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Characteristics of dry forest in West Africa and the influence of fire

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Abstract. The climate, soil, structure and floristics of dry forests in West Africa are summarised. Data from Ghana show that these forests have two-peak annual rainfall between 850 and 1350 mm, with 6-10 dry months (< 100 mm rain) each year; by relatively nutrient-rich soils developed over a variety of rock types; by short stature (tallest trees 10-40 m) relatively high deciduousness in the upper canopy and evergreenness in the understorey; and by a distinctive flora which changes gradually towards areas of higher rainfall but abruptly at the forest-savanna boundary. Dry forests near the forest-savanna boundary form a distinctive sub-type as a result of occasional encroachment by litter fires which have become more common in the 1980's.

Evidence is presented to suggest that many parts of the forest zone in West Africa may have been subject to fires most often in the dry forest types. Past fires are likely to have had a profound influence on the composition of the present forest canopy. Fire mortality is greatest in small trees, whilst drought (without fire) kills more large trees. This thinning process allows rapid recolonisation especially by Marantaceous and Zingiberaceous forbs and by pioneer trees. Seedlings of canopy trees grow beneath these colonising plants. Recurrent fires seriously impede the recovery of burnt forest and are a principal concern for the rehabilitation of dry forests.

Keywords: Climate; Drought; Evapotranspiration; Rehabilitation; Soil; Structure.

Abbreviation: PET = Potential Evapotranspiration.

Introduction

The epithet 'dry' applied to tropical forests implies that moisture conditions are limiting for tree growth. Forest specifically excludes consideration of savanna vegetation, which in West Africa at least is quite distinct from forest in having a grass ground layer and an almost completely different species composition. The mutually exclusive natures of these two major biomes are apparently less clear in parts of eastern and southern Africa.

In West Africa, the broad geographical distribution of forest is closely correlated with the balance between annual rainfall and annual potential evapotranspiration (PET) (Fig. 1), but shows poor correlation with mean annual rainfall alone (see Fig. 3). With few exceptions, forest vegetation predominates where the ratio of rainfall to PET is greater than unity. Where rainfall exceeds PET by a factor of two, leaching of soil nutrients, creating desaturated soils of low pH is evident (Ahn 1970; Hall & Swaine 1976; Hall 1977).

The dry limit to dry forest in West Africa is clearly the forest-savanna boundary, usually abundantly clear on satellite images; the wet limit is less clear, as both forest structure and floristic composition change only gradually to that of wetter forest types. Locally the forest-savanna boundary is typically abrupt, accentuated by annual fires which are normally (see below) extinguished at the boundary.

There is no simple definition of dry forest available: Holdridge's (1967) use of the term appears to include forests with rainfall (and equivalent PET) ranging from 500 - 2000 mm/yr. In West Africa, forests with ≥ 2000 mm/yr of rainfall have strongly desaturated soils, reduced leaf litter fall, indicating lower productivity, high species richness and a high proportion of evergreen species (Swaine & Hall 1986). These are characteristics of the wetter forests in Africa, and are associated with a distinctive flora (Hall & Swaine 1976, 1981; Hall 1977). For the purpose of this paper, I regard dry forests as those which form the outer periphery of the forest zone of West Africa (Fig. 2). The possible causes of the limits to forest distribution will be discussed below. This account is centred on Ghana which has a wide range of dry forest types, many of which are recognisable in other West African countries (Swaine & Hall 1986).

