Tropical Ecosystems and **Ecological Concepts**

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Chapter 1

The tropical environment

1.1 The tropics

The tropics may be defined as that portion of the earth situated between the Tropics of Cancer (23° 28′N) and Capricorn (23° 28′S). This area includes about 50 million km^2 of land, with almost half of it in Africa. Other substantial portions lie in Central and South America, southern Asia, northern Australia, with smaller areas in the Pacific Islands. Plant and animal distributions, however, are not constrained by these lines on the globe but are determined by variations in climate, soil type and other features of the environment. However, it is interesting that the distributions of tropical rain forests, mangroves and coral reefs do fall largely between these lines (Figures 8.2, 10.2 and 11.10). Therefore, it is appropriate to use the Tropics of Cancer and Capricorn as guides to the parts of the earth described in this book even though the distribution of tropical plants and animals may not, in some places, extend as far as these lines or, in others, extend north or south of them.

In 1855, Alphonse de Candolle proposed that the boundaries to major plant formations were set by climate. He suggested that the limits to deserts and grasslands were set by moisture, but that the latitudinal arrangement of the other plant formations suggested that temperature was the dominant factor. Köppen (1884, 1931) developed climate maps based on vegetation types. In this way, he was able to produce a climate map of the world even though he had very little climatic data from many parts of it. He assigned to each plant formation the climate that seemed appropriate to it. Since his climate map was based on the global distribution of vegetation types, it is not surprising that climate and vegetation maps were similar.

It has subsequently been shown, using independent measures, that the distribution of the world's climatic regions are indeed closely related to vegetation and that Köppen's vegetation-derived climate map has been verified through climatic measures. Figures 1.1 and 1.2 show the relationship between rainfall and vegetation in Africa. Clearly climate plays a major role in determining the global distribution of plants and animals. An explanation of plant and animal distributions also requires an understanding of the theory of plate tectonics. In this chapter, we describe climate in the tropics and the theory of plate tectonics and their role in determining the global distribution of plants and animals.

1.2 Climate in the tropics

Climatic variations are largely determined by latitude and altitude. In concentrating on tropical latitudes, we have narrowed the latitudinal range but significant climatic shifts can still be related to geographical position. The major climatic factors are temperature (daily and seasonal variations) and rainfall (total rainfall and its seasonal distribution).

1.2.1 Temperature

In contrast to temperate regions of the earth, the most significant climatic feature of the tropics at

