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A STUDY OF THE
PLANT ECOLOGY
OF THE
COAST REGION
OF KENYA COLONY
BRITISH EAST AFRICA

by
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A Study of the Plant Ecology of the Coastal Region of Kenya Colony, British East Africa

INTRODUCTION

At the request of the Kenya Department of Agriculture through the East Africa Agriculture and Forestry Research Organization, an ecological study of the coastal regions of Kenya was undertaken. The study was supported by funds from the United States International Educational Exchange Service (Department of State) and from the Kenya Department of Agriculture (Ministry of Agriculture, Animal Husbandry and Water Resources).

The purpose of the study was to delineate major vegetation, soil and climatic types and to study their composition, structure, and succession using quantitative ecological methods. From these basic ecologic data and their relationships, an assessment was made of the land-use potential of the principal types and of the present cropping practices, along with recommendations for further research and for the direction which future development might take.

In a sense the ecological study of the coast was undertaken prematurely. Since good taxonomy is prerequisite to good ecology, a thorough study of the vegetation distribution in relation to any of the environmental variables assumes that the identity of most of the plants is known and readily available. In the case of the Kenya coast and the Colony as a whole, for that matter, there is a dearth of published information of a general taxonomic nature. The flora of East Tropical Africa is slowly coming into being but is not yet approaching the stage where it can be called useful and it must wait on the time and energy of botanists in Kew Gardens. A "flora" for the area does not exist but must be substituted by a check list prepared for Tanganyika Territory (Brenan and Greenway, 1949) which deals only with the woody plants and does not contain keys for identification. The grasses are better treated by the new *Revised List of Kenya Grasses* by A. V. Bogdan (1958) but this volume is admittedly incomplete. The woody vegetation of Kenya is soon to be treated in a revision of the old Battiscombe (1939) list by Dale and Greenway but will be a semi-popular book and again incomplete although keys for identification will be included. The training of any substantial numbers of people to a familiarity with the native vegetation cannot be done by herbarium identification of specimens especially with a small staff. The training of agricultural, veterinary, and tsetse control officers in the principals of wild land ecology will be both speeded and improved by publication of complete taxonomic manuals at an early date.

The nature of the knowledge of the coastal vegetation can be judged by the fact that of somewhat more than a thousand collections of mostly dominant or important secondary and weedy plants, at least three were new

to science or at least not previously described, several were known previously only from the type specimens, and about ten were new records for Kenya, including an important understory tree in one of the forest stands.

More than 10,000 miles were covered by Land-Rover making the collections of plants and soils, taking photographs, and making counts, clippings and measurements of plants in selected areas. The information collected will probably not be completely analyzed and published for some time but the main outlines of the vegetation, soils, and land-use information will be presented here.

In practice, several concessions were made with respect to methods and scope of the project because of the limited time available for study and the size of the area involved. It was deemed wise to concentrate the research effort in the areas of higher rainfall within 20 miles of the coast and in the southern portion of the 20-mile strip. Although the Lamu-Witu areas east of the Tana River have rainfall adequate for intensive cultivation, the coast north of Malindi is drier and more sparsely populated and was given only brief attention. Difficult access also limited the time for study in the northern areas more so than in the south since the Tana could not be crossed when in flood. The most serious impediment to the work, other than the enervating effect of the climate, proved to be the size, diversity and unfamiliarity of the flora. While this had been anticipated to some degree, it was found that the plant communities ranged from the rain forest flora of the Usambara Mountains in Tanganyika to components of the flora of the Somalia desert with several intermediate and specialized habitats to add to the complexity.

ACKNOWLEDGEMENTS

Liberal use was made of the help offered by well qualified agricultural officers and botanists in and out of government service. Thanks are due to Dr. E. W. Russell, Director of the East African Agriculture and Forestry Research Organization and to Mr. C. G. Trapnell, ecologist, for initial planning and arrangements and for help with classification in the final phases. The library and laboratory facilities of the E.A.A.F.R.O. station at Muguga were frequently used. The staff of the East African Herbarium generously supplied time and space for identification of more than 1,000 plant specimens. Dr. Bernard Verdcourt, Miss Diane Napper and Dr. P. J. Greenway were most helpful, as was Mr. J. Newbold.

The Kenya Department of Agriculture under the direction of Mr. R. J. M. Swynnerton kindly supplied transport, housing and a generous vote for local transport. L. H. Brown, Deputy Director of Agriculture, was especially helpful with administrative details as well as with suggestions concerning the ecology; R. Melville, Chief Research Officer, was responsible for making available the facilities of Scott Agricultural Laboratories and Mr. E. Bellis supervised the chemical analyzes of soil samples. The author is especially

grateful to Mr. R. H. Bennison, agricultural officer (L.H.P.) in charge of the Coast Investigational Station, Matuga, for innumerable amenities and assistance in the daily prosecution of the research as well as for highly competent local knowledge of the ecology and botany of the Coast Province. The agricultural officers at Matuga and in the Districts at Kwale, Kilifi, Malindi, Kaloleni, and Lamu (ALDEV) gave freely of their time and provided valuable information from Agriculture files which are not all cited. The Provincial Agricultural Officer, Mr. E. C. M. Green, gave valuable assistance both in his administrative capacity and from his detailed knowledge of tropical agriculture and long experience in Kenya. Free use was made of Agriculture Department information, as is mentioned above, especially the District Gazetteers and current research results.

Valuable help was obtained from personnel in other Government departments principally the Department of Veterinary Services, Tsetse Survey and Control Branch, and the Department of Forests. E. C. Trump and J. G. LeRoux of the former department were especially informative and in the latter, Mr. Bookless, the Kwale District Forester, rangers and guards were most co-operative as was Mr. J. A. Pereira, assistant forest officer in charge of the Jilore Forest Station.

Aerial photograph cover of several areas on the coast was furnished by the Survey of Kenya.

Dr. James Thorp, soil scientist with the I.C.A. team in Kenya, was kind enough to spend a day on *safari* to explain some of the coastal soil types and Mr. Ralph Scott at E.A.A.F.R.O. was also a source of enlightenment at an earlier stage.

Many private individuals in Kenya, especially Mr. S. P. Rawlins at Malindi, proved to be most helpful and generous with valuable information. Finally, to my wife, Carolyn, for her many miles and hours of work and companionship, in note-taking and labelling, organizing and packing, goes my gratitude and much of the responsibility for whatever success the Kenya tour may have had.

HISTORY

The long history of settlement and cultivation on the eastern coast of Africa has a direct bearing on the distribution of the present vegetation. The coast was known to the ancient civilizations of Egypt, Phoenecia, and Greece (Reusch, 1954) principally for its exports of slaves, ivory, and precious metals but also partly for agricultural produce and natural products (probably mostly gum arabic, gum copal, myrrh and perhaps timber), some of which came from the interior and some directly from the coastal lands and forests. The earliest peoples were mostly Bantu and Nilotic tribes that were hunters, gatherers, and later pastoral peoples. A later development still was the relatively settled process of shifting cultivation which is still practiced. These peoples migrated and fought their way back and forth along the coast being

alternately mixed with or killed by the Zulu and Masai from the south and west and the Galla and Somals in the north until the later Arab, Portuguese, and British domination led to the present stable distribution. The south coast is now occupied by the Digo tribe and the coast hinterland from Mombasa to Malindi by Giriama and Swahili peoples. Beyond the Mambui area, there are the smaller tribes of Bajun, Boni and Sanya (Galla), while in the south there are locations of Duruma, Kamba, and Rabai, the latter being really a part of the Giriama tribe.

Beginning in about A.D. 900, the coast was occupied by a succession of Arabian sultans of the Shirazian sect of Islam presumably exiled by or fugitive from the wars and intrigue that divided Islam after the death of Mohammed. These imperialists built a series of stone towns and ports which were loosely federated by blood relationships into the "Zenj Empire" which stretched from Kilwa in Tanganyika to what is now Mogadishu. These Arab city-states thrived on trading by sea and were mainly interested in slaves, ivory and gold but records indicate that grains, timber and fibres may have played a part in the economy. By the time of Vasco da Gama's first visit in 1493, the sultanates had begun to break up and many of the stone towns were abandoned either because the inhabitants were killed and/or eaten by Galla or other raiders from the interior, or because changes in the water table supply caused the wells to become salt or dry. Both theories have adherents and good evidence but lack conclusive proof. The city of Gede is only one of a dozen or more ruined stone towns along the East African coast that bear testimony to the power of the Sultan of Kilwa. It is known that at the same time there were traders and settlement by Chinese, Abyssinians, Persians and possibly Malaysians.

The time of decline of the Shirazian sultanates coincided with the approximate peak of the slave trade and the control of the coastal lands, at least nominally, by the Portuguese. Portuguese power was never strong and in the early eighteenth century Arabs from Oman drove them out and in 1832 established the Zanzibar Sultanate.

From 1650 until late in the nineteenth century, slavery and the slave trade were the major economic factors in the development of the lands on the Kenya coast when approximately 100,000 Africans were shipped each year from Bagamoyo, Zanzibar, Malindi, Lamu, etc., to supply the plantation labour in the Americas. This was probably a period of extensive cultivation to supply food for the large transient population as well as for an export commodity. In the vicinity of Lamu, Patterson (1955) has calculated that some 27,000 acres of cultivation were required to supply the produce for the presumed population of the city and its slaves. Fitzgerald (1898) states that cultivation in the Malindi area declined rapidly after the Anti-Slavery Decree of the Sultan of Zanzibar in 1890.

From 1887 until 1895 the Imperial British East Africa Company operated the coastal regions under a lease from the Sultan of Zanzibar when

Government took over from the company and Kenya became a Crown Colony. The Mombasa to Kisumu railroad was completed in 1901 and Tanganyika became a British Mandated Territory after the First World War.

The Coastal Strip is still formally the Zanzibar Protectorate for which an annual rental is paid to the Sultan of Zanzibar.

GEOLOGY

The geology of the south coastal area has been fully covered in a series of four reports by the Geological Survey of Kenya (Caswell, 1953, 1956; Miller, 1952; Thompson, 1956) with reports for the northern areas soon to be published. The major ecological interest in the coastal geology centres on the soils derived from the wide variety of parent materials afforded. The major geologic materials are deposited or exposed in bands parallel with the beach and also parallel with the principal physiographic regions so that the effects of geology and orographic rainfall tend to reinforce each other. The result is, in some cases, to produce very well defined habitats and communities but to render the etiology of their formation considerably more difficult.

Physiography

Physiographically, the coast is divided into four major components:—

- I—Coastal Plain.
- II—Foot Plateau.
- III—Coast Range.
- IV—Nyika.

I. The Coastal Plain varies in width from two to five miles and consists of pleistocene deposits of corals and sands. The Coastal Plain lies generally below the 100-ft. contour and displays a series of old, flat-bedded coral reefs formed at different eustatic levels, and their associated lagoonal deposits of coral breccia, calcareous sands and beach sands. The reef is backed by a series of variable sands which may be lagoonal, aeolian or alluvial in origin, but which form a complex pattern of derived soil types. To the north of the Sabaki River and in places near the mouth of the Tana River, true dune sand formations occur but are of limited extent. Much of what has been called "lagoonal" sand appears to be derived from windblown deposits or to be alluvial material from the higher Foot Plateau and Range as is pointed out only in the Malindi area by Thompson (1956).

II. The Foot Plateau, lying between 200 and 450 ft., is based on marine shales, mudstones and limestone of Jurassic age. The Jurassic shales are exposed only in the area between Kilifi Creek and a point just east of Kwale, where the shale soils derived from them support an arid type of vegetation because of the low moisture permeability and infiltration rate. In the north the Kambe limestone soils of the same relative age are among the most fertile natural soils on the coast and are deep permeable loamy soils. Accentuating

the eastern edge of the plateau and rising abruptly from the plain is the low ridge of the Pliocene Magarini sands. The ridge of Magarini sands is found at intervals throughout the entire length of the coast. In the south, near the Tanganyika border, it is very low and spread out and abuts directly on the Duruma sandstone series of the Nyika. The Maraginis appear, interrupted only by the major creeks and rivers, also nearly at the Somaliland border where they form the "Mundane Range". Between the Sabaki and Tana Rivers it forms only a wide, low, intermittent ridge of dark reddish soil.

III. Behind the Foot Plateau, another abrupt rise takes one up on to the Coast Range. It occurs only intermittently and largely south of Kilifi Creek, except for Mangea Hill, and is best represented by the horst-like Shimba Hills in Kwale District. These hills consist of Mazeras sandstone capped with a layer of Shimba grits at a more or less uniform 1,200 to 1,300 ft. South of the Shimba Hills, the intrusive igneous cones of Jombo and Mrima Hills were once covered to the same level, although of different geologic origin. In the north, toward the Jibana and Chonyi heights, the range is composed of Mazeras sandstone which produces a lighter soil than that derived from the Shimba grits.

IV. The Nyika occupies the lower lying ground to the west of the Coast Range beginning at about 600 ft. at the eastern edge and gradually rising to 1,000 ft. or more many miles westward. The Nyika soils and vegetation are developed on the Duruma sandstone series which is correlated with the great Karoo system of South and Central Africa, and which is subdivided into bands of exposure from east to west. The "upper" component is the Mazeras sandstone and Shimba grit, followed by the "middle" Mariakani sandstones and Maji-ya-Chumvi beds, and finally the "lower" Taru grits beginning about at Samburu and continuing westward. Beyond these and underlying the whole is the Basement System of gneisses and schists.

Drainage and Hydrology

The major drainage of the region follows the general dip towards the east-south-east with a secondary trend at right angles where the eastward flow is prevented by the height of the Coast Range. The Tana River rises on the north slopes of Mount Kenya and flows for 300 miles through the very arid Northern Frontier Province before entering the Indian Ocean near Kipini. Its flow is dependent on rains in the Highlands but it is a permanent water course and provides water transportation as well as irrigation water for a short distance on the east bank in the Coast Province. The Sabaki (or Galana) River drains the south slopes of Mount Kenya, the north of Kilimanjaro, and the Taita Hills. It is the Athi River of the Nairobi-Machakos area, and is the only other major drainage of the eastern half of the Colony. As with the Tana, the Sabaki gradient is very low in the coastal area and the yearly flooding supplies great quantities of alluvium along its meandering course and is a source of irrigation water on a small scale for part of the year.

