# A SURVEY OF ANTHROPOGENIC VEGETATION CHANGES IN WEST AFRICA DURING THE LAST CENTURY – CLIMATIC IMPLICATIONS

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**Abstract.** The extent of albedo change resulting from anthropogenic modification of the vegetation cover over the last century has been investigated in West Africa. The climatic implications of these changes are briefly discussed.

West Africa spans a suite of vegetation zones ranging latitudinally northward from tropical rainforest to desert scrub, and comprises environmental problems from extremely rapid deforestation of the tropical forests in Ivory Coast or Ghana to desertification in the Sahel.

Historical vegetation changes have been digitized on a 1° x 1° grid map based on a literature survey of government censuses, forestry and agricultural reports, supplemented by atlases, and other historical, economic and geographic sources.

The principal processes of land cover modification during the last century include clearing of the natural vegetation for agriculture, grazing, logging, and degradation of marginal semi-arid to arid ecosystems by excessive grazing or cultivation. Forestry surveys for West Africa suggest clearance of around 56% of the forest zone; estimated losses for Ivory Coast, Ghana, and Liberia range between 64% and 70%. Estimates of total land conversion range between 88 million ha, from the digitized land use map (Figure 4) to 122.8 million ha, from extrapolation of forestry data (Section 3.1).

The change in albedo corresponding to the land use modification is relatively small, using conservative estimates for desertification amounting to an increase of around 0.4% regionally over 100 yr and 0.5% since agriculture began. Thus 4/5 of the total albedo may have occurred within the last century. Additional assumptions regarding desertification and a lower albedo value for tropical forest compensate for each other and do not significantly alter the result of the initial calculation. The maximum zones of increased albedo are concentrated in the forest zone (4° –8° N) and savanna-southern sahel (10° – 12°) which correspond to zones of maximum agricultural and population growth. Between 13° N and 17° N, the albedo change is small or negative due to both less intensive land utilization and replacement of scattered vegetation on exposed sandy soil by lower albedo irrigated crops.

These estimates may represent a lower limit, particularly if desertification is more extensive than initially assumed. Under an extreme assumption that the entire Sahel zone between 14° – 20° N has been desertified, the regional mean albedo could increase by as much as 4%. This represents an upper limit to likely historical anthropogenic disturbances of the land surface.

Although historical climate records show three major droughts during the 20th century (1910–1920, 1940's, 1969–1975, possibly continuing into the 1980's; Nicholson, 1980a; Hare, 1983), and stream flow fluctuations which correlate well with precipitation (Faure and Gac, 1981; Palutikof *et al.*, 1981), these records do not appear to indicate a regional secular decrease in precipitation as suggested by several climate models. Evidence for apparent desiccation or 'desert creep' (= 'desertification') may be attributed, in large part, to adverse changes in soil and stream hydrology caused by anthropogenic disruption of the vegetation cover.

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## 1. Introduction

Anthropogenic modification of the vegetation cover may affect the climate by altering the atmospheric $CO_2$ content and the surface albedo. The influence of the biosphere on atmospheric $CO_2$ is discussed by Olson, 1982; and Woodwell *et al.*, 1983, among others. However, this paper will primarily establish the extent of surface albedo change in one critical region, associated with vegetation changes resulting from deforestation and agricultural expansion over the last century. This research on quantitative historical vegetation changes is relevant to a wide segment of the scientific community including climate modelers, hydrologists, agronomists and foresters. Although the emphasis here is on albedo changes, the underlying vegetation changes are pertinent to the $CO_2$ problem, and to the question of causes of desertification.

The change in surface albedo caused by land cover modification has been investigated as a potential cause of climatic variation. Surface albedo varies as a function of terrain type, and season (Henderson-Sellers and Wilson, 1983). For the most part, man-induced land-use changes tend to increase albedo. Several climate models find a decrease in rainfall over overgrazed, devegetated, brighter terrain (Charney, 1975; Charney *et al.*, 1977; Berkovsky, 1976; Chervin, 1979; Sud and Fennessy, 1982), whereas Lettau *et al.* (1979), conclude the reverse for Amazonian deforestation. Contradictory results are also reported for the relation between albedo change and temperature. Otterman (1974, 1977) suggests that the higher albedos caused by overgrazing in the Sinai desert lead to lower surface temperatures, whereas Jackson and Idso (1975) and Idso *et al.* (1977) find that on denuded soil, the reduced evapotranspiration exceeds the cooling due to higher albedo, producing a net warming. Sagan *et al.* (1979) estimate a global cooling of 1 K from anthropogenic albedo changes over several millennia, and 0.2 K, over the last 25 yr. Potter *et al.* (1981), using the same albedo changes as Sagan *et al.* (1979) but a different climate model calculate a decrease of only 0.2 K for the cumulative vegetation change. Henderson-Sellers and Gornitz (1984), updating the albedo data of Sagan *et al.* (1979), find roughly half the albedo change computed by Sagan *et al.* (1979) over the last 25–30 yr, which corresponds to a temperature decrease of around 0.1 K, using the sensitivity results of Hansen *et al.* (1981).

The wide diversity of opinion on the climatic consequences of land cover disturbance may stem from the complex interaction between surface albedo, vegetation, and the hydrologic cycle and their relative contribution to the net radiative balance. Furthermore, some of the models assume unrealistically large albedo changes. Additional uncertainties result from a poor knowledge of the history and areal extent of land conversion. Because of the significance of surface albedo changes to climate studies, it is important to derive a more reliable estimate of man-induced changes in the distribution of major vegetation types over a given time period, from actual historical records. While global coverage is preferable, because of time constraints, a preliminary survey to assess the magnitude of the climatic impact should concentrate on a specific region. Two recent conferences on global deforestation have begun to address this issue (Tucker and Richards, 1983; Richards and Tucker, 1984); however, only a limited regional coverage has been completed to date.

In this paper, the historical pattern of conversion of the natural vegetation to agriculture in West Africa over the last century has been reconstructed from a literature survey of government censuses, and reports of forestry and agriculture ministries, supplemented by descriptive accounts of forest clearance for lumber and expansion of both traditional and commercial agriculture, based on historical economic and geographic sources (Sections 2 and 3). This scattered, heterogeneous information has been organized, interpreted and synthesized to yield estimates of the magnitude of land conversion. However, the spatial pattern of albedo changes (Section 4) must be inferred from land use maps, which have been compiled from current atlases (Appendix 1), forestry, agricultural and population censuses (Section 3), together with descriptive historical data (Appendix 2). These materials provide the basic input to the calculation of albedo changes described in Section 4 of this paper. The calculated albedo changes are more realistic in terms of actual land use changes and avoid extreme assumptions (i.e. that desertification means replacement of original vegetation by sand). Climatic impacts are briefly discussed in Section 5.

West Africa, comprising 17 countries (Figure 1) has been selected for study because it spans a variety of vegetation zones grading latitudinally northward from rainforest to desert scrub. The region encompasses both desertification in the Sahel, and extremely rapid deforestation of the tropical forest zone (e.g. Ivory Coast, Nigeria, Benin-Dahomy), and therefore offers a good sample of the range of vegetation transformations affecting the tropical zone. Although the natural vegetation has been greatly altered during several thousand years of cultivation and livestock grazing, major changes have occurred since

Fig. 1. Index map of study area.

European colonization in the 1890's and subsequent independence. *Clearing of the natural vegetation* for agriculture, grazing and/or logging, and *'desertification'* – or more precisely – the *degradation* of semi-arid to arid vegetation under the combined influence of drought and over-exploitation of a marginal ecosystem – have been the major anthropogenic processes transforming the land cover during the last century.

## 2. Historical patterns of anthropogenic vegetation changes

### *2.1. Long-range Anthropogenic Changes*

The natural vegetation of West Africa is described in Church (1974, Chapter 4), Keay (1959), Hopkins (1965), Aubréville (1949) and in the references of Appendix 1. Botanical and forestry surveys indicate a long history of anthropogenic vegetation alteration and degradation. Some of the evidence for long-range human disturbance is briefly summarized below.

*Tropical forest zone (Figure 2)* – > 1400 mm $yr^{-1}$ rainfall includes lowland rainforest, mixed deciduous or seasonal forest, mangrove and freshwater swamp.

Dense forest once extended along the West African coast as far north as the Casamance River, Southern Senegal. Closed forests grew to around 8° N in the Ivory Coast, Ghana, and Nigeria (Aubréville, 1949). Very little virgin tropical forest remains today in West Africa. Much of the closed forest is mature secondary forest, which was once cleared for agriculture and later abandoned. In SE Nigeria, and elsewhere in the forest zone, oil palms have largely replaced the natural vegetation (Hopkins, 1965, p. 39–40; Morgan and Pugh, 1969, p. 214). Evidence for secondary growth includes presence of artifacts (Allison, 1962), trees requiring light to germinate or grow – such as the iroko and oil palm (Elaeis guineensis), abundance of lianas and thick undergrowth (Hopkins, 1965; Begue, 1937; Rosevear, 1953). Small clearings gradually revert back to secondary forest, but frequent clearing, burning and reduced fallows lead to a forest-savanna mosaic, or 'derived savanna' (Clayton, 1958; 1961). Dense forest survives only on isolated hills and ridges. The abrupt and irregular boundary between forest and 'derived savanna' is largely artificial, enhanced by fire (Aubréville, 1932, p. 247–8) although locally, soil types may determine its position (Cole, 1963; Moss and Morgan, 1977). The 'derived savanna' zone largely of anthropogenic origin, lies between closed forest (south) and Guinea savanna (north, Figure 2). In spite of recent population pressure, the forest-savanna boundary may be relatively stable, at least in western Nigeria (Morgan and Moss, 1965).

*Guinea savanna zone* – 1000–1400 mm $yr^{-1}$ rainfall. Centuries of repeated grassfires and farming have reduced the original closed woodland climax to a more open savanna woodland, consisting of scattered fire-resistant short trees and tall grass. At present, in densely populated areas, only the most useful fruit or lumber trees are preserved.

*Sudan savanna* – 600–1200 mm $yr^{-1}$ rainfall. Dense shrub thickets with scattered trees

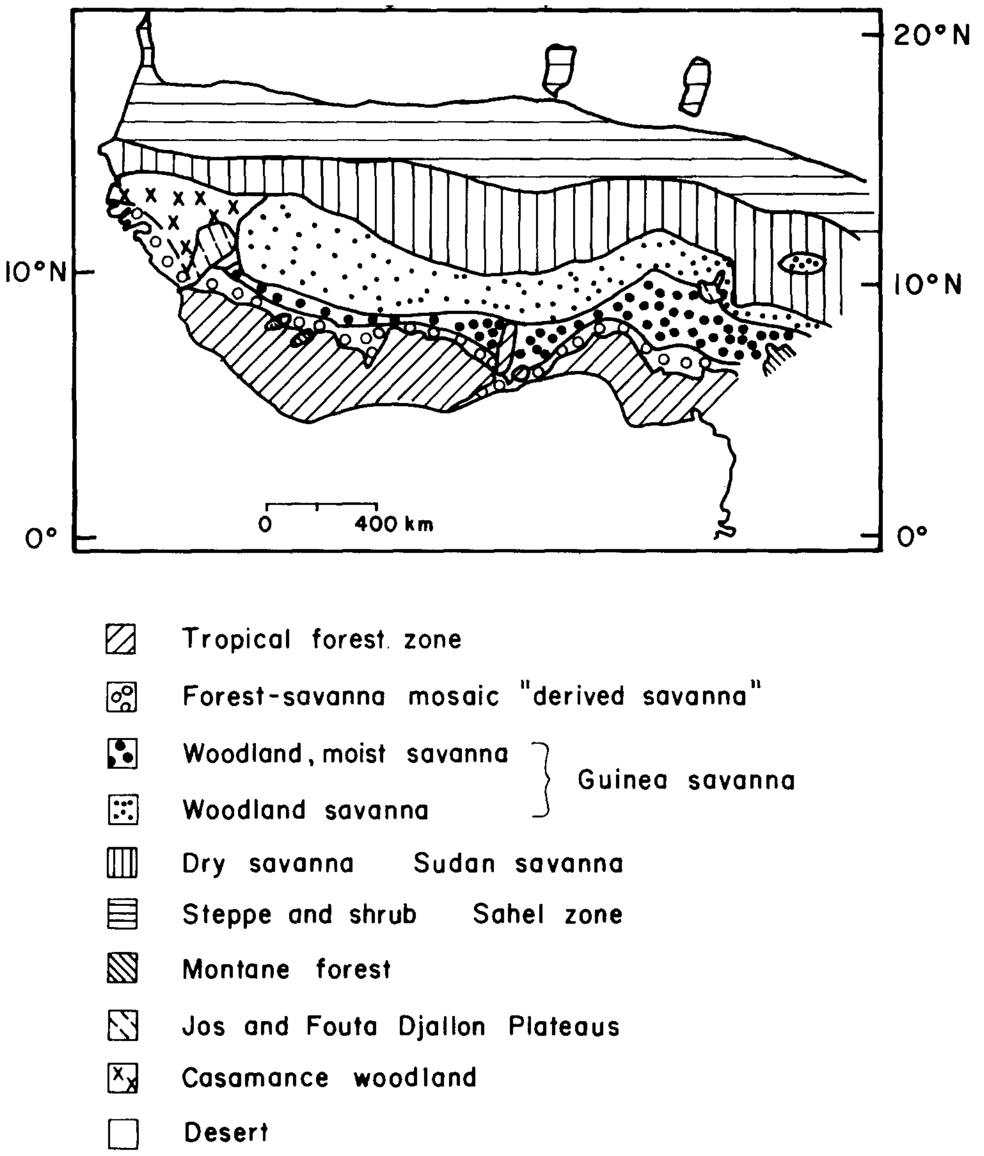


Fig. 2. Generalized vegetation map of West Africa (after Church, 1974).

