in the number of species and the height of the plants, an increase in carbon storage and enhanced biogeochemical cycling and soil formation.

Each individual sere is referred to by one or more of the larger species within that community – the so-called **dominant species**. The dominant species may be the **largest** plant or tree in the community which exerts the maximum influence on the local environment or habitat, or the most **numerous** species in the community. In parts of the world where the climatic climax is forest – i.e. areas with higher rainfall – the plant community tends to be structured in layers (Figures 11.2 and 12.4). It can take several thousand years to reach a climatic climax. Communities are, however, relatively ephemeral on timescales of millennia. When climatic change does occur, temperature and/or precipitation alterations often only affect individual species rather than changing the community as a whole. This concept, the 'individualistic concept of plant association', was originated by H.A. Gleason in 1928. In recent years this has become widely accepted as a result of the analysis of pollen taken from lake sediments and peats (page 294).

Figure 11.1

A seral progression, with possible interruptions



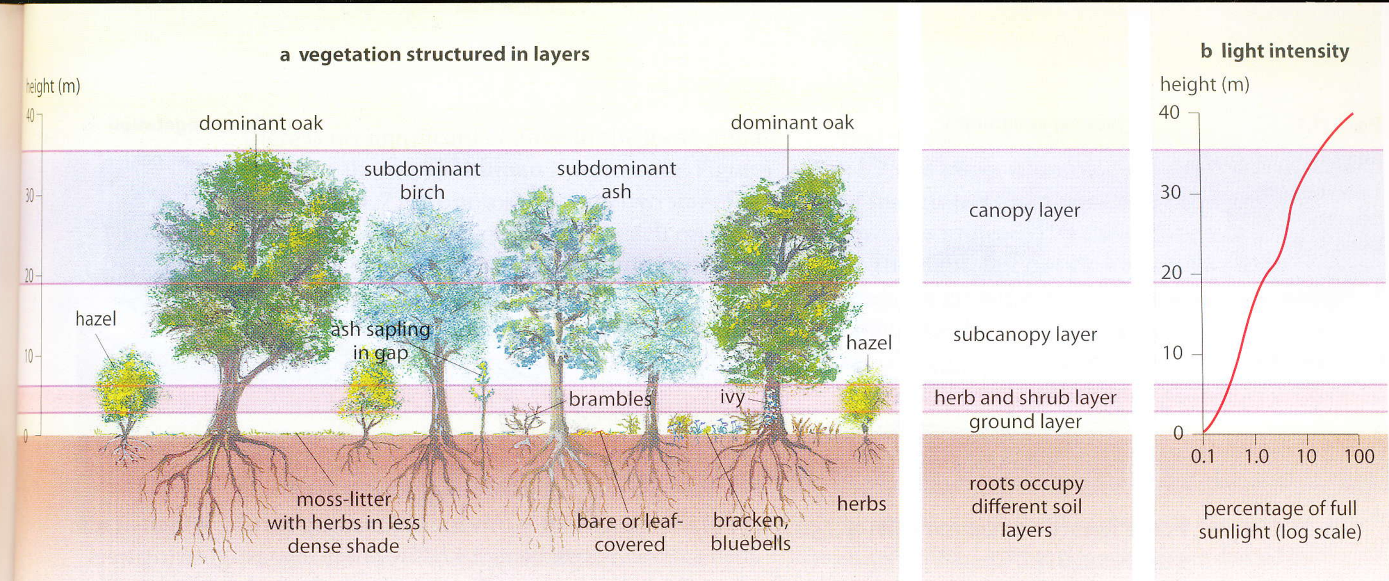


Figure 11.2

Vegetation structure and light intensity typical of a temperate deciduous woodland (*after* O'Hare)

There are, however, very few parts of today's world with a climatic climax. This is partly because few physical environments remain stable sufficiently long for the climax to be reached: most are affected by tectonic or temporary climatic changes (an area becomes warmer, colder, wetter or drier). More recently, however, instability has resulted from such human activities as deforestation, the ploughing of grassland, and acid rain. Where human activity has permanently arrested and altered the natural succession and the ensuing vegetation is maintained through management, the resultant community is said to be a **plagioclimax** (Figure 11.1b) – examples of which include heather moorlands in Britain, and the temperate grasslands (page 326).

While it is still accepted that climate exerts a major influence upon vegetation, the linear monoclimax concept has been replaced by the **polyclimax theory**. This theory acknowledges the importance not only of climate, but of several (poly) local factors including drainage, parent rock, relief, microclimate and source of plants. The polyclimax theory, therefore, relates the climax vegetation to a variety of factors. Figure 11.3 shows how the climax vegetation may result from a **primary** or a **secondary succession**. A primary succession occurs on a new or previously unvegetated land surface, or in water. Figure 11.4 shows how the four more commonly accepted non-vegetated environments in Britain develop until they all reach the same climax vegetation: the oak woodland. A secondary succession is more likely to occur on land on which the previous management has been discontinued, e.g. abandoned farmland due to shifting cultivation in the tropical rainforest (Places 66, page 480). A **subclimax** occurs when the vegetation is prevented from reaching its climax due to interruptions by local factors such as soils and human interference.

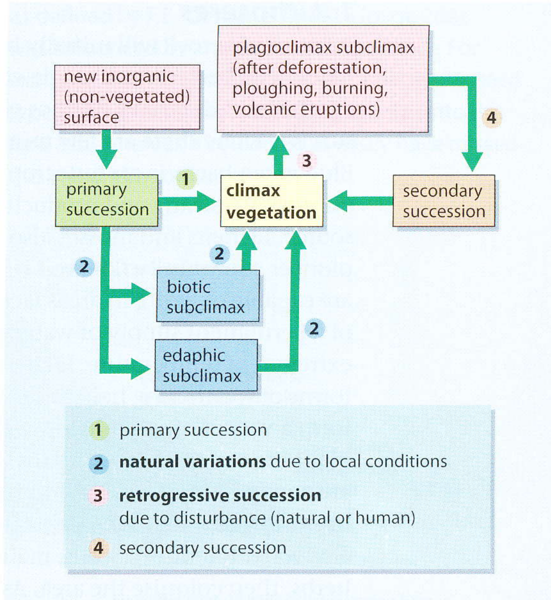


Figure 11.3

The polyclimax theory

Figure 11.4

Primary successions

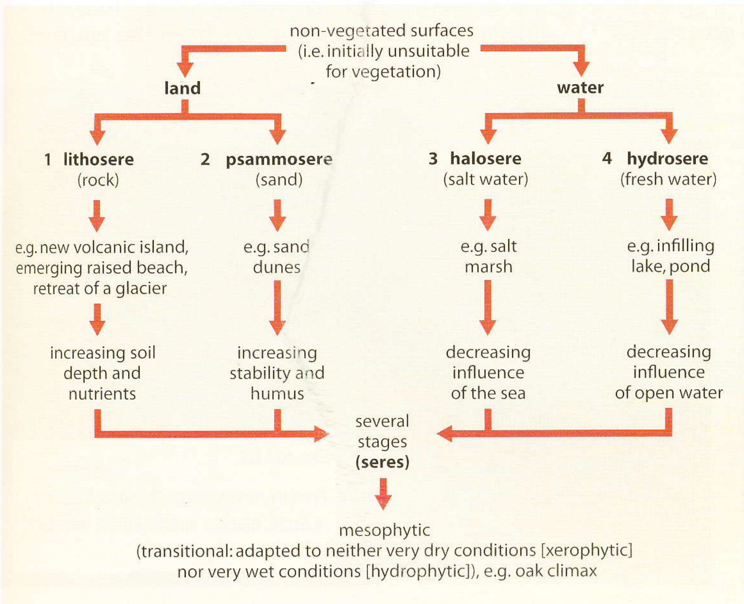
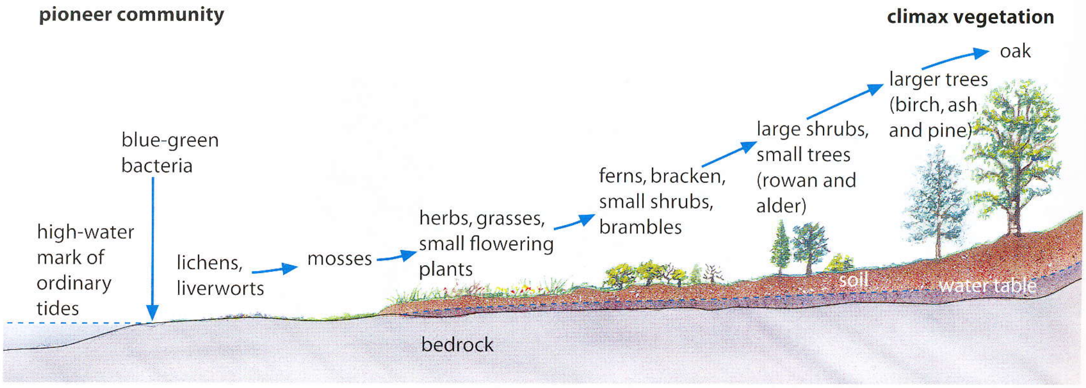


Figure 11.5

Fieldsketch of a lithosere on a newly emerging rocky coastline (raised beach), Arran



Four basic seres forming a primary succession

1 Lithoseres

Areas of bare rock will initially be colonised by blue-green bacteria and single-celled photosynthesisers that have no root system and can survive where there are few mineral nutrients. Blue-green bacteria are autotrophs (page 296), photosynthesising and producing their own food source. Lichens and mosses also make up the pioneer community (Figure 11.5). These plants are capable of living in areas lacking soil, devoid of a permanent supply of water and experiencing extremes of temperature. Lichen and various forms of weathering help to break up the rock to form a veneer of soil in which more advanced plant life can then grow. As these plants die, they are converted by bacteria into humus which helps in the development of increasingly richer soils and aids water retention. Seeds, mainly of grasses and herbs, then colonise the area. As these plants are taller than the pioneer species, they will replace the lichen and mosses as the dominants, although the lichens and mosses will still continue to grow in the community. As the plant succession evolves over a period of time, the grasses will give way as dominants to fast-growing shrubs, which in turn will be replaced by relatively fast-growing trees (rowan). These will eventually face competition from slower-growing trees (ash) and, finally, the oak which forms the climax vegetation. It should be noted that although each stage of the succession is marked by a new dominant, many of the earlier species continue to grow there, although some are shaded out.

Figure 11.5 shows an idealised primary succession across a newly emerging rocky coastline. It excludes the increasing number of species found at each stage of the seral succession. The species are determined by local differences in rainfall, temperature and sunlight, bedrock and soil type, aspect and relief. Lithoseres can develop on bare rock exposed by a retreating glacier (page 294), on ash or lava following a volcanic eruption on land (Krakatoa, Places 35) or forming a new island (Surtsey, Places 3, page 16), or, as in Figure 11.5, on land emerging from the sea as a result of isostatic uplift following the melting of an icecap (page 163).

Over time, the area shown to have the pioneer community passes through several stages until the climatic climax is reached – assuming that the land continues to emerge from the sea, that

Figure 11.6

Primary succession on a lithosere on the Isle of Arran: lichens, mosses and grasses on a rocky coastline

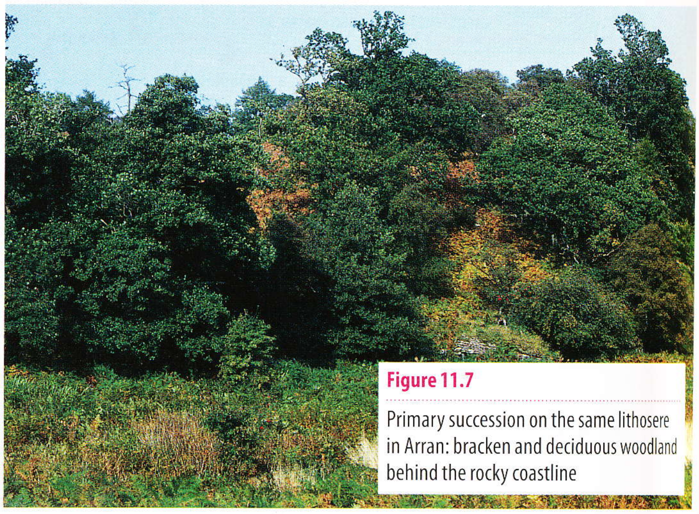


Figure 11.7

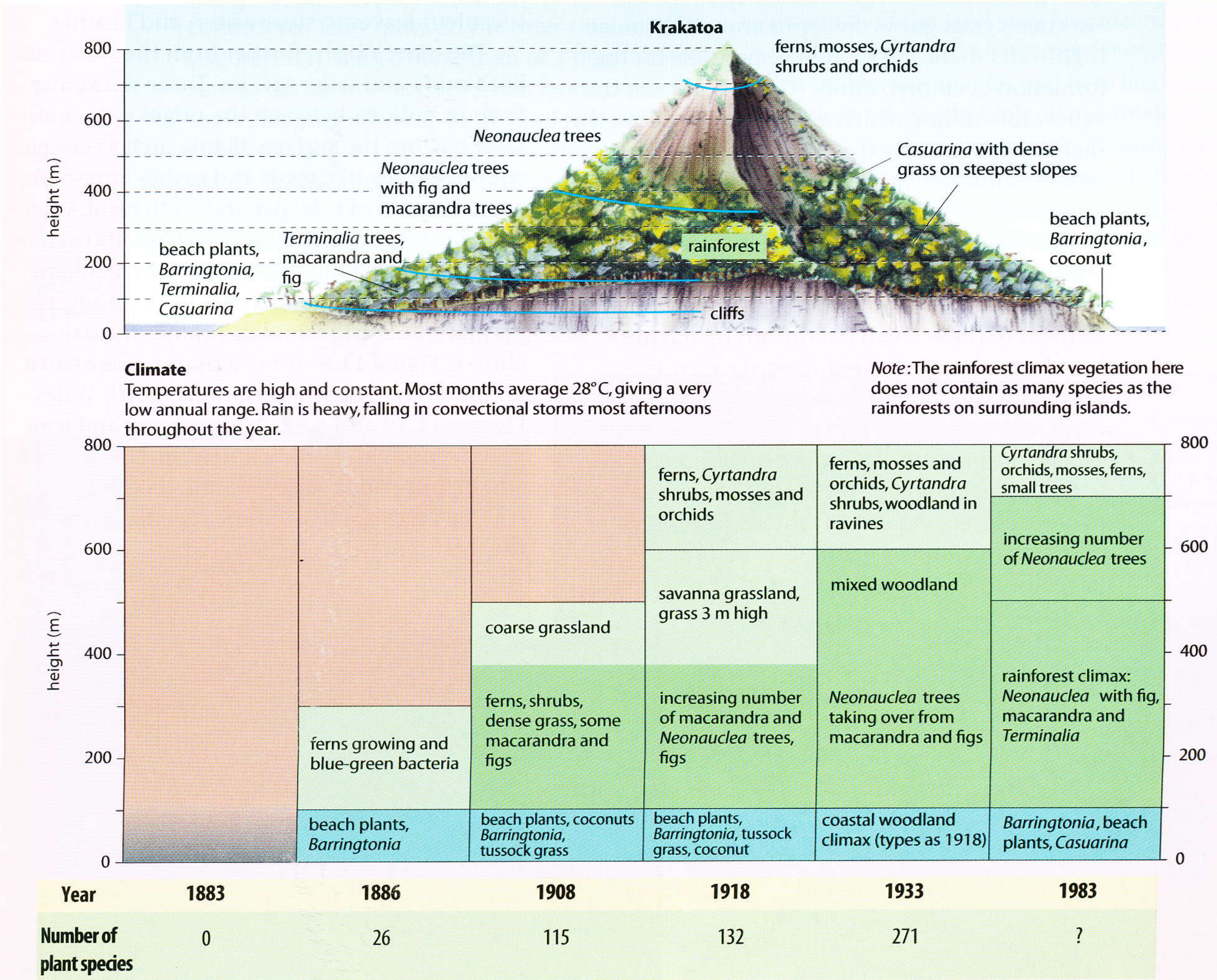
Primary succession on the same lithosere in Arran: bracken and deciduous woodland behind the rocky coastline there is no significant change in the local climate, and that there is no human interference. Figures 11.6 and 11.7 are photos showing two stages in the succession, taken on a raised beach on the east coast of Arran. Figure 11.6 shows lichen, favouring a south-facing aspect on gently dipping rocks, and mosses, growing in darker north-facing hollows. Beyond, where soil has begun to form and where the water table is high, grasses and bog myrtle have entered the succession. Figure 11.7 was taken where the soil depth and amount of humus have increased and the water table is lower, as indicated by the presence of bracken. To the right, but not clearly visible on the photo, reeds are growing in a hollow where the water table is nearer to the surface. In the middle distance are small deciduous trees with, behind them, taller oaks indicating a climax vegetation.