The Ramisi River rises in the coast hinterland and probably gets some water at times from the Usambara Mountains and from Kilimanjaro. It flows most of the year and provides irrigation for the Ramisi Sugar Estates. The Voi River reaches Kilifi Creek only in times of exceptional flood, and the others, Uмба, Mwachi, Maji-ya-Chumvi, Manolo, Kombeni, Koyeni, Dodori, etc., are flowing streams only during the rainy seasons, although it was reported that the latter "never dries" by Fitzgerald (1898).

Underground water supplies are related to the geology but are difficult to obtain and of variable quality. In general, the Mariakani sandstones yield variable supplies of moderate to poor quality, the Mazeras sandstones yield better supplies of better quality, the Jurassic rocks yield low supplies of poor quality (with exceptions), and the Cainozoic rocks yield very variable supplies of moderate quality.

In the Taita Hills beyond Voi there occurs a succession of vegetation types up the mountain to elevations above 5,000 ft. It has been stated that these vegetation types are the same as those on the coast and are telescoped into narrower bands than are found on the lowlands. This assertion does not coincide with the observations of the author but others have studied the flora of this region and some results will probably soon be published. The gneisses and schists that form the parent material for these hills along with the higher elevation and cooler environment produces quite a different flora for the most part that has affinities with the montane vegetation types of the Highlands as much as with the coastal species.

CLIMATE

The coast of Kenya lies in the latitudes of the truly hot tropics extending from 1° 40' to about 4° 40' south latitude. The weather of the area is largely controlled by the great monsoonal air currents of the Indian Ocean in combination with orographic effects of the coastal hills and convection over the hot, dry hinterland immediately to the west. From November until March, high pressure areas exist over the land mass of Asia and over that part of the Indian Ocean south of 30° S. latitude. Between these high pressure areas a broad belt of low pressure covers the area between 10° N. and 20° S. latitude, with winds blowing into this low pressure belt from each side. In the northern hemisphere the air stream is from the north-east until it crosses the Equator. In the southern hemisphere the prevailing wind is from the south-east. The axis of the low pressure belt varies from day to day somewhat but on the whole tends to "follow the sun"—moving southward in November and December and returning slowly northwards from its extreme position (15° S.) in January. In the period May to December, pressure is high over the Indian Ocean south of latitude 10° S. and very low over north-west India so that there is a continuous pressure gradient between these two areas. The "Inter-tropical Low" is then completely obliterated and there is one great airstream across the Indian Ocean from the south to the north which, owing to the rotation of the earth, crosses the coast of Kenya from a south-easterly direction, but which tends to swing toward the north-east on crossing the Equator.

Much of the rainfall of the Kenya coast is associated with the Inter-tropical Low or "Convergence Zone" which lies over southern Tanganyika in January, as stated above, and over mid-Sudan in July. The south-east monsoon brings the "long rains" in April, May and June when more than half the annual precipitation usually falls. The long rains end in June in the north (Lamu) and in July in Mombasa. The short rains begin in October or November and produce a marked bimodal distribution in the rainfall for most of the coast districts. Rain showers occur mainly in morning or midday hours in the coastal regions (Thompson, 1957) and the annual average fall and reliability decreases from south to north (Griffiths, 1958A) along the coast, Lamu, for instance, having a higher coefficient of variation (1.6) than Mombasa (1.1). The number of rainy days increases southwards from about 90 to 140 and it can be seen from the selected rainfall statistics (Table 1) and the distribution map (Survey, 1959) that the south coast provides a much more mesic environment. It can be seen that there is a gradual transition in the climatic regime from north to south towards the single-season rainfall and "trade wind" climate that prevails south of Dar es Salaam. The long rains are later to end and the short rains begin earlier in the region south of Mombasa so that in some seasons there is scarcely a break in the cloudy, cool, wet season from May to December. This climatic transition has an important effect on the vegetation and soils.

TABLE 1.—TABLE OF ANNUAL PRECIPITATION DATA FOR SELECTED COASTAL LOCATIONS (FROM GRIFFITHS, 1958)

Station*	Years of record	Mean rainfall, annual	Standard deviation
Amani	47	<i>inches</i> 75.26	13.71
Dar es Salaam .. .	55	41.34	9.38
Tanga	36	52.00	9.64
Mombasa	67	47.25	11.91
Malindi	58	40.94	11.66
Lamu†	43	36.86	—

*All stations except Amani and Lamu meet Griffiths criteria for normality.

†From E.A. Meteorological Department, 1950. Collected Climatological Statistics for East African Stations. 44 pp.

Table 2 serves to illustrate the transition in rainy days (days on which rain falls, however small the amount) from south to north along the East African coast from the winter dry season (June, July, August) to the summer dry season (December, January, February) at Lamu.

Much of the rainfall in coastal regions falls as passing showers, frequently heavy. From July to March inclusive, the weather is usually clear with only occasional showers especially in November and December.

TABLE 2.—AVERAGE NUMBER OF DAYS OF RAIN FOR SELECTED COASTAL STATIONS. (E.A. METEOROLOGICAL DEPARTMENT, 1950)

Station	Month												Year	
	J	F	M	A	M	J	J	A	S	O	N	D		
Lamu	0	0	2	10	20	17	13	11	7	5	3	3	91	
Malindi .. .	1	1	3	13	19	16	15	14	10	7	3	3	105	
Mombasa .. .	6	3	7	15	20	15	14	16	14	10	10	9	139	
Dar es Salaam ..	10	6	14	21	17	7	6	8	9	9	10	12	129	

TABLE 3.—MEAN MONTHLY PRECIPITATION FOR SELECTED COASTAL STATIONS. (E.A. METEOROLOGICAL DEPARTMENT, 1950)

Station	J	F	M	A	M	J	J	A	S	O	N	D
Lamu	0.20	0.11	0.82	4.95	14.13	6.71	2.66	1.64	1.17	1.63	1.33	1.15
Malindi .. .	0.43	0.26	1.24	5.88	13.41	6.41	3.58	2.02	1.69	2.48	1.91	0.94
Mombasa .. .	1.03	0.65	2.49	7.73	12.59	4.72	3.52	2.53	2.50	3.43	3.76	2.38
Dar es Salaam ..	2.76	3.21	5.63	11.83	7.44	1.11	1.14	1.06	1.38	2.25	2.75	3.12

Annual Total.
 71%
 64%
 53%
 57%

The wind direction is mainly dependent on the land and sea breezes which are superimposed on the major monsoonal air currents. Surface wind velocity is usually of the order of 12-15 m.p.h. and achieves maximum velocity at about 4 p.m. when the sea breeze is strong. During the hot season the sea breeze does not start until mid-morning and maximum temperatures are frequently attained at this time. This condition is not so pronounced in the north where the land breeze seldom prevails.

Just across the Tanganyika border near Tanga, the land rises sharply inland to the Usambara Mountains, which attain a height of 3,000 ft. at a distance of 25 miles from the coast. This mountain mass gives rise to increased rainfall near the coast (Tanga = 54 in., Amani = 75 in.) but to a slight rain-shadow effect in the coastal hinterland immediately over the Kenya border (LungaLunga = 36 in.) during the south-east monsoon even though the coastal hills of Kenya do not begin for some miles north of the Ramisi River.

Fog is virtually unknown along the Kenya coast but light radiation mists may occur inland in the early morning especially in the rainy season. Also during the rainy season the cloud base may be very low (500 ft.), causing mist on the higher points of elevation and, of more general importance, the relative humidity is high most of the time, 75 to 80 per cent. This high humidity condition persists for a long distance inland, giving rise to a more mesic environment than would be predicted from the rainfall statistics and producing a "mist forest" type of epiphytic lichen (*Usnea* sp.) growth in some areas. Mean diurnal range in relative humidity is 26 to 31 per cent.

The temperature is high all year, averaging about 82° F. from December to March, with a mean maximum of about 93° F. Extremely high temperatures do not occur in the coastal belt. The maximum temperature recorded in Mombasa was 98° F. in 1951. The period from the end of June to the middle of September is pleasant, with the mean temperature varying between about 76° F. and 79° F. The diurnal temperature range is small, 11° to 14° F.

Evaporation in some of the inland portions of the coastal hinterland exceeds 100 in. per year (Mandera, and probably Garsen), but for the most part is slightly less than the precipitation in the coastal strip itself (Mombasa = 31.65 in.).

A number of records for climatic extremes have been awarded coastal locations by Griffiths (1958a). Chukwani, in Zanzibar, is the only coastal location to record a temperature higher than 100° F. and it has never had a temperature lower than 67° F. The maximum daily sunshine amount has also been recorded at Chukwani (12.3 hours), as has a high monthly rainfall (34.5 in.). Malindi has recorded 48.7 in. of rainfall in one month, the highest in Kenya, while Mandera has had the least in one year (1.7 in.). Mandera actually in the Northern Frontier Province has the highest temperature (104°), and the least rainy days per year, 22. Voi and Wajir each have had zero rain in each month. Lamu has the lowest average afternoon and daily total cloud amount but at the same time has the highest average annual relative humidity,

79 per cent. Lamu has 11 months each year with relative humidity over 75 per cent at 2.30 p.m. Mombasa has recorded the maximum annual daily total sunshine of 8.5 hours.

Classification

Sansom (1954) has recently classified the climates of East Africa according to Thornthwaite's system. The data from this study of interest to the coastal ecology pertain mostly to soil moisture and evaporation since the coast is placed within the dry subhumid climatic region based on the moisture index. Malindi and Mombasa are shown to have a "Theoretical Growing Season" of five to eight months, while Lamu, Dar es Salaam and Mombasa fall within the class of two- to five-month growing seasons.

The elements accounting for the classification of climate according to the Thornthwaite scheme include a "moisture index" and an index of "thermal efficiency" with values for the seasonal variation of each. Thornthwaite incorporates in the moisture index, indices of humidity in arid climates and of aridity in humid climates to account for seasonal water surplus and deficiency. Since subsoil and ground water can be drawn upon by deeply rooted plants in times of moisture deficiency, Thornthwaite assumes that a surplus of 6 in. in one season can balance a deficiency of 10 in. in another and accordingly gives the humidity index more weight than the aridity index in the full moisture index. Sansom adapts the Thornthwaite system to East African conditions by omitting the concept of seasonal variation in thermal efficiency, which does not really apply to the tropics, and by modifying the humidity and aridity indices to make them more sensitive to small season moisture surpluses or deficiencies.

All the stations studied fall within the classification limits of the dry, subhumid (C), megathermal (A') climates with a small (m) to moderate (m) water surplus. With the exception of Kibarani, which is about a mile inland and has little or no water surplus (m), all stations are immediately on the beach, and thus give little indication of the details of climatic variation within the coastal belt. The method is only cited to give the broad climatic classification in relation to the rest of the Colony, and the world-wide classification system.

Orography plays an extremely important part in the rainfall pattern of the coastal belt as can be seen from the distribution map (Survey, 1959). The highest average precipitation on the coast falls in the Ramisi River valley and the south Shimba Hills where the south-east monsoon is forced to rise over these hills. Rainfall is also high along the ridge north of Mombasa beginning at Rabai and including the Ribe, Chonyi and Jibana locations. There is a pronounced suggestion of an influence of inland water bodies and forests. The high evaporation from bodies of water such as Port Reitz and Tudor, Mida and Kilifi Creeks, the Tana delta and the Witu Forest may contribute to the higher rainfall in some of the low elevation locations. The Witu Forest is especially interesting since it is in an isolated location of high

TABLE 4.—SUMMARY OF CLIMATIC DATA AND THORNTHWAIT'S CLASSIFICATION FOR COASTAL STATIONS IN EAST AFRICA. (AFTER SANSON, 1954)

Station	Potential Evapo- transpir. (Index)	Rainfall (inches)	Aridity Index	Humidity Index	Moisture Index	Classification		
						Moisture Index	Seasonal Variat.	Thermal Efficiency
Lamu	61.3	36.6	52	13	-19	C ₁	m ₂	A'
Malindi	63.9	40.3	45	10	-17	C ₁	m ₁	A'
Mombasa	65.2	47.3	35	9	-12	C ₁	m ₁	A'
Dar es Salaam	59.9	43.7	33	9	-11	C ₁	m ₁	A'
Kibarani	62.6	41.5	36	4	-18	C ₁	m ₀	A'
Chukwani	65.5	55.8	30	15	-3	C ₁	m ₂	A'

rainfall with little relationship to a higher elevation of land during either monsoon and can attribute its favoured condition partly to the fact that the tropical rain forest remains relatively intact, with its consequent high evapo-transpiration rate, but principally to the coastal configuration. As will be pointed out, the forest is partly dependent on ground water for its continued survival but does in all likelihood contribute substantially to the stability of its own environment.

That portion of the coast between Malindi and the Tana River is one of arid vegetation and soils and demonstrates another facet of orography that influences the moisture distribution along the coast. In this area the coastline runs nearly straight north to form the southern arc of Formosa Bay, thus lying nearly parallel with the south-east monsoon which at this latitude has begun to swing toward the north-east. Further up the coast where the Tana delta and the Lamu archipelago form the north shore of Formosa Bay, the shoreline lies athwart the prevailing wind and precipitates the last moist island before the consistently arid Somalilands are reached. This last island of moisture coincides with the delta of the Tana River and its meandering flood plain which tend to reinforce the mesic tendency, and the Witu Forest as mentioned above.

Behind the low range of coastal hills, the rainfall drops off sharply to 20-25 in. in a broad belt of about 25 miles until it reaches the low of 10 in. in the hinterland and then slowly increases again as the higher elevations of the approaches to the Highlands are gained.