and no grass have gradually degenerated into an open tree savanna due to repeated burning (Keay, 1959). This zone is one of the more densely settled in West Africa, with permanently cultivated land in a radius of 12–25 km around major towns. Even by the 1850's, continuous farmland and closely spaced villages existed between Bichi and Kano, and Katsina, northern Nigeria (Barth, 1857, vol. I). A widespread anthropogenic landscape, termed 'farmed parkland' in the northern Guinean and southern Sudan zones, consists of farmland with scattered trees of economic utility (Pullan, 1974).

*Sahel zone* – 200–600 mm $yr^{-1}$ rainfall. The climatic climax – a thorn woodland – is now largely open thorn tree, often species of Acacias, and shrub savanna. Grasses are short, tussocky and are extensively grazed by livestock.

### *2.2. Changes since 1890 – Colonial period to the present*

European colonialism contributed to a major modification of the natural vegetation of West Africa after 1890, because of the vast expansion of commercial agriculture, logging and the rapid growth in population stimulated by introduction of modern medicine and hygiene. These developments intensified the need for land, thus extending cultivation into previously unoccupied or sparsely settled areas, and shortening the length of fallow, contributing to a loss in soil fertility. Deforestation of the forest zone accelerated following a southward population migration from traditional trade centers (e.g. Timbuktu, Mali; Oyo, Nigeria) during the 19th century, partly triggered by tribal warfare, but also by better economic opportunities near the coast, and the development of commercial crops (Morgan and Pugh, 1969, p. 313; Allison, 1962; Morgan, 1959). Although difficult to document, it is possible that the southward spread of the 'derived savanna' coincided with this population shift (Allison, 1962).

Major clearing of the West African rainforest began in the 1840's in Sierra Leone (Dorward and Payne, 1975). By the 1930's, only 6% of Sierra Leone remained forested (Sierra Leone, 1937, 1939). Widespread planting of rice in coastal mangroves began in northern Sierra Leone in the 1880's but intensified since the 1930's (Kaplan *et al.*, 1976; Church, 1974, pp. 312–313; Morgan and Pugh, 1969, p. 655).

Growth of the oil palm industry by mid-19th century also greatly affected the forest zone. Oil palms were originally grown near Old Calabar, Niger Delta in the 1830's, but spread shortly thereafter to Dahomey, Togo and Ghana. Cocoa, another important tree crop was first cultivated in southeast Ghana, but by the 1890's had spread into central and western Ghana, SW Nigeria, Ivory Coast and Cameroon (Morgan and Pugh, 1969, p. 474; Agboola, 1979). By the 1950's, the cocoa belt in Ghana had reached the Ivory Coast border (White and Gleave, 1971, p. 115). Coffee, another forest zone cash crop, has been grown extensively in the Ivory Coast since the 1930's (Church, 1974, p. 349). Rubber was introduced into Southern Nigeria at the turn of the century, and now occupies large areas of Calabar Province and near Benin city. In Liberia, the area planted in rubber grew from 800 ha in 1910 to 81 000 ha by 1960 (Morgan and Pugh, 1969, p. 480).

The Ivory Coast has a long history of deforestation. By 1980, around 70% of the forest present in 1900 had been cleared (Table I). The coastal forests of Dahomey and Togo were largely cleared by the 1930's (Aubréville, 1937). In Ghana, by the 1950's, less than half the forest zone remained under tree cover (Table II). The rainforests of Abeokuta province, Western Nigeria were largely destroyed by 1920 (Unwin, 1920), and further clearance occurred in the 1950's and early 1960's (White and Gleave, 1971, p. 158).

A widespread expansion of peanut cultivation took place in the Sudanian zone of Senegal (Atlas National du Sénégal, 1977) and northern Nigeria, and also cotton in the latter country early in the 20th century (White and Gleave, 1971, pp. 122–124; Church,

TABLE I: Deforestation history of Ivory Coast

| Year | Area of closed forests, x $10^3$ ha | | Reference |
|---|---|---|---|
| ~1900 | 15 000 | | FAO, 1981 |
| | (14 500) | *moist* forest | |
| 1920 | 12 140 | | Zon and Sparhawk, 1923 |
| 1933/34 | 13 000 | | Ann. Stat. A.O.F. 1933/34 |
| 1950 | 7 000 | (seems low) | Haden-Guest *et al.*, 1956 |
| 1955 | 11 800 | (moist forest) | FAO, 1981 |
| 1958/63 | 8 000 | | FAO, 1967 |
| 1965 | 8 983 | (moist forest) | FAO, 1981 |
| 1966 | 9 000 | | Persson, 1977 |
| 1973 | 6 200 | (moist forest) | FAO, 1981 |
| 1980 | 4 458 | | |
| | 3 993 | (moist forest) | |

TABLE II: Deforestation History of Ghana

| Year | Area of closed forests, $10^3$ ha | | Area of woodland and open forest x $10^3$ ha | Total forest area x $10^3$ ha | References |
|---|---|---|---|---|---|
| 1920 | 9871 | 'forest area' | | | Zon and Sparhawk, 1923 |
| 1937/38 | 4789 | | 11 111 | 15 900 | Gold Coast Report on the Forestry Dept. for the year |
| 1946/47 | 4375 | | | | " |
| 1948/49 | 4236 | | 11 085 | 15 321 | " |
| 1950/51 | 4087 | | 11 045 | 15 132 | " |
| 1953 | 2810 | | | | Charter, 1953 |
| 1958 | 2493 | | 11 331 | 13 824 | Ghana Ann. Rept. Forestry Dept. 1958 |
| 1960/61 | 2424 | | 10 687 | 13 111 | 1962 Ghana Stat. Yearbook |
| 1968 | 2207 | | 9 711 | 11 918 | 1967-8 Ghana Stat. Yearbook |
| 1980 | 1718 | | 6 975 | 8 693 | FAO, 1981 |

1974, p. 219). Irrigation has transformed the natural vegetation in the inland delta of the Niger River, Mali, starting in the 1920's. Main crops are rice and cotton (Morgan and Pugh, 1969, pp. 645–654). Creation of large artificial lakes (Lake Volta, Ghana, Lake Kossou, Ivory Coast) has inundated vast areas of forest and savanna.

In the sahelian zone, since the beginning of this century, sedentarization of nomads has accelerated; cultivation has extended further north into former grazing land marginal to agriculture; and the number of well and bore holes has increased (Ware, 1977, Baier, 1980, Dresch, 1959). The rapid expansion of cattle herd size, together with areal reduction of grazing lands, and concentration of herds around bore holes has led to severe overgrazing around wells and towns, even prior to the 1970's drought (Mabbutt and Floret, 1980).

Appendix 2 provides more detailed documentation of vegetation changes in individual countries. Figure 3 is a schematic map of deforestation and vegetation degradation. It is

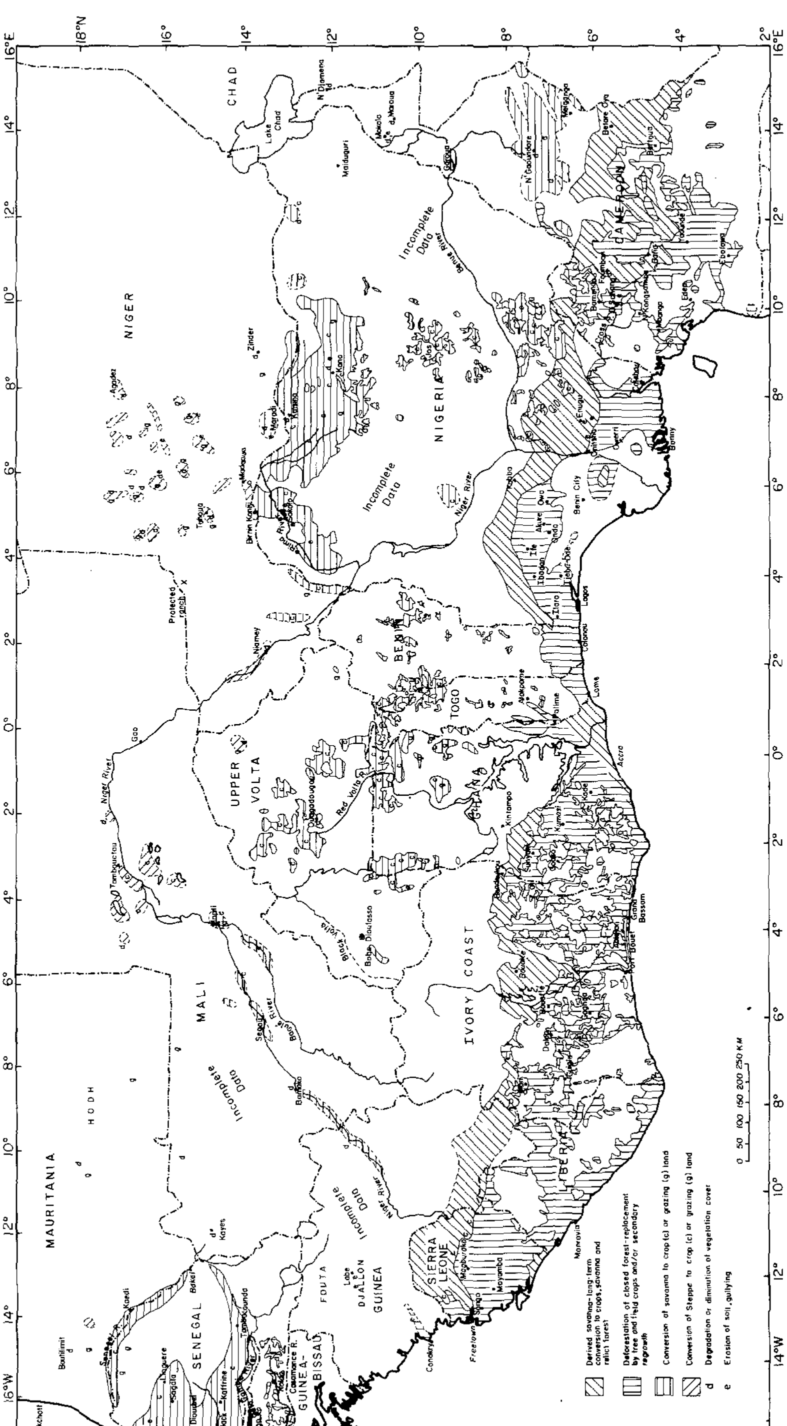


Fig. 3. Schematic map of anthropogenic vegetation changes in West Africa during the last century.

incomplete in certain areas due to inadequate data. The reliability is greater for countries like Senegal, Ivory Coast, Ghana and southern Nigeria.