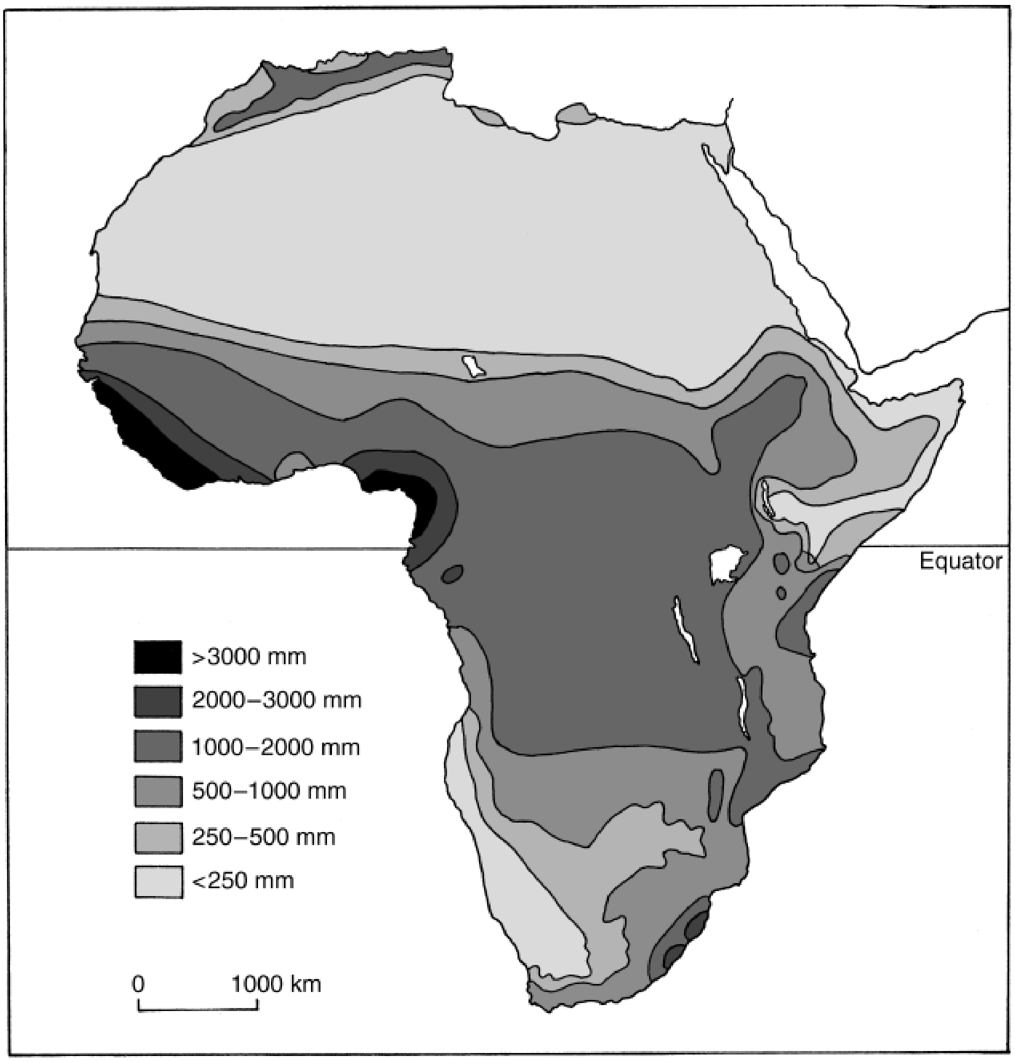

Figure 1.1 Distribution of total annual rainfall in Africa (after Pomeroy and Service 1986 reprinted by permission of Pearson Education Limited, Longman Group Limited).

sea level is the absence of a cold season. The mean annual temperature at sea level usually exceeds 18 °C and seasonal fluctuations in temperature and daily solar radiation are small (Table 1.1). Consequently, seasonality in temperature has less effect on biological activity in the tropics than it has in temperate regions. At higher altitudes in the tropics, diurnal temperature fluctuations can be significant: high during the day and down to, or below, freezing at night (see chapter 9).

Temperatures on the earth's surface follow daily and seasonal cycles; daily because the earth rotates on its axis and seasonal because the earth's axis of rotation is not at right angles to the line joining the earth and sun (Figure 1.3). If it were at right angles, the sun would be overhead at the equator every noon throughout the year. As the earth is tilted, the noon position of the sun moves progressively north after 21 March (**equinox**) and at noon on 21 June (**summer solstice**) it is directly overhead the Tropic of Cancer. The sun then appears to move south, crossing the equator on 23 September (equinox) to be directly over the Tropic of Capricorn at noon on 22 December (**winter solstice**). The solstices are

