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Distribution and Characteristics of African Dry Forests and Woodlands

Jonathan Timberlake, Emmanuel Chidumayo and Louis Sawadogo

INTRODUCTION

It is important to define and characterize dry forests and woodlands as these forms of vegetation mean different things to different people depending on their discipline and background. This chapter provides the reader with a description of the dry forest and woodland types of sub-Saharan Africa and illustrates some of their basic biological features. Here we define dry forest and woodland as vegetation dominated by woody plants, primarily trees, the canopy of which covers more than 10 per cent of the ground surface, occurring in climates with a dry season of three months or more. Such a broad definition – wider than those used by many authors – incorporates vegetation types commonly termed woodland, shrubland, thicket, savanna and wooded grassland, as well as dry forest in its strict sense. However, it does not include moist evergreen forest (rainforest), grasslands and dwarf shrublands, such as heathlands and fynbos. Where more specific vegetation types are being described, the appropriate term (e.g. dense woodland, wooded grassland) is used.

Forest Structure at Landscape Level

The terminology used in describing African vegetation is often confusing, with many different approaches. In the 1950s, a continent-wide framework was established at a meeting in Yangambi, Belgian Congo (now Democratic Republic of Congo) (CCTA/CSA, 1956), but this was considered by many as too biased towards the moist forest and dense woodland formations of humid western Africa. Workers more concerned with rangeland and land-use planning developed a well-structured system based on percent canopy cover and canopy height (Greenway, 1973; Pratt et al, 1966), while the worldwide UNESCO vegetation mapping legend (UNESCO, 1973) provided a middle ground, but was only really usable at very broad scales. The most recent, and perhaps most thorough overview of African vegetation is that by White (1983), who made a point of avoiding the use of terms such as steppe and savanna owing to difficulties in their definition and usage. White himself, for example, uses the term 'dry forest' very specifically to mean vegetation dominated by a continuous stand of trees over 10m in height which experience a dry season of a few months during which atmospheric humidity is low – a quite restricted vegetation type. In this book we use the term 'dry forest' for the tall closed-canopy seasonal or deciduous forests that separate tropical rainforest from the mesic woodlands to the immediate south and north of the equator. The term woodland is used to include vegetation types ranging from open woodlands and wooded grassland with greater than 10 per cent woody cover, sometimes loosely termed savanna. Also included are shrublands with a canopy at only 2m or so high. Dry forests and woodlands therefore incorporate seven of White's structural vegetation formations including forest, woodland, transition woodland, bushland and thicket (see Box 2.1), scrub woodland, shrubland and wooded grassland.

Box 2.1 Itigi-Sumbu thicket

A thicket is a low forest consisting of a closed stand of bushes and climbers between 3 and 7m tall (White,1983). Itigi-Sumbu thicket is a unique vegetation form surrounded by almost unrelated vegetation types (Almond, 2000). The thicket occurs in Tanzania (central parts of the country) and Zambia (between Lakes Mweru Mweru-Wantipa and Tanganyika (Wild and Fernandes, 1967) and covers a total area of about 7800km^2. Little is known about the ecology of the Itigi-Sumbu thicket but it has a woody flora of about 100 species (Fanshawe, 1971) and characteristic species include *Baphia burttii, B. massaiensis, Bussea massaiensis, Burttia prunoides, Combretrum celastroides, Grewia burttii, Pseudoprosopsis fischeri* and *Tapiphyllum floribunda*. The vegetation type is considered endangered with about 50 per cent of it in Tanzania and as much as 71 per cent in Zambia having been cleared; apparently clearing takes place even in protected areas (Almond, 2000). In Tanzania none of this vegetation is in protected areas. However, protection status does not appear to prevent clearing of Itigi-Sumbu thicket.

Source: Based on World Wide Fund for Nature (2001)

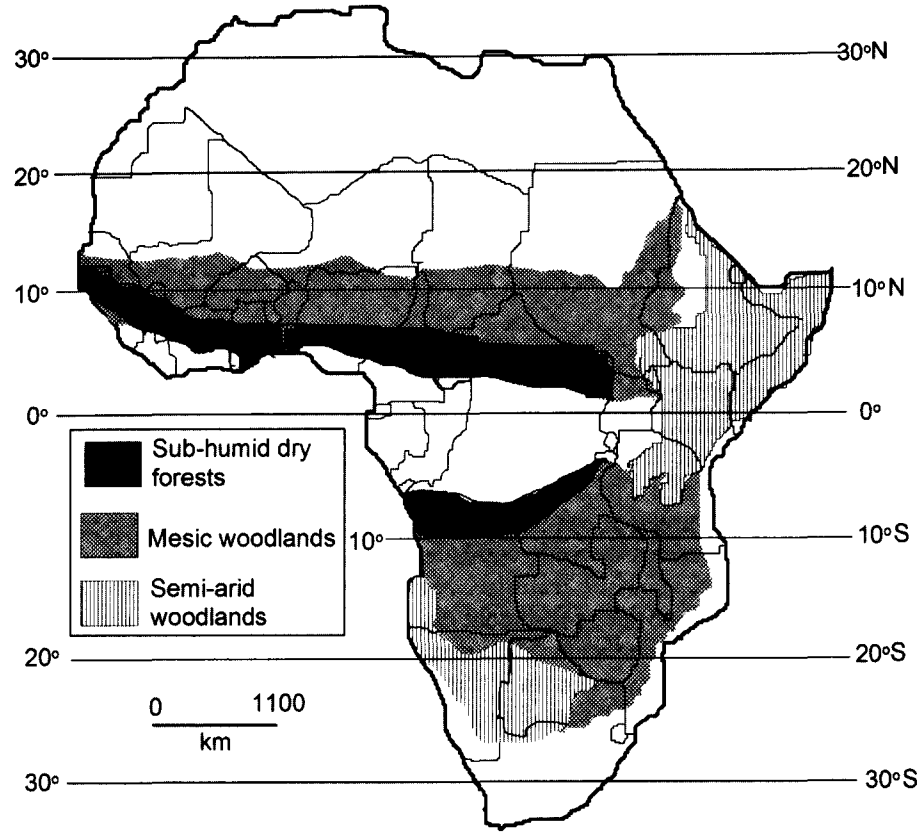

Figure 2.1 *Distribution of dry forest and woodlands across sub-Saharan Africa*

Source: Based on White (1983)

Another important consideration is the difference – in composition, structure and ecological processes – between woodlands dominated by broader-leaved species, such as *Brachystegia, Isoberlinia* and *Combretum*, and those dominated by fine-leaved or microphyllous species such as *Acacia* (Frost, 1996). Most of the dry forests and woodlands discussed here are dominated by trees of the legume family (Leguminosae or Fabaceae), but broad-leaved woodlands are mostly composed of species from the Caesalpinoid subfamily of the legumes, while microphyllous savannas are dominated by species from the Mimosoideae subfamily. The difference is not just in species composition, but also in ecology, and hence response to management. Broad-leaved woodlands, such as miombo, teak woodland and *Isoberlinia* woodlands in western Africa, tend to occur on nutrient-poor soils, are slower-growing when regenerating from seedlings and also comprise species that do not fix nitrogen. Whereas microphyllous savannas, such as the Kalahari *Acacia* woodlands of southern Africa,

the eastern African *Acacia–Commiphora* savannas, and those across the Sahel region, often occur on nutrient-richer soils with more nitrogen-fixing species. This is partly a function of climate – soils under higher rainfall conditions are more leached of nutrients than those in much drier areas. These features are of great significance in determining the responses of different dry forest and woodland types to utilization and management interventions.

Physical Environment

Climate

According to the Köppen classification, the climate types associated with dry forests and woodlands in sub-Saharan Africa include 3Af (warm sub-humid), 4Af (warm dry) and 5Af (very dry). These types are tropical with alternating wet and dry seasons in which precipitation is caused by the penetration of the inter-tropical convergence zone during the period of high sun. The period of low sun is characterized by trade winds associated with a distinct dry season. On the basis of these climatic features, we can divide dry forests and woodlands into three main types: warm sub-humid dry forests, warm mesic dry woodlands and warm semi-arid woodlands. The warm sub-humid dry forests occur in two of White's (1983) floristic regions – the Guinea-Congolia/Zambezian regional transition zone and the Guinea-Congolia/Sudanian regional transition zone. Warm mesic dry woodlands occur in the Zambezian and the Sudanian regional centres of endemism, while the semi-arid dry woodlands cover most of the Somali-Masai regional centre of endemism, and the Kalahari-Highveld regional transition zone. These vegetation formations, which occur between 20°N and 30°S, are shown in Figure 2.1.