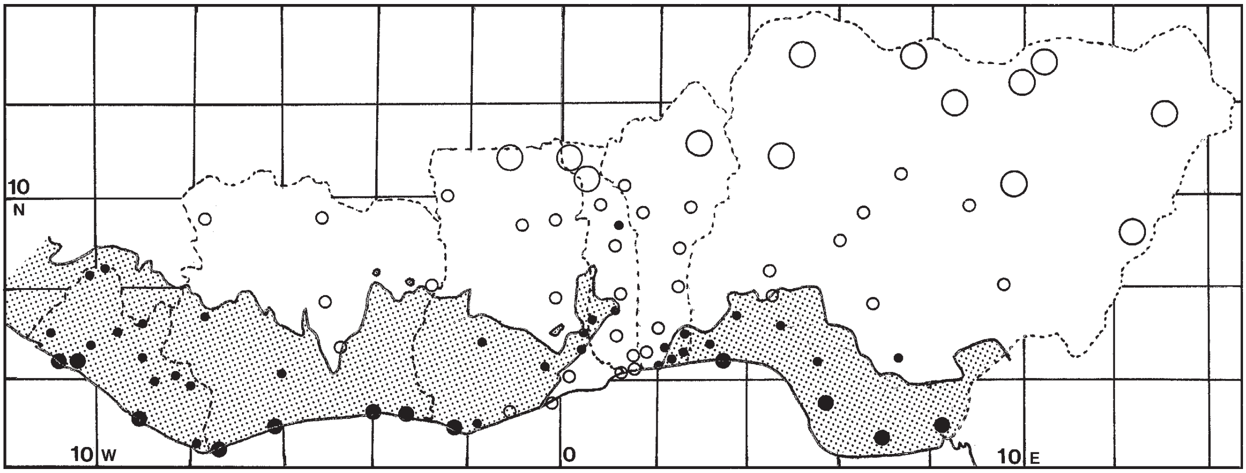

Fig. 1. Ratio of mean annual rainfall and potential evapotranspiration (PET) in relation to the distribution of forest (shaded) in West Africa. Filled circles: annual rainfall equals or exceeds PET for the larger circles by a factor of two or more; open circles: rainfall less than PET, for the larger circles by 50% or less. Data of Papadakis (1966).

Dry forest characteristics

Climate

Forests in Ghana, and in most West African countries, show a strong floristic and structural gradient correlated with climate (Swaine & Hall 1986). Fig. 3 shows the main features of the forest zone in Ghana, with a western core of wet forest and a peripheral zone of dry forest which will be discussed in this paper. The forest types recognised in Ghana are based on floristic analysis and do not match the annual rainfall gradient precisely. Evaporation data is insufficient at present to say if the rainfall : PET ratio would provide a better correlation.

The distribution of rainfall : PET ratio shown in Fig. 1 argues strongly for a climatic control of the distribution of forest in West Africa. On a local scale, however, the change from forest to savanna is complex and fragmentary, with a mosaic of the two vegetation types apparently determined by a variety of factors. Subtle differences in water regimes caused by changes in evapotranspiration due to relatively small variation in altitude, or by variation in soil drainage and water retention properties, assume greater importance and correlate with the local pattern of forest and savanna (Swaine, Hall & Lock 1976). The importance of local variation in moisture is most clearly demonstrated in the association of forest in savanna areas with streamsides or seasonal drainage channels (fringing or gallery forest).

As shown in Fig. 3, savanna occurs in the 1250 - 1500 mm annual rainfall zone only on the sandstones of the Voltaian Basin, whose soils have low clay content and are subject to drought (Ahn 1970). Low soil fertility, also characteristic of these soils (Ahn 1970), has

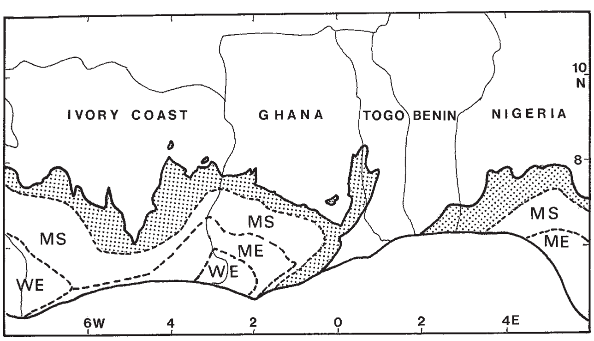

Fig. 2. Distribution of forest types in West Africa based on floristic equivalence with Ghanaian forest types. The forest zone is enclosed by the heavy line (drawn from Landsat imagery), forest types by thin lines. Dry forests (shaded) include the Dry Semi-deciduous, Southern Marginal and South-east Outlier types. Wetter forests types are: Wet Evergreen (WE), Moist Evergreen (ME), and Moist Semi-deciduous (MS). All types are defined in Hall & Swaine (1976, 1981). After Swaine & Hall (1986).

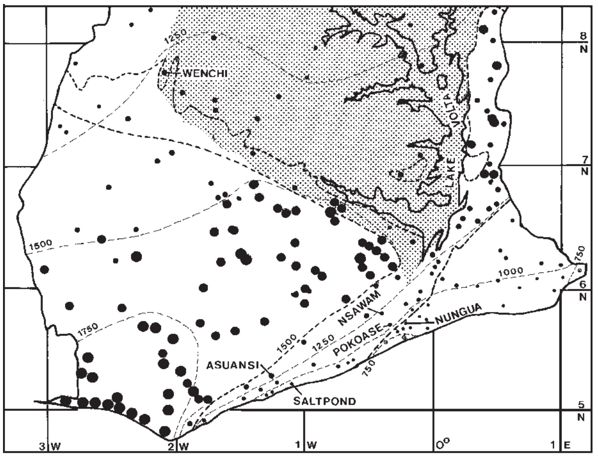

Fig. 3. Distribution of mean annual rainfall (prior to 1963) in relation to wet and dry forests in Ghana. Dry forest is enclosed by heavy broken lines, and forms the northern and eastern limits of the forest zone. Dots indicate classes of annual rainfall: smallest, 750 - 1000 mm; 1000 - 1250; 1250 - 1500; 1500 - 1750; largest > 1750 mm. The small circles show three stations with mean annual rainfall < 750 mm. Approximate 250 mm isohyets are dotted. Locations in dry forest for the climatic diagrams in Fig. 4 are named. The Voltaian Basin sandstone is shown shaded.

been advanced by Olivares & Medina (1992) and others as a reason for the occurrence of savanna in relatively high rainfall areas in South America. In Ghana, the poor water retention and low fertility of these sandy soils combine to limit the extent of forest to more southerly latitudes. Forest occurs on sandstone only on the more elevated parts of the Voltaian Basin, especially along the southern rim (Fig. 3).