## 3. Estimation of the Extent of Anthropogenic Vegetation Changes

### *3.1. Records of Deforestation*

Although forestry records in West Africa span a period of 60 yr, incomplete coverage in earlier surveys and revised definitions of vegetation type over time make it difficult to quantify the regional deforestation history. On the other hand, data for several West African countries (Ghana, Benin-Dahomey, Ivory Coast, Liberia, and Nigeria) suggest forest reduction during this century. The data for these three countries (Tables I–III) are considered to be accurate to within 20% (Persson, 1977). The area of closed forest in Ivory Coast decreased from 15 million ha in 1900 to 4.46 million ha in 1980 (Table I), representing a decrease of 70.3%. The current rate of deforestation of closed forest (7% $yr^{-1}$) is the highest in the tropics (FAO, 1981). In Ghana, closed forest shrank from 4.79 million ha in 1937/38 to 1.72 million ha in 1980 (–64.1%), and open forest and woodland diminished from 11.11 million ha to 6.98 million ha (–37.2%) in 43 yr (Table II). The present rate of deforestation is 1.6% $yr^{-1}$ (FAO, 1981). Liberian closed forests decreased from 6.5 million ha in 1920 to 2.0–2.5 million ha by the late 1970's (Table IIIa) or a 69% reduction in 60 yr.

However, deforestation in these three countries may be higher than for West Africa as a whole. Phillips (1974) estimates that out of 49 million ha of potential closed forest (in suitable climate) in the Guinean and Nigerian blocks (excluding Cameroon), only 21 million ha, or 43%, are actually forested, suggesting a 57% loss (over an unspecified time period). Vegetation maps indicate that tropical forests should cover around 83.6 million

TABLE IIIa: Deforestation History of Liberia x $10^3$ ha

| Year | | | References |
|---|---|---|---|
| 1920 | 6475 | 6475 | Zon and Sparhawk, 1923 |
| ~1950 | 5520 | | Haden-Guest *et al.*, 1956 |
| 1968 | 2500 | | Persson, 1977 |
| 1980 | 2000 | 2040 | FAO, 1981 |

TABLE IIIb: Forest Resources, West Africa x $10^3$ ha

| | Zon and Sparhawk, 1923 | Haden-Guest *et al.*, 1956 | Persson, 1977 | FAO, 1981 |
|---|---|---|---|---|
| Closed forest | – | 34 500 | 38 540 | 36 632 |
| Total forest land, incl. open woodland | 102 659 | 89 340 | 182 189 | 136 298 |

ha in West Africa (Matthews, 1983); however existing closed forest only occupies 36.6 million ha (Table IIIb; FAO, 1981). Thus, a 56.3% loss may be inferred, which agrees remarkably well with Phillips' (1974) estimate, although somewhat lower than the data from Ghana and Ivory Coast. Using a conservative figure of 56% reduction in closed forests over the last 60–80 yr, 46.8 million ha have been cleared. If the decrease in open woodland and savanna in Ghana is representative of the whole region, then 37.2%, or 76 million ha could have been degraded and/or converted to agriculture. Adding these two figures, up to 122.8 million ha of forest, woodland and savanna may have been cleared.

### *3.2. Expansion of Agriculture*

A direct determination of changes in forest area from forestry statistics, as outlined above, can only provide a rough estimate. Changes in the area of cropland may serve as an indirect measure of vegetation change. Although exports (tonnages) of certain commercial crops (i.e. oil palm products, cocoa, rubber, coffee) are recorded for several countries since around 1900, surveys of the total cultivated area cover a period of 50 yr or less. Permanently cultivated land has increased by 12.9 million ha for 8 former French West African countries, between 1930 and 1979 (IIA, 1939; FAO, 1980). Applying the same proportion to all of West Africa, permanently cultivated land could have increased by 42.7 million ha over this period.

### *3.3. Population Growth*

Population growth can be used as a surrogate for cropland expansion and hence indirectly changes in the natural vegetation, particularly in predominantly rural regions where traditional agricultural methods still prevail. Population growth between 1910 and 1980, compiled from various sources is summarized in Table IV. The population figures for several countries can have uncertainties of 10–15%.

The agricultural population[1] of West Africa was 74% of the total population in 1980 and 79% in 1970 (FAO Prod. Yearbooks), and 77% and 82% respectively for former French West Africa. Between 1940 and 1960, the agricultural population was assumed to have decreased by 5% per decade, and prior to 1940, it was assumed to have comprised 95% of the total population. The permanently cultivated area is calculated by multiplying the agricultural population by the average area cultivated/farmer, and with certain assumptions of the ratio of cultivated to fallow land, the total area under cultivation can be derived. The cultivated area can range between 0.3 and 0.7 ha/farmer depending on the crop combinations used, regional population density, soil and micro-climate. A representative value of 0.55 ha/person was used and assumed not to have changed over time. The ratio of cultivated to fallow land depends on population density, soils and agricultural systems (Thomas and Whittington, 1969). Most recent national atlases and censuses report ratios

[1] The rural population, as a percent of total population, which is equivalent to the percent of the economically active population engaged in agriculture.

in the range of 1:2 to 1:5 for the last few decades (Appendix 1). These ratios were probably closer to 1:6–1:8 in 1910. For the present calculation, a ratio of 1:3 for 1980 was assumed, decreasing to 1:6.5 in 1910 (Table IV).

Given this set of assumptions, the permanently cultivated area, for former French West Africa has expanded by 10.5 million ha, between 1930 and 1980, as compared with 12.9 million ha from IIA (1939) and FAO (1980). Over this period, the permanently cultivated area for all of West Africa increased by 39.4 million ha, which is close to the 42.7 million ha derived from agricultural surveys. The permanently cultivated land increased by 44.3 million ha and total area cultivated (including fallow) by 114.9 million ha, between 1910 and 1980 (Table IV).

## 4. Changes in Albedo Associated with Changes in Land Use

Estimates of anthropogenic vegetation change inferred from forestry, agriculture and population data (Section 3) are still inadequate for assessing the impact of albedo changes in a GCM. A more useful compilation of surface albedo data for climate modeling requires reformatting the vegetation (and corresponding albedo) data into a grid system ($8^\circ \times 10^\circ$ resolution for the GISS GCM Models I and II; Hansen *et al.*, 1983). Matthews (1983) has compiled a high resolution ($1^\circ \times 1^\circ$) global vegetation and land use data base designed specifically for climate studies. In order to construct an albedo change map for West Africa, the natural potential vegetation classification of Matthews (1983) was retained, but the land use classification was modified, as described below.

### *4.1. Land-use Changes*

The present-day cultivation intensity for each $1^\circ \times 1^\circ$ cell, based on maps and atlases (Appendix I) was digitized on an ordinal scale from 1 to 5, corresponding to an increasing percent of the land area under permanent cultivation and in commercial agriculture (Table V, after Matthews, 1983). The land use classification differs from Matthews (1983) chiefly in assigning cells of greater than 70–100 people km$^{-2}$ to cultivation intensity class 4; population density over 30–40 people km$^{-2}$ to class 3; over 10–20 km$^{-2}$ to class 2 (traditional subsistence economy) and fewer than 10–20 km$^{-2}$ to class 1. Population density and grazing pressure fall off sharply north of 17° N lat. which has therefore been taken as a northern boundary for this exercise.

Land use intensities of 100 yr ago are much more difficult to estimate than current ones, since very few atlases present such data. Exceptions include the Atlas National du Sénégal (1977) (Appendix 1) which shows expansion of peanut cultivation and changes in population density (1900–1970). However, a historical pattern of land use changes for other countries has been reconstructed from the sources listed in Appendices 1 and 2, together with population growth curves, and agricultural forestry surveys (Section 3). Changes in land use (cultivation) intensities are summarized on Figure 4.

TABLE IV: Growth of cultivated land, based on population growth, West Africa

| | 1910 | 1920 | 1930 | 1940 | 1950 | 1960 | 1970 | 1980 | |
|---|---|---|---|---|---|---|---|---|---|
| Population x $10^3$ | 34171 | 39237 | 43559 | 49318 | 65605 | 87778 | 113274 | 152831 | [1] |
| % population in agriculture | 95 | 95 | 95 | 95 | 90 | 85 | 79 | 74 | [2] |
| Agricultural population x $10^3$ | 32462.4 | 37275.2 | 41381.1 | 46852.1 | 59044.5 | 74611.3 | 89486.5 | 113094.9 | |
| Average area cultivated per agriculturist | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55[3] | |
| Area cultivated | 17854.3 | 20501.4 | 22759.6 | 25768.7 | 32474.5 | 41036.2 | 49217.6 | 62202.2 | |
| Ratio of cultivated to fallow land | 1:6.5 | 1:6 | 1:5.5 | 1:5 | 1:4.5 | 1:4 | 1:3 | 1:3 | [4] |
| Total area cultivated | 133907.3 | 143509.8 | 147937.4 | 154612 | 178609.8 | 205181 | 196870.4 | 248808.8 | |

[1] Sources: Appendix 1 and references.

[2] FAO Production Yearbooks, 1970, 1980. Decreases approximately 5% per decade between 1960–1940. Assumed to be 95% prior to 1940.

[3] This is a composite figure derived from a number of sources. For example: Laclavère, 1979 (Cameroon); Mali, Rapport de l'enquête agricole 1970–71; Togo, Enquête Agricole Gén. 1970; Kaplan *et al.*, 1976 (Sierra Leone); Agboola, 1979; Nelson *et al.*, 1972 (Nigeria); Nigeria Ann. Abstr. Stat. 1970; Oluwasami, 1966 (Nigeria); Birmingham *et al.*, 1966 (Ghana). (See also Appendix 1).

[4] Sources include those of [3] and Appendix 1.

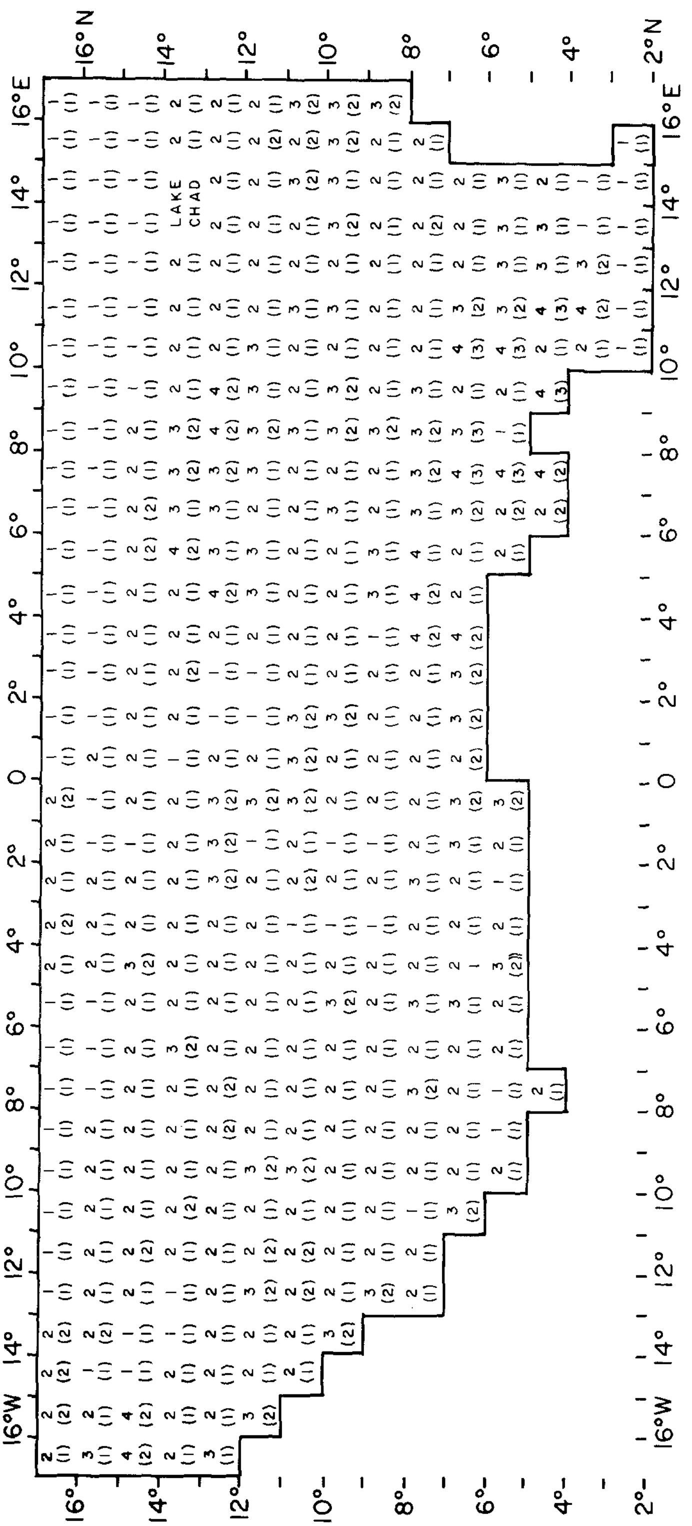


Fig. 4. Map of cultivation intensities for each 1° × 1° cell. The top number (see Table VII) refers to 1980; the number below it, in parenthesis, to 1880.

