12

World climate, soils and vegetation

'There was … an instant in the distant past when the living things, the rocks, the air and the oceans merged to form the new entity, Gaia.'

James Lovelock, *The Ages of Gaia*, 1989

Although it is possible to study climatic phenomena in isolation (Chapter 9), an understanding of the development of soils (Chapter 10) and vegetation (Chapter 11) necessitates an appreciation of the interrelationships between all three (Figure 12.1a). This chapter attempts to show how the integration and interaction of climate, soils and vegetation give the world its major ecosystems, or biomes, and how these have often been modified, in part or almost totally, by human activity (Figure 12.1b).

Soils can be grouped, at the simplest of levels, under zonal, azonal and intrazonal (page 273) with each group, in turn, being subdivided (zonal Figure 12.2, azonal page 273, and intrazonal page 274). Likewise, the major vegetation and fauna groupings (biomes) were listed on page 306 and their generalised global locations and distributions shown in Figure 11.38. In a similar way, geographers seek – despite the difficulties and limitations – to classify different world climates (Framework 7, page 167).

Classification of climates

By studying the weather – the atmospheric conditions prevailing at a given time or times in a specific place or area – it is possible to make generalisations about the climate of that place or area, i.e. the average, or 'normal' conditions over a period of time (usually 35 years). Any area may experience short-term departures from its 'normal' climate, especially if the 35-year mean coincided with an unusually wet/dry or hot/cold period, but, at the same time, it may have long-term similarities with regions in other parts of the world.

In seeking a sense of order, the geographer tries to group together those parts of the world that have similar measurable climatic characteristics (temperature, rainfall distribution, winds, etc.) and to identify and to explain similarities and differences in spatial and temporal distributions and patterns. Areas may then be compared on a global scale – bearing in mind the problems resulting from short-term and long-term climatic change – to help to identify and to explain distributions of soil, vegetation and crops.

Bases for classification

The early Greeks divided the world into three zones based upon a simple temperature description: torrid (tropical), temperate, and frigid (polar); they ignored precipitation.

In 1918, **Köppen** advanced the first modern classification of climate. To support his claim that natural vegetation boundaries were determined by climate, he selected as his basis what he considered were appropriate temperature and seasonal precipitation values. His resultant classification is still used today, although a modification by **Trewartha**, with 23 climatic regions, has become more widely accepted.

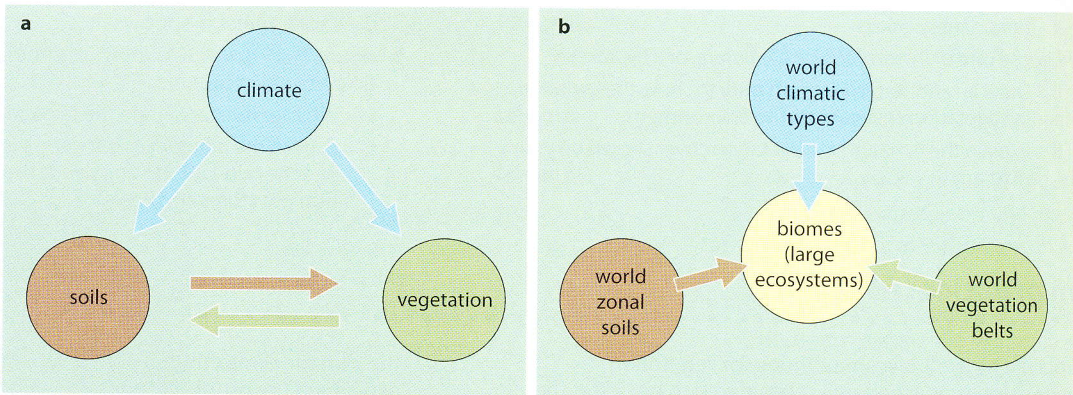


Figure 12.1

Relationship between climate, vegetation and soils

Thornthwaite, in the 1930s and 1940s, suggested and later modified a classification with a more quantitative basis. He introduced the term 'effectiveness of precipitation' (his P/E index – page 178) which he obtained by dividing the mean monthly precipitation of a place by its mean monthly evapotranspiration, and taking the sum of the 12 months. The difficulty was, and still is, in obtaining accurate evapotranspiration figures. (How can you measure transpiration loss from a forest?) This classification resulted in 32 climatic regions.

In Britain, in the 1930s, **Miller** proposed a relatively simple classification based on five latitudinal temperature zones which he determined by using just three temperature figures: 21°C (the limit for growth of coconut palms); 10°C (the minimum for tree growth); and 6°C (the minimum for grasses and cereals). He then subdivided these zones longitudinally according to seasonal distributions of precipitation. The advantages of this classification include its ease of use and convenience; and its close relationship to vegetation zones and also, as these are a response on a global scale to climate and vegetation, to zonal soils.

All classifications have weaknesses: none is perfect.

- They do not show transition zones between climates, and often the division lines are purely arbitrary.
- They do not allow for mesoscale variation (the Lake District and London do *not* have exactly the same climate) or microscale (local) variation.
- They can be criticised for being either too simplistic (Miller) or too complex (Thornthwaite).
- They ignore human influence and climatic change, both in the long term and the short term.
- Most tend to be based upon temperature and precipitation figures, and neglect recent studies in heat and water budgets, air-mass movement and the transfer of energy.
- All suffer from the fact that some areas still lack the necessary climatic data to enable them to be categorised accurately.

However, climatic classifications such as those named above are rarely used today. Instead, as we saw in Chapter 11, the relationship between climate, vegetation and soils can best be described and understood at this level through the study of ecosystems, especially the largest of the ecosystems: the **biomes** (Figure 12.1b). Figure 12.2 lists eight of the more important biomes and shows, simplistically, the links between climate, vegetation and soils. These links are described in more detail and explained in the remainder of this chapter, using knowledge and understanding gained from Chapters 9, 10 and 11.

Climate type		Text reference number	Climatic characteristics	Biome (based on NPP)	Soil (zonal type)
arctic		8	very cold all year	tundra	tundra
cold		7	cold all year	coniferous forest (taiga)	podsols
cool temperate	western margin	6	rain all year, winter maximum	temperate deciduous forest	brown earths
	continental	5	summer rainfall maximum	temperate grassland	chernozems prairie chestnut
warm temperate	western margins: Mediterranean	4	winter rain	Mediterranean	Mediterranean
	eastern margins: monsoon	4A	some rain all year, summer maximum	tropical deciduous forest	
tropical	desert	3	little rain	desert (xerophytes)	desert
	continental	2	summer rain	tropical grassland (savanna)	ferruginous
	monsoon	1B		jungle	
	tropical eastern margins	1A	rain all year	rainforest	ferralitic
	equatorial	1			

Figure 12.2

World biomes: the relationship between climate, vegetation and soils at the global scale

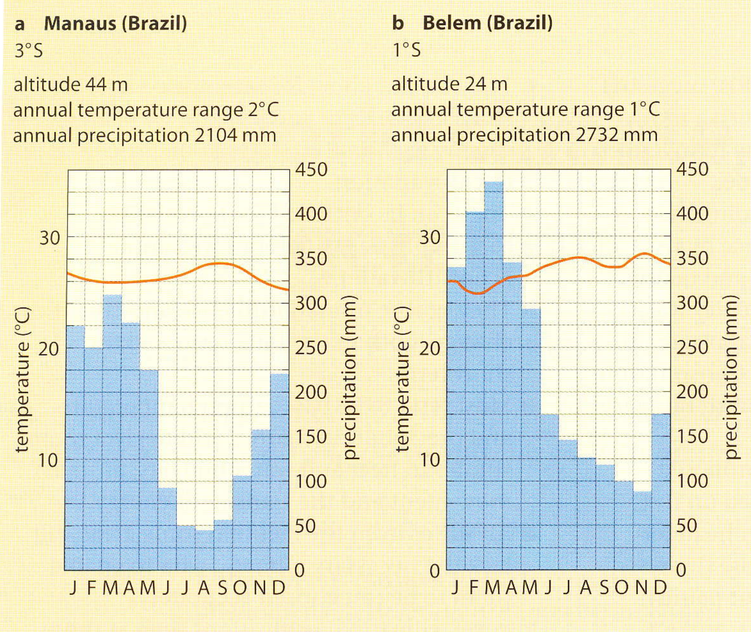


Figure 12.3

Climate graphs for the equatorial biome

1 Tropical rainforests

The rainforest biome is located in the tropics and principally within the equatorial climate belt, 5° either side of the Equator. It includes the Amazon and Congo basins and the coastal lands of Ecuador, West Africa, and extreme south-east Asia (Figure 11.38).

Equatorial climate

Temperatures are high and constant throughout the year because the sun is always high in the sky. The annual temperature range is under 3°C inland (Manaus, Figure 12.3a) and 1°C on the coast (Belem, Figure 12.3b). Mean monthly temperatures, ranging from 26°C to 28°C, reflect the lack of seasonal change. Slightly higher temperatures may occur during any 'drier' season. Insolation is evenly distributed throughout the year, with each day having approximately 12 hours of daylight and 12 hours of darkness. The diurnal temperature range is also small, about 10°C. Evening temperatures rarely fall below 22°C while, due to the presence of afternoon cloud, daytime temperatures rarely rise above 32°C. It is the high humidity, with its sticky, unhealthy heat, that is least appreciated by Europeans.

Annual rainfall totals usually exceed 2000 mm (Belem, 2732 mm) and most afternoons have a heavy shower (Belem has 243 rainy days per year). This is due to the convergence of the trade winds at the ITCZ and the subsequent enforced ascent of warm, moist, unstable air in strong convection currents (Figure 9.34). Evapotranspiration is rapid from the many rivers, swamps and trees. Most storms are violent, with the heavy rain, accompanied by thunder and lightning, falling from cumulo-nimbus clouds. Some areas may have a drier season when the ITCZ moves a few degrees away from the Equator at the winter and summer solstices (Belem), and others have double maxima when the sun is directly overhead at the spring and autumn equinoxes. The high daytime humidity needs only a little night-time radiation to give condensation in the form of dew. The winds at ground-level at the ITCZ are light and variable (doldrums) allowing land and sea breezes to develop in coastal areas (page 240).

Rainforest vegetation

It is estimated that the rainforests provide 40 per cent of the net primary production of terrestrial energy (NPP, page 306). This is a result of high solar radiation, an all-year growing season, heavy rainfall, a constant moisture budget surplus, the rapid decay of leaf litter and the recycling of nutrients.

Figure 12.4

Emergents rising above the rainforest canopy, Borneo

Figure 12.5

Buttress roots, Queensland, Australia

Figure 12.6

Rainforest vegetation has to adapt to the wet environment: water lilies, *Victoria regia*, native to the Amazon Basin

In just one hectare of rainforest in Amazonian Ecuador, researchers recorded 473 species of tree, including rosewood, mahogany, ebony, greenheart, palm and rubber, which is more than twice the total number found in all of North America.

The trees, which are mainly hardwoods, have an evergreen appearance for, although deciduous, they can shed their leaves at any time during the continuous growing season. The tallest trees, **emergents**, may reach up to 50 m in height and form the habitat for numerous birds and insects. Below the emergents are three layers, all competing for sunlight (Figure 12.4).

The top layer, or **canopy**, forms an almost continuous cover which absorbs over 70 per cent of the light and intercepts 80 per cent of the rainfall. The crowns of these trees merge some 30 m above ground-level. They shade the underlying species, protect the soil from erosion, and provide a habitat for most of the birds, animals and insects of the rainforest.

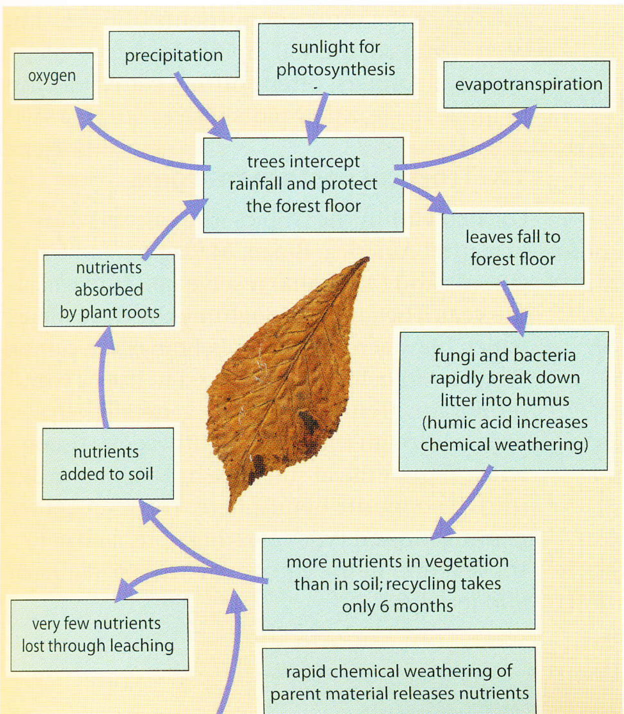
The second layer, or **undercanopy**, consists of trees growing up to 20 m (similar in height to deciduous trees in Britain). The lowest, or **shrub layer**, consists of shrubs and small trees which are adapted to living in the shade of their taller neighbours.

The climate is at the optimum for photosynthesis. The trees grow tall to try to reach the sunlight, and the tallest have buttress roots which emerge over 3 m above ground-level to give support (Figure 12.5). The trunks are usually slender and branchless. Some, like the cacao, have flowers growing on them, and their bark is thin as there is no need for protection against adverse climatic conditions. Tree trunks also provide support for lianas, vine-like plants, which can grow to 200 m in length. Lianas climb up the trunk and along branches before plunging back down to the forest floor. Leaves are dark green, smooth and often have **drip tips** to shed excess water.

Epiphytes – plants that do not have their roots in the soil – grow on trunks, branches and even on the leaves of trees and shrubs. Epiphytes simply 'hang on' to the tree: they derive no nourishment from the host and are *not* parasites. Less than 5 per cent of insolation reaches the forest floor, with the result that undergrowth is thin except in areas where trees may have been felled by shifting cultivators or where a giant emergent has fallen, dragging with it several of the top canopy trees. Vegetation is also dense along the many river banks, again because sunlight can penetrate the canopy here. Alongside the Amazon, many trees spend several months of the year growing in water as the river and its tributaries rise over 15 m in the rainy season. Huge water lilies with leaves exceeding 2 m in width are found in flooded areas adjacent to rivers (Figure 12.6). Mangrove swamps occur in coastal areas.

Figure 12.7

The rainforest nutrient cycle



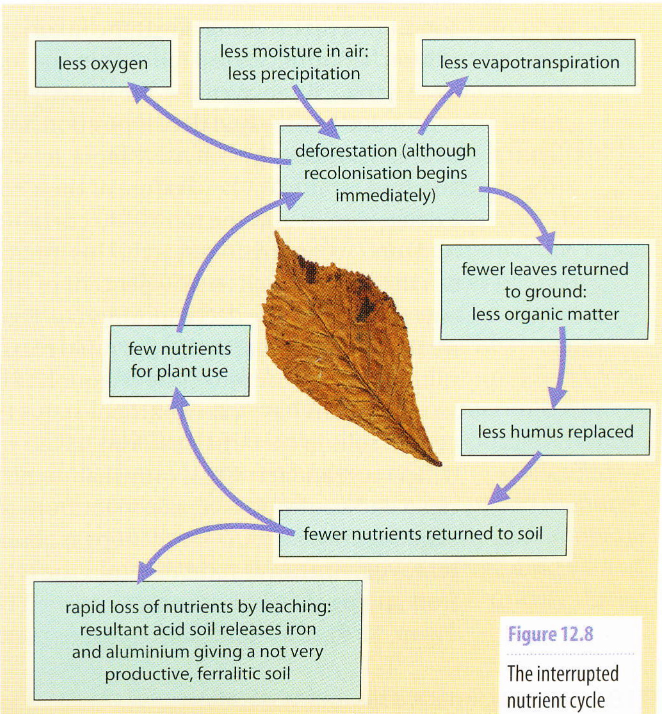


Figure 12.8

The interrupted nutrient cycle

Figure 12.9

A ferralitic soil profile

Although ground animals are relatively few in number, the rainforests of Brazil alone are said to be the habitat for 2000 species of birds, 600 species of insects and mosquitoes, and 1500 species of fish.

The productivity of this biome, upon which the world depends to replace much of its used oxygen, is due largely to the rapid and unbroken recycling of nutrients. Figure 12.7 shows the natural nutrient cycle and Figure 12.8 the consequences of breaking the system, e.g. by felling the forest. In areas where the forest has been cleared, the secondary succession differs from that of the original climax vegetation. The new dominants are less tall;the trees are less stratified; there are fewer species and many are intolerant of shade – even though there is more light at ground-level which encourages a dense undergrowth.