Places 35 Krakatoa: a lithosere

In August 1883, a series of volcanic eruptions reduced the island of Krakatoa to one-third of its previous size and left a layer of ash over 50 m deep. No vegetation or animal life was left on the island or in the surrounding sea. Yet within three years (Figure 11.8), 26 species had reappeared and, in 1933, 271 plant and 720 insect species, together with several reptiles, were recorded. The first recolonisers arrived in three ways. Most were seeds blown from surrounding islands by the wind, while others drifted in from the sea or were carried by birds. However, on Krakatoa the plant succession, as defined by F.E. Clements in 1916 (page 286), was influenced by another variable: chance. For example, a piece of driftwood with a particular seed type just happened to be washed ashore onto the new ash, whereas it could just as easily have missed the island altogether.

Figure 11.8

Primary succession, Krakatoa: vegetation distribution according to height above sea-level, 1983



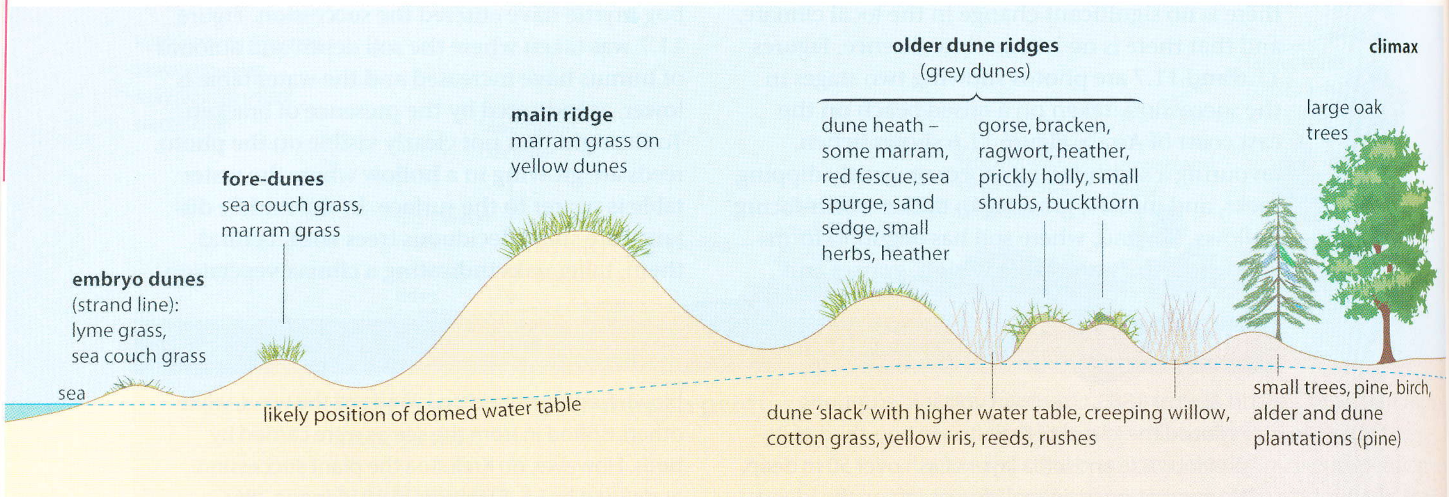


Figure 11.9

Transect across sand dunes to show a psammosere, Morfa Harlech, north Wales

2 Psammoseres

A psammosere succession develops on sand and is best illustrated by taking a transect across coastal dunes (Figure 11.9). The first plants to colonise, indeed to initiate dune formation, are usually lyme grass, sea couch grass and marram grass. Sea couch grass grows on berms around the tidal high-water mark and is often responsible for the formation of embryo dunes (Figure 6.31). On the yellow fore-dunes, which are arid, being above the highest of tides and experiencing rapid percolation by rainwater, marram grass becomes equally important.

The main dune ridge, which is extremely arid and exposed to wind, is likely to be vegetated exclusively by marram grass. Marram has adapted to these harsh conditions by having leaves that can fold to reduce surface area, which are shiny and which can be aligned to the wind direction: three factors capable of limiting evapotranspiration. Marram also has long roots to tap underground water supplies and is able to grow upwards as fast as sand deposition can cover it. Grey dunes, behind the main ridge, have lost their supply of sand and are sheltered from the prevailing wind. Their greater humus content, from the decomposition of earlier marram grass, enables the soil to hold more moisture. Although marram is still present, it faces increasing competition from small flowering plants and herbs such as sea spurge (with succulent leaves to store water) and heather.

The older ridges, further from the water, have both more and taller species. Dune slacks may form in hollows between the ridges if the water table reaches the surface. Plants such as creeping willow, yellow iris, reeds and rushes and shrubs are indicators of a deeper and wetter soil. On the landward side of the dunes, perhaps 400 m from the beach, are small deciduous trees including ash and hawthorn and, as the soil is sandy, pine plantations. Furthest inland comes the oak climax. Figure 11.9 shows a psammosere based on sand dunes at Morfa Harlech, north Wales. Figures 11.10 and 6.32 show marram and lyme grass forming the yellow fore-dunes, with gorse and heather on the greyer dunes behind. Figures 11.11 and 6.33 show vegetation on the inland ridges.

Figure 11.10

Primary succession on a psammosere: colonisation of fore-dunes, Winterton, Norfolk (compare Figures 6.32 and 6.33)

Figure 11.11

Primary succession on a psammosere: vegetation on a grey dune ridge and on a dune slack, Braunton Burrows, Devon

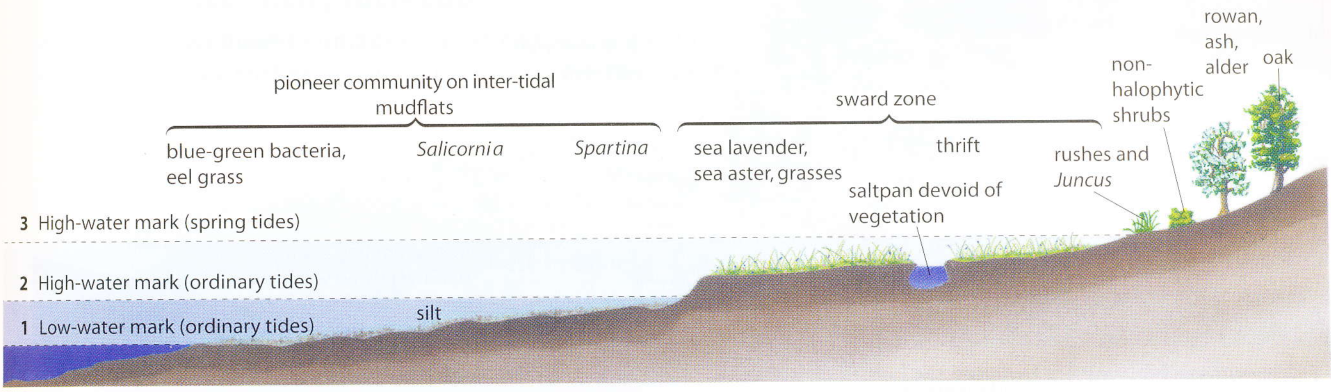


Figure 11.12

Transect showing a primary succession in a halosere, Llanrhidian Marsh, Gower Peninsula, south Wales

3 Haloseres

In river estuaries, large amounts of silt are deposited by the ebbing tide and inflowing rivers. The earliest plant colonisers are green algae and eel grass which can tolerate submergence by the tide for most of the 12-hour cycle and which trap mud, causing it to accumulate. Two other colonisers are *Salicornia* and *Spartina* which are **halophytes** – i.e. plants that can tolerate saline conditions. They grow on the inter-tidal mudflats (Figure 6.34), with a maximum of 4 hours' exposure to the air in every 12 hours. *Spartina* has long roots enabling it to trap more mud than the initial colonisers of algae and *Salicornia*, and so, in most places, it has become the dominant vegetation. The inter-tidal flats receive new sediment daily, are waterlogged to the exclusion of oxygen, and have a high pH value.

The sward zone (page 158), in contrast, is inhabited by plants that can only tolerate a maximum of 4 hours' submergence in every 12 hours. Here the dominant species are sea lavender, sea aster and grasses, including the 'bowling green turf' of the Solway Firth. However, although the vegetation here tends to form a thick mat, it is not continuous. Hollows may remain where the seawater becomes trapped leaving, after evaporation, saltpans in which the salinity is too great for plants (Figure 11.13). As the tide ebbs, water draining off the land may be concentrated into creeks (Figure 6.35). The upper sward zone is only covered by spring tides and here *Juncus* and other rushes grow. Further inland, non-halophytic grasses and shrubs enter the succession, to be followed by small trees and ultimately by the climax oak vegetation. Figure 11.12 is a transect based on the saltmarshes on the north coast of the Gower Peninsula in south Wales. Figure 11.14 shows several stages in the halosere succession.

Figure 11.13

Primary succession in a halosere: a saltpan on the Suffolk coast, covered only by the highest of tides

Figure 11.14

Primary succession in a halosere: Blakeney Point, Norfolk

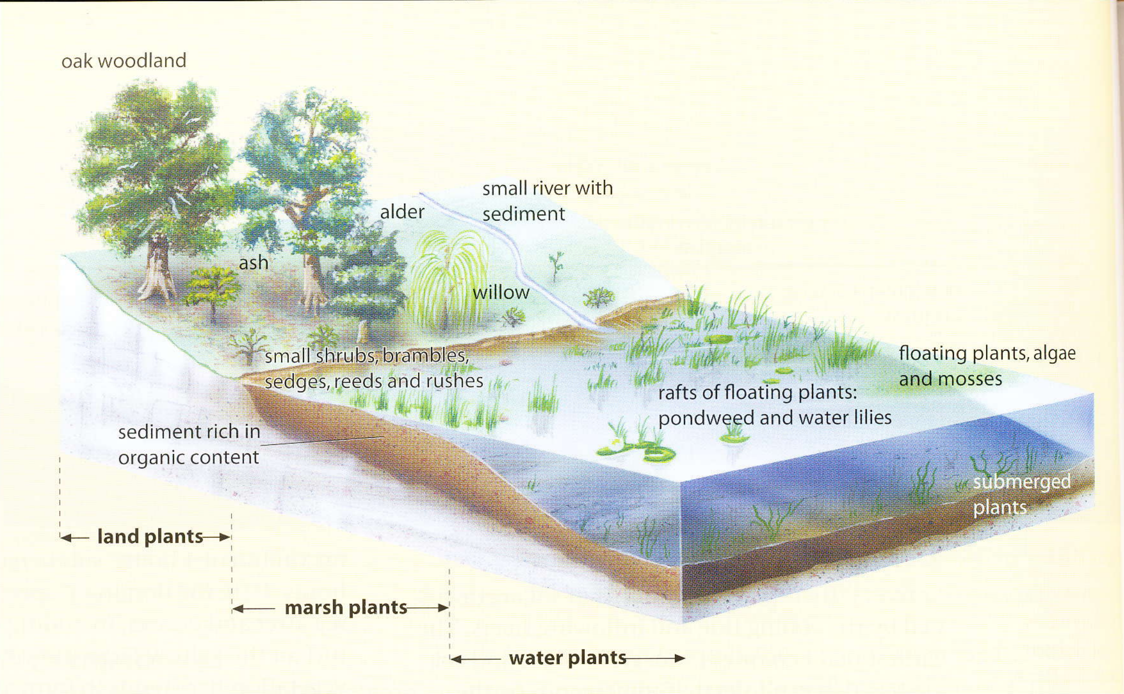


Figure 11.15

Idealised primary succession in a hydrosere

Figure 11.16

Primary succession in a hydrosere at the head of a reservoir in Cumbria

4 *Hydroseres*

Lakes and ponds originate as clear water which contains few plant nutrients. Any sediment carried into the lake will enrich its water with nutrients and begin to infill it. The earliest colonisers will probably be algae and mosses whose spores have been blown onto the water surface by the wind. These grow to form vegetation rafts which provide a habitat for bacteria and insects. Next will be water-loving plants which may either grow on the surface, e.g. water lilies and pondweed, or be totally submerged (Figure 11.15). Bacteria recycle the nutrients from the pioneer community, and marsh plants such as bulrushes, sedges and reeds begin to encroach into the lake. As these marsh plants grow outwards into the lake and further sediment builds upwards at the expense of the water, small shrubs and trees will take root forming a marshy thicket. In time, the lake is likely to contract in size, to become deoxygenised by the decaying vegetation and eventually to disappear and be replaced by the oak climax vegetation. This primary succession is shown in Figure 11.15. Figure 11.16 shows land plants encroaching at the head of a reservoir, while Figure 11.17 illustrates the water, marsh and land plant succession in and around a small lake.

Incidentally, it is not necessary to be an expert botanist to recognise the plants named in these primary successions; you just need a good plant recognition book!

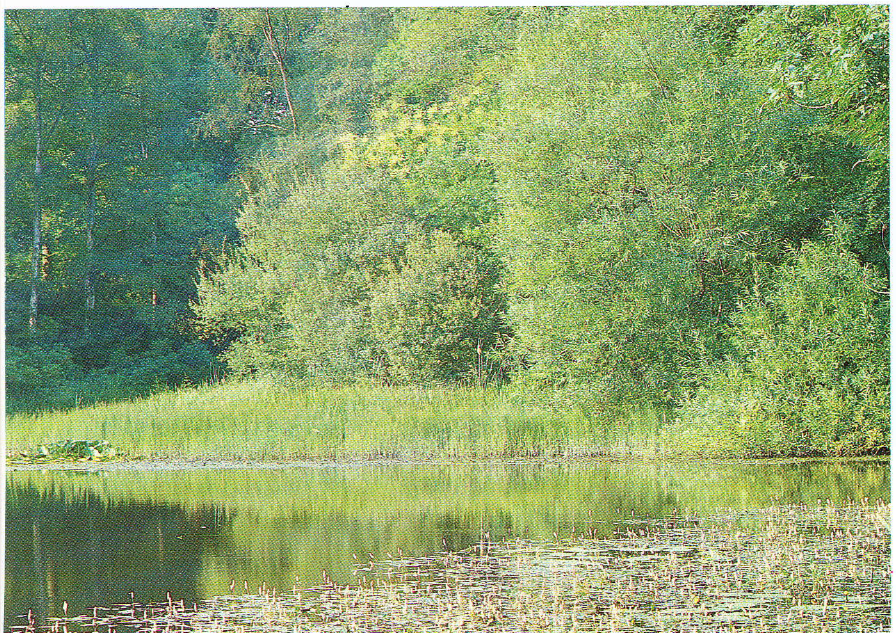


Figure 11.17

Primary succession in a small lake, Sussex

Secondary succession

A climatic climax occurs when there is stability in transfers of material and energy in the ecosystem (page 295) between the plant cover and the physical environment. However, there are several factors that can arrest the plant succession before it has achieved this dynamic equilibrium, or which may alter the climax after it has been reached. These include:

- a mudflow or landslide (Places 36)
- deforestation or afforestation
- overgrazing by animals or the ploughing-up of grasslands
- burning grasslands, moorlands, forests and heaths
- draining wetlands
- disease (e.g. Dutch elm), and
- changes in climate (page 286).