### *4.2. Calculation of Albedo Changes Associated with Land Use Changes*

The natural vegetation classification was based on Matthews (1983), and their associated albedos were adapted from Matthews (1984) (Table V). Albedos for various West African crops are taken from Oguntoyinbo (1970a, b) (Table VI). Where known, the average albedo of the 3 to 4 dominant crop types present in a grid cell was used; otherwise the annual mean value of 17% for mixed crops was taken (Oguntoyinbo, 1970a, b).

The cell albedo is calculated as an area-weighted average of the crop albedo and the natural vegetation albedo, using the digitized land use intensity scale (Table VII) as weighting factors for the percent area cultivated. Crop combinations and hence their albedos are assumed not to have changed, but the cultivation intensity has generally increased over time. The ordinal scale of 1–5 sets broad limits for different levels of cultivation intensities, which are generally not known to be better than 20% over large areas. The present land use intensities are based on population densities and land-use maps (Appendix 1).

TABLE V: Albedo of natural vegetation (after E. Matthews, 1984)

| Vegetation type | Winter | Spring | Summer | Fall | Annual average |
|---|---|---|---|---|---|
| Tropical evergreen rainforest | 11 | 11 | 11 | 11 | 11 |
| Tropical evergreen rainforest | 13 | 13 | 13 | 13 | 13 [1] |
| Tropical evergreen seasonal forest | 11 | 11 | 11 | 11 | 11 |
| Tropical evergreen seasonal forest | 13 | 13 | 13 | 13 | 13 |
| Xeromorphic forest/woodland | 28 | 32 | 28 | 28 | 29 |
| Evergreen sclerophyllous woodland | 15 | 13 | 12 | 13 | 13.3 |
| Tropical drought-deciduous woodland | 20 | 18 | 17 | 18 | 18.3 |
| Xeromorphic (dwarf) shrubland | 28 | 32 | 28 | 28 | 29 |
| Tall/medium/short grassland with 10–40% woody tree cover | 14 | 15 | 17 | 15 | 15.3 |
| Tall/medium/short grassland with <10% woody tree cover | 14 | 15 | 16 | 14 | 14.8 |
| Tall/medium/short grassland with shrub cover | 16 | 18 | 25 | 20 | 19.8 |
| Tall grassland, no woody cover | 17 | 17 | 20 | 17 | 17.8 |
| Medium grassland, no woody cover | 16 | 20 | 20 | 18 | 18.5 |
| Desert | 30 | 30 | 30 | 30 | 30 |

[1] (Oguntoyinbo, 1970; Pinker *et al.*, 1980)

TABLE VI: Albedo of various African crops (Oguntoyinbo, 1970a, b)

| | | |
|---|---|---|
| Cocoa | 16 | |
| Kola nuts | 13 | |
| Cotton | 21 | |
| Sorghum | 20 | |
| Millet | 20 | – not listed, but assumed 20, for purposes of calculation |
| Groundnuts | 17 | |
| Yams | 19 | |
| Cassava (manioc) | 19 | |
| Tobacco | 19 | |
| Maize | 18 | |
| Swamp rice | 11 | |
| Sugar cane | 15 | |
| Mixed crops | 17 | |

Those of 100 yr ago are based on population densities and descriptive accounts of agricultural and economic activity, scattered references to forest clearing, logging, mining, soil erosion, etc., and discussions of settlement patterns and population shifts. Population statistics can have uncertainties of 10–15% for most countries, but errors as high as 20–30% can occur in some countries and for older dates (~1900). For areas of currently low population density (class 1, $< 20$ km$^{-2}$) the land use intensity of 100 yr ago must have also been low – thus no change is indicated. Those areas of current subsistence agriculture (classes 2, 3) are assumed to have been class 1, 100 yr ago, except where historical data indicates settled areas, which are then assigned to class 2. Only in SE Nigeria (Ofomata, 1975), and possibly near Kano, N. Nigeria, were population densities at the turn of the century high enough to merit class 3 status. The difference in albedo between 1980 and 1880 (100 yr change) and that between 1980 and the original vegetation (no agriculture – cumulative change), is then determined for each cell, summed for each latitude band and, finally for the entire region (Figures 5, 6; Table VIII).

In addition, albedo changes were calculated, using two modifying assumptions. The albedo of 11% assigned to tropical rainforest and tropical seasonal forest (Matthews, 1984) may be too low. Recent studies suggest a value closer to 13% (Oguntoyinbo, 1970b; Pinker *et al.*, 1980). The regional albedo has been recalculated, as above, changing albedos of tropical forests from 11% to 13%, between latitudes 2° – 8° N.

The second modifying assumption involves an estimate of the effects of desertification on albedo. The zone of pastoral land use in the Sahel likely to be affected by overgrazing includes all cells between 14° – 17° N lat., except agricultural areas of Senegal (14° – 16° N, 15° – 17° W) and desert areas of Niger (15° – 17° N, 9° – 17° E). In regions of sufficient rainfall ($\geqslant 600$ mm yr$^{-1}$), overgrazing may reduce the surface albedo, inasmuch as it diminishes the normally green vegetation canopy, which is highly reflecting in the near infra-red. On the other hand, in semi-arid or arid regions such as the Sahel ($\leqslant 400$ mm yr$^{-1}$ rainfall), the vegetation is often grayish-brown, and grows in isolated tussocks, having a vertical structure. The IR reflectivity of such plants is lower than that of plants growing in a moister environment and of the underlying sandy soil. Thus the removal of vegetation by overgrazing and exposure of sandy soil often leads to an increase in albedo

TABLE VII: Cultivation intensities and land-use associations (Matthews, 1983)

| | | | | | |
|---|---|---|---|---|---|
| Cultivation intensity | 5 | 4 | 3 | 2 | [illegible] |
| Percent cultivated (approx.) | 100 | 75 | 50 | 20 | 0 |
| Land use | Large-scale | Small-scale | Extensive | Rudimentary | Nomadic |
| | Commercial | Commercial | Subsistence | Subsistence | herding |
| | Intensive subsistence with rice dominant | Intensive subsistence with some cash crops | with marginal cash crops | | grazing |
| Population density | – | $\geqslant$ 70–100 $km^{-2}$ | $\geqslant$ 30–40 $km^{-2}$ | $\geqslant$ 10–20 $km^{-2}$ | < 10–20 $km^{-2}$ |

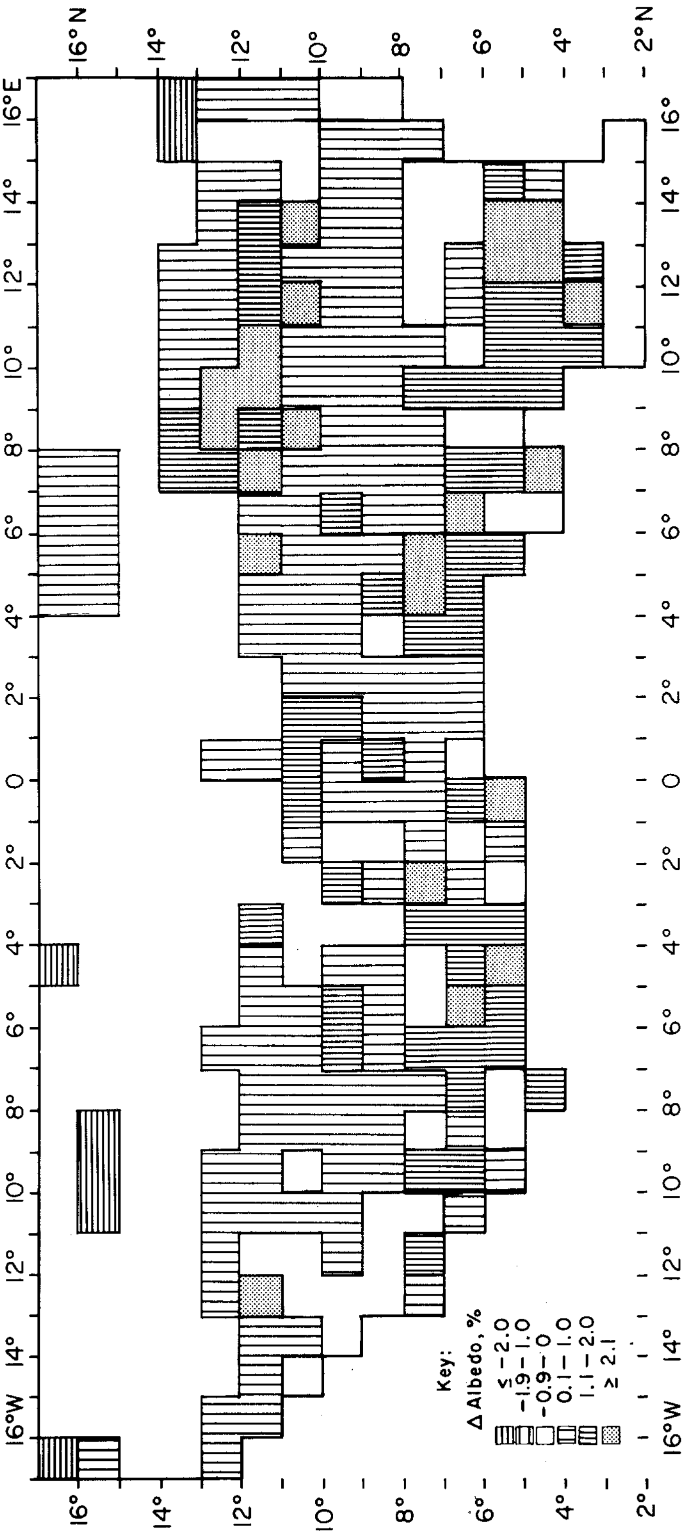


Fig. 5. Map of albedo changes, 1880–1980.

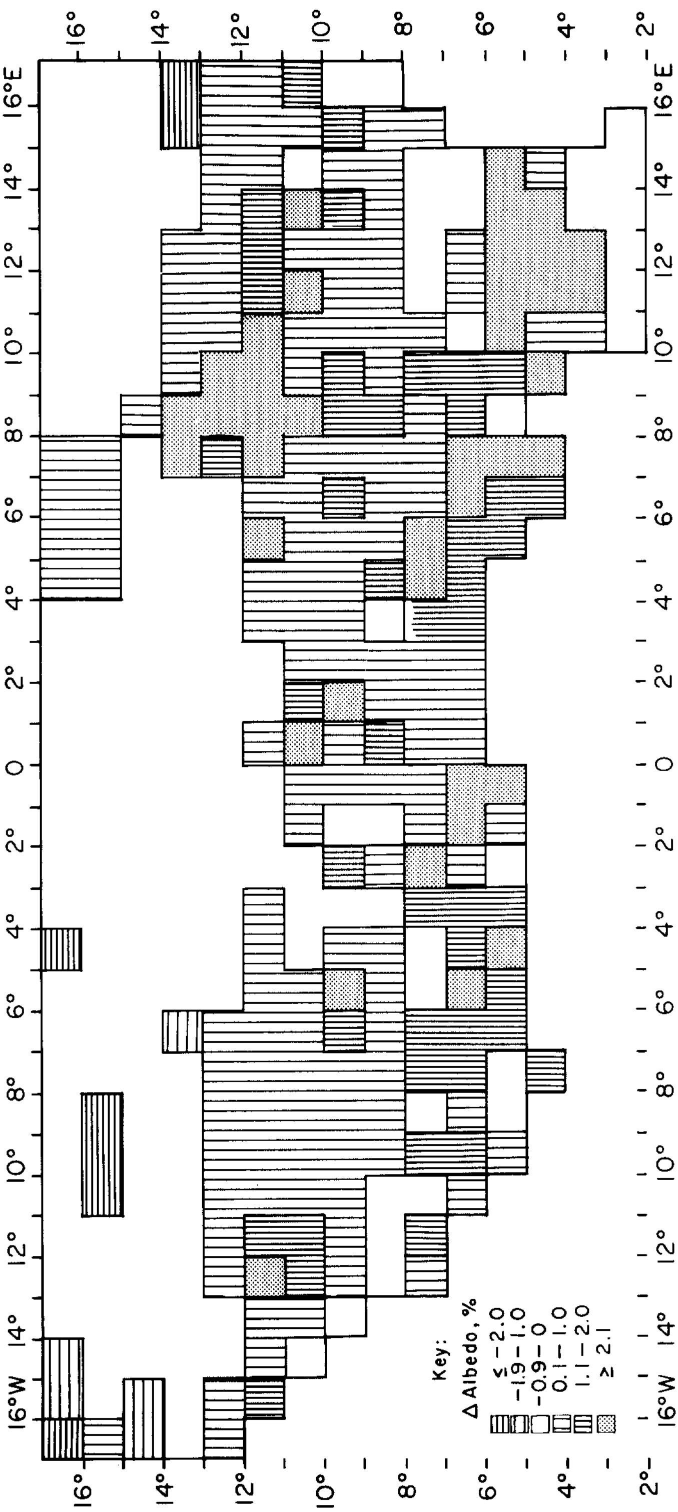


Fig. 6. Map of cumulative albedo changes, pre-agriculture to present.