METHODS

Mapping

The first step in the ecological survey of the coastal area was a reconnaissance survey of the entire Province to become familiar with the roads, names and the broad outlines of the geology, soils and vegetation. Nearly the first month was spent travelling by road and by air over the Province from the Tanganyika border to Kiunga about ten miles from Somalia. Following this, a like period was spent in identifying the collected specimens and becoming familiar with the literature directly related to the work.

The original plan had been to study a small area in Kenya in detail as part of an ecological survey team, but on arrival it was found that the requirements of the Department had changed and that the entire coast area was to be treated as an individual research project. It was immediately apparent that 6,000 square miles could not be mapped or studied with any very detailed methods in six months. Instead, a series of five transects were selected, extending from the beach to the hinterland, through what was believed to be the major representative vegetation types and soils. These five transects of about 300 square miles each were mapped from unrectified aerial photographs at the 1:32,000 scale of the photos.

The resultant maps were taken in the field and used as guides for locating areas for detailed studies and were themselves completed to some degree on the ground by drawing in soil boundaries and vegetation type lines. This phase of mapping was completed to varying degrees for each of the maps but only one of the more satisfactory one is reproduced with this report. (Appendix 3.)

From the detailed maps and information acquired on the reconnaissance surveys a map of the general ecological land use types was projected on a base map of 1:500,000 scale, reduced, and is included as Appendix 2.

Quantitative Studies

Where stands were located that appeared to be relatively representative of widespread vegetation types they were sampled in detail using one of a number of quantitative methods. Many other areas were simply collected as thoroughly as the time and condition of the vegetation would allow. In general, collection for identification and distribution record purposes was carried out in December and January, just after the short rains. Much of the quantitative work was done during the dry season from January to March.

A "point" method was used throughout for the measurement of vegetation. For grassland types the Step-Point Method (Brown, 1957) was used, and for woody plants and forest vegetation, the Point-Centred Quarter Method of Cottam and Curtis (1956) was used. Since this was not a study in methods, the details, difficulties and advantages of the methods will not be discussed. Ten square-yard plots were clipped and air dry forage weights obtained where grasslands were thus sampled.

Soils were sampled by horizons and were described in American terminology (U.S.D.A. Soil Survey Manual). Samples were analyzed at the Scott Agricultural Laboratories and the chemistry is tabulated in the appendix.

Classification

The area has been divided into ecologic land-use units based on evidence from the vegetation, soils and climate that are admittedly conditioned by suppositions about climax types. "Climax" vegetation is impossible to find in many of the areas where cultivation has been going on for a thousand years, but in many instances reasonable projections can be made.

Land-use observations are recorded but are incomplete as are the research recommendations. In part it was felt that insufficient information had been collected and time was too short for a complete analysis. In addition, it is recognized that many of the agricultural officers are better able to interpret response of individual crops with which they have had far more experience than the author.

VEGETATION AND SOILS

Previous Work

Several studies of the broad vegetation types of Africa, or of parts of it, have appeared in the literature (Engler, 1910; Shantz and Marbut, 1923; Gillman, 1949; Burtt, 1942) and a few have described vegetation types in Kenya (Edwards, 1940, 1956; Scott, *et al.*, 1951; Dale, 1939), but only two papers pertain directly to the coastal vegetation in major emphasis. Fitzgerald, in the 1890's, spent more than two years (Fitzgerald, 1898) travelling and writing about the agriculture and trade of the coastal areas and islands while he was employed by the British East Africa Company. Dale (1939) is the author of the only modern paper dealing specifically with the Province, but limits himself to consideration of the woody vegetation. Scott Elliot (1896) and others have made passing references to coastal vegetation in early travel books and papers.

Gillman (1949) uses eight physiognomic vegetation types to describe the vegetation types of Tanganyika:—

- (1) Forest, including rain forest, upland or lowland dry and moist forests, deciduous forests, groundwater and riverine forest, swamp forest and mangrove forest.
- (2) Woodland, including such types as *Brachystegia*, *Isobertinia*, *Afromosia*, *Acacia*, *Combretum* and *Uapaca* types; bamboo thickets.
- (3) Bushland and thicket, including primary and secondary types, dominated by *Acacia*, *Euphorbias* or other species and "semi-thicket low forest".
- (4) Wooded grassland, of many types and sub-types, including "palm stand-grasslands".
- (5) Grassland. Topographic designations are all lumped together: high altitude, ridge and slope types, river valley, etc.
- (6) Permanent swamp vegetation: principally grasses, sedges, rushes and a few shrubs.
- (7) Desert and semi-desert: ranging from salt pans, rock and ice to the shrubs, trees and grasses of dry or cold regions.
- (8) Actively induced vegetation.

The vegetation of the coast of Tanganyika immediately adjacent to the Kenya border consists of permanent swamp vegetation, forest and actively induced vegetation at places within a matrix of wooded grassland.

A similar designation is used by Edwards (1956), although considerably more detailed vegetation description is offered. His "Coastal High Grass-bush" is probably the equivalent of the "High Grass—Low Tree Savanna" of Shantz (1923) and Gillman's "Wooded Grassland".

In Shantz and Marbut (1923), Shantz describes 21 vegetation types in three broad groups: Forest, Grassland and Desert. Of these, six are mapped

in the coastal belt of Kenya although, as Shantz points out, others probably occur but could not be mapped on the scale of his map (1:10,000,000). The described types are:—

- (1) Mangrove forest.
- (2) Tropical rain forest. Mixed and heterogeneous vegetation is the rule, but some genera from the West African forests described are found in common.
- (3) Thorn forest. Described as thickened form of the acacia-desert grass savanna, it is said to occur in Abyssinia, Somaliland and south to central Tanganyika. Major genera are: *Acacia*, *Combretum*, *Boscia*, *Zizyphus*, *Balanites*, *Sansevieria*, *Asparagus* and *Euphorbia*, *Carissa*, *Ehretia*.
- (4) Acacia-desert grass savanna. This type forms a narrow strip between the acacia-tall grass savanna on the humid side and the desert shrub-desert grass on the arid side. Shrubs are principally *Acacias*, *Terminalia*, *Tarchonanthus* and *Zizyphus* with *Aristida* as the grass cover.
- (5) Acacia-tall grass savanna. The most extensive plant formation in Africa, this type covers parts of Somaliland, Kenya, Tanganyika and parts of the lower Sahara, as well as extending down into southern Africa. *Acacia* and *Combretum* are the principal shrubs, along with *Sclerocarpa* and several large grasses such as *Themeda triandra*, *Andropogon*, *Heteropogon* and *Hyparrhenia*.
- (6) Desert shrub-desert grass. This is the most productive part of the African desert vegetation composed of many species of *Aristida* and *Eragrostis* covering the ground between the scattered *Euphorbias*, *Pelargonium*, *Crassula* and other typical desert shrubs and succulents.

At least two other of Shantz's described types can be correlated with the vegetation now found in the Coast Province:—

- (7) Dry forest. (Miombo, Tree Steppe, Mrihi.) This is the great south-central African "Miombo" dominated by *Brachystegia spiciformis*.
- (8) High grass-low tree savanna. Forming an almost complete border around the tropical rain forest, this type of vegetation is an immense prairie dominated by *Pennisetum* and *Andropogon* with a scattering of small trees such as *Philiostigma*, *Acacia*, *Parkia*, *Annona*, *Erythrina*, *Strychnos*, *Cussonia*, *Borassus*, *Hyphaene*, *Gardenia* and many others.

The soils of the region are described by Marbut (Shantz and Marbut, 1923) as being of the Chernozem group, but are principally the light-coloured members of that group. Some of the red loams are also mapped but few of them have since proved to be of the loamy texture, although they show the red colour indicative of lateritic weathering.

Pichi-Sermolli (1957) has mapped 24 vegetation types in Eritrea, Ethiopia and Somalia including that part of Kenya north and east of the Tana River. Nine of these types are represented in Kenya:—

- (7) Xerophilous open woodland—"Boscaglia xerofila". This type covers a large part of the arid and semi-arid areas in Kenya including much of the Northern Frontier Province and the arid zone behind the coastal strip. It is dominated by species of *Acacia*, *Combretum* and *Terminalia*. Gillett (1941) has described several associations within this type.
- (9) Lowland evergreen thicket—"Boscaglia sempreverde planiziale". This type is similar to that called by Dale (1939) "Secondary scrub on coastal sands" and by Edwards and Bogdan (1951) "Coastal bush with open high grass glades" or Edwards (1945, 1951) "Coastal high grass-bush". It is considered to be a secondary type and to be composed of trees such as *Adansonia digitata*, *Combretum schumannii*, *Fagare olitoria*, *Carpodiptera africana*, *Sterculia triphaca*, *Cussonia zimmermannii*, *Lannea stuhlmannii*, etc. The understory and the openings between clumps of bush are dominated by *Hyparrhenia rufa*, *Digitaria*, *Setaria*, *Panicum*.
- (11) Savanna (various types)—"Savana (vari tipi)". The *Andropogon* savanna with *Hyparrhenia*, *Piliostigma thonningii*, *Gardenia lutea*, *Acacia* sp. and *Combretum* sp. is mentioned. Another type with *Hyparrhenia rufa*, *Combretum trichanthum*, *Piliostigma thonningii*, *Entada abyssinica*, *Gardenia lutea*, *Cussonia ostinii*, *Stereospermum kunthianum*, etc., and a third, with *Phoenix abyssinica*, *Cassia goratensis*, *Cordia abyssinica*, *Gardenia lutea*, *Croton macrostachys* with lianes and herbs are found in the lower elevations in Abyssinia. The herbaceous stratum may also consist of species of *Aristida*, *Cenchrus*, *Chloris*, *Cynodon*, *Dactyloctenium*, *Digitaria*, *Eragrostis*, *Panicum*, *Sporobolus* and *Tetrapogon*.
- (14) Lowland dry evergreen forest—"Foresta secca sempreverde planiziale". It corresponds with the "Evergreen dry forest" of Dale (1939) and with the "Coastal forest" of Edwards (1945, 1951).
- (16) Lowland moist evergreen forest—"Foresta umida sempreverde planiziale". This follows Dale's description of the Witu.
- (21) Coastal formations—"Formazioni costiere".
- (22) Mangrove forest—"Mangroviato". Good descriptions are given in Walter and Steiner (1936) and in Dale (1939) and others.
- (23) Riparian formations—"Formazioni riparie". Palms, rushes and shrubby species like *Lawsonia inermis*, *Tarandus indica*, *Salvadora persica*, *Dobera glabra*, *Cordia ovalis*, *Sansevieria* and *Aloe*

are cited in addition from Gilliland (1952). In Eritrea and in Kenya's Northern Frontier, the dun palm, *Hyphaene*, is found in places where phreatic water is expected.

(24) Swamp formations—"Formazioni palustri".

Dale (1939) proposes ten primary woodland formations and two secondary woodland formations in the Coast Province with three additional subdivisions. Four of these pertain to the higher elevations (above 2,000 ft.) in the Taita and Bura Hills and Kasigau and do not occur in the coastal belt proper:—

- (1) Mangrove. A good account is given of the occurrence, extent and composition on the coastal mangrove forests.
- (2) Littoral flora. It is stated that the littoral flora is not distinctive but usually takes on the character of the scrub immediately behind the beach.
- (3) Lowland evergreen rain forest. Classed in this type are the forest stands at Witu, Mida-Gede, Tezo, Gongoni, Kaya Rabai, Kaya Chonyi, Cha Simba and others.
- (4) Lowland evergreen edaphic forest:—
 - (a) Riparian forest.
 - (b) Palm stands.
- (8) Evergreen dry forest.
- (9) Savanna woodland:—
 - (a) Mrihi savanna.
 - (b) Shale flora.
- (10) Thornland:—
 - (a) Sandy red earth scrub.
 - (b) Plains soils *Acacia-Commiphora*.

Classification of Major Types

In the coastal belt nine broad ecologic units or land-use classes have been distinguished on the basis of vegetation, climate and soils. Each of these units contains subdivisions and variants bringing the total number of vegetation types recognized to nearly 30, but for the sake of simplicity all stages and variants will be discussed together. Of the nine basic land-use classes discussed only five, or perhaps six, are of sufficient size and agricultural importance to be of concern with respect to management. These are treated much more fully than the others which comprise the dune sand, swamp and pond, and beach littoral communities.

The vegetation types discussed are for the most part quite distinct and the boundaries (ecotones) between them apparent. The principal exceptions to this statement are the interfingering and invasion of the *Acacia* Thorn-bushland types of the hinterland with the *Diospyros-Manilkara* forest and the coppice and savanna formation that takes place at the edge of the tropical rain forest types.

Each of the major types will be discussed in detail below under the following headings:—

- (1) *Name*. The name of each type is derived for convenience from the botanical name of the dominant species or some conspicuous, familiar and easily recognizable constituent species that may have some indicator value. Some of the nomenclatural equivalents from the past literature are given in many cases. The name given is a combination of physiognomic (after Trapnell, 1959) and the ecological designation.
- (2) *Extent*. The distribution (also on the map) and size is described.
- (3) *Soils* and geology are given according to the latest information and something of the fertility and drainage problems discussed.
- (4) *Climate*. The more detailed climatic limits are mentioned where known.
- (5) *Botanical composition* and variations are presented at least in part. Data from enumerations are shown where available and the plant succession with the composition of the several seral stages given.
- (6) *Land-use potential* and cropping practices, present and past, are shown from observations.
- (7) Some of the *research problems* and suggestions for future development are considered.

The major ecologic land-use units or associations recognized are as follows:—

- I—*Acacia-Euphorbia*: *Acacia* Thorn-bushland.
- II—*Manilkara-Diospyros*: lowland dry forest:—
 - (a) *Cynometra-Manilkara sulcata*/Croton: Sokoke Forest.
 - (b) *Manilkara-Dalbergia/Hyparrhenia*: shale soil savanna.
- III—*Brachystegia-Afzelia*: lowland woodland.
- IV—*Combretum schumannii-Cassipourea*: lowland dry forest on coral rag.
- V—*Sterculia-Chlorophora/Memecylon*: lowland rain forest.
- VI—*Albizia-Anona/Panicum*: lowland moist savanna.
- VII—Sand beach and dune communities.
- VIII—Mangrove swamps and saline margins.
- IX—Pan and pond.