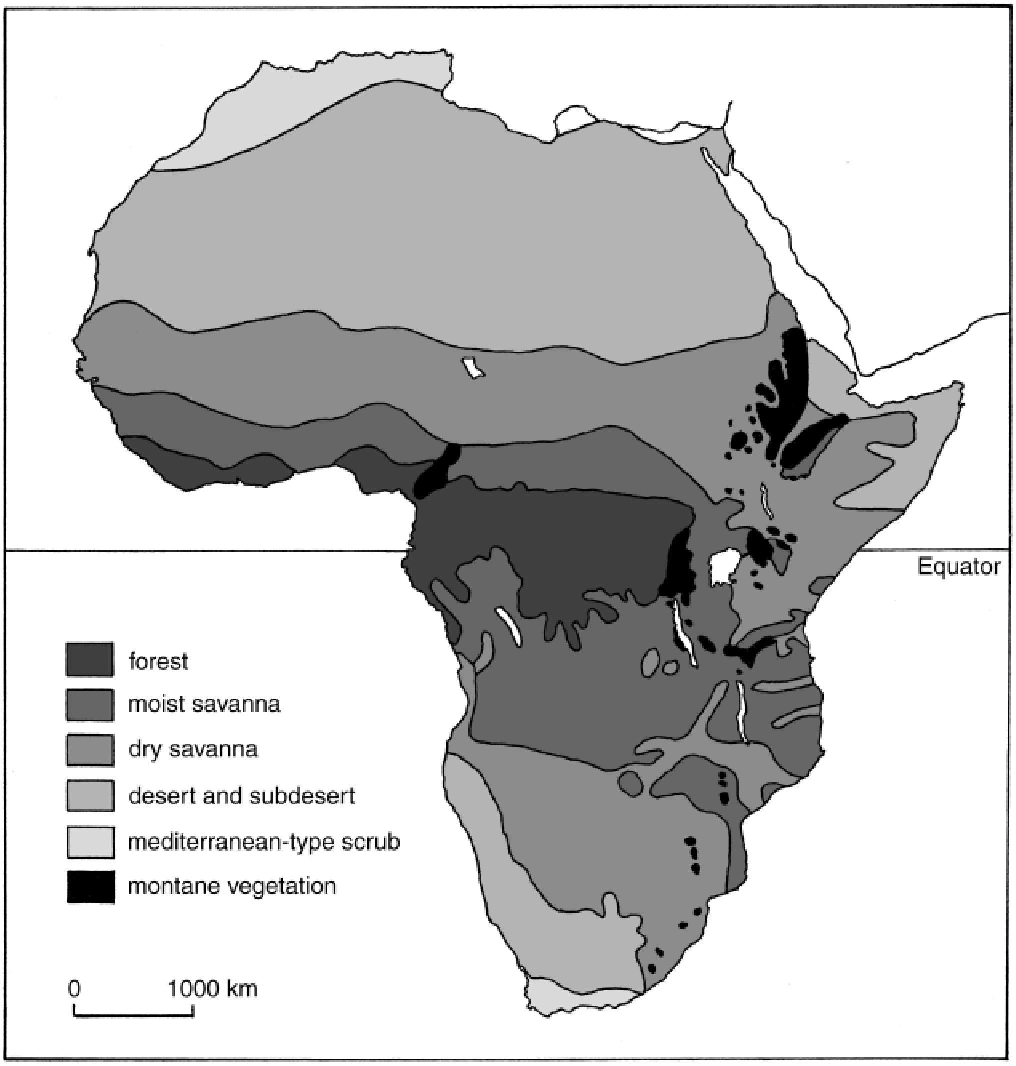

Figure 1.2 Distribution of the main types of vegetation in Africa. Note the relationship between the distribution of rainfall (Figure 1.1) and vegetation type (after Ewer and Hall 1978).

named after the prevailing season in the northern hemisphere. After 21 December, the sun appears to move north again and is directly over the equator at noon on 21 March.

The tropics are hotter than temperate regions because the sun's rays strike almost at right angles near the equator but at an increasingly acute angle towards the poles. Therefore the same amount of radiant heat is concentrated over a smaller area in the tropics than it is nearer the poles (Figure 1.4a). Moreover, near the poles the sun's rays have to pass through a deeper layer of atmosphere and lose more energy by absorption, reflection and scattering. Day-length changes at latitudes away from the equator partially compensate for the reduced heat input (Figure 1.4b), but total annual insolation is still lower at higher latitudes.

As a result of the variations in energy supply with latitude, lower latitudes have more heat, delivered at a more constant rate than higher latitudes. There is a mass transfer of heat away from the equator, towards the poles. This transfer occurs in both the oceans and the atmosphere.

Table 1.1 Annual range of daily solar radiation at the top of the atmosphere at tropical and temperate latitudes.

Latitude	Daily max J cm^{-2} d^{-1}	Daily min J cm^{-2} d^{-1}	Maximum/minimum	[(Max − Min) × 100]/Min
0°	3890	3430	1.13	13.4
10° N	3786	3180	1.19	19.1
23° N	4100	2552	1.61	60.7
50° N	4309	878	4.90	390.5

Notes: Note that, at the equator, the annual maximum solar radiation is only 13% higher than the minimum. This percentage increases sharply outside the tropics and reaches almost 400% at 50° N and S.
Source: List 1971.

Oceanic heat transfer is significant since the heat capacity of water (see Box 2.1) is high, but heat transfer through the atmosphere is more rapid and is mostly responsible for the climatic shifts we observe on a daily basis.

1.2.2 The inter-tropical convergence zone and rainfall

The concentration of radiant heat above the equator warms the air and it expands and rises. As it rises, the air cools and, since cold air holds less moisture, rain falls. The air near the ground is replaced by air from the north and south. The rising air spreads out and falls again at about 30° N and S (see Figure 2.2). In this region, cool, dry air warms as it falls to earth and this explains why deserts are often found at these latitudes (chapter 2).

The rotation of the earth results in the deflection of these northerly and southerly winds so that they blow from the north-east (northern hemisphere) and south-east (southern hemisphere) respectively. This deflection is caused by the **Coriolis** force. The earth rotates from west to east. At the equator, the rate of rotation is faster than it is either to the north or south, since, at the equator, the earth's surface is furthest from the axis of rotation. This force causes oceanic and atmospheric currents to be deflected to the right in the northern hemisphere and to the left in the southern hemisphere.

These winds (north-east (northern hemisphere) and south-east (southern hemisphere)) are known as **trade winds** (they powered the sailing ships that plied the trade between the Orient and Europe) and are renowned for their consistent speed and direction. These winds meet in an equatorial low-pressure trough, warm air ascends and precipitation results. This zone, the **Inter-Tropical Convergence Zone (ITCZ)**, is where mixing of trade winds from the northern and southern hemispheres often results in zones of low atmospheric pressure (depressions) or cyclones.

