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MANGROVE VEGETATION AND SOILS ALONG AN ACCRETING PART OF THE COAST OF WEST AFRICA AND THEIR IMPLICATION TO CONSERVATION

I. UKPONG

Dept. Geography/Regional Planning, University of Uyo
P. M. Box 1017, Uyo, Akwa Ibom State, Nigeria

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Mangrove vegetation and soil along an accreting estuary in West Africa were studied with a view to understanding the community structure and soil characteristics of the ecosystem. To obtain representative data the vegetation and soil were sampled on the basis of habitat differentiation. Species dominance varied between the habitats. Overlapping boundaries between habitats resulted in mixed interface vegetation. Although *Rhizophora racemosa* appeared to be the pioneer colonizer of mudflats, the mature vegetation was structurally more complex; species occurrences consisted of mixed stands of tree species and aberrants of shrubs and ferns. *Nypa fruticans*, an introduced species was ecologically more important than other species. Soil analysis indicated hypersalinity although the surface water system generally varies from brackish / fresh to saline. The soils are silty, organic and peaty with a high cation sink in terms of exchangeable magnesium. The distinguishing characteristics of the habitats were mainly in the substrate texture. The findings could be used to initiate baseline studies aimed at the conservation of estuarine mangrove forests.

Key words: conservation, mangrove, soil, W Africa

Introduction

Mangroves are halophytic in nature, occupying brackish and saline shorelines in the tropics and subtropics. But in West Africa the coastline does not favour extensive mangrove growth due to the presence of fault lines and rising sea level (Ibe and Antia 1983), and subsidence outstripping the supply of sediments with the result that the coastline displays an erosional trend (Hoyt 1967). However, along the deltas and estuaries, shallow water depths lead to reduced wave energy resulting in inlets predominantly depositional. In this area, sedimentation has tended to keep pace with tidal inundation resulting in the formation of mudflats which support mangrove vegetation. Due to the predominance of inlets, Keay (1953) maintained that the most mature mangroves in the West African mangrove subregion occur along the Nigerian–Cameroun coast where the Cross River estuary is found (Fig. 1).

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The growth of mangrove is associated with substrate transformation; upon colonization of mudflats, the soil becomes firm through entrapment of sediments and addition of organic detritus as the mangrove develop. This study aims at analysing the mangrove vegetation and soil with a view to understanding the community structure, soil characteristics of accretive mangrove swamps and their implications to the conservation of coastal/estuarine vegetation in general.

Study area

The Cross River estuary in West Africa (Fig. 1) typifies a tropical ever-wet mangrove swamp with an annual rainfall of 3886 mm, relative

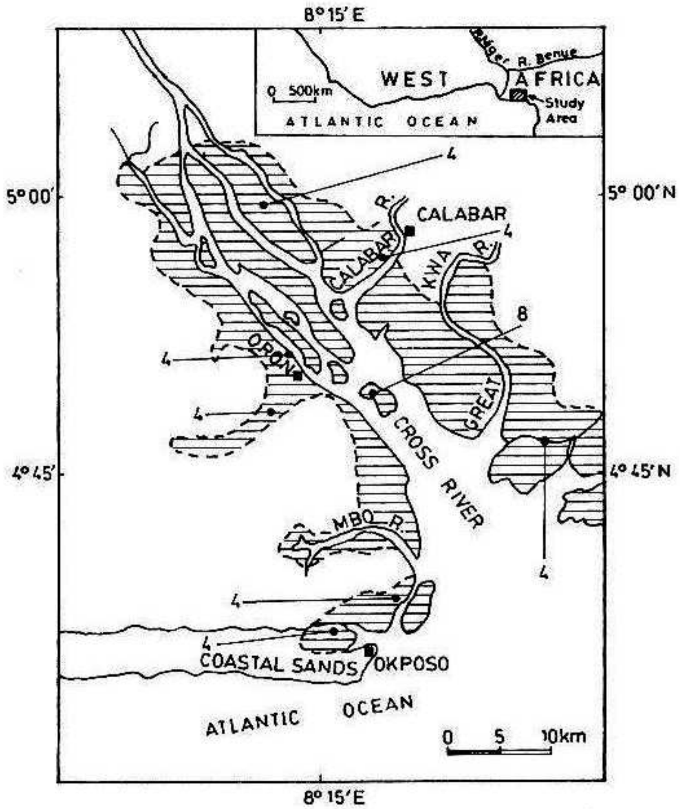

Fig. 1. Map of the study area showing location of transects and number of quadrats on each transect

humidity averaging 80% and mean annual temperature of 27 °C. Tidal amplitude in the estuary averages 2.01 m at spring tides and 1.07 m at neap tides (Nigerian Navy 1986).

