3 The Organic World

Having just discussed the global patterns of climate, and how they have changed through time and may change in the future, we now move on to a consideration of some of the global patterns of organic phenomena: plants, animals and soils. These are components of what is often called the *biosphere*.

3.1 Major Vegetation Types

Just as it is possible to classify and map major climatic types, so it is possible to classify and map the main types of vegetation on the face of the earth (window 3.1). At a very gross scale, the distribution of vegetation types is closely related to the distribution of climatic types, and one of the classic ideas of biogeography was that if an area of land – bare of vegetation because of some event like a volcanic eruption – became colonised by vegetation, there would be a gradual *succession* of vegetation changes until the optimum for the conditions, known as the *climatic climax community*, established itself (see chapter 10).

There is no doubt that climate does affect plant growth. In a broad sense, meagre rainfall results in desert vegetation, light rainfall causes grassland and abundant rainfall produces forest. Likewise, temperature plays a large part in accounting for the differences between, by way of example, tropical rainforest and the coniferous forests of higher latitudes. Low temperatures tend to result in lower plant growth and smaller size, and frosts can be lethal to certain species. Many plants cannot make active growth if the temperature is below 6 °C and for most of the species of temperate deciduous forest there must be at least six months with temperatures above such a minimum.

On the other hand, any simple relationship between the climate and vegetation type may be obscured by differences in such factors as soil type, the activity of fires and the actions of man. The problem of mapping the major zones is compounded by the fact that their delimitation will inevitably be arbitrary, for there are very few clear-cut lines in nature. There is also the perennial problem of whether the zones should be small in number, simple in type – and thus probably overgeneralised – or whether one should go for more categories, but then inevitably cause a lack of clarity.

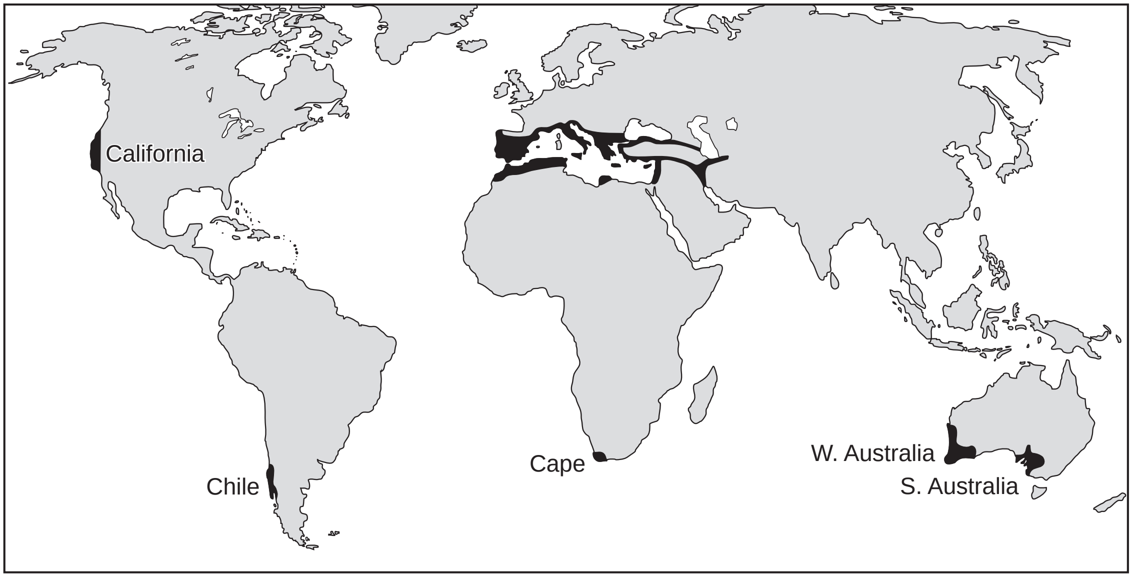
Bearing these problems in mind, one can see that the map of vegetation types (figure 3.1) is remarkably similar to a map of major climatic types, and this is brought out further in table 3.1.

The rate at which vegetative matter is produced, together with the actual amount of vegetative material that exists in a particular area (the *biomass*), also shows broad patterns that are related to climate (figure 3.2). In desert areas and in the tundra, biomass levels are very low; they are intermediate in the boreal forest and mid-latitude deciduous forests, and reach their highest levels in the humid tropical rainforest. These differences in the production of organic matter have great importance in terms of soil development and rock weathering in different parts of the world.

Window 3.1 *Mediterranean vegetation*

Regions with Mediterranean climates tend to occur on the western coasts of continents between 30° and 40° latitude. Although these regions are separated by thousands of kilometres of oceans, they support superficially rather similar plant life because the plants (though unrelated to each other in terms of their lineage) have independently succeeded in evolving similar adaptations to this distinctive climatic environment.

The Mediterranean type of environment is unique because it has cool, wet winters and dry, hot summers. Plants therefore have had to adapt to severe droughts and to periodic wildfires. Their distinctive shrub communities, many of them now much modified by human activities, are variously called chaparral, mattoral, macchia, maquis or fynbos (see window 3.3).



Areas of Mediterranean vegetation.

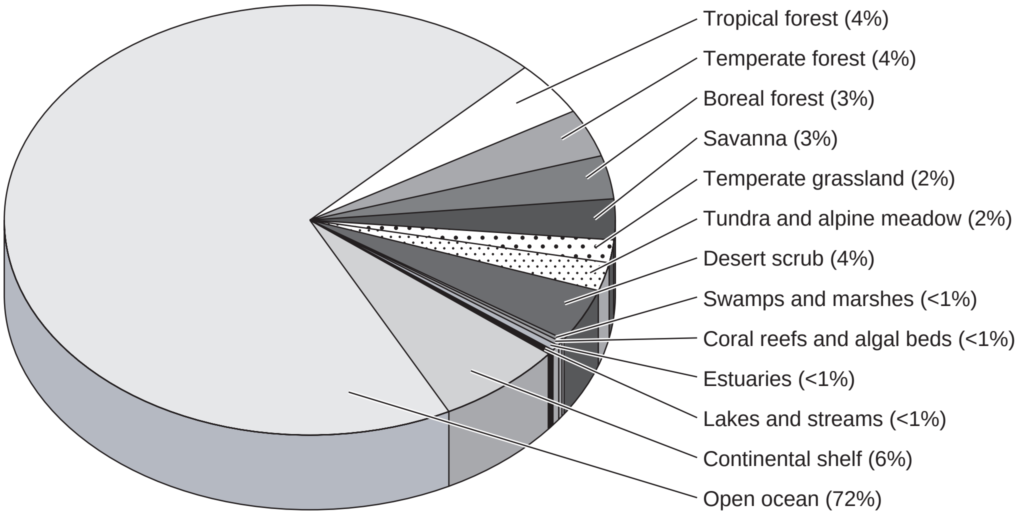
Table 3.1 The relationship between climatic zone and vegetation type

Climate	*Vegetation*
Humid tropical zone	Rainforests, with mangroves on coasts
Semi-arid seasonal tropics	Savanna
Arid tropics	Desert scrub, or vegetationless
'Mediterranean'	Evergreen woodlands and shrubs
Humid temperate (maritime)	Temperate deciduous forest
Cool temperate (continental)	Temperate grasslands, steppe etc.
Boreal zone	Coniferous and birch forests
Arctic zone	Tundra, shallow-rooted shrubs

Figure 3.1 Vegetation types of the world.

Altitude modifies the general distribution pattern, and introduces local complexity (figure 3.3). Unless the relief is very slight, each altitudinal zone will afford suitable conditions for the appearance of plants in general characteristic of a zone or zones in higher latitudes; subtropical plants will occur here and there in tropical regions, temperate plants will occur in both tropical and subtropical zones, and so on. The effect of altitude is discussed further in chapter 8.