The ITCZ is not a continuous feature in either time or space. The ITCZ moves north of the equator during the northern summer (June–August) bringing rain to the underlying regions. At the end of the northern summer, the ITCZ migrates south of the equator and these regions have a wet season between November and January. Equatorial regions exhibit a bimodal rainfall pattern, with peak rainfall occurring each time the ITCZ crosses the equator. In other words, there is a seasonal migration of a rain belt that follows the seasonal movement of the sun. At the higher tropical latitudes, a single rainy season occurs following the summer solstice in each hemisphere. Two peaks in the mean annual rainfall are recorded at sites near the equator in response to the passage of the overhead sun at the equinoxes. There are days when ITCZ-generated cloud stretches in an almost unbroken band around the globe, but it is often broken into strips

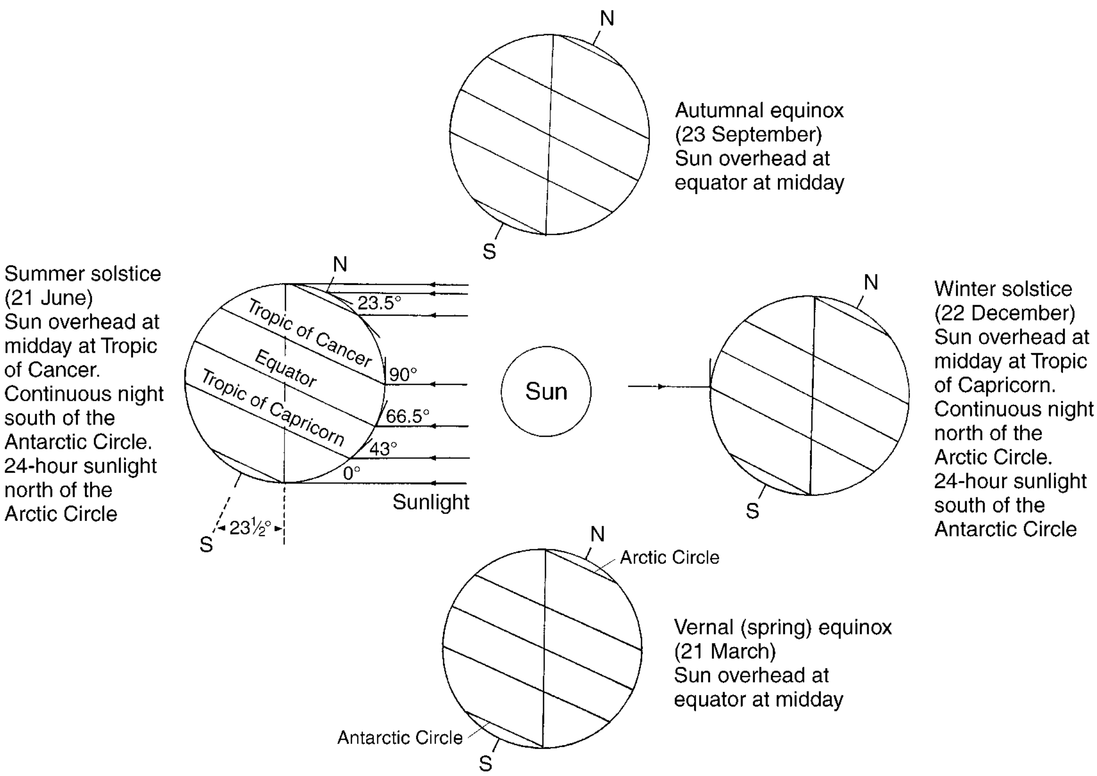

Figure 1.3 Rotation of the earth around the sun. The axis of rotation is tilted at 23°28′ from the vertical. At the summer solstice (northern hemisphere summer) the sun is overhead at midday at the Tropic of Cancer. At this time of the year, above the Arctic circle, the sun does not set and below the Antarctic circle the sun does not rise. At the winter solstice (northern hemisphere winter), the sun is overhead at midday at the Tropic of Capricorn. At this time of the year, above the Arctic circle, the sun does not rise and below the Antarctic circle the sun does not set. At the autumnal (23 September) and vernal (21 March) equinoxes the sun is directly over the equator at midday (after Pomeroy and Service 1986 reprinted by permission of Pearson Education Limited, Longman Group Limited).

and may disappear entirely. The mean position of the ITCZ in January and July is shown in Figure 1.5.

1.2.3 Monsoons, typhoons and tropical storms

To the north and south of the trade winds, beyond 40 degrees, lie the westerlies. The equatorial westerlies are responsible for the monsoons that occur over West Africa and the Indian subcontinent (Figure 1.5). Land masses heat more rapidly during summer than do the adjacent oceans and, conversely, the land cools more rapidly following the onset of winter. These differential rates of heating and cooling cause seasonal switches in winds. From May to October, air rises over the warm Asian interior and draws in moisture-laden air from the Indian Ocean over the Indian subcontinent (**south-west monsoon**) and air drawn from the Pacific flows over Asia (**south-east monsoon**). From November to April, air sinks over the cold Asian interior resulting in the north-east monsoons. Monsoons also occur in northern Australia and West Africa.