TABLE VIII: Mean regional albedo and albedo change in West Africa

| Assumptions | Natural vegetation | 1880 Land use | 1980 Land use | ΔA 100 yr | ΔA cum. |
|---|---|---|---|---|---|
| 1. 2°–17° N<br>No desertification<br>Albedo tropical forests 11% | 17.3 | 17.4 | 17.8 | 0.41 | 0.54 |
| 2. 2°–17° N<br>Albedo tropical forests 13%<br>Desertification affects 10% land area between 14°–17° N, except for 14°–16° N, 15°–17° W and 15°–17° N, 9°–17° E | 17.6 | 17.7 | 18.1 | 0.42 | 0.54 |
| 3. 2°–20° N<br>Otherwise same assumptions as 2. | 19.9 | 20.0 | 20.4 | 0.44 | 0.54 |
| 4. 2°–20° N<br>Desertification affects the entire area between 14°–20° N, with the exceptions noted in 2.<br>Albedo contrast ratio 1.74 on 10% land surrounding boreholes, 1.5 on remaining non-agricultural land. | 19.9 | 20.0 | 24.3 | 4.31 | 4.4 |

(J. Otterman, priv. comm., 1984). A measure of the albedo contrast due to desertification may be derived from protected exclosures. A protected ranch in Niger, near the Mali border (15° – 54′ N, 4°7′° E) has an albedo of 34.2% compared to 42.3% for the overgrazed terrain outside (Otterman and Fraser, 1976; Otterman, 1981), yielding an albedo contrast ratio of 1.24. A figure of ~10% potentially heavily grazed land in the Eghazer and Azaouak region of Niger (15° – 18° N, 4° – 8° E), (Mabbutt and Floret, 1980), is assumed to be representative for the entire Sahel. The increase in albedo due to desertification was recalculated by multiplying the previously calculated 1980 cell albedo for the Sahelian region by 1.24 and giving this 'desertified' albedo an areal weight of 0.1 (Table VIII, Case 2).

### *4.3. Results*

The mean area-weighted regional change in albedo is 0.41% (100 yr) and 0.54% (cumulative change) (Table VIII, Case 1). The average regional albedo of natural vegetation is 17.3. Thus, the regional albedo increases from 17.3% to 17.4% by 1880 and 17.8% by 1980. Based on this study's reconstruction of land use changes, around 4/5 of the total albedo change associated with anthropogenic activity have occurred within the last century in West Africa.

The maximum zones of increased albedo are concentrated in the forest zone between 4° and 8° N, and in the savanna and southern Sahel, between 10° and 12° N; which correspond to zones of maximum agricultural and population growth (Figures 5, 6). North of 13° N, the albedo change is small or negative. Areas of relatively large albedo differences result from two major factors: (1) increase in land use intensity, as inferred from population densities, (2) a large albedo contrast between the original vegetation and the crops replacing it (usually, but not always resulting in an increase in albedo). For example, in southern Cameroon (4° – 6° N, 11° – 14° E), there is an increase in both cultivation intensity and in albedo from tropical rainforest (11%) going to mixed crops (17%). Similar effects are noted for southern Nigeria, southern Ghana, and southern Ivory Coast. On the other hand, in western Senegal, the albedo differences are small or zero, in spite of a significant increase in cultivation intensity over the last century, in the 'peanut basin' (Thies-Diourbel-Kaolack). In this case, the albedos of the crops replacing the natural vegetation (peanuts (17%), sorghum, (millet) (20%) are close to the indigenous vegetation (drought-deciduous woodland, 18.3%, and shrub grassland, 19.8%). The strongly negative albedo change at 16° – 17° N, 16° – 17° W reflects irrigated rice cultivation (11%) replacing xeromorphic woodland (29%); (Morgan and Pugh, 1969, pp. 646–653; Church, 1974, pp.250–1), while at 15° – 16° N, 8° – 11° W, (millet, sorghum and peanuts) (19%) replace xeromorphic shrub (29%).

With the modifying assumptions of (1) a higher albedo value for tropical rainforest (13%, instead of 11% and (2) including an estimate for the effects of desertification, the regional area-weighted mean albedo change is now 0.42% (100 yr) and 0.54% (cumulative) (Table VIII, Case 2). These values are nearly the same as before. The albedo *change* in the forest zone, is now smaller than before because of a lower albedo contrast between forest and the replacing crops. This decrease is nearly equally counterbalanced by an increase in Sahelian albedo due to the estimated extent of desertification (Table VIII, Figure 6).

In addition to errors based on land use intensities or assigned albedos, the calculation may overestimate albedo change during the last century relative to the cumulative change, but could significantly underestimate the cumulative vegetation change, because the role of anthropogenic fire and long-term overgrazing in expanding savanna areas has been neglected (Aubreville, 1949; Korlowski and Ahlgren, 1974). Dry deciduous wood land has been largely replaced by a fire climax wooded savanna. The degradation of closed forest has accelerated within the last 100 yr, to a mosaic of secondary forest, tree crops (i.e. oil palm, cocoa, coffee), bush fallow, and 'derived savanna' (Aubréville, 1949; Hopkins, 1965; Allison, 1962). On the other hand, the inference of a once more densely wooded vegetation (Phillips, 1974; Aubréville, 1949) may be partially based on the geographic distribution of forest relicts from a formerly more humid climate, possibly dating to the last climatic optimum (Aubréville, 1932, 1937, 1939).

## 5. Discussion

### *5.1. Regional Albedo Changes*

The calculation of regional albedo changes caused by man-induced vegetation changes has only been determined up to 17° N latitude (Section 4). Although rainfall, human and livestock population density and concentration of boreholes fall off sharply north of 17° N latitude, some pastoral activity and hence land potentially subject to desertification could extend as far north as 20° N latitude. Extending the calculation to include the zone between 17° – 20° N (using the same assumptions as the second case, Table VIII) raises the mean regional albedo from 17.3 to 19.9, (due largely to desert sands) without significantly altering the 100-yr (+0.44) or the cumulative (+0.53) albedo increase (Case 3, Table VIII).

The albedo contrast ratio between overgrazed land and a protected 'exclosure' in the northern Sinai has recently been found to be higher (1.74) than previously reported (Otterman and Tucker, 1984). Furthermore, Otterman (1984, priv. comm.) suggests that the albedo increase for the northern Sinai is representative of the effects of desertification throughout the entire Sahel. Therefore the albedo calculation has been repeated, assuming 100% desertification, using an albedo contrast ratio of 1.74 for 10% of land immediately surrounding boreholes, but a slightly lower factor (1.5) to the remainder of the zone between 14° – 20° N latitude (with the exceptions noted in Case 2, Table VIII). In this case, the regional mean albedo increases by around 4% above that of natural vegetation for both the 100 yr and cumulative periods (Case 4, Table VIII).

This result represents an upper bound to the albedo effect of overgrazing. Because of the sparcity of vegetation north of 18° N, vegetation changes (both natural and man-made) are expected to be much less than further south. The largest seasonal changes in surface albedo are concentrated between 13° – 18° N (Courel *et al.*, 1984; Norton *et al.*, 1979). The seasonal and interannual albedo changes, however, far exceed the long-term anthropogenic effects in the Sahel. In addition, the spatial pattern of desertification is highly nonuniform. Land degradation is concentrated around towns and villages (Delwaulle, 1973), and in a radius of 6–10 km surrounding larger boreholes and wells (Warren and Maizels, 1977; Mabbutt and Floret, 1980). Skylab imagery shows a granular and cellular pattern of cultivation in the Sahel. Extensively cultivated areas appear brighter than their surroundings (MacLeod *et al.*, 1977; see also Appendix 2). The albedo of the Niger-Mali exclosure, as seen on Landsat imagery, is also non-uniform, due to dunes, drainages, soil variations and localized grazing. Similarly, the area surrounding the exclosure exhibits considerable natural variability in albedo. Therefore, it may be inappropriate to apply the high albedo contrast ratio over the entire area. Unlike the northern Sinai, desertification in the Sahel appears to be more sporadic, and therefore the initial assumption of 10% of the land desertified surrounding boreholes, while perhaps low, is more reasonable than assuming 90 or 100%.

Furthermore the albedo contrast ratio of 1.74, inferred from modeling studies (Otterman and Tucker, 1984) may be too high. Ground measurements of an overgrazed vs protected area in Tunesia suggest a ratio of 1.4 (Wendler and Eaton, 1983).

### *5.2. Sources of error*

Because of the nominal nature of vegetation and land used data, albedo measurements taken by different instruments under different conditions, and the synthesis of this disparate assemblage of data into maps, quantitative error estimates for the computed albedo changes cannot be readily determined. At best, some of the sources of uncertainty can be indicated. Potential sources of error in the global vegetation data base (Matthews, 1983, 1984) include differences in classification schemes and definitions of vegetation types, poorly surveyed areas, obsolete data and discrepancies among multiple sources for a given area. Each 1° x 1° cell has been ranked into one of nine 'reliability classes', 9 being the most reliable (Matthews, 1983). Instrumental and atmospheric effects can introduce relative errors of 10–25% in measured albedos over the Sahel (Norton *et al.*, 1979; Courel *et al.*, 1984). Seasonal and interannual variability can be much greater, especially in the Sahel. In years of normal precipitation, seasonal reflectance variations can range up to 80%, dropping to less than 50% in dry years (Norton *et al.*, 1979). Between 1973–1979, albedos decreased by 20–60% in the western Sahel, as compared with changes of ±15% in the Sahara. Another source of variability is in terrain inhomogeneity. The assigned natural vegetation albedos show a spatial variability of around 4% for Cases 1 and 2; and 6% for Cases 3 and 4. A measure of the sensitivity of the calculated regional mean albedo of natural vegetation to a change in specified vegetation albedo can be seen by replacing the albedo of tropical rainforest from 11% to 13% (Case 1 to 2) which introduces a change of 0.3% in the regional mean albedo (Table VIII).

Given the potentially large (but often undefined) uncertainties attached to albedo maps, the specified vegetation and crop albedos nevertheless represent reasonable average values, based on currently available data in the absence of more detailed land surveys and more adequate albedo measurements. The results reported here provide an estimate of the relative magnitude of albedo changes associated with anthropogenic activity, based on a plausible historical scenario of land use changes.

### *5.3. Climatic Implications of Anthropogenic Vegetation Modification*

The energy and hydrological cycles are closely interrelated. Disturbance of the vegetation cover not only changes the surface albedo, but also can affect the surface-atmosphere energy exchange, by altering the relative proportions of sensible to latent heat (the Bowen ratio), largely through changes in evapotranspiration. Up to 50% of the rainfall on Amazonian tropical forests may be recycled through evapotranspiration (Marques *et al.*, 1977; Salati and Vose, 1984). Thus large-scale forest clearance could significantly affect evapotranspiration and precipitation.