(A) Relative area of world biomes



(B) Global primary production of the earth's biomes

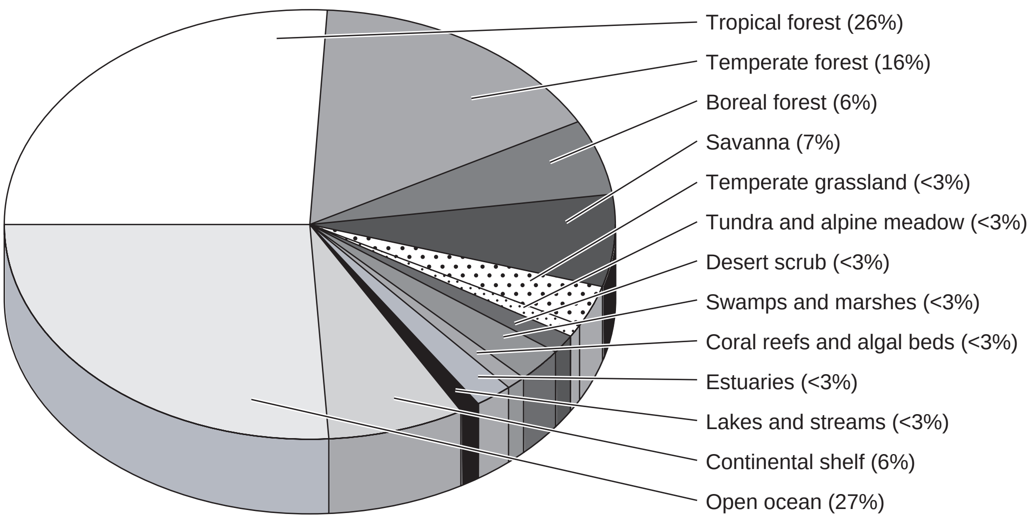
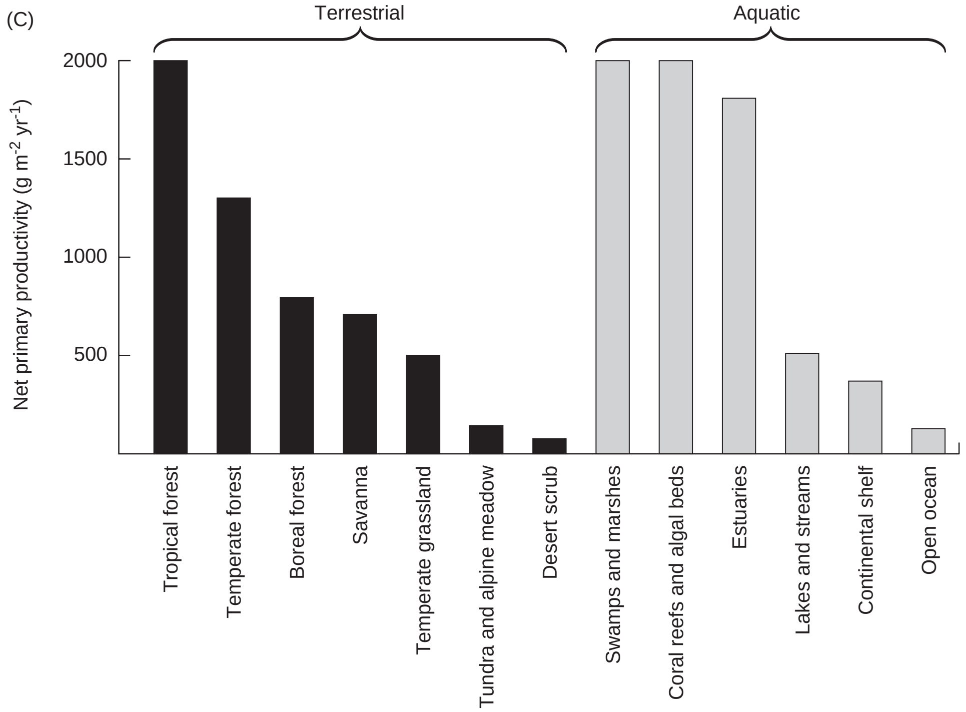
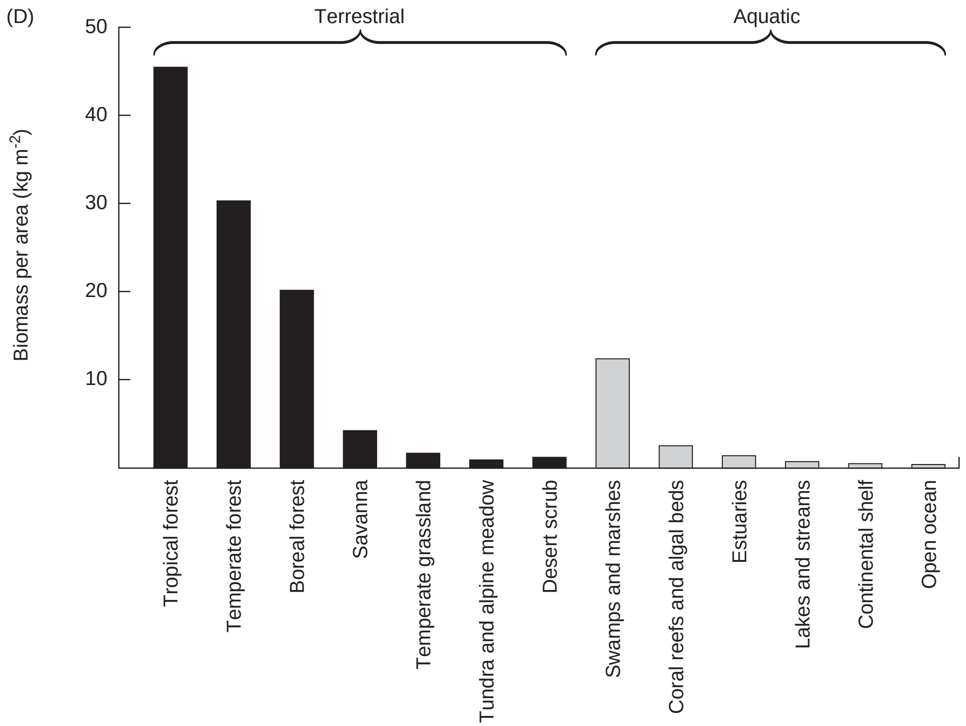


Figure 3.2 (above and overleaf) Characteristics of world biomes: (A) relative areas; (B) global primary production; (C) primary productivity; (D) biomass in relation to area.


(C)
Terrestrial
Aquatic
Net primary productivity (g m-2 yr-1)
2000
1500
1000
500
Tropical forest
Temperate forest
Boreal forest
Savanna
Temperate grassland
Tundra and alpine meadow
Desert scrub
Swamps and marshes
Coral reefs and algal beds
Estuaries
Lakes and streams
Continental shelf
Open ocean


(D)
Terrestrial
Aquatic
Biomass per area (kg m-2)
50
40
30
20
10
Tropical forest
Temperate forest
Boreal forest
Savanna
Temperate grassland
Tundra and alpine meadow
Desert scrub
Swamps and marshes
Coral reefs and algal beds
Estuaries
Lakes and streams
Continental shelf
Open ocean

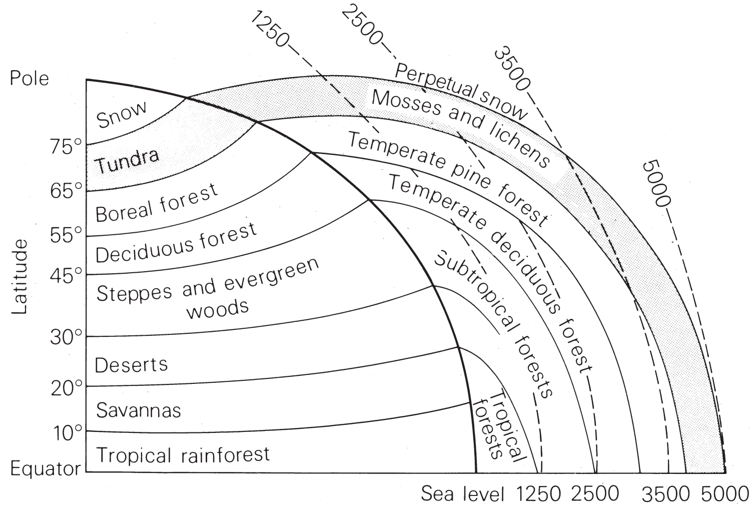


Figure 3.3 The modification of the world's major vegetation zones by altitude.

3.2 Human Modification of Major Vegetation Types

The global patterns and nature of some of the earth's important vegetation assemblages are being substantially changed by human actions, including fire, grazing and deforestation.

The use of fire

There are many good reasons why humans, from our early Stone Age ancestors onwards, have found fire useful:

- to clear forest for agriculture;
- to improve the quality of grazing for game or domestic animals;
- to deprive game of cover or to drive them from cover;
- to kill or drive away predatory animals, insects and other pests;
- to repel or attack human enemies;
- to make travel quicker and easier;
- to provide light and heat;
- to enable them to cook;
- to transmit messages, by smoke signals;
- to break up stone for making tools or pottery, smelting ores, and hardening spears or arrowheads;
- to make charcoal;
- to protect settlements or camps from larger fires by controlled burning;
- to provide spectacle and comfort.

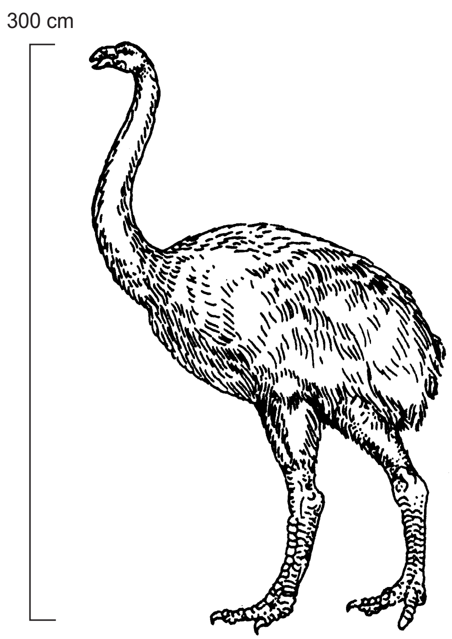
Fire has been central to the life of many groups of hunter-gatherers, pastoralists and farmers (including shifting cultivators in the tropics). It was much used by peoples as different from one another as the Aboriginals of Australia, the cattle-keepers of Africa, the original inhabitants of Tierra del Fuego ('the land of fire') in the far south of South America and the Polynesian inhabitants of New Zealand (window 3.2). It is still much used especially in the tropics, and above all in Africa. Biomass burning appears to be especially significant in the tropical environments of Africa in comparison with other tropical areas. The main reason for this is the great extent of savanna which is subjected to regular burning. As much as 75 per cent of African savanna areas may be burned each year. This is probably an ancient phenomenon in the African landscape which occurred long before people arrived on the scene. Nevertheless, humans have greatly increased the role of fire in the continent, where they may have used it for over 1.4 million years.