Air converging upon a low-pressure cell (**cyclone**) rises, the air cools, clouds form and rain falls. This contrasts with the warming and drying that occurs in a high-pressure cell (**anticyclone**). In the tropics, cyclones may form a rotating storm known as a **hurricane** or **typhoon**. These storms can be devastating, causing flooding in coastal areas through storm surges and torrential rains. High wind speeds wreak further havoc. In 1991, a typhoon struck the Bay of Bengal and was

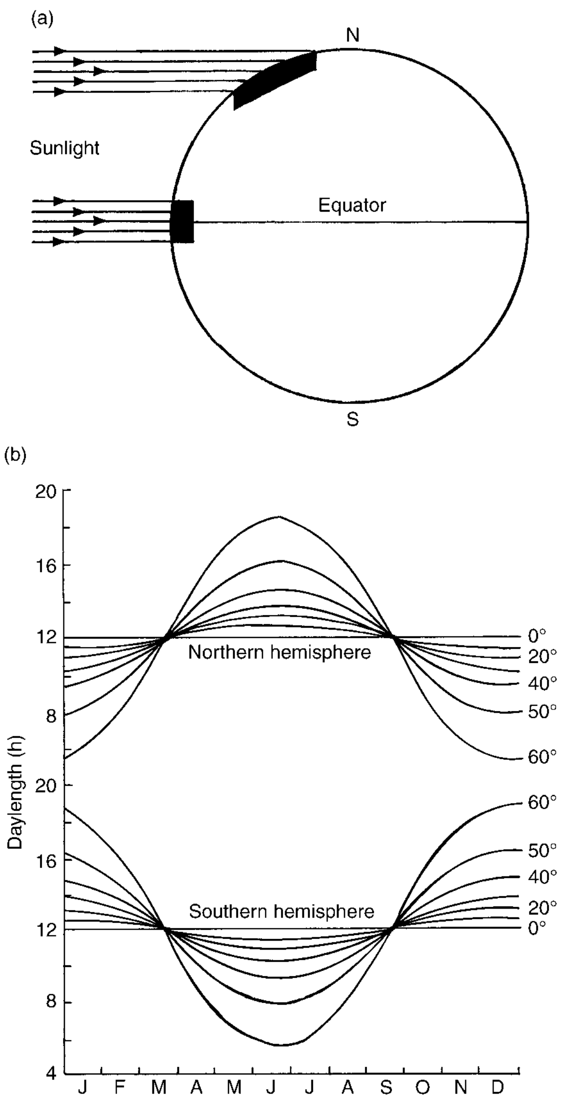

Figure 1.4 (a) Owing to the spherical shape of the earth, solar energy is concentrated over a smaller area in equatorial regions than in polar regions. Distance travelled through the atmosphere is also shorter at the equator. Consequently, tropical regions are warmer than polar regions. (b) Variations in day length throughout the year in relation to latitude in the northern and southern hemispheres.

responsible for 250000 deaths in Bangladesh. Hurricane Mitch devastated communities in Central America in 1998. These storms not only affect the lives of humans living in their path but also cut a swath through the forests, resulting in the destruction of large trees and providing an opportunity for their replacement with new individuals. This regeneration process plays an important role in maintaining species diversity in tropical forests (see chapter 8).

1.2.4 Rainfall patterns and seasonality

Since land and sea absorb heat at different rates, diurnal and seasonal changes are larger on land than in water. Tropical deserts are hot during the day but they lose their heat rapidly at night by radiation of infra-red energy and by conduction and convection (Figure 1.6). In contrast, tropical rain forests, with their mantle of cloud and vegetation are much cooler by day and retain warmth at night. The vegetation and clouds act as a blanket absorbing and reflecting radiation. Loss of heat by conduction and convection is minimised because the thick forest undergrowth reduces heat gradients and wind speeds (Table 1.2).

Variations in rainfall and humidity are extreme within the tropics and largely determine the suite of organisms that live in a particular region. Some desert areas receive no rainfall, rain forests may be deluged with more than 10 m of rain in a year. The intensity of storms and the total amount of rain falling in heavy storms are considerably higher in the tropics than in temperate areas. Raindrops in tropical downpours are often larger and contain more potential energy and, therefore, more erosive power.

Considerable variation in rainfall can occur within a relatively short distance, especially where the topography is steep and mountainous. Rain may fall in heavy, localised storms and therefore rainfall, even within a small area, may be highly variable and unpredictable (Figure 1.7). The impact of this variability (and indeed the variability itself) is probably greater in areas where water is scarce (see chapter 2). In higher rainfall areas, where variability receives less attention, it is likely that variability is similar to that recorded at higher latitudes.