Ferralitic soils (latosols)

These soils result from the high annual temperature and rainfall which cause rapid chemical weathering of bedrock and create the optimum conditions for breaking down the luxuriant vegetation. Continuous leaf fall within the forest gives a thick litter layer, but the underlying humus is thin due to the rapid decomposition and mixing of organic matter by intensive biota activity, e.g. ants and termites. A key feature of these soils is a dense root mat in the top 20–30 cm of the *A* horizon. According to research, this intercepts and can take up as much as 99.9 per cent of the nutrients released by the decomposition of organic matter. The root map helps the rapid recycling of nutrients in the humus cycle (Figure 12.7). Even so, many soils have a low nutrient status (94 per cent of soils in the Amazon Basin have a nutrient deficiency) and fertility is only maintained by the rapid and continuous replacement from the lush vegetation. Where the tree canopy is absent, or is removed, the heavy rainfall causes the release of iron (giving the soil its characteristic red colour – Figure 12.9) and aluminium (most ferralitic soils

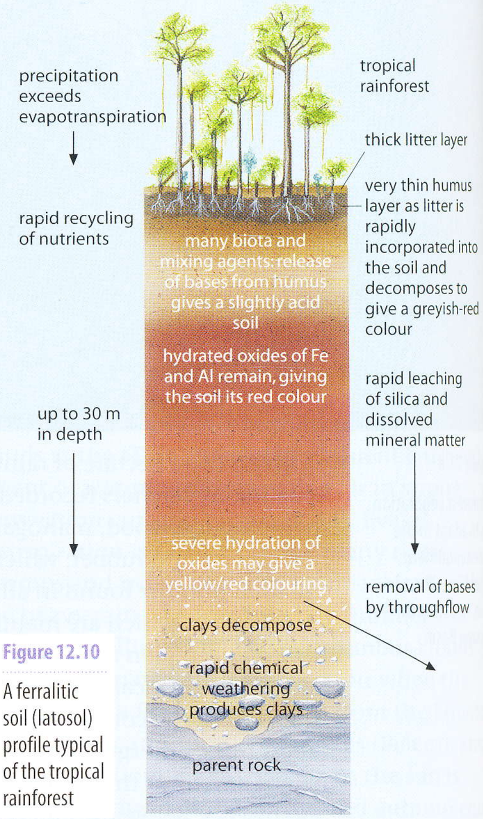


Figure 12.10

A ferralitic soil (latosol) profile typical of the tropical rainforest

suffer from aluminium toxicity) from the parent material. Leaching results in the removal of silica.

The continual leaching and abundance of mixing agents inhibit the formation of horizons (Figure 12.10). The lower parts of the profile may have a more yellowish-red tint due to the extreme hydration of aluminium and iron oxides. The clay-rich soils are also very deep, often up to 20 m, due to the rapid breakdown of parent material. Ferralitic soils have a loose structure and, if exposed to heavy rainfall, are easily gullied and eroded. Despite their depth, the soils of the rainforest are not agriculturally productive. Once the source of nutrients (the trees) has been removed, the soil rapidly loses its fertility and local farmers, often shifting cultivators, have to move to clear new plots (Places 66, page 480).

1A Tropical eastern margins

Located within the tropics, the eastern coasts of central America, Brazil, Madagascar and Queensland (Australia) receive rain throughout the year. The rain is brought by the trade winds which blow across warm, offshore ocean currents (Figure 9.9) before being forced to rise by coastal mountains. Temperatures are generally very high, although there is a slightly cooler season when the overhead sun appears to have migrated into the opposite hemisphere. The resultant vegetation and soil types are, therefore, similar to those found in the equatorial belt, i.e. rainforest and ferralitic.

2 Tropical grasslands

These are mainly located between latitudes 5° and 15° north and south of the Equator and within central parts of continents, i.e. the Llanos (Venezuela), the Campos (Brazilian Highlands), most of central Africa surrounding the Congo Basin, and parts of Mexico and northern Australia (Figure 11.38).

Tropical continental climate

Although temperatures are high throughout the year, there is a short, slightly cooler season (in comparison with the equatorial) when the sun is overhead at the tropic in the opposite hemisphere (Figure 12.11). The annual range is also slightly greater (Kano 8°C) due to the sun's slightly reduced angle in the sky for part of the year, the greater distance from the sea, and the less complete cloud and vegetation cover. Temperatures may drop slightly at the onset of the rainy season. For most of the year, cloud amount is limited, allowing diurnal temperatures to exceed 25°C.

The main characteristic of this climate is the alternating wet and dry seasons. The wet season occurs when the sun moves overhead bringing with it the heat equator, the ITCZ, and the equatorial low pressure belt (Figure 12.12). Heavy convectional storms can give 80 per cent of the annual rainfall total in four or five months. The dry season corresponds with the moving away of the ITCZ, leaving the area with the strong, steady trade winds. The trades are dry because they are warming as they blow towards the Equator and they will have shed any moisture on distant eastern coasts. Places nearer to the desert margins tend to experience dry, stable conditions (the subtropical high pressure) caused by the migration of the descending limb of the Hadley cell (page 226). Humidity is also low during this season.

Figure 12.11

Climate graph for a tropical continental biome

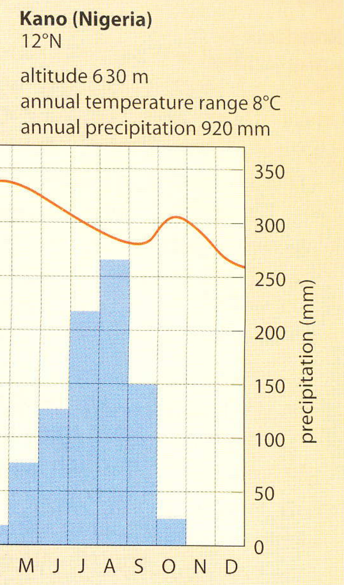
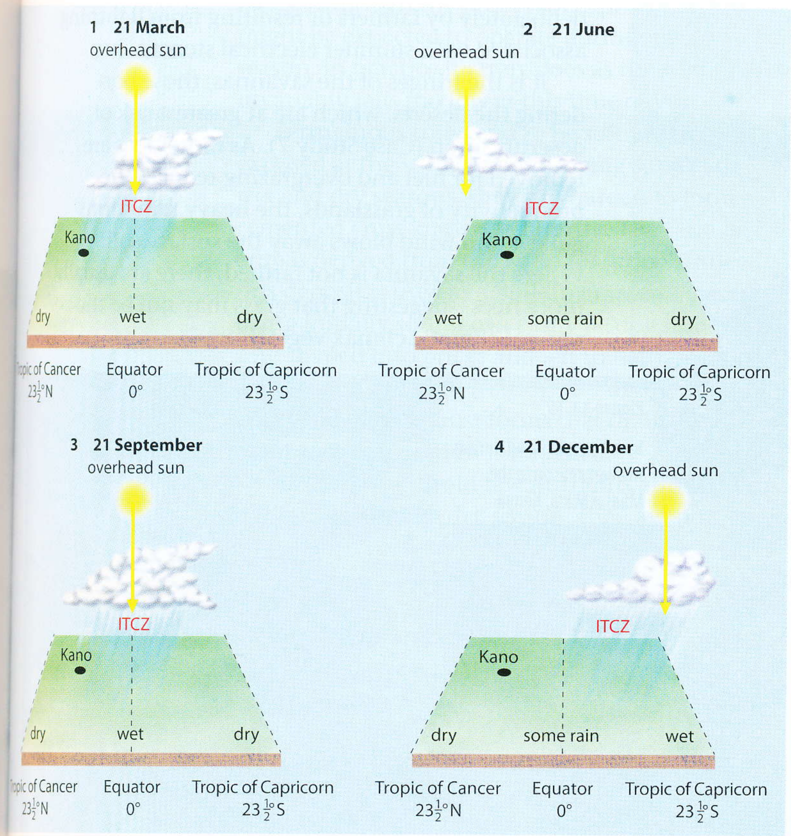


Figure 12.12

Causes of seasonal rainfall in places with a tropical continental (savanna) climate



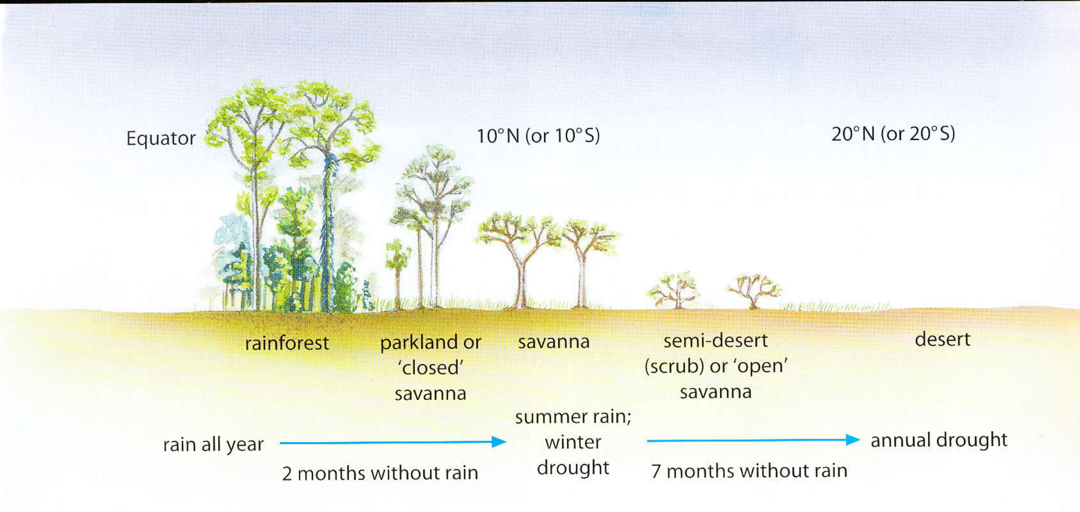
Tropical or savanna grassland vegetation

The tropical grasslands are estimated to have a mean NPP of 900 $g/m^2/yr$ (page 306). This is considerably less than the rainforest, partly because of the smaller number of trees, species and layers and partly because, although grasslands have the potential to return organic matter back to the soil, the rate of decomposition is reduced during the winter drought leaving considerable amounts left stored in the litter.

As shown in Figure 12.13, the savanna includes a series of transitions between the rainforest and the desert. At one extreme, the 'closed' savanna is mainly trees with areas of grasses; at the other, the 'open' savanna is vegetated only by scattered tufts of grass. The trees are deciduous and, like those in Britain, lose their leaves to reduce transpiration, but, unlike in Britain, this is due to the winter drought rather than to cold. Trees are xerophytic, or drought-resistant. Even when leaves do appear, they are small, waxy and sometimes thorn-like. Roots are long and extend to tap any underground water. Trunks are gnarled and the bark is usually thick to reduce moisture loss.

Figure 12.13

Transect across the savanna grasslands



The baobab tree (also known as the 'upside-down tree') has a trunk of up to 10 m in diameter in which it stores water. Its root-like branches hold only a minimum number of tiny leaves in order to restrict transpiration (Figure 12.14). Some baobabs are estimated to be several thousand years old and, like other savanna trees, are pyrophytic, i.e. their trunks are resistant to the many local fires. Acacias, with their crowns flattened by the trade winds (Figure 12.15), provide welcome though limited shade – as do the eucalyptus in Australia. Savanna trees reach 6–12 m in height. Many have Y-shaped, branching trunks – ideal for the leopard to rest in after its meal! The number of trees increases near to rivers and waterholes. Grasses grow in tufts and tend to have inward-curving blades and silvery spikes. After the onset of the summer rains, they grow very quickly to over 3 m in height: elephant grass reaches 5 m (Figure 12.15). As the sun dries up the vegetation, it becomes yellow in colour (Figure 12.46). By early winter, the straw-like grass has died down, leaving seeds dormant on the surface until the following season's rain. By the end of winter, only the roots remain and the surface is exposed to wind and rain.

Over 40 different species of large herbivore graze on the grasslands, including wildebeest, zebra and antelope, and it is the home of several carnivores – both predators, such as lions, and scavengers, such as hyenas. Termites and microbes are the major decomposers. As previously mentioned (page 293), fire is possibly the major determinant of the savanna biome – either caused deliberately by farmers or resulting from lightning associated with summer electrical storms.

It is the fringes of the savannas, those bordering the deserts, which are at greatest risk of desertification (Case Study 7). As more trees are removed for fuel and overgrazing reduces the productivity of grasslands, the heavy rain forms gulleys and wind blows away the surface soil. Where the savanna is not farmed, there are usually more trees, suggesting that grass may not be the natural climatic climax vegetation.

Figure 12.14

A baobab tree, Malawi

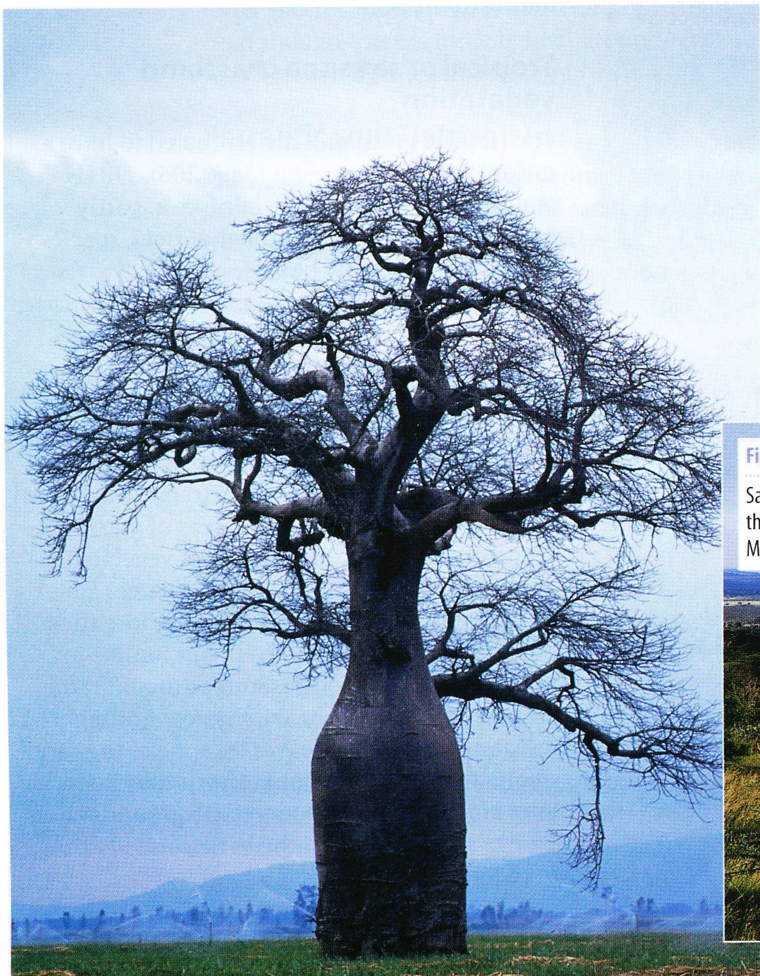
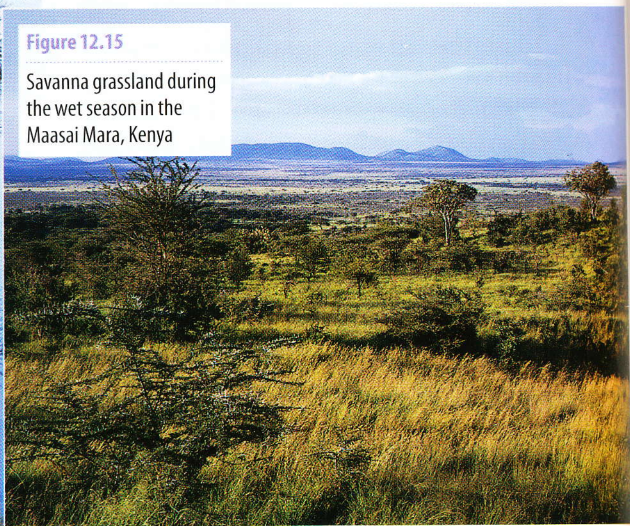


Figure 12.15

Savanna grassland during the wet season in the Maasai Mara, Kenya



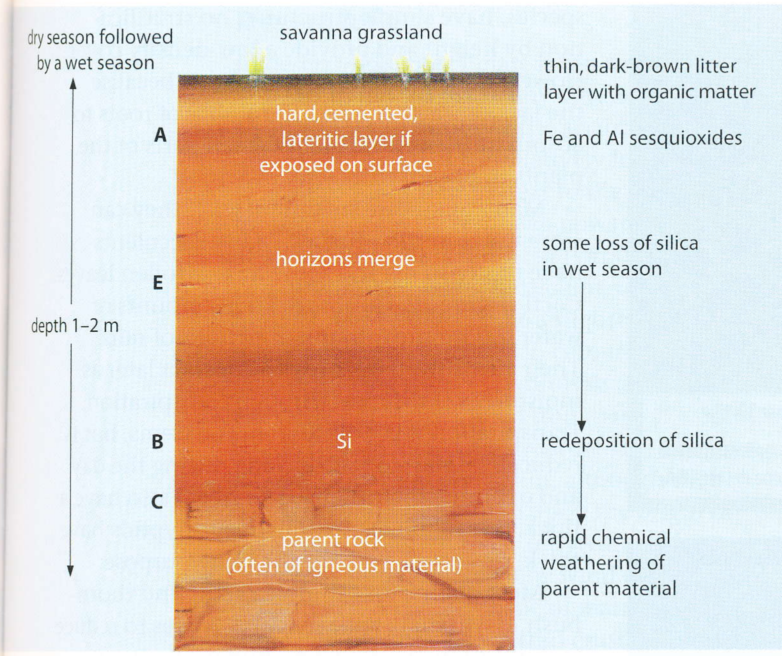


Figure 12.16

A ferruginous soil profile

Ferruginous soils

As savanna grasses die back during the dry season, they provide organic matter which is readily broken down to give a thin, dark-brown layer of humus (Figure 12.16). During the wet season, rapid leaching removes silica from the upper profile, leaving behind the red-coloured oxides of iron and aluminium. As these soils contain few nutrients, they tend to be acidic and lacking in bases. Although the process of capillary action might be expected to operate during the dry season, in practice it rarely does as the water table invariably falls too low at this time of year.