Methods

Aerial photographs (scale 1 : 5,000) of the study area were used in the investigation of vegetation distribution patterns. Environmental transects were located on physiographic mangrove habitats identified and modified after Lugo and Snedaker (1974) as: (i) Tidal inlets/hinterland dune habitats – consisting of ebbflood rills and adjacent "old" levees where intense sedimentation had caused channels to abandon their former courses; (ii) Braided channel habitats, which are vegetated longitudinal intertidal bars found within the river channel, and (iii) Wooded levee habitats – consisting of accreting natural channel levees that merge inshoreward into the low freshwater swamps. The transects were at least 100 m long across the habitats and were oriented at right-angles from the water channels inland. On each transect 10 m × 10 m quadrats were established at regular 20 m intervals. A total of thirty-six quadrats were sampled (see Fig. 1). Habitat classification eliminated a bias for sampling only the more accessible forest types.

The mangrove vegetation was categorised into overstorey (> 3 m tall), understorey (1–3 m tall) and groundlayer (< 1 m tall). Vegetation measurements included crown cover of each species, obtained by the crown-diameter method (Mueller-Dombois and Ellenberg 1974); species density, frequency and tree basal area excluding *Rhizophora* props); and tree height using Hagar altimeter. The understorey and groundlayer species coverage were estimated visually in 25 m^2 and 1 m^2 subplots, respectively. The relative measures of frequency, density, and coverage were summed to obtain the ecological importance values of each species in the mangrove swamps (Stephenson 1986). In the dry season (December/January) during low tides, soil samples were obtained from each quadrat using a corer. Each observation consisted of three bulked samples obtained at 20 cm intervals to a depth of 60 cm, which appeared to be the mean rooting depth for the mangrove species. Soil properties analysed for were: percentage of sand, silt and clay (Bouyoucos 1962); percentage of field moisture from oven-dry weight of field moist samples; bulk density, in cores of volume 550 cm^3; percentage of organic carbon by the Walkley–Black method, and pH in 1:2

soil to water suspension using glass electrode (Jackson 1962). Exchangeable cations (K, Mg, Ca, Na) were extracted in 1 N ammonium acetate at pH 7 and their concentration determined by atomic absorption and flame photometry; cation exchange capacity (CEC) was obtained by the summation method; exchangeable acidity was determined by NaOH titration and aluminium by EDTA titration (Jackson 1962). Soluble sulphate was by turbidimetric determination (Tabatabai 1974). Chloride content was determined by $AgNO_3$ titration while total salinity was calculated as total water soluble salts, mainly chlorides + sulphates (USDA 1969). Carbonate content was measured using the Bromo Thymol Blue indicator titration method. Available phosphorus levels were obtained by the Bray method while total nitrogen was measured by the Macro-Kjeldahl method (Jackson 1962).

Results

Vegetation analysis

The results of vegetation analysis of the overstorey are shown in Table 1. The most important species in this layer is *Nypa fruticans* with a density of 151 stems/hectare and ecological importance value (I.V.) 81.5. *Avicennia africana*, *Rhizophora mangle* and *Rhizophora racemosa* had closely similar frequencies of occurrence. The relatively rare species included *Rhizophora harrisonii*, *Laguncularia racemosa* and *Triumfetta rhomboideae* with frequencies of occurrence < 5%. Although the vegetation was generally shrubby, the forest contained tall trees, e.g. *Rhizophora harrisonii* (8.5±2.3 m), *R. racemosa* (6.9±5.9 m), *R. mangle* (6.6±2.8 m) and *Avicennia africana* (6.1±2.7 m).