In western Africa, the sub-humid dry forests and warm mesic dry woodlands correspond to the Guinea savanna and the Sudan savanna of Keay (1959), respectively. In eastern Africa the semi-arid dry woodlands correspond to the *Acacia–Commiphora* region, and in southern Africa the warm mesic dry forests correspond predominantly to the *Brachystegia–Julbernardia* (miombo) woodlands while the semi-arid dry woodlands correspond to *Acacia–Combtretum* formations. Within the miombo woodlands are embedded other vegetation types such as undifferentiated woodlands and mopane woodlands.

The broad climatic features associated with dry forests and woodlands are summarized in Figure 2.2. The sub-humid dry (Guinea) forests of western Africa have a shorter rainy season of about 7 months compared to 8 months in the southern sub-humid dry forests; mean annual rainfall is similar and ranges from 1200 to 2000mm. In contrast, the warm mesic dry (Sudanian) woodlands of western Africa experience a longer wet period of about 4.5 months compared to 4 months in the warm mesic dry (Zambezian) woodlands of southern Africa, but the range in mean annual rainfall of 600 to 1200mm is again similar in the two woodland regions. In the semi-arid dry woodlands the rainy season is shorter (2 months) in eastern Africa and 4.5 months in southern Africa. Another

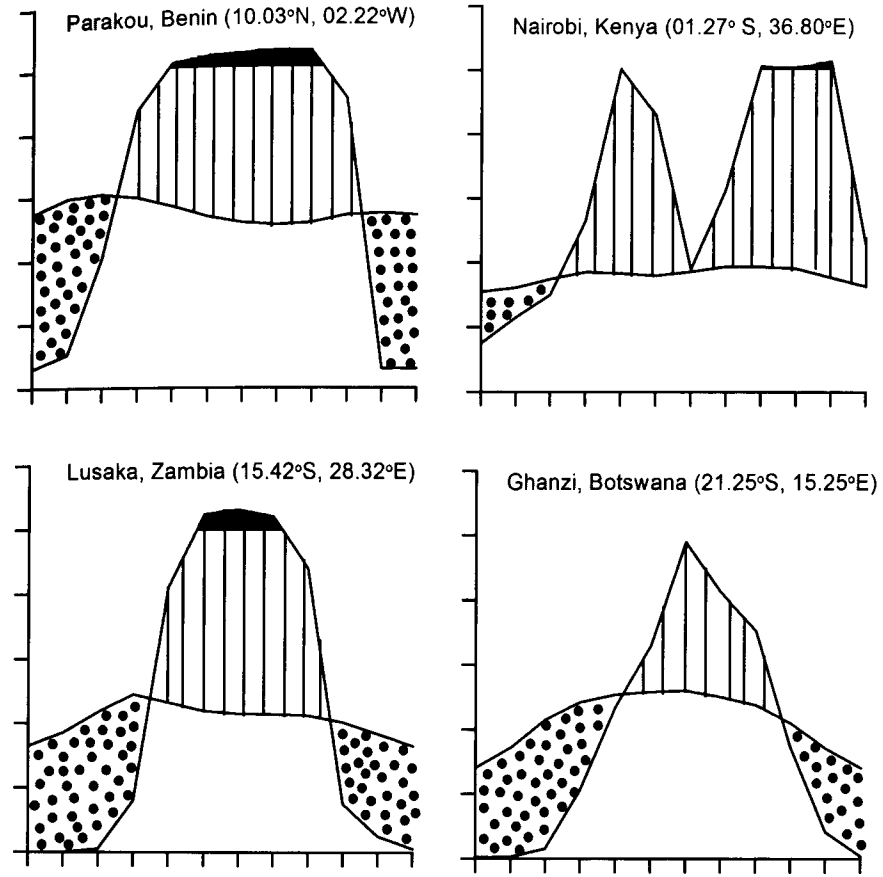

Figure 2.2 *Climate diagrams for stations in the warm dry woodland areas of western Africa (Parouku) and southern Africa (Lusaka), and in semi-arid areas of eastern Africa (Nairobi) and southern Africa (Ghanzi)*

Note: The drought period is shown by dots while the humid period is vertical hatched
Source: Chapter authors

characteristic feature of semi-arid formations of eastern Africa is the bimodal rainfall pattern, which contrasts with other semi-arid formations in which the rainfall pattern is basically unimodal (see Figure 2.2). Annual precipitation is lower (around 250mm) in the semi-arid areas of eastern Africa and higher (around 450mm) in southern Africa.

Soils

Soils in the dry forest and woodland areas are usually shallow (less than 1.5m deep) with a high sand content in the range 30–90 per cent, while the clay content is 5–20 per cent and silt is 5–45 per cent. Texturally they range from silt loam in eastern Africa to sandy loam in western Africa and the Zambezian dry forests and woodlands of southern Africa, and loamy sand in the Kalahari-Highveld area. Total soil nitrogen is very low (0.02–0.10 per cent), as is the organic matter content (1–3 per cent) and available phosphorus (2–30mg kg^{-1}). Soils are generally acid in the Zambezian dry forests, (pH 4–5), intermediate in western Africa and the Kalahari-Highveld semi-arid dry forests (pH 6.0–6.5) and with a tendency towards alkalinity in the eastern African semi-arid dry forests (pH 7–8).

Floristic Composition

Much of what follows under this section is based on White (1983) as we are not aware of more recent work on floristic composition of the vegetation in sub-Saharan Africa.

Western Africa

The dry forests and woodlands of western Africa stretch west–east from the Atlantic coast, across the southern fringes of the Sahara Desert to the Ethiopian Highlands and Red Sea coast. They can be categorized under the three broad climatic zones – sub-humid, warm mesic and warm dry – each forming a relatively narrow band. Much of the area is low (under 750m altitude) and gently undulating, with a few higher areas such as the Jos Plateau in northern Nigeria. It has also been extensively modified by human activities such as cultivation and fire so that the natural vegetation is often not easy to determine – most vegetation now present is secondary wooded grassland and grassland.

The Guinea sub-humid dry forest stretches from the Atlantic coast in Guinea across the middle regions of Ivory Coast, Ghana, Nigeria and Cameroon to the Central African Republic and northern Democratic Republic of Congo (DRC), covering an extent of around 1.4 million km^2. Locally it verges into Guineo-Congolian rainforest in both structure and species composition, while elsewhere, to the north, it can be difficult to separate from the warm mesic dry Isoberlinia woodlands. Rainfall ranges from 1200–1500mm per year in the east to 1500–2000mm per year in the west. A characteristic species is *Parinari excelsa*, sometimes forming a forest 18–20m high, along with *Erythrophleum suaveolens*, *Detarium senegalense*, *Khaya senegalensis* and *Afzelia africana*. At the western extent *Berlinia grandiflora*, *Cynometra vogelii* and others are typical, while in the eastern parts in the Central African Republic *Isoberlinia doka*, *Afzelia africana*, *Anogeissus leiocarpus*, *Burkea africana*, *Borassus*

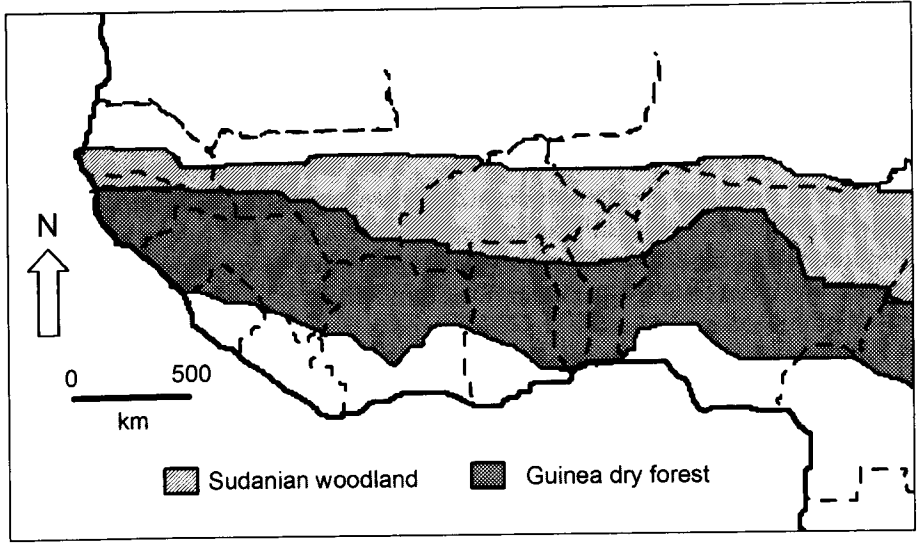

Figure 2.3 *Distribution of dry forest and woodland in western Africa*

Note: Broken lines represent national boundaries.
Source: Based on Keay (1959)

aethiopicum and *Terminalia* species are found. The oil palm *Elaeias* and *Parkia* are commonly found across transformed landscapes.