The climate of the dry forests in Ghana (Fig. 4) is thus rather varied; it is shared by extensive areas of savanna. The southerly latitudes of these forests cause the strong bimodality of rainfall as evident from Fig. 4.

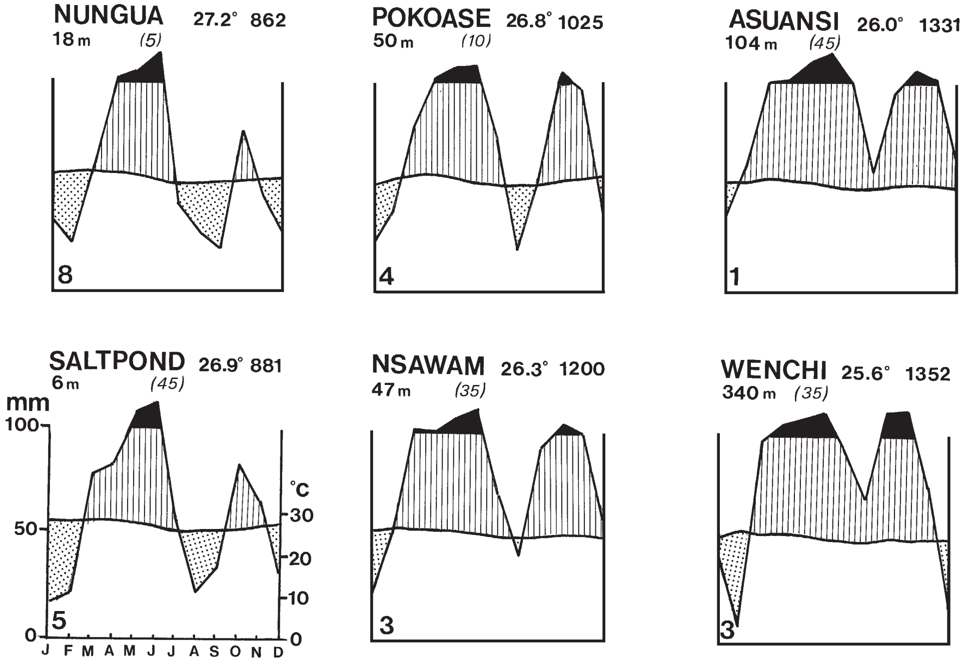

Fig. 4. Climatic diagrams (following Walter 1973, p. 20) of six dry forest stations in Ghana, arranged in order of mean annual rainfall. The number of months with a potential water deficit are shown in the lower left corner. Diagrams compiled from data in the Ghana Meteorological Office Monthly Weather and Rainfall Reports for 1963.

Annual rainfall in these dry forests varies between 850 and 1350 mm with concomitant variation in the number of months with less than 100 mm (6 to 10 months). At their driest extreme, in S.W. Ghana, these forests receive annual rainfall more typical of the Sahel; their existence is probably due to the wider seasonal distribution of rainfall, combined with the greater fertility of the soils found on the Basic Gneiss inselbergs of the Accra Plains (Swaine, Lieberman & Hall 1990).

Soils

Soil conditions generally reflect the rainfall gradient in the country (Hall & Swaine 1976), with the dry forest types showing less evidence of desaturation than the wetter forest (Fig. 5). pH values > 6 and total exchangeable base concentrations > 10 meq/100g predominate in dry forest, and available phosphorus concentrations typically exceed 12 ppm, occasionally well in excess of 50 ppm. This general trend of increasing fertility is also shown in the higher proportion of low C/N ratios in dry forest (Fig. 5d), but may be locally confounded by differences in the geological origin of the soil parent material, especially where the soils are thin on rocky hills. These forests lie on a great variety of geological forms and rock types, including granite, sandstone, schist, shale, quartzites and basic gneiss (Hall & Swaine 1981). The lower clay content of the dry forest soils, for example, which cannot easily be attributed to the rainfall gradient, is partly because the sandy soils of the Voltaian Basin (see above) only occur in the drier forest types.

Forest structure

Forest stature is greatest under moderate rainfall in Ghana, where leaching of soil nutrients is not severe, and is somewhat reduced under higher rainfall, but more markedly with declining rainfall (Hall & Swaine 1976, 1981).