Places 36 Arran: secondary plant succession

The mudflow shown in Figure 2.16 occurred in October 1981 and completely covered all the existing vegetation. Twelve months later it was estimated that 20 per cent of the flow had been recolonised, a figure that had grown to 40 per cent in 1984 and 70 per cent in 1988. Had this been a primary succession, lichens and mosses would have formed the pioneer community and they would probably have covered only a small area. The pioneer plants would probably also have been randomly distributed and, even after seven years, the species would have been few in number and small in height.

Instead, by 1988, much of the flow had already been recolonised. It could be seen that most of the plants were found near the edges of the flow and were not randomly distributed, and there were already several species including grasses, heather, bog myrtle and mosses, some of which exceeded 50 cm in height.

These observations suggest a secondary succession with plants from the surrounding climax community having invaded the flow, mainly due to the dispersal of their seeds by the wind.

The effect of fire

The severity of a fire and its effect on the ecosystem depend largely upon the climatic conditions at the time. The fire is likely to be hottest in dry weather and, in the northern hemisphere, on sunny south-facing slopes where the vegetation is driest. The spread of a fire is fastest when the wind is strong and blowing uphill and where there is a build-up of combustible material. The extent of disruption also depends upon the type and the state of the vegetation. The following is a list of examples, in rank order of severity.

1. Areas with a Mediterranean climate, where the chaparral of California and the maquis/ garrigue of southern Europe are densest and tinder-dry in late summer after the seasonal drought. Since 2005, major bush fires, which are occurring more often, have threatened Sydney in Australia, Olympia (site of the first Olympics) in Greece, parts of the south of France and, in California, Los Angeles (Case Study 15A). In early 2009, over 200 people lost their lives in bushfires, in the Australian state of Victoria.
2. Coniferous forests where the leaf litter burns readily.
3. Ungrazed grasslands and, especially, the savannas, which have a low biomass but a thick litter layer (Figure 11.28). **Biomass** is the total mass of living organisms present in a community at any given time, expressed in terms of oven-dry weight (mass) per unit area.
4. Intensively grazed grasslands in semi-arid areas which have a lower biomass and a limited litter layer.
5. Deciduous woodlands which, despite the presence of a thick litter layer, are often slow to burn.

Following a fire, the blackened soil has a lower albedo and absorbs heat more readily and, without its protective vegetation cover, the soil is more vulnerable to erosion. Ash initially increases considerably the quantity of inorganic nutrients in the soil and bacterial activity is accelerated. Any seedlings left in the soil will grow rapidly as there is now plenty of light, no smothering layer of leaf litter, plenty of nutrients, a warmer soil and, at first, less competition from other species. Heaths and moors that have been fired are conspicuous by their greener, more vigorous growth. A fire climax community, known as **pyrophytic** vegetation, contains plants with seeds which have a thick protective coat and which may germinate because of the heat of the fire. The community may have a high proportion of species that can sprout quickly after the fire – plants that are protected by thick, insulating bark (cork oak in the chaparral (page 324) and baobab in the savannas (Figure 12.14)), or which have underground tubers or rhizomes insulated by the soil. It has been suggested that the grasslands of the American Prairies and the African savannas are not climatic climax vegetation, but are the result of firing by indigenous Indian and African tribes (Case Study 12).

Vegetation changes in the Holocene

The Holocene is the most recent of the geological periods (Figures 1.1 and 11.18). The last glacial advance in Britain ended about 18 000 years ago. Although the extreme south of England remained covered with hardy tundra plants, most of northern Britain was left as bare rock or glacial till. Had the climate gradually and constantly ameliorated, a primary succession would have taken place, from south to north, as previously described for a lithosere. It has been established that there have been several major fluctuations in climate during those 18 000 years which have resulted in significant changes in the climax vegetation (Figure 11.18).

There are several techniques that help to determine vegetation change: pollen analysis, dendrochronology, radio-carbon dating, and historical evidence (page 248). Families of plants have the same pollen grain in terms of its shape and pattern. Where pollen is blown by the wind onto peat bogs, such as at Tregaron in west Wales, the grains are trapped by the peat. As more peat accumulates over the years, the pollen of successively later times indicates which were the dominant and subdominant plants of the period (Figures 11.18 and 11.19). As each plant grows best within certain defined temperature and precipitation limits, it is possible to determine when the climate either improved (ameliorated) or deteriorated. Dendrochronology – dating by means of the annual growth-rings of trees – has shown that the bristlecone pine of California can be dated back some 5000 years, while European dendrochronology, based on bog oaks in Ireland and Germany, extends back some 10 000 years. Radio-carbon dating is based on changing amounts of radioactivity in the atmosphere and in plants. Notice in Figure 11.18, which links climatic and vegetation changes, how forests increase as the climate ameliorates, and how heathland and peat moors take over when the climate deteriorates.

Figure 11.19

Changes in the surface of lowland England, Wales and Scotland over the last 12 000 years (*after* Wilkinson)

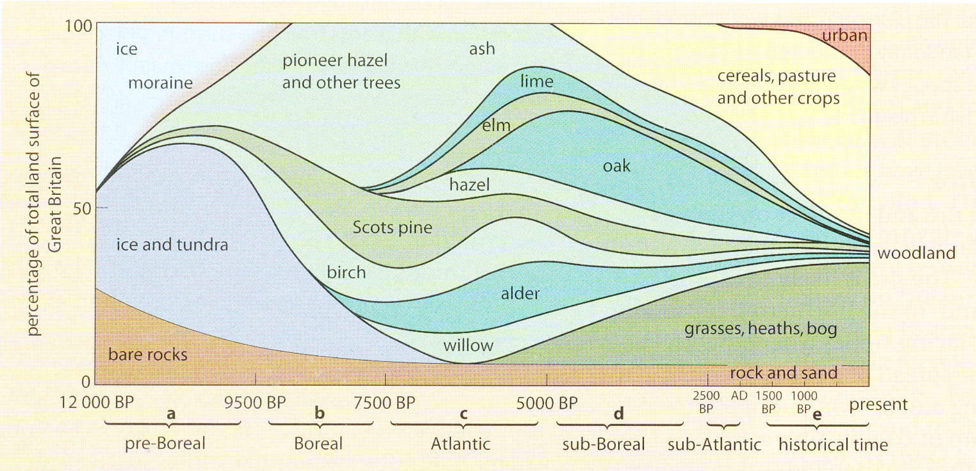


Figure 11.18

Climatic and vegetation change in Britain since the Holocene (BP = Before Present)

Date BP	Phase/period	Climate	Vegetation	Cultures
pre-17 000	final glaciation	glacial	none in northern Britain; tundra in southern England	none
17 000–14 000	periglacial	cold, 6°C in summer	tundra	Palaeolithic
14 000–12 000	Allerød	warming slowly to 12°C in summer	tundra with hardy trees, e.g. willow and birch	Palaeolithic
12 000–10 000	pre-Boreal	glacial advance: colder, 4°C in summer	Arctic/Alpine plants, tundra	Mesolithic
10 000–8000	Boreal	continental: winters colder and drier, summers warmer than today	forests: juniper first then pine and birch and finally oak, elm and lime	Mesolithic
8000–5000	Atlantic	maritime: warm summers, 20°C; mild winters, 5°C; wet	our 'optimum' climate and vegetation: oak, alder, hazel, elm and lime (too cold for lime today); peat on moors	beginning of Neolithic; first deforestation about 3500 BC
5 000–2500	sub-Boreal	continental: warmer and drier	elm and lime declined; birch flourished; peat bogs dried out	Neolithic period, settled agriculture; beginning of Bronze Age
2500–2000	sub-Atlantic	maritime: cooler, stormy and wet	peat bogs re-formed; decline in forests due to climate and farming	settled agriculture
2000–1000	historical times	improvement: warmer and drier	clearances for farming	Roman occupation during early part
1000–450		decline: much cooler and wetter	further clearances: little climax vegetation left; medieval farming	
450–300		'little ice age': colder than today		
post-300–present		gradual improvement	recently some afforestation: coniferous trees	Agrarian and Industrial Revolutions

Ecology and ecosystems

The term **ecology**, which comes from the Greek word *oikos* meaning 'home', refers to the study of the interrelationships between organisms and their habitats. An organism's home or **habitat** lies in the biosphere, i.e. the surface zone of the Earth and its adjacent atmosphere in which all organic life exists. The scale of each home varies from small **micro-habitats**, such as under a stone or a leaf, to **biomes**, which include tropical rainforests and deserts (Figure 11.20). Fundamental to the four ecological units listed in Figure 11.20 is the concept of the **environment**. The environment is a collective term to include all the conditions in which an organism lives. It can be divided into:

1 the physical, non-living or **abiotic environment**, which includes temperature, water, light, humidity, wind, carbon dioxide, oxygen, pH, rocks and nutrients in the soil, and
2 the living or **biotic environment**, which comprises all organisms: plants, animals, humans, bacteria and fungi.

The ecosystem

An ecosystem is a natural unit in which the life-cycles of plants, animals and other organisms are linked to each other and to the non-living constituents of the environment to form a natural system (Framework 3, page 45). The **community** consists of all the different species within a habitat or ecosystem. The **population** comprises all the individuals of a particular species in a habitat.

An ecosystem depends on two basic processes: **energy flows** and **material cycling**. As the flow of energy is only in one direction and because it crosses the system boundaries, this aspect of the ecosystem behaves as an **open** system. Nutrients, which are constantly recycled for future use, are circulated in a series of **closed** systems.

1 Energy flows

The sun is the primary source of energy for all living things on Earth. As energy is retained only briefly in the biosphere before being returned to space, ecosystems have to rely upon a continual supply. The sun provides *heat energy* which cannot be captured by plants or animals but which warms up the communities and their non-living surroundings. The sun is also a source of *light energy* which can be captured by green plants and transformed into chemical energy through the process of **photosynthesis**. Without photosynthesis, there would be no life on Earth. Light, chlorophyll, warmth, water and carbon dioxide are required for this process to operate. Carbon dioxide, which is absorbed through stomata in the leaves of higher plants, reacts indirectly with water taken up by the roots when temperatures are suitably high, to form carbohydrate. The energy needed for this comes from sunlight which is 'trapped' by chlorophyll. Oxygen is a by-product of the process. The carbohydrate is then available as food for the plant.

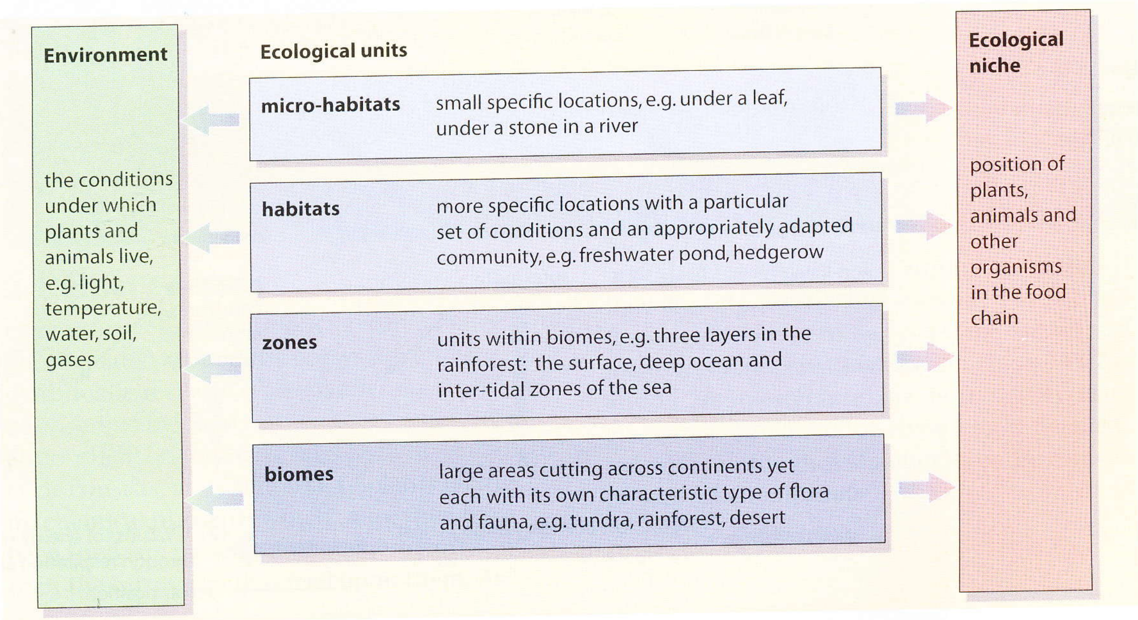


Figure 11.20

A hierarchical structure of ecological units

Food chains and trophic levels

A food chain arises when energy, trapped in the carbon compounds initially produced by plants through photosynthesis, is transferred through an ecosystem. Each link in the chain feeds on and obtains energy from the one preceding it, and in turn is consumed by and provides energy for the following link (Figure 11.21).

Figure 11.21

Three examples of food chains through four trophic levels

Level 1	Level 2	Level 3	Level 4
grass	worm	blackbird	hawk
leaf	caterpillar	shrew	badger
phytoplankton	zooplankton	fish	human

There are usually, but not always, four links in the chain. Each link or stage is known as a **trophic** or **energy level** (Figure 11.22). In order for the first link in the chain to develop, the non-living environment has to receive both energy from the sun and the other factors (water, CO_2, etc.) needed for photosynthesis.

The **first trophic level** is occupied by the **producers** or **autotrophs** ('self-feeders') which include green plants capable of producing their own food by photosynthesis. All other levels are occupied by **consumers** or **heterotrophs** ('other-feeders'). These include animals that obtain their energy either by eating green plants directly or by eating animals that have previously eaten green plants. The **second trophic level** is where **herbivores**, the primary consumers, eat the producers. The **third trophic level** is where smaller **carnivores** (meat-eaters) act as secondary consumers feeding upon the herbivores. The **fourth trophic level** is occupied by the larger carnivores, the tertiary consumers. Also known as **omnivores** (or diversivores), this group – which includes humans – eat both plants and animals and so have two sources of food. Figure 11.22 shows the main trophic or feeding levels in a food chain. **Detritivores**, such as bacteria and fungi, are consumers that operate at all trophic levels.