The Sudanian warm mesic dry woodland lies in a parallel band, perhaps 500–700km wide, to the north of the Guinea dry forest belt, and covers around 2.6 million km^2. Stretching from the Atlantic coast in Senegal, it includes much of Mali, northern Ghana and northern Nigeria, to the southern Sudan and southwest Ethiopia. Soils are predominantly recent and sandy. The major part of the vegetation is disturbed, consisting of open broad-leaved woodland to wooded grassland and bush fallow, often maintained by frequent fire. The moister southern portion, from Guinea to Nigeria, is typified by low woodland, rarely more than 5m high, of *Isoberlinia doka*, *I. angolensis*, *Burkea africana*, *Daniellia diveri* and *Erythrophleum africanum*, with tall *Hyparrhenia* grass. It has been likened to a depauperate miombo woodland, but without the *Brachystegia* and *Julbernardia*.

To the drier north, the environment is marginal for agriculture and the microphyllous vegetation types are naturally more open, characterized by species of *Acacia* (especially *Acacia laeta*, *A. nilotica var. adansonii*, *A. senegal*, *A. seyal*, *A. macrostachya*), *Balanites aegyptiaca*, *Bauhinia rufescens*, *Boscia salicifolia*, *Capparis tomentosa*, *Commiphora africana*, *Dalbergia melanoxylon*, *Grewia flavescens*, *G. vilosa*, *Pterocarpus lucens*, *Saba senegalensis*. The combretaceae family is well represented with *Combretum micranthum*, *C. glutinosum*, *C. nigricans*. Scattered remnant trees, such as baobab (*Adansonia digitata*) and Shea tree (*Vitellaria paradoxa*) are common in the landscape. The most common grass species are *Aristida hordeacea*, *Schoenefeldia gracilis*,

Brachiaria xantholeuca, *Cenchrus biflorus*, *Chloris lamproparia*, *C. prieurii*, *Ctenium elegans* and scattered taller *Andropogon gayanus*.

Eastern Africa

Compared to western and southern Africa, the woodlands of eastern Africa are much less varied and it is difficult to separate them out. The typical sub-humid dry forests and mesic woodlands, so well represented in western and southern Africa, are very restricted in extent in eastern Africa.

By far the most extensive woodland type is in the semi-arid zone, covering 1.6 million km^2. This comprises deciduous microphyllous bushland and thicket dominated by spiny species of *Acacia* and *Commiphora*. The canopy is rarely taller than 10m, but is often only 3–5m high and sometimes quite dense. Grasses surprisingly generally contribute little to the biomass. Other common woody plants include *Grewia* species, *Balanites*, and various members of the Capparidaceae family such as *Boscia* and *Cadaba*. Succulents such as *Euphorbia* and *Adenium* are not uncommon. The baobab tree (*Adansonia*) is also characteristic at lower altitudes towards the coast. Some of the most diverse vegetation is found in a narrow band along perennial or seasonal rivers, and on rocky outcrops and hills. True moist forest, outside the scope of this book, is found above 2000m on larger mountains, or lower down closer to the coast.

Southern Africa

The sub-humid dry forests of southern Africa mostly comprise forest or dense woodlands, much of which has now been reduced to wooded grassland or secondary grassland with scattered forest trees after destruction by humans and fire. Total extent is around 980,000km^2. The larger forest remnants have canopies about 25m high, but elsewhere this is only around 10m. In these remnants characteristic species are *Marquesia macroura*, *M. acuminata*, *Berlinia giorgii*, *Daniellia alsteeniana*, *Brachystegia spiciformis*, *B. wangermeeana* and *Parinari curatellifiolia*. However, in the more common secondary vegetation comprising grassland and wooded grassland ('mikwati') the most frequent fire-resistant trees are *Erythrophleum africanum*, *Dialium englerianum*, *Burkea africana*, *Diplorhynchus condylocarpon*, *Pterocarpus angolensis* with an under storey comprising species of *Protea*, *Combretum* and *Strychnos* with tall *Hyparrhenia* grasses.

Within the warm dry forest and woodland area of southern Africa there are four extensive vegetation types: undifferentiated woodland, miombo woodland, mopane woodland and semi-arid shrubland (White, 1983; Figure 2.4).

Undifferentiated woodlands

The most extensive undifferentiated woodlands are teak and acacia woodlands. Teak woodland is a deciduous broad-leaved dry forest or woodland type dominated by *Baikiaea plurijuga*, often called Zambezi Teak that occurs on Kalahari sands. This species, much valued for its hard heavy timber, is common, along with other valued timbers such as *Pterocarpus angolensis*, *Guibourtia coleosperma* and *Schinziophyton rautanenii*. *Baikiaea* woodland areas cover around 265,000km^2 on the Kalahari sands of northwestern Zimbabwe, northeast Botswana, southwest Zambia, northeast Namibia and southeast Angola (Figure 2.4) at an elevation of around 900–1100m on the gently undulating plateau. This area is a mosaic of *Baikiaea*-dominant dry forest and woodland on the deeper sands, *Burkea africana* on shallower sands and a wide network of shallow valleys with seasonally wet grasslands called dambos or vleis. Many of these are associated with the headwaters of the Upper Zambezi and Kavango rivers. To the north and to the southeast in western Zimbabwe, *Brachystegia spiciformis* comes in, forming a transition to more typical miombo woodland. *Baikiaea* woodland is generally 6–10m high, with few emergents. Although deciduous, *Baikiaea* itself can remain green long into the dry season owing to its ability to access moisture from deep in the soil profile. In some regards,

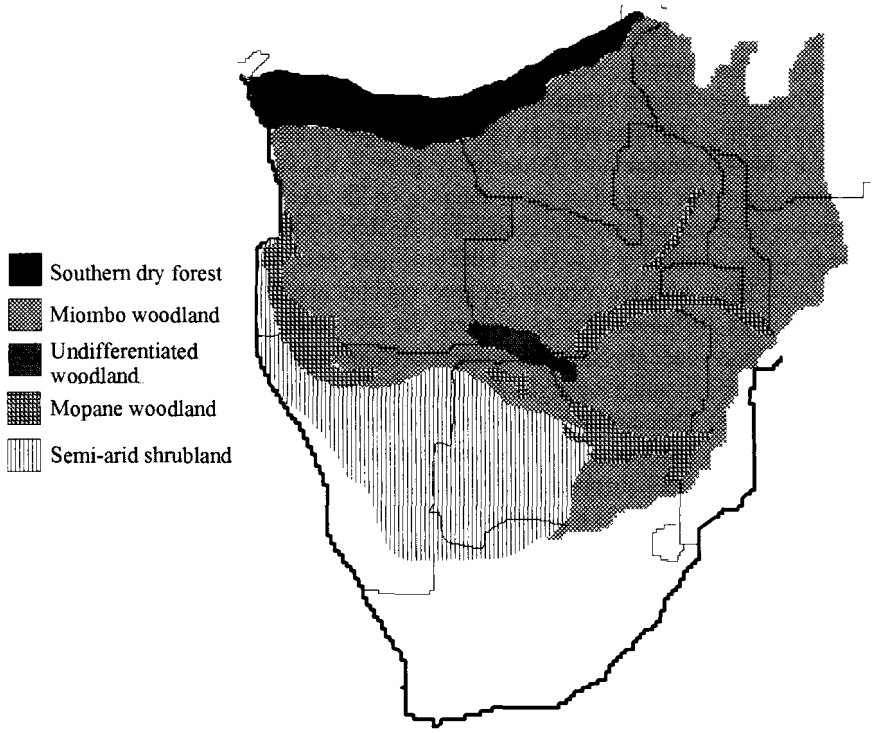

Figure 2.4 *Distribution of dry forest and woodland types in southern Africa*

Source: Based on White (1983)

Baikiaea woodland, occurring as it does on deep sandy soils that are not prone to erosion, is resilient in the face of major perturbations such as drought, frost, herbivory, fire and, more recently, logging and clearance.

In the drier southeastern parts of the warm dry forest region open mixed (microphyllous and broad-leaved) acacia woodlands, dominated by *Acacia* (especially *A. nigrescens*, *A. nilotica* and *A. gerrardii*) and *Combretum* (especially C. *apiculatum*), are found. Other characteristic and useful species include *Burkea africana*, *Terminalia sericea*, *Kirkia acuminata*, *Pseudolachnostylis maprouneifolia*, *Sclerocarya birrea* and *Ziziphus mucronata*. Fruit trees and species with useful woods are more commonly found here than in the miombo or mopane woodlands. The grass growing on these more fertile soils generally has a high grazing value. Fire is an important ecological feature, and a number of species are tolerant of it.