Ferruginous soils tend to be soft unless exposed at the surface where, being subject to wet and dry seasons, they can harden to form a cemented crust known as **laterite**. The term laterite is derived from the Latin for 'brick'. Indeed this deposit is used as a building material because, being initially soft, it can easily be dug from the soil, shaped into bricks and left to harden by exposure to cycles of wetting and drying. It is only when the laterite crust forms that drainage and plant root penetration is impeded.

As these soils hold few nutrients and tend to dry out during the dry season, they are not particularly suited to agriculture; together with the grassland they support, they are better suited to animal rearing than to arable farming. Where a lateritic crust forms on the surface, or when deep ploughing removes the surface vegetation, the upper soil tends to dry out during the dry season, becoming highly vulnerable to erosion by wind and, when the rains return, by water.

3 Hot deserts

The hot deserts of the Atacama and Kalahari-Namib and those in Mexico and Australia, are all located in the trade wind belt, between 15° and 30° north or south of the Equator, and on the west coasts of continents where there are cold, off-shore, ocean currents (Figures 7.2, 9.9 and 11.38). The exception is the extensive Sahara-Arabian-Thar desert which owes its existence to the size of the Afro-Asian landmass.

Climate

Desert temperatures are characterised by their extremes. The annual range is often 20–30°C and the diurnal range over 50°C (Figure 12.17). During the daytime, especially in summer, there are high levels of insolation from the overhead sun, intensified by the lack of cloud cover and the bare rock or sand ground surface. In contrast, nights may be extremely cold with temperatures likely to fall below 0°C. Coastal areas, however, have much lower monthly temperatures (Arica in the Atacama has a warmest month of only 22°C) due to the presence of offshore, cold, ocean currents (Figure 9.9).

Although all deserts suffer an acute water shortage, none is truly dry. Aridity and extreme aridity have been defined by using Thornthwaite's P/E index (Figure 7.1), and four of the main causes of deserts are described on page 179. Amounts of moisture are usually small and precipitation is extremely unreliable. Death Valley, California, averages 40 mm a year, yet rain may fall only once every two or three years. Whereas mean annual totals vary by less than 20 per cent a year in north-west Europe, the equivalent figure for the Sahel is 80–150 per cent (Figure 9.28). Rain,

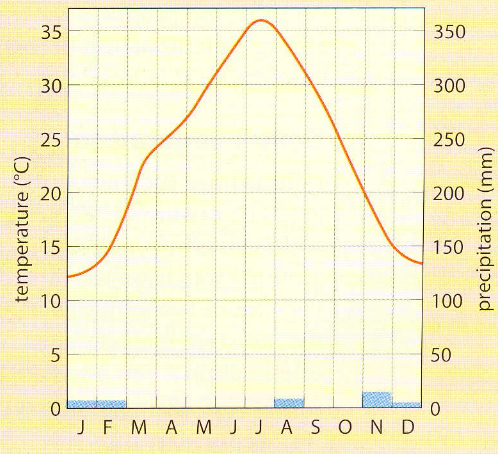


Figure 12.17

Climate graph for a hot desert biome

Figure 12.18

Saguaros cacti in the Arizona desert, USA

Figure 12.19

Ephemerals in flower following a desert rainstorm

when it does fall, produces rapid surface runoff which, together with low infiltration and high evaporation rates, minimises its effectiveness for vegetation. The Atacama, an almost rainless desert, has some vegetation as moisture is available in the form of advection fog (Places 24, page 180). The subsiding air, forming the descending limb of the Hadley cell, creates high pressure and produces the trade winds which are strong, persistent and likely to cause localised dust storms (Figures 7.9 and 9.34).

Desert vegetation

Deserts have the lowest organic productivity levels of any biome (Figure 11.40). The average NPP is 90 g/m^2/yr, most of which occurs underground away from the direct heat of the sun. Vegetation has to have a high tolerance to the moisture budget deficit, intense heat and, often, salinity. Few areas are totally devoid of vegetation, although desert plants are few in species, have simple structures, no stratification by height and provide a low-density cover. However, plants must be xerophytic because the lack of water hinders the ability of roots to absorb nutrients and of any green parts of the plants to photosynthesise.

Many plants are **succulents**, i.e. they can store water in their tissues. Many succulents have fleshy stems and some have swollen leaves. Cacti (Figure 12.18) absorb large amounts of water during the infrequent periods of rain. Their stems swell up, only to contract later as moisture is slowly lost through transpiration. Transpiration takes place from the stems, but is reduced by the stomata closing during the day and opening nocturnally. The stems also have a thick, waxy cuticle. Australian eucalyptids have thick, protective bark for the same purpose.

Most plants, for example cactus and thornbush, have small, spiky or waxy leaves to reduce transpiration and to deter animals. Roots are either very long to tap groundwater supplies – those of the acacia exceed 15 m – or they spread out over wide areas near to the surface to take the maximum advantage of any rain or dew, like those of the creosote bush. Bushes are, therefore, widely spaced to avoid competition for water. Some plants have bulbous roots for storing water. Seeds, which usually have a thick case protecting a pulpy centre, can lie dormant for months or several years until the next rainfall.

Following a storm, the desert blooms (Figure 12.19). Many plants are **ephemerals** and can complete their life-cycles in two or three weeks. Others, like the saltbush, are **halophytic** and can survive in salty depressions; yet others, like the date-palm, survive where the water table is near enough to the surface to form oases. Due to the lack of grass and the limited number of green plants, there are very few food chains: desert biomes have a low capacity to sustain life. There is insufficient plant food to support an abundance of animal life. Food chains (page 296) are simple, often just a single linear sequence (in contrast to the interlocking webs characteristic of, for example, forests). This is why the desert ecosystem is 'fragile': organisms do not have the alternative sources of food which are available in more complex ecosystems. Many animals are small and nocturnal (the camel is an exception) and burrow into the sand during the heat of the day. Reptiles are more adaptable, but bird life is limited. The desert fringes form a delicately balanced ecosystem which is being disturbed by human activity and population growth which are, together, increasing the risk of desertification (Case Study 7).

Desert soils

In desert areas, the climate is too dry and the vegetation too sparse for any significant chemical weathering of bedrock or the accumulation of organic material. In the relatively few places where the water table is near to the surface, soil moisture is likely to be drawn upwards by capillary action. This process causes salts and bases, such as magnesium, sodium and calcium, to be deposited in the upper profile to give a slightly alkaline soil. Many desert soils are grey in colour as the lack of moisture often restricts hydrolysis and, therefore, the release of red-coloured iron (page 42). Soils, which tend to lack both structure and horizons (Figure 12.20), are often thin, although their depth can vary depending upon the origin of the parent material, i.e. *in situ* weathering or the deposition of material by wind or water (Chapter 7). A characteristic of many desert soils is the presence of either a thin crust, 2 to 3 mm thick, caused by the impact of high-intensity rainfall, and/or a 'desert pavement' (Figure 7.10) which consists of small stones, often ventifacted and covered in desert varnish (page 182), which help stabilise the surface.

Desert soils are unproductive mainly because of the lack of moisture and humus, but potentially they are not particularly infertile. Areas under irrigation are capable of producing high-quality crops, although this farming technique is being threatened by salinisation (Figures 10.22 and 16.53).

4 Mediterranean (warm temperate, western margins)

This type of biome is found on the west coasts of continents between 30° and 40° north and south of the Equator, i.e. in Mediterranean Europe (which is the only area where the climate penetrates far inland), California, central Chile, Cape Province (South Africa) and parts of southern Australia (Figure 11.38).

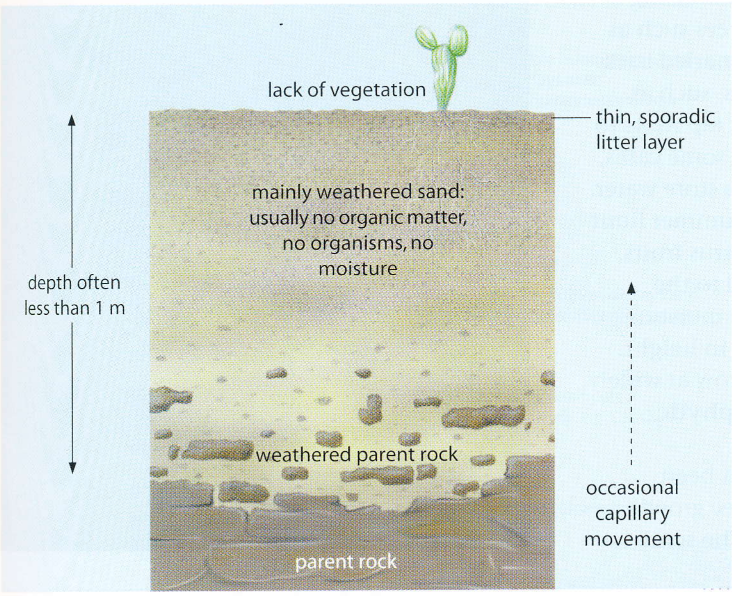
Climate

The climate is noted for its hot, dry summers and warm, wet winters (Figure 12.21). Summers in southern Europe are hot. The sun is high in the sky, though never directly overhead, and there is little cloud. Winters are mild, partly because the sun's angle is still quite high but mainly due to the moderating influence of the sea. Other 'Mediterranean' areas are less warm in summer and have a smaller annual range due to cold, offshore currents (compare San Francisco, 8°C in January and 15°C in July, with Malta). Diurnal temperature ranges are often high due to the fact that many days, even in winter, are cloudless.

As the ITCZ moves northwards in the northern summer, the subtropical high pressure areas migrate with it to affect these latitudes. The trade winds bring arid conditions, with the length of the dry season increasing towards the desert margins. In winter, the ITCZ, and subsequently the subtropical jet stream (page 228), move southwards allowing the westerlies, which blow from the sea, to bring moisture. Most areas are backed by coastal mountains and so the combined effects of orographic and frontal precipitation give high seasonal totals. Areas with adjacent, cold, offshore currents experience advection fogs (California). The Mediterranean Sea region is noted for its local winds (Figure 12.22). The **sirocco** and **khamsin** are two of the hot, dry winds that blow from the

Figure 12.20

A desert soil profile



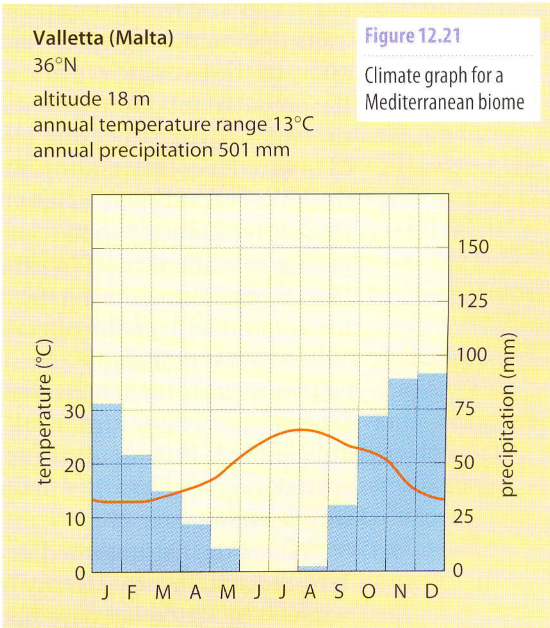


Figure 12.21

Climate graph for a Mediterranean biome

Figure 12.22

Mediterranean winds

Sahara and can raise temperatures to over 40°C. The **mistral** is a cold wind which originates over the Alps and is funnelled at considerable speed down the Rhône valley.

Vegetation

The NPP of Mediterranean ecosystems is about 700 g/m^2/yr (Figure 11.40). It is limited by the summer drought and has probably been reduced considerably over the centuries by human activity. Indeed, human activity, together with frequent fires, has left very little of any original climatic climax vegetation. The climax vegetation was believed to have been, in Europe at least, open woodland comprising a mixture of broad-leaved, evergreen trees (e.g. cork oak and holm oak) and conifers (e.g. aleppo pines, cypresses and cedars). The sequoia, or giant redwood, is native in California.

The present vegetation, which is mainly **xerophytic** (drought-resistant), is described as 'woodland and sclerophyllous scrub'. **Sclerophyllous** means 'hard-leaved' and is used to describe those evergreen trees or shrubs that have small, hard, leathery, waxy or even thorn-like leaves and which are efficient at reducing transpiration during the dry summer season. Many of the trees are evergreen, maximising the potential for photosynthesis. Trees such as the cork oak have thick and often gnarled bark to help reduce transpiration. Others, such as the olive and eucalyptus, have long tap roots to reach groundwater supplies and, in some cases, may have bulbous roots in which to store water. High temperatures during the dry summer limit the amount and quality of grass. Citrus fruits, although not indigenous, are suited to the climate as their thick skins preserve moisture. Most trees only grow from 3 to 5 m in height. They provide little shade, as they grow at widely spaced intervals, and they are **pyrophytic** (fire-resistant, page 293).

Where the natural woodland has been replaced, and in areas too dry for tree growth, a scrub vegetation has developed. The scrub is known as *chaparral* in California, *maquis* or *garrigue* in Europe, *fynbus* in South Africa and *mallee* in Australia. In Mediterranean Europe, the type of scrub depends on the underlying parent rock. **Maquis** (Figure 12.23), which is taller, denser and more tangled, grows in areas of impermeable rock (granite). It consists of shrubs, such as heathers and broom, which reach a height of 3 m. **Garrigue** (Figure 12.24) grows on drier and more permeable rocks (limestone). It is less tall and less dense than maquis. Apart from gorse, with its prickles, the more common plants include aromatic shrubs such as thyme, lavender and rosemary.

The limited leaf litter tends to decompose slowly during the dry summer, even though temperatures are high enough for year-round bacterial activity. Wildlife and climax vegetation have retreated as human activity has advanced. Arguably, the Mediterranean regions of Europe and California (together with the temperate deciduous forests) form the biome most altered by human activity.

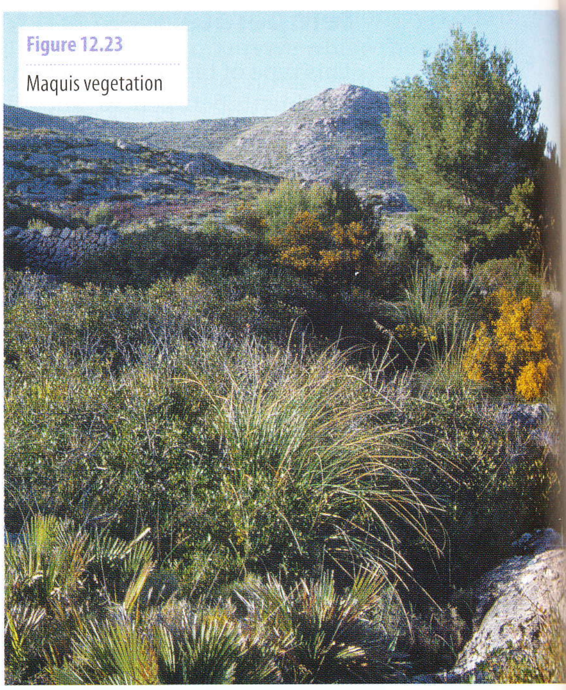


Figure 12.23

Maquis vegetation

Figure 12.24
Garrigue vegetation

Soils

Mediterranean soils are transitional between brown earths on the wetter margins and desert soils at the drier fringes. Initially formed under broad-leaved and coniferous woodland, the soil is partly a relict feature from a previously forested landscape.

There are often sufficient roots and decaying plant material to provide a significant humus layer. Winter rains cause some leaching of bases, sesquioxides of iron and aluminium and the translocation of clays. The *B* horizon is therefore clay-enriched and may be coloured a bright red by the redeposition of iron and aluminium. The soils, which are often thin, are less acid than the brown earths as there is less leaching in the dry season and calcium is often released, especially in limestone areas (Figure 12.25).

In many Mediterranean areas, parent rock is locally a more important factor in soil formation than climate. This leads to the development of intrazonal soils such as rendzina and terra rossa (Figures 10.23 and 10.24).

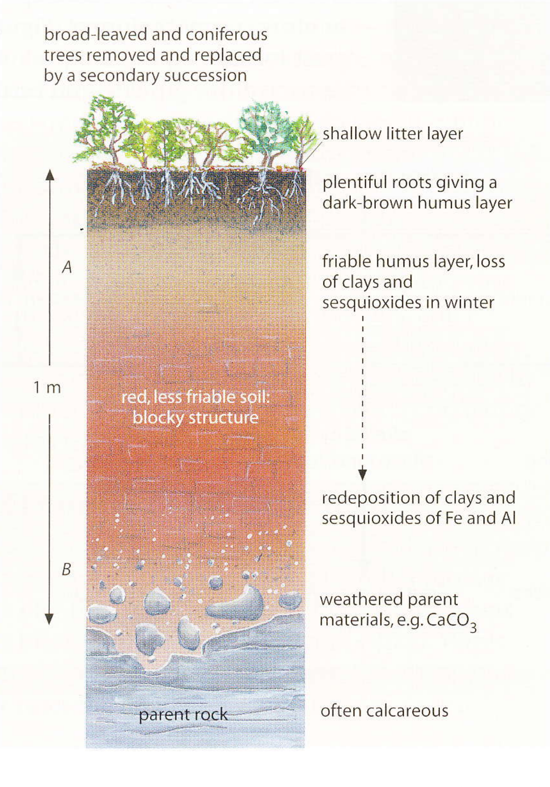


Figure 12.25
A Mediterranean soil profile

4A Eastern margin climates in Asia (monsoon)

South-east and eastern Asia are dominated by the monsoon (page 239). Temperature figures and rainfall distributions are similar to those of places having a tropical continental climate with a very warm and dry season from November to May and a hot and very wet season from June to October (Places 32, page 240). The major difference between the two climates is that monsoon areas receive appreciably higher annual amounts of rain. The natural vegetation is jungle (tropical deciduous forest) and the dominant soil type is ferralitic. Both vegetation and soils, therefore, share many similarities with the tropical rainforest.