Figure 11.22

Trophic levels

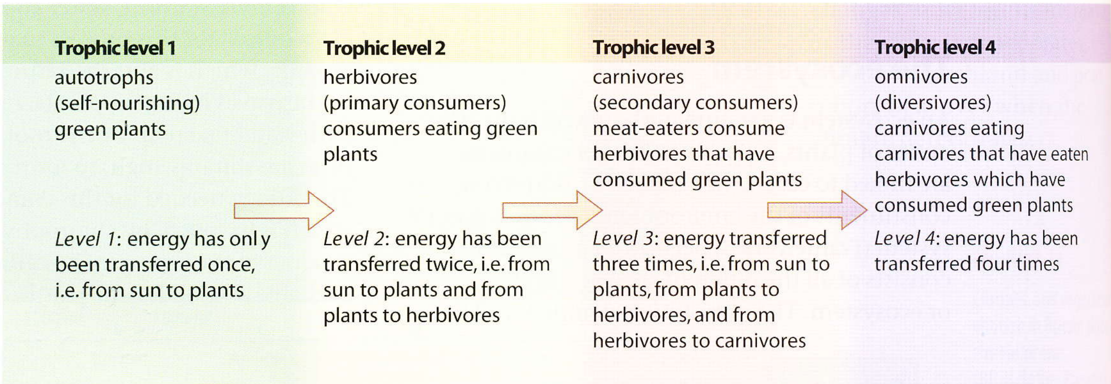
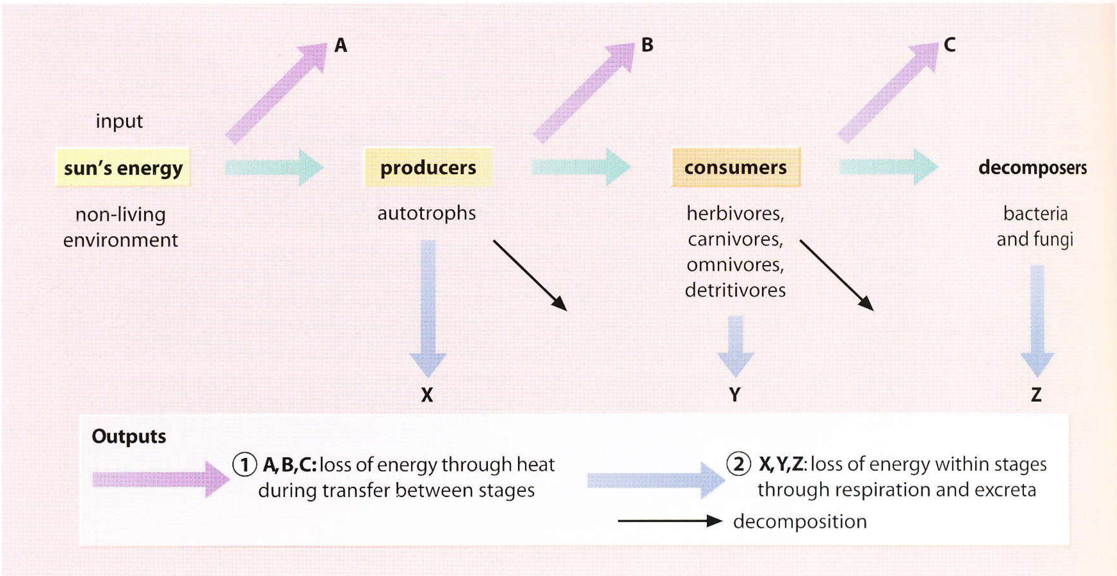


Figure 11.23

Energy flows in the ecosystem

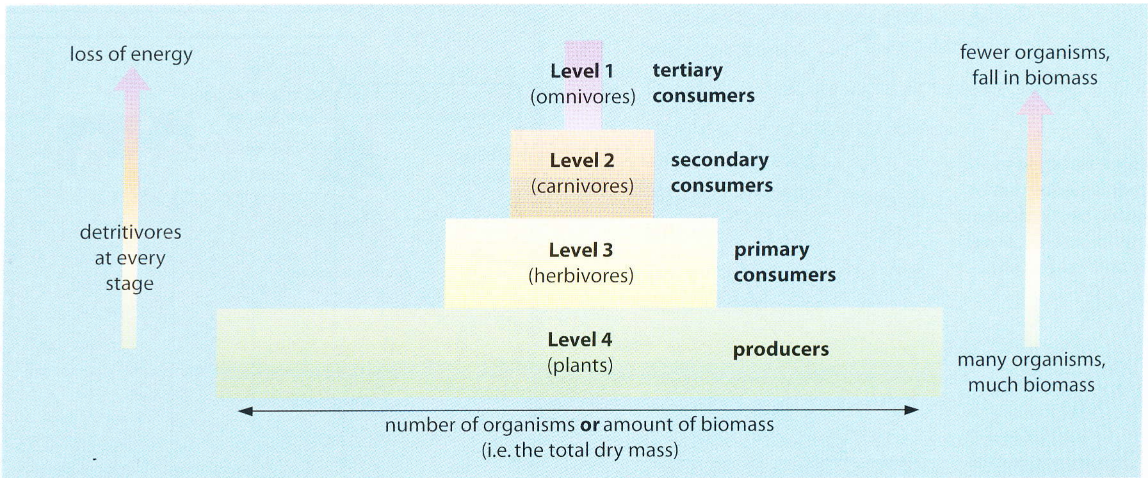


However, no transfer of energy is 100 per cent efficient and, as Figure 11.23 shows, energy is lost through respiration, by the decay of dead organisms and in excreta within each unit of the food chain, and also as heat given off when energy is passed from one trophic level to the next. Consequently, at each higher level, fewer organisms can be supported than at the previous level, even though their individual size generally increases. Simple food chains are rare; there is usually a variety of plants and animals at each level forming a more complicated **food web**. This range of species is necessary since a sole species occupying a particular trophic level in a simple food chain could be 'consumed' and this would adversely affect the organisms in the succeeding stages.

The progressive loss of energy through the food chain imposes a natural limit on the total mass of living matter (the **biomass**) and on the number of organisms that can exist at each level. It is convenient to show these changes in the form of a pyramid (Figure 11.24). A pyramid of organism numbers is of limited value for comparing ecosystems for two reasons. First, it is difficult to count the numbers of grasses or algae per unit area. Secondly, it does not take into account the relative sizes of organisms – a bacterium would count the same as a whale! A pyramid of biomass takes into account the difference in size between organisms, but cannot be used to compare masses at different trophic levels in the same ecosystem or at similar trophic levels in different ecosystems. This is because biomass will have accumulated over different periods of time.

Humans are found at the end of a food chain and human population is dependent upon the length of the chain (and therefore the amount of energy lost). In other words, in a shorter food chain, less energy will have been lost by the time it reaches humans and so the land can support a higher density of population. In a longer food chain, more energy will have been lost by the time the food is consumed by humans, which means that the carrying capacity (page 378) is lower and fewer people can be supported by a given area of land – as in western Europe, where most of the population are accustomed to animal products as well as crops.

Figure 11.24
The trophic pyramid

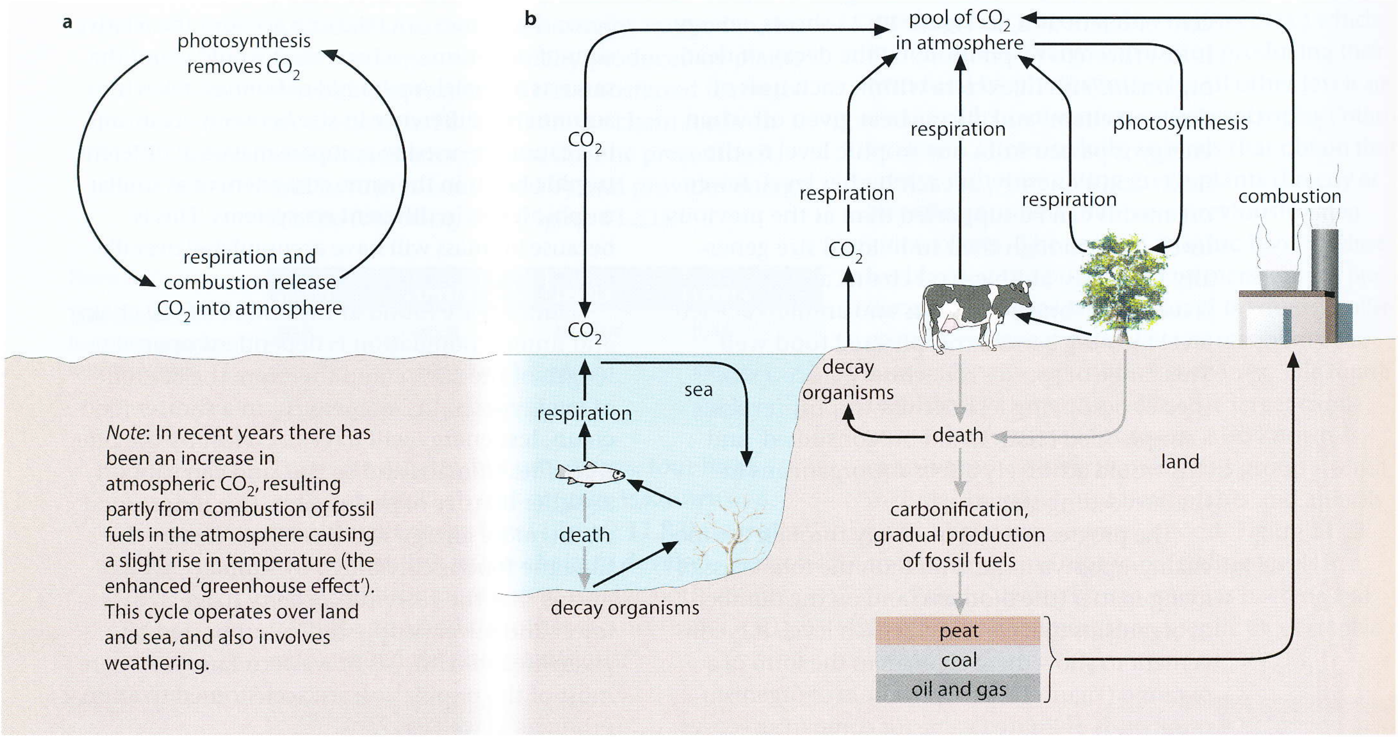


2 Nutrient cycling

Chemicals needed to produce organic material are circulated around the ecosystem and are continually recycled. Various chemicals can be absorbed by plants either as gases from the atmosphere or as soluble salts from the soil. Each cycle consists, at its simplest, of plants taking up chemical nutrients which, once they have been used, are passed on to the herbivores and then the carnivores that feed upon them. As organisms at each of these trophic levels die, they decompose and nutrients are returned to the system. Two of these cycles, the carbon and nitrogen cycles, are illustrated in Figures 11.25 and 11.26. In each case, the most basic cycle is given (diagram **a**); followed by a more detailed example, although still not in its entire complexity (diagram **b**).

Figure 11.25

The carbon cycle (*after* M.B.V. Roberts)



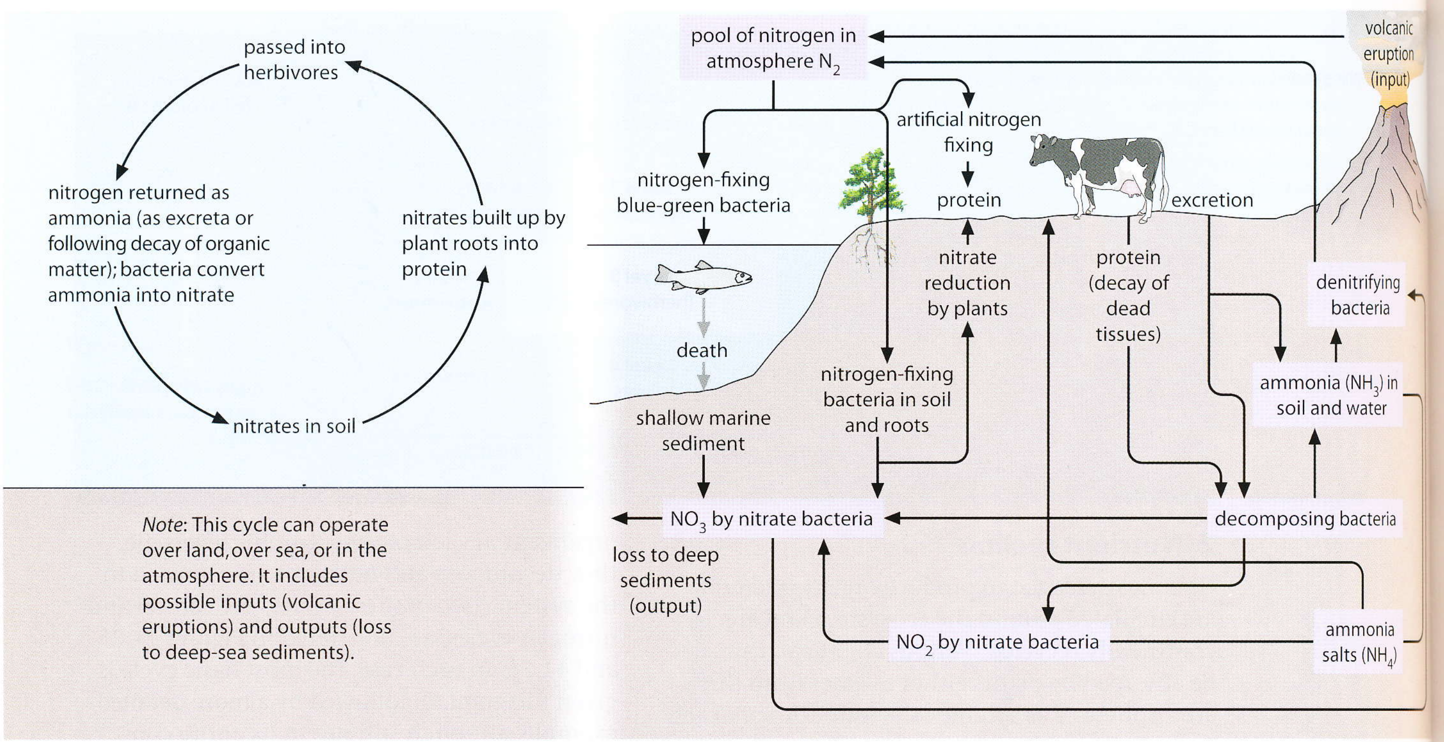


Figure 11.26

The nitrogen cycle (*after* M.B.V. Roberts)

Recent investigations, mainly in New Zealand and the Andes, have shown that nitrogen from seawater, or released by plants and animals as they die on the seabed, can be channelled upwards, together with magma, at subduction (destructive) plate margins. The nitrogen can later be released back into the atmosphere, either as water or as a gas, through volcanic eruptions. Once in the atmosphere, the nitrogen can return to Earth and the sea in rainwater – so completing another nitrogen cycle.

Framework 10 Scientific enquiry: hypothesis

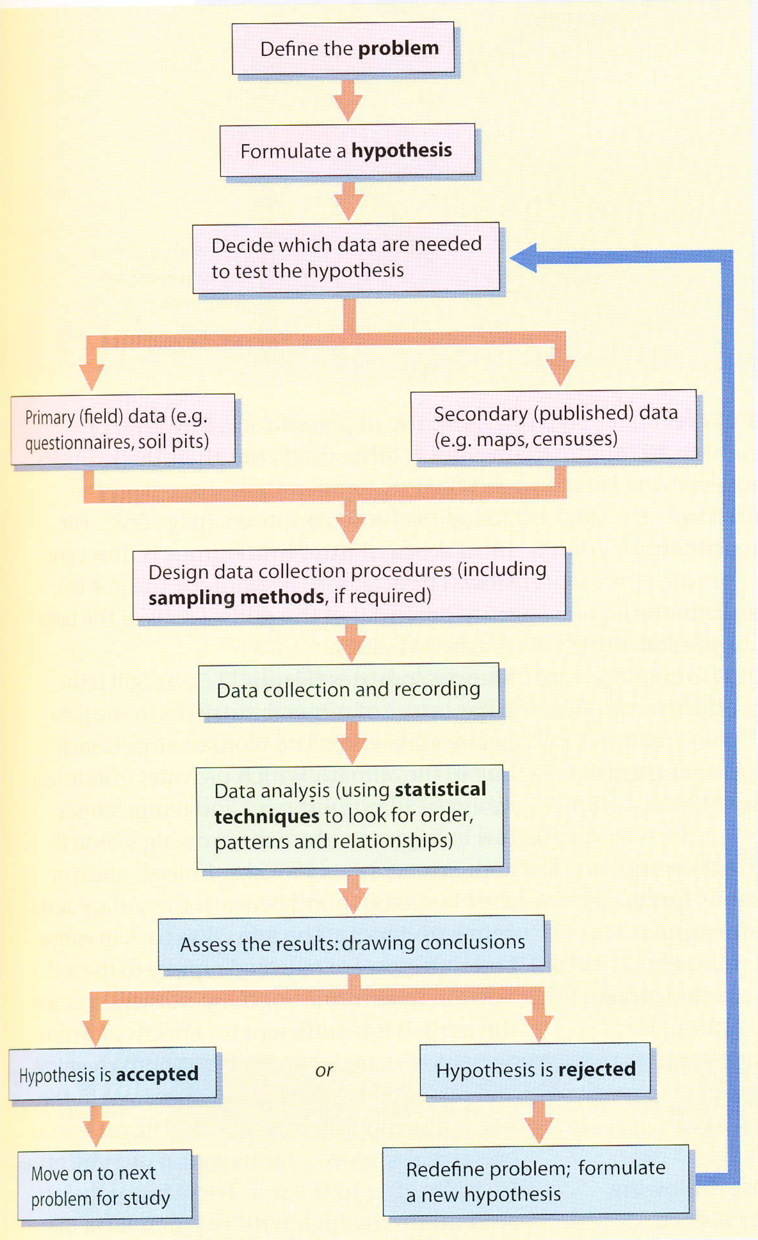
Since the 1960s, geographers have felt an increasing need to adopt a more scientific approach to their studies. This stemmed from a number of changes that were taking place in attitudes to the study of geography and to science in a broader sense:

- The increasing scale and complexity of the subject's material and the data available.
- The rapid development of theory, often using computer modelling, from which predictions could be made.
- The realisation that, despite great care, all human observers have their own, subjective, opinions which influence an assessment or conclusion (i.e. scientific objectivity could not be guaranteed).