The driest forests in West Africa are highly distinctive (Swaine, Lieberman & Hall 1990), with a smooth canopy surface at about 10 - 12 m, few trees of large girth, but with high stem density (Fig. 6a). Perhaps surprisingly, most trees are evergreen, so that the contrast in appearance between dry and wet seasons is less striking than is the case in other tropical dry forests (e.g. Janzen 1986). These forests are small outliers surrounded by savanna, and appear to be unique to the very dry south east corner of Ghana.

Under more favourable moisture conditions, forest stature increases and deciduous canopy trees become more evident (Fig. 6). The Southern Marginal forest type (Fig. 6b), examples of which have been identified from floristic analysis in other West African countries (Swaine & Hall 1986), generally has a canopy < 30 m in height. The upper storey is composed of tree species of which about half are deciduous, whilst the smaller tree species are almost all evergreen.

The wettest of the dry forest types, the Dry Semi-deciduous, is also the most extensive, occurring widely in West Africa (Fig. 2) with outlying examples recorded from Casamance in Senegal. The canopy in the type may exceed 40 m in height, occasionally approaching 50 m (Fig. 6d), which is similar to the tallest forest in Ghana, more commonly found in wetter forests. Hall & Swaine (1976) have divided the Dry Semi-deciduous type into two subtypes (the Fire Zone and the Inner Zone), on the basis of floristic composition. These two subtypes are structurally distinct, evidently due to occasional ground fires in the Fire Zone (see below). The Fire Zone was first defined from surveys in the 1970s when it was found only along the northern fringe of the forest zone where it abuts with savanna. Deciduous species are particularly abundant in the Fire Zone canopy, which is generally of lower stature than that of the Inner Zone (Fig. 6c). In some sites, the upper canopy may be composed entirely of deciduous species.

Floristics

The differences in species composition of these dry forests is the basis of their differentiation into types (Hall & Swaine 1976) and show a strong trend of declining diversity with increasing dryness. This leads to relatively large populations of relatively few tree species in the driest forests - in South-east Outlier forest, for example, 93 % of the trees in one sample were comprised of only six species (Swaine, Lieberman & Hall 1990). Further details of the floristic characteristics of and differences between these forest types can be found in Hall & Swaine (1981).

Dynamics

Little detailed work has been done on the dynamics of dry forests in West Africa though the South-east Outlier type was studied over ten years (Swaine, Lieberman & Hall 1990). In this uniquely dry forest, the trees are mostly of species confined to dry climates, and some are of very restricted or disjunct distribution. We may therefore regard them as well-adapted to the long periods of moisture deficit, and this is supported by their relative growth rates which appear to be very similar to forests under much higher rainfall (Swaine, Lieberman & Hall 1990). Mortality and recruitment rates are similarly within the ranges recorded for wet tropical forests. See also the contribution by Lieberman & Li (1992) in

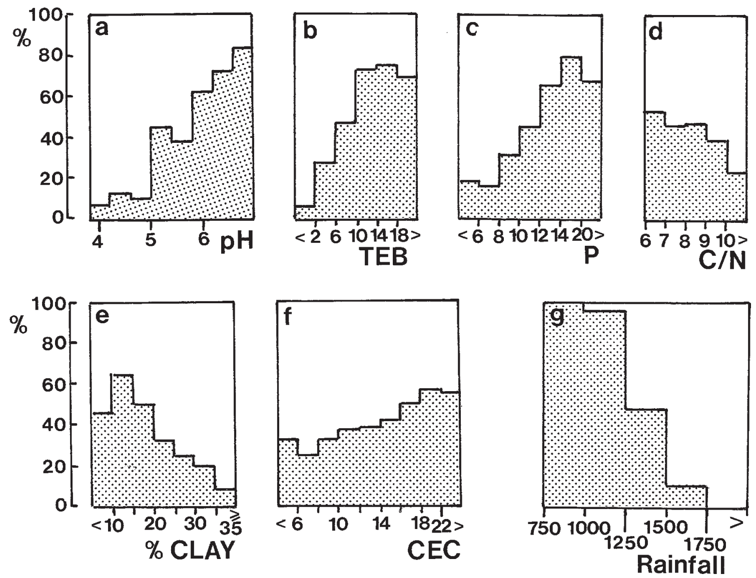

Fig. 5. Soil characteristics of Ghanaian dry forests. The histograms (shaded) show the % of dry forest samples in each soil class. The unshaded upper part of each diagram represents the remaining, wet forests. TEB (total exchangeable bases) and CEC (cation exchange capacity) in m-equiv. / 100 g soil; P (phosphorus) in ppm; rainfall in mm/yr. Data are for 153 topsoil (0 - 15 cm) samples from the survey (Hall & Swaine 1976; methods therein).