5 Temperate grasslands

The temperate grassland biome lies in the centre of continents approximately between latitudes 40° and 60° north of the Equator. The two main areas are the North American Prairies and the Russian Steppes (Figure 11.38).

Cool temperate continental climate

The annual range of temperature is high as there is no moderating influence from the sea (38°C at Saskatoon, Figure 12.26). The land warms up rapidly in summer to give maximum mean monthly readings of around 20°C. However, the rapid radiation of heat from mid-continental areas in winter means there are several months when the temperature remains below freezing point. The clear skies also result in a large diurnal temperature range.

In Russia, precipitation decreases rapidly towards the east as distance from the sea – and therefore from the rain-bearing winds – increases; in North America, however, totals are lowest to the west which is directly in the rainshadow of the Rockies. Annual amounts in both areas only average 500 mm and there is a threat of drought, as experienced in North America in 1988. Although, fortuitously, 75 per cent of

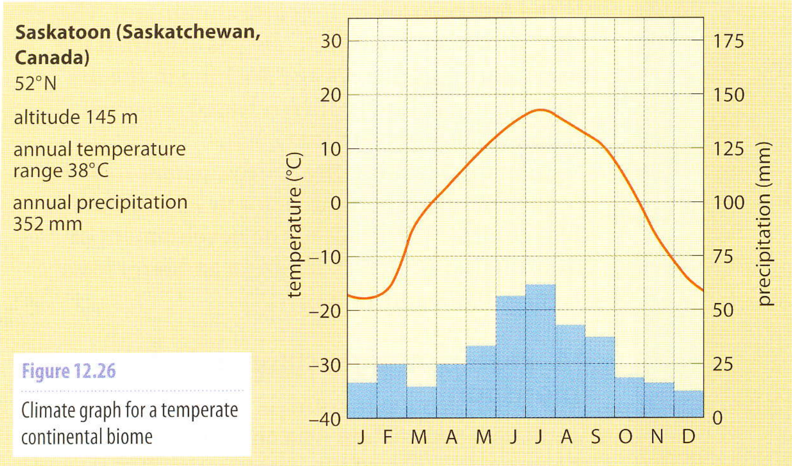


Figure 12.26
Climate graph for a temperate continental biome

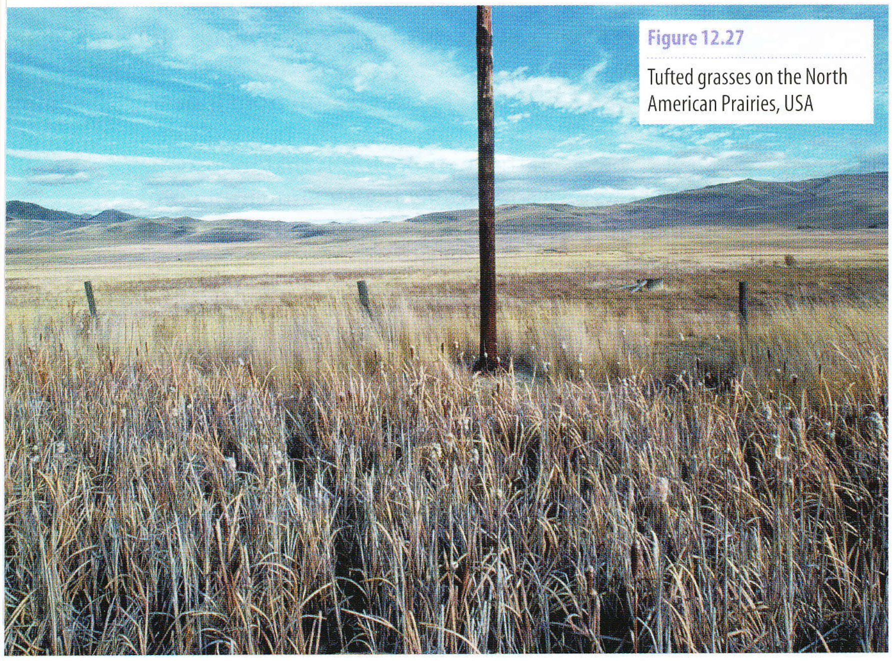


Figure 12.27
Tufted grasses on the North American Prairies, USA

precipitation falls during the summer growing season, it can occur in the form of harmful thunderstorms and hailshowers. The ground can be snow-covered for several months between October and April. Overall, there is a close balance between precipitation and evapotranspiration. In winter, both areas are open to cold blasts of arctic air, although the chinook may bring temporary warmer spells to the Prairies (page 241).

Temperate grassland vegetation

This type of vegetation lies to the south of the coniferous forest belt in the dry interiors of North America and Russia. Temperate grasslands are, however, also found sporadically in parts of the southern hemisphere, where they usually lie between 30° and 40°S. The Pampas (South America) and the Canterbury Plains (New Zealand) are towards the eastern coast, while the Murray–Darling basin (Australia) and the Veld (South Africa) are further inland. The NPP of 600 g/m^2/yr is considerably less than that of the tropical grasslands because the vegetation grows neither as rapidly nor as tall (Figure 11.40). Whatever the original climax vegetation of the biome may have been, the ecosystem has been significantly altered by fire and human exploitation to leave, today, grama and buffalo grass as the dominants. There are two main types of grass. Feather grasses grow to 50 cm and form a relatively even coverage, whereas tufted (tussock) grasses, reaching up to 2 m, are found in more compact clumps (Figure 12.27). The grass forms a tightly knit sod which may have restricted tree growth, and certainly made early

Figure 12.28
Land uses of the temperate grassland, a changed biome

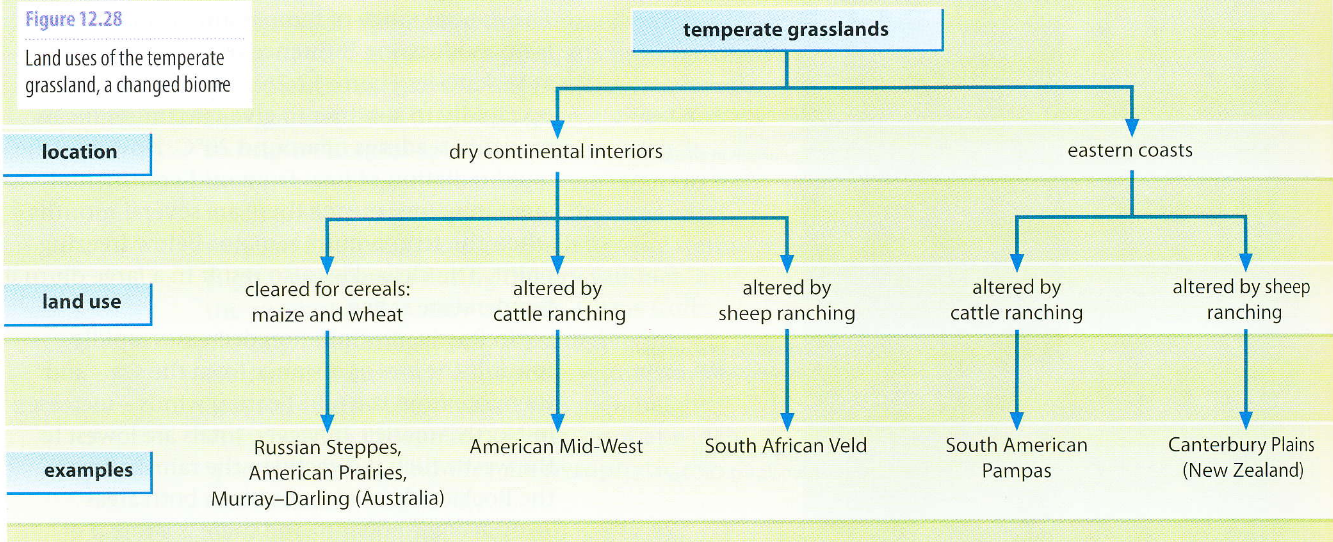


Figure 12.29

A chernozem (black earth) soil profile

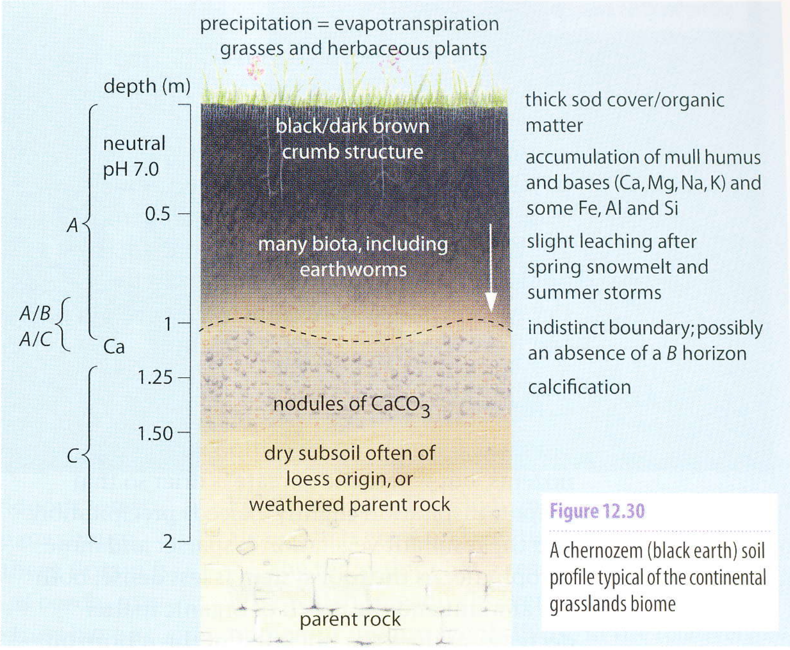


Figure 12.30

A chernozem (black earth) soil profile typical of the continental grasslands biome

ploughing difficult. The deep roots, which often extend to a depth of 2 m in order to reach the water table, help to bind the soil together and so reduce erosion. Most of the organic material is in the grass roots and it is the roots and rhizomes that provide the largest store of nutrients (Case Study 12B).

During autumn, the grasses die down to form a turf mat in which seeds lie dormant until the snowmelt, rains and higher temperatures of the following spring. Growth in early summer is rapid and the grasses produce narrow, inward-curving blades to limit transpiration. By the end of summer, their blue-green colour may have turned more parched. Herbaceous plants and some trees (willow) grow along water courses. In response to the windy climate, many prairie and steppe farms are protected by trees planted as windbreaks. The decay of grasses in summer causes a rapid accumulation of humus in the soil, making the area ideal for cereals or, in drier areas, for cattle ranching (Figures 12.27 and 12.28).

The temperate grasslands are a resilient ecosystem. The grasses provide food for burrowing animals such as rabbits and gophers, and for large herbivores such as antelopes, bison and kangaroos. These, in turn, may be consumed by carnivores (wolves and coyotes) or by predatory birds (hawks and eagles).

Chernozems or black earths

The thick grass cover and the importance of roots as a source of organic matter together provide a plentiful supply of mull humus which forms a black, crumbly topsoil (Figure 12.29). While the abundance of biota, especially earthworms, causes the rapid decay and mixing of organic matter during the warm summer, decomposition is arrested during drier spells and in the long, cold winter. Due to rapid mixing, humus is spread throughout the *A* horizon, and as a result of rapid decomposition there is effective recycling as the grasses take up and return nutrients to the soil. The late spring snowmelt and early summer storms cause some leaching (Figure 12.30), and bases such as potassium and magnesium may be slowly moved downwards. In late summer, and in places where the water table is near to the surface, capillary water may bring bases nearer to the surface to maintain a neutral or slightly alkaline soil (pH 7 to 7.5). The grasses have an extensive root system which gives a deep (up to 1 m) dark-brown to black *A* horizon.

The alternating dry and wet seasons immobilise iron and aluminium sesquioxides and clay within aggregates (peds) in the upper horizon and this, together with the large number of mixing agents, limits the formation of a recognisable *B* horizon. The subsoil, often of loess origin (page 136), is usually porous and this, together with the capillary moisture movement in summer, means that it remains dry. This upward movement of moisture causes calcium carbonate to be deposited, often in the form of nodules, in the upper *C* horizon.

Chernozems are regarded as the optimum soil for agriculture as they are deep, rich in organic matter, retain moisture, and have an ideal crumb structure with well-formed peds. After intensive ploughing, chernozems may require the addition of potassium and nitrates.

Prairie soils

These lie on the wetter margins of the chernozems and form a transition between them and the brown forest earths. As precipitation exceeds evapotranspiration, there is an absence of capillary action and the soil lacks the accumulation of calcium carbonate associated with chernozems. The *A/B* horizons tend to merge, as there is limited leaching and strong biota activity. Decaying grasses provide much organic material and the soils are ideal for cereal crops.

Chestnut soils

These are found in juxtaposition with the chernozems, but where the climate is drier so that evapotranspiration slightly exceeds precipitation and the resultant vegetation is sparser and more xerophytic. As the root system is less dense, both the amount and the depth of organic matter decrease, as does the thickness of the *A* horizon, and the colour becomes a lighter brown than in chernozems. Chestnut soils are more alkaline, due to increased capillary action, and suffer from more frequent summer droughts. Deposits of calcium carbonate are found near to the surface and the soil is generally shallower than a chernozem. Chestnut soils are agriculturally productive if aided by irrigation, but mismanagement can quickly lead to their exhaustion and erosion.

6 Temperate deciduous forests

Temperate deciduous forests are located on the west coasts of continents between approximately latitudes 40° and 60° north and south of the Equator. Apart from north-west Europe (which includes the British Isles), other areas covered by this biome include the north-west of the USA, British Columbia, southern Chile, Tasmania and South Island, New Zealand (Figure 11.38).

Cool temperate western margins climate

Summers are cool (Figure 12.31) with the warmest month between 15°C and 17°C. This is a result of the relatively low angle of the sun in the sky, combined with frequent cloud cover and the cooling influence of the sea. Winters, in comparison, are mild. Mean monthly temperatures remain a few degrees above freezing due to the warming effect of the sea, the presence of warm, offshore ocean currents and the insulating cloud cover. Diurnal temperature ranges are low; autumns are warmer than springs; and seasonal temperature variations depend on prevailing air masses (Figure 9.41).

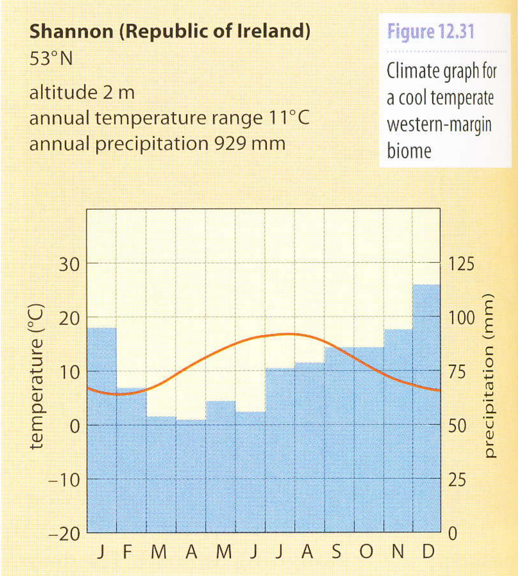


Figure 12.31 Climate graph for a cool temperate western-margin biome

This climatic zone lies at the confluence of the Ferrel and Polar cells (Figures 9.34 and 9.35), where tropical and polar air converge at the Polar Front. Warmer tropical air is forced to rise, creating an area of low pressure and forming depressions with their associated fronts. The prevailing south-westerlies, laden with vapour after crossing warm, offshore currents, give heavy orographic and frontal rain. Precipitation, often exceeding 2000 mm annually, falls throughout the year but with a winter maximum when depressions are more frequent and intense. Although snow is common in the mountains, it rarely lies for long at sea-level. Fog, most common in the autumn, forms under anticyclonic conditions (page 234).

Deciduous forests

Although having the second-highest NPP of all biomes (1200 g/m^2/yr), the temperate deciduous forest falls well short of the figure for tropical rainforests, mainly because of the dormant winter season when the deciduous trees in temperate latitudes shed their leaves (Figure 11.40). Leaf fall has the effect of reducing transpiration when colder weather reduces the effectiveness of photosynthesis and when roots find it harder to take up water and nutrients.