The scientific approach to geography involves a series of logical steps, already practised in the physical sciences, which enabled conclusions to be drawn from precise and unbiased data (Framework 8, page 246). This approach is summarised in the flow diagram (Figure 11.27).

Figure 11.27

Hypothesis testing



During a sixth-form field week on the Isle of Arran, one day was set aside for hypothesis testing. This involved seeking possible relationships between several variables on Goatfell (Figure 11.37). The hypotheses included:

- Vegetation density decreases as altitude increases.
- Soil acidity increases as altitude increases.
- Soil acidity increases as the angle of slope increases.
- Soil moisture increases as the angle of slope increases.
- Depth of soil increases as altitude decreases.
- Height of vegetation increases as altitude decreases.
- Number of species increases as altitude increases.
- Soil temperature increases as altitude decreases.

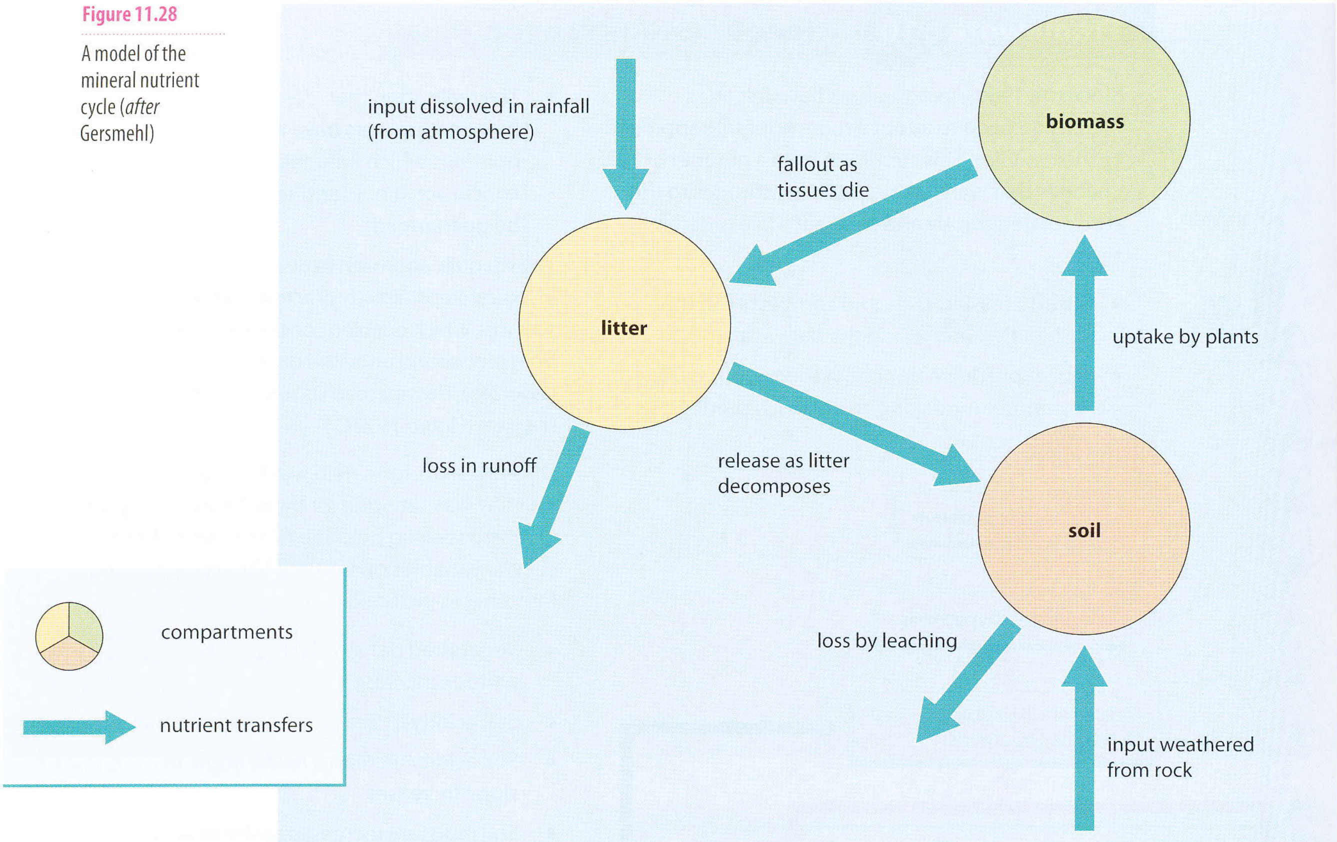
Data collection required the taking of readings at a minimum of 15 sites from sea-level to the top of Goatfell. It is important that the selection of sites is made without introducing bias (see Framework 6, page 159).

Data analysis may include drawing a scattergraph to investigate the possibility of any correlation between the two variables; calculating the strength of the relationship between the variables by using the Spearman's rank correlation coefficient (Framework 19, page 613); and then testing the result to see how likely it is that the correlation occurred by chance (page 614).

It should then be possible to determine whether the original hypothesis is acceptable as an explanation of the data, or not. If it is rejected, then a new hypothesis should be formulated.

Figure 11.28

A model of the mineral nutrient cycle (*after* Gersmehl)



Model of the mineral nutrient cycle

This model, developed by P.F. Gersmehl in 1976, attempts to show the differences between ecosystems in terms of nutrients stored in, and transferred between, three compartments (Figure 11.28):

1 **Litter** – the total amount of organic matter, including humus and leaf litter, in the soil (it is, therefore, more than just the *L* or litter layer as shown in the soil profile in Figure 10.5).

2 **Biomass** – the total mass of living organisms, mainly plant tissue, per unit area.

3 **Soil**.

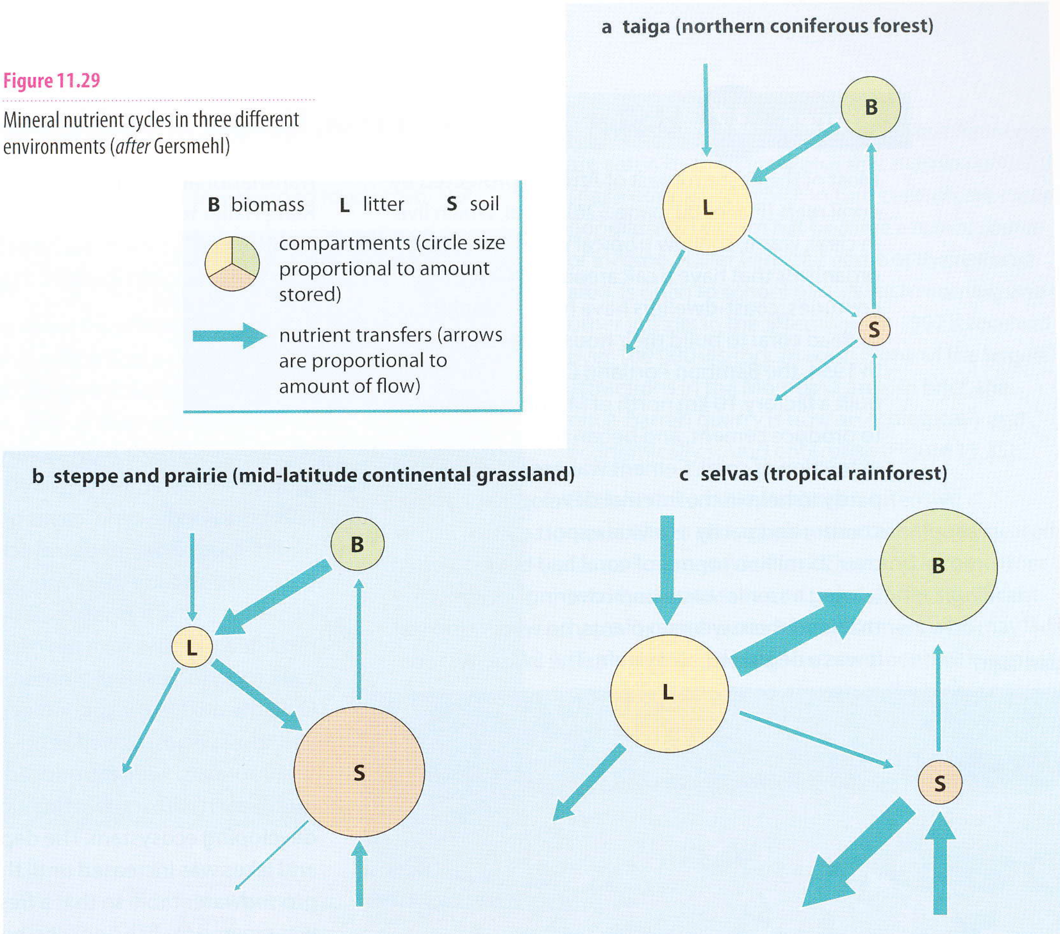
Figure 11.29 shows the mineral nutrient cycles for three selected biomes: the coniferous forest (taiga), the temperate grassland (prairies and steppes), and the tropical rainforest (selvas).

1 **Taiga** (Figure 11.29a) Litter is the largest store of mineral nutrients in the taiga. Although forest, the biomass is relatively low because the coniferous trees form only one layer, have little undergrowth, contain a limited variety of species, and have needle-like leaves. The soil contains few nutrients because, following their loss through leaching and as surface runoff (after snowmelt when the ground is still frozen), replacement is slow: the low temperatures restrict the rate of chemical weathering of parent rock. The layer of needles is often thick, but their thick cuticles and the low temperatures discourage the action of the decomposers (page 268). The breakdown of litter into humus is thus very slow. These factors account for the low fertility potential of the podsol soils of the taiga (pages 331–332).

2 **Steppes/prairies** (Figure 11.29b) Soil is the largest store of mineral nutrients in the temperate grasslands. The biomass store is small due to the climate, which provides insufficient moisture to support trees and temperatures low enough to reduce the growing season to approximately six months. Indeed, much of the biomass is found beneath the surface as rhizomes and roots. The grass dies back in winter and nutrients are returned rapidly to the soil. The soil retains most of these nutrients because the rainfall is insufficient for effective leaching and the climate is conducive to both chemical and physical weathering which release further nutrients from the parent rock. The presence of bacteria also speeds up the return of nutrients from the litter to the soil. These factors help to account for the high fertility potential of the black chernozem soils associated with temperate grasslands (pages 327 and 340).

Figure 11.29

Mineral nutrient cycles in three different environments (*after* Gersmehl)



3 **Selvas** (Figure 11.29c) The tropical rainforests have, of all the major environments, the highest rates of transfer – an annual rate ten times greater than that of the taiga. The biomass is the largest store of mineral nutrients in the tropical rainforests. High annual temperatures, the heavy, evenly distributed rainfall and the year-long growing season all contribute to the tall, dense and rapid growth of vegetation. The biomass is composed of several layers of plants and countless different species. The many plant roots take up vast amounts of nutrients. In comparison, the litter store is limited, despite the continuous fall of leaves, because the hot, wet climate provides the ideal environment for bacterial action (both in numbers and type) and the decomposition of dead vegetation. In areas where the forest is cleared, the heavy rain soon removes the nutrients from the soil by leaching or surface runoff. The leaf litter content rapidly decomposes due to the high temperatures and heavy rainfall. The rainforests are characterised by 'tight' biogeochemical cycling between the litter and the top layers of the soil in which most tropical species are rooted, and the biomass. This means that the soil component, and by proxy the bedrock that is usually found at some considerable depth (Figure 12.10), is only a small component in the nutrient cycle. Initially nutrients such as phosphorus may increase if the forest is burnt, but deforestation usually leads to a rapid decline in soil fertility (pages 317–318).

Figure 11.30 compares the storage and transfer of nutrients in four major biomes (i.e. ecosystems on a large scale). Remember that these figures refer to natural cycles which, in reality, have often been interrupted or modified by human activity.

Figure 11.30

Storage and transfer of nutrients within selected biomes

			Nutrient storage			Annual nutrient transfer		
		Ecosystem type	Stored in biomass	Stored in litter	Stored in soil	Soil to biomass	Biomass to litter	Litter to soil
Forest cycles	A	Equatorial rainforest	11 081	178	352	2 028	1 540	4 480
		Coniferous forest	3 350	2 100	142	178	145	86
Grassland cycles	B	Tropical savanna	978	300	502	319	312	266
		Temperate prairie/steppe	540	370	5 000	422	426	290

All measurements in kg/ha

Places 37 Haller Park, Mombasa, Kenya: creating an ecosystem

Most of the eastern coast of Africa is protected by coral reefs (Places 80, page 526). Coral, which live in clear, warm, shallow tropical waters, are small organisms that have a calcareous skeleton. For centuries, coast-dwellers have hacked out blocks of dead coral to build their houses and mosques. In 1954, the Bamburi Portland Cement Company built a factory 10 km north of Mombasa, Kenya, to produce cement, and began the open-cast extraction of coral. Cement was essential to Kenya, partly to help in the internal development of the country and partly as a vital export earner. By 1971, over 25 million tonnes of coral had been quarried, leaving a sterile wasteland covering 3.5 km^2. On that land there were no plants, no wildlife, no soil: it was a degraded ecosystem. The Swiss-owned transnational cement company then appointed Dr Rene Haller to restore the environment from what he himself described as 'a lunar landscape filled with saline pools' (Figure 11.31).

Figure 11.31

The Bamburi Quarry

Figure 11.32

Casuarina trees planted in coral rubble, Bamburi Quarry

After trying 26 different types of tree, Dr Haller found the key to be the *Casuarina* tree (Figure 11.32). This pioneer tree grew by 3 m a year, flourished in the coral rubble, and was able to withstand both the high salinity and the high ground temperatures (up to 40°C). The constant fall of the needle-type leaves provided a habitat for red-legged millipedes which, together with the *Casuarina* 's ability to 'fix' atmospheric nitrogen, helped with the formation of the first soil and provided the base for a new ecosystem. As the soil began to develop, more trees were planted. Over the next few years, indigenous herbs, grasses and tree species, as well as beetles, spiders and small animals, were introduced into the young forest, each with its own function (niche) in the developing ecosystem. The depth of the ponds and lakes was increased until they reached the groundwater table so that a freshwater habitat was created for fish (initially the local tilapia which are tolerant of saline water), crocodiles and hippopotami. Hippopotami excrement stimulated the growth of algae which oxygenated the water, preventing eutrophication. After only 20 years, the soil depth had reached 20 cm and the rainforest, with over 220 tree species, had become sufficiently restored to be home for over 180 recorded species of bird. The ecosystem was completed with the introduction of grazing animals (herbivores) such as the buffalo, oryx, antelope and giraffe. The re-creation of the rainforest (Figure 11.33) had been completed without the use of artificial fertiliser and insecticides, as Dr Haller considered these to be incompatible with his concept of a complex, balanced ecosystem.

The project has not only been an environmental success, it has also become a sustainable commercial venture with income derived from, for example, the sale of timber, bananas, vegetables, crocodiles and honey. The main source of the economy is the integrated aquaculture system (Figure 11.34) with, at its centre, the tilapia fish farm. The nutrients in the effluent water are used as fertiliser in the adjacent fruit plantation and for biogas to operate the pumps. From here, the water is led through a rice field into settlement ponds, where 'Nile cabbage' is grown for use in clearing the fish ponds. A crocodile farm is attached to the

Figure 11.33

The re-created rain-forest ecosystem, Haller Park

water system, as crocodile waste, which is rich in phosphate and nitrogen, is a valuable fertiliser. The crocodiles are part of a planned food chain. Not only are they fed on surplus tilapia, but their eggs are eaten by monitor lizards that help to control the snake population which in turn controls the rodent population. Tourism has become a recent source of income. Haller Park, the name of the restored area, is open to school parties each morning and to other visitors in the afternoon. In 1992 it received over 100 000 visitors, making it one of the largest attractions in the Mombasa area. In brief, the once-barren quarry is now an ecologically and economically sound enterprise (Figure 11.35).