Results of several climate model studies (Charney, 1975; Charney *et al.*, 1977; Chervin, 1979; Sud and Fennessy, 1982) support the traditional view linking deforestation to decrease precipitation at least on a local scale (Aubréville, 1949; Thompson, 1980). An estimate of the maximum likely impact of tropical deforestation has been derived, using the GISS GCM Model II (Hansen *et al.*, 1983). In that experiment, 4.94 x $10^6$ $km^2$ of tropical moist forest in Amazonia (albedo 11%), lying between 7.8° N – 15.6° S and 45° – 75° W (an area roughly equal to West Africa) was arbitrarily cleared and replaced by a grass/crop cover (albedo 17%; Henderson-Sellers and Gornitz, 1984). In spite of a surface albedo increase of 6% and planetary albedo increase of 1–1.5%, locally precipitation and evapotranspiration decreased by 0.4–0.6 mm $day^{-1}$, whereas surface temperature showed no significant change, suggesting that a temperature rise from reduced evapotranspiration may offset the decreased temperature caused by increased surface albedo (Jackson and Idso, 1975; Idso *et al.*, 1977).

A more thorough investigation into the effects of evapotranspiration is beyond the scope of this paper. On the other hand, turning to the historical climate records for West Africa, what evidence exists, if any, that the anthropogenic changes discussed above have affected the hydrological cycle, and thus indirectly, climate. Three major droughts have occurred in the 20th century: from 1910–1920, 1940's and 1968–1974 (Nicholson, 1980a). (The 1970's Sahelian drought may not have ended yet – the early 1980's have been as dry as 1972 and 1977 (Hare, 1983). It is much too early to conclude whether this drought is part of a longer-term cycle, with eventual amelioration or the beginning of a permanent change toward desiccation.) Although biogeophysical feedback mechanisms (Charney, 1975; Chervin, 1979) may help exacerbate drought, the geological record indicates that major climatic changes have occurred since the end of the last glaciation (Nicholson and Flohn, 1980). Recent rainfall anomalies show analogous patterns to Holocene fluctuations (Nicholson, 1980a, b; Nicholson and Flohn, 1980).

Over the last few centuries, the 'Little Ice Age' (16–18th century) in West Africa was, on the whole, wetter than present (Nicholson, 1980b). Lake levels and historical records indicate a drying trend during the late 18th–early 19th centuries, followed by a partial return to a more humid climate between 1875–1895 (Nicholson, 1980b). Description of lusher vegetation in the Sahel reported by 19th century European travelers (Barth, 1857; Depierre and Gillet, 1971) may correspond to this moister period. Early 20th century references to the desiccation of Africa (Hubert, 1920; Migeod, 1922, Stebbing, 1935) could represent the effects of the 1910–1920 drought.

Fluctuations in streamflow during the 20th century (Sircoulon, 1976; Faure and Gac, 1981) correlate well with precipitation variations (Nicholson, 1980a, Palutikof *et al.*, 1981), but there is not definitive evidence yet of a long-term decrease in precipitation such as predicted by several climate models (Charney, 1975; Chervin, 1979; Sud and Fennessy, 1982), although if the 1970's Sahelian drought persists into the future, this may provide the first indication.

On the other hand, widespread planting of commercial trees (coffee, cocoa, oil palm, rubber) in the forest zone of West Africa, may have mitigated some of the adverse consequences of deforestation on the hydrological cycle (e.g. replacement of rainforest by tea plantations in Kenya has had negligible impact on runoff or evapotranspiration, Pereira, 1973). However, even in more humid areas, under suitable geological conditions, devegetation can lead to serious soil erosion and gullying (Grove, 1951; Floyd, 1965 – Appendix 1). Devegetation in semi-arid environments has produced increases in runoff, flooding and siltation (e.g. the Rima basin, northern Nigeria, Ledger, 1961; the Niger River at Niamey, Delwaulle, 1973). Sharp increases in runoff and soil erosion are measured on cropped, and especially on bare (fallow) surfaces as compared with vegetated ground (Goudie, 1982, p. 128). Chevalier (1950) observed widespread lowered water tables, dried river beds and increased laterization over a 50 yr period, due to deforestation and over-cultivation. Deforestation affects the position of the water table. In elevated areas, the reduced water infiltration over a cleared surface lowers the water table, while increased stream flow expands seepage into the water table beneath the streambed, causing water levels to rise (as at Potiskum, Bornu Prov., N. Nigeria, Morgan and Pugh, 1969, p. 235). If deeper-rooted trees are cleared over permeable soils, infiltration may increase, thus raising the water table, whereas the reverse may occur over impermeable soils. Because of the heavier sediment load, intermittent streams may experience longer periods of reduced flow, as well as heavier floods. Anthropogenic vegetation disturbances therefore can produce effects similar to a climatic desiccation (so-called 'desertification'). It has been suggested that the devegatation-soil-hydrology feedback may be more important for surface properties than the albedo-precipitation (or temperature) feedback (Verstraete, 1981).

## 6. Summary and Conclusions

(1) Although the natural vegetation of West Africa has been modified during several thousand years of cultivation and livestock grazing, even more pronounced transformations have occurred since European colonization in the 1890's, largely attributable to the commercialization and expansion of agriculture and rapid population growth (Figure 3; Table IV). Estimates from forestry records (Tables I–III) suggest reductions in the closed forests of up to 70%, 64%, and 69% in Ivory Coast, Ghana and Liberia respectively, in this century. Data for these three countries are accurate to within 20%. For West Africa as a whole, comparison of the area of existing forest to that climatically capable of supporting forest implies a reduction of around 56% (Phillips, 1974; FAO, 1981; Matthews, 1983).

(2) Estimates of total land conversion range between 88 million ha (based on the digitized land use map, Figure 4), 114.9 million ha (from population statistics, Section 3.3) and 122.8 million ha (extrapolation of forestry data, Section 3.1). The mean of these three values is $108.6 \pm 18.2$ million ha.

(3) Anthropogenic vegetation changes have led to a fairly small increase in surface albedo of 0.4% over 100 yr and 0.5% cumulatively, with conservative estimates of desertification (Figures 5, 6, Table VIII, Cases 1–3). Under the extreme assumption of total desertification, the albedo changes increase to 4.3% and 4.4% respectively (Table VIII, Case 4).

(4) This study suggests that replacement of moist tropical forest by a combination of tree crops, field crops and secondary regrowth could yield a much lower albedo change than that commonly assumed in most climate modelling studies. Consequently, the anticipated climatic impact should be correspondingly less. The largest increase in albedo for any given $1° \times 1°$ cell was only 5.3% (Figure 5). The change in albedo for other cells was lower, due to a small change in land use intensity or to replacement of natural vegetation by crops of similar albedo (as in Western Senegal). Increases of up to 10% have been measured, locally, in more arid environments (Wendler and Eaton, 1983).

(5) Historical records show fluctuations in stream flow (Sircoulon, 1976; Faure and Gac, 1981) that correlate well with precipitation variations (Nicholson, 1980a; Palutikoff

*et al.*, 1981) but there has been no apparent regional secular decrease in precipitation such as predicted by several climate models (e.g. Charney, 1975; Chervin, 1979; Sud and Fennessy, 1982). On the other hand, human-induced devegetation has locally disrupted the hydrological cycle particularly in semi-arid environments (Ledger, 1961; Delwaulle, 1973; Chevalier, 1950; Morgan and Pugh, 1969, p. 235), leading to increased runoff, soil erosion, siltation and reduced water infiltration capacity. Anthropogenic vegetation disturbances therefore can mimic the effects of a climatic desiccation (so-called 'desertification'), by adversely affecting the soil hydrology. The reduction in soil moisture places plants under increased stress and makes them more vulnerable to natural periods of drought, which they might otherwise have survived. Thus, desertification is more likely the consequence of altered soil hydrology than of diminished precipitation, on the scale of a century or less.

(6) The new microenvironment resulting from disruption of the vegetation cover hinders reestablishment of vegetation and stabilization of soil. Thus, on a local scale, desertification is a circular process that feeds itself (Hare, 1983). On the other hand, this study has not found evidence for historical regional increases in albedo due to land-use changes on a scale likely to produce or intensify drought.

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## Appendix 2: Documentation of Deforestation History in Individual Countries

*Benin-Dahomey.*

Zon and Sparhawk (1923) reported a 50 mile wide coastal plan covered by around 1.12 million ha of dense, tropical forest. Forests also grew along river banks. The interior was described as an 'undulating plain with only occasional patches of forest, which contain baobab and coconut and oil palms'. Approximately 500 000 ha of equatorial forest were reported around 1930 (Ann. Stat. A.O.F., 1933/34) although according to Aubreville, (1937) the coastal forests of Benin had nearly all disappeared by 1937. By the 1970's, Persson (1977) reports 200 000 ha of closed forest (1971) and FAO (1981) only 47 000 ha – a large difference, yet clearly much reduced from the estimates of 50–60 yr ago. As much as 3/4 of the original woody vegetation is estimated to have been either cleared or converted to secondary formations or bare soil (FAO, 1981). The present deforestation rate is 3.2% $yr^{-1}$.

Deforestation has been more intensive in the south, where the majority of the population is concentrated. The salt industry and fishing degrade coastal mangroves. In the north, annual bush fires and overgrazing are gradually transforming around 65 000 ha of open forest and wooded savanna into shrub savanna, and agriculture consumes an additional 50 000 ha $yr^{-1}$ of savanna (FAO, 1981).

*Cameroon*

Vegetation zones in Cameroon range from dense rain forest along the coast, semi-deciduous forest in the south, sudano-guinean tree and shrub savanna and woodland in the middle, and sahelian tree and shrub steppe in the north (Letouzy, 1959).

Much of the original forest between 4° and 6° N has been replaced by a tree or shrub savanna, over centuries of shifting cultivation. Degradation of the natural vegetation and erosion are particularly marked around towns (Dshang, Mokolo, Maroua). Migrations have occurred since the late 19th century from the Bamenda highlands to Yaounde and coastal towns and plantations (e.g. Douala; Nelson *et al.* 1974). The lowland rainforest has been partially replaced by oil palms (Elaeis guineensis) around Yabassi, Diboum, Edea and Eseka, and by cultivation between Douala and Mbanga (Letouzy, 1959). Banana and coffee plantations supplant montane forests between Mbanga, Nkongsamba and Dschang. Development of new settlements, plantations and lumbering followed the extension of the railroad from Douala to Yaoundé in 1927, east to Belabo by 1969, and north to Ngaoundere in the 1970's, (Nelson *et al.*, 1974). Dry deciduous forest is being cleared in an E–W strip between Yaoundé and Bertoua, and north into Bafia and Foumbam and around towns such as Mbalmayo, Ebolowa, Sangmelima – south of Yaoundé; also NE of Bamenda and Bwam-Bertoua (Letouzy, 1959; FAO, 1981, Figure 3).

In the northern savanna zone, heavy overgrazing and fires related to cultivation, and collection of firewood are reducing thorny shrub savanna around larger towns such as Foumbam, Banyo, Ngaoundere, Maroua, Mokolo, Betare Oya–Garoua Boulai and Meiganga (Letouzy, 1959; FAO, 1981).

Forestry data for Cameroon are contradictory. Zon and Sparhawk (1923) report 10.1

million ha of 'virgin tropical rainforest' and 14.2 million ha of total 'forest land'. Haden-Guest *et al.* (1956) list 15.9 million ha in the wet forest zone, of which 13.1 are actual forest; and 27.3 million ha in the dry forest zone, of which only 12 million are forested, giving a total of 25.1 million ha of forest. Persson (1977) finds 17.5 million ha of closed forest and an additional 12.5 million ha of open woodland (total 30 million ha); while FAO (1981) reports 17.9 million ha of closed forest, 7.7 million ha open woodland and 9.5 million ha shrub savanna.

*Chad*

Historical accounts describe mature forests and dense, throny underbrush (Depierre and Gillet, 1971; Barth, 1857, Vol. I, pp. 271, 259, 201). Desiccation of lakes and rivers (Migeod, 1922) and abandonment of towns (Depierre and Gillet, 1971) may be a response to the early 20th century drought (Nicholson, 1980a). Nevertheless, vegetation is being degraded by cutting trees for firewood, clearing trees along river banks, thereby lowering the water table and drying streams, cattle overgrazing and trampling, and burning, which exposes the soil to erosion and destroys humus (Depierre and Gillet, 1971).