In Britain, oaks, which can reach heights of 30 to 40 m, became the dominant species as the climax vegetation developed through a series of several primary successions (Figure 11.4). Other trees, such as the elm (common before its population was diminished by Dutch elm disease), beech, sycamore, ash and chestnut, grow a little less tall. They all develop large crowns and have broad but thin leaves (Figure 12.32). Unlike

Figure 12.32

Broad-leaved deciduous oak woodland in Surrey, England

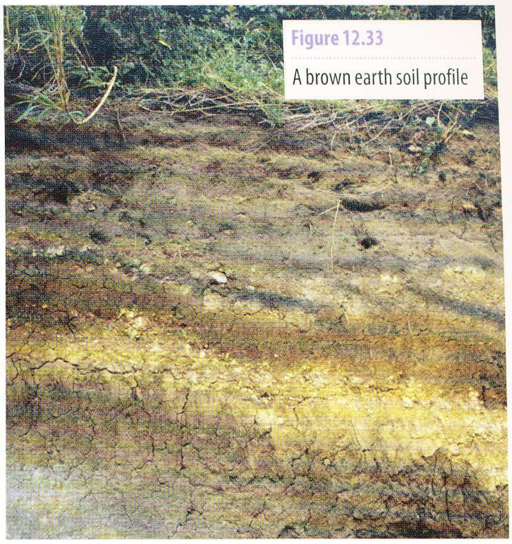


Figure 12.33

A brown earth soil profile

the rainforests, the temperate deciduous forests contain relatively few species. The maximum number of species per km^2 in southern Britain is eight, and some woodlands, such as beech, may only have a single dominant. The trees have a growing season of 6 to 8 months in which to bud, leaf, flower and fruit, and may only grow by about 50 cm a year.

Most woodlands show some stratification (Figure 11.2). Beneath the canopy is a lower shrub layer varying between 5 m (holly, hazel and hawthorn) and 20 m (ash and birch). This layer can be quite dense because the open mosaic of branches of the taller trees allows more light to penetrate than in the rainforests. The forest floor, if the shrub layer is not too dense, is often covered in a thick undergrowth of brambles, grass, bracken and ferns. Many flowering plants (bluebells) bloom early in the year before the taller trees have developed their full foliage.

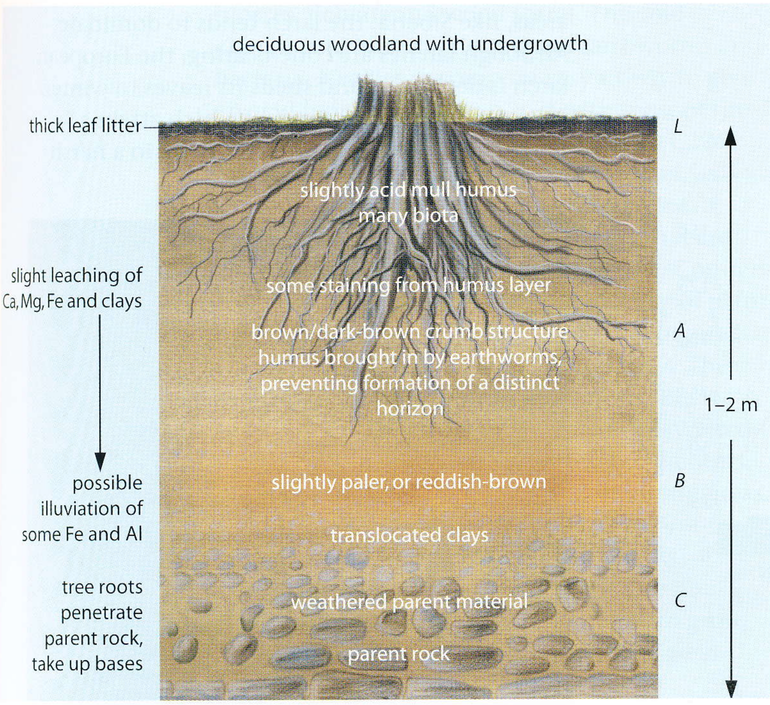


Figure 12.34

A brown earth soil profile typical of a temperate deciduous woodland biome

Epiphytes, which include mosses, lichens and algae, often grow on tree trunks.

The forest floor has a reasonably thick leaf litter which is readily broken down by the numerous mixing agents living in the relatively warm soil. There is a rapid recycling of nutrients, although some are lost through leaching. The leaching of humus and nutrients and the mixing by biota produce a brown-coloured soil. Soil type contributes to determine the dominant tree: oaks and elms prefer loams; beech the more acid gravels and the drier chalk; ash the lime-rich soils; and willows and alder wetter soils. There is a well-developed food chain in these forests, with many autotrophs, herbivores (rabbits, deer and mice) and carnivores (foxes).

Most of Britain's natural primary deciduous woodland has been cleared for farming, for use as fuel and in building, and for urban development. Deciduous trees give way to conifers towards polar latitudes and where there is an increase in either altitude or steepness of slope.

Brown earths

The considerable leaf litter, which accumulates in autumn, decomposes relatively quickly due to the activity of soil biota. Organic matter is incorporated as mull into the *A* horizon by the action of earthworms, giving it a dark-brown colour (Figure 12.33). Precipitation exceeds evapotranspiration sufficiently to allow leaching. Bases, especially calcium and magnesium, are absent in the upper horizons and, in some instances, there may be a loss of clay and sesquioxides (Figure 12.34). Because there is greater biota activity, the horizons merge more gradually than in a podsol (Figure 12.39), while the colour may become increasingly reddish-brown with depth if iron and aluminium are redeposited.

Brown earths tend to be free-draining as they do not have a hard pan. There is considerable recycling as the deciduous trees take up large amounts of nutrients from the soil in summer, only to return them through leaf-fall the following autumn. Brown earths are usually deeper than podsols, partly because tree roots can penetrate and break up the bedrock (Figure 2.5) and are more fertile, mainly because of the higher content of organic matter and clay (although they often benefit from liming).

7 Coniferous forests

The coniferous forest, or taiga, biome occurs in cold climates to the poleward side of 60°N in Eurasia and North America as well as at high altitudes in more temperate latitudes and in southern Chile (Figure 11.38).

Cold climates

Winters are long and cold. Minimum mean monthly temperatures may be as low as –25°C (–24°C at Fairbanks, Figure 12.35) – there is little moderating influence from the sea and no insolation as, at this time of year, the sun never rises in places north of the Arctic Circle. Strong winds mean there is a high wind-chill factor (frostbite is a hazard to humans); any moisture is rapidly evaporated (or frozen); and snow is frequently blown about in blizzards. Summers are short, but the long hours of daylight and clear skies mean that they are relatively warm. Precipitation is light throughout the year because the air can hold only limited amounts of moisture, and

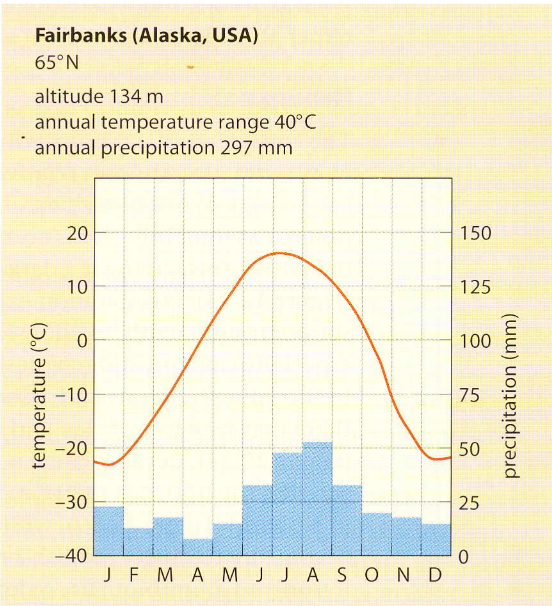


Figure 12.35

Climate graph for a cold climate biome

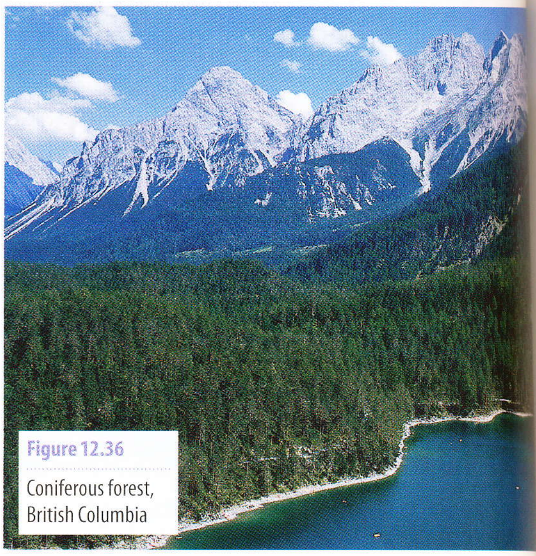


Figure 12.36

Coniferous forest, British Columbia

most places are a long way from the sea. The slight summer maximum is caused by isolated convectional rainstorms.

Coniferous forest or taiga

The coniferous forest has an average NPP of 800 g/m^2/yr (Figure 11.40). The coniferous trees have developed distinctive adaptations which enable them to tolerate long, cold winters; cool summers with a short growing season; limited precipitation; and podsolic soils. The size of the dominant trees and the fact that they are evergreen – giving them the potential for year-round photosynthesis – result in their relatively high NPP. The trees, which are softwoods, rarely number more than two or three species per km^2. Often there may be extensive stands of a single species, such as spruce, fir or pine. In colder areas, like Siberia, the larch tends to dominate. Although larches are cone-bearing, the European larch is deciduous and sheds its leaves in winter. All trees in the taiga, some of which attain a height of 40 m, are adapted to living in a harsh environment (Figure 12.36).

Figure 12.37

Forest floor in a coniferous forest, Cumbria

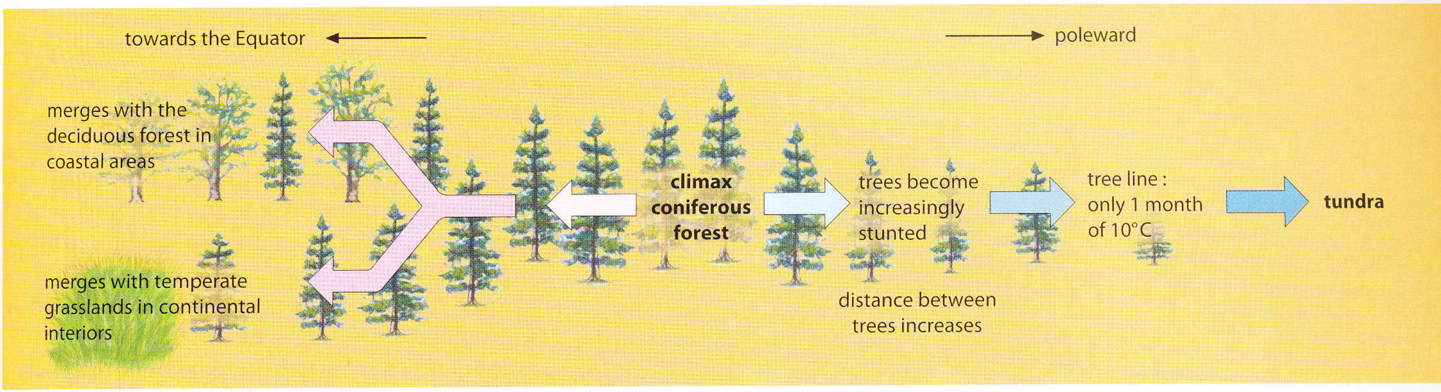


Figure 12.38

The coniferous forest and its transition zones

Conditions for photosynthesis become favourable in spring as incoming radiation increases and water becomes available through snowmelt (days in winter are long and dark and soil moisture is frozen). The needle-like leaves are small and the thick cuticles help to reduce transpiration during times of strong winds and during the winter when moisture is in a form unavailable for absorption by tree roots. Cones shield the seeds and thick, resinous bark protects the trunk from the extreme cold of winter and the threat of summer forest fires. The conical shape of the tree and its downward-sloping, springy branches allow the winter snows to slide off without breaking the branches. The conical shape also gives some stability against strong winds as the tree roots are usually shallow. There is usually only one layer of vegetation in the coniferous forest. The amount of ground cover is limited, due partly to the lack of sunlight reaching the forest floor and partly to the deep, acidic layer of non-decomposed needles (Figure 12.37). Plants that can survive on the forest floor include mosses, lichens and wood sorrel. The cold climate and acid soil discourage earthworms and bacteria. Needles decompose very slowly to give an acid mor humus (page 262) with most of the nutrient's held within the litter (Figure 11.29a). Evapotranspiration rates are very low and, as they are usually less than precipitation totals, leaching occurs and the few nutrients that are returned to the podsol soil are soon lost. Conifers require few nutrients, taking only 225 kg of plant nutrient annually from each hectare compared with the 430 kg taken by deciduous trees. The limited food supply means that animal life is not abundant. The dark woods are not favoured by bird life, although deer, wolves, brown bears, moose, elk and beavers are found in certain areas.

In North America and Eurasia, the coniferous forest merges into the tundra on its northern fringes (Figure 12.38). The tree line, the point above which trees are unable to grow, is often clearly marked in mountainous areas (Figure 12.36). South of the taiga lie either the deciduous forest or the temperate grassland biomes (Figure 11.38), depending upon whether the location is coastal or inland.

Podsols

Podsols develop in areas where precipitation exceeds evapotranspiration; under coniferous forest, heathland and other vegetation tolerant of low-nutrient-status soils; and where parent materials produce coarse-textured soils. Although podsols usually occur in places with a cool climate, they can be found virtually anywhere between the Equator and the Arctic, providing the required conditions are present.

Figure 12.39

Soil profile of a podsol

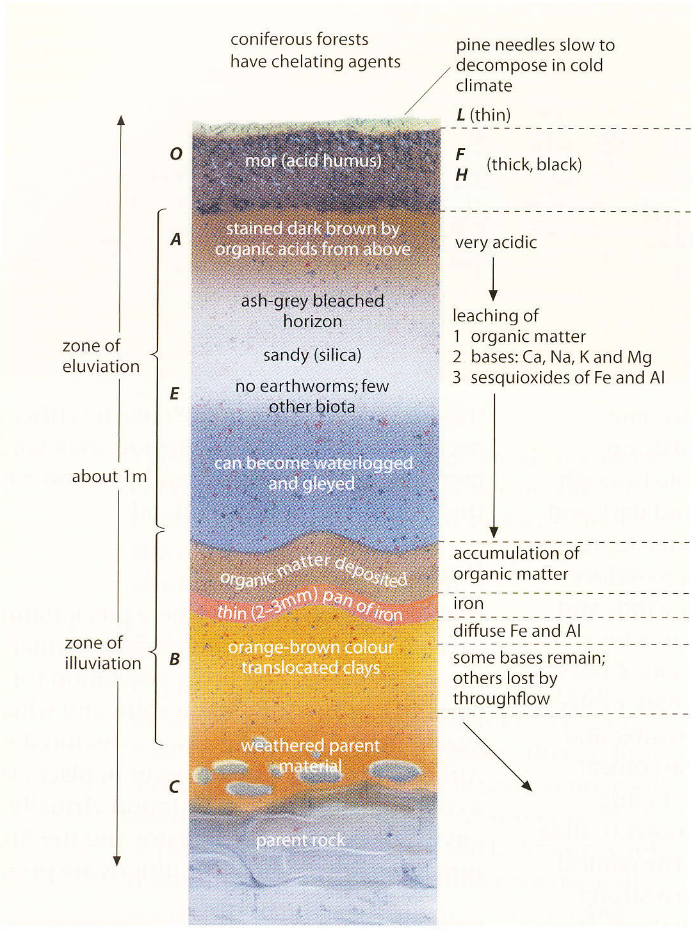


Figure 12.40

Soil profile of a podsol, typical of coniferous forests

Pine needles, with their thick cuticles, provide only a thin leaf litter and inhibit the formation of humus. Any humus formed is very acid (mor) and provides chelating agents and fulvic acid which help to make the iron and aluminium minerals more soluble. The cold climate discourages organisms and the soil is too acidic for earthworms. Consequently, well-defined horizons develop due to the slow decomposition of leaf litter and the lack of mixing agents. The downward percolation of water through the soil, especially following snowmelt, causes the leaching of bases, the translocation of organic matter, and the eluviation of the sesquioxides of iron and aluminium. This leaves an ash-grey, bleached *A* horizon (podsol is Russian for 'ash-like') composed mainly of quartz sand and silica (Figures 12.39 and 12.40).

Pedologists accept that different processes (physical, chemical and biological) can be employed in the translocation of materials, e.g. humus and clay in suspension, bases in solution, sesquioxides by biochemical agents in solution and, perhaps most significantly, movement caused by soil fauna mixing the soil.

The dark-coloured humus is redeposited at the top of the *B* horizon. Beneath this the sesquioxides of iron and aluminium are often – though not always – deposited as a thin, rust-coloured, hard pan. Where it is developed, this pan is rarely more than 2 or 3 mm in depth and often has a convoluted shape. It acts as an impermeable layer restricting the downward movement of moisture and the penetration of plant roots. This can cause some waterlogging in the *E* horizon to give a gleyed podsol. The lower *B* horizon, an area of diffuse accumulation of iron and aluminium, has an orange-brown colour and overlies weathered parent material. Any throughflow from this horizon is likely to contain bases in solution. Although these soils are not naturally fertile, they can be improved by the addition of lime and fertiliser, or by ripping the iron pan with a deep, single-line plough.

8 The tundra

The tundra, which lies to the north of the taiga, includes the extreme northern parts of Alaska, Canada and Russia, together with all of Greenland (Figure 11.38). The ground, apart from the top few centimetres in summer when temperatures are high enough for some plant growth, remains permanently frozen (the permafrost, Chapter 5).