Dr Haller also believes that his intensive aquaculture and agroforestry techniques, geared to maximum yield of food, fuel and income from minimum land area and inputs, offer significant hope for small-scale African farmers who may be short of fertile land in a continent with an explosive population growth and which is ravaged by environmental and human-created disasters. He suggests that these methods could easily be adapted by Africans since their genesis lies in tribal techniques taught to him by local farmers.

Figure 11.34

The Haller Park integrated aquaculture system

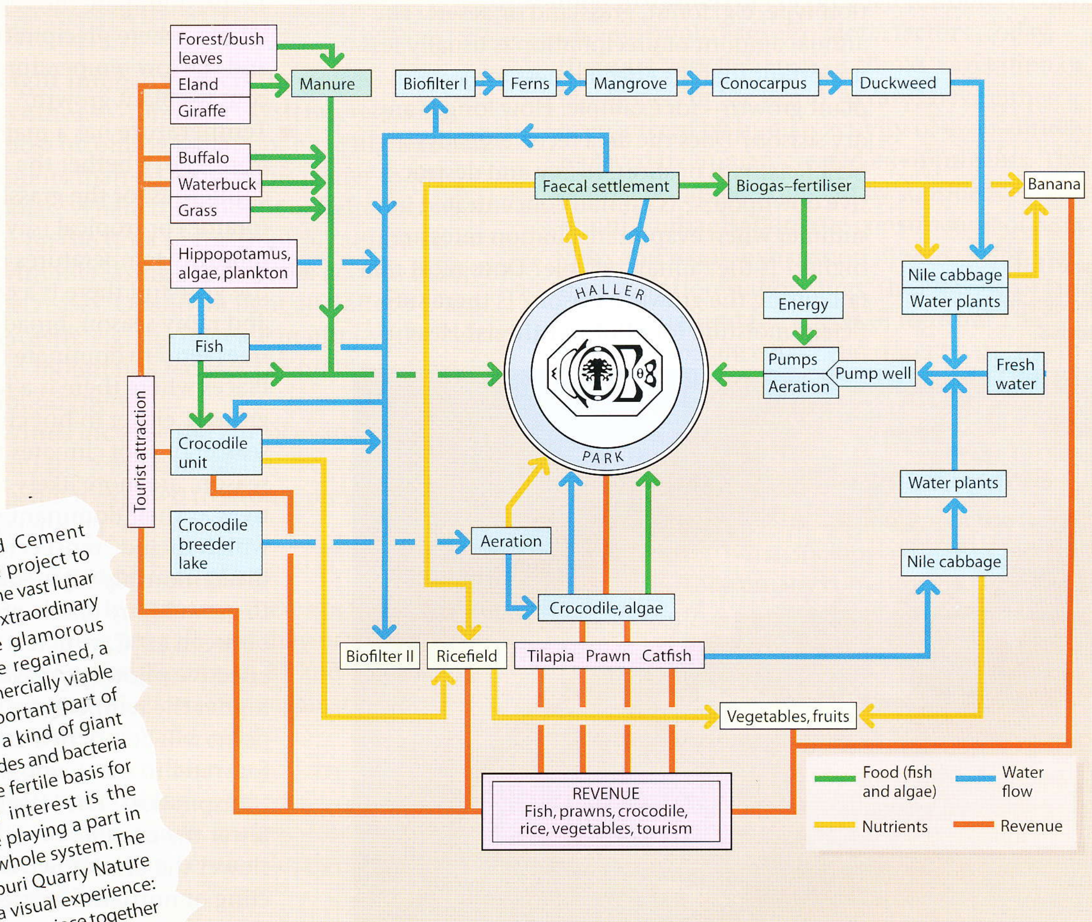


Figure 11.35

From the Bamburi Quarry Nature Trail leaflet

In 1971 the Bamburi Portland Cement Company embarked on a unique project to re-create a living environment in the vast lunar landscape of its quarry. Today an extraordinary change is evident. Behind the glamorous façade of the tropical paradise regained, a completely balanced and commercially viable aquaculture complex is an important part of the established ecosystem. In a kind of giant jig-saw, casuarina trees, millipedes and bacteria work together, to provide the fertile basis for reclamation. Of particular interest is the surprising variety of wildlife playing a part in the natural balance of the whole system. The living creation of the Bamburi Quarry Nature Trail holds more than just a visual experience: a walk around will enable you to piece together the giant jig-saw puzzle of wasteland rehabilitation.

Biomes

A biome is a large global ecosystem. Each biome gets its name from the dominant type of vegetation found within it (temperate grassland, coniferous forest, etc.). Each contains climax communities of plants and animals and can be closely linked to zonal soil types and animal communities. Climate has usually been the major controlling factor in the location and distribution of biomes, but economic development has transformed many of these natural systems. A biome can extend across a large part of a continent while its characteristics may be found in several continents (deserts and tropical rainforests). Although some authorities suggest that it is 'old-fashioned' to link together climate, vegetation and soils in a 'natural region', the concept is still useful and convenient as a framework of study and as a valid hypothesis for investigation. Four main factors – **climatic**, **topographic**, **edaphic** and **biotic** – interrelate to produce and control each biome.

1 Climatic factors

- **Precipitation** largely determines the vegetation type, e.g. forest, grassland or desert. The annual amount of precipitation is usually less important than its effectiveness for plant growth – for example: How long is any dry season? Does the area receive steady, beneficial rain or short, heavy and destructive downpours? Is rainfall concentrated in summer when evapotranspiration rates are higher? Is the rainfall reliable? Does most rain fall during the growing season? Is there sufficient moisture for photosynthesis? Heavy rainfall throughout the year enables forests to grow. These may be tropical rainforests, where the plants need a constant and heavy supply of water, or coniferous forests, where trees can grow due to the lower rates of evapotranspiration. Many other parts of the world receive seasonal rainfall. Rainfall is more effective, as in places with a Mediterranean climate, when it falls in winter rather than in summer, as this coincides with the time of year when evapotranspiration rates are at their lowest. However, as Mediterranean areas receive little summer rainfall, trees and shrubs growing there have to be **xerophytic** (drought-resistant) in order to survive. Rain is less effective when it falls in the summer because much of the moisture is lost through surface runoff and evapotranspiration. Effective precipitation is insufficient for trees, and so savanna grasses grow in tropical latitudes and prairie grasses in more temperate areas. Places where rainfall is limited throughout the year have either a desert biome, where **ephemerals** (plants with very short life-cycles, Figure 12.19) dominate the vegetation, or a tundra biome, where precipitation falling as snow and the low temperatures combine to discourage plant growth.
- **Temperature** has a major influence on the flora – i.e. whether the forest is tropical or coniferous, or the grassland is temperate (prairie) or tropical (savanna). Where mean monthly temperatures remain above 21°C for the year and there is a continuous growing and rainy season, broad-leaved evergreen trees tend to dominate (tropical rainforests). Places where there is a resting period in tree growth, either in hot climates with a dry season or cool climates with a short growing season, are more likely to have coniferous trees as their dominant vegetation. Grasses, which include most cereals, need a minimum mean monthly temperature of 6°C in order to grow. Many plants prefer temperatures between 10°C, which is the minimum for effective photosynthesis, and 35°C. The higher the temperature, the sooner wilting point will be reached and the greater the need for water to combat losses through evapotranspiration. The lower the temperature, the fewer the number of soil organisms and the slower the breakdown of humus and recycling of nutrients needed for plant growth (Figure 12.7).

Figure 11.36

Wind-distorted tree, Mauritius

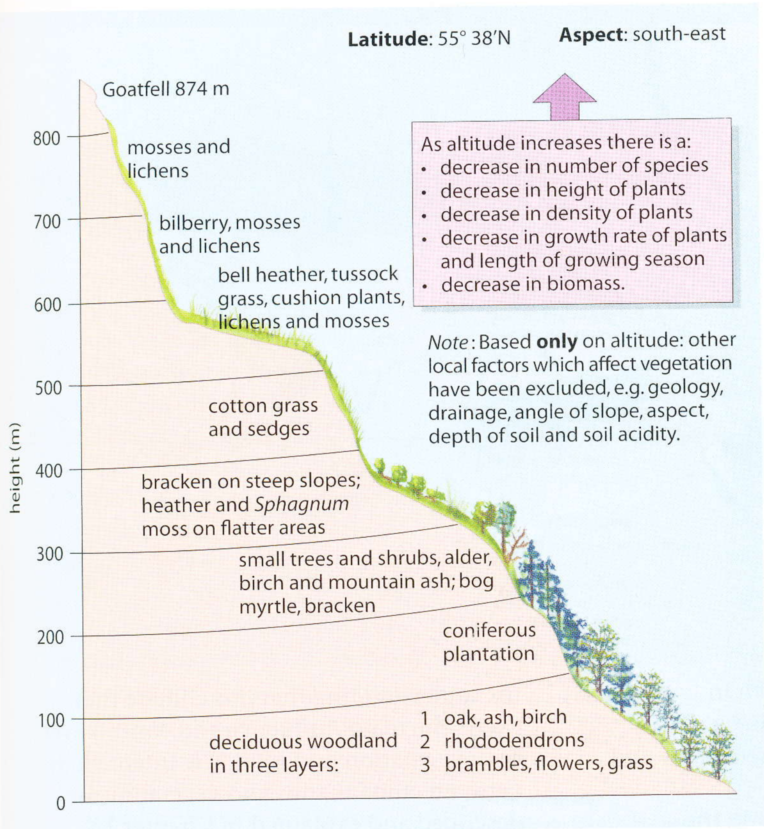


Figure 11.37

The effect of altitude on vegetation, Goatfell, Arran

- **Light intensity** affects the process of photosynthesis. Tropical ecosystems, receiving most incoming radiation, have higher energy inputs than do ecosystems nearer to the poles. Where the amount of light decreases, as on the floor of the tropical rainforests or with increasing depth in the oceans, plant life decreases. Quality of light also affects plant growth, e.g. the increase in ultra-violet light on mountains reduces the number of species found there.
- **Winds** increase the rate of evapotranspiration and the wind-chill factor. Trees are liable to 'bend' if exposed to strong, prevailing winds (Figure 11.36).

2 Topographic factors

- As **altitude** increases, there are fewer species; they grow less tall; and they provide a less dense cover (Figures 11.37 and 16.4b). Relief may provide protection against heavy rain (rainshadow) and wind.
- **Slope angle** influences soil depth, acidity (pH) and drainage. Steeper slopes usually have thinner soils, are less waterlogged and less acidic than gentler slopes (soil catena, page 276).
- **Aspect** (the direction in which a slope faces) affects sunlight, temperatures and moisture. South-facing slopes in the northern hemisphere are more favourable to plant growth than those facing north because they are brighter, warmer and drier (Places 28, page 213).

3 Edaphic (soil) factors

In Britain, there is considerable local variation in vegetation due to differences in soil and underlying parent rock, e.g. grass on chalk, conifers on sand, and deciduous trees on clay. Plant growth is affected by soil texture, structure, acidity, organic content, depth, water and oxygen content, and nutrients (Chapter 10).

4 Biotic factors

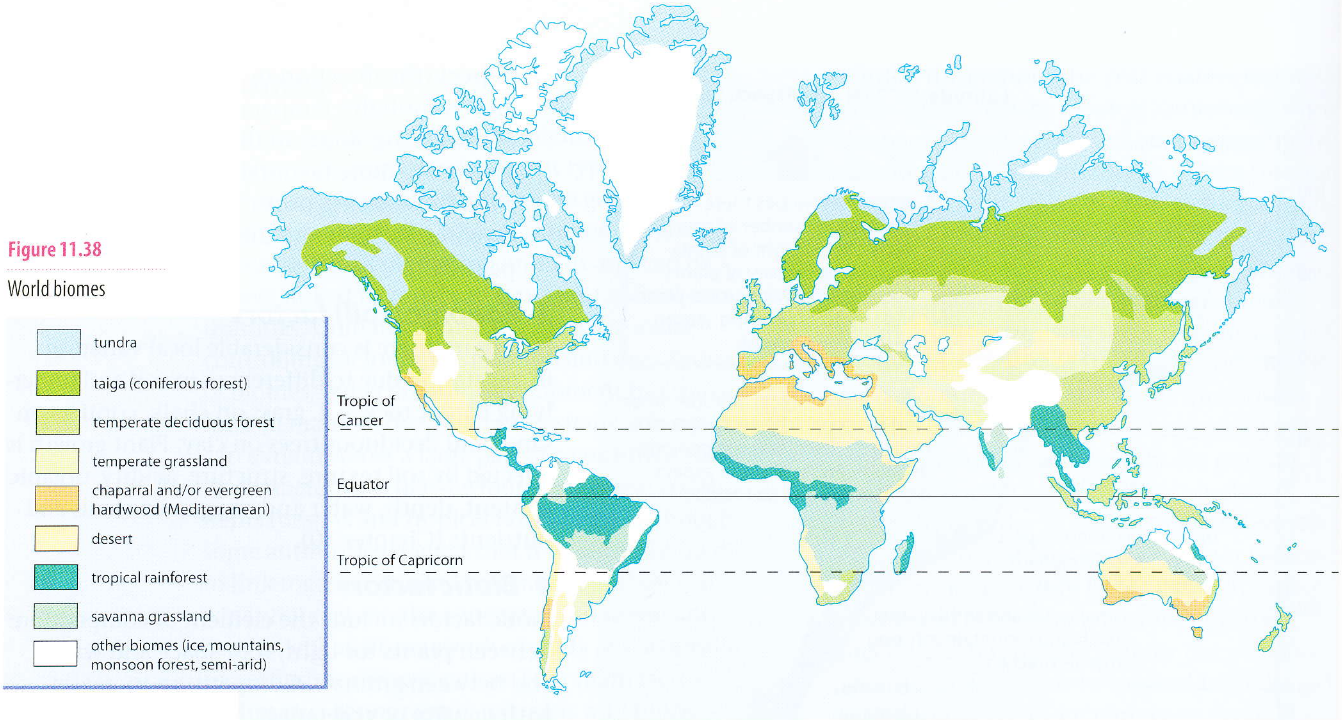
Biotic factors include the element of competition: between plants for light, root space and water, and between animals. Competition increases with density of vegetation. Natural selection is an important biotic factor. The composition of seral communities and the degree of reliance upon other plants and animals either for food (parasites) or energy (heterotrophs feeding on autotrophs) are also biotic factors. Today, there are very few areas of climax vegetation or biomes left in the world, as most have either been altered by human activity or even entirely replaced by human-created environments. The landscape has been altered by subsidence from mining, urbanisation, the construction of reservoirs and roads, exhaustion of soils, deforestation and afforestation, fires, the clearing of land for farming, and the effects of tourism. The ecological balance has been upset by the use of fertiliser and pesticides, the grazing of domestic animals, and acid rain.

The spatial pattern of world biomes

Figure 11.38 shows the distribution of the world's major biomes. When looking at maps of biomes in an atlas (they usually come under the heading 'Vegetation'), remember that all vegetation maps are very generalised (Framework 11, page 347). Vegetation maps do not show local variations, transition zones or, except in extreme cases, the influence of relief. Nor is there any universal consensus among geographers and biogeographers as to the precise number of biomes. Bradshaw has suggested 16 land biomes and 5 marine; Simmons describes 13 (11 land biomes plus islands and seas); O'Hare accepts 11; while Goudie (in common with most examination syllabuses) restricts his list, as does this text, to 8 land biomes.

Figure 11.38

World biomes



The eight major biomes, as shown in Figure 11.38, can be determined using a variety of criteria; two examples are discussed below and summarised in Figure 11.39.

1 **The traditional method** This links the type and global distribution of vegetation with that of the major world climatic types and zonal soils. This method was based on the understanding that it is climate that exerts the major influence and control over both vegetation and soils. The interactions between climate, soils and vegetation are described and explained in Chapter 12.