Fire is crucial to an understanding of some major biome types, and many biota have become adapted to it. For example, many savanna trees are fire-resistant (plate 3.1). The same applies to the shrub vegetation (*maquis*) of the Mediterranean lands, which contains certain species which thrive after burning by sending up a series of suckers from ground level. Mid-latitude grasslands (e.g. the prairies of North America) were once thought to have developed in response to drought conditions during much of the year. Now, however, some have argued that this is not necessarily the case and that, in the absence of fire, trees could become dominant. The following reasons are given to support this suggestion:

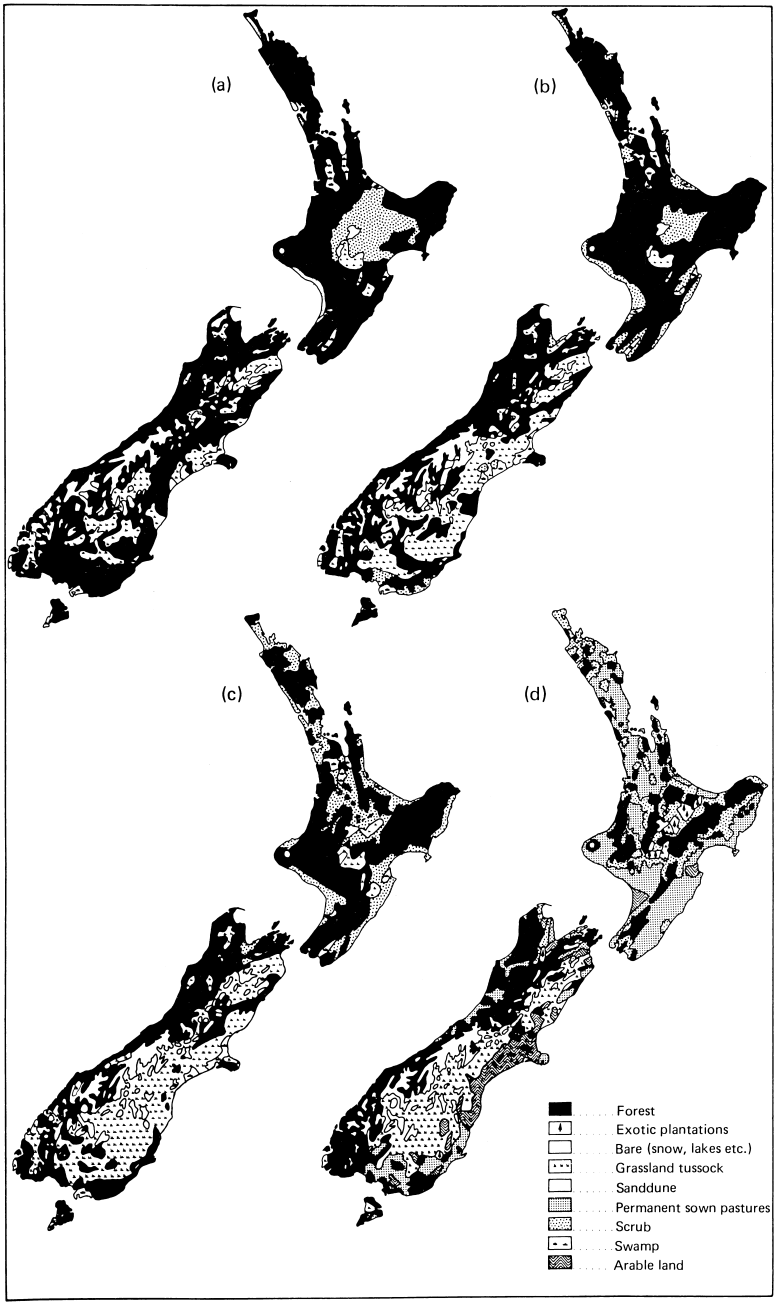
Window 3.2 ***The transformation of New Zealand***

New Zealand was only settled very recently, first by Polynesians (around 1200 years ago) and then by Europeans (around 200 years ago). The Polynesians carried out extensive firing of vegetation in pre-European settlement times, and hunters used fire to facilitate travel and to frighten and trap a major food source – the flightless moa (now extinct). The changes in vegetation that resulted were substantial. The forest cover was reduced from about 79 per cent to 53 per cent, and fires were especially effective in the drier forests of central and eastern South Island in the rain shadow of the Southern Alps. The fires continued over a period of about a thousand years up to the period of European settlement.

Islands like New Zealand have been vulnerable to the effects of introduced plants, which spread explosively. Gorse is one pernicious example, and nearly 60 per cent of all plant species in New Zealand are now aliens. It has often been proposed that the introduction of exotic terrestrial mammals has had a profound effect on the flora of New Zealand. Among the reasons that have been put forward for this belief are that the absence of native terrestrial mammalian herbivores permitted the evolution of a flora highly vulnerable to damage from browsing and grazing, and that the populations of wild animals (including deer and opossums) that were introduced in the nineteenth century grew explosively because of the lack of competitors and predators.



The now-extinct moa (*Diornis giganteus*) of New Zealand (1500 years BP).



The changing state of the vegetation cover in New Zealand: (a) early Polynesian vegetation, *c.*AD 700; (b) pre-classical Maori vegetation, *c.*AD 1200; (c) pre-European vegetation, *c.*AD 1800; (d) present-day vegetation.
Source
R. Cochrane in A. G. Anderson (ed.) (1977) *New Zealand in Maps*, section 14 (London: Hodder and Stoughton).

Plate 3.1 The 'Pindan' savanna of tropical north-western Australia. This landscape is frequently burnt by the Aboriginal inhabitants and has been for thousands of years. This probably has a profound effect both on the distribution and the characteristics of this wooded grassland.

- planted groves and protected trees seem able to flourish;
- some woodland species, notably junipers, are remarkably drought-resistant;
- trees grow along escarpments and in deep valleys where moisture is concentrated at seeps and in shaded areas, and where fire is least effective: the effects of fire are greatest on flat plains where there are high wind speeds and no interruptions to the course of the fire;
- where fires have been restricted, woodland has spread into grassland.

Fire rapidly alters the amount, form and distribution of plant nutrients in ecosystems, and has been used deliberately to change the properties of the soil. Both the release of nutrients by fire and the value of ash have long been recognised, notably by those involved in slash-and-burn techniques. However, once land has been cultivated, the loss of nutrients by leaching and erosion is very rapid. This is why the shifting cultivators have to move on to new plots after only a few years. Fire quickly releases some nutrients from the soil in a form that plants can absorb. The normal biological decay of plant remains releases nutrients more slowly. The amounts of phosphorus (P), magnesium (Mg), potassium (K) and calcium (Ca) released by burning forest and scrub vegetation are high in relation to both the total and the available quantities of these elements in soils.

Grazing

A second major means of transforming vegetation assemblages is through the grazing and trampling activities of domestic stock. In particular, many of the world's grasslands have long been grazed by wild animals like the bison of North America or the large game of East Africa, but the introduction of pastoral economies also affects their nature and productivity.

Light grazing may increase the productivity of wild pastures. Nibbling, for example, can encourage the vigour and growth of plants, and in some species the removal of coarse, dead stems permits succulent sprouts to shoot. Likewise the seeds of some plant species are spread efficiently by being carried in the guts of cattle, and then placed in favourable seedbeds of dung or trampled into the soil surface. Moreover, the passage of herbage through the gut and out as faeces modifies the nitrogen cycle, so that grazed pastures tend to be richer in nitrogen than ungrazed ones. Also, grazing can increase species diversity by opening out the community and creating more niches.

On the other hand, heavy grazing may be detrimental. Excessive trampling when conditions are dry will reduce the size of soil aggregates and break up plant litter to a point where they are subject to removal by wind. Trampling, by puddling the soil surface, can accelerate soil deterioration and erosion as infiltration capacity is reduced. Heavy grazing can kill plants or lead to a marked reduction in their level of photosynthesis. In addition, when relieved of competition from palatable plants or plants liable to trampling damage, resistant and usually unpalatable species expand their cover.

In general terms it is clear that in many parts of the world the grass family is well equipped to withstand grazing. Many plants have their growing points located on the apex of leaves and shoots, but grasses reproduce the bulk of fresh tissue at the base of their leaves. This part is least likely to be damaged by grazing and allows regrowth to continue at the same time that material is being removed.

Communities severely affected by the treading of animals tend to have certain distinctive characteristics. These include diminutiveness (since the smaller the plant is the more protection it will get from soil-surface irregularities); strong ramification (the plant stems and leaves spread close to the ground); small leaves (which are less easily damaged by treading); tissue firmness (cell-wall strength and thickness to limit mechanical damage); a bending ability; strong vegetative increase and dispersal (for example, by stolons); small hard seeds which can be easily dispersed; and the production of a large number of seeds per plant (which is particularly important because the mortality of seedlings is high under treading and trampling conditions).