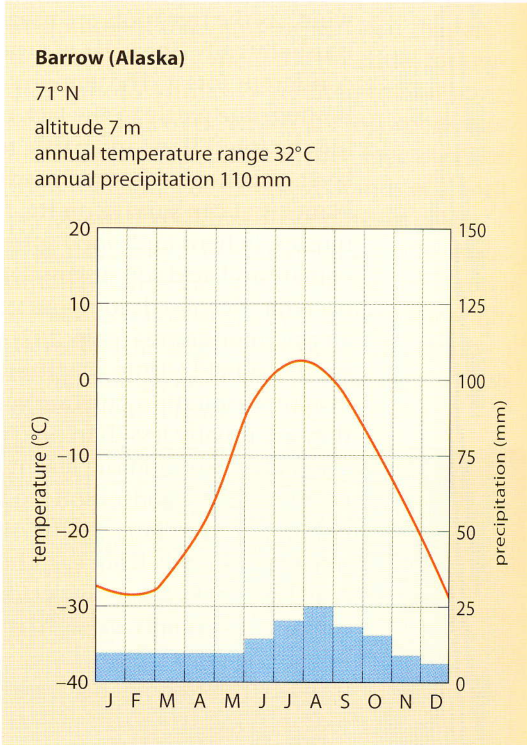


Figure 12.41

Climate graph for a tundra biome

Arctic climate

Summers may have lengthy periods of continuous daylight but, with the angle of the sun so low in the sky, temperatures struggle to rise above freezing-point (Barrow 3°C, Figure 12.41) and the growing season is exceptionally short. Nearer the poles, the climate is one of perpetual frost. Although winters are long, dark and severe, and the sea freezes, the water has a moderating effect on temperatures, keeping them slightly higher than inland places further south (Siberia). Precipitation, which falls as snow, is light – indeed, Barrow with 110 mm would be classified as a desert if temperatures were high enough for plant growth.

Tundra vegetation

The tundra ecosystem is one with very low organic productivity. The NPP of only 140 g/m^2/yr is the second-lowest of the major land biomes (Figure 11.40). In Finnish, *tundra* means a 'barren or treeless land', which accurately describes its winter appearance, and in Russian a 'marshy plain', which is what large areas are in summer. Any vegetation must have a high degree of tolerance of extreme cold and of moisture-deficient conditions – the latter because water is unavailable for most of the year when it is stored as ice or snow. There are fewer species of plants in the tundra than in any other biome. Most are very slow- and low-growing, compact and rounded to gain protection against the wind (plants as well as people are affected by wind-chill), and most have to complete their life-cycles within 50 to 60 days. There is no stratification of vegetation by height.

The five main dominants, each with its specialised local habitat, are lichens, mosses, grasses, cushion plants, and low shrubs (Figure 12.42). Most have small leaves to limit transpiration and short roots to avoid the permafrost. Lichens are pioneer plants in areas where the ice is retreating, and they can help date the chronology of an area following deglaciation (page 288). Much of the tundra is waterlogged in summer (Figures 5.18 and 12.43) due to the impermeable permafrost preventing infiltration. Where relief is gentle and evaporation rates are low, mosses, cotton grass and sedges thrive. On south-facing slopes and in better-drained soils, cushion plants provide a mass of bright colour in summer (Figure 12.44). These 'bloom mats' include arctic poppies, anemones, orchids, pink saxifrages and gentians. Where decaying vegetation accumulates (there is little bacterial action to decompose dead plants), the resultant peat is likely to be covered in heather, whereas

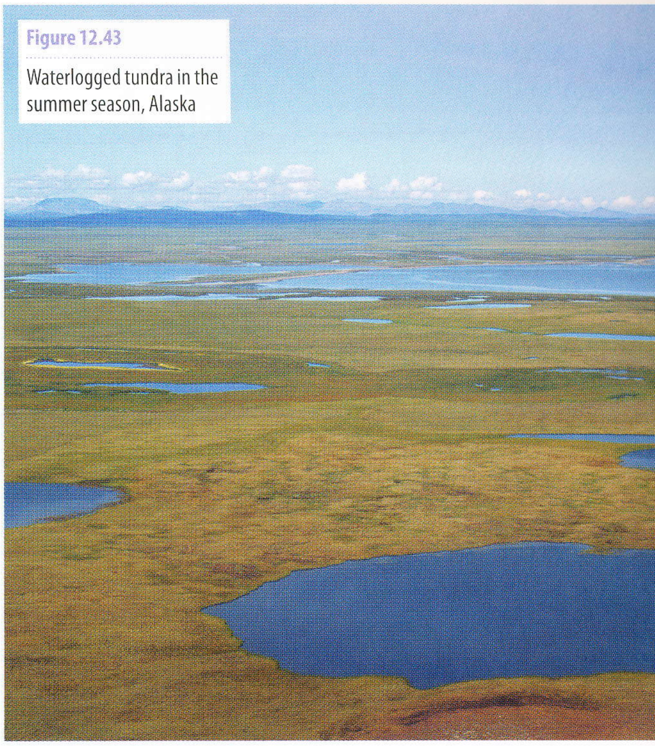


Figure 12.43
Waterlogged tundra in the summer season, Alaska

Figure 12.42
Relationship between vegetation and site factors in the tundra

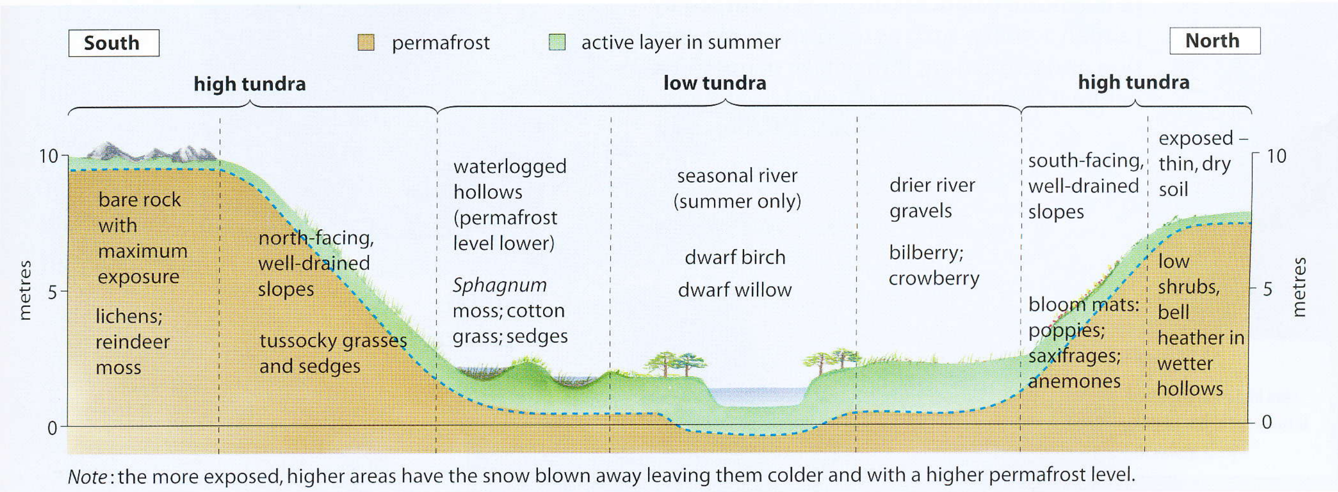


Figure 12.44

'Bloom mats' at Prudhoe Bay, Alaska

on drier gravels, berried plants (e.g. bilberry and crowberry) are the dominants. Adjacent to the seasonal snowmelt rivers, dwarf willows, horizontal junipers and stunted birch grow, but only to a maximum of about 30 cm; even so their crowns are often distorted and misshapen by the wind. In winter, the whole biome is covered in snow, which acts as insulation for the plants.

The lack of nitrogen-fixing plants, other than in the pioneer community (page 286), limits fertility, and the cold, wet conditions inhibit the breakdown of plant material. Photosynthesis is hindered by the lack of sunlight and water for most of the year, though the presence of autotrophs, such as lichens and mosses, does provide the basis for a food chain longer than might be expected. Herbivores such as reindeer, caribou and musk-ox survive because plants like reindeer moss have a high sugar content. However, these animals have to migrate in winter to find pasture that is not covered by snow. The major carnivores are wolves and arctic fox; owls are also found here.

The tundra is an extremely fragile ecosystem in a delicate balance. Once it is disturbed by human activity, such as tourism or oil exploration and extraction, it may take many years before it becomes re-established.

Tundra soils

The limited plant growth of this biome only produces a small amount of litter and, as there are few soil biota in the cold soil, organic matter decomposes only very slowly to give a thin peaty layer of humus or mor. There are many sites where there is free drainage. Where this occurs, water is able to percolate downwards, usually as meltwater in late spring, giving limited leaching and, due to the fulvic acid within it (the pH can be under 4.5), allowing the release of iron. Underlying the soil, at a very variable depth but usually under 50 cm, is the permafrost. This, acting as an impermeable layer, severely restricts moisture percolation and causes extreme waterlogging and gleying (Figure 12.45). Few mixing agents can survive in the cold, wet, tundra soils, which are thin and have no developed horizons (an exception is the arctic brown soil which develops on better-drained sites). Where bedrock is near to the surface, the parent material is physically weathered by freeze–thaw action. The shattered angular fragments are raised to the surface by frost-heave, preventing the formation of horizons and creating a range of periglacial landforms (Figure 5.21).

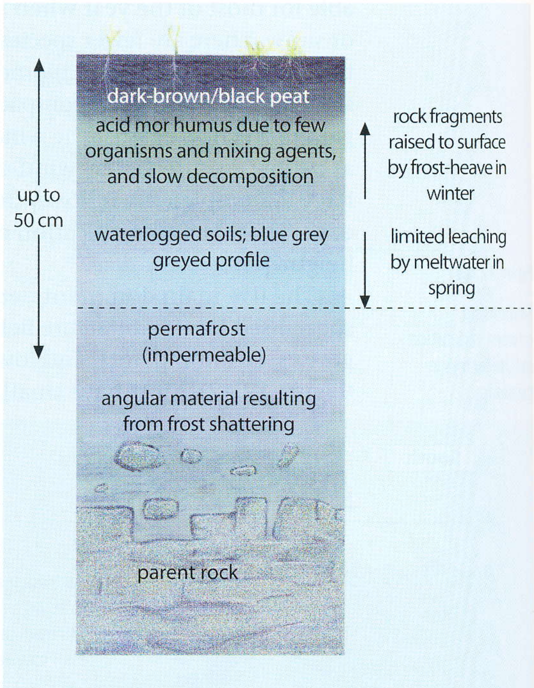


Figure 12.45

Soil profile of a typical tundra soil

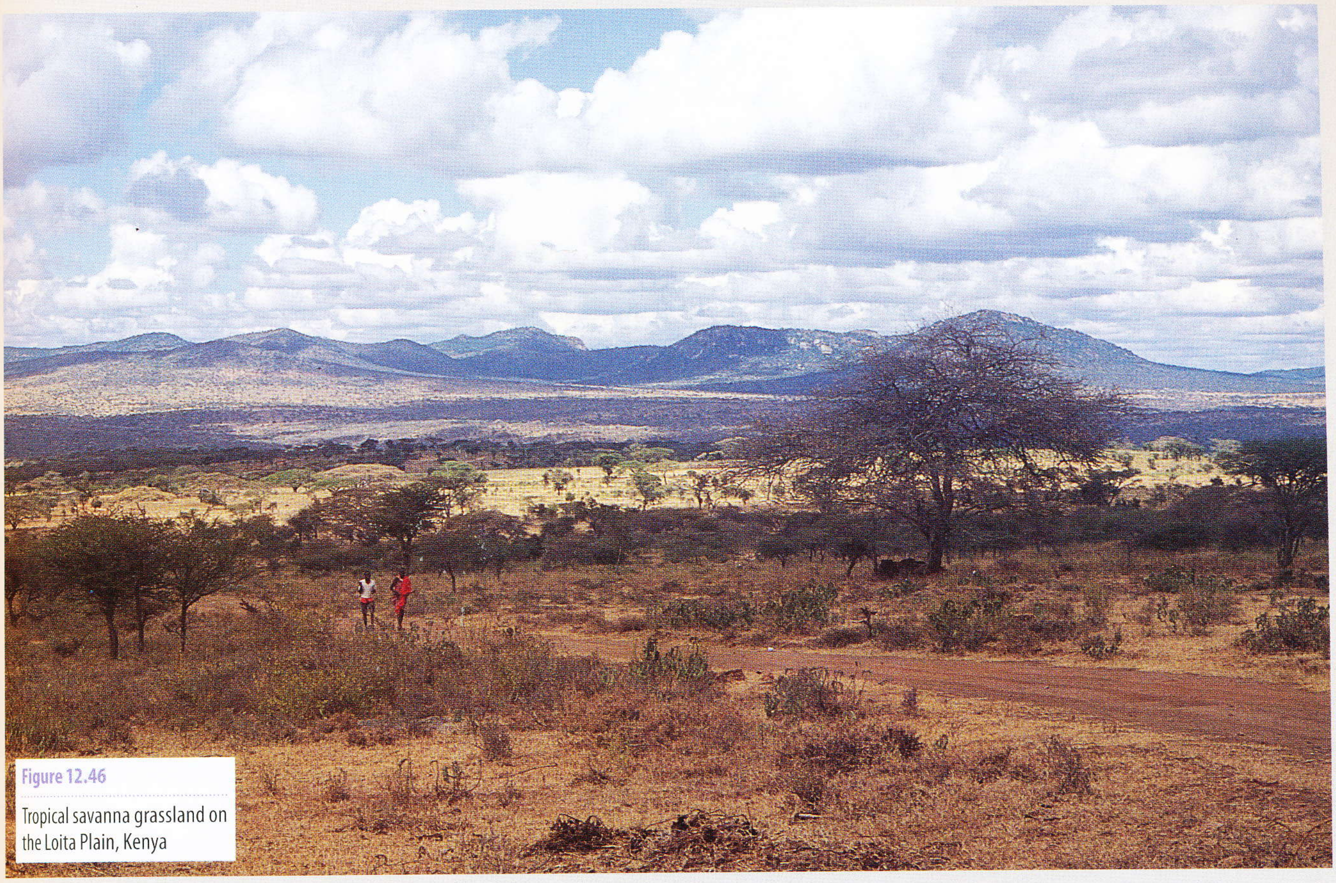


Figure 12.46

Tropical savanna grassland on the Loita Plain, Kenya

A Tropical grasslands in Kenya

The main expanses of tropical grassland in Kenya lie within the Rift Valley and on the adjacent plains of the Mara (an extension of the Serengeti) and Loita (Figure 12.48). Their appearance is one of open savanna (Figures 12.13 and 12.46) with small acacia and evergreen trees (Figure 12.15). There is evidence, however, that the original climax vegetation was forest, but that this has been altered by fires, started both naturally and by humans (page 293), by overgrazing (Figure 12.47) and by climatic change.