2 **The modern method** This is based upon differentiating between relative rates of producing organic matter – i.e. the speed at which vegetation grows. The rate at which organic matter is produced is known as the **net primary production** or NPP, expressed in grams of dry organic matter per square metre per year ($g/m^2/yr$). As shown in Figure 11.40, it is the tropical rainforests, with their large biomass resulting from constant high temperatures, heavy rainfall and year-round growing season, that produce on average the greatest amount of organic matter annually. The tundra (too cold) and the deserts (too dry) produce the least. It may be noted that the average NPP for arable land is 650, lakes and rivers 400 and oceans 125.

Figure 11.40

Net primary production (NPP) of eight major biomes

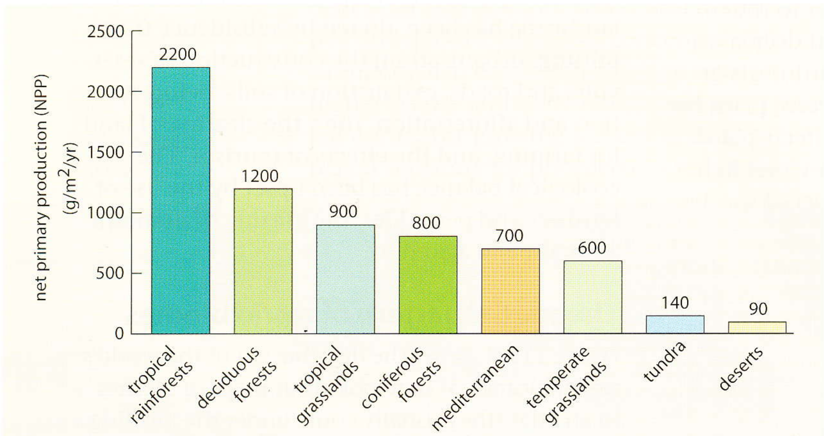


Figure 11.39

Two methods of clarifying the major biomes (*after* I. Simmonds)

1 Traditional method (vegetation, climate and soils subjectively linked)		
Tropical	1	Rainforests
	2	Tropical grasslands
	3	Deserts
Warm temperate	4	Mediterranean
Cool temperate	5	Deciduous forest
	6	Temperate grasslands
Cold	7	Coniferous forest
	8	Tundra

2 Modern method (scientifically based on net primary production)		
High energy	1	Rainforests
	2	Deciduous forest
Average energy	3	Tropical grasslands
	4	Coniferous forest
	5	Mediterranean
	6	Temperate grasslands
Low energy	7	Tundra
	8	Deserts

The forests of south-west Australia

The situation before 2000

Western Australia is ten times the size of the UK, and about 2 per cent of the state was forested before white settlement began in 1829. The forested area stretches from Gingin, 75 km north of Perth, to Walpole, 400 km to the south (Figure 11.41). The Darling and Stirling ranges form the edge of the Darling Plateau and consist mainly of ancient igneous and metamorphic rocks. A number of river valleys cut into the plateau edge. These have broad, flat valley floors.

East of the plateau the old river valleys (now largely dry) are very broad and flat. At the western edge of the scarp, the drainage has been rejuvenated and recaptured by newer fast-flowing streams.

The Blackwood River is an exception. It has maintained enough flow to continue erosion of its bed as the plateau was uplifted. Therefore it has an old meandering course within which is a new cross-sectional V-shaped profile.

Figure 11.41

South-western Australia

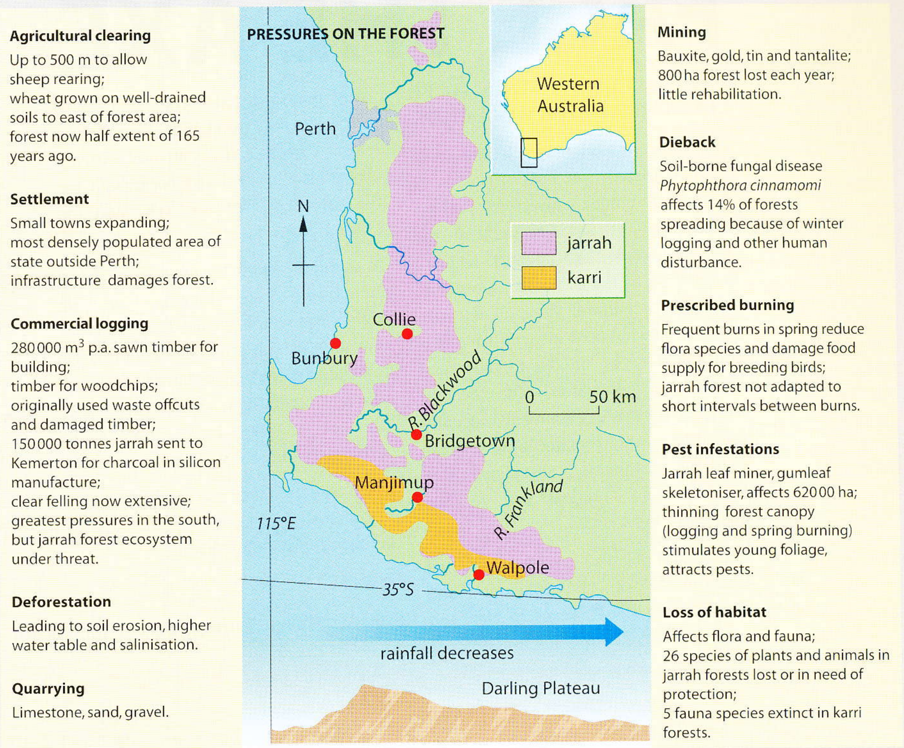


Figure 11.42

Jarrah forest

The climate of this region is Mediterranean in type, with most rainfall in winter from May to October (700 mm); rainfall is highest (1100 mm) on the western edge of the plateau and decreases rapidly to the east. Temperatures are high in the summer (18–27°C) and lower in the winter (7–15°C). Snow has been known to fall in the Stirling Range!

These conditions allowed the development of high forests, unique to Western Australia, of hardwood trees: varieties of eucalyptus known as karri, jarrah and marri. Jarrah forest is the only tall forest in the world to grow in a truly Mediterranean type.

The great karri trees, which grow to over 80 m in height, are found in the south-west where the soils have a higher moisture content and are more fertile (Figure 11.17). The quality of the forest deteriorates to the east, with a variety of eucalypts reflecting lower rainfall. The jarrah forest is more extensive and has a very high species diversity (Figure 11.42). The forests provide important wild-life habitats for birds and animals – over 50 species live in the hollows of the trees.

Since the coming of the white settlers in 1829, half the tall forest cover has been removed (nearly 2 million ha). Much of the early clearance was for agriculture, with pastures of clover and grasses for sheep and cattle replacing the 500-year-old trees. Although the timber provided a valuable secondary source of income for the farmers, they were never able to sell it for themselves at a commercial rate. Instead, the state sold it for 'royalty' to timber industry firms as the commercial value of the tall forests was realised.

The situation in 2000

In 2000, the Western Australian government controlled 1260 ha of native trees in so-called 'State Forests'. The Department of Environment and Conservation (DEC) claimed that there was 139 000 ha of 'old growth' forest left (unlogged virgin forest) and 1 120 000 ha of 'regrowth' forest (areas that had been logged in the last 100 years). Despite opposition from conservation groups, including the Western Australian

11 Case Study The forests of south-west Australia

HERITAGE FORESTS FACE THE AXE

IRREPLACABLE FORESTS TO BE CLEAR FELLED FOR WOODCHIPS

The Australian Heritage Commission (AHC) officially includes 40 areas of WA's world-unique native forests on the interim list of the Registers of the National Estate, the highest national recognition of the ecological, aesthetic, scientific or cultural value of an area. Once an area has been interim-listed, it is considered to be on the Register and entitled to protection. The Federal Minister for the environment is legally bound to prevent logging in these areas until an examination has shown that there are no 'prudent and feasible alternative log sources'.

In spite of this protection, the Department of Environment and Conservation (DEC) plans to clear-fell many interim-listed forests, mainly to produce export woodchips. Some of the listed areas are already being clear-felled, roaded and burnt with the full knowledge of the AHC and the Federal government.

In addition, there is supposed to be a moratorium on logging in all high-conservation value forests. Now that at least some of the best of WA's remaining native forests have been given official recognition, each of these agencies must back up their self-congratulations with action.

The only action they can reasonably take is to stop all roading and logging in WA's heritage forests immediately.

Figure 11.43

By the Western Australian Forest Alliance, Perth (Adapted)

Forest Alliance and the Global Warming Forest Group, the annual cut had increased to over 1 500 000 m^3 with the large timber companies using the timber to produce woodchips, saw-logs and poles. The residue was sent in large quantities to be used as charcoal in a silicon smelter. The timber mills provided work for 2000 people, an important source of employment in a sheep-rearing region adversely affected by the low world price for wool. At the same time, the state was encouraging agroforestry, a form of plantation agriculture (page 482).

Meanwhile, conservationists were trying to stop the rapid increase in logging in the virgin forests (Figure 11.43). The rate of loss of forests, with their unique wild species of small mammals, birds and flora, raised the question of sustainability. Fears were raised that, at the then present rate of deforestation, all the 'old growth' forest would have disappeared by 2030.

The DEC now has total responsibility for the logging and regeneration of felled areas within State Forests (Figure 11.44). It invites tenders for cutting and hauling and then selling the logs to sawmillers and woodchippers. The chief market for Western Australian timber is Japan. Since 1976 over 15 million tonnes of karri have been exported as woodchip through the port of Bunbury.

The main method of removal is by clear felling (Figure 11.45). An area of land is divided into sections referred to as coupes. Coupes vary in size from 60 ha in karri forests down to 10 ha in the jarrah. In clear felling, every tree in the coupe is felled and the logged area is then burnt. Most coupes are in the 'old growth' native forests, areas not previously touched, where the trees have reached their greatest height. Each of the felled giant karri needs a double trailer to take it to Bunbury, and often 12 of these can be seen on the main road to the port every hour. The DEC regeneration programme involves the hand-planting of karri seeds as they grow more quickly than jarrah. This is leading to a growing concern over what appears to be a deliberate phasing out of the jarrah, especially as in drought years, which are increasing in frequency, the karri is the less likely to survive.

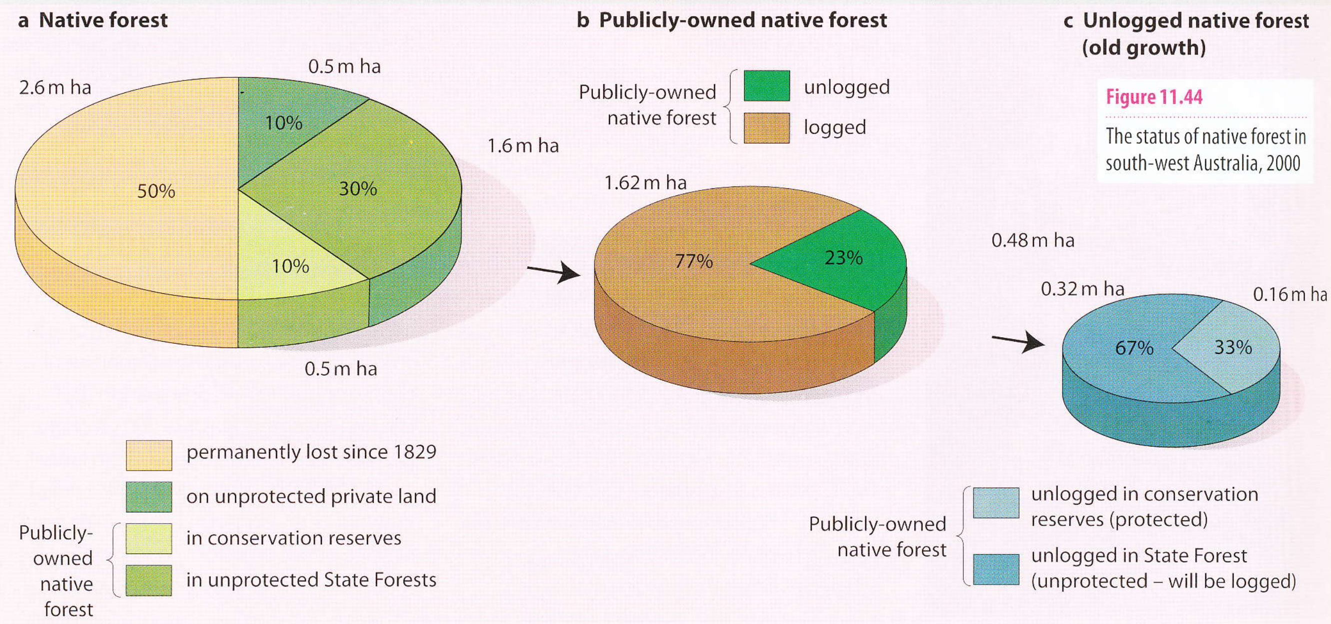


Figure 11.44

The status of native forest in south-west Australia, 2000

Jarrah timber is commercially valuable for its dark-red colour, hardness and durability. However, it grows far more slowly, and is less in demand, than karri – hence the difficulty in maintaining sustainable production - even though the state government has restricted extraction to 500 000 m^3 per year. Marri, the third type of eucalyptus growing in Western Australia, tends to be found within the jarrah forest and, like the karri, its main use is for woodchip.

Effects of deforestation

Visual and physical degradation of the landscape

This is especially bad in clear-felled areas. Where the land is steep, tree removal means there is no canopy to intercept heavier rainfall, nor roots to hold the soil together. This results in an increase in surface runoff and consequent problems of soil erosion, the sedimentation of rivers and a greater risk of flooding (page 63). Any nutrients in the soil, including those released by burning the cleared forest, will be lost due to leaching.

Loss of native flora and fauna

The south-west of Western Australia is noted for its wildflowers, typical of other regions with a Mediterranean-type climate (page 324). These are threatened, as are birds and small animals that at present rely on the groundcover of the forest. In total, 27 native species are listed as rare, including the chuditch, which is a marsupial, and the Western ring-tailed possum.

Salinisation of streams

This, resulting from the loss of the forest canopy, has become a serious problem in the region (page 496). Salts, previously trapped by the laterite soils (page 321), can be transported relatively easily by the increase in groundwater which itself becomes more saline. In time this water finds its way into streams and, eventually, the main watercourses.

Eutrophication

As forest land is cleared for agriculture, the nitrates used in fertilisers are also transferred by groundwater to rivers (page 281 and Figure 16.50). The nitrates enrich plant life which uses up more oxygen. This leaves less for fish and other water-inhabiting organisms.

The situation since 2000

In early 2001, the state government ended logging in all the 'old growth' forests in the care of the Conservation Commission of Western Australia and began, under the DEC, a process of creating the conservation parks and the 12 National Parks proposed in its 'Protecting our old growth forests' policy. A major capital works programme was established to upgrade visitor facilities, and to encourage tourism and leisure along with nature conservation.

The Forest Management Plan 2004–13 came into effect in 2004. This provided for increased protection of forest values, improved forest management and, coming into being later that year, 29 National Parks and other conservation reserves and forest areas. At the same time, landowners were encouraged to practise agroforestry by planting fast-growing trees on agricultural land in belts separated by grass pasture usable for sheep grazing. This was to use up surplus fertiliser in the soil and to reduce nitrates flowing into streams.

Although deforestation in Western Australia may not be on the scale of that in the Amazon rainforest or Indonesia, to the people living in the south-west corner of the state it is just as damaging. To some people deforestation means the destruction of a non-replaceable ecosystem and a loss for future generations. To others logging means employment in an area with relatively few job opportunities. It is easy to become emotive on a topic such as this, especially if the question is oversimplified to 'Which is the more important – jobs provided by the production of paper or the protection of trees and wildlife?' It revives a question long asked in Geography of which is the more important: economic gain or environmental loss? At present the answer appears to lie in the prospect of 'sustainable development' (Framework 16, page 499).

Figure 11.46 describes the viewpoints given in 2008 by, on one hand, the state government and representatives of the timber workers and, on the other, conservation groups.