Deforestation

Clearing forests is probably the most obvious way in which humans have transformed the face of the earth. Forests provide wood for construction, for shelter and for making tools. They are also a source of fuel, and, when cleared, provide land for food production. For all these reasons they have been used by humans, sometimes to the point of destruction.

Forests, however, are more than an economic resource. They play several key ecological roles. They are repositories of biodiversity; they may affect regional and local climates and air quality; they play a major role in the hydrological cycle; they influence soil quality and rates of soil formation; and prevent or slow down soil erosion.

We do not have a clear view of how fast deforestation is taking place. This is partly because we have no record on a global scale of how much woodland there is today, or how much there was in the past. It is also because there are disagreements about the precise meaning of the word 'deforestation'. For example, shifting cultivators and loggers in the tropics often leave a certain proportion of trees standing. At what point does the proportion of trees left standing permit one to say that deforestation has taken place? Also, in some countries scrub is included as forest while in others it is not.

What we do know is that deforestation has been going on for a very long time. Pollen analysis shows that it started in prehistoric times, in the Mesolithic (around 9000 years ago) and Neolithic (around 5000 years ago). Large tracts of Britain had been deforested before the Romans arrived in the islands in the first century BC. Classical writers refer to the effects of fire, cutting and the destructive nibble of goats in Mediterranean lands. The Phoenicians were exporting cedars from Lebanon to the Pharaohs and to Mesopotamia as early as 4600 years ago. A great wave of deforestation occurred in western and central Europe in medieval times. As the European empires established themselves from the sixteenth and seventeenth centuries onwards, the activities of traders and colonists caused forests to contract in North America, Australia, New Zealand and South Africa, especially in the nineteenth century. Temperate North America, which was wooded from the Atlantic coast as far west as the Mississippi River when the first Europeans arrived, lost more woodland in the following 200 years than Europe had in the previous 2000. At the present time, the humid tropics are undergoing particularly rapid deforestation. Some areas are under particularly serious threat, including south-east Asia, West Africa, Central America, Madagascar and eastern Amazonia (figure 3.4).

Since pre-agricultural times approximately one-fifth of the world's forests has been lost. The highest losses (about a third of the total) have been in temperate areas. However, deforestation is not an unstoppable or irreversible process. For example, a 'rebirth of forest' has taken place in the USA since the 1930s and 1940s. Many forests in developed countries are slowly but steadily expanding as marginal agricultural land is abandoned. This is happening both because of replanting schemes and because of fire suppression and control. Also, in some cases the extent and consequences of deforestation may have been exaggerated.

Views vary as to the present rate of rainforest removal but estimates by the Food and Agriculture Organization put the total annual deforestation in 1990 for 62 countries (representing some 78 per cent of the tropical forest area of the world) at 16.8 million hectares. This figure is significantly higher than the one obtained for these same countries for the period 1976–80 (9.2 million hectares per year).

The loss of moist rainforests in some of the world's humid tropical regions is a very major concern. The consequences are many and serious (table 3.2). The causes are also diverse and include encroaching cultivation and pastoralism (including cattle ranching), mining and hydroelectric schemes, as well as logging operations themselves.

One particular type of tropical forest ecosystem coming under increasing pressure from various

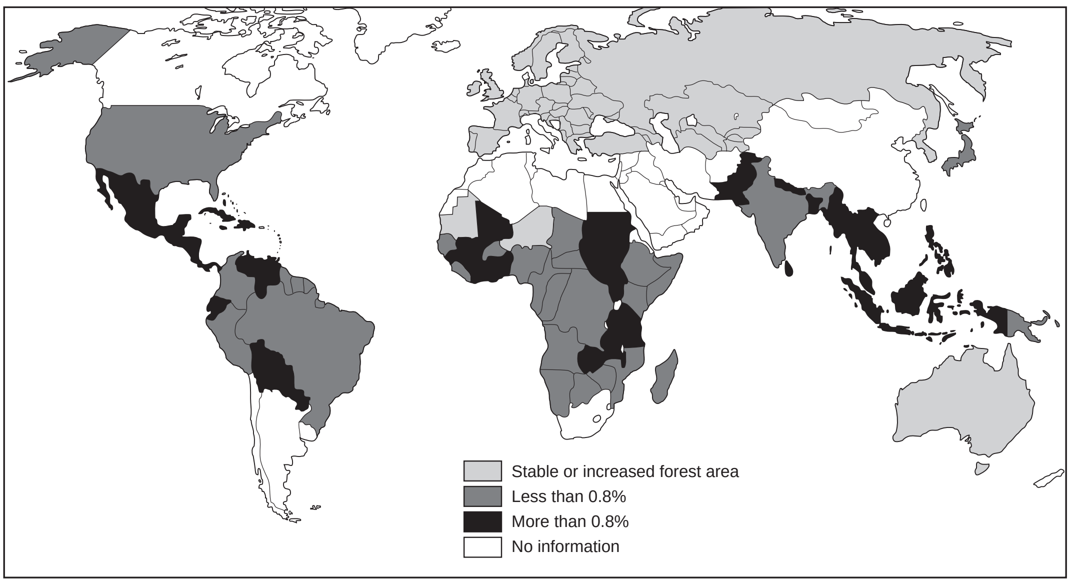


Figure 3.4 Estimated annual forest change rates, 1981–1990.

Table 3.2 The consequences of tropical deforestation

Type of change	*Examples*
Reduced biological diversity	Species extinctions Reduced capacity to breed improved crop varieties Inability to make some plants economic crops Threat to production of minor forest products
Changes in local and regional environments	More soil degradation Changes in water flows from catchments Changes in buffering of water flows by wetland forests Increased sedimentation of rivers, reservoirs etc. Possible changes in rainfall characteristics
Changes in global environments	Reduction in carbon stored in the terrestrial biota Increase in carbon dioxide content of atmosphere Change in global temperature and rainfall patterns through greenhouse effects Other changes in global climate due to changes in land surface processes

Source: A. Grainger (1992) *Controlling Tropical Deforestation* (London: Earthscan)

Plate 3.2 Mangrove forests, which fringe the coastlines of many tropical regions, as here in Mauritius in the Indian Ocean, are an important wetland habitat that is under increasing human pressure.

human activities is the mangrove forest characteristic of inter-tidal zones (plate 3.2). These ecosystems constitute a reservoir, refuge, feeding ground and nursery for many useful and unusual plants and animals. In particular, because they export decomposable plant debris into adjacent coastal waters, they provide an important energy source and nutrient input to many tropical estuaries. In addition they can serve as buffers against the erosion caused by tropical storms – a crucial consideration in low-lying areas like Bangladesh. In spite of these advantages, mangrove forests are being degraded and destroyed on a large scale in many parts of the world, either through exploitation of their wood resources or because of their conversion to single-use systems such as agriculture, aquaculture, salt-evaporation ponds or housing developments. To give two examples: mangrove areas in the Philippines converted to fish ponds have increased from less than 90 000 hectares in the early 1950s to over 244 000 hectares in the early 1980s; while in Indonesia logging operations are claiming 200 000 hectares of mangrove each year.

On a global basis, it has been calculated that since 1700 about 19 per cent of the world's forests and woodlands have been removed. Over the same period the world's cropland area has increased by over four and a half times, and between 1950 and 1980 it amounted to well over 100 000 km^2 per year.

3.3 Floral Realms

From the time in the distant geological past when plants spread rapidly around the world until the present, the plant cover has never ceased to evolve. Mutations have emerged continuously, and their survival and establishment have depended on ecological circumstances at the time of their appearance. Climates have changed; continents have shifted, isolating some plant groups and joining others; new mountain barriers have developed; and sea level has varied, creating or destroying land-bridges between continents. For these reasons the world today does not have a uniform flora, but we can none the less detect areas where there is some coherence in the distribution pattern of particular species. These can be generalised into maps – maps of *flora* and not of vegetation types. The distinction between the two is an important one: the flora of an area is the sum total of all the plant species in it; vegetation is the kind of plant cover in that area. Thus, although two floral regions may be similar in their vegetation, because, for example, they are both areas of tropical rainforest, they do not necessarily have much in common botanically or share more than a few genera.

An example of floral regionalisation is shown in figure 3.5a, and it has certain broad similarities to a map of the faunal realms, a topic we shall turn to shortly. Although there can be many small regions (in this example, 37), they can be lumped into six major groups called *kingdoms*: Holarctic, Palaeotropical, Neotropical, Cape (window 3.3), Australian and Antarctic.

The nature of the floral realms has been modified by human activities, for people are important agents in the spread of plants and other organisms. Some plants are introduced deliberately by humans to new areas: these include crops, ornamental varieties and miscellaneous landscape modifiers (trees for reafforestation, cover plants for erosion control and so on). Indeed, some plants, such as bananas and breadfruit, have become completely dependent on people for reproduction and dispersal, and in some cases they have lost the capacity for producing viable seeds and depend on human-controlled vegetation propagation.

However, some domesticated plants, when left to their own devices, have shown that they are capable of at least ephemeral colonisation, and a small number have successfully naturalised themselves in areas other than their supposed region of origin. Examples of such plants include several umbelliferous annual garden crops (fennel, parsnip and celery) which, though native to Mediterranean Europe, have colonised waste lands in California. The Irish potato, which is native to South America, grows unaided in the mountains of Lesotho. In Paraguay, orange trees (originating in south-east Asia and the East Indies) have demonstrated their ability to survive in direct competition with natural vegetation.