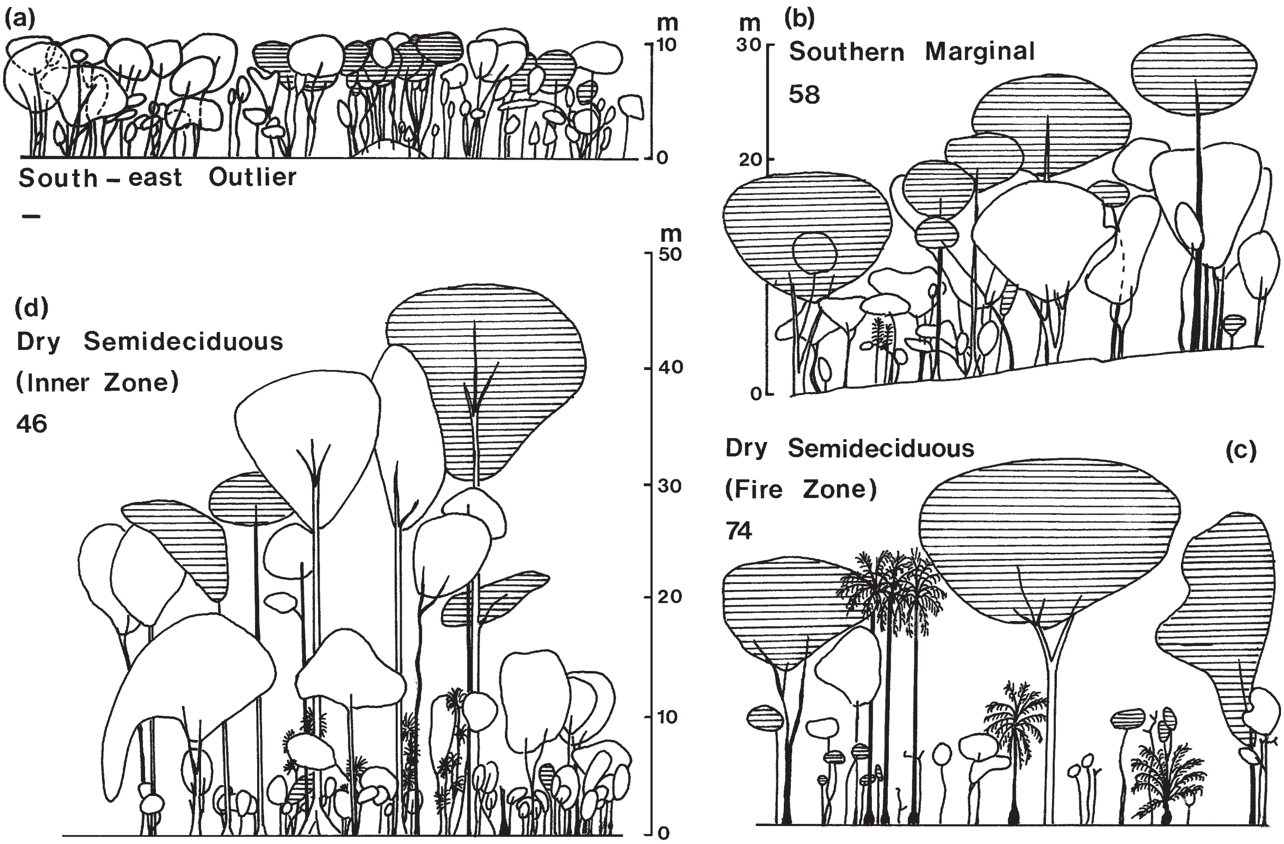

Fig. 6. Profile diagrams (8 m wide transects) from different dry forest types in Ghana. Crowns of deciduous tree species are shaded. Only trees > 3 m tall are shown. Values given are the % of megaphanerophyte trees > 10 cm dbh for all samples in the type which are deciduous species. South-east Outlier forest has no megaphanerophytes. From Hall & Swaine (1976, 1981); Swaine, Lieberman & Hall (1990).

Table 1. Seedling and resprout regeneration in Ghanaian dry forests. IZ = Inner zone; FZ = Fire zone.

	Forest type			
	SE	Southern	Dry Semi-deciduous	
	outlier	marginal	IZ	FZ*
Number of seedlings	232	139	594	5
Number of resprouts	55	16	5	63
% seedlings	81	88	99	7
Number of species	8	25	22	20
Area of sample (m^2)	240	2545	2810	320

*1 yr after litter fire.

this issue on regeneration by seed in the Pinkwae Forest in Ghana.

Regeneration by seed does occur, but is often unsuccessful; most species show a strong capacity for resprouting, and many are characterised by multiple stems. In surveys of regeneration in Ghanaian dry forests, trees < 10 cm gbh (3.2 cm dbh) were recorded either as seedlings or as resprouts from pre-existing plants (Table 1). There is an increase in the proportion of the tree regeneration due to seed germination with increasing rainfall, with the notable exception of the Fire Zone sample which was taken about 1 yr after a light ground fire in 1973. Here, over 90 % of the young trees were resprouts from roots or tree boles.