Expansion of agriculture is estimated to consume 80 000 ha $yr^{-1}$ at the expense of wooded savanna and open forest (FAO, 1981).

*Ghana (Gold Coast)*

A modest alteration and degradation of the rainforest began with the commercialization of the palm oil trade in the 1840's. However, a more systematic destruction coincided with the rapid spread of cocoa cultivation in the late 19th and early 20th centuries (Dickson, 1969). Cocoa was first cultivated along the Akwapim Ridge, SE Ghana, and spread west to Akim Abuakwa and Kumasi in the 1880's and 1890's (Hopkins, 1973, p. 216, Figure 3a). The cocoa belt gradually moved further west to the Brong-Ahafo district west-central Ghana, near the Ivory Coast border, between the 1920's and the mid-1950's (Morgan and Pugh, 1969, p. 525; White and Gleave, 1971, pp. 114–115, Figure 10).

The timber industry in the late 1880's affected Aowin, Western region, but exploited only a few species. Logging of the rainforests early this century occurred along the Pra, Ofin, Ankobra and Tano Rivers of SW Ghana (Wills, 1962, p. 213). In more recent years, timber extraction has centered around Goaso (west of Kumasi) and Wiawso (to the south) (White and Gleave, 1971, p. 158). Other areas of rapid clearing include the Akan district (Wills, 1962, p. 212), areas around towns like Asankrangwa, Sefwi-Jabeso, Debiso, along the Bia River tributaries and the Dormaa-Ahenkro-Berekum belt (east of Sunyani) in SW Ghana (Ahn, 1959). Forests near Kade (between Kumasi and Accra) and the Kwaho plateau, formerly more productive, have now been largely worked out (White and Gleave, 1971, p. 159). Other deforested areas of Ghana include the margins of the forest zone in NE and N. Ashanti, N and E of Afram Valley, the Krobo hills, the SW Akwapim Range to Accra and south of the closed forest zone of the Volta region (Wills, 1962, p. 230) (Figure 3). Forests were also cleared for mining, and building of railroads and highways.

Zon and Sparhawk (1923) list 9.87 million ha of *total* forestland, which is probably an underestimate. The Annual Reports of the Forestry Department indicate that closed forests have decreased from 4.79 million ha in 1937/38 to 2.21 million in 1968; and open woodlands went from 11.11 million ha to 9.71 million during this period. By the 1970's Persson (1977) reports only 1.8 million ha of closed forest left and FAO (1981) show as little as 1.72 million ha (Table II). Open woodlands declined from around 10 million ha in the 1970's to 6.98 million ha by 1980 (Table II). These figures imply a 64% areal reduction of closed forest and a 37% decrease of open woodlands within the last 40 yr. (See also maps in Charter, 1953 and Chipp, 1922; Appendix 1).

Virtually no virgin forest remains. Rain forest has been degraded by gold and manganese mining particularly along the Ankobra and Ofin rivers, and around Tarkwa (Map III, in Birmingham *et al.*, 1966). The moist semi-deciduous forests have been largely modified by cocoa plantations and farming. In the drier northern interior, periodic fires have enabled 'derived woodland savanna' to encroach into forest. Open broad leaved forests (wooded savanna) occupy the northern 2/3 of the country. Deforestation of closed forests is estimated at 27 000 ha $yr^{-1}$ (1976–1980), somewhat less than the 45 000 ha $yr^{-1}$ prior to 1976 (FAO, 1981).

*Ivory Coast*

Ivory Coast has two major vegetation zones: the zone of open (dry) forest and guinean wooded savanna in the north, and closed tropical moist forest in the south, separated by a transitional forest-savanna mosaic. Savannas penetrate south in a pronounced salient near Bouaké, in Central Ivory Coast.

Exploitation of the forests for timber and introduction of commercial crops began in the 1890's, along the coast and gradually penetrated deeper into the interior along major rivers. Roads built for the lumber industry made the interior accessible, attracting peasants who cleared more land for shifting agriculture. However, the rate of deforestation due to lumbering increased rapidly after 1958; initially localized around southern lagoons, but gradually expanding northeastward. After 1960, a pioneer front developed in the center-west, and after 1970 to the southwest. Today, the forest resources around Abidjan have been largely exhausted (Arnaud *et al.*, 1978). However, clearings for agriculture have destroyed much more of the tropical forest than lumbering. At the beginning of the colonial era (1890–1900), closed forests covered an estimated 15 million ha (including 0.5 million ha of dense dry (deciduous?) forests (FAO, 1981). The dense, closed forest measured some 12–13 million ha, 50–60 yr ago (Zon and Sparhawk, 1923; Ann. Stat. A.O.F., 1933/34). Even then, deforestation was occurring around Koun to Bondoukou, Bouaflé, Bouaké, Daloa, and Man, and between Dbou, Port-Bouet and Grand Bassam along the coast (Begué, 1937; Aubréville, 1932). By 1965/66, the dense forest area had decreased to around 9 million ha (FAO, 1967; Persson, 1977 (the figure refers to 1966); FAO, 1981). By 1980, only 4.5 million ha were left (including 4 million ha, moist rainforest; FAO, 1981; Table I). Thus the area of closed forests decreased by 70% over the last 80 yr, or an average of 0.9% $yr^{-1}$. However, the rate of deforestation has accelerated from around 54 500 ha $yr^{-1}$ between 1900 and 1955, to 280 000 ha $yr^{-1}$ between 1966 and 1973; 350 000 ha $yr^{-1}$ from 1966–1973, and 315 000 ha $yr^{-1}$, 1974–1980 FAO, 1981, Table I. In the last 15 yr, a large migration has occurred into the west-central region (Daloa-Issia-Gagnoa-Bouaflé) where coffee and cocoa cultivation is being rapidly expanded, and into the southwest since 1970.

*Liberia*

Liberia was once entirely forested. Coastal savannas were probably once covered by closed high forests; and northern grass-woodland savanna by semi-deciduous forests; both types of savanna have probably formed by anthropogenic degradation of the original vegetation (Von Gnielinski; 1972). Species composition and human artifacts suggest that much of the existing high forest in Liberia is mature secondary growth (FAO, 1981).

The second wave of deforestation began early this century, as logging roads opened the interior to shifting cultivators. Liberia had around 6.5 million ha of forest land in 1920, mostly dense, tropical forests (Zon and Sparhawk, 1923). By the late 1940's, forest fallow covered around 4.1 million ha, leaving around 7 million ha in forest, roughly the same as the 1920 estimate. But by 1950, closed forests occupied around 5.5 million ha (Haden-Guest *et al.*, 1956) and by the late 1970's, the closed forest area had decreased to 2.0–2.5 million ha (Persson, 1977; FAO, 1981), or a 59% reduction over 60 yr. Forest fallow estimated at 4.1 million ha in the 1940's, now occupies 5.5 million ha. Deforestation rates, around 20 000 ha $yr^{-1}$ of closed forests in the 1940's, now have doubled to 41 000 ha $yr^{-1}$ (FAO, 1981).

*Mali*

Mali lies partly in the Sudanian zone (south) and partly in the Sahel (north). The natural climax vegetation of the Sudan zone should be an open woodland (forêt claire), with shrub or bush undergrowth, but centuries of shifting cultivation and repeated burning have degraded this to a wooded savanna (Jaeger, 1960). Recently, this fire climax is being further degraded by additional clearing for cultivation. The tree cover becomes more sparse, and grasses extend their range. Denudation and soil impoverishment are particularly acute around major towns like Kayes, Bamako, Kenieba, and the hills near Guenou Gore (Jaeger, 1960).

Growth of the arable land from 1.65 million ha in 1961–65 to 2.05 million ha in 1978 has led to an annual deforestation rate (closed forests) of 27–30 000 ha. Another 5000 ha are destroyed annually for firewood. Altogether, up to 40 000 ha $yr^{-1}$ are lost to various causes (FAO, 1981). Although degradation of forests is not serious in southern Mali, it is acute around urban areas and especially in the Sahelian zone, due to the recent drought and overgrazing.

*Mauritania*

The vegetation zonation of Mauritania follows the increasing degree of aridity from south to north. The Senegal River Valley is surrounded by woodlands dominated by Acacia nilotica and other acacia species. The Sahelian zone extends to around 18° N, to the 150 mm isohyet. North of that lies the Sahara desert (Toupet and La Clarère, 1977).

Establishment of French rule in the early 20th century encouraged immigration by many farmers and herders from the south. Cattle population growth exceeded that of the human population (between 1959 and 1968, cattle increased from 1.25 million head to 2.3 million, while during this period, the human population increased by only 170 000). These increases have led to severe overgrazing. Cropland has increased by 78 000 ha between 1930–1980 (IIA, 1939; FAO Prod. Yearbook, 1980). In recent decades, wooded areas have been cut to provide firewood and more grazing land, and many once common wild edible plants have become nearly extinct (Gritzner, 1979). Further reductions in vegetation occurred during the 1970's drought (Toupet and Laclarère, 1977).

*Niger*

The natural vegetation of Niger has been largely modified by human activity and reflects only imperfectly the initial climax (FAO, 1981). H. Barth (1857) described the region along the Niger/Nigeria border as relatively forested in between major towns. But by the 1930's, Aubréville (1936) already noted the deforestation that accompanied clearing for agriculture in populated areas such as the Niger Valley, the larger dallols (fossil river valleys), Adar Doutchi Valley and the area between Madaoua and Birnin n'Konni, Maradi and Tahoua. Yet further north, between Tessaoua and Agadez, there was still relatively little degradation in spite of grazing (Aubréville, 1936).

Partly as a result of French military pacification, herders and farmers migrated to southern Niger from adjacent northern Nigeria. Nearby rail transportation (Kano, Nigeria) to the south also promoted the expansion of commercial agriculture (peanuts, cotton), esp. after the 1930's, and also of the cattle industry (Baier, 1980; Dresh, 1959). The rapid increase in cattle population put pressure on the natural vegetation. Yet, prior to the 1970's drought, severe overgrazing and trampling were confined to a radius of 8–12 km, around larger wells and boreholes. The drought led to a serious decline in annual grasses (particularly desirable species), and heavy losses of perennial trees and shrubs such as Commiphora africana and Acacias (Mabbutt and Floret, 1980, Atlas du Niger, 1980). Although the regrowth on bare, denuded soil is slow, in some areas there has been relatively rapid regeneration of Acacia Senegal.

The population of Niger has grown from an estimated 1.7 million in 1920 to 5.3 million in 1980 (Atlas du Niger, 1980). The cultivated area (excluding fallow) increased from 945 000 ha in 1930 (IIA; 1939) to 3.29 million ha in 1977 (FAO Prod. Yearbook, 1980). But much of this expansion has occurred since the 1960's. Between 1961 and 1978, around 75 000 ha $yr^{-1}$ of savanna woodland have been converted to fields. An additional 5000 ha $yr^{-1}$ of woodland is consumed for firewood, giving an approximate deforestation rate of around 80 000 ha $yr^{-1}$ (FAO, 1981).

*Nigeria*

Vegetation zones of Nigeria include coastal mangrove, freshwater swamps, rainforest, derived savanna, Guinea and Sudan savanna and the Sahel zone in the NE corner of the country (Keay, 1959; Rosevear, 1953).

Closed forest occupied some 11.3 million ha in 1920 (Zon and Sparhawk, 1923). The Nigeria Handbook (1929) lists around 14.5 million ha. The rainforests of Abeokuta province, western Nigeria, were largely cleared by 1920 but good forests still remained in

Ondo province. Only 1.81 million ha of high forest remained in the southern provinces of Nigeria by 1920. An estimated 7.25 million ha or nearly 3/4 had been cleared in the preceding 14 yr (Unwin, 1920). By the late 1940's, the total closed forest was down to around 7 million ha (Info. in respect of Nigeria, 1947/48), although Haden-Guest *et al.* (1956) list 4.1 million ha by 1950. Logging cleared large forest tracts in Western Nigeria in the late 1950's, and eastern region forests in the early 1960's. More recently, the main zones of extraction lie south of the 'cocoa crescent', and along the Ijebu-Ode-Benin road and in the Niger Delta (White and Gleave, 1971, pp. 158–159; Adeyojo, 1965). By the late 1970's, closed forests covered an estimated 4.5–5.95 million ha.