Plants that have been introduced deliberately (plate 3.3) because they have recognised virtues can be usefully divided into an economic group (for example, crops, timber trees etc.) and an ornamen-

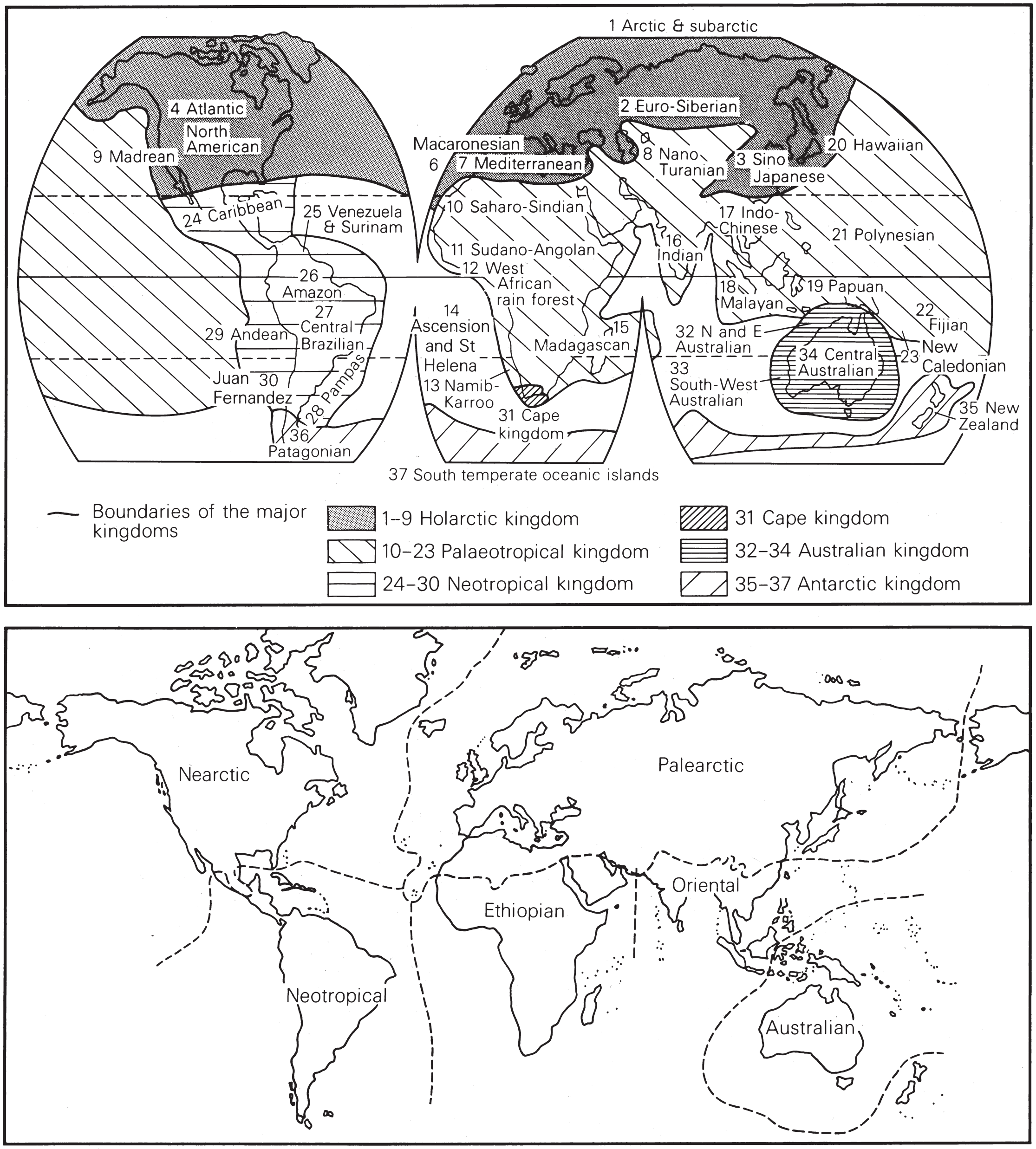


Figure 3.5 The major (a) floral and (b) faunal realms of the world.

Window 3.3 ***The Cape floral kingdom***

The world has six floral kingdoms. Five of these cover huge areas (such as Australia or the Northern Hemisphere), but one of them is small and restricted to only the southern tip of Africa. This is the Cape floral kingdom. Although it is small, it is immensely rich in plant species – 1300 per 10 000 km^2. An important component of this flora is called fynbos, which is dominated by woody shrubs, including the famous proteas. Over 7700 plant species are found in fynbos and of these roughly 70 per cent are endemic to the area – that is, they are found nowhere else in the world. There are, for example, 600 different species of ericas or heaths in the fynbos, but only 26 in the rest of the world. The plants have evolved in virtual isolation from the rest of the world over tens of million of years, and have developed adaptations to the area's Mediterranean climate.

The state of the fynbos has been undermined by miscellaneous human activities, including the spread of towns, land clearance for agriculture, and afforestation. However, one of the most severe human impacts is caused by the explosive spread of a variety of introduced exotic plants, including trees or large shrubs belonging to the genera *Acacia*, *Hakea* and *Pinus*. Many of these were introduced from Australia and have overwhelmed the native flora over extensive areas.

Visit this web site:http:/www.botany.uwc.ac.za/fynbos/

Typical fynbos vegetation with proteas in the Cederberg Mountains of the Cape, South Africa.

Plate 3.3 Many plants were moved around the world deliberately to stock botanical gardens. The wonderful gardens at Pamplemousses in Mauritius were established in part to aid the dissemination of useful plants. As the inscription says (in French), 'The gift of a useful plant appears more precious to me than the discovery of a gold mine and is a more durable monument than a pyramid.'

tal or amenity one. In the British Isles, the great bulk of deliberate introductions before the sixteenth century had some sort of economic merit, but only a handful of the species introduced thereafter were brought in because of their utility. Instead, plants were introduced increasingly out of curiosity or for decorative value.

Many plants, however, have been dispersed accidentally as a result of human activity: some by adhesion to moving objects, such as individuals themselves or their vehicles; some among crop seed; some among other plants (like fodder or packing materials); some among minerals (such as ballast or road metal); and some by the carriage of seeds for purposes other than planting (as with drug plants).

The accidental dispersal of such plants and organisms can have serious ecological consequences. In Britain, for instance, many elm trees died in the 1970s because of the accidental introduction of Dutch elm disease fungus which arrived on imported timber at certain ports, notably Avonmouth and the Thames Estuary ports. There are also other examples of the dramatic impact of some introduced plant pathogens. In western Australia the great jarrah forests have been invaded and decimated by a root fungus, *Phytophthora cinnamomi*. This was probably introduced on diseased nursery material from eastern Australia, and the spread of the disease within the forests was facilitated by road building, logging and mining activities that involved movement of soil or gravel containing the fungus. More than 3 000 000 ha of forest have been affected.

Ocean islands have often been particularly vulnerable. The simplicity of their ecosystems inevitably leads to diminished stability, and introduced species often find that the relative lack of competition enables them to broaden their ecological range more easily than on the continents. Moreover, because the natural species inhabiting remote islands have been selected primarily for their dispersal capacity, they have not necessarily been dominant or even highly successful in their original continental setting. Therefore, introduced species may prove more vigorous and effective. There may also be a lack of indigenous species to adapt to conditions such as bare ground caused by humans. Thus introduced weeds may catch on.

There are a number of major threats that invasive plants pose to natural ecosystems:

1 Replacement of diverse systems with single species stands of aliens, leading to a reduction in biodiversity, as for example when Australian *acacias* have invaded the fynbos heathlands of South Africa.
2 Direct threats to native faunas by change of habitat.
3 Alteration of soil chemistry. For example, the African *Mesembryanthemum crystallinum* ac-

cumulates large quantities of salt. In this way it salinizes invaded areas of Australia and may prevent the native vegetation from establishing.

4 Alteration of geomorphological processes, especially rates of sedimentation and movement of mobile landforms (e.g. dunes and salt marshes).
5 Plant extinction by competition.
6 Alteration of fire regime. For example, in Florida, USA the introduction of the Australasian *Melaleuca quinquenervia* has increased the frequency of fires because of its flammability, and has damaged the native vegetation which is less well adapted to fire.
7 Alteration of hydrological conditions (e.g. reduction in groundwater levels caused by some species having high rates of transpiration).

3.4 Faunal Realms

Next, in this study of present global patterns, we must take a look at the distribution patterns of the world's animals, and try to subdivide the world into zoogeographical regions or realms (figure 3.5b). Of the various attempts that have been made to do this, the most famous is that of a contemporary of Charles Darwin, A. R. Wallace (plate 3.4). In the late nineteenth century Wallace established six major regions, to which he gave specific names as they do not correspond very precisely with political or cultural areas. They are still widely accepted as useful, though subdivisions and amalgamations have been made from time to time. Some scientists have considered the Neotropical and Australian regions to be zoologically so different from the rest of the world, and from one another, as to rank as regions equivalent to the remaining four put together. In this classification there are three realms: Neogea (Neotropical), Notogea (Australia) and Arctogea (the rest of the world). Another proposal is that Palearctic and Nearctic do not merit separate regional status, and should thus be combined into one region – the Holarctic. As with all schemes of regionalisation and classification, some people are 'lumpers' and some are 'splitters'.