Miombo woodland

This is by far the most extensive warm dry forest type in southern Africa (Frost, 1996). Miombo (or muombo) is a common local name for various species of *Brachystegia* in parts of Malawi, Tanzania and Zambia, which are the woodland type's most characteristic species. These broad-leaved deciduous woodlands, dominated by species of *Brachystegia*, *Julbernardia* and *Isoberlinia*, are found in areas of over 700mm annual rainfall on nutrient-poor soils where there is distinct seasonality.

Miombo is found from the Atlantic coast in Angola, across Zambia, the southern DRC, Malawi and much of Zimbabwe, almost to the eastern African coast in Mozambique and Tanzania (Figure 2.4). Given its large extent, with surprisingly little variation from Angola to Tanzania and south to Zimbabwe, miombo is often arbitrarily divided into dry and wet types. Dry miombo is found where rainfall is less than 1000mm per year, the canopy is generally less than 15m high, and the dominant tree species are *Brachystegia spiciformis*, *B. boehmii* and *Julbernardia globiflora*. In wet miombo rainfall is more than 1000mm per year, the canopy exceeds 15m in height and the characteristic dominants are *Brachystegia floribunda*, *B. longiflora*, *Julbernardia paniculata* and *Isoberlinia*. Wet miombo, covering 1.36 million km^2, extends from near the coast in central and northern Angola, through northern Zambia and southern DRC to central and northern Malawi and western Tanzania, with small extents in northern Mozambique and Burundi. Dry miombo covers a similar extent (1.21 million km^2) across southeastern Angola, southern Zambia and Zimbabwe to south, central and northern Mozambique, southern Malawi and much of central and southern Tanzania.

Mopane woodland

Whereas miombo woodland is generally found on lighter-textured, nutrient-poor, well-drained soils on the African Plateau, mopane woodland is mostly confined to lower-lying areas with clay- and nutrient-rich soils. The dominant

tree, often to the exclusion of many others, is *Colophospermum mopane*, commonly known as mopane or chanate.

Mopane woodland, covering 380,000km^2, is a dry broad-leaved woodland type found on heavier-textured soils in the wide, flat valley bottoms of lower-altitude river valleys of southern Africa, such as the Limpopo, Zambezi, Okavango, Cunene, Shire and Luangwa (Mapaure, 1994; Timberlake, 1999) in southern Angola, northern Namibia, northern and eastern Botswana, Zimbabwe, northern South Africa, southern Zambia, southern Malawi and south and central Mozambique (Figure 2.4), at an elevation of 200–1200m, but normally from 300–900m. Rainfall in these areas ranges from 400 to 700mm per year, although the species itself can be found in drier areas in northwestern Namibia.

Semi-arid shrubland

Semi-arid shrubland types in southern Africa cover over 900,000km^2 and comprise either microphyllous wooded grassland or shrubland in which there is a more-or-less continuous grass layer. Due to water stress, the sparse tree canopy is around 5–8m high. Characteristic species in the drier Kalahari sands area, at around 1000m altitude, include various *Acacia* (*A. erioloba*, *A. luederitzii*, *A. fleckii*, *A. hebeclada*, *A. mellifera*, *A. tortilis*), *Boscia albitrunca*, *Dichrostachys cinerea* and *Terminalia sericea*. In the northern, less arid parts, broad-leaved trees such as *Combretum collinum*, *Lonchocarpus nelsii* and *Ziziphus mucronata* are common, while on more stony soils towards the South Africa Highveld these are replaced by *Acacia karroo* and numerous shrub species, with an increasing dominance of the grass *Themeda triandra*.

FOREST DYNAMICS

Spatial integrity

Large areas of African dry forests have been subjected to clearing for agriculture, which has greatly affected their spatial integrity (Table 2.1). In addition, logging and wood harvesting for fuel have exacerbated this fragmentation process. The greatest impact of agriculture has been in western and eastern Africa, where more than 50 per cent of dry forest land has been converted to agricultural use. Because of the nature of shifting cultivation that is widely practiced in Africa, land under agriculture represents a number of cover types, including cropland, abandoned fields and fallows at various stages of recovery. For example, Lanly and Clement (1982) estimated that 20 per cent of open woodland in Africa is made up of fallows. When converting woodland to agriculture not all trees are necessarily cleared and, as a result, cultivated land is often dotted with trees: *Adansonia digitata*, *Vitellaria paradoxa*, *Sclerocarya*, *Borassus*, *Faidherbia albida*. Such landscapes are called farmed parklands in western Africa. Population pressure on dry forests is growing. For example, land per person in the Zambezian dry forest zone decreased from 1.45ha in 1975 to

Table 2.1 *Woodland and conversion to agriculture in sub-Saharan Africa in 2000*

White's phytoregion	*Woodland area (km²)*	*Extent under agriculture (km²)*	*(%)*
Sudanian	3,233,160	1,900,850	58.79
Somali-Masai	875,880	706,880	80.70
Zambezian	4,483,380	679,700	15.16

Source: Based on Mayaux et al (2004)

1.05ha in 2000, and corresponding values for the Sudanian zone of western Africa are 1.58ha in 1975 and 1.28ha in 2000 (Eva et al, 2006).

Plant cover and phenology

The level of vegetation cover in dry forests depends on its structure and phenology, but generally tree cover is highest in sub-humid dry forests (over 70 per cent) and lowest in semi-arid woodlands (10–40 per cent). Because of its deciduous nature, vegetation cover also varies seasonally (Figure 2.5). The increase in greenness during the late dry season is due to the woody component, while that in the early wet season is due to the grass component (Chidumayo, 2001).

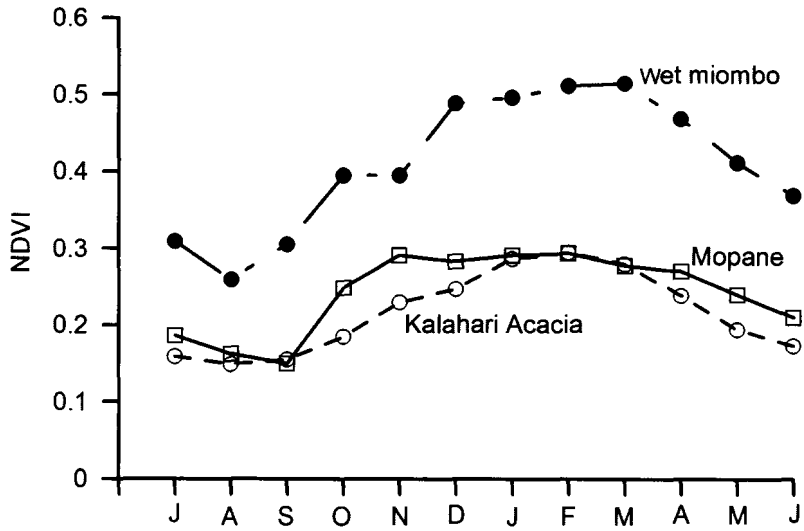

Figure 2.5 *Monthly changes in vegetation greenness as determined by the Normalized Difference Vegetation Index (NDVI) in wet miombo at Mpika (Zambia), mopane woodland at Francistown (Botswana) and Kalahari Acacia savanna at Ghanzi (Botswana) in southern Africa*

Source: Based on Chidumayo (2001)

Changes in the tree component caused by fire, timber and wood harvesting, drought or browsing/grazing by wildlife or livestock, tend to reduce dominance of the woody component in favour of the grass component. This grass dominance can then be maintained by fire or grazing.

Climate change and land use

There will undoubtedly be some marked changes in distribution and extent of African vegetation types over this century, probably resulting from an increased tendency in many areas to lower mean annual precipitation. But such effects have also got to be seen in the context of equally – or more – rapid changes in land use resulting from intensification and increased population pressures. However, climate change and increased human impacts on vegetation are likely to be intertwined, and it is difficult to predict the consequences. There are also the changes in land-use practices caused by concentration of people and control of fire that lead to increased woody cover in some places, and such changes may be more profound over short periods than those predicted from the increases in carbon dioxide (CO_2) or temperature or rainfall.

One approach is to model climate change and determine what the impacts on vegetation would be 50 years hence of, for example, decreased rainfall. Such a study has been done for southern Africa (Hulme, 1996), but also recognizes that global models of climate change, whether resulting from higher CO_2 levels, higher temperatures or decreased precipitation, are inherently weaker in such seasonal environments where there are naturally large annual fluctuations in temperature and rainfall. The models can only predict what might happen at a very coarse, sub-continental level, but not the local detail. Indeed, the study points out that local vegetation patterns are determined more by local differences in moisture and nutrient availability than global changes in annual means, and the response of vegetation in such areas to extreme wet or dry years is possibly more important than the response to long-term averages.