I—ACACIA-EUPHORBIA: ACACIA THORN-BUSHLAND

This has been called "Bushland and thicket" by Gillman (1949), "Thorn Forest" or, in its more open phases, "Acacia desert grass savanna" by Shantz (1923), "Commiphora-Acacia desert grass" and "Acacia-Themedra" by Edwards (1956), "Xerophilous open woodland" by Pichi-Sermolli (1957) and "Sandy red earth scrub thornland" by Dale (1939). It is called "Dry Acacia bush" by Watson (1957) and "Hinterland vegetation" by Allen (1949) and others.

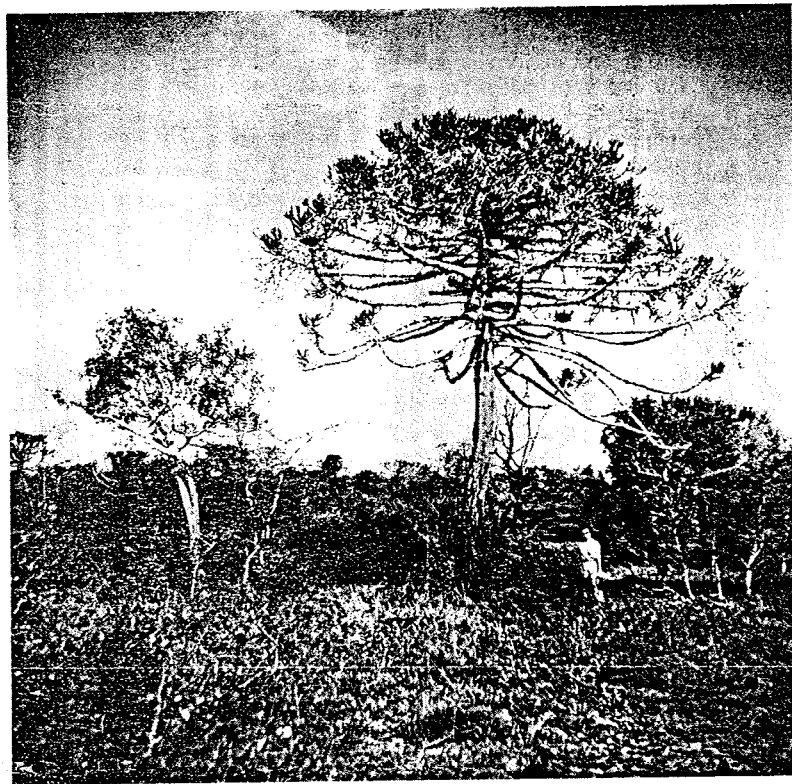


Fig. 1.—Acacia-Euphorbia: Acacia Thorn bushland. A "Candelabra" Euphorbia a few miles south of Garsen, with *Acacia zanzibarica*, *Commiphora* spp., *Boscia*, *Grewia*, *Dobera*, etc. Soils are varied and rainfall below 20 in. per year.

The extent of this vegetation type is vast and its boundaries are unknown. In the south coastal districts, it lies to the west of the Kinango-Samburu area, a short distance west of Bamba and Mangea Mountain, while

north of the Sabaki River it swings eastward, approaching the coast between Mambui and the Tana River and again north of the Mundane Range on the Somalia border.

The type lies in the region receiving fewer than 20 inches of rainfall per year and in most of the area probably under 15 inches. Few records are available in the area, but a few such as Samburu (19.7), Voi (21.75), Mackinnon Road (23.32) and Bamba (25.41) are probably representative. The variability is high, probably exceeding 50 per cent of the mean in any given year. To the north and west in the Northern Frontier District the rainfall falls even lower and true desert conditions are found.

The soil types encountered in this large vegetation type are numerous and varied. They include soils derived from the Basement Complex system of gneisses and schists, from the Taru grits, from the Duruma sandstones, and from various sands and alluvial materials over a large part of the dry areas of the Colony. On the soil map of Scott (1959) soils are mapped in the following categories:—

- (1) Yellow-red loamy sands (podzolic soils).
- (2) Dark red sandy loams (latosolic soils). These are the low humic derivatives of Basement Complex and volcanic rocks. They are considered to be relict soils developed under a more humid climate.
- (3) Light yellow-brown sandy loams with laterite horizon.
- (4) Seasonally waterlogged very pale brown mottled loamy sands with laterite horizon (groundwater laterite).
- (5) Brown clay (Grumusolic soils) with impeded drainage.
- (6) Shallow stony soils with rock outcrops.

Many of these are components of catenary complexes. No samples were taken.

This arid vegetation type is dominated by species of *Acacia* and *Euphorbia*, while the type farther west is dominated by *Acacia* and *Commiphora*. The Acacias include *A. lahai*, *A. seyal*, *A. senegal*, *A. zanzibarica* and several others. The frequent large "Candelabra" Euphorbia, *E. nyikae*, and the trailing *E. tirucalli* are two among a number of representatives of the genus. Other frequent shrubs are *Commiphora scheffleri*, *Commiphora* spp., *Newtonia hildebrandtii*, *Grewia* spp., *Terminalia prunoides*, *T. spinosa*, *Boscia* spp., including *B. salicifolia*, *Hibiscus aponeuris*, *H. spp.* and *Salvadora persica*, and *Thespesia danis* in dense thickets in disturbed places. *Cissus rotundifolia*, *Vanilla* spp. and *Adenia globosa* twine in the branches of *Dobera glabra*, and *Sansevieria kirkii* and others form a thick ground cover in many places.

In open areas grasses achieve a measure of dominance, but usually this is an indication of past fire or of a waterlogged condition of the soil at some season of the year. *Chloris myriostachya* is locally common as is *C. gayana* and *Cenchrus ciliaris*. Others that occur in mixed stands are

Urochloa panicoides, *Enteropogon somaliensis*, *E. macrostachys*, *Dinebra retroflexa*, and species of *Sporobolus*, *Tetrapogon*, *Latipes*, *Enneapogon*, *Eragrostis*, *Digitaria* and *Leptochloa*. *Aristida* species are present, especially on heavily grazed areas.

This hinterland vegetation is useful principally for grazing and for wildlife purposes, but it is an area where much of the research in wild land management needs to be done. Water is a limiting factor in the development of most of the area for ranching but in areas where it is available, such as near the Taita Hills, Vigurungani, and many other scattered water points, substantially better utilization of the forage and water could be developed. Tsetse infestation is low to moderate and can apparently be controlled by using drugs. Even in areas where fly is heavy, it can probably be controlled by controlling the vegetation. Several locations in the dry areas have been regulated in one form or another either by burning under control or by removing livestock for various periods of time. The tsetse control people are conducting experimental work on drug régime, ranching, bush control and grazing stocking rates and this is information very basic to sound development of the vegetation type. Unfortunately a large part of the work could be greatly improved by closer examination and recording of the results. In many cases no records of vegetation change are kept and where there are records they are usually simply observation and opinion recorded on the basis of a quick *safari*. What is badly needed is a full-fledged study using quantitative methods by an officer trained in range ecology or forage crops in close co-operation with the staff of the tsetse control and veterinary divisions of the Ministry.

Estimates of the carrying capacity of the type have been made by Poultney (1958) and by Edwards (1952) using the "eyeball" method, but they are probably good estimates since made by experienced officers. A value of 30 to 50 acres per head would be realistic for most of the portions where fire and other factors have controlled the bush to some degree, but would approach 100 acres on an annual basis in the areas of dense bush. From this it can be seen that vast areas must be controlled and watered if substantial numbers of livestock are to be produced in competition with the grazing species of game.

II—MANILKARA-DIOSPYROS: LOWLAND DRY FOREST

This is the "Black-barked Manilkara forest" of the Boni described by Rawlins (1957) and Watson (1957). It is part of the "Bushland and Thicket" of Gillman (1949) and a part of the "Coastal High Grass-bush" of Edwards (1956) mentioned as transitional to the semi-desert vegetation and is probably included in the "High Grass-Low Tree Savanna" of Shantz (1923). Pichi-Sermolli (1957) includes this type in his "Lowland dry evergreen forest" which corresponds with the "Evergreen dry forest" of Dale (1939) and with the "Coastal forest" of Edwards (1945, 1951). The Shale flora is included in the "Savanna Woodland" by Dale (1939) along with the *Brachystegia* type.

This vegetation type at one time may have occupied considerable area and its remnants still occupy a narrow belt between the Acacia-Euphorbia Thorn-bushland and the *Brachystegia* Woodland. The type is partly transitional and has been largely destroyed by fire, cultivation and grazing but still retains recognizable identity. It may have occupied 800-1,000 square miles at one time, including the two subtypes to be discussed. It is found the entire length of the coast from the Boni Forest in the Lamu hinterland to the Gonja area near Vanga.

Incident rainfall is between 25 to 35 in. per year on the average. Kinango (31.3 in.), Mariakani (29.1 in.), Dagamra (28.09 in.) and Ndavaya (26.5 in.) are representative.

Soils under the Manilkara-Diospyros type are principally the Coastal Sands (Scott, 1959) in the drier parts of the soils derived from Duruma sandstones which may be of heavier texture. There is some evidence that the type may be favoured by impeded drainage, as on the Grumusolic brown clays. Subtypes develop on edaphically determined situation as is pointed out below for the Magarini sands and the Jurassic shale soils. An interesting soil profile (10-2-1) from the Mariakani sandstones east of Gotani is described in Appendix I. They are clearly seasonally waterlogged and are high in calcium and magnesium.

The principal species in the type are medium to small trees varying in stature with the suitability of the site. *Manilkara densiflora* is one of the most important dominants but this species is at the moment being rearranged by workers on the Sapotaceae at Kew Gardens and may be called something else soon. A complex of species including *M. densiflora*, *M. eichii*, *M. discolor*, and *M. zanzibarica* occurs in the area and includes at least one new species (Moomaw 1642, 1595) but does not include *M. sulcata* and *M. cuneifolia* which are quite distinct species with different ecology.

Others of the forest canopy species are *Azelia quanzensis* (a stunted form), *Diospyros vaughanii*, *Olea africana*, *Oldfieldia somalensis*, *Brachylaena hutchinsii*, *Terminalia prunoides*, and *Combretum schumannii*. Shrubs of prominence in the understory include *Sideroxylon diospyroides*, *Croton pseudopulchellus*, *Euclea bilocularis*, *Lannea stuhlmannii*, *Combretum constrictum*, *Carissa edulis*, *Sterculia africana*, *Psychotria punctata*, *Notobuxus hildebrandtii*, *Grewia villosa*, *G. plagiophylla*, *Allophylus alnifolius*, *Xeromphis nilotica*, *Cassine aethiopica*, *Adenium coetaneum*, and *Trianthema pentandra*, with occasional plants of *Pyrenacantha malvifolia*, *Acacias*, and a *Panicum*.

This forest has been all but destroyed in the south and is rapidly disappearing in the north as well. Fire and cultivation, and the two combined are chiefly responsible. When burned, grasses of fair to good grazing value seem to come in slowly and a savanna grassland is produced similar to the shale soil flora described later. The grasses include *Cenchrus ciliaris*, *Enteropogon somalensis*, *Digitaria mombasana*, *Setaria* spp., and some *Panicum maximum* and *P. hypothyrix*. When the savanna is overgrazed or when



Fig. 2.—Manilkara-Diospyros: Lowland Dry Forest. An open, seasonally burned phase of the Boni "Forest" between Duldul and the Dodori River. The grasses are principally *Digitaria mombasana* and *Chloris* spp.

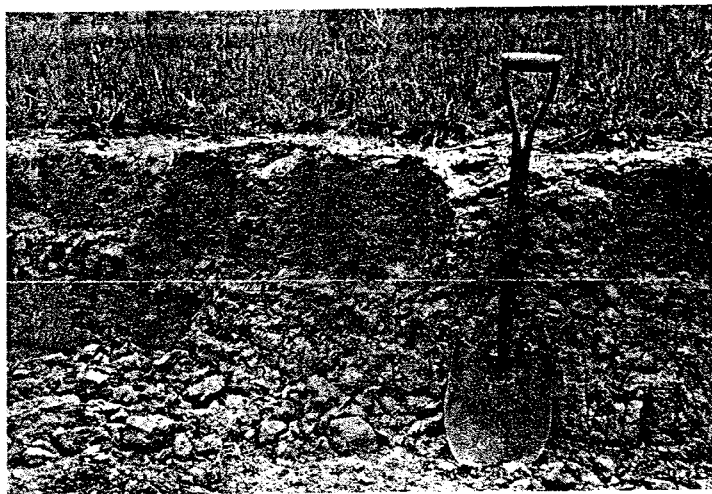


Fig. 3.—Manilkara-Diospyros: Lowland Dry Forest. Soil profile 10-2-1 (see Appendix I) between Kaloleni and Gotani. In the absence of fire and cultivation, an open dry forest probably develops on these soils. Note the strong columnar structure in the surface horizon.

cultivation is abandoned after repetition in the same place, the species from the drier *Acacia-Euphorbia* community readily invade. The result is much interfingering of the types which narrows the belt of Manilkara-Diospyros vegetation and in places obliterates the original character of the type.