Table 1

Summary of vegetation analysis of the overstorey in 36 quadrats (100 m²)

Species	Frequency (%)	Density (stems/ha)	Mean coverage (%)	Mean tree height (m)	Mean basal area (cm²)	Importance value (I.V.)
Nypa fruticans	70.0	151	28.1	2.5 (54)	–	81.5
Avicennia africana	51.4	105	14.6	6.1 (39)	258.1 (31)*	52.3
Rhizophora mangle	54.8	81	13.5	6.1 (29)	216.7 (21)	47.8
Rhizophora racemosa	46.2	79	14.2	5.2 (18)	305.2 (22)	45.2
Raphia vinifera	27.2	51	10.3	3.3 (11)	–	29.5
Pandanus candelabrum	9.6	31	6.4	4.0 (5)	159.3 (8)	15.8
Phoenix reclinata	13.4	14	1.7	5.0 (3)	94.8 (3)	8.9
Conocarpus erectus	9.0	9	1.0	8.5 (4)	189.7 (2)	5.8

* Numerals in parentheses indicate actual number of trees measured

Table 2

Summary of vegetation analysis of the B and C strata in 36 quadrats (100 m²)

Species	Frequency (%)	Density (stems/ha)	Coverage (%)	Basal area (cm²)	Importance value (I.V.)
Understorey					
Nypa fruticans	82.0	201	24.5	–	86.9
Avicennia africana	61.8	167	16.8	45.6	65.8
Rhizophora mangle	58.4	96	16.2	38.5	53.0
Rhizophora racemosa	52.8	92	12.6	37.3	46.1
Phoenix reclinata	38.2	42	6.4	40.9	26.8
Groundlayer					
Acrostichum aureum	46.2	–	1.5	–	59.6
Nypa frusticans	51.4	350	0.8	–	42.9
Mangrove saplings	70.0	480	0.4	–	39.7
Raphia saplings	54.8	160	0.6	–	38.8

In the understorey (Table 2), there was the expected increase in stem density usually associated with lower stratum vegetation. However, the sequence of ecological importance for the major species was similar to the overstorey structure.

Groundlayer analysis revealed the overwhelming importance of *Acrostichum aureum*, *Nypa*, mangrove and *Raphia* saplings, which contracts with the generally open groundlayer reported in the literature for littoral mangrove swamps (Tomlinson 1986).

Soil analysis

The summary of soil analysis is reported in Table 3. Bulk density was low (72.8±0.05 g cm⁻³), and the soils were dominantly silty. While total salinity and chloride values indicate hypersalinity, high field moisture values reflect waterlogging of the soils. The mangrove soils have a high sink for cations. Total nitrogen values are low, but organic carbon (5.7±2.8%)

Table 3

Physical and chemical properties of soil in the mangrove swamp (values are means±SE)

Soil properties	Values	Soil properties	Values
Bulk density (g cm^{-3})	72.8±0.05	Magnesium (meq/100 g)	18.4±1.5
Field moisture (%)	119.2±10.4	Potassium (meq/100 g)	0.23±0.1
Sand (%)	25.8±2.8	Sodium (meq/100 g)	1.7±0.2
Silt (%)	56.5±4.5	Total nitrogen (%)	0.8±0.3
Clay (%)	17.7±3.9	Phosphorus (µg ml1)	7.2±1.3
Clay (%)	5.3±0.1	Organic carbon (%)	5.7±2.8
pH total salinity (%)	4.1±0.2	Aluminium (meq/100 g)	0.21±0.1
Chloride (%)	2.9±0.2	Sulphate (meq/100 g)	0.06±0.1
CEC (meq/100 g)	34.4±2.5	Exchange acidity (meq/100 g)	0.87±0.2
Calcium (meq/100 g)	13.1±1.7	Carbonate (meq/100 g)	6.7±1.8

and available phosphorus values (7.2±1.3 µg ml^{-1}) are high. The high carbonate contents are indicative of saline soils with a high molluscan population.