The influence of fire

Fire Zone forest in Ghana

It will be evident from the foregoing summary that the broad climate-related trend in these forests is confounded in forests adjacent to the savanna zone by fire which occasionally spreads in the litter layer from adjacent savanna or farms. In the 1970s, when this forest sub-type was first recognised (Hall & Swaine 1976), such fires were evidently rare and the forest was able to recover. The generally drier climate in the late 1970s and 1980s combined perhaps with increased farming and associated fires made forest litter fires more common and they were exceptionally severe in the main dry season of 1982 - 1983.

An inventory of the reserves in the forest zone in 1985 - 1988 (Wong 1990) recorded the frequency of fire damage. 55 % of all sample plots in the Dry Semi-deciduous type showed evidence of recent fires. In the wetter Moist Semi-deciduous type, 4 - 19 % had been burnt, and only in the wettest forest, where annual rainfall normally exceeds 1750 mm, was no fire damage recorded. The Fire Zone is evidently now much extended and forest fires have become a serious preoccupation of the Ghana Forestry Department.

History of fire and drought in tropical forest

The extraordinary events of 1983 were related to an exceptional El Niño southern oscillation (ENSO) which is now known to have caused droughts throughout the tropics with forest fires occurring in forests normally receiving very high rainfall in the Amazon (Sanford et al. 1985), and in Borneo (Woods 1985, 1989; Beaman et al. 1985; Goldammer & Seibert 1990) and elsewhere.

Historical records of fire in tropical forests are scarce, but there is good evidence that the prerequisite droughts are not uncommon. These have been reviewed for Africa by Schove (1977) and others in the same volume. Using a variety of evidence from archaeology, oral and written history, changes in lake levels and climatic records, Schove enumerates a long series of more or less protracted rainfall shortages. Much attention has been given to the Sahel zone, where drought has the most immediate and serious effects. Serious droughts in this zone of marginal rainfall are not always parallelled by reduced rainfall in the equatorial (forest) zone, but Schove (1977) recognises ‘international droughts’ which are effectively pan-tropical, as in 1983. These occurred in 1822 - 1825, 1833 - 1836, 1866 - 1868, 1940 - 1942 and in 1971 - 1974. Pan-African droughts are recorded for the 1910s and the 1940s.

Such ubiquitous droughts are likely to be marked by low water levels in tropical lakes. Maley (1989) has reconstructed lake levels for Lake Chad from 1000 AD which show at least five periods of exceptionally low levels. More pertinently, Talbot & Delibrias (1977, 1980) have reconstructed lake levels for Lake Bosumtwi, in the forest zone of Ghana, and show that between about 1500 and 1800 AD the lake was exceptionally low.

Although direct evidence of forest fires over the last millennium prior to this century are apparently lacking, the conditions necessary for them have probably occurred repeatedly. Goldammer & Seibert (1990) have assembled convincing evidence of both drought and fire in Bornean rain forest, the earliest from about 1880 and Johns (1986) found clear records of lowland rain forest fires in New Guinea in 1885 and on several occasions in subsequent decades. Indeed, charcoal has been found in all tropical forest soils where it has been sought (Sanford et al. 1985; J. Proctor pers. comm.; P. Becker pers. comm.). It is probably wise to regard fire as endemic, though rare, in tropical forests becoming more frequent in the drier forest types.

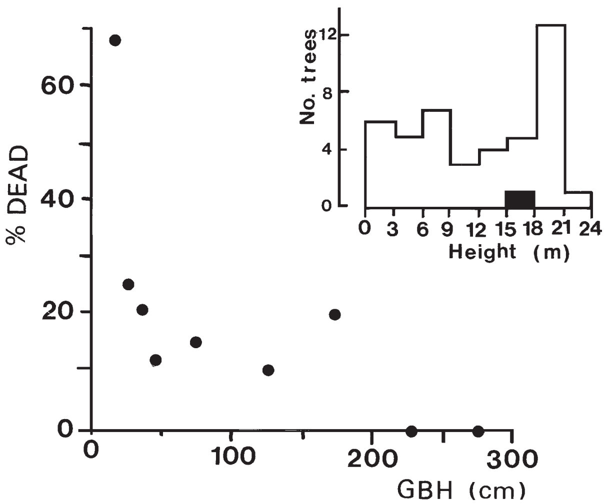

Fig. 7. Dead trees as a % of total trees enumerated on a 0.25 ha sample plot in 1974, 1 yr after a fire in Nsemre Forest Reserve. Inset: height class distribution of *Elaeis guineensis* Jacq. (oil-palm) and one tree of *Borassus aethiopum* Mart. (black).