Although this ecologic unit appears to be more or less marginal for cultivation, it has been growing African crops for many years. South of the Sabaki it is almost completely cropped on a shifting basis and north of the river a rapid destruction of the forest is extending cultivation into areas without permanent water. In the Boni Forest the process has been going on for somewhat longer and burning of the forest appears to have been less from cultivators than from hunters for game, honey, etc., and for various other reasons. The wanton destruction of the natural forest cover is to be deplored but when the result is an agricultural settlement resulting from pressures on the land elsewhere, it cannot be condemned out of hand. The real danger in the cultivation of this vegetation type lies not in the erosion hazard of the denuded land, or even in the drying of the general environment, but rather in the possibility that a drought of long duration could lead to starvation or at least displacement of a large segment of the population back to "where they came from". The area in question lies below the 30 per cent rainfall probability contour for 20 in. (Glover and Robinson, 1955) so that fewer than 20 inches of precipitation can be expected in three years out of ten making it a rather risky proposition even for long-rains maize.

Since the rainfall is low and variable and the original forest and bush vegetation unproductive as such, and supports little game, it seems advisable to make some effort to investigate the grazing potential of the type. Little is known specifically about the fire succession but weeds after cultivation are dominated in the first year by *Dyschoriste radicans*, *Aerva leucura*, *Tridax procumbens*, and *Solanum incanum*, with *Chloris myriostachya* the only grass. In the second year and later the *shamba* frequently becomes a solid stand of *Thespesia danis*. This will undoubtedly be invaded further by species from the drier hinterland to the west.

The Manilkara-Diospyros association in its intact form, is quite resistant to fire having a sparse understory with little highly inflammable herbaceous material to carry a fire. Fires are set by cultivators by piling brush and branches after they are cut and dried for some time. Only in the dry season will fire move very far or fast, but at this time even the humid rain forest community will burn.

Much research needs to be done on fire effects on vegetation and on soils from a fertility and moisture retention point of view.

An example of the forage production that can be attained in the Manilkara-Diospyros association with application of management techniques is seen at the Veterinary Department Breeding Centre at Mariakani. A pasture has been developed consisting chiefly of *Digitaria milaniana*, *Eragrostis*

superba, *Chloris gayana*, *C. myriostachya*, *Bothriochloa insculpta*, *Enteropogon* sp. and *Cynodon dactylon*. In the eight years since 1951, this pasture has been brought from dense *Acacia* thorn-bushland which was probably invaded due to overgrazing, to a carrying capacity of four acres per beast. The technique has been to use heavy seasonal grazing with supplemental irrigated forage for the dry season and to pursue a vigorous programme of manual control of invading shrubby species. *Panicum maximum* has been increasing which will tend to raise the carrying capacity with time and *Cynodon* has increased in areas of heavy use around water. The general estimate for the carrying capacity of the surrounding country is about 20-30 acres per beast and in most of the Mariakani area, the figure is probably now much lower. It is not to be proposed that this method can be universally applied but a good example is presented of what can be achieved. Less expensive methods of brush control will have to be found for any large areas even at African labour costs because of low efficiency. The lesson of primary interest, however, is that control of numbers and movement of livestock can achieve a three to four-fold increase in the productivity of the natural pastures of the area without reseeding, once removal of the bush can be effected.

II (a)—CYNOMETRA-MANILKARA (SOKOKE): LOWLAND DRY FOREST

The Sokoke Forest community is the "Lowland Evergreen Dry Forest" of Pichi-Sermolli (1939) and the "Evergreen Dry Forest" of Dale (1939). It has been universally recognized as a distinctive vegetation type and has been gazetted as Forest Reserve for many years. The Arabuko-Sokoke Crown Forest encompasses more than 92,000 acres but the type as a whole probably exceeds 200 square miles, including the northern areas (Lungi), on the Mundane Range. The southern limits of the community are unknown but in one place it abuts very distinctly on the Kambe limestone soils behind Kilifi Creek. The Magarini Ridge extends down the coast into northern Tanganyika and a vegetation type similar to the Manilkara-Diospyros community is found in the Vanga area on it. Soil fertility and cropping practice information has been developed for the Magarini sands at Matuga at the Coast Investigational Station and is cited here although it is not known that the environmental conditions ever allowed the development of the typical forest south of Mombasa. It is probable that it did exist at one time but has been destroyed perhaps for several hundred years.

The Sokoke Forest community is essentially confined to the Magarini sand soils or dark red loamy sands (Latasolic soils) although some similar development is evident on soils that are developed from windblown materials. These soils are extremely infertile, are probably excessively drained, and are lateritized throughout the profile or at least exhibit the dark red colour of lateritic soils. This soil is of great age but shows signs of having developed under a more humid environment as has been suspected of several other of the soils in the area. No samples or descriptions were taken in the present

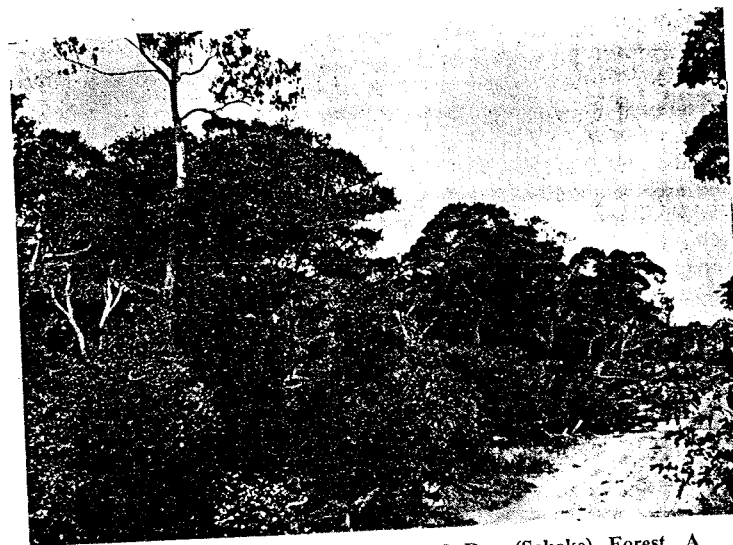


Fig. 4.—Cynometra-Manilkara: Lowland Dry (Sokoke) Forest. A cut-over region of the forest with a remnant *Brachylaena* at left and *Encephalartos hildebrandtii* visible in the under-story.

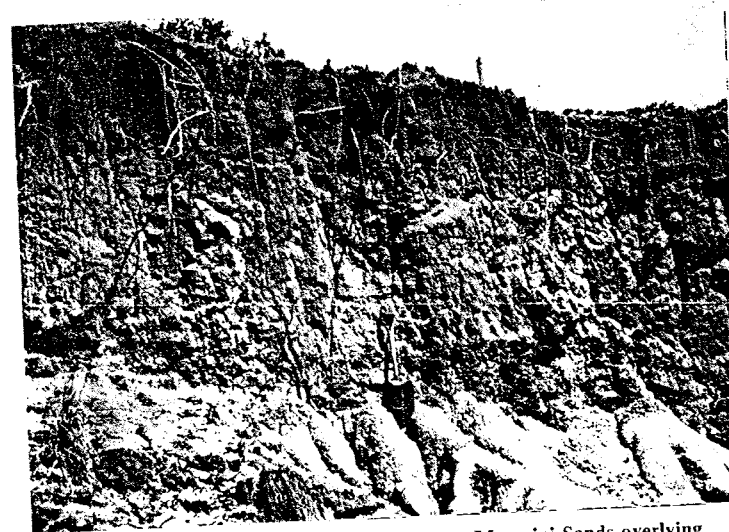


Fig. 4a.—A profile near Matuga showing the Magarini Sands overlying the Jurassic Shales. The stone-line visible at the base of the Magarini is only partly lateritized.

study but this has been done routinely by agriculture officers in the Matuga area. Fertilizer responses to phosphorus and manure are usual depending on the crop.

The rainfall on the Magarini sands is slightly higher than in the Manilkara-Diospyros type to the west but seldom exceeds 35 in. per year. The records for Matuga (38.0 in.) and Jilore (41.0 in.) are higher than is received on most of the area. Humidity is again a factor and the moist sea breeze prevents excessive drying of the air while the mists in the rainy season contribute a share to the effective moisture.

The species composition is reasonably well known. The overstory is dominated by *Cynometra webberi* (which may not be a *Cynometra* at all), *Manilkara sulcata*, and *Brachylaena hutchinsii* with occasional plants of *Cistanthera parvifolia*, *Oldfieldia somalensis*, and *Combretum schumannii*. The understory is dominated by *Croton pseudopulchellus*, *Memecylon verruculosum*, *M. melindense*, and *Notobuxus obtusifolius* with a liberal sprinkling of the tree cycad, *Encephalartos hildebrandtii*. *Combretum hildebrandtii* and *Strychnos dryophylla* are sometimes frequent and the grasses which are very sparse, are a *Panicum* sp., *P. maximum*, *P. brevifolium*, and *Brachiaria* sp. *Salacia* sp. occurs as a small tree and the liane, *Rhoicissus revoluta*, is seen as is the *Euphorbia nyikae*, but herbs are almost absent. *Ochna mossambicensis* and *Vepris lanceolata* occur.

An analysis of a stand of the Cynometra-Manilkara association was made using the point-centred quarter method, as is shown in table 6.

TABLE 6.—AN ANALYSIS OF THE CYNOMETRA-MANILKARA (SOKOKE FOREST):
LOWLAND DRY FOREST, MARCH, 1959

Species	Mean Distance (feet)	Size classes (inches)				Total
		2-3.9	4-5.9	6-7.9	8	
		Number of stems				
Cynometra webberi	11.3	4	20	28	6	58
Manilkara sulcata	12.0	5	6	1	4	16
Brachylaena hutchinsii	12.8	2	5	0	5	12
Strychnos dryophylla	6.6	0	1	2	2	5
Combretum hildebrandtii	13.7	3	0	0	0	3
Encephalartos hildebrandtii	6.0	0	0	0	2	2

The Sokoke Forest has been exploited since about 1920 by European sawmill operators for the Muhuhu (*Brachylaena hutchinsii*), Mngambo (*Manilkara ?cuneifolia*), and Mbombakofi (*Azelia quanzensis*). Before that time and for a while later, it had been used slightly by indigenous people and Arabs for building poles and boat building materials. There has been very little planned utilization or sustained-yield development of the timber and it appears now that the economic species have been nearly depleted for the

time being. The table shows the removal of the 6 to 8-in. size class of *Brachylaena* which is the most valuable size tree for buildings and for sawing floor blocks. Most of the older trees were diseased. *Manilkara* has apparently been exploited to nearly the same extent, although not sampled intensively, probably for poles and posts. Reports from the foresters and local sawmillers indicate that saw timber is becoming increasingly hard to find and of poor quality.

The forest does not burn readily and has been fairly well protected from *shambas* except on the eastern slopes of the Magarini ridge outside the forest proper. It supports a considerable population of elephant and buffalo as well as other game some of which are said to be quite distinctive species. The elephant and buffalo are reported to be of dwarf races attesting to the general infertility of the environment although it is unlikely that elephant would be confined to the one area for long enough to become affected.

The low productivity of the site has been adequately tested by Agriculture Department experimental work at Matuga. It has been found that the general nitrogen and phosphorus deficiency can be corrected with about 100 lb. of double superphosphate per acre and that a residual effect can be detected for three to five years. Pulses and sweet potatoes do better with manure than with phosphate and the the cassava response is uneconomic. Tree crops do fairly well, especially cashew. Grapefruit and limes should be irrigated and mangoes will produce well if the right variety is used. Coconuts do not produce well but groundnuts give reasonable crops and respond well to fertilization. Chillies do well but give better crops of higher quality on the less fertile soils of the Shimba Hills and Duruma sandstones. Sisal is very successfully cultivated as a plantation crop on these soils but pineapples are of poor quality and most vegetable crops do not survive.

An earlier suggestion that the Arnotto plant (*Bixa orellana*) would be worth cultivating, has apparently been found sufficiently promising to follow up. It seems to thrive in the climate of the coast and to be free from disease and insect pests. Plantings at the forest station at Jilore appeared to be as healthy as those at Matuga.

II (b)—MANILKARA-DALBERGA/HYPARRHENIA: LOWLAND CULTIVATION SAVANNA

This association is a small one of about 200 square miles confined to the Jurassic shale soils lying between the Magarini ridge and the Shimba Hills. It is entirely secondary being brought about by fire and the heavy texture of the soils and in no place was the vegetation found in what could be considered original condition. The community has not been treated as a separate entity by any of the previous authors except Dale (1939).

The shale soils underlying this vegetation type are called the brown clay (Grumusolic soils) by Scott (1959) and are described in Appendix I as profile 20-1-1. This was the only soil encountered that developed a distinct calcium

carbonate horizon and is therefore placed in a category of lower effective moisture, or at least moisture penetration, than its neighbours. The surface heavy clay is very slowly permeable to water once it is wetted, is quite easily erodible, produces a high amount of runoff water, and is of low to moderate fertility. One of the factors limiting the cultivation of the soil is the high "power requirement" for effective cultivation so that even though reasonable crops can be raised it is simply too much work to do it with a *jembe*.

The grassland species and composition are presented in table 5. It can be seen that *Hyparrhenia*, *Cymbopogon*, and *Themeda* predominate in most stands. *Themeda triandra* seems to be the most vigorous in the first season after fire when it is replaced by the *Hyparrhenias*, *H. rufa* and *H. filipendula*. With grazing these are displaced with *Digitaria mombasana* and eventually *Heteropogon contortus*.

The major savanna trees over most of the association are *Manilkara densiflora*, *Dalbergia melamoxylon*, *Acacia mellifera*, *Sterculia africana*, *Terminalia prunoides*, *Diospyros* sp., *Commiphora* sp., *Sclerocarya caffra*, *Lonchocarpus ?bussei*, and *Cassia singueana*. A few herbs are present in the grassland, especially *Asparagus* sp., *Lippia* sp., *Teramnus labialis*, *Alysicarpus ovalifolius*, *Aspilia abyssinica*, and others. There is a tendency for *Manilkara* and *Diospyros* to be more frequent in the north.