The southern African study suggested an increase in mean annual temperature (based on the 1961–1990 mean) of 1.5°C over the period 1990 to 2050, a figure supported by the observed increase in southern Africa over the last century of 0.05°C per decade. Inherent uncertainties in the study suggest that this figure could be reached by 2030, or as late as the end of the 21st century. Such a warming will result in lower annual rainfall. Using the BIOME model (Prentice et al, 1992), which predicts the distribution of broad vegetation types based on climate, soils and CO_2 concentrations, the study went on to predict changes in vegetation distribution across the region. Under the 'dry' (20 per cent less moisture) scenario, there would be a 10 per cent increase in what we term sub-humid dry forest, which would be derived from moist evergreen forest, a 30 per cent increase in acacia semi-arid bushland and wooded grassland at the expense of warm dry forest, and a significant change in the distribution of warm dry woodland types and those in the semi-arid region. Increasing temperatures in southern Africa are also predicted to either extend

the growing season in some ecosystems or shorten it in others (Rutherford et al, 1999).

Elsewhere in Africa, retraction of sub-humid and warm dry climate species to areas of higher rainfall and lower temperature has been recorded as a result of desertification in the latter part of the 20th century in Senegal (Gonzalez, 2001), while modelling of the distribution of forest species has projected changes from warm dry forests to semi-arid forests in Tanzania and Gambia (Jallow and Danso, 1997).

Added to these impacts of climate change will be the reduced productivity that comes with reduced rainfall, and the effects of reduced and perhaps much more variable rainfall on regeneration and reproductive success. With the increase in bushland vegetation, cattle-raising may become less significant, to be replaced by increased numbers of small stock, which may in turn also impact on both vegetation structure and regeneration. Climate change is also likely to alter the frequency, intensity and seasonality of fires that are so characteristic of dry forests and woodlands in Africa, which may also change both in structure and composition.

However, under these predicted changes in climate, it must be remembered that species will respond individually, perhaps with substantial time lags, rather than there being major shifts in vegetation formations and their associated fauna.

Herbivory

There are various types of impact of herbivory and herbivores on dry forests and woodlands. The most obvious are vertebrate herbivores, which can have marked effects on both structure and composition of woodlands through physical damage, through browsing and indirectly through grazing. Invertebrates are also important herbivores, and can influence woodlands through defoliation and seed predation. The impacts of herbivores, both direct and indirect, are often larger than realized.

Elephant impacts on vegetation are very marked, but tend to be confined to protected areas or adjacent lands. Principally confined to the warm dry woodlands of eastern and southern Africa, in particular miombo and mopane woodland types, these impacts are also seen in semi-arid acacia woodlands such as in Tsavo and Amboseli in Kenya. In Tarangire National Park in Tanzania, for example, the impacts varied significantly between tree species. The density of *Balanites aegyptiaca*, *Maerua triphylla* and *Commiphora* and *Combretum* species declined while that of *Cordia* and *Acacia tortilis* increased (Figure 2.6). Although elephants affected the tree size distribution, the decline in density of small trees in both *Acacia* and *Combretum* woodlands was attributed to a severe drought in 1993 (Van de Vijver et al, 1999). Under certain circumstances, elephant can reduce large areas of woodland to coppice shrubland by pushing over and breaking larger trees, particularly with *Colophospermum mopane*. This results in a 'lawn' of young coppice foliage about 2m high, which the elephant

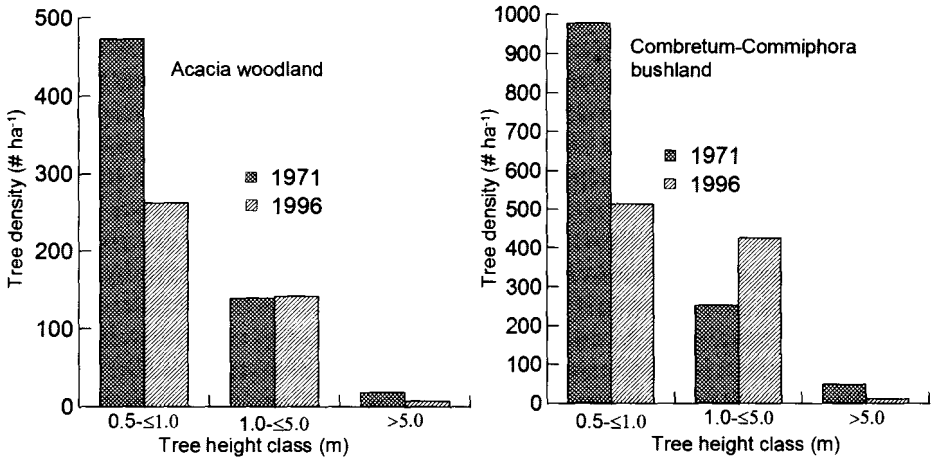

Figure 2.6 *Changes in tree density caused by elephants and drought over 25 years in Tarangire National Park, Tanzania*

Source: Based on data from Van de Vijver et al (1999)

maintain by browsing (Conybeare, 2004). In miombo woodland such destruction can also result in larger quantities and a greater depth of grass growth, leading to greater fire risk and fuel loads. The more frequent and more intense fires, coupled with increased frost risk and higher grazing pressures, help maintain the areas as open woodland or wooded grassland, rather than the dense woodland they once were, as can be seen in some protected areas in Zimbabwe and southern Tanzania.

Impacts by other browsers such as giraffe, kudu and eland, are more local, although they can be marked. For example, many *Acacia* trees in the eastern African savannas are shaped by giraffe, and acacias generally have developed thorns as a defence against such herbivory (Pellew, 1983). Browse lines are common in areas with many livestock – these are at 1.5–2m high in areas with goats, and 2–2.5m high in areas with many cattle, although the latter are primarily grazers except during the dry season. Such pressures can maintain the grass–shrub–tree balance in areas that, without browsing, would revert to woodland.

Many browsers help disperse woody plants by ingesting seeds that are then deposited elsewhere in the faeces. Species such as *Acacia nilotica* and *A. erioloba* have hard impervious seeds adapted to ingestion and dispersal by mammals, while elephants are known to disperse palms such as *Hyphaene* and *Borassus*. It is likely that the baobab (*Adansonia digitata*), through its useful fruits, has a wider range across Africa owing to its dispersal by humans, and likewise with the tamarind (*Tamarindus indica* and *Sclerocarya birrea*).

The impacts on woody vegetation by grazing mammalian herbivores are more indirect as these animals primarily eat grasses. They also depend on the intensity,

duration and season of grazing. At low grazing levels, grass growth can be encouraged, which tends to shade and kill off woody seedlings inhibiting recruitment and regeneration. But when an area is more heavily grazed, the woody seedlings can be eaten. When grazing pressure is reduced, seedlings and suppressed saplings can grow rapidly to form what is often termed bush encroachment – the beginnings of woodland regeneration. However, the species involved tend to be those that grow rapidly from seed and with invasive properties, such as many *Acacia* species and *Dichrostachys cinerea*, rather than the slower growing broad-leaved species such as *Brachystegia*, that reproduce more by resprouting.

Although relatively minor compared to the effects of browsers, seed predation can be significant. A large proportion of a seed crop can be lost by weevil damage (Ernst et al, 1989) and from small rodents (Walters et al, 2005).

Normally insect herbivory is minor, perhaps 10–20 per cent of the leaf crop. However, defoliation by caterpillars of various moths can be very severe, as in the case of the mopane worm (*Imbrasia*) in eastern Botswana that consumes 19.5 tonnes per hectare of mopane leaves in just a few weeks (Styles, 1994). Outbreaks of defoliating behaviour can also be seen with other moths in broad-leaved or nutrient-poor semi-arid and warm dry forests, such as with *Julbernardia paniculata* (Malaisse, 1997) and *Burkea africana*, but rarely in microphyllous savannas. It is not clear if this phenomenon significantly changes woodland composition or structure.

Fire

Although some fires originate from lightning around the start of the rainy season, most are caused by humans. Some originate accidentally from burning undertaken during land preparation, from making charcoal or from honey collecting, but others are set deliberately to flush out mammals or birds for hunting or to stimulate new grass growth for livestock (Frost, 1996). Some have suggested that savannas (here taken to be the more open types of dry forest, including woodland) are anthropogenic and not natural. It must be recognized that fire is a natural feature of dry forests and woodlands in Africa, although its frequency is probably now much higher than historically. Nevertheless, in some areas there has been a deliberate control of fire with widespread increase in woody growth and a total change in woodland dominance. Fire has a composite nature (Frost and Robertson, 1987), its behaviour, timing, intensity, frequency all vary independently, and all affect vegetation structure and composition differently. Fire can kill individual organisms, such as trees, but it can also change the competitive status, allowing vegetation to change over time through differential recruitment and survival of seedlings and saplings.