The nature of tropical forest fires

These are fires essentially fueled by litter on the forest floor, only rarely extending into the canopy. They are often smouldering, rather than flaming, and may be halted by minor barriers like fallen, ashed logs or even by footpaths. Fire damage is greater, or more frequent on the upper parts of the topography (Hawthorne 1991). Bassini & Becker (1990) found that charcoal in soil was less common in streamside soils in the Amazon. The small plants suffer greatest mortality, including young trees (Fig. 7). Large trees are less likely to die, though bole damage can lead to increased mortality of large trees for 2 - 4 yr after fire (Berthault in press). Structurally, recently burnt forest is characterised by a very open understorey and a variable but generally light upper canopy.

The effects of light litter fires on forests form a striking contrast with the effects of drought with which they are associated. In the driest West African forests such as the South-east Outlier type, drought is an annual event, and is no doubt a principal selective pressure in the evolution of dry forest species. In very severe droughts, such as that of 1983, forests which normally receive high rainfall suffer greater mortality which is first seen in the tallest trees, especially those on the upper parts of the topography (Woods 1989; Goldammer & Seibert 1990). In Borneo, some areas which escaped burning in 1983 showed the effects of drought alone: 70 % of trees > 60 cm dbh died, but only 20 - 25 % of trees < 30 cm dbh. In contrast, a forest which burnt during the drought suffered 75 % mortality of trees < 5 cm dbh, and only 8 - 15% of trees > 10 cm dbh. (Wirawan, unpubl. rep. 1983, in Goldammer & Seibert 1990). In Ghana, following a light litter fire in Nsemre Forest Reserves in 1973, a similar pattern of tree mortality was recorded one year after the fire (Fig. 7). In this respect, the effects of drought are somewhat similar to logging, when only big trees are felled.

There is good evidence that both logged forest and burnt forest are more prone to renewed burning (Hawthorne 1991; Berthault in press). Furthermore, the severity of fires is greater in such forests, presumably because the reduced canopy cover provides a drier biomass. Berthault (in press) found 37 % tree mortality 9 yr after fire in undisturbed forest in Ivory Coast, but 55 % mortality in logged forest and 68 % in logged and thinned forest. Similar differences in fire damage in logged and unlogged forest are reported by Goldammer & Seibert (1990) and Woods (1989).

Recovery after fire

Without further fires, such forests very rapidly develop a dense undergrowth of herbs, shrubs and young trees derived from both seeds and vegetative reprouts (see Kauffman 1991) because of the increased illumination at ground level. The nature of the regrowth is very variable, depending on how much the fire has depleted the soil seed bank, the fecundity of the surviving trees and the recovery (by whatever means) of the surviving trees.

In Borneo, surviving adult dipterocarps in one burnt forest (Beaufort, Hill Sabah) set abundant seed one year after the 1983 fire and covered the forest floor with young seedlings (R.S. Beaman, pers. comm.). Similar reports from Kalimantan are referenced in Goldammer & Seibert (1990). Elsewhere in Borneo following the 1983 drought, plants in the soil seed bank germinate and quickly form a stand of pioneer trees in which *Macaranga* spp. are normally common (Woods 1989; M. Leighton pers. comm.). Similar regrowth of pioneer trees occurred widely in burnt forest in West Africa, though in places where the fire was more severe (e.g. in previously logged forest), Marantaceous and Zingiberaceous forbs tended to be more conspicuous, as well as the pantropical weed *Eupatorium* (=*Chromolaena*) *odoratum* L. (Berthault in press; Hawthorne 1991; see also Woods 1989).

A light upper canopy over a denuded forest floor is an ideal seed bed for many large timber tree species. Dipterocarps, for example, do not germinate or cannot establish in fully open conditions, and the same is true of

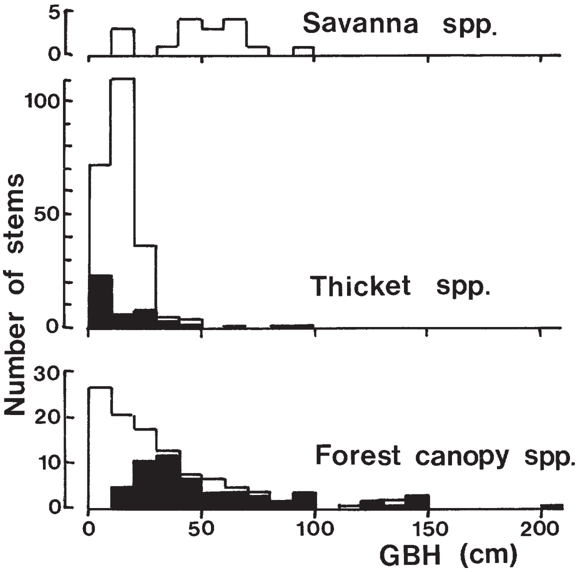

Fig. 8. Girth class distributions in 1989 of woody plants in a 0.175 ha sample plot, formerly Guinea savanna, now forest after ca. 32 yr of protection from fire at Kpong Agricultural Research station, Ghana (6° 08' N, 0° 04' W). The biggest trees are forest species (c) [*Ceiba pentandra* (Linn.) Gaertn. is shaded]; the shaded area included for the thicket species (b) is the introduced and naturalised Neem (*Azadirachta indica* A. Juss.); the savanna species (a) are: *Combretum fragrans* K. Hoffm. *Lonchocarpus sericeus* (Pior.) H.B. & K. and *Lannea* spec.

some West African *Meliaceae*. An intervening period of pioneer trees may also provide nursery conditions for shade-tolerant big-tree species, but research is lacking on this point.