The climate is very warm and dry for most of the year with, usually, a short season (three months) of fairly reliable and abundant rainfall and an even shorter period known as the 'little rains' (Figure 12.49). Both periods of rainfall follow soon after the ITCZ and the associated overhead sun have passed over the

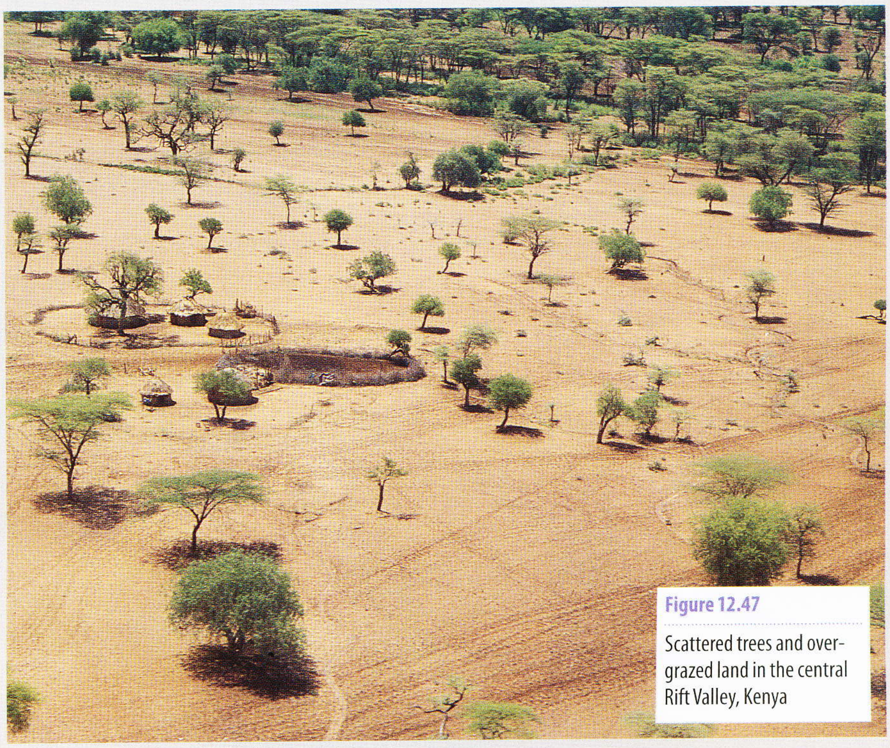


Figure 12.47

Scattered trees and overgrazed land in the central Rift Valley, Kenya

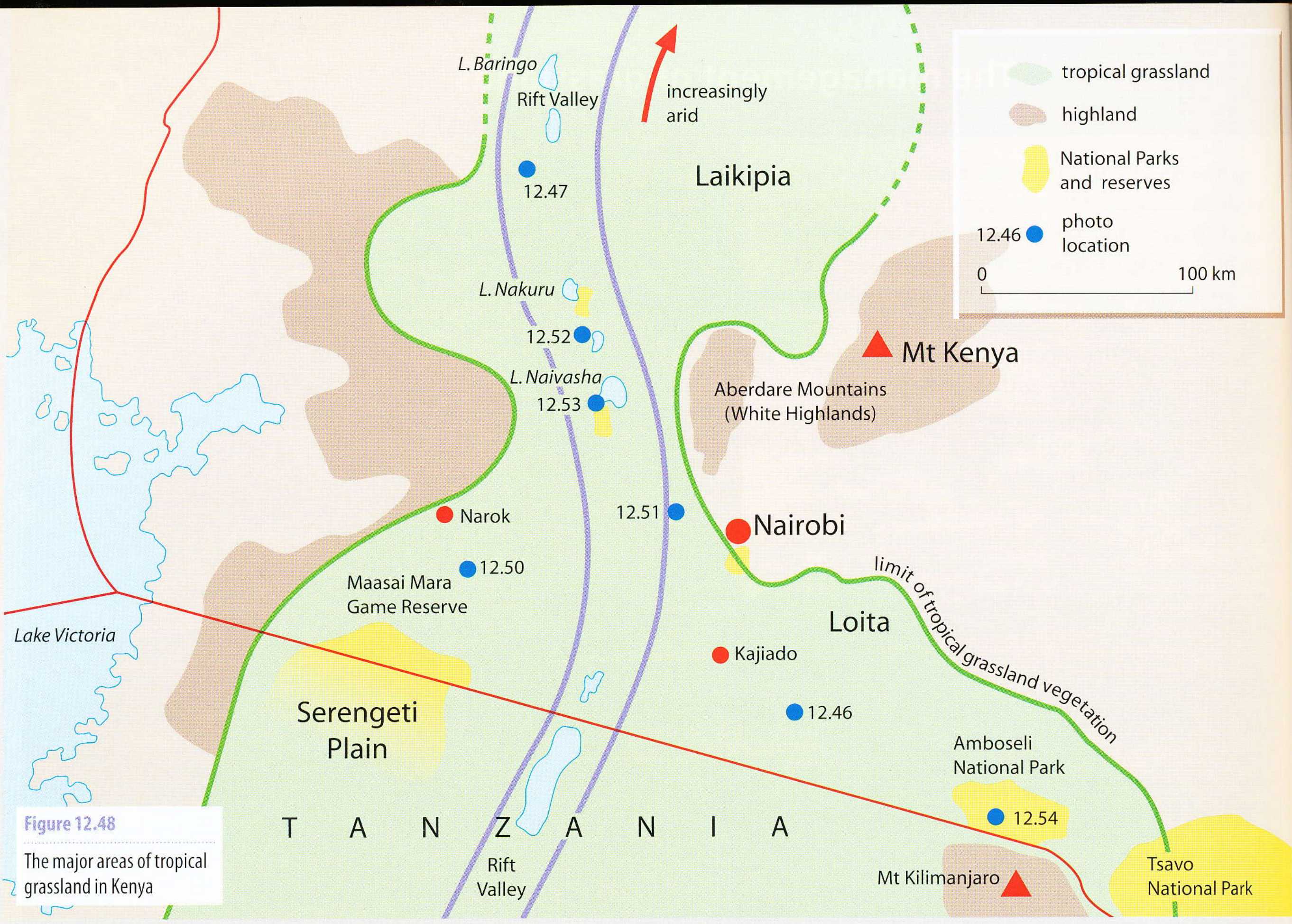


Figure 12.48

The major areas of tropical grassland in Kenya

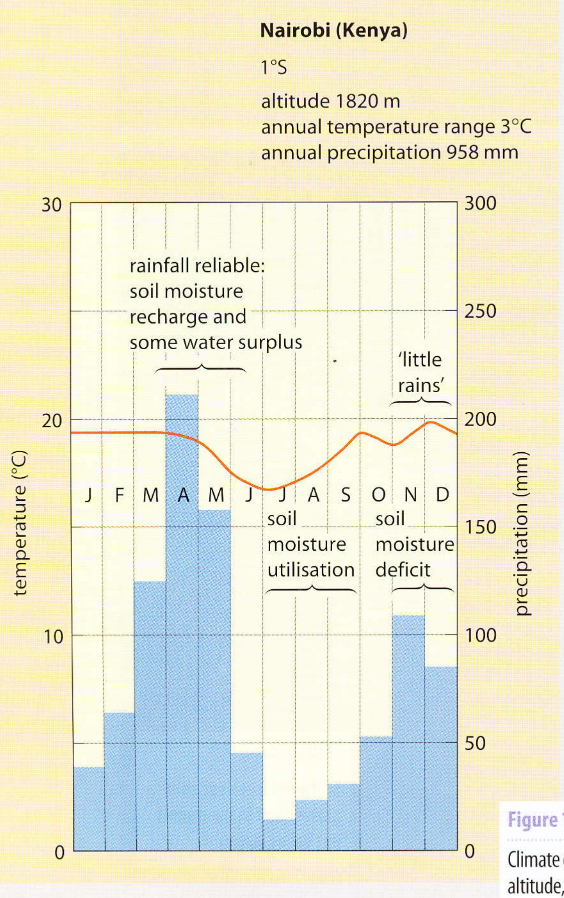


Figure 12.49

Climate graph and water balance for Nairobi (note that, due to its higher altitude, Nairobi is cooler and wetter than the surrounding grasslands)

Equator (Figure 12.12). The annual water balance shows a deficit (Figure 3.3) so that, although there is some leaching during the rainy season, for most of the year capillary action occurs. This has resulted in the development of ferruginous soils with, in places, a lateritic crust (page 321). Water supply is therefore a major management problem in this part of Kenya.

Water is obtained from springs at the foot of Mount Kilimanjaro – the mountain itself is in Tanzania – which are fed by melting snow; from several of the Rift Valley lakes (not all, as some are highly saline); from rivers (many of which are seasonal); and from waterholes. Even so, there have been, in the last 100 years alone, several major droughts when the carrying capacity of the region was exceeded. The **carrying capacity** (page 378) is the maximum number of a population (people, animals, plants, etc.) that can be supported by the resources of the environment in which they live, e.g. the greatest number of cattle that can be fed adequately on the available amount of grassland.

Human pressure on the natural resources

Maasai pastoralists

Maasai are defined as 'people who speak the Maa language'. Their ancestors were Nilotic, coming from southern Sudan during the first millennium AD. They kept cattle and grew sorghum and millet. The present Maasai may be descendants of the last of several migration waves. Latest evidence suggests that they may have only been in Kenya for 300 years. Over time, they specialised more in cattle and came to see themselves, and to be seen by others, historically and ethnically, as 'people of cattle'. Figure 12.50 is a stereotype photo of the Maasai, dressed in their red cloaks and with their humped zebu cattle. While all Maasai are Maa speakers, not all Maa speakers are Maasai – nor, today, are all Maasai pastoralists! The Maasai became semi-nomadic, moving seasonally with their cattle in search of water and pasture (two wet seasons and two dry seasons meant four moves a year; Figure 12.49). Herds had to be large enough to provide sufficient milk and meat for their owners and to reproduce themselves over time, including the ability to recover from drought and disease.

Kikuyu (Bantu) farmers

The Kikuyu were one of several Bantu tribes who arrived in Kenya, from the south, some 2000 years ago. They became subsistence farmers growing crops on the higher land which bounded the eastern side of the Rift Valley. The Kikuyu and Maasai often lived a complementary life-style. For the Maasai, Kikuyu in the highlands were a secure source of foodstuffs and a place of refuge during times of drought and cattle disease. For the Kikuyu, Maasai provided a constant supply of cattle products and wives. The division between them only appeared in early colonial times when the Maasai were forcibly moved from places like Laikipia (Figure 12.48) southwards onto the newly created Maasai reservation (the districts of Narok and Kajiado). The vacuum left was filled by newly arrived European settlers, and by Kikuyu (their rising numbers were causing a land shortage in the highlands). Figure 12.51 shows numerous, small, Kikuyu shambas (smallholdings) on the eastern edge of the Rift Valley to the north-west of Nairobi.

Colonial (European) settlers

While many Europeans settled in the so-called 'White Highlands', others developed huge estates within the Rift Valley. The most famous was Lord Delamere from Cheshire. He introduced, in turn, Australian sheep (they died, as the local grass was mineral-deficient); British sheep and clover (the sheep died, as African bees did not pollinate British clover); British cattle (wiped out by local diseases); wheat (which was more successful unless trampled by wild animals); and, finally and successfully, drought-resistant beef cattle. The present Delamere estate (Figure 12.52) covers 22 600 hectares (divided into 180-hectare paddocks); it has 10 900 long-horned Boran cattle (the carrying capacity is 12 000) crossed with 300 Friesian bulls; and 280 permanent workers. Although the estate is managed by 'whites', the stockmen are Maasai. More recently, transnational firms have set up large flower farms (Figure 12.53) and vegetable (especially peas and beans) farms in and near the Rift Valley. The closeness to Nairobi airport means that these perishable products can be transported to and sold in European markets, out of season, the day after they are picked.

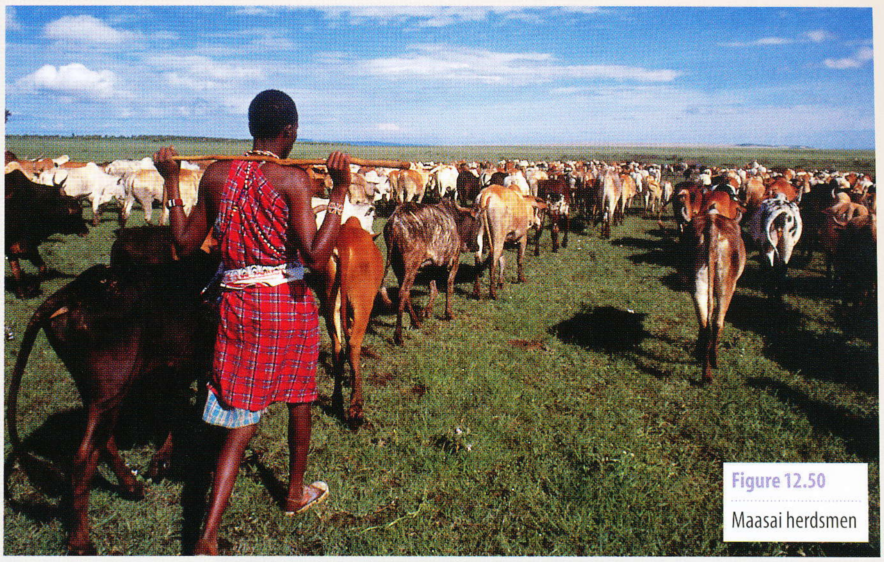


Figure 12.50 Maasai herdsmen

Figure 12.51 Kikuyu shambas near Nairobi

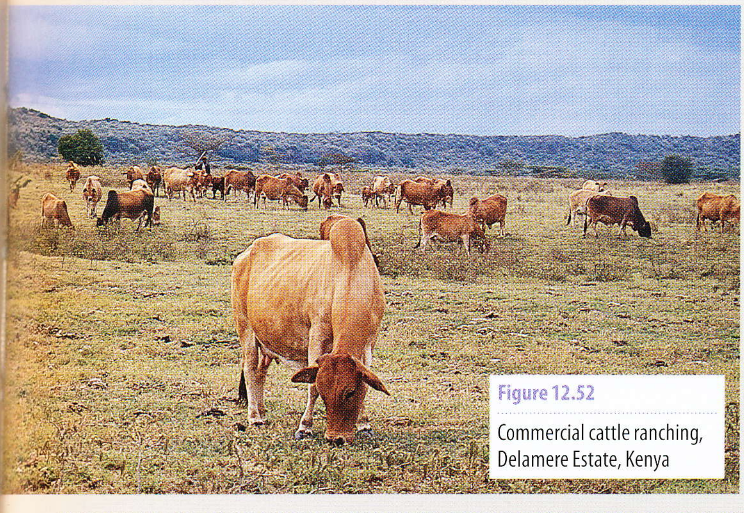


Figure 12.52 Commercial cattle ranching, Delamere Estate, Kenya

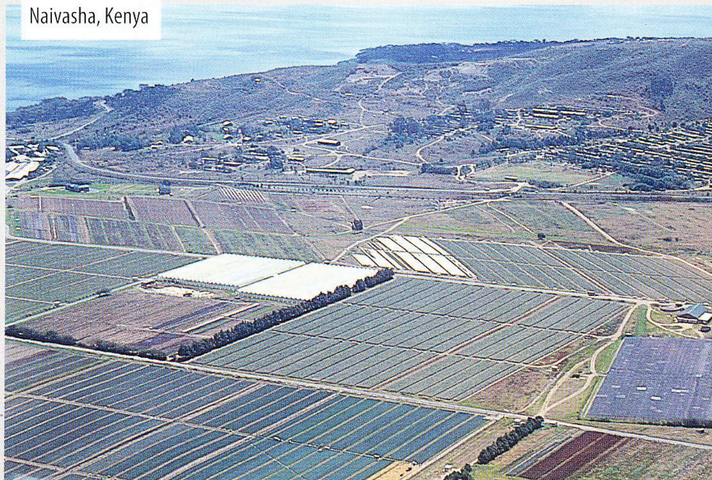


Figure 12.53 Flower-growing estate near Lake Naivasha, Kenya

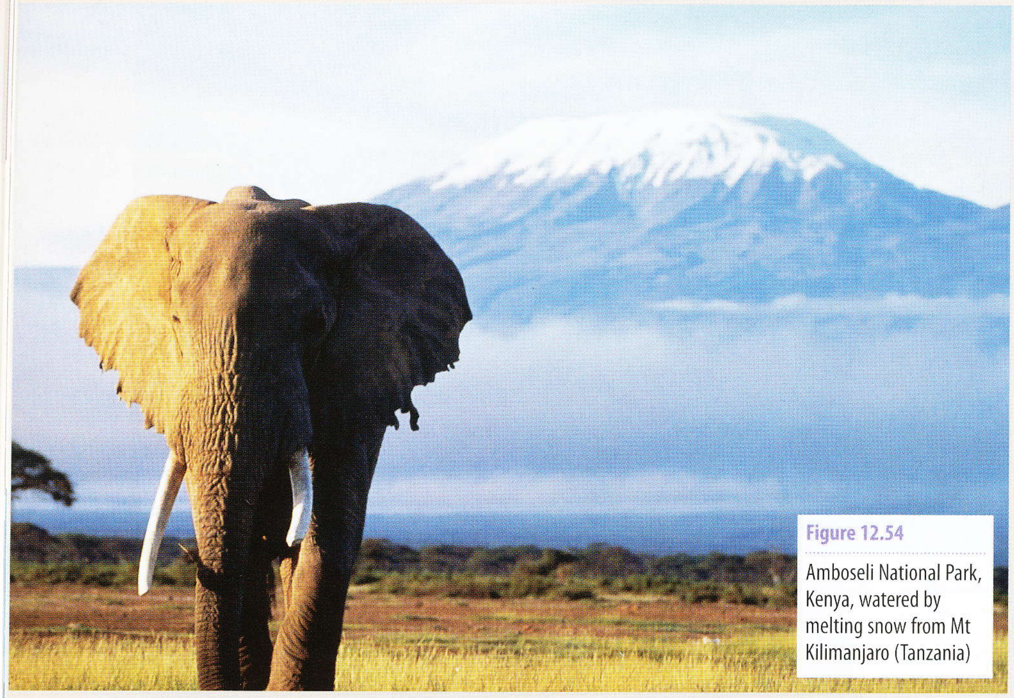


Figure 12.54
Amboseli National Park, Kenya, watered by melting snow from Mt Kilimanjaro (Tanzania)

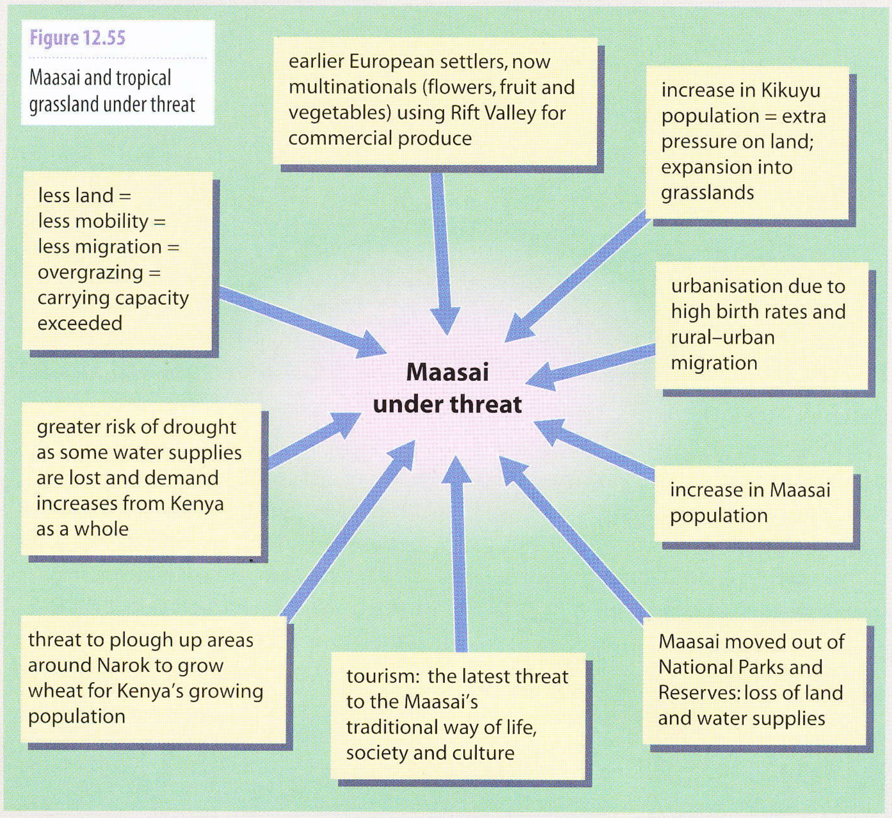


Figure 12.55
Maasai and tropical grassland under threat

National parks and reserves
The passing of the National Parks Ordinance in 1945 meant that specific areas were set aside either exclusively for wildlife (no permanent settlement in National Parks other than at tourist lodges) or where other types of land use were permitted only at the discretion of local councils. While wildlife has become a major source of income for Kenya, it has meant less land being available for crops and, to the Maasai, denial of access to important resources of dry-season water and pasture (Amboseli; Figure 12.54). Maasai herds were heavily depleted during the droughts of 1952 and 1972–76.