Fire is one of the few dry forest and woodland determinants that can be readily manipulated, and so has great importance to managers. In most cases the plants that burn – the fuel – predominantly comprise grass and other herbaceous material, and not the woody material. This fuel load can be from a few centimetres to 2m in height. However, woody material does burn and often

continues to smoulder long after the main fire has passed.

Most fires occur during the dry season or at the start of the rains – from May to October in the southern hemisphere and from November to February north of the equator. The impact depends on the intensity and timing in relation to plant phenology. For example, late dry season fires are more intense and destructive, particularly if they occur after leaf flush. Other important determinants of impact are the amount of moisture in the fuel load, the atmospheric temperature and relative humidity, and the wind speed.

Although hot intense fires can cause quite spectacular changes to vegetation, it is the frequency – the period between fires in any one area – which causes many of the changes in vegetation structure and composition, changes that can be both subtle and only become apparent over a decade or so. Fire frequency is often higher in vegetation types having higher fuel loads, such as moist miombo woodland (warm dry woodland), with fire return intervals of between 1 and 5 years (Frost and Robertson, 1987). In Zambia, Chidumayo (1995) reports a fire-return interval of 1.6 years, while remote-sensing across a much larger area of miombo woodland shows that only 37 per cent of land is burnt in any one year, suggesting an average fire-return interval closer to 3 years (Frost, 1996). In more arid savannas (semi-arid shrubland), a much longer fire return interval of 5–50 years is suggested, depending on fuel loads.

Frequent late dry season ('hot') fires can transform woodland into open tall grass savanna with only isolated fire-tolerant canopy trees and scattered under storey trees and shrubs. In Africa a number of long-term fire exclusion experiments have shown that tree cover in sub-humid and warm dry forests is limited by fire, notably the analysis by Trapnell (1959) of the fire plots in moist miombo woodland in northern Zambia and that by Geldenhuys (1977) in the drier forest types in northern Namibia. The major structural change that occurs under early burning and fire protection relates to the greater thickening of the shrub layer (Figure 2.7) and occasionally the colonization by fire-sensitive sub-humid forest trees (Trapnell, 1959; Louppe et al, 1995). Trapnell recognized four categories of species with regard to fire:

- fire-intolerant mostly evergreen species which occur only where there is protection from fire (e.g. *Parinari excelsa, Entandrophragma delevoyi, Syzygium guineense*);
- fire-tender species which decline under regular burning and increase under protection, with higher mortality rates under late dry season burning than under early dry season burning (e.g. *Brachystegia spiciformis, Julbernardia paniculata*);
- semi-tolerant species that are relatively unaffected by early dry season fires but decline under late dry season fires (e.g. *Uapaca kirkiana, Pseudolachnostylis maprouneifolia, Strychnos pungens*);
- fire-tolerant species that are able to survive late dry season fires (e.g. *Pterocarpus angolensis, Parinari curatellifolia, Erythrophleum africanum, Anisophylla boehmii, Diplorhynchus condylocarpon, Detarium microcarpum, Combretum glutinosum, Combretum nigricans*).

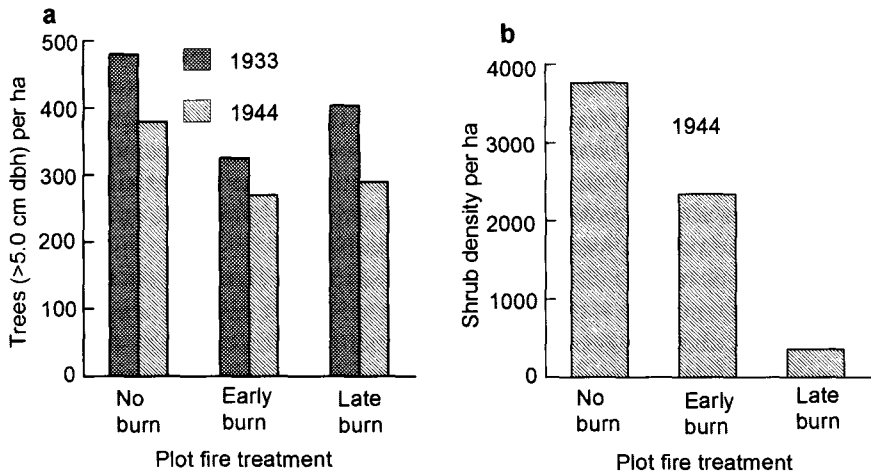

Figure 2.7 *Changes in tree density and shrub density, only enumerated in 1944, after 11 years of fire protection, early burning and late burning in old-growth miombo woodland at Ndola, Zambia*

Source: Based on data from Trapnell (1959)

However, even early dry season ('cool') fires can have a significant impact on vegetation structure and composition, as shown by the long-term fire plots in *Baikiaea* woodland in western Zimbabwe (Calvert and Timberlake, 1993). Plots protected from fire for 35 years reverted to dense *Baikiaea* woodland, but annual or biennial late dry season burns did not eliminate, only suppress, the woody component, shifting the regrowth underground. A resilient reservoir of underground rootstocks remained, which could rapidly grow up with protection.

Although often regarded as a negative feature, with care, fire can be used as a management tool to increase desirable attributes. Ranchers use it both to stimulate new grass growth and to control encroachment or recruitment of woody plants in rangeland, while foresters have used cool fires in mature stands to clear undergrowth or to reduce the risk of hotter, more damaging fires late in the dry season.

Stem density, basal area and wood biomass

The analysis of data from literature (as cited in next paragraph) for 164 dry forest sample plots revealed that stem density does not vary significantly in African dry forests and woodlands. Density ranged from 300 to 900 per hectare with a tendency for higher stem densities in semi-arid dry forests (800–900 per hectare) and lower densities in warm dry forests (700–800 per hectare). However, data for 92 sample plots indicated that basal area varies significantly

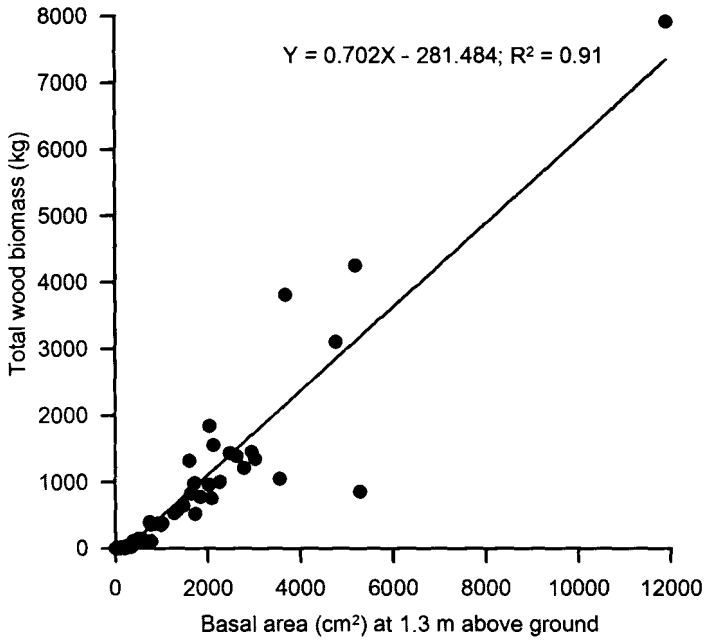

Figure 2.8 *Linear equation for determining total above ground wood biomass (oven-dry basis) from basal area of individual and stand trees in African dry forests and woodlands*

Source: Based on data from Chapter authors

among African dry forests. The highest basal area at breast height occurs in sub-humid dry forests (24–28m^2 per hectare) and this declined to a range of 11.5–14.1m^2 per hectare in warm dry forests in southern Africa and 8.4–11.0m^2 per hectare in Kalahari-Highveld semi-arid dry forests. The basal area in the Sudanian warm dry forests of western Africa ranges from 3.6 to 10.1m^2 per hectare.