Goats are grazed to some extent on the shale savanna and a few cattle but for the most part surface water is unavailable except for springs at the boundary of the shales with the overlying materials. The *shambas* that are found in the association are usually confined to the drainageways and valleys where more water is available from runoff and seepage. This leads to the development of a dense secondary bush in these drains on the abandoned cultivation. The first weeds on cultivation here are *Panicum trichocladum*, *Bothriochloa glabra*, *Cissus adenocaulis*, and *Abutilon asiaticus*. The cover is next dominated by *Commiphora* sp. and *Alophyllus alnifolius*, *Securinea virosa*, etc., forming the dense short bush until fire allows the re-establishment of *Hyparrhenia rufa*, *Setaria holstii*, etc., in the grassland.

III—BRACHYSTEGIA-AFZELIA: LOWLAND WOODLAND

The *Brachystegia spiciformis* forest is the great Central African "Miombo" and is universally recognized as such although not always called that. Gillman (1949) calls it "Woodland", Shantz (1923) calls it "Dry Forest", and Dale (1939) classes it as "Savanna Woodland" or "Mrihi".

The remnants of the *Brachystegia* forest are now scattered and of limited extent but the original area and the present site potential must cover more than 200 square miles. The full northern extent is unknown but there are well developed stands north of Adu, at Marafa, Garashi, and around Mangea Mountain. A broad band of the forest extends from north of Bamba to Gotani behind the Sokoke Forest and again occurs on the east side of the



Fig. 5.—*Manilkara-Dalbergia/Hyparrhenia*: Lowland cultivation savanna on shale soils. A frequently burned type, now dominated by *Hyparrhenias*, *Cymbopogon*, *Themeda* and other grasses. Kwale District, between Matuga and Kwale.



Fig. 6.—*Brachystegia-Afzelia*: Lowland Woodland. Between Jilore and Dida where fire prevents re-establishment of the closed shrubby understorey, this woodland supports a stand of *Panicum maximum* and *Digitaria mombasana*.

TABLE 5.—PERCENTAGE COMPOSITION OF THREE GRASSLAND TYPES. PERCENTAGES ARE FOR AERIAL COVER BY THE STEP-POINT METHOD. JANUARY, 1959

Species No. Stands (200 points)	Shale Soil 2	Shimba Hills 2	Coral Soil 1
<i>Hyparrhenia disoluta</i>	5	—	36
<i>H. rufa</i> (M.1194, M.1204)	19	2	2
<i>H. filipendula</i> (M.1224)	—	2	—
<i>Themeda triandra</i>	19	—	—
<i>Panicum maximum</i>	17	—	—
<i>Setaria holstii</i> (M.1197, 1208)	7	—	—
<i>Cymbopogon excavatus</i> (M.1195)	8	1	—
<i>Andropogon sp.</i> (M.1216, 1220, 1315)	—	38	18
<i>A. dummeri</i>	—	30	18
<i>Digitaria mombasana</i>	—	5	23
<i>Heteropogon contortus</i>	4	1	14
<i>Setaria sphacelata</i>	1	2	—
<i>Panicum trichocladium</i>	—	1	—
<i>Ctenium concinnum</i>	—	1	—
<i>Aristida lommellii</i>	—	—	1
<i>Carex sp.</i>	1	1	2
<i>Desmodium barbatum</i>	1	4	—
<i>Asparagus sp.</i>	2	—	—
<i>Desmanthus sp.</i>	1	—	—
<i>Pseudostheria hookeri</i> (M.1209, 1319)	1	—	3
<i>Crotalaria sp.</i>	—	7	—
<i>Acacia mellifera</i>	1	—	—
<i>A. zanzibarica</i>	1	—	—
<i>Piliostigma thonningii</i>	5	—	—
<i>Tetracera boiviniana</i>	—	2	—
<i>Heeria reclinata</i>	—	1	6
<i>Hyphaene</i>	—	—	21
<i>Strycnos sp.</i> (1322)	—	—	11
Soil	1	2	21
Rock	—	—	3

Magarini ridge behind the Mida Creek forest. South of Mombasa it is found on the Mwachi Forest and on the Shimba grits on the slopes of the Shimba Hills as well as to the south and west of the Shimba Hills between Kinango and LungaLunga, including the western slopes of Jombo.

In the Coast Province, the *Brachystegia* forest is an edaphic type which develops only on freely drained sands and its climatic limits are consequently relatively broad, 25 to 40 in. rainfall. The soils under *Brachystegia* are deep, loose, light grey to buff, medium to coarse sands (analysis 20-1-2). They often exceed 10 ft. in depth but in most situations there is evidence of groundwater at depth for part of the dry season. In the north of Kilifi District *Brachystegia* is usually confined to the stream bottoms where the alluvial sands are deep but in the country south of Bamba, the sands are overlying the fine-textured materials derived from the Mariakani and other sandstones that develop an impervious layer. These sands are slightly acid, very infertile, low in organic matter and extremely erosive where they have any slope at all. In parts of the

Gotani area, it is probable that considerable depth of sand has been removed by erosion. These soils are about as poor a prospect for agricultural development as any on the coast and are rarely cultivated by Africans.

An analysis of the *Brachystegia-Afzelia* community was made between the Sokoke Forest and the Mida Creek *Trachylobium-Macrolobium* forest. This site is more moist than the equivalent occurring on the west of the Sokoke but it represents a condition that must have been widespread at one time.

TABLE 7.—AN ANALYSIS OF THE BRACHYSTEGIA-AFZELIA ASSOCIATION BY THE POINT-CENTRED QUARTER METHOD. MARCH, 1959

Species	Mean Distance (feet)	Size classes (inches)				Total
		4-15.9	16-29.9	28-39.9	40+	
		Number of stems				
Brachystegia speciformis ..	53.8	31	27	7	6	71
Afzelia quanzensis	59.0	1	1	0	1	3
Trachylobium verrucosum ..	63.5	4	4	1	0	9
Sclerocarya birrea	21.0	7	1	0	0	8
Manilkara ?sp. nov.	68.7	2	1	1	0	4
Lannea stuhlmannii	36.0	0	1	0	0	1
Maerua sp.	54.0	0	1	0	0	1
Boscia ?sp.	38.0	1	0	0	0	1
Craibia sp.	18.0	1	0	0	0	1

Although the sample may not be statistically valid for more than the *Brachystegia*, the overwhelming dominance of that species can be seen. In fact, some removal of the *Afzelia* was going on at the time of sampling and undoubtedly had been done before. The *Trachylobium* was damaged by previous tapping for the gum copal and nearly every tree had a scar on one side of the bole running up to about 10 ft. from the ground. In spite of these circumstances, the general character of the forest is evident from the sample: the large size of the tree and the great distance between them as well as the dominance of the *Brachystegia* giving the open character to the woodland.

Species of the understory were rarely shrubby but were dominantly grasses such as *Digitaria mombasana*, *Panicum maximum*, *Dignathia gracilis*, *Eragrostis perbella*, *Panicum sp.*, with *Stylosanthes mucronata*, *Cassia mimoides*, *Capitania otostegioides*, *Hibiscus micranthus*, *Vepris lanceolata*, *Pyrenacantha Kamassana*, *Gisekia pharmacoides*, *Rothmannia fischeri*, *Tinnea aethiopica*, *Gelonium zanzibarense*, *Ximenia americana*, and a few others.

Isoberlinia magnistipulata is a codominant understory tree in many of the more favoured sites within the association and must at one time have been much more in evidence than now. After fire, the understory of this forest becomes nearly a solid stand of the above-mentioned *Digitaria* and



Fig. 7.—*Combretum schumannii*-*Cassipourea*: Lowland Dry Forest on Coral Rag. The dense coastal thicket occupies these coral soils after removal of the forest. Dominants are *Lantana*, *Grewia*, *Combretum*, *Securinega*, *Commiphora*, etc. The soils are frequently shallow over the impervious coral.



Fig. 8.—*Hyparrhenia*-*Digitaria*/Doom Palm savanna on coral soils. The composition is described in Table 5.

Panicum which appears to be very productive for grazing and will probably yield 15 tons of dry matter per acre per year. Stocking of the area should be kept very much below the apparent carrying capacity, however, because of the danger of damage from trampling. In areas to the north of Gotani it appears that even relatively light grazing has eliminated much of the forage by trampling and by pulling the plants out of the loose sand. The more compact grey-buff, saline? sands, dominated by *Isoberlinia* would probably yield a higher carrying capacity of fire-savanna. Research to determine the validity of these conjectures needs to be carried out.

It has been asserted by some writers that the main Miombo forest in Central Africa is a fire climax but recent research by Trapnell (1958) has shown that *Brachystegia* is semi-tolerant to fire and that it can be destroyed by late burning. Research with fire should be directed toward preserving the canopy of trees while destroying the shrubby understory and allowing the grasses to increase.

IV—*COMBRETUM SCHUMANNII*-*CASSIPOUREA*: LOWLAND DRY FOREST ON CORAL RAG

The flora of the coral soils at the coast is distinct but for the most part was destroyed long ago. An attempt was made to determine the original nature of the forest at a few places where fire and cultivation had not been carried on in recent history. The vegetation type has not been recognized by previous authors and Dale (1939) states that the coral carries secondary bush.

The area covered by the Coral Rag forest is small and does not extend north of Mida Creek any great distance. It probably never exceeded three miles in width and so only perhaps 150 square miles is involved.

The soils are described as coral rag by Scott (1959) and are similar to those known as Terra rossa and Rendzina in other parts of the world. Profiles 31-1-1 and 23-1-1 (Appendix I) are appropriate to a large part of the area but also there are considerable outcroppings of pure coral, coral gravel, and coral covered with a thin mantle of windblown and lagoonal sand. The soils are similar in many respects to those of the Kambe limestone area except that less rainfall is incident on the site. Rainfall varies between 30 and 40 in. but occasionally goes higher as at Msambweni (52.1 in.). Where it does, the character of the forest is more nearly that of the rainforest.

Combretum schumannii and *Cassipourea euryoides* are present together and dominate but one or the other may be the major species. *Fagara holtziana* and *F. chalybea* are striking members of the community with the knobby trunks and sharp spines. Others present are *Adansonia digitata*, *Mallotus oppositifolius*, *Rinorea* sp., *Hunteria africana*, *Erythroxylon emarginatum*, *Sideroxylon diospyroides*, and *Drypetes* sp. The understory is frequently of *Pemphis acidula*, *Pycnocoma littoralis*, *Notobuxus obtusifolius*, and *Grewia vaughanii*.

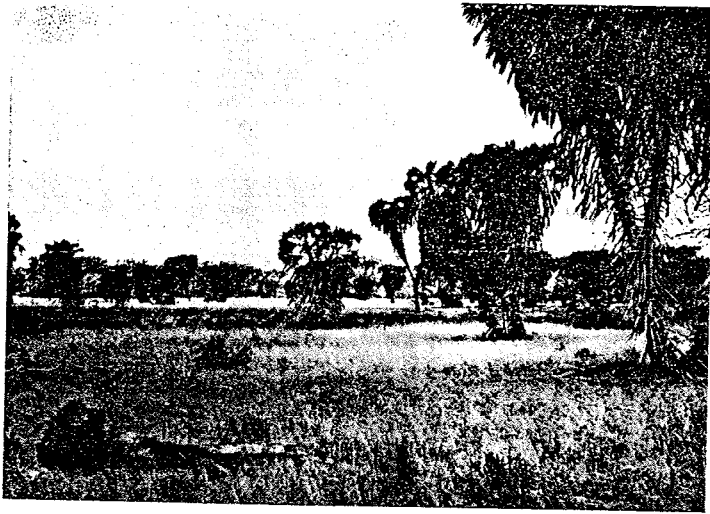


Fig. 9.—Doum Palm savanna on sandy soils after frequent burning and grazing. The picture, taken between Witu and Lamu, is representative of large areas in the northern half of the coast.



Fig. 10.—*Sterculia-Chlorophora/Memecylon*: Lowland Rain Forest. A portion of the Makadara Forest described in Table 8. Kwale District.

When the forest is destroyed, the characteristic and widespread coastal bush quickly dominates. It is the same dense thicket that was described on the Kambe limestone soils in the rain forest, on the shale soils, and it occurs in the savanna formation as an early stage after cultivation. On the coral soils it is usually dominated by *Lantana camara*, *Commiphora* spp., *Combretum constrictum*, *Rhus natalensis*, *Securinega virosa*, *Hoslundia opposita*, *Grewia glandulos*, etc.

At least two further retrogressive stages are found on the coral soils. Where fire follows cultivation and dense thicket formation, there is developed a savanna of *Hyparrhenia*, *Digitaria*, and *Heteropogon contortus* in scattered trees and shrubs including *Hyphaene compressa* (Rawlins, 1958) as illustrated in table 5, and included in VI, below. The second and lower stage occurs when most of the shrubs and trees are destroyed leaving the Doum Palms (*Hyphaene compressa*) and a weedy grassland of *Hyparrhenia dissoluta*, *H. rufa*, *Heteropogon contortus* and *Wedelia* and *Oldenlandia*.

The soil fertility in this type is relatively high and it has been used for African cultivation for many years even where the coral outcrops very near or at the surface. Maize, beans, cassava, and a wide variety of vegetable crops are produced with little effort and the association furnishes the site for much of the coconut growing.

V—*STERCULIA-CHLOROPHORA/MEMECYLON*: LOWLAND RAIN FOREST

The rain forest community is widely recognized and described as "Forest," "Tropical Rain Forest", "Lowland Moist Evergreen Forest", and "Lowland Evergreen Rain Forest", by Gillman (1949), Shantz (1923), Pichi-Sermolli (1957), and Dale (1939).

The rain forest association is being continually depleted in the coastal lands by the combination of fire, logging and cultivation, but at present relatively intact stands must cover nearly 100 square miles. This is about 10 per cent or less of the area that seems to have the potential still to produce this type forest. Although the composition differs from stand to stand in the remnants, they are here grouped together following Dale's work. The areas involved include the Witu Forest in the north, the Mida-Gede Forest, areas near Malindi and along the Sabaki, the Kayas and adjacent areas near Chonyi, Rabai, Ribe, Jibana, Gongoni Forest, the Shimba Hills remnants, much of the Ramisi River Valley including Mrima and eastern slopes of Jombo Hill, and portions of the Uмба River Valley.