Population growth and urbanisation
Kenya, an economically less developed country, has one of the world's fastest-growing population rates. This means increased pressure on the land, especially the grasslands, to grow more subsistence crops to feed the growing domestic market; more cash crops to earn needed money from increased exports; and more land lost to urban growth.

Maasai in the late 2000s

The traditional Maasai way of life and their grassland habitat are under constant threat. Figure 12.55 summarises, but does insufficient justice to, some of the present-day problems. Change, as in many societies, is being forced upon the Maasai. While many values and traditions are still known and held, the basis of their economy – the concept of land as territory – has been so transformed that the survival of the herding system is in jeopardy. For some years, many Maasai have tried either to buy individual ranches (IRs) or to amalgamate to create group ranches (GRs), a practice which seems to fail at times of severe drought. The Maasai are also having to come to terms with a sedentary rather than a semi-nomadic lifestyle. Practical Action (PA), a British development group (Places 90, page 577), has been working with Maasai people to improve the standard of housing. In response to the main complaint of Maasai women, PA has helped to design a watertight cement skin which can be laid over an old mud roof (it was the women's job to apply more dung and mud onto a leaking roof during a wet night), and have improved ventilation within the house (where all the cooking is done). The government have laid a pipeline from Kilimanjaro to Kajaido, to ensure a more reliable water supply. The quality of Maasai herds has improved, with some cattle being sold for meat in Nairobi. The improvement to herds has been aided by PA which has helped train local villagers to become 'vets' (*wasaidizi*, Figure 21.5) capable of vaccinating animals and dealing with common diseases. Some Maasai have begun to grow crops, while others have begun to benefit from tourism. In Amboseli National Park, the Maasai are allowed to sell artefacts from their own shop. They can retain all the income which had, previously, gone to the government.

B The temperate grasslands in North America: the Prairies

Early travellers such as the Spaniard Coronado in the 16th century, who rode into Kansas from Mexico, and later French trappers and explorers in Canada, reported vast extents of waist-high, green grasses sometimes so tall that men on horseback stood in their stirrups to see where they were going. The plains seemed so vast that no limit could be found. Nineteenth-century settlers moving westwards across the Mississippi–Missouri in their wagons or drawing their handcarts, must have wondered if they would ever see woods, forests and mountains again. Today, the extent of the interior grasslands of North America is well known (Figure 12.56).

The Native Americans, who used the ecosystem, did little to alter the grassland, which remained in its original state of natural balance until the late 19th century. One visitor described it thus:

'It is a wild garden. Each week from April through September, about a dozen new kinds of flowers come into bloom. Once the

Figure 12.56
The North American Prairies

The management of grasslands

Figure 12.57

Short-grass prairie with deciduous trees (cottonwoods and aspen) and some conifers: west central Wyoming

Figure 12.58

Long-grass prairie (buffalo grass): Saskatchewan

layer of dead grass gets too thick, though, it starts to choke off the smaller grasses and wild flowers. Meantime, woody plants – they like shade and moisture – can gain a foothold in the sod and spread. If you go long enough without fire, much of this countryside will be covered with trees.'

Grasses such as blue stem and buffalo grass have a network of roots which can extend to considerable depth to absorb water and obtain nutrients. Root systems may make up over 80 per cent of the vegetative biomass in the prairie. These, together with the smaller herbs, have helped to develop a thick sod close to the surface. Plants can survive from year to year because they die back to the ground and lie dormant during the cold winters (page 327).

Soils grade in colour and fertility from brown in the western short-grass prairie (Figure 12.57) through chestnut in the mixed-grass zone to the fertile black chernozems (millisols) of the tall-grass eastern zone (Figure 12.58). The chernozems have a high humus content (page 327).

Decaying humus releases minerals slowly for the grasses. The soils are kept light and aerated which helps to prevent compaction under heavy rain (summer convection storms) and the weight of heavy animals (bison and humans). The presence of humus also helps to conserve moisture. Due to frequent droughts, the vegetation has developed protective mechanisms, such as leaves that curl up to prevent evaporation loss, and well-developed root fibres which can obtain moisture from deep in the soil.

The rapid spring growth and early maturity of grass allows it to produce seeds early. It then becomes semi-dormant until autumn and can survive heat and drought. Late-growing species may not be able to compete and this has led to an extension of short grass into the mixed-grass zone during a succession of long dry periods.

In the 17th century, there were estimated to be 60–70 million bison roaming the grasslands with 50 million antelope, plus grizzly bears, wolves and prairie dogs, together with many species of birds – hawks, larks, buntings, etc. – and insects and reptiles such as snakes and lizards. Today there are few of the larger mammals left except in wilderness refuges such as National Parks.

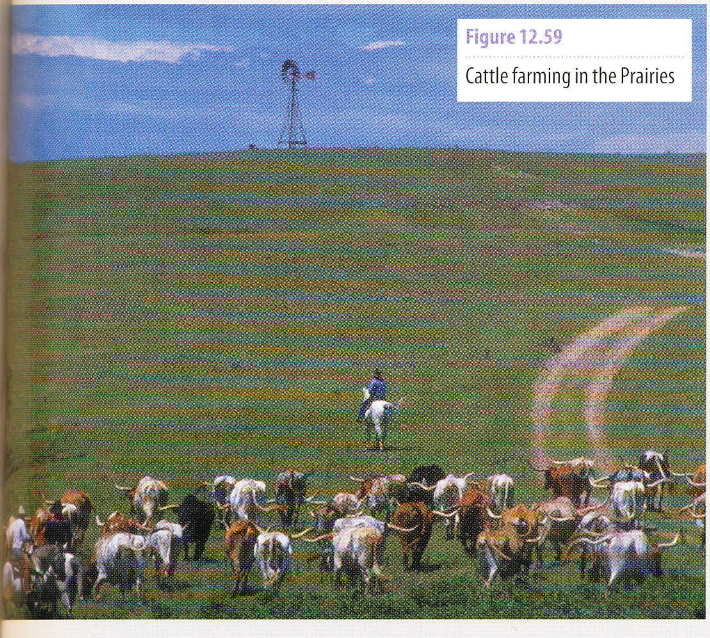


Figure 12.59
Cattle farming in the Prairies


Figure 12.60
Cattle feed lots in Denver

Nutrient cycling within the prairie ecosystem

In Figure 11.29b, the small litter store reflects the relatively small amount of vegetative matter and low leaf fall. Litter decomposes into humus and nutrients are released to the soil, giving it good crumb structure. Moderate rainfall reduces loss from runoff. The large soil storage is a result of the weathering of rock and the presence of deep, rich chernozems (in the eastern and central prairies) which have accumulated a high proportion of humus (organic matter) in the temperate continental conditions. There is little or no leaching because the rainfall is exceeded by evaporation in the summer months.

How and why may this ecosystem change?

There is little tall-grass prairie left, and estimates by government agencies indicate that there is less than 34 per cent true mixed-grass prairie and less than 23 per cent true short-grass prairie in existence. This is mainly due to conversion to crop production, damming of major rivers together with flood control and irrigation systems, and in favourable areas the draining of wetlands for crops.

1 Natural conditions

- **Unpredictable rainfall** and **drought** have been a major factor in change in the North American Prairies. Low rainfall in the 1930s allied to bad farming practices led to the creation of the American Dust Bowl; reduced the natural fodder for animals; and permitted an eastward extension of the short-grass prairies into the eastern tall grass.
- **Lightning** is a frequent cause of fire in the grasslands in summer. This destroys the surface vegetation; kills small animals; and damages the food supply. In the years following serious fires, lower bird numbers have been recorded, as many nest on the ground.
- **Bison herds** have been effective in change. They are heavy grazers and reduce the coarser medium grasses, leaving short grasses. In the spring and early summer when mosquitoes hatch they plague the bison, causing them to roll on the ground to reduce the itching! This forms depressions in the prairie surface. These bare soils may be re-colonised later by seeds carried by birds.

2 Human activity

- **Hunting** The earliest inhabitants were the Native Americans who hunted animals for food, using fire and traps to kill unselectively. With the coming of the Europeans and the introduction of the horse and the rifle, they were able to kill large numbers of bison almost to extinction. It was only in the late 20th century that the number of bison began to increase, as a result of careful management in the National Parks, such as the Houck Ranch in South Dakota.
- **Cereal farming** Initially the prairie sod proved too difficult to remove using only wooden or iron ploughs, but after the 1840s this became possible following the development of the steel plough. Cereal crops were successfully introduced and were soon to be exported in huge quantities to Western Europe (Places 70, page 486). Overcultivation by the 1930s, when there was also a severe drought, led to extensive soil erosion and, especially in the southern Prairie states of Kansas and Oklahoma, the creation of the 'dust bowl'. Despite soil conservation methods on a large scale, which reduced some of the damaged areas, further droughts during the late 20th century caused an estimated loss of up to 1 m of topsoil in some ploughed areas.
- **Cattle ranching** became the main farming activity on the western Prairies (Figure 12.59) on land previously grazed by bison. Serious problems of overgrazing occurred in areas with lower rainfall Although irrigation is used to grow fodder cops in states such as Alberta, Montana and the western

The management of grasslands

Dakotas, the extraction of water has led to a lowering of the water table. Intensive ranching now takes place on huge feed lots close to railheads such as Denver (Figure 12.60). Young cattle are fattened in stockyards on grain transported from the eastern Prairies before being moved further east to the slaughter yards.

- **Mineral extraction** has increased since the 1970s, with extensive strip mining for coal and the construction of over 50 wells for the extraction of oil and natural gas. This, together with the roads, railways and pipelines needed to transport both workers and the minerals across the Prairies, has had an adverse effect on parts of the grasslands.
- **Other land uses** include areas set aside for military training and recreational activities including camping and bird watching.

Can the grassland ecosystem be saved?

Many species of grass found only in temperate grassland ecosystems have declined substantially in recent years. This has been blamed on a combination of factors including poor grazing management, the effects of fire, the spread of invasive, non-native plants and, in places, urban development. Estimates suggest that the prairie grasslands decreased by almost 30 million hectares between 1986 and 2002. The Grassland Reserve Programme (GRP) came into effect in 2002 as a result of the unlikely co-operation of the Nature Conservancy and the National Cattlemen's Beef Association (Figure 12.61). It was designed to be a buffer against the continuing loss of grassland areas and to ensure that the native prairie remained a viable, productive and important ecosystem for present, and future, generations. This was necessary if indigenous plant and animal species were to survive. The GRP programme imposes no regulations on grazing and allows private entities, such as ranching land trusts, to have rights of way over other properties.

Under the GRP, ranchers and other private grassland owners who enrolled had to agree to placing 10, 15, 20 or 30-year contracts on their land, prohibiting changes in land use, such as the growing of crops, and other activities incompatible with conserving the grassland ecosystem. In return, the landowners receive annual payments for short-term contracts or a one-time payment for which they agree to rights of way over their property. The GRP also provided additional resources to assist landowners wishing to restore former grassland areas.

All went well until 2007, when America's open plains and prairies were threatened by soaring global grain prices that increased the land's value as cropland. Grain prices were driven up partly by an increase in world demand for food, especially in the emerging economies of China and India, and partly by the American Congress voting to double the production of corn-based ethanol, a cleaner-burning fuel that can reduce greenhouse gas emissions. Both of these factors appear to work contrary to the government's programmes designed to conserve the grasslands. Landowners in many parts of the Prairies, especially the Dakotas, began converting to cropland some marginally productive areas that for decades – in some case centuries – had remained uncultivated as it would have been unprofitable to turn them into arable.

In 2008 a growing number of farmers chose not to re-enroll when their GRP contracts expired, potentially enabling over 2 million hectares of grassland, 15 per cent of the GRP total, to become available for cropland by 2010. With wheat that earned $4 or $5 a bushel in 2006 getting $12 a bushel in 2008, it is a case of short-term incentives overtaking long-term benefits. Conservationists warn that the hard work of the last few years could easily be undone and can only hope that grain prices will drop again in the near future – another example of global uncertainty.

Cattle ranchers believe that ...	Conservationists believe that ...
controlled burning to renew pasture should be allowed (this was a Native American custom)	there is too much burning; the prairie does not recover; burns are too frequent
overgrazing can be avoided by careful pasture management	new information gained from research will help both graziers and conservation
soil and water conservation are already practised	the prairie needs restoration to maintain its ecosystem
tourists, picnic sites and more roads will damage the environment	the prairie has already been damaged by cattle grazing

Figure 12.61

Conflict before the introduction of GRP in2002

Further reference

Goudie, A.S. (2001) *The Nature of the Environment*, WileyBlackwell.

Money, D.C. (1978) *Climate, Soils and Vegetation*, Harper Collins.

Oxfam's Cool Planet tropical rainforest: www.oxfam.org.uk/coolplanet/ontheline/explore/nature/trfindex.htm

West Tisbury School, Massachusetts biome: www.blueplanetbiomes.org/climate.htm

World Wildlife Fund, ecoregions: www.worldwildlife.org/ecoregions/

Questions & Activities

Activities

1 a What is the 'climate' of a place? *(3 marks)*
b What is the reason for wanting to classify climates? *(3 marks)*
c Why do many geographers use the natural vegetation of a place as an indication of the climate? *(3 marks)*
d For any **one** world climatic zone:
i Name the climatic zone and identify **two** places which experience this climate.
ii Draw and annotate a graph to show the pattern of temperature and precipitation which is typical of the climatic zone.
iii Name the typical natural vegetation cover of the climatic zone and a typical zonal soil type. *(10 marks)*
e Explain the causes of **one** of the climatic characteristics (temperature or precipitation) you have identified in **d ii**. *(6 marks)*

2 a Describe the climate of the areas which have natural temperate deciduous forests. *(3 marks)*
b Draw a diagram to show the characteristic structure and composition of the vegetation of temperate deciduous forests. *(6 marks)*
c Explain **one** way in which the vegetation of the temperate deciduous forests is adapted to the climate of the area. *(4 marks)*
d Describe **one** zonal soil type of the temperate deciduous forests. *(4 marks)*
e Why is there litter on the forest floor in the temperate deciduous forests? *(3 marks)*
f Explain what has happened to most of the world's temperate deciduous forests since the settlement of these areas by people. *(5 marks)*

Exam practice: basic structured questions

3 Choose **one** of the world biomes that you have studied.
a i Describe the main characteristics of the climate. *(5 marks)*
ii Describe and explain the nutrient cycle in your chosen biome. You should include a diagram of the mineral nutrient cycle in your answer. *(6 marks)*
b Describe the zonal soil of your chosen biome. *(6 marks)*
c How is the natural vegetation of the biome adapted to the climatic conditions there? *(8 marks)*

4 a Describe the climate of the tropical rainforest. *(5 marks)*
b Draw a diagram to show the composition and structure of the characteristic vegetation of the tropical rainforest. *(6 marks)*
c Explain how the vegetation of the tropical rainforest is adapted to the climate of the area. *(8 marks)*
d Describe **one** zonal soil type of tropical rainforest areas and explain how it developed. *(6 marks)*

Exam practice: structured questions

5 a Describe and account for the climatic pattern experienced in areas with a Mediterranean climate. *(8 marks)*
b Describe the vegetation and explain **two** ways in which it is adapted to the climatic conditions of the Mediterranean. *(9 marks)*
c How has the long-term presence of people affected the relationship between climate, soils and vegetation? *(8 marks)*

6 Choose **one** biome and answer the following questions about it.
a Describe and explain the relationships within the nutrient cycle of the biome. *(10 marks)*
b Describe **one** way the natural vegetation of the area is used by people and the effect of this use on the structure and composition of the vegetation. *(10 marks)*
c How can damage due to past human uses of the biome be reduced? *(5 marks)*

Exam practice: essays

7 Choose **one** grassland biome and discuss the comparative importance of climate and human activity in influencing the nature of the vegetation cover. *(25 marks)*

8 Outline the basic features of **one** system of climate classification that you have studied and assess the importance of climate classifications in the study of geography. *(25 marks)*