Rainfall intensity in the tropics is commonly so high that infiltration capacity is exceeded regardless of land management. This leads to water-logging on flat ground or soil erosion on slopes. The ratio run-off : infiltration depends on

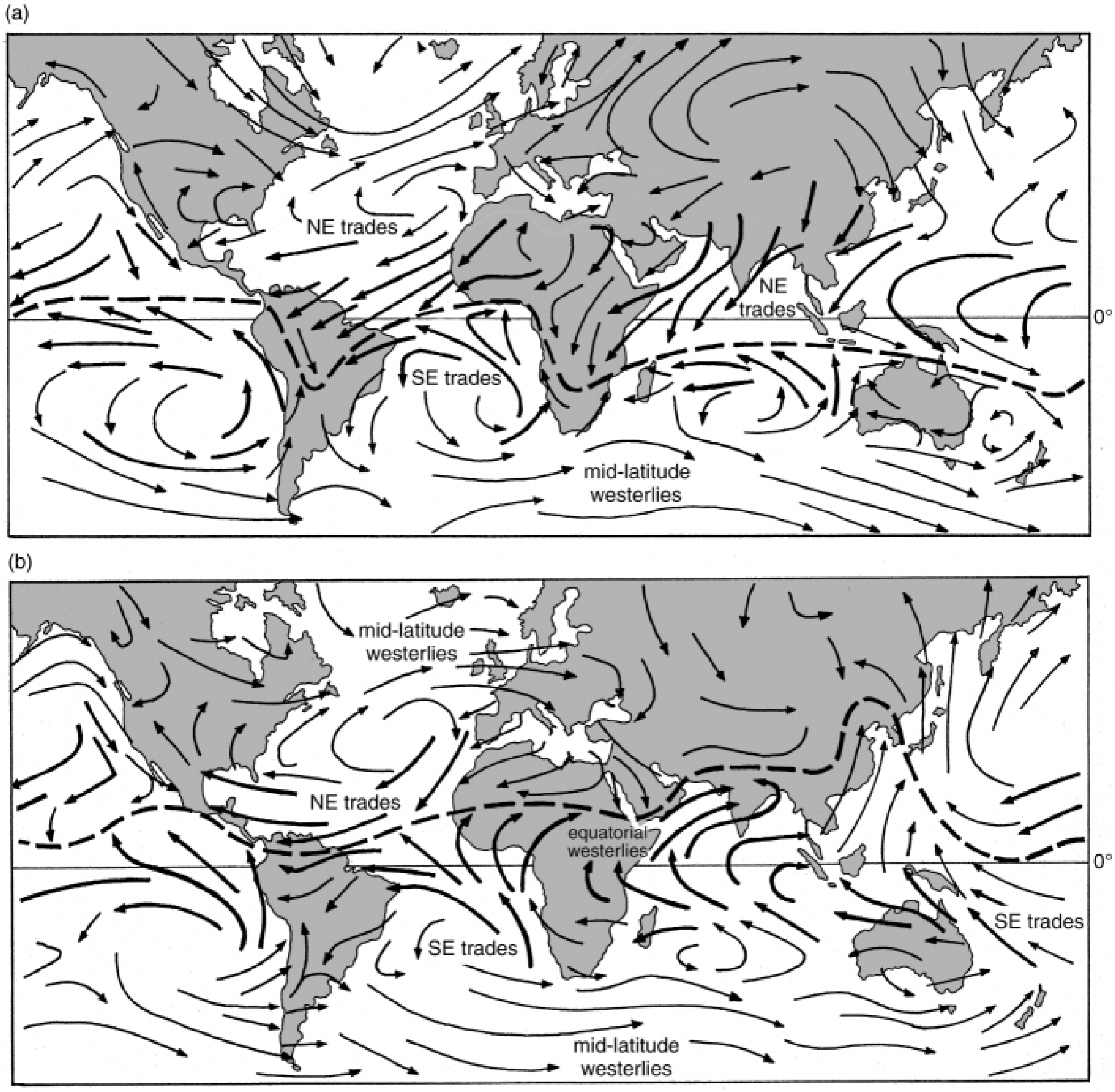

Figure 1.5 Mean surface winds over the earth in (a) January and (b) July showing the approximate position of the Inter-Tropical Convergence Zone (dashed line) (after White *et al.* 1993 with kind permission from Kluwer Academic Publishers).

the rate of precipitation (drizzle or downpour), vegetation cover, soil porosity, litter cover and organic matter content of the soil, soil moisture level and topography.

The decrease in mean annual rainfall at increasing distances from the equator is accompanied by increasing seasonality. The increase in seasonality is linked even more closely with the magnitude of change in day length with increasing latitude (Figure 1.4b). In temperate regions, day length plays a key role in providing organisms with a biological clock. However, within the tropics, seasonality in rainfall has greater impact on the life of tropical organisms. Germination, flowering and fruiting in tropical plants and breeding, feeding and life history strategies in tropical animals are markedly affected by rainfall.

Seasonal movements of animals (migration) are often made in response to food supply which, in turn, fluctuates in abundance with rainfall. The influence of environmental factors on organisms

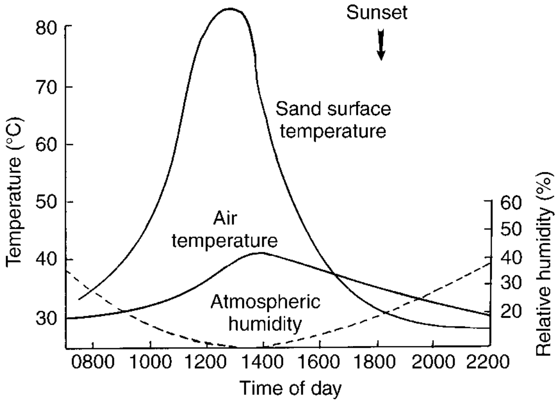

Figure 1.6 Diurnal variations in air and soil surface temperature and humidity recorded in September at Wadi Halfa, Sudan (after Cloudsley-Thompson and Chadwick 1964).