The determination of above ground wood biomass of trees is generally achieved using the relationship between tree diameter and/or height and biomass derived from felled sample trees. For the purposes of this chapter, a combination of tree- and stand-based basal area (derived from diameter measurements) was used to develop a common equation (Figure 2.8) for estimating wood biomass from basal area data. This approach is particularly useful because most forest standing stocks are reported as basal area per hectare and an equation based on basal area could have a wider application in estimating wood biomass in dry forests and woodlands of Africa. The equation in Figure 2.8 was applied to basal area data from different dry forests in Africa to compute wood biomass. Data for a total of 92 sample plots in Benin (Schreckenberg, 1999), Burkina Faso (Nikiema, 2005; Zida et al, 2007), DRC (Malaisse, 1978, 1984; Malaisse and Binzangi, 1985; Malaisse et al, 1970,

1975), Mali (Picard et al, 2006), Mozambique (Musanhane et al, 2000; Sambane, 2005; Williams et al, 2008), South Africa (Shackleton et al, 1994; Scholes, 1990), Tanzania (Banda et al, 2006; Byström et al, 1987; Isango, 2007; Mugasha and Chamshama, 2002), Zambia (Araki, 1992; Chidumayo, 1985, 1986, 1987, 1997a, 1997b; Endean, 1968) and Zimbabwe (Ward and Cleghorn, 1970) were used in the analysis.

The basal area data that were originally based on stump height (between 15 and 30cm above ground) measurements were converted to basal area at breast height using the following equation:

$$\text{Basal area} = -0.0019 + 0.71 \times \text{stump height basal area},$$
$$r^2 = 0.999, P < 0.0001$$

In addition direct estimates of wood biomass were obtained from literature for 73 sample plots in Benin (Orthmann, 2005), Ivory Coast (Lamotte, 1979; Menaut and Cesar, 1979), Kenya (Okello et al, 2001; Western and Ssemakula, 1981), Mozambique (Sambane, 2005), Nigeria (Fatubarin, 1984), South Africa (Higgins et al, 1990) and Zimbabwe (Kelly and Walker, 1976).

Above ground biomass was highest in sub-humid dry forests (160–209 tonnes per hectare) followed by the Zambezian woodlands (88–97 tonnes per hectare), Sudanian woodlands (56–78 tonnes per hectare), Kalahari scrubland (22–34 tonnes per hectare) and lastly Somali-Masai bushland (13–18 tonnes per hectare).

Dry Forest and Woodland Regeneration

Regeneration in dry forest and woodland trees occurs through either sexual or vegetative means. Sexual regeneration is achieved through seed germination and establishment of seedlings and their recruitment into the tree phase. Vegetative regeneration occurs through the recruitment of sprouts or resprouts into the tree phase from pre-existing trees that get cut or damaged, sometimes termed coppice. Sprouting is the production of secondary trunks as an induced response to injury or to profound changes in growing conditions. There are four types of sprouts: sprouts from the trunk, sprouts from specialized underground stems (lignotubers and rhizomes), sprouts from roots (root suckers), and opportunistic sprouts from layered branches. Seed dispersal, predation, desiccation and seedling mortality can act as strong constraints that impede dry forest and woodland recovery after disturbance. The ability to sprout after severe injury from disturbances such as herbivory, fire, floods, logging or drought overcomes these barriers, as these individuals bypass the seed stage and tend to have more vigorous shoots than seedlings presumably because vegetative shoots may take advantage of the extensive root system and the substantial food storage in the remaining parts of the parent plant. However, sprouting ability varies with the age or size of a plant and also with the type and severity of injury.

Figure 2.9 *Common regeneration mechanisms in dry forests: true seedling, seedling sprout, stump sprouts or coppice and root sucker*

Source: Chapter authors

The common mechanisms of regeneration in dry forests and woodlands include current-year seedlings, seedling sprouts that occur after seedling shoot dieback (including sprouts from underground rootstocks), coppice or sprouts from stumps of mature trees and root suckers that arise from lateral roots (Figure 2.9). The importance of each of these regeneration mechanisms depends on the floristic composition of the forest/woodland and the type of disturbance. Ky-Dembele et al (2007) found that the regeneration pool in a Sudanian savanna dominated by *Detarium microcarpum*, *Terminalia avicennioides* and *Acacia* species in Burkina Faso was dominated by seedlings and seedling sprouts that made up 88 per cent of the regeneration stock, while these sources of regeneration constituted nearly 95 per cent of the regeneration pool in a Zambian miombo woodland (Chidumayo, 1993; Table 2.2). However, true seedlings made up only 3.5 per cent of the regeneration pool in the Sudanian savanna compared with 56 per cent of the regeneration pool in miombo woodland. Although root suckers and water sprouts (plantlets developed at the base of live mature trees) were observed in the Sudanian woodland, these were absent in miombo woodland.

Seedlings and sprouts face frequent and severe fire damage that can retard their recruitment into the tree layer (Figure 2.10). Between fires, seeds have to germinate and build enough root reserves to survive the next fire. However, given that fires usually occur once in every 2–4 years (Chidumayo, 2004; Sankaran et al, 2007; Jacobs and Schloeder, 2002), sprouts would need to grow rapidly to escape damage. Once dry forest has been cleared and the land abandoned, regeneration often takes place but the speed of forest/woodland recovery depends on the methods used in clearing, the sources available for regeneration and site history (type, frequency and intensity of stress and/or disturbance). Initially regeneration is mostly from trunk and root sprouts, hence tree species composition in regrowth stands tends to remain similar to that of the preceding old-growth stand. Consequently, the regrowth forest consists of

Table 2.2 *Structure of the tree regeneration pool one year after clear cutting miombo woodland in Zambia and two years after cutting a Sudanian woodland in Burkina Faso*

Regeneration type	*Miombo woodland*		*Sudanian savanna*	
	Plants per ha	*Percent*	*Plants per ha*	*Percent*
True seedlings	14,575	56.4	1154	3.5
Seedling sprouts	9850	38.1	28,269	84.5
Stump sprouts	1425	5.5	2000	6.0
Root suckers	0	0.0	1308	3.9
Water sprouts	0	0.0	718	2.2

Source: Based on Chidumayo (1993) for miombo woodland and Ky-Dembele et al, (2007) for Sudanian savanna

Table 2.3 *Stem density in old-growth and regrowth stands in woodlands in sub-Saharan Africa*

Woodland type	*Stem density (number per hectare)*	
	Old-growth stands	*Regrowth stands*
Kalahari	837–1131	7264–9700
Sudanian	425–590	1280–2250
Zambezian	710–820	2446–2830

Source: Calculated by Chapter authors from data in various literature sources (see text)

multi-stemmed trees often with a stem density higher than in the previous old-growth woodland it replaced (Table 2.3).

Much work has been done on the effects of fire on woodland recovery following clearing. In Mozambique the number of sprouts produced per stump declined with increasing fire frequency. For example, the average number of *Diplorhynchus condylocarpon* and *Julbernardia globiflora* sprouts per plant decreased from 14.7 under fire protection to 7.7 when burnt once and 6.4 and 4.6 when burnt twice and three times, respectively (Zolho, 2005). However, in Burkina Faso fire protection or burning had no significant effect on stump mortality, although mortality was highest (15 per cent) in the first year after cutting and only increased marginally by 1 per cent in subsequent years (Sawadogo et al, 2002). In Zambia, stem density in an 11-year-old regrowth miombo was significantly higher under fire protection and lower under late dry season burning (Table 2.4). Similar results have been reported for Sudanian woodland in Ghana (Figure 2.11). The density of trees (>0.5cm dbh, i.e. diameter at 'breast height', which is deemed to be 1.3m) was also lower under late dry season burning (214/ha) in a 65-year-old fallow located in the transitional zone between the Guinea-Sudan woodland and Guinea dry forest in Ivory Coast, compared to 2244/ha and 6877/ha under early dry season burning and fire protection (Louppe et al, 1995). Clearly, some degree of fire control is important in enhancing dry forest recovery after clearing.