Discussions

Since *Nypa fruticans* is an introduced species (Mercer and Hamilton 1984), its importance indicates the extent of human interference in the ecology of mangroves in West Africa. Generally in West Africa *Rhizophora racemosa* is important along shorelines, while *Avicennia africana* and *Rhizophora mangle* tend to favour elevated and somewhat more inland portions of the swamp. Occurrence of *Raphis vinifera*, basically an upland freshwater species in the upper estuary, reflects a salinity gradient between the wet and relatively dry periods of the climate during which the swamps vary from nearly fresh to saline. Tall trees occur particularly on channel levees where *Rhizophora racemosa* stands > 25 m tall were observed. *R. mangle* were tallest in the inner swamp but shrubby on the channel margins, while *Avicennia africana* showed no observable height gradient across the swamps. The height structure of *Nypa fruticans* and *Raphis vinifera* were similar. *Rhizophora racemosa* (excluding props) had the highest mean basal area, although *Avicennia africana*, usually with straight trunks had the widest range. The spatial distribution of understorey species apart from frequency and density increases was similar to the overstorey. In the groundlayer, *Acrostichum aureum* was frequent on topographic mounds and sandy deposits (Ukpong 1995a). The distribution of mangrove saplings did not reflect a relationship with mature mangrove stands since saplings were most numerous within *Nypa fruticans* stands. Entrapment of propagules within the dense *Nypa* growth, in contrast to the generally open groundlayer in mature mangrove stands appeared to account for this distribution.

Silt was the dominant particle size fraction in the West African mangrove soils, consequent to a slow rate of sedimentation of fine particles out of suspension in the swamp. The low bulk density and high field moisture values indicate daily inundation of the soils by tides as well as the relatively low sand content of the sample profiles (Ukpong 1995b, Anderson 1995). The soils (air-dry) are acidic; the low pH values indicate acidity conditions usually associated with empoldered mangrove soils (Boto and Wellington 1984). The relatively large organic carbon contents are indicative of the peaty nature of waterlogged soils and preponderance of fibrous roots and pneumatophore. The mangrove soils have a high capacity to adsorb cations, particularly magnesium, probably due to the abundance of magnesium in tidal waters. Exchangeable potassium and sodium are comparatively small. As the soils are appreciably acidic (pH 5.3±0.1), phosphorus is probably fixed by aluminium. Aluminium and soluble sulphate probably were the main contributors to hydrogen ion concentrations in the soil; exchangeable acidity value stood at 0.87±0.2 meq/100 g. The high carbonate value reflects precipitation of carbonate mud in soil with fresh saline water wedge (Clarke and Hannon 1967). The soils are hypersaline on account of soil salinity in mangroves being usually much higher than that of the surface water (Ukpong 1991).

According to the Soil map of Africa (D'Hoore 1963) estuarine mangroves occur on soils described as "Juvenile soils on marine alluvium", classified in the order "Weakly developed soils". In the elevated landward segments of the swamp, the soils classify as "Halomorphis soils" because the uppermost horizons are not flooded during part of the year (in the dry season) and the profiles become differentiated. According to Soil Survey Staff (1990), the soils classify as Aquents since they are wet at depths < 50 cm. Soils close to the channel margins fall into the great soil groups of Hydraquents. Depending on their texture, degree of flooding and topographic position some of the soils may be classified as Epiaquents and Psammaquents.

Table 4

Mean values of species coverage (%) and stem density (stems/hectare) (across all strata) of the mangrove vegetation in three physiographic habitats

Species	Tidal inlets/hinterland dunes (12)		Braided channel (12)		Wooded levee (12)	
	Cover (%)	Density (stems/ha)	Cover (%)	Density (stems/ha)	Cover (%)	Density (stems/ha)
Nypa fruticans	6.6	82	24.8*	152	6.2*	94
Avicennia africana	8.4*	79	6.1	58	12.7*	110
Rhizophora mangle	10.2*	68	2.8	41	–	–
Rhizophora racemosa	14.5*	60	6.4	98	4.6	54
Raphia vinifera	3.2	42	–	–	4.4	46
Phoenix reclinata	2.4	32	1.8	24	3.6	38
Pandanus candelabrum	2.8	26	1.9	17	1.2	11
Triumfetta rhomboideae	1.5	16	–	–	0.4	8
Conocarpus erectus	0.2	6	0.2	8	0.3	10
Acrostichum aureum	1.4	–	0.6		0.8	–

+ Numerals in parentheses indicate number of quadrats/observations in each habitat
* Indicate the dominant species in each habitat

Aerial photograph analyses revealed that the mangroves occur in defined physiographic habitats although due to gradual sediment accretion, the habitat boundaries overlap. The habitats are geomorphic landforms arising from the fluvial processes of channel lengthening, abandonment and downwarping of sediments (Thom 1967). There appear to be a correlation between species structure and fluvial habitat types (Neave et al. 1995), and soil types (Ukpong 1995a). Table 4 shows the vegetation characteristics computed for each physiographic habitat, while Table 5 shows the corresponding soil properties.