Table 1.2 Mean maximum temperatures and daily temperature range at two heights above the ground in tropical rain forest

	Dry season		Wet season	
Sampling height (m)	0.7	24.0	0.7	24.0
Mean maximum (°C)	29.7	33.9	26.8	30.9
Daily range	5.8	9.9	5.5	9.2

Source: Richards 1952.

Figure 1.7 Localised rainfall on the Chilwa Plain, Malawi (Photo: Patrick Osborne).

and their populations will be discussed in chapters 2, 3 and 4. An important general difference between tropical and temperate environments is that the wet tropics have seasonal rainfall and near constant temperatures, whereas, in temperate areas, rainfall varies less during the year but temperature is markedly seasonal. Climate diagrams provide a convenient way to display temperature and rainfall patterns, and construction and interpretation of these diagrams is described below.

1.2.5 Climate diagrams

A good, comparative way of presenting climatic data is through climate diagrams developed by Walter and Leith (1967). In these figures, seasonal variations in temperature and rainfall are plotted on one diagram (Figure 1.8). The lower curve shows the mean monthly temperature (10 °C intervals on the *y*-axis); the upper curve presents mean monthly rainfall (20 mm intervals on the *y*-axis, except where rainfall exceeds 100 mm when the scale is reduced by 10 : 1). The area under this reduced scale is conventionally shaded black to indicate very wet periods. The reduced scale serves to keep the diagrams to a manageable size. Periods in which the curve for rainfall falls below that for temperature indicate arid months.

Another important convention in drawing these diagrams is that data from the northern hemisphere are plotted from January to December, those from the southern hemisphere are plotted from July to June. This facilitates visual comparison of diagrams from opposite sides of the equator (Figure 1.9). These diagrams are compiled from mean values and therefore do not provide information on interannual or diurnal variations.

1.2.6 World distribution of tropical climates

Climate not only varies spatially and seasonally but variations also occur from one year to the next. We are gradually beginning to understand some of these variations between years, and significant progress has been made in documenting and predicting the occurrence of one process which has world-wide impact. In the

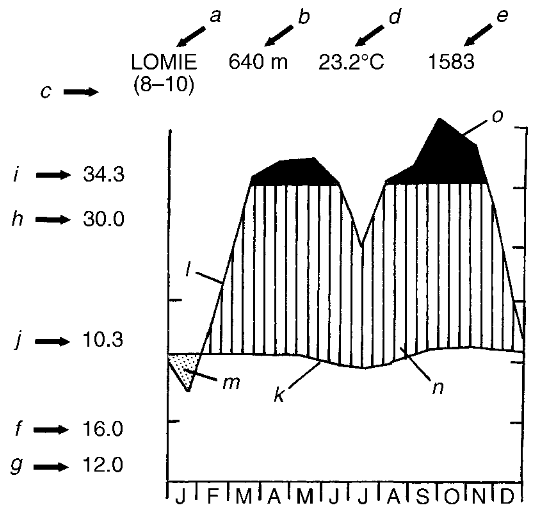

Figure 1.8 Example of a climate diagram for Lomie in Cameroon. The symbols and figures on the diagram have the following meaning: (a) station name; (b) station altitude; (c) number of years of observations (first figure: temperature; second figure: rainfall); (d) mean annual temperature; (e) mean annual rainfall mm; (f) mean daily minimum of coldest month; (g) lowest temperature recorded; (h) mean daily maximum of warmest month; (i) maximum temperature recorded; (j) mean daily temperature range; (k) graph of monthly mean temperatures (scale divisions are 10 °C); (l) graph of monthly mean rainfall (scale divisions are 20 mm); (m) drought period; (n) humid period; (o) monthly rainfall greater than 100 mm (scale 1/10 that of rainfall) (after Walter 1971 with kind permission from Gustav Fischer Verlag, Stuttgart 1991 © Spektrum Akademischer Verlag, Heidelberg, Berlin).