Figure 11.45

Clear felling of karri, near Bridgetown

The forests of south-west Australia

The **Global Warming Forest Group** claimed that the logging of a 62 m tall, 500-year-old karri tree near Pemberton showed that the old growth protection policy was a sham and that they, and other environmental groups, had been double-crossed on definitions as, according to present government policy, a single stump in a hectare of virgin forest disqualifies it as 'old growth'. To them, forests containing huge centuries-old trees have a high conservation value and it is absurd that these old trees should be logged before they die and fall naturally. Such trees are more valuable as wildlife habitats than as woodchip or sawdust, which is the end product of most harvested timber.

The **Forest Industries Federation** stated that it had ensured that 1.2 million ha of 'old growth' forest was now totally protected by state law in the south-west corner of Western Australia. However, it also said that there was never a commitment to protect individual trees, but rather to conserve areas as a whole. Admittedly, there were still old karri trees that had not been logged in 'regrowth forests' which might in time might have to be felled, but these were outside 'old growth protection areas'. The federation also said that over a dozen karri trees, both bigger in diameter and taller in height than the felled Pemberton tree, were under protection, including one growing near Manjimup (Figure 11.41) which was 61 m tall and had a diameter of 291 cm – 26 cm greater than that of the Pemberton tree.

Austwest, the biggest karri miller in the state, said it was rare to receive timber from trees the size of the one near Pemberton. When it did, it was put to the most valuable use which was usually for flooring or staircases (Figure 11.47).

Figure 11.47

A single large karri tree

Figure 11.46

Adapted from material on the official Serengeti website (www.serengeti.org)

Further reference

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Cary Institute of Ecosystem Studies: www.ecostudies.org/

International Biogeography Society: www.biogeography.org/

National Association of Forest Industries (Australia): www.nafi.com.au

Radford University Virtual Geography Department's 'Biome': www.runet.edu/~swoodwar/CLASSES/GEOG235/biomes/main.html#tabcont

Union of Concerned Scientists (UCS), 'Understanding biodiversity': www.ucsusa.org/ – use search option

Management of the Serengeti

Issues Analysis

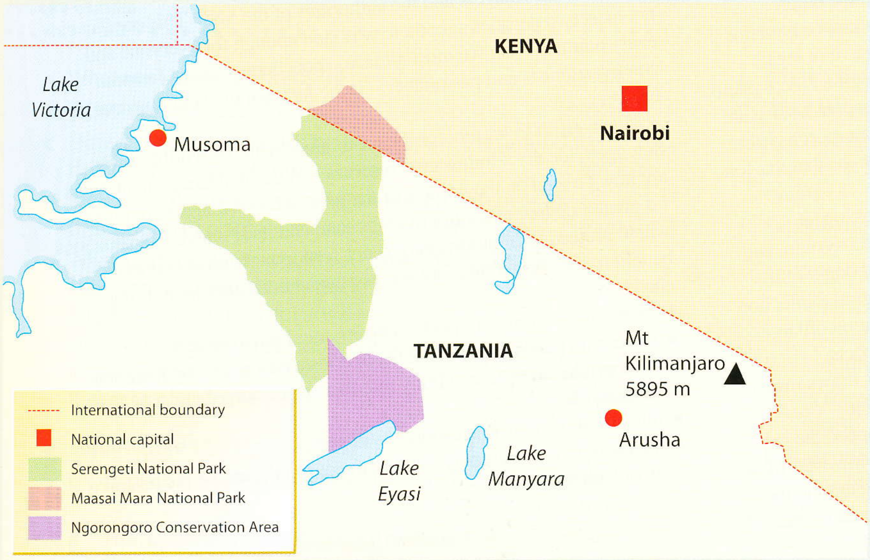


Figure 11.48

Location of the Serengeti

Before starting this exercise, read pages 319–321, Tropical grasslands, and pages 335–338, Tropical grasslands in Kenya.

Serengeti National Park's website is at: www.serengeti.org

The Serengeti Shall Not Die area is useful for this exercise.

The Serengeti grasslands

The Serengeti grasslands lie just south of the Tanzanian/Kenyan border, between 2° and 4° South (Figure 11.48). Mean maximum temperatures are 24° to 27°C, and mean minimum temperatures 15° to 21°C. Mean annual rainfall varies from 1050 mm in the north-west to 550 mm in the south-east. Rainfall peaks in March to May, and November to December (compare Figure 12.49).

The soils are formed from volcanic ash. The eco-region consists of slightly undulating grassy plains, interrupted by scattered rocky areas (kopjes) which are parts of the Precambrian basement rocks protruding through the ash layers.

Biodiversity features

The Serengeti grasslands are vital to the cyclical movement of millions of large mammals. Populations fluctuate, but about 1.3 million blue wildebeest, 200 000 plains zebra, and 400 000 Thomson's gazelle migrate between Serengeti and southern Kenya each year. Many associated predators are also involved in these movements. By the onset of the dry season (late May), the grasses on the plains have either dried out or been eaten down to stubble, and water is scarce. This triggers the massive migration from the plains northwards. Then, at the start of the wet season, the animals complete the cycle, and return to the plains.

Fires, usually set by humans, are an important disturbance in this eco-region. The burning helps provide accessible pasture for the herds of cattle that are kept here but other species, including wildebeest, also favour grazing on the green flush that emerges after burning.

Current status

Much of the eco-region occurs within protected areas, most of which are joined into a continuous block. The protected area includes Serengeti National Park (SNP) and Ngorongoro Conservation Area (NCA), both of which are World Heritage Sites (page 596). This area is probably large enough to ensure the survival of the habitat and its biodiversity. There has been little loss of habitat within the protected areas, except for small areas used for tourist hotels. Outside the protected areas, however, there has been a rapid expansion of human settlement and agriculture in recent years.

Types and severity of threats

While Maasai pastoralists occupy the NCA, there are no people living within the SNP. However, the western frontier of this park has a dense population, growing at 4 per cent a year. Livestock numbers are increasing, and much of the area is being converted into cropland. Agriculture is the main source of income, but many people have been attracted to the area by the wildlife resources and tourism opportunities that the park presents.

Many animals within the SNP are killed by poachers, who may be local people hunting 'bush meat' for subsistence, organised commercial hunters taking meat for sale in the cities, or Big Game hunters taking part in organised illegal safaris.

However, it is hoped that schemes to give local communities legal rights to manage the wildlife around their villages will reduce the worst excesses of the hunting. There are also plans to channel more money earned from tourist activities within the park back into the community as, so far, the contribution from tourism to the local economy has been relatively low.

Are the Serengeti grasslands natural?

The Serengeti changed from a grassland state to woodland twice in the last century. The few old, large trees dotting the landscape started life about 1900, followed by a slow decline in numbers due to elephants, fire, disease, and natural thinning, leaving the few that we see today. The second group of smaller trees established themselves between 1976 and 1983, and these trees are still growing in abundance. Both groups were able to grow because for two periods there were neither elephants nor fires.

Rinderpest, a cattle disease, came to East Africa in about 1896. Most of the Serengeti wildebeest died in a few years, as did the cattle herds. There was famine, followed by

Issues Analysis **Management of the Serengeti**

Figure 11.49

Information from the Serengeti website

In recent years human population has increased, putting pressure on park resources. Conflicts arise as wild animals damage property and even threaten life. Illegal poaching activities create conflict. In some sections cultivation is right on the park border and this fuels conflict as animals destroy the crops on one side or are illegally hunted on the other.

The Serengeti is a prime example of how many natural ecosystems are being eroded by human population effects, irrespective of legal boundaries. The original Serengeti-Ngorongoro 'undisturbed' ecosystem (which included indigenous hunters with traditional weapons), set aside in the 1950s, has declined steadily. Some 40% of the natural ecosystem has been lost to farming and herding. Today, there are signs that this loss may be accelerating.

The Serengeti is also losing species. Thus, rhinoceros, once abundant, have been effectively exterminated from the ecosystem, and elephants were reduced by 80%, both by poaching. Wild dogs went extinct in the early 90s, due to contact with domestic dogs and infection with diseases like distemper and rabies. Unregulated hunting of large predators in areas around Serengeti has had dramatic impacts. Over-hunting of male lions alters the local adult sex ratio, draws males out from the park, and thus disrupts populations within in it.

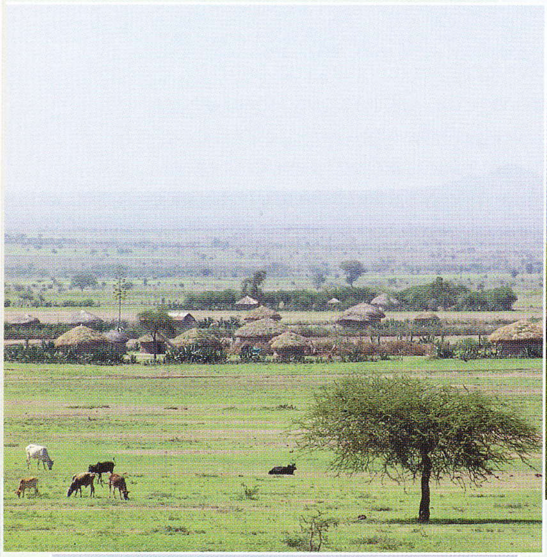
The 1989 worldwide ivory ban almost completely stopped the poaching of elephants and their numbers are recovering. However, meat poaching continues. In an average year, local people living around the park illegally kill about 40,000 animals, mainly wildebeest and zebra, but also giraffe, buffalo and impala. The populations of these animals seem to be able to survive this poaching without any long-term decline but the killing is a manifestation of growing antagonism between the impoverished villagers and the authorities of the SNP. This conflict did not exist two decades ago; there was land enough for everyone and every animal. What we must all face – poachers, tourists, farmers, conservationists and pastoralists – is the fact that the land does not go on forever.

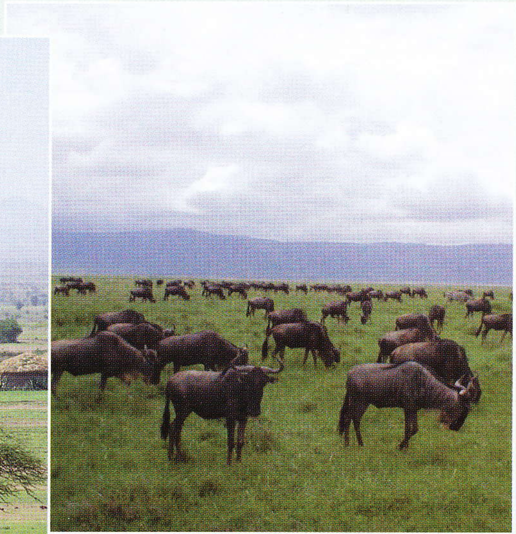
In an effort to harmonize the pastoralists with the wildlife in the Serengeti, locally administered reserves – Wildlife Management Areas – are now created on the borders of the park, where villagers are given a far greater degree of control over the land and its resources. In situations where protection of biodiversity is not seen to be of clear economic benefit to the community, outside assistance must attempt to bring change by:

- increasing community pride in their natural environment
- increasing the economic benefits of conservation, e.g. by fostering ecotourism, hiring community members as resource stewards, rangers, etc.
- rehabilitating depleted resource systems
- increasing the community's ability to control the use of the resource by outside interests.

Figure 11.50

Scenes in the Serengeti





emigration. With no people there was no one to light fires and the Serengeti went un-burnt. At the same time, the trade in ivory was at its peak. With no fires and no elephants, young trees were able to grow and flourish in the first big establishment of the century. Then, gradually, the wildebeest and cattle recovered and by the 1930s elephants started to return, and growth of new trees ceased.

Between 1976 and 1984 the weather patterns in and around Serengeti changed. The seasonal rains became more spread out, so the grasslands did not dry and burn during the 'dry season'. During this time there was an enormous upswing in the illegal ivory trade. With fire and elephants removed, the trees again established themselves in a burst. These trees are now about 30 years old and range from 2 to 5 m tall, often forming dense thickets.

There has been a large increase of impala inside the park. They seem to be much more successful in the woodlands than in the grasslands, and have increased as the woodlands have increased. In the past, elephants and fire have controlled the establishment of new trees. Today, both elephants and fire are monitored closely. The Park Ecology Department burns fire-breaks to stop the spread of large fires, and conducts 'cool' early burns in fire-prone areas. It is also monitoring the ecosystem carefully to see how all aspects interact.

The Serengeti National Park Authorities have two main aims:

1. to conserve the natural environment of the SNP
2. to support the traditional way of life of the people who live around the SNP.

Draw up a list of management objectives for the Park, justifying each of your objectives and explaining how individual objectives combine to form a coherent management plan for the area.

Questions & Activities

Activities

1 a What are: **i** herbs **ii** shrubs **iii** trees? *(3 marks)*
b What is plant succession? *(3 marks)*
c How do herbs and shrubs help to prepare the ground so that trees can grow? *(6 marks)*
d How would you carry out a field survey to discover the distribution of plants in the area of a playing field? *(5 marks)*
e What kinds of plants would you expect to find on an abandoned urban railway track?
Suggest reasons for your answer. *(4 marks)*
f Flowers that grow in deciduous woodland are early spring flowers such as bluebell and primrose. Why do these plants flower so early in the year? *(4 marks)*

2 **a** Study Figure 11.25 (page 298).
i Explain the roles played by plants in the carbon cycle. *(4 marks)*
ii Human activity (combustion) releases CO_2 into the air. What is the source of this carbon? *(3 marks)*
b i Study Figure 11.26 (page 298). Why is nitrogen important for plant life? *(2 marks)*
ii What is the main source of new nitrogen into the nitrogen system? *(2 marks)*
iii What is the main cause of loss of nitrogen from the system? *(2 marks)*
c What is the meaning of the term 'biomass'? *(2 marks)*
d What is the role of humans in the food chain? *(2 marks)*
e As CO_2 builds up in the atmosphere, plant growth is increased. Suggest **two** effects of this on the material cycles. *(4 marks)*
f Explain the 'greenhouse effect'. *(4 marks)*

3 Study Case Study 11 (pages 307–310).
a i What is the extent of deforestation in south-west Australia since white settlement started? *(2 marks)*
ii Identify the proportion of:
(i) conserved native forest (ii) public ownership of the forest (iii) forest in danger of being logged. *(3 marks)*
iii Identify and explain **three** reasons for deforestation in south-west Australia. *(6 marks)*
b Explain **two** impacts of deforestation on areas such as south-west Australia. *(6 marks)*
c Describe **two** advantages of the native forest to south-west Australia and its people. *(4 marks)*
d Explain **one** way of protecting the forest lands of south-west Australia. *(4 marks)*

Exam practice: basic structured question

4 **a** What is meant by:
i seral change
ii climatic climax vegetation cover? *(6 marks)*
b Why is vegetation cover within an urban area different from the climatic climax vegetation in a similar rural area? *(7 marks)*
c Assume that there has been a landslide on an area of non-calcareous rock in lowland Britain. Describe and explain the sequence of vegetation that would occur so that the area eventually achieved a climatic climax vegetation cover. *(12 marks)*

Exam practice: structured questions

5 **a** Explain the meaning of:
i seral progression *(2 marks)*
ii dominant species. *(2 marks)*
b Choose **one** of a *psammosere*, a *halosere*, or a *hydrosere*.
i Draw an annotated diagram **only** to show the variation in vegetation cover across the environment. *(6 marks)*
ii Explain the variation in vegetation cover shown on your diagram. *(15 marks)*

6 **a** Study Figure 11.28 (page 300).
i Explain the meaning of the term 'litter'. *(2 marks)*
ii Explain what the arrows show. *(2 marks)*
b Figure 11.29 (page 301) shows the nutrient cycles in three different environments.
i Why are the transfers in the taiga so small? *(6 marks)*
ii Explain the differences between the tropical forests and the mid-latitude grasslands in terms of their nutrient stores and flows. *(15 marks)*

Exam practice: essay

7 Explain why the 'polyclimax' theory of vegetation progression is now generally considered to be better than the climatic climax theory of F.E. Clements as a way of explaining the distribution of vegetation types. *(25 marks)*