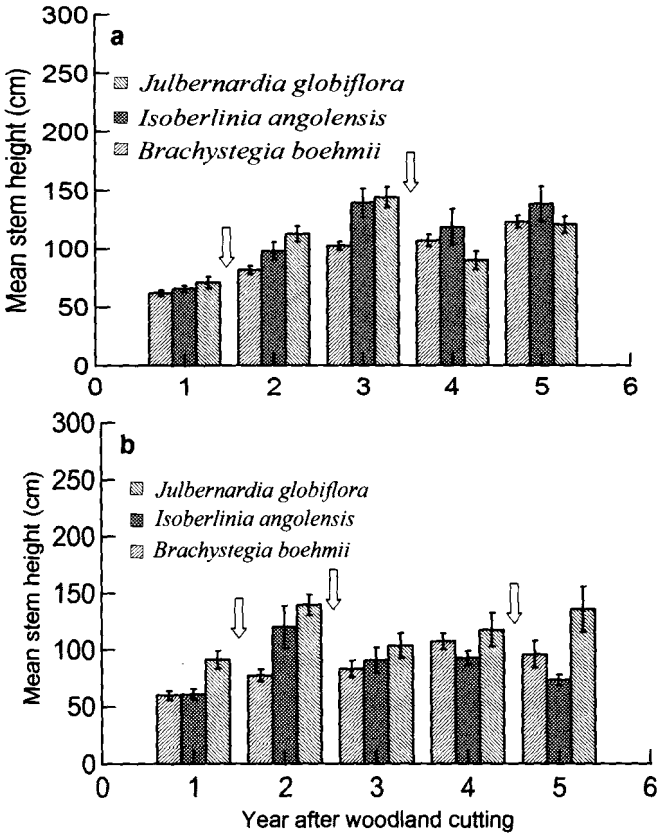

Figure 2.10 *Mean height development of sprout stems of miombo trees at sites and during five years following clear cutting of forest*

Note: Vertical lines on bars indicate 1SE and inverted arrows indicate fire occurrence at each site.
Source: Based on Chidumayo (unpublished data)

Table 2.4 *Stem density in wet miombo woodland plots before clear-cutting in 1933 (stems >6.4cm dbh) and in regrowth (stems >0.9m tall) under three fire treatments at Ndola in Zambia*

Fire treatment	*Woodland type*	*Stems per hectare*
Fire protection	Before cutting	205
	11-year-old regrowth	2963
	49-year-old regrowth	393
Early dry season fire	Before cutting	550
	11-year-old regrowth	2080
	49-year-old regrowth	520
Late dry season fire	Before cutting	455
	11-year-old regrowth	475
	49-year-old regrowth	no data

Source: Based on Chidumayo (1997b)

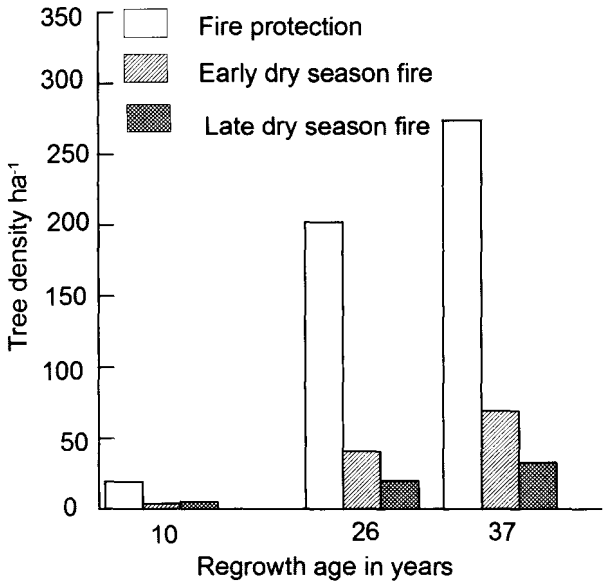

Figure 2.11 *Changes in tree (>9.0cm dbh) density in regrowth Sudanian savanna in northeast Ghana under different fire treatments*

Source: Based on Swaine and Brookman-Amissah (1987)

Tree Growth Rates and Wood Biomass Production

Tree growth is influenced by many factors, including genetic, climate and soils, as well as levels of disturbance such as fire and disease. The majority of tree species studied have diameter increments ranging from 0.03 to 2.6cm per annum. Among the most studied species in the Zambezian savannas are *Brachystegia spiciformis* (Grundy, 2006; Holdo, 2006; Trouet et al, 2006) and *Pterocarpus angolensis* (Boaler, 1966; Holdo, 2006; Stahle et al, 1999). *Brachystegia spiciformis* in western Zambia grew by 0.24 to 0.33cm diameter per annum while in Zimbabwe the species grew by 0.03 to 0.27cm per annum (Grundy, 2006; Trouet et al, 2006). A study in Tanzania (Jeffers and Boaler, 1966) revealed that humidity and minimum temperature were the most significant factors affecting the seasonal growth of *Pterocarpus angolensis* and, in a similar study, Boaler (1966) found that the annual diameter increment ranged from 0.08 to 0.48cm. However, growth ring bands indicated that the species also exhibited inter-decadal variations in growth rate. The annual diameter growth of *Isoberlinia doka* and *Anogeisus leiocarpus* in western Africa is estimated at 0.44cm and 0.45cm (Schöngart et al, 2006) while that of *Acacia drepanolobium* in eastern Africa is estimated at 0.7cm (Okello et al, 2006).

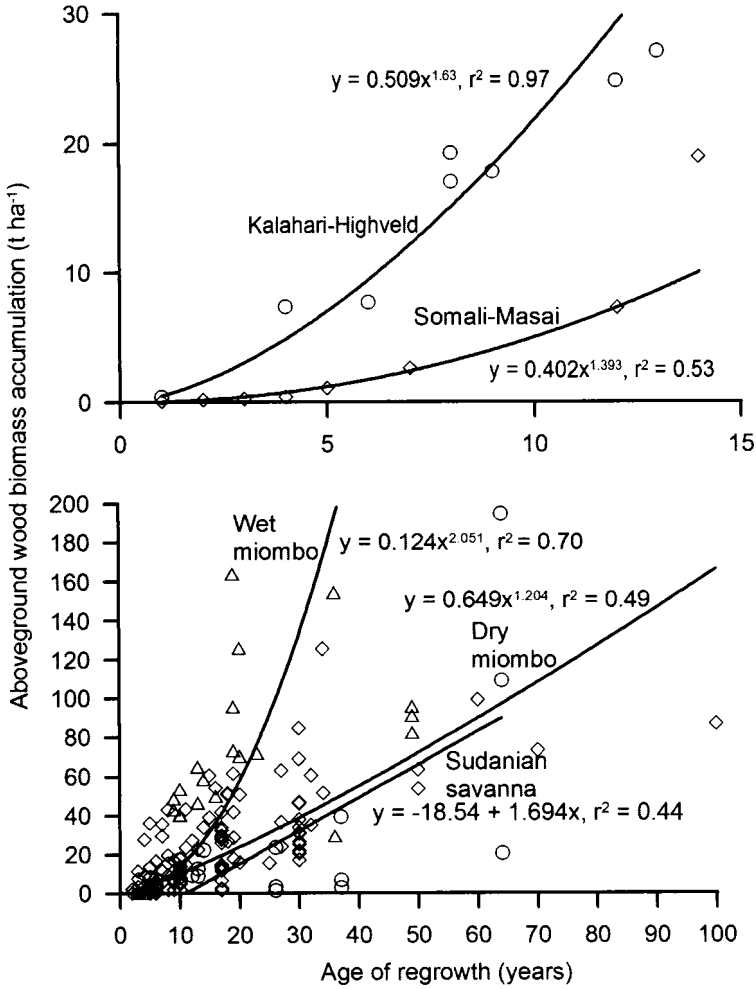

Figure 2.12 *Above ground wood biomass accumulation in Kalahari and Somali-Masai woodlands and wet miombo, dry miombo and Sudanian woodland*

Source: Based on data from literature (see text)

In most dry forests and woodlands woody biomass accumulation with increasing age was best explained by a steep rise in biomass with increasing age of regrowth (Figure 2.12). The steepness of the slope of the line relating biomass to age was highest in wet miombo followed by dry miombo and semi-arid savannas of the Kalahari region of southern Africa suggesting that these woodlands may be more productive than those in eastern and western Africa. The lowest biomass accumulation was observed in the Somali-Masai region. Generally, however, the age of regrowth was more important in determining woody biomass than phytoregion.

Key Issues and Questions

The chapter has described the distribution and general characteristics of dry forests and woodlands in sub-Saharan Africa and raised a number of issues concerning the management of these forests. Among the management issues raised, six key questions stand out as particularly important to sustainable management of dry forests and woodlands. These are:

- What will the response of dry forests/woodlands to predicted changes in regional climate be? We need to develop scenarios that will assist continued management of existing natural stands, and also guide us in re-establishment practices, where these are called for.
- What ability and capacity do these dry forests/woodlands have, through coppicing, to respond to harvesting? We need to determine what the limits are to this, and find out whether we are pushing the woodlands beyond them.
- What is the long-term impact of repeated fire on dry forest/woodland regeneration and production? Is fire protection a necessity, and is it worth the high cost. What is the regeneration potential of these forests and woodlands in the face of frequent fire.
- Although we have many scattered data, we still do not have a comprehensive idea of dry forest/woodland productivity levels in relation to stage of growth, moisture availability, nutrient status, forest/woodland type or composition. We need to understand what the main determinants of productivity are for each type, so that management practices can be more strategically applied.
- It appears that most dry forests and woodlands regenerate and spread by means of root suckers, and only locally through seed. We need to find out if this observation is correct and, if so, is there a particular impediment to regeneration of these species that improved management practices could readily overcome.

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