Much of the deforestation was caused by introduction and expansion of commercial agriculture, largely tree crops, in addition to lumbering. By the 1840's, external trade had developed in palm oil and kernels, centered originally along the Niger Delta at New Calabar and Bonny on the coast (Morgan and Pugh, 1969, p. 402). By the late 19th century rainforest was largely replaced by oil palm groves. Large tracts of virgin rainforest were cleared at the beginning of the 20th century in Ife and Ondo provinces (SE Nigeria), for timber, rubber and cocoa plantations (Morgan, 1959). The rubber industry began in 1893 near Lagos, replacing oil palm, but was succeeded by cocoa plantations, especially near Ilaro and Ibadan. With declining productivity and the growth of transportation, cocoa areas moved further east and southeast from Ibadan to Ife, Ilesha, Owo, Ondo, and Akure (Figure 3, Morgan and Pugh, pp. 439–40, 475, 525; Agboola, 1979). However, the oil palm region of Onitsha-Owerri-Rivers has remained fairly stable in area since 1900 (Morgan and Pugh, 1969, p. 525). Clearance of primary or mature secondary rainforest and a population shift into formerly little occupied territory accompanied this expansion (Morgan and Pugh, pp. 474, 525; Morgan, 1959).

In intensely farmed areas, such as in Kabba province and around Ibadan, 'derived savanna' has replaced rainforest (Clayton, 1958, 1961). In the 1870's, rainforest still existed near Ibadan, but by 1903, only remnants were left (Adeyoju, 1965). However, the forest/savanna boundary now is relatively stable or changes only gradually, north and west of Ibadan (Moss and Morgan, 1977).

The central Nigerian Guinean zone remained less economically developed, and more traditional agriculture persisted there (Morgan, 1959). However, grassy vegetation has replaced the original open savanna woodland on the Jos plateau, over centuries of farming and overgrazing. Mining since European occupation has caused further deforestation (Adeyoju, 1975; Morgan and Pugh, 1969, pp. 283–284; Church, 1974, p. 69). Since British occupation, many farmers who had formerly fled into the hills have resettled on the plains, so that new areas are being cleared, as in the Kauru Hills.

Clearing of forests for farming between Awka, Enugu, and Nsukka (SE Nigeria) has accelerated natural processes of gullying along escarpments, especially after 1920 (Grove, 1951; Floyd, 1965; Ofomata, 1965). Soil erosion is also prevalent in the drier, middle and northern agricultural belts (Stamp, 1938). Local remobilization of fixed sand dunes by removal of the protective vegetation cover for farming near Katsina led Stebbin (1935) to believe that the Sahara was advancing southward. Soil erosion, flooding and gullying have increased on upper reaches of the Rima river (tributary of Niger, near Sokoto), and siltation, aggradation occur further downstream near the confluence with the Niger (Ledger, 1961). These problems have intensified within the last 60 yr, during which period there has been no discernible shift in climate.

In northern Nigeria, growth of agriculture, especially around major towns (Sokoto, Katsina, Kano) and increased sedentarization of nomads together with a rapid increase in cattle population and limited grazing lands has led to deforestation and has aggravated erosion there (Frantz, 1975). The area surrounding Kano, northern Nigeria, in the heart of the peanut-growing district, was fairly closely settled even in the last century (Barth, 1857), but has become even more densely populated within the last 60 years (Morgan and Pugh, p. 362).

The Kano close-settled zone has a population density of over 350 mile$^{-2}$, one of the densest in West Africa (Hill, 1977). Almost all land is under cultivation, and forest formerly occupying no-man's land between major towns (e.g. Kano-Katsina, or Katsina-Gazawa) as described by Barth (1857) are either destroyed or considerably reduced in area (Morgan and Pugh, 1969, p. 368). Between 1911 and 1937, 400 000 ha were brought under cultivation for peanuts (Helleiner, 1966). By 1960, 647 500 ha had been planted for peanuts in northern Nigeria (Helleiner, p. 107–111).

The total area of forests, in 1980, including disturbed land and tree crops, is estimated at around 5.95 million ha (FAO, 1981). Most remaining closed moist forest lies in reserves. Reserves cover 2.3 million ha in the moist forest and derived savanna, of which 1.64 million are still forested; the balance consists of forest fallow (370 000 ha), plantations (180 000 ha) or savanna (FAO, 1981). Secondary growth occupying extensive areas include oil palm and rubber forests, in blocks or intermixed with other trees (1.27 and 9.56 million ha respectively in 1976). Woodlands and shrubland, including fallow, cover some 50.6 million ha or ~55% of the country, in the Guinean, Sudanian and Sahelian zones. Annual deforestation of closed forest runs to 285 000 ha; and ~92 000 ha yr$^{-1}$ in woodlands (FAO, 1981).

*Senegal*

Vegetation zones include (1) the *Sahelian* zone to the north of the 550 mm isohyet, (2) the *Sudanian*, occupying nearly 2/3 of the country, between the Sahelian zone to its north and the Guinean zone; (3) the *Guinean* zone, southwest of the line Banjul (Gambia)-Kolda (on the Casamance R) lying between the 1250– 1700 mm isohyets.

Until quite recently, there have been no reliable figures for areas of different vegetation types. Zon and Sparhawk (1920) report 384 450 ha of 'forest land'. Persson (1977) lists 220 000 ha of closed forest, including mangrove and bamboo, plus an additional 200 000 ha of dry, dense forest in the Casamance region; and 5.1 million ha of open woodland (including scrub and brush). The latest FAO estimates report 220 000 ha of closed forest (including mangrove and gallery forest); 10.83 million ha of 'open' formations including 2.81 million ha of open woodland and wooded savannas, and 8.06 million ha of tree savannas, and 1.37 million ha of shrub and steppe (FAO, 1981, 1981).

The population of Senegal has increased from around 1 million in 1900 to 5.66 million in 1980. Most of the population was concentrated near the coast between Dakar-Cap

Vert-Thies-Diourbel, and has expanded south toward Kaolack and east toward Tambacounda, and south in the Casamance. Additional growth occurred between Kaedi and Bakel along the Senegal River (Atlas du Sénégal, 1977, plate 31). The area under cultivation has expanded along with the population growth. Permanent cropland went from 1.35 million ha in 1930 (IIA, 1939) to 2.54 million in 1976 (Sénégal en Chiffres, 1978), or an increase of 1.19 million ha. Most of this growth, particularly for peanut cultivation has taken place in a zone east of the line Kaolack-Diourbel-Sagata, extending to Linguere-Kaffrine, and as far southeast as Tambacounda. Subsidiary areas have opened around Sehiou and Kolda in the Casamance (Atlas du Sénégal, 1977, plate 37).

The agricultural expansion has impacted the natural vegetation, particularly in the sudano-sahelian zones (Figure 3). The climax vegetation in the new agricultural lands was once probably a xerophile open forest (forêt claire) transformed over the centuries into a tree savanna. In the peanut belt (centered between Kaolack-Kaffrine-Diourbel-Thies), the pseudoclimax which characterized the region at the end of the 19th century has largely disappeared, and the forest land there has been reduced to a mere 25 000 ha. Only trees protected by the farmers survive (Acacia albeda, baobab, degraded stands of Acacia Seyal). In the saline terrain of Sine-Saloum, mangroves survive only along the estuary. In the Sahelian zone, 24 800 ha of forest have been reserved along the Senegal River, but elsewhere, farmers have cut the Acacia nilotica forests. Clearing of wooded savanna for new agricultural land is estimated to remove 40 000 ha $yr^{-1}$ (FAO, 1981).

*Sierra Leone*

Most of Sierra Leone was formerly covered by evergreen and semi-deciduous forest, while a belt of moist savanna woodland extended to the north. Mangrove swamps form along coastal estuaries and freshwater swamps grow further inland. Grasslands develop on lateritic hardpans and along certain river valleys (Clark, 1966; Kaplan *et al.*, 1976). Lumbering, farming and burning have considerably modified the natural vegetation, so that the prevailing land cover of the former forest zone is a mixture of secondary forest, forest-savanna mosaic and 'farm-bush' – land subject to the bush-fallowing system, which now occupies most of southern Sierra Leone. Even the secondary forest is being reduced rapidly as fallow periods are shortened. Repeated burning is degrading the savanna woodland into an open, scattered tree savanna. Closed forest occupies no more than 4% of the total area since at least the 1930's (Table III). Closed forest (FAO, 1981) covers 740 000 ha, but includes an unspecified amount of secondary forest regrowth. Mixed forest/grassland covers around 1 315 000 ha and fallow totals 4 275 000 ha. Deforestation rates average around 5800 ha $yr^{-1}$ (FAO, 1981).

The widespread deforestation of Sierra Leone began with the settlement of Freetown and environs in the early 19th century (Dorward and Payne, 1975). Logging for teak and other hardwoods began along the rivers of northern Sierra Leone, and expanded southward by the 1840's. Oil palms replaced much of the original forest. However, the interior of the country remained largely forested until early in this century. For example, in 1912, the country between Mongeri and Magburaka (37 miles apart) was described as being 'densely wooded', the nearby mountains were 'densely clothed in thick forest'. But by

1947, the mountains were bare and the plains were largely grassland with only patches of secondary thickets (Dorward and Payne, 1975). Around 1900, the area between Songo and Moyamba was still forested; by 1920, it had been reduced to low scrub (Sierra Leone Report 1921, Annual Colonial Reports No. 1150). The Lower Rokel basin, where timbering began, is now a mixture of grassland and savanna woodland (Dorward and Payne, 1975).

Coastal mangroves have been cleared for rice production, starting near the Great and Little Scarcies Rivers in 1880. Clearing of mangrove swamps intensified after the 1930's, partly to compensate for the severe soil erosion in upland rice areas. By 1964–1965, 61 500 ha of mangroves were planted for swamp rice, as compared with 238 800 ha in upland rice (Kaplan *et al.*, 1976). (Figure 3).

*Togo*

Southern coastal Togo was covered, until probably as recently as the last century, by a dense xerophile (dry) deciduous forest, now largely an anthropogenic landscape of oil palms, crops and secondary bush (Aubréville, 1937). The wetter parts of the Guinean zone were densely wooded, esp. between Bassila and Sokode. These forests, along rivers, ridges or on moist clayey soil, may be relicts of a formerly wetter climate and are therefore more vulnerable to anthropogenic fires. Highland forests were once continuous between Adele, Litime and Palime in the west, to Atakpame (central Togo), but have been largely replaced by agricultural clearings and wooded and grassy savanna (Aubréville, 1937).

Wooded savanna covers around 60% of the land area, including degraded vegetation (FAO, 1981). Northernmost Togo is relatively dry (Sudanian zone), but also supports a large pastoral and agricultural population, which tends to preserve only useful trees.

Estimates of natural vegetation cover are inconsistent. Zon and Sparhawk (1923) report 137 595 ha of 'forest land', of which 60 704 are 'virgin forest', and 76 891 ha occur along river banks. Between 2 849 000–3 108 000 ha are agricultural (including oil palm bush). The balance is said to be steppe and 'scattered, scrubby trees'. Persson (1977) lists 380 000 ha of closed forest, 70 000 ha of dense, dry forest, 3 million ha of open woodland (savanna?) and 115 000 ha of scrub and brushland (mostly secondary growth). FAO (1981) indicates 304 000 ha of closed forest, 1.28 million ha of mixed forest/savanna, 1.45 million ha of bush fallow and 2.27 million ha of shrub. Deforestation averages around 2000 ha $yr^{-1}$.

*Upper Volta*

The vegetation of Upper Volta exhibits a latitudinal zonation ranging from Sudano-Guinean wooded savanna in the south to Sahelian steppe in the north (Atlas de la Haute-Volta, 1977). Relict 'islands' of dense, dry closed forest occur – these may have constituted the climax vegetation or are relicts of a moister climate. However, most of the vegetation is open woodland or wooded savanna (savanna, grassland) and degraded secondary formations (wooded or shrub savanna) of anthropogenic origin occur in regions of dense population, such as the Mossi Plateau (central U.V.).

Areal estimates of vegetation cover are very sketchy. Dense forests probably occupy no more than 100 to 150 000 ha. Open forest and tree savanna may include 890 000 ha. All savanna formations occupy around 7 200 000 ha and shrub formations another 3 million ha. Deforestation is estimated to affect 60 000 ha $yr^{-1}$, corresponding mainly to the growth of agriculture (FAO, 1981).

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