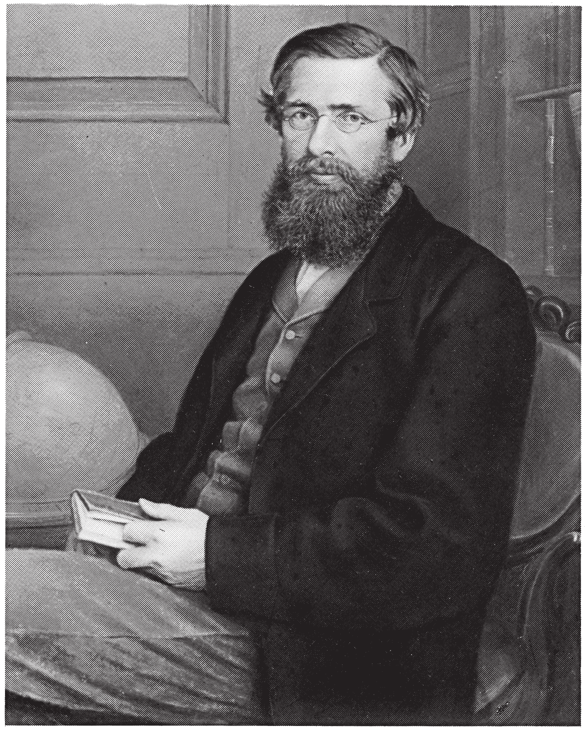


Plate 3.4 One of the greatest zoogeographers of all time was A. R. Wallace, who divided the world up into a series of faunal realms or regions. He noted the considerable differences between the fauna of Australia and of Asia, and the boundary between these two faunal areas is normally called Wallace's Line.

The important point, however, is that there are major differences in the nature of the species of animals found in different parts of the world. This reflects many factors, including present and past climates, the absence or presence of former land connections between continents, the operation of continental drift and the different operation of evolution in different parts of the world. For example, the fauna of Australia may have been similar at one time to that in other parts of the world because it was part of the great supercontinent of Pangaea or Gondwanaland. However, for some considerable time it has been isolated by a zone of deep water from Asia, and so exchanges have been limited, and evolution has been able to take place in comparative isolation, producing some unique species that are adapted to the particular environmental conditions of that continent. It is for these sorts of reasons that the Australian fauna is so special (plate

Plate 3.5 Australia has many endemic species of fauna, including marsupials. Isolation has enabled the evolution of such strange beasts as the koala bear (bottom, right) and the platypus (top).

3.5). Apart from bats, there are only nine families of mammals, and eight of these are unique. The dominant mammal fauna is marsupial; it is made up of six families, none of which occurs in the New World, where are found the only other living marsupials. The remaining two families of Australian mammals belong to a separate subclass of mammals, Monotremata. They are those bizarre egg-laying beasts, the duckbilled platypus and the spiny ant-eaters.

Since we have developed the means of long-distance travel, particularly across the oceans, we have greatly modified the distribution of animal species. In some cases people have been the unwitting cause of the introduction of foreign species to an area, as for example when cats and rats escaped from ships that visited tropical islands. At other times they have deliberately introduced particular species – for sport, for economic gain or from nostalgia – and as a consequence some species, like the trout, have a vastly greater distribution than they would have had without our assistance.

3.5 The World's Great Soil Orders

When a rock is first exposed at the earth's surface by erosion, it becomes subjected to the action of atmospheric and biological agents. Mechanical weathering by frost and other such processes achieves the first stages in soil formation by fragmenting the rock. Chemical weathering gradually changes the minerals of the rock, and some of the easily soluble components thus released are removed into streams by being *leached* out of the surface layers, while others may be involved in the nourishment of invading micro-organisms. As time passes, these increase in bulk, in complexity of life form and in their effect on the soil mantle, and eventually an organic rich layer may form at the surface. A soil may therefore be defined as an aggregate of many individual physical, chemical and biological processes that can be classified into various types, which gradually lead to the development of distinct layers or horizons by additions, removals, transfers and transformations of materials and energy. Most notable additions are organic matter and gases; removals involve salts and carbonates; transfers are of humus and sesquioxides; and transformations occur of, for example, primary minerals to secondary clays. All these processes take place in various combinations more or less simultaneously, the balance between them governing the nature of the soil profile.

Thus, within the soil numerous processes go on continuously as matter is transferred from one horizon to another, is added to the soil from above and is lost to plant roots from below. Such processes (which are discussed in greater detail in chapter 13) depend in part upon climatic conditions, so that at a gross scale certain patterns of soil development can be identified.

Soils that develop in areas of low precipitation, where rates of evaporation are high, have a water deficit for much of the time and undergo a process called *calcification*. When rain does fall it is sufficient to penetrate the upper soil layer, dissolve some calcium and percolate downwards. However, there is insufficient rainfall to leach the soil effectively, and soon the available water is evaporated or absorbed, leading to the deposition of the calcium carbonate.

In cool, moister climates, soil development tends to be influenced by *podzolisation* (window 3.4). Under such circumstances the water supply is more ample, so that the rainfall is sufficient to leach soluble materials quite thoroughly from the upper horizons, leaving only the rather inert silica behind. The leaching is assisted and accelerated by the presence of organic matter from the upper humus layer, and the minerals are transferred downwards to accumulate in the B horizon as an iron-cemented layer called an ironpan (section 13.2).

The hot wet regions of the tropics undergo *lateritisation*. High rainfall and high temperatures combine to promote intense chemical weathering; high temperatures promote bacterial action and organic matter is rapidly destroyed so that only a very limited humus layer is developed. These soils are often red in colour, and are dominated by large quantities of iron and aluminium sesquioxides.

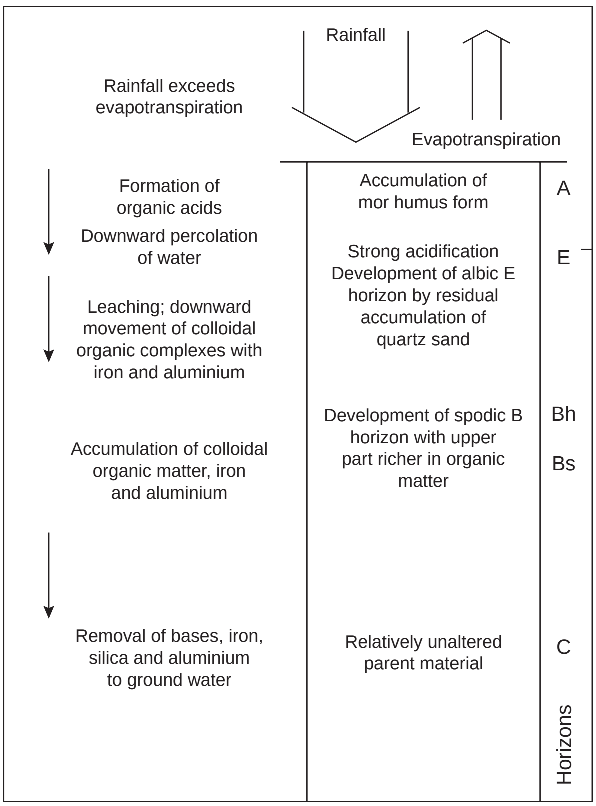
Processes such as these help to account for the major differences in soils in different major climatic zones. The US Department of Agriculture has identified ten main soil *orders*, and their classification is called the Comprehensive Soil Classification System (CSCS) or, alternatively, *The Seventh Approxi-*

mation. We can appreciate their distribution and character by taking a hypothetical continent from the Northern Hemisphere (figure 3.6).

In the south-east region of this hypothetical continent, hot, moist conditions produce lateritisation processes and lead to *oxisols*. In the dry, hot south-west are the *aridisols*, which are affected by calcification processes. In the cool and cold north pod-

Window 3.4 **Podzols**

Podzols are characterised by the presence, just below the surface, of an ashy-coloured horizon. It is from this that they derive their Russian name (*pod*, 'under' and *zola*, 'ash'). They are very extensive in a circumpolar belt which extends approximately from the Arctic Circle southwards to the latitude of St Petersburg (in Europe) and the northern shores of the Great Lakes (in North America). They are particularly well developed on permeable sands and gravels and occur on some of the heathlands of Britain. They are frequently associated with coniferous boreal forest. Their horizons are as follows. Below the raw humus layer there is a grey and somewhat structureless Ea horizon from which virtually all free iron has been removed. Beneath this is the B horizon of illuviation which typically includes a humus-enriched layer (Bh) and a strong brown or rusty coloured Bs horizon of iron and aluminium enrichment. High available soil moisture and organic material promote the development of these horizons.



The process of podzolisation.