The *Sterculia-Chlorophora/Memecylon* association is the most moist of the terrestrial types requiring a minimum of 40 in. of annual precipitation. Compensating factors may operate to permit survival at less than this, such as a high ground water table at Witu, but usually the character of the forest is slightly different when this occurs. The Kenya Lowland Rain Forest type

cannot qualify as a true rain forest since a pronounced dry season is experienced especially in the northern districts. The southern remnant patches of the forest have a striking similarity to the forests of the Eastern Usambara Mountains in Tanganyika.

The soils associated with the rain forest are varied and derived from dune and alluvial sands, the Shimba grits and the "lagoonal" and wind-blown sands. They are usually classed as the yellow-red loamy sands (podzolic soils) and to a lesser degree the brownish-yellow loamy sands with laterite horizon. These are in general very infertile soils (see analyses 5-12-2 and 12-12-1 in Appendix) and similar soils (yellow-red podzolic) in other parts of the world are not successfully cropped for more than a few years after removal of the forest without heavy applications of fertilizer.

The composition of this, as of most rainforest, is complex and the species list is long. No attempt will be made to be complete or to describe all the observed variation in detail. The following table of analysis is interesting mainly for what it shows of the structure of the forest and because the major understory tree, here identified as *Olex dissitiflora*, was not previously recorded from Kenya in the East African Herbarium.

TABLE 8.—AN ANALYSIS OF THE STERCULIA-CHLOROPHORA/MEMECYLON ASSOCIATION BY THE POINT-CENTRED QUARTER METHOD. DECEMBER, 1958

Species	Mean Distance (feet)	Size classes (inches)				Total
		4-5.9	6-7.9	8-9.9	10+	
		Number of stems				
Cylicodiscus battiscombii ..	18.7	0	0	0	2	2
Trachylobium verrucosum ..	20.7	1	0	2	2	5
Bombax rhodognaphalon ..	8.4	0	0	1	1	2
Macrobium coeruleum ..	10.6	1	3	0	9	13
Manilkara ? cuneofolium ..	9.7	4	2	0	3	9
Celtis soyauxii ..	13.2	6	4	2	1	13
Olex dissitiflora ..	14.2	24	7	4	6	41
Combretum schumannii ..	10.2	1	0	0	4	5
Cola sp. aff. minor ..	9.4	3	0	0	0	3
Conopharyngia holstii ..	10.0	0	2	0	0	2
Albizia gummifera ..	10.2	0	0	0	2	2
Cistanthera parvifolia ..	11.9	0	1	0	1	2
Macaranga kilimandscharica	8.8	0	0	0	1	1

Although the table is not presented in its entirety here, it is seen from the size class distribution that there is little replacement of the tall forest species such as *Cylicodiscus*, *Macaranga*, *Antiaris toxicaria*, *Chlorophora excelsa* or *Bombax*, but that *Macrobium*, *Trachylobium*, *Combretum* and *Manilkara* show a tendency to replace them. The composition of the understory, which is only apparent when one is familiar with the stature of the listed species, contains a small tree layer dominated by *Olex dissitiflora*, *Celtis soyauxii*, *Conopharyngia holstii* and *Angylocalyx braunii* and a shrub and herb layer dominated in various places by *Memecylon verrucosum*, *Hypoestes verticillaris*, *Dracaena usambarensis*, *Olyria latifolia*, *Vismia*

orientalis, *Megastachya mucronata*, *Aframomum angustifolium*, *Eragrostis tenuifolia*, *Sporobolus tenuissimus*, *Panicum brevifolium* and *Geophila* sp. *Asplenium ?nidus* is a common epiphyte and lianes include *Saba* (formerly *Landolphia*!) *comorensis* var. *florida* and *Entada pursaetha*.

The rain forest type has largely been destroyed by fire and logging and at present many of the remnant patches are confined to protected valleys in the Shimba Hills and the areas already mentioned. Much of the remainder of the area is left in savanna dominated by species of *Andropogon* and *Hyparrhenia* (see Shimba Hills Grassland in table 5) with clumps of trees and shrubs which include *Macrobium coeruleum* on sandier soils and *Manilkara ?cuneifolia*, *Trichilia roka*, *Azelia quanzensis*, *Erythrophleum guineense*, *Phoenix reclinata*, *Sorindeia obtusifoliolata*, *Apodytes dimidiata*, and with *Tetracera boiviniana* and *Vernonia ?holstii* frequent invaders in the grassland. The thickets and clumps are frequently but not always centred around termite mounds. The regeneration of the high forest from the savanna appears to be possible in many places but is probably a very slow process. Dale (1939) has postulated, very plausibly, that loss of soil materials following destruction of the forest limits its potential for regeneration. While no differences are apparent in soils inside and outside the forest in either morphology or chemistry (Analyses 5-12-1, 5-12-2, 5-12-3), it is possible that the closed nutrient cycle, on which the forest persists, is broken and the potential for reproduction lost. There is observational evidence, however, that where coppice species have persisted for long periods in valleys that the high forest species again come in, probably in response to better moisture and fertility conditions.

A different phase of the forest is found on the lowland alluvial soils of the Ramisi Valley and in the Witu Forest (see descriptions by Dale, 1939, and Rawlins, 1957). Another type is found on the Kayas persisting because of local sanctity on the Mazeras sandstones and Kambe limestones. The Kambe limestone terra rossa soil is among the most fertile in the Province under natural conditions and an area of expanding agricultural development, especially citrus and coconut, and is admirably suited for African style cultivation because of the remnant pillars and columns of limestone remaining in the soil. The outcroppings of limestone themselves develop a unique flora which includes some of the rainforest species, such as *Sterculia*, *Chlorophora*, etc., but also a *Ficus* sp., *Euphorbia wakefieldii*, *Saintpaulia* sp., *Cissus quadrangularis*, *Zamioculcas zamiifolia* and others. Profile 11-2-1 shows the sample taken from an African *shamba* which had been recently cultivated (see Appendix). After cultivation, a dense shrubby thicket develops in this association which is nearly the same as the thicket on coral soils described above. *Vernonia hildebrandtii*, *Bridelia melanthesoides*, *Rhus natalensis*, *Securinega virosa*, *Phyllanthus guineensis*, *Antidesma* sp., *Ritchea* sp., *Byrsocarpus orientalis*, *Hibiscus micranthus*, *Capparis* sp., and some invading trees, *Syzgium cumini* (the "Jambolan"), *Gyrocarpus*, *Cynometra* and *Albizia* are present.

In the Mrima-Jombo volcanic complex of the Ramisi River Valley a segment of the rain forest develops on the fertile chocolate volcanic soils that has been described by B. Verdcourt as being dominated by *Sterculia appendiculata*, *Antiaris Toxicaria*, *Newtonia paucijuga* and *Combretum schumannii* with *Terminalia kilimandscharica*, *Lovaa swynnertonii*, *Lannea ?amaniensis*, *Chlorophora excelsa*, *Albizia* spp., *Cola* spp., *Pachystela*, *Fagara*, *Vitex*, *Uvaria*, *Oplismenus*, *Olyra*, *Ageratum*, etc.

In the Sabaki River Valley, on the alluvial soils and adjacent lowlands, the forest is less well developed and includes *Acacia clavigera* subsp., *usambarensis*, *Dobera loranthifolia* and *Newtonia* sp.

The three above situations represent lands with high potential for agricultural development and much progress is being made. The cotton crop in the Sabaki Valley can be further expanded and greatly improved as can the production of other crops in the Chonyi-Jibana locations and the Ramisi area. Cotton apparently does not do well in the southern locations because the longer wet season limits ripening and increases the probability of disease. Intensive cultivation of many African crops as well as cash crops such as tobacco and chillies can be increased in the southern regions although as pointed out the natural fertility is lower as one proceeds away from the volcanic soils, except downstream. It seems reasonable to assume that these volcanic soils contribute to the apparent higher fertility level of the Ramisi Valley. No specific evidence of this fact is offered and could not be obtained without a detailed soil survey of the area.

Assumptions about the agricultural development of the rain forest association rest on the ground that timber production is not the highest use of the land. Present stands of timber seem to be cut over so that logging is ever more expensive to undertake on a commercial basis. The only successful sugar plantation is located in this area and is expanding. Sisal is grown as well but seems to suffer from the vigorous competition from grasses and shrubs, quickly becoming choked into low productivity. Pineapples can be grown with relative ease but the product is not of high quality nor is it uniform enough to be easily packed with modern methods. With pineapple as with so many other of the potential coastal crops, the major limiting factor in the production of high quality crops is the industry of the peasant farmer. Until the desire to produce a higher quality product for a higher standard of living with the work that it involves is found in the local African there will be no highly developed peasant agriculture. These and the problems of land tenure and ownership are outside the scope of this report.

High populations of game animals and heavy infestations of tsetse severely limit the production of beef from the savanna grassland associated with the fire-destroyed forest.

VI—AFZELIA-ALBIZIA/PANICUM: LOWLAND MOIST SAVANNA

This association is described in the "Coastal high grass-bush" of Edwards (1956), "Savanna" of Pichi-Sermolli (1957), in part as the "Lowland ever-green edaphic forest" and "Secondary scrub on coastal sands" by Dale (1939).

The moist lowland savanna in all its phases is an extensive type covering probably 800 to 1,000 square miles. It was almost certainly less extensive in the past and is being expanded by fire and cultivation, since the majority of the savanna areas on the coast are secondary to other types.

The *Azelia-Albizia* association occurs on many of the more moist soil types. The major distribution is on the coastal sands (Lagoonal) and on the yellow-red loamy sands (podsollic soils) in the coast south of Mombasa. The rainfall in most of the area is above 30 in. and includes some areas with precipitation in excess of 50 in. where the type is secondary to the rain forest.

Many of the species of the wooded portions of the savanna are species of the rain forest type from which it was derived. Others of this higher story are *Azelia quanzensis*, *Albizia* spp. (*A. adianthifolia*, *A. gummifera*, *A. anthelmintica*, *A. versicolor*, *Fiscus* spp., *Paramacrolobium coeruleum*, *Vitex mombassae*, *Syzygium cordatum*, *Erythrina saculeuxii*, *Vangueria tomentosa*, *Trichilia roka* and *Hyphaene compressa*. *Saba comorensis* var. *florida* and *Entada pursaetha* are frequent lianas. Small trees and shrubs are usually scattered in the more open sites and are usually represented by several of the following: *Strychnos* spp., *Thylachium africanum*, *Stereospermum kunthianum*, *Lonchocarpus ?bussei*, *Securidaca longipedunculata*, *Crossopteryx febrifuga*, *Urginea altissima*, *Vernonia* spp., *Polysphaeria parvifolia*, *Gardenia* sp., *Markhamia* sp., *Dalbergia melanoxylon*, etc. The grasses are many and varied in their ecology since the savanna may be produced by several different agents, including impeded drainage or a high water table. Observed species include: *Panicum maximum*, *P. deustum*, *Pennisetum polystachyon*, *Imperata cylindrica*, *Dactyloctenium* sp., *Paspalum commersonii*, *Sporobolus pyramidalis*, *Echinochloa haploclada*, *Eragrostis perbella*, *Digitaria mombasana*, *Setaria trinervia*, *Perotis patens* and others.

Lying between the *Azelia-Albizia/Panicum savanna* and the secondary associations on coral rag soils, occurs a type best described as the *Heeria-Anona/Hyparrhenia savanna*. It is best developed on a thin-mantle of wind-blown and alluvial sand overlying the coral or may occur on quite deep sands either as a fire-induced type or in some instances of impeded drainage. The taller trees are usually completely missing except for the Doum Palm and a few others. The major grass vegetation has already been described in table 5 and the description following. The two savanna types intergrade with a very diffuse ecotone if they are really distinct at all. The shrubs usually found are *Anono chrysophylla*, *Piliostigma thonningii*, *Heeria mucronata*, *Markhamia zanzibarica*, *M. hildebrandii*, *Ehretia* sp., *Lannea stuhlmannii*, *Ziziphys mauritiana*, *Dichrostachys cinerea*, with the grasses as already stated.

The savanna associations include also two which are dominated by palms. Large areas on the Shimoni peninsula and in the Shimba Settlement Scheme area have prominent stands of *Borassus aethiopum*. The origin of the plant and the etiology of the *Borassus savanna* are largely unknown and were not particularly studied at this time, but is included in the general association.



Fig. 11.—Sand-dune and beach community north of Malindi. The fore-dune on the right is covered with the viney *Ipomea pes-caprae*. The first interdune in left-centre is carpeted with *Cyperus maritimus*, while the stable dune on the left is occupied by the *Hyphaene parvula*, *Scaevola*, and taller shrubs.



Fig. 12.—African cultivation on the lagoonal sands of the Digo Native Land Unit (Kwale District). Crops that can be seen growing together include coco-nut, cashew, cassava, banana, mango, kapok, native vegetable and pasture plants.

As was described in section IV for the *Combretum-Cassipourea* forest, so in the *Azelia-Albizia* association, the Doum Palm, *Hyphaene compressa*, increases to a great degree with fire and disturbance by man. *Hyphaene* is a regular component of relatively undisturbed savanna, but it occurs only rarely in most of the stands. The Doum Palm of the north coast has been studied by Rawlins (1958) and found to spread rapidly by animal vectors, including baboons, elephants and man. The Doum Palm is thought to have spread from a habitat on the margins of ponds and temporary lakes in the forest to colonize the coastal sands after fire, especially where the water table is fairly high. The plant is very resistant to fire in the seedling stage and, as a coppicing shrub, can survive long continued browsing and harvesting for fibre. Because of the frequency with which even-aged stands occur, it is thought that they are readily established only in years of favourable weather conditions.