1920s, attention was drawn to an oscillation in atmospheric pressure between the east and west sides of the Pacific Ocean. This phenomenon was called the **Southern Oscillation (SO)**. It has now been shown that the SO is related to variations in rainfall and sea surface temperatures in the equatorial eastern Pacific. The irregular occurrence of warmer than usual water off the Peruvian coast has been known there a long time and is locally called **El Niño**. Under normal conditions, the winds and ocean currents of the tropical Pacific travel from east to west, producing a large reservoir of warm water around Indonesia. El Niño is a reversal of winds and ocean currents across the Pacific that usually lasts for a year or two, and occurs typically every four to five years. Recent **El**

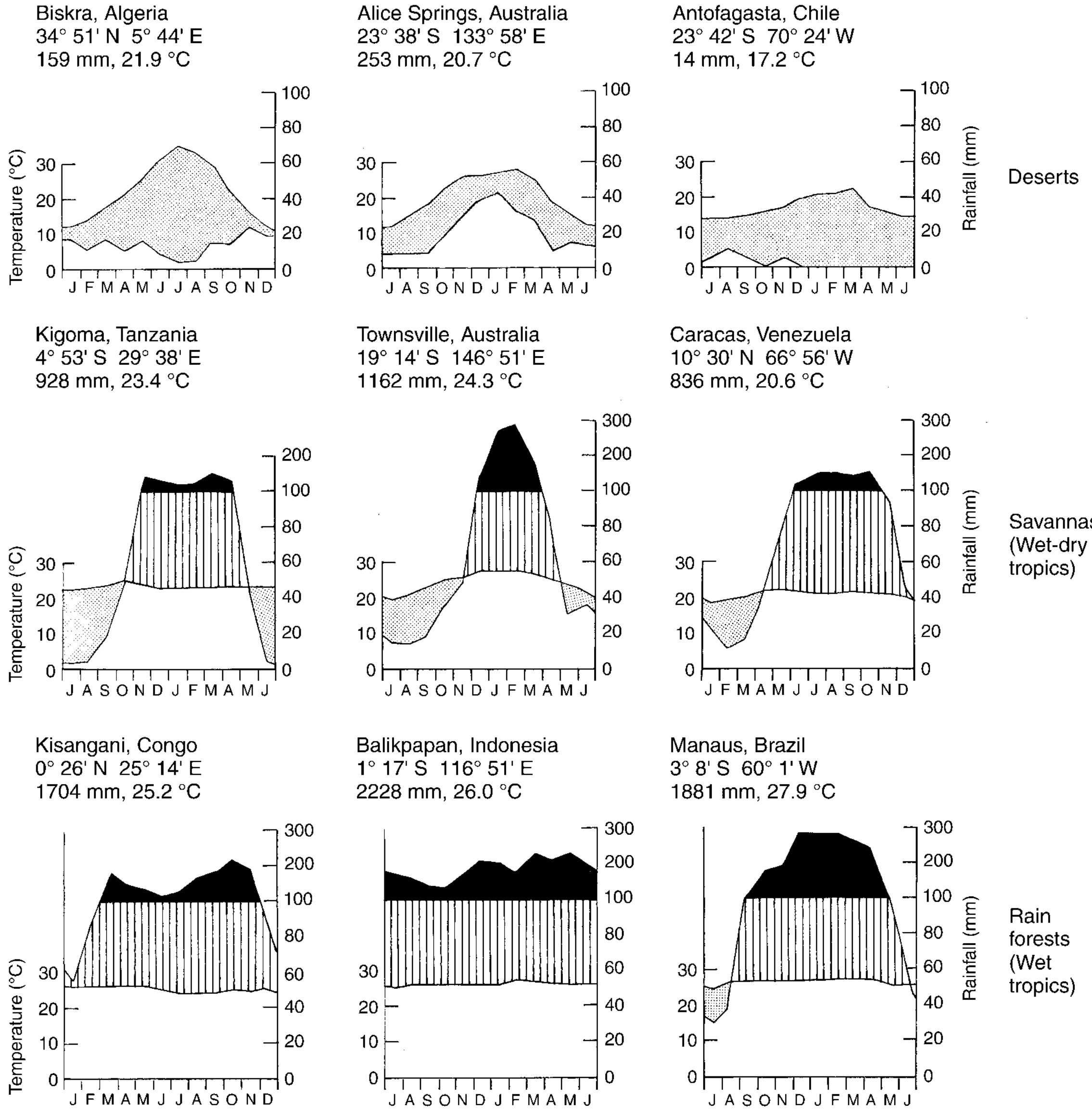

Figure 1.9 Homoclimes of desert, savanna and rain forest regions in Africa, Australia, South-East Asia and South America (after Walter and Leith 1967 with kind permission from Urban and Fischer Verlag).

Niño Southern Oscillation (ENSO) events have occurred in 1972–73, 1976–77, 1982–83, 1992–93 and 1997–98. The impact of these ENSO events is of global significance with common features including droughts in southern Africa, eastern Australia and Brazil, forest fires in Indonesia, storms and wet weather along the American coast from Alaska to Peru and warmer winters in the American mid-west.

The 1982–83 ENSO was one of the strongest this century and regions as far apart as Australia, the Philippines, southern India and southern Africa suffered severe droughts. In East Kalimantan, the impact of the drought was exacerbated when some 3.5 million hectares of forest were destroyed by fires. In both 1991–92 and 1997–98, El Niño struck again with floods, famines and forest fires occurring in regions