We may expect that after the more severe fires, and especially after repeated fires, forest recovery will be slower because the mortality of the potential parent trees is greater, and the soil seed bank of tree species is more depleted (Kauffman & Uhl 1990; Uhl et al. 1981). Fires have recurred in several years since the main outbreak in 1983 in Ghana; as they continue, the regrowth becomes predominantly herbaceous (Berthault in press; Hawthorne 1991), and grasses may invade. It is uncertain if such continued pressure will convert forest to true savanna, as this would require the invasion of savanna tree species.

Thompson (1910) reported forests near Kintampo, in Ghana which "… are very open [his emphasis] and contain trees of lofty growth… the undergrowth … consists mainly of … species of *Amomum*, *Costus* and *Phrynium* …". French workers (in Maley, in press) describe essentially similar forests in Gabon and Cameroon close to the forest-savanna boundary, known as 'Forêts clairsemées' [sparse forests] à *Marantacées* et *Zingiberacées*". These were characterised by scattered large trees of primary forest species, with large gaps in the canopy and abundant pioneers and 'heliophytes'. *Elaeis guineensis* was common, as well as large forbs in the *Marantaceae* and *Zingiberaceae*.

These are clearly forests which have been burnt, matching the accounts of Berthault (in press), Hawthorne (1991) and my own observations. Rhizomatous herbs are well-equipped to survive fire, and *Elaeis guineensis* Jacq. (the oil palm), in common with other palms (Kauffman 1991), is resistant to fire, having no cambium and stem tissues protected by persistent woody leaf bases. These forests, and those of streamsides in savanna, are thought by A.C. Zeven (see Swaine & Hall 1986) to be the natural habitat of the species. *Elaeis* was already abundant in Nsemre Forest Reserve in Ghana prior to the 1973 fire (Figs. 6c and 7).

A long history of rare and variable fires in West African forest seems probable in view of the evidence for past droughts, and the distinctive floristics and structure of Fire Zone forest. They are a potent influence on the determination of forest composition, and could, for example, account for the commonly observed disparity in composition between the upper canopy trees and the younger trees of canopy species beneath them (Swaine & Hall 1988).

Management and rehabilitation of dry forests

The principal management objective for dry forest must be its maintenance as forest, which is more productive and biologically diverse than the savanna which might replace it. Forest conserves water resources and protects soil resources which are quantitatively and qualitatively superior to those of savanna.

In West Africa, at least principal concern is with the prevention of fire, especially in disturbed forests. This involves education of local farmers whose fires may be a major source of ignition in forest, and who may believe that forest, once burnt, is more likely to be dereserved and offered for farming. Direct protection of forests by firebreaks is costly, but 'green' firebreaks have been proposed, formed by swathes of non-inflammable vegetation which would require little maintenance compared with traditional, bare-soil firebreaks.

Forests of the Southern Marginal type in Ghana appear to be less prone to fire, and this may be because they are mostly fringed by shrubby thickets which seem not to burn readily. Alternatively, dense stands of fleshy forbs (e.g. *Zingiberaceae* and *Commelinaceae*) may retard both woody regrowth and the spread of fire, but research is needed to test these ideas.

Remaining large trees in burnt forest, of any species, are valuable both as a source of seeds and for the shade they provide. Guevara, Purata & van der Maarel (1986) have shown that isolated trees in Mexican pastures act as foci for birds and the forest species seeds they disperse. Many large tree species in West Africa grow as well, or better, in light shade as in full sun. For these reasons and because any further disturbance increases the chance and severity of fires, all timber exploitation in burnt forests should cease, at least until they are fully recovered.

Planting trees in degraded forest is expensive and often unsuccessful if regular tending lapses. The initial investment needs to be protected by further investment to ensure a good return. However, the technical means for such enrichment planting are well-known and may be a suitable option in some circumstances.

Forests, once burnt are sometimes seen as a lost cause, but there is clear evidence, from experiments in savanna vegetation close to the forest-savanna boundary, that they can be re-established. At Olokemeji Forest Reserve, Nigeria (Charter & Keay 1960) at Kokondekro, Ivory Coast (de la Mensbruge & Bergeroo-Campagne 1961) and at Kpong, Ghana (Swaine, Hawthorne & Orgle in press) experiments on the effects of fire protection on savanna vegetation all offer the same conclusion: savanna thus protected rapidly becomes invaded by forest trees and forms a closed canopy in 20 years or less (Fig. 8).

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