Clipping studies of a few stands in the *Azelia-Albizia* and *Heeria-Anona* savanna have shown that the forage produced in one season is between 10 and 15 tons per acre, on a dry-weight basis. This amount of forage will provide one animal unit of grazing per acre per year even if only utilized at 50 per cent by local cattle. Unfortunately the association as a whole is heavily infested with tsetse fly and the pronounced seasonal fluctuation in production limits the carrying capacity to a very low figure.

In general the soil fertility seems to be low and African cultivation is carried on only intermittently with population being sparse. In part this is the result of elephant populations that damage cultivations. When the forest patches are cultivated, they regenerate very quickly with shrubs and grasses, and if not burned will return to forest. Portions of the more heavily forested parts are being cleared for plantations. Tree crops are particularly well adapted to the conditions in this area, although forestry is not highly productive. Coconut, citrus, cashew, mango, kapok, etc., are grown. With fertilization an additional range of cash and food crops can be grown.

VII—SAND DUNE AND BEACH LITTORAL

Dune sands are a common feature of the coast north of Malindi and in the Lamu vicinity. The flora and structure of this type has been studied by Rawlins (1958) in the Lamu district.

Many of the strand species from the beaches on the south coast occur along the foredunes in the northern parts, but many of the associated species in the north are derived from the flora of more arid areas. *Ipomea pes-caprae* is almost universally present as the leading seaward plant and is frequently associated with *Cyperus maritimus*, *Halopyrum mucronatum*, *Scaevola plumieri*, *Suaeda monoica* and *Tephrosia noctiflora*. On the second dune from the high-tide mark and in the interdunes, a more stable vegetation appears consisting of *Hyphaene parvula*, *Salvadora persica*, *Garcinia livingstonei*, *Flacourtia indica*, *Sideroxylon diospyroides*, *Cordia somalensis*, *Ehretia*

petiolaris, *Cadaba farinosa*, *Croton menyhartii*, *Enteropogon macrostachyus*, *Haplocoelum inopleum*, *Sterculia africana*, etc. In places the line of the beach is clearly marked by a line of *Casuarina equisetifolia* trees.

The dune sand community furnishes no agricultural potential although some of the more stable ancient dune formations are used for African agriculture.

VIII—MANGOVE THICKET AND ADJACENT SALINE AREAS (NOT MAPPED)

(a) Mangrove thickets, mangrove swamps or mangrove forests are those easily identifiable communities dominated by *Rhizophora mucronata* and a few other species with similar ecology. The mangrove has not been considered in the present study since the area is of little agricultural use and has been the object of considerable study by foresters and ecologists (Dale, 1939; Pichi-Sermolli, 1957; Shantz and Marbut, 1923; Walter and Steiner, 1936).

Mangroves are confined to tidal estuaries and lagoons along the coast where they are protected from the force of the open sea, have a supply of fresh water in some cases, and have a supply of heavy, waterlogged mud. These areas are usually not far distant from the mouths of the coastal streams and range from the tidal flats only occasionally inundated by the sea to stands in several feet of water.

The area in mangroves is estimated at 111,000 acres (Dale, 1939). The major stands are in the Lamu area, including the islands of Patte and Manda, and in the Vanga-Funze system near the Tanganyika border. Other less extensive mangrove stands occur at Mtwapa, Mida and Kilifi Creeks, Gazi, Mombasa-Port Reitz area, Ngomeni-Fundi Isa and the mouth of the Tana. All are areas of very flat topography within a few feet of mean sea level.

The principal trees, other than *Rhizophora*, are found on the landward and seaward fringes of mangrove stands. These are *Avicennia marina*, *Bruguiera gymnorhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Sonneratia caseolaris* and *Xylocarpus benadirensis*.

(b) *Sporobolus virginicus*-*Arthrocnemum*: Saline grassland.—The flats on the landward margins of mangrove thickets usually support an open, low grass and shrub mixture characteristic of saline soils and pond margins. These soils are compact lacustrine or lagoonal clays and are of little consequence for agriculture except for their occurrence along the stock driveway from the north and in the areas of rice cultivation along the Tana and Umba Rivers. They were not closely examined in this study, but a few of the dominant species can be listed as follows: *Sporobolus virginicus*, *Panicum pinifolium*, *Dactyloctenium* sp., *Cenchrus ciliaris*, *Echinochloa haploclada*, *Fuirena* sp. (Cyperaceae), *Arthrocnemum indicum*, *Suaeda monoica* and a few trees like *Acacia zanzibarica* and *Dobers glabra*.

IX—PAN AND POND

Temporary pans or areas of impeded drainage ("Zewa") are frequent in the Coast Province, occurring where clays have accumulated or where

the water table is high during some part of the season. Perhaps the low relief of the coast with the consequent slow movement of groundwater has allowed the clays to accumulate in low places to form black cotton soils and other types.

Pans are usually dry for long periods during the dry season and develop a flora of their own. In most of the places observed it consisted of a pure stand of grass of a few species or of a single species and often of several acres in extent. *Echinochloa haploclada*, *Setaria sphacelata* and *Sorghum verticilliflorum* (possibly cultivated) were frequently encountered. These areas furnish considerable grazing during dry seasons and sometimes if not usually are cultivated with rice or other grains.

Ponds or permanent water sources are marked by a range of sedges and rushes, ferns, lilies (*Nymphaea* sp.) and characteristic shrubs that might be mentioned only as indicators of groundwater, but are usually unnecessary as water is fully utilized by the local people.

GENERAL RECOMMENDATIONS

Since many suggestions have been made, included in the body of the report in the appropriate ecological unit, the observations made here will be brief and of a general nature.

1. It is hoped that agricultural research will be guided by ecology and that this report will offer a beginning in the direction of careful definition of ecological land-use units. It has been found helpful in most countries to specify ecological types within which research is conducted and to which results apply. Careful attention to initial definition, mapping and examination of the ecologic unit frequently results in economies of research effort and successful application of results obtained. This is already being done in many cases.

2. Research in grazing-land management needs to be carried out much more vigorously. Brush control methods, the use of fire as a tool in management, the determination of stocking rates, seasonal use and supplementary forage requirements, nutritional and dietary requirements of local breeds, competition from and complementary use of range by game, and the economics of production are all little-known subjects under Coast Province conditions. Much of this research is of interest to other departments and divisions of agriculture and is being carried out by them. It would be of immense value to all concerned if many of these problems were approached on a co-operative basis. Much of the research now under way in this area is suffering from a somewhat one-sided approach. As an example, much could be gained by attaching an agricultural officer with range management or forage crops experience and training to the Mariakani Breeding Centre, or again, to the Tsetse Control experimental pastures at Vigurungani.

It is recognized that some enormous administrative problems are encountered when trying to regulate and remove African livestock, but it is certainly to be hoped that when the administrative problems are solved that research will be far enough along to give concrete answers to the questions of how to best preserve the productive capacity of the land.

3. Some specific suggestions should be made for the initiation of a programme of testing, selecting and even breeding of local grasses and legumes. The best answers to management problems in pasture production will probably come from development of the plants already at hand. The grasses of particular interest are the local *Hyparrhenias*, *H. rufa*, *H. filipendula* and *H. dissoluta*, *Digitarias*, especially *D. mombasana* and some of the *Eragrostis*, *Andropogon*, *Setaria* and *Cenchrus* species. The legumes of interest include *Leuceana glauca* and species in the genera *Stylosanthes*, *Indigofera*, *Desmodium*, *Teramnus*, *Canavalia*, *Galactea*.

4. It has been suggested by others that detailed soil surveys be conducted in the Coast Province as a series of transects from the beach into the hinterland to give a picture of the nature and variability of the soils. An initial attempt was made in the present study to do just that for the plant ecology and as a result it is suggested that three areas would be especially profitable for such an attempt. They are: (a) the Ramisi River valley and the lowlands, including the volcanic intrusions of Mrima and Jombo; (b) a transect from Mtwapa Creek toward the north-west to include the Kambe limestone soils and the sands north of Gotani; (c) the Sabaki alluvial soils and a strip to the north of the river which furnishes some agricultural potential and is being expanded now by the Giriama.

5. Continued work and expansion of research in drug, dye and resin plants will probably be fruitful.

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APPENDIX I.—DETAILED SOIL DESCRIPTIONS AND CHEMISTRY. DATA ARE FROM THE SOIL ANALYSIS SECTION, SCOTT AGRICULTURAL LABORATORY

Name and Description	Depth Inches	pH	N		C	P ppm	Mn	Mg	m.e. %		
			%						Ca	K	Na
31-1-1 Jadini Beach "terra rossa" = dark reddish brown fine sandy loam over coral .. Coral breccia	0-8 8x	5.9	.04		.61	11	0.4	1.0	3.6	0.3	0.1
23-1-1 Diane Beach—dark reddish-brown, pris- matic to subangular blocky, loam deposited between rounded bosses of weathered coral nearly at surface. 2.5 % gravel	0-16 16-33x	7.0 8.1	.11 .04		.93 .29	9 8	0.6 <0.1	1.2 0.7	10.0 34.0	0.2 0.1	0.1 0.2
11-2-1 Kambe limestone "Jembe layer" brown blocky or structureless vesicular but hard fine sandy loam	0-8	6.1	.12		1.05	7	0.7	1.9	4.8	0.5	0.2
Medium brownish-red fine sandy loam, trace gravel	8-24	6.5	.05		.30	7	0.6	1.0	2.8	0.3	0.1
Medium brownish-red massive fine sandy loam with laterized granules, trace gravel	24-30	6.5	.06		.21	2	0.5	0.8	2.8	0.1	0.1
24-1-1 Lagoonal sands. Light grey loose sand. 0.2 % gravel	0-10	7.0	.03		.35	11	0.3	0.3	2.4	0.1	0.1
Light orange massive but friable medium sand. 0.6 % gravel	10-23	6.0	.03		.23	9	0.4	0.3	1.2	0.1	0.1
Medium reddish-brown (dark orange), massive and partially indurated clayey sand. 0.5 % gravel	23-40x	5.4	.04		.17	8	0.2	0.9	1.6	0.1	0.1

APPENDIX I.—DETAILED SOIL DESCRIPTIONS AND CHEMISTRY.
DATA ARE FROM THE SOIL ANALYSIS SECTION, SCOTT AGRICULTURAL LABORATORY—(Contd.)

Name and Description	Depth	pH	N	C	P	Mn	Mg	Ca	K	Na
	Inches									
20-1-1 Jurassic shales. Medium grey, subangular blocky clay (very dry) 0.7 % gravel... Medium yellow-brown subangular blocky to crumb heavy clay (slightly moist) 3.7 % gravel Light brownish-yellow friable sandy clay. CaCO ₃ concretions in upper portion. 4.1 % gravel	0-9	6.2	.14	1.80	10	0.2	2.0	16.0	0.2	0.2
	9-25	6.8	.09	.79	11	0.3	1.9	18.0	0.1	0.3
	26-35x	8.1	.06	.44	10	<0.1	1.7	29.6	0.1	0.3
20-1-2 Deep sand, buff to white, loose, 3.0 % gravel	0-120	6.6	.02	.09	6	0.1	0.2	1.2	<0.1	0.1
14-1-2 Shimba Macrolob. thickest sand light brown friable, loamy sand. 0.4 % gravel Light brownish-red, compact loamy sand. 1.0 % gravel	0-24	4.5	.05	.63	5	<0.1	0.1	0.2	<0.1	0.1
	24-28	4.2	.04	.51	11	0.1	0.1	0.2	0.1	0.1
14-1-1 Shimba grassland. Light reddish-brown, massive loamy sand, major root zone, 6.7 % gravel, 5 % slope NW. Decomposed rock and quartzitic concretionary material (murrum), red and purple mottled rocky to gravelly compacted material in sandy red-brown matrix, 6.1 % gravel	0-8	5.3	.06	.66	4	0.1	0.5	0.4	0.4	0.1
	8-16x	5.0	.04	.60	5	0.1	0.2	0.2	<0.2	0.1

APPENDIX I.—DETAILED SOIL DESCRIPTIONS AND CHEMISTRY.
DATA ARE FROM THE SOIL ANALYSIS SECTION, SCOTT AGRICULTURAL LABORATORY—(Contd.)

Name and Description	Depth	pH	N	C	P	Mn	Mg	Ca	K	Na
	Inches									
5-12-3 Shimba grassland, Longo Magandi. Dark grey-brown structureless loamy sand. 0 gravel. 0 slope. 150 feet outside forest	0-14 14x	5.7 5.4	.07 .05	1.04 .49	5 4	0.1 <0.1	1.0 0.4	1.0 0.2	<0.1 <0.1	0.1 0.1
5-12-1 L.M. Reddish-brown structureless loamy sand. 0 gravel. 0 slope. 50 feet inside forest Medium grey-brown sand	0-16 16-24x	6.0 5.5	.09 .04	.61 .31	5 9	0.2 0.1	1.0 0.6	1.6 0.2	<0.1 <0.1	0.1 0.1
5-12-2 L.M. Medium grey-brown sand. 0 gravel. 0 slope. 150 feet inside forest Medium grey-brown sand, more compact? 12-12-1	0-12 12-24x	5.8 5.7	.09 .05	.92 .37	6 7	0.3 0.1	1.2 0.5	2.8 1.2	0.1 0.1	0.1 0.1
Makadara Mod. friable reddish-brown sand. Trace gravel Trans. 3. 0 gravel. Massive Trans. 3. 0 gravel	0-13 13-19 19-24	3.7 3.9 4.0	.07 .07 .03	1.01 0.43 0.46	9 5 7	0.1 <0.1 <0.1	0.1 0.1 0.1	0.2 0.2 0.2	0.1 <0.1 <0.1	0.1 0.1 0.1
10-2-1 Mariakani sandstone profile. Medium grey columnar indurate silt loam. Trace gravel 2 % slope Dark yellow-orange prismatic—blocky silty clay. 2.2 % gravel. Mottled with iron concretions	0-10 10-24	4.1 6.0	.04 .05	0.61 0.31	6 7	0.5 0.1	3.2 5.7	2.4 2.6	0.2 0.1	0.1 0.7

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