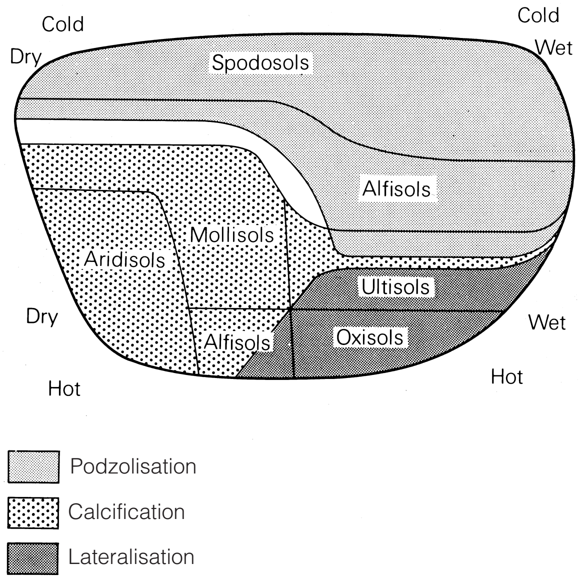


Figure 3.6 Schematic representation of the great soil orders on a hypothetical continent in the Northern Hemisphere.

zolisation occurs, producing *spodosols*. *Mollisols* are located in the intermediate positions between dry and moist climates, in areas of grassland vegetation. They display some calcification, but in addition possess a dark humus-rich upper layer. On the moist side of the mollisols lie the *alfisols*, located between arid and subhumid soils on one side and more humid ultisols on the other. These are grey-brown soils that commonly occur beneath deciduous forest. They are acid and have a lower horizon of clay accumulation. *Ultisols* develop where there is a pronounced summer wet season and a water-deficit dry season. They are quite deeply weathered and are transitional towards oxisols, often displaying the characteristic reddish-yellow coloration in the B horizon owing to the concentration of iron oxides.

The other four main soil orders are less clearly associated with any particular climatic regime. *Entisols* are soils that either have not existed long enough to develop mature horizonation (i.e. they are rec*ent*) or lie on parent materials, such as quartz

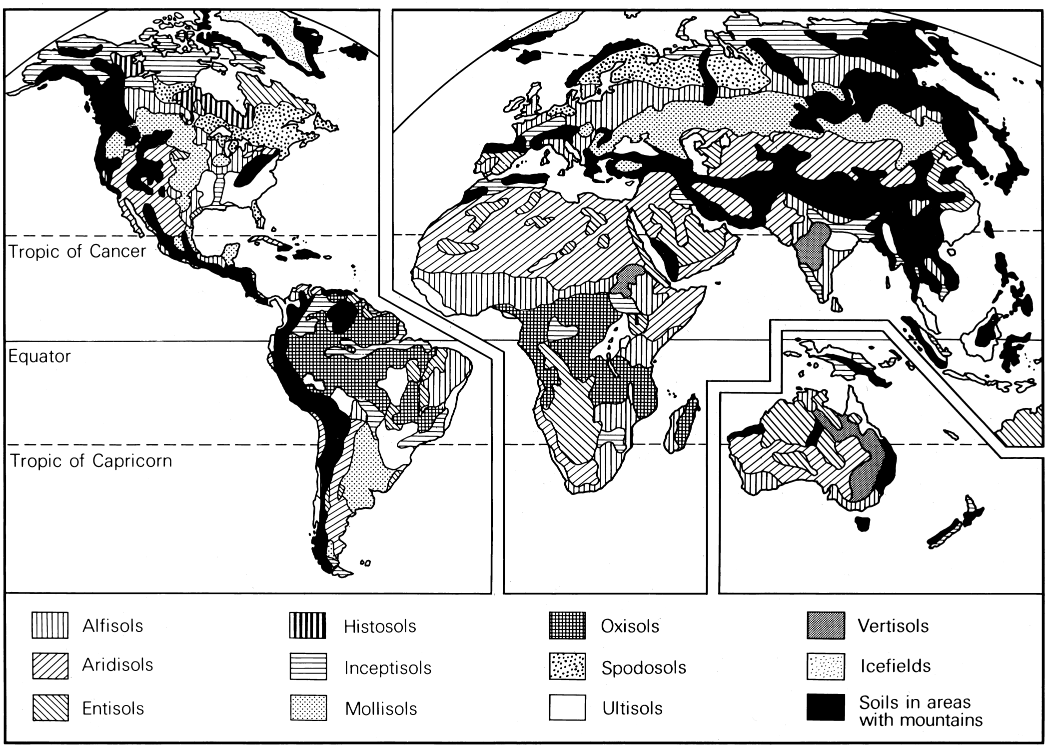


Figure 3.7 The global distribution of the main world soil orders according to the Seventh Approximation.

Table 3.3 US Department of Agriculture soil classification: the Seventh Approximation (1975)

Order	*Suborder*	*Characteristics/environment*
Alfisols (soils with an argillic horizon and moderate to high base content)	Aqualfs	Gleying features
	Boralfs	Others in cold climates
	Udalfs	Others in humid climates (including most leached brown soils)
	Ustalfs	Others in subhumid climates
	Xeralfs	Others in sub-arid climates
Aridisols (desert and semi-desert soils)	Argids	With argillic horizon (i.e. zone of clay accumulation)
	Orthids	Other soils of dry areas
Entisols (immature usually azonal soils)	Aquents	Gleying features
	Arents	Artificially disturbed
	Fluvents	Alluvial deposits
	Psamments	Sandy or loamy sand textures
	Orthents	Other entisols
Histosols	Fibrists	Plant remains very little decomposed
	Folists	Freely draining histosols
	Hemists	Plant remains not recognisable because of decomposition; found in depressions
	Saprists	Plant remains totally decomposed (black)
Inceptisols (moderately developed soils, not in other orders)	Andepts	Volcanic ash
	Aquepts	Gleying features
	Plaggepts	Man-made surface horizon
	Tropepts	Tropical climates
	Umbrepts	Umbric epipedon (i.e. dark-coloured surface horizon of low base status); hills and mountains
	Ochrepts	Other inceptisols (including most brown earths) of mid-high latitudes
Mollisols (soils with a dark A horizon and high base status, e.g. chernozems, rendzinas)	Albolls	With argillic and albic horizons
	Aquolls	Gleying features
	Rendolls	Highly calcareous materials
	Borolls	Others in cold climates
	Udolls	Others in humid climates
	Ustolls	Others in subhumid climates
	Xerolls	Others in sub-arid climates
Oxisols (soils with an oxic horizon or with plinthite near surface)	Aquox	Gleying features
	Humox	With a humose A horizon
	Torrox	Oxisols of arid climates
	Orthox	Others in equatorial climates
	Ustox	Others in subhumid climates
Spodosols (soils with accumulation of free sesquioxides and/or organic carbon e.g. podzols)	Aquods	Gleying features
	Ferrods	Much iron in spodic horizon
	Humods	Little iron in spodic horizon
	Orthods	Both iron and humus accumulation
Ultisols (soils with an argillic horizon, but low base content)	Aquults	Gleying features
	Humults	With a humose A horizon
	Udults	Others in humid climates
	Ustults	Others in subhumid climates
	Xerults	Others in sub-arid climates
Vertisols (cracking clay soils with turbulence in profile)	Torrerts	Usually dry (cracks open for 300 days per year)
	Uderts	Usually moist (cracks open and close several times a year)
	Usterts	Cracks remain open 90 days per year (in monsoon climates)
	Xererts	Cracks remain open 60 days per year

dune sand, that do not readily evolve into horizons. *Inceptisols* include soils formed on the alluvium deposited by major rivers. *Vertisols* are clayey soils characterised by deep, wide cracks in the dry season. These cracks close up in the wet season when the available moisture increases causing the clays to swell, but before it does so a portion of the surface material has washed into the cracks: it becomes in*vert*ed. Finally *histosols* are primarily organic matter rather than mineral soils and occur in bogs, moors or as peat accumulations where waterlogging is prevalent.

Thus the Seventh Approximation has ten soil orders (table 3.3 and figure 3.7), and although their terminology may at first sight appear forbidding and bewildering, it is relatively easy to understand once the principles of its construction have been grasped. The name of each order is based on syllables that are intended to convey the major attributes of that class, and we have already seen the origin of the terms entisol and vertisol. To construct class names at the suborder level we take two formative elements: the first indicating the characteristics of the soil or its environment (such as *aqu*, indicating wetness; see table 3.4), and the second being a suffix derived from the name of the order. Thus we could have the suborder *Aquox*, being an oxisol with gleying features indicative of wetness.

3.6 Human Modifications of Soil

Soils, being thin, heavily exploited and taking a long time to form, are prone to profound modifications in the face of human pressures. Some of the modifications are beneficial (plate 3.6), but others are detrimental as can be seen when we consider the ways in which humans alter some of the key soil-forming factors:

1 *Parent material*
Beneficial: adding mineral fertilisers; accumulating shells and bones; accumulating ash locally; removing excess amounts of substances such as salts.

Table 3.4 Formative elements in names of suborders of Seventh Approximation

Formative element	*Meaning*
alb	Presence of albic horizon (a bleached eluvial horizon)
and	Ando-like (i.e. volcanic ash materials)
aqu	Characteristics associated with wetness
ar	Mixed or cultivated horizon
arg	Presence of argillic horizon (a horizon with illuvial clay)
bor	Of cool climates
ferr	Presence of iron
fibr	Fibrous
fluv	Floodplain
fol	Presence of leaves
hem	Presence of well-decomposed organic matter
hum	Presence of horizon of organic enrichment
ochr	Presence of ochric epipedon (a light-coloured surface horizon)
orth	The common ones
plagg	Presence of a plaggen epipedon (a man-made surface 50 cm thick)
psamm	Sandy texture
rend	Rendzina-like
sapr	Presence of totally humified organic matter
torr	Usually dry
trop	Continually warm
ud	Of humid climates
umbr	Presence of umbric epipedon (a dark-coloured surface horizon)
ust	Of dry climates, usually hot in summer
xer	With annual dry season

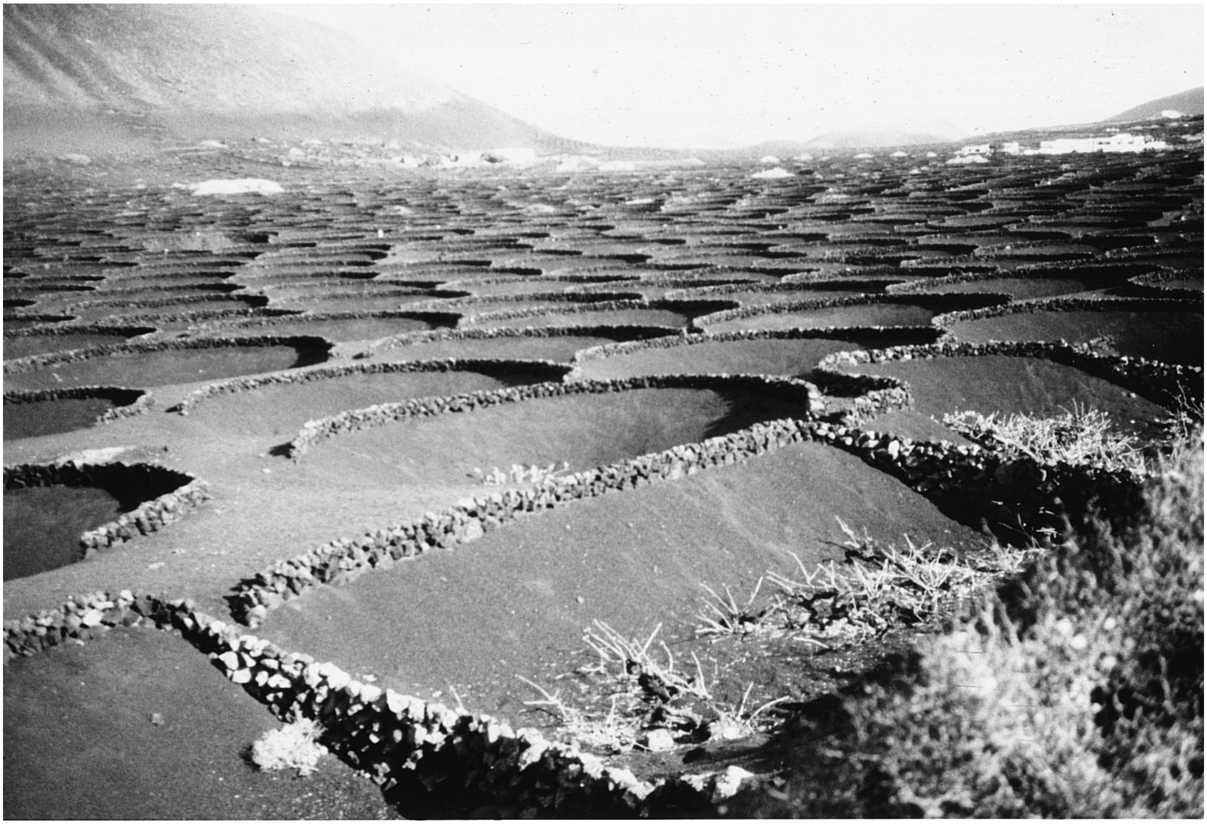


Plate 3.6 The micro-plots in Lanzarote, Canary Islands, used for growing vines and other tree crops, are essentially composed of soils that have been created from volcanic deposits by the labours of the islanders.

Detrimental: removing through harvest more plant and animal nutrients than are replaced; adding materials in amounts toxic to plants or animals; altering soil constituents in a way to depress plant growth.

2 *Topography*
Beneficial: checking erosion through surface roughening, land forming and structure building, raising land level by accumulation of material; land levelling.
Detrimental: causing subsidence by drainage of wetlands and mining; accelerating erosion; excavating.

3 *Climate*
Beneficial: adding water by irrigation; rainmaking by seeding clouds; removing water by drainage; diverting winds etc.
Detrimental: subjecting soil to excessive insolation, to extended frost action, to wind etc.

4 *Organisms*
Beneficial: introducing and controlling populations of plants and animals; adding organic matter including 'night-soil', loosening soil by ploughing to admit more oxygen; fallowing; removing pathogenic organisms, e.g. by controlled burning.
Detrimental: removing plants and animals; reducing organic content of soil through burning, ploughing, over-grazing, harvesting etc.; adding or fostering pathogenic organisms; adding radioactive substances.

5 *Time*
Beneficial: rejuvenating the soil by adding fresh parent material or through exposure of local parent material by soil erosion; reclaiming land from under water.
Detrimental: degrading the soil by accelerated removal of nutrients from soil and vegetation cover; burying soil under solid fill or water.

Among the more important human modifications of soil types are salinisation in irrigated areas and soil erosion and degradation by wind and water (see sections 6.14 and 13.6).

3.7 Climatic Geomorphology: The Influence of Climate, Soil and Vegetation

Although we started this part of the book by considering the pattern of major world landforms (shields, ocean ridges etc.) in terms of plate tectonics and global geology, it is also undoubtedly true that the nature of the landforms may, at a global scale, owe much also to the nature of the climate in the area, and to the influence that climate has through its effect on the nature of soil and vegetation. Because of this, attempts have been made by various climatic geomorphologists to delimit *mor-*

Table 3.5 Büdel's morphogenetic zones of the world

Zone	*Present climate*	*Past climate*	*Active processes (fossil ones in brackets)*	*Landforms*
(1) Of glaciers	Glacial	Glacial	Glaciation	Glacial
(2) Of pronounced valley formation	Polar, tundra	Glacial, polar, tundra	Frost, mechanical weathering, stream erosion (glaciation)	Box valleys, patterned ground etc.
(3) Of extra-tropical valley formation	Continental, cool temperate	Polar, tundra continental	Stream erosion (frost processes, glaciation)	Valleys
(4) Of subtropical pediment and valley formation	Subtropical (warm; wet or dry)	Continental, subtropical	Pediment[a] formation (stream erosion)	Planation surfaces and valleys
(5) Of tropical planation surface formation	Tropical (hot, wet or wet–dry)	Subtropical, tropical	Planation, chemical weathering	Planation surfaces and laterite[b]

[a] A pediment is a low-angle, concave rock surface at the base of a high-angle slope.
[b] Laterite is an iron-rich and/or aluminium-rich crust characteristic of a tropical region and caused by rock weathering.

Table 3.6 Wilson's morphogenetic systems of the world

System	*Dominant geomorphological processes*	*Landscape characteristics*
(1) Glacial	Glaciation, snow action (nivation), wind action	Glacial scour, alpine topography, moraines, kames, eskers etc.
(2) Periglacial	Frost action, solifluction	Patterned ground, outwash plains, solifluction, lobes etc.
(3) Arid	Desiccation, wind action, running water	Dunes, salt pans, deflation basins etc.
(4) Semi-arid (sub-arid)	Running water, rapid mass movements, mechanical weathering	Pediments, fans, badlands, angular slopes with coarse debris
(5) Humid temperate	Running water, chemical weathering, creep (and other mass movements)	Smooth slopes, soil-covered, ridges and valleys, extensive stream deposits
(6) Selva	Chemical weathering, mass movements, running water	Steep slopes, knife-edge ridges, deep soils (laterites included), coral reefs

phogenetic regions. The concept behind this is the theory that, under a certain set of climatic conditions, particular geomorphological processes will predominate; these will give to the landscape of a region characteristics that will set it apart from those of other areas developed under different climatic conditions. Because of the frequency and nature of climatic changes, it is necessary to consider the influence not only of present climates, but also of past climates.

One classification attempt has been that of Büdel, a German geomorphologist. His regionalisation scheme is illustrated in table 3.5. For comparison, table 3.6 sets out a more recent scheme, that of Wilson, an American geomorphologist. Whichever scheme is adopted, it is evident that climate does control the distribution of certain important phenomena and processes, including glaciation, permafrost, coral-reef growth, dune formation, frost weathering and wind erosion. These are the topics that we shall consider further in Part II.

■ *Key Terms and Concepts*

biomass
biomes
climatic climax community
climatic geomorphology
deforestation
faunal realms
fire
floral kingdoms
floral realms
introductions
lateritisation
leaching
maquis
morphogenetic regions
net primary productivity
podzolisation
Seventh Approximation
soil orders
succession

■ *Points for Review*

- Which are the world's most and least productive biomes?
- How does fire modify ecosystems?
- Describe and account for the distribution of the world's grasslands.
- How does grazing modify the ecosystem?
- Describe the location, causes and consequences of deforestation.
- What are plant invasions and why is their study important?
- What do you think are the main soil types in the world and what are their main characteristics?
- Give examples of beneficial and detrimental alteration of soil properties by humans.

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