The most luxuriant growth of *Rhizophora* spp. is found on the tidal inlets/hinterland dune habitat (Table 4). Mixed stands of *Rhizophora* spp. and *Avicennia africana* are fronted by dense growth of *Nypa fruticans*, *Raphia vinifera* and *Rhizophora harrisonii* at the foot of the "old" hinterland dunes. With increasing distance from diurnal flooding, the mangroves become shrubby, occurring with *Acrostichum aureum* as groundlayer vegetation. In the landward portions of this habitat, true mangroves (with pneumatophore/viviparous fruits) are completely replaced by *Raphia* spp. The most

distinguishing characteristics of the tidal inlets/hinterland dune soils (Table 5) are the relatively high bulk density values (78.5±0.08 g cm^{-3}), high sand and low clay contents. Clearly, bulk density increases as sand content increases. The lowest CEC values occur in this habitat (30.6±3.5 meq/100 g) which reflects the low calcium and magnesium concentrations when compared with the other habitats. The tidal inlets have gradients > 0.5 in 500 m. At mean low water neap tides (1.04 m) the hinterland dunes are flooded while the inlets remain flooded by mean low water spring tides (0.45 m).

Table 5

Mean values of soil physical and chemical properties in three physiographic mangrove habitats (values are means±SE)

Soil properties	Tidal inlets/hinterland dunes (12)	Braided channel	Wooded levee (12)
Bulk density (g cm^{-3})	78.5±0.08	66.2±0.12	70.8±0.06
Field moisture (%)	120.8±11.3	124.6±2.2	115.2±9.4
Sand (%)	41.5±8.2	58.4±5.8	32.8±2.6
Silt (%)	33.7±3.4	18.0±4.9	40.2±4.8
Clay (%)	14.8±4.6	5.3±0.1	27.0±3.2
pH	5.4±0.1	4.3±0.2	5.6±0.1
Total salinity (%)	4.0±0.3	3.1±0.2	4.3±0.2
Chloride (%)	2.9±0.4	3.1±0.2	3.0±0.1
CEC (meq/100 g)	30.6±3.5	36.8±4.8	37.2±1.2
Calcium (meq/100 g)	11.8±1.4	14.2±1.5	15.8±1.8
Magnesium (meq/100 g)	15.6±2.1	198±1.8	18.4±1.2
Potassium (meq/100 g)	0.24±0.1	0.33±0.2	0.26±0.1
Sodium (meq/100 g)	2.0±0.4	1.9±0.3	1.9±0.5
Total nitrogen (%)	0.8±0.2	0.7±0.1	0.8±0.4
Phosphorus (µg ml^{-1})	7.5±2.3	8.1±1.5	6.6±1.3
Organic carbon	5.4±1.5	6.8±2.9	5.6±2.4
Aluminium (meq/100 g)	0.22±0.1	0.22±0.3	0.20±0.1
Sulphate (meq/100 g)	0.08±0.01	0.7±0.01	0.07±0.01
Exchange acidity (meq/100 g)	1.0±0.4	0.6±0.1	1.2±0.2
Carbonate (meq/100 g)	5.1±2.8	7.5±2.5	8.2±1.6

( ) Parentheses indicate number of quadrats/observation in each habitat

The braided channel habitat is dominated by *Nypa fruticans* (Table 4), in association with *Avicennia africana* and *Rhizophora racemosa*. The species may occur in pure stands along those segments of the channels favourable for their establishment and growth; e.g. on the raised braided levees, *Avicennia africana* is the dominant species, while *Nypa fruticans* and *Rhizophora racemosa* are adapted to the constantly submerged margins on account of their extensive fibrous and prop roots. Species distribution shows close relationship with occurrence of distributary channels; e.g. *Nypa* and mangrove propagules are seasonally dispersed along the minor channels, resulting in greater competition among species in the inner swamp. The distinguishing soil characteristics of this habitat are the relatively low bulk density values (Table 5), low sand content (23.6±2.2%) and high silt value (58.4±5.8%). The high organic carbon value (6.8±2.9%) correlate with high phosphorus value (8.1±1.5 $\mu g\ ml^{-1}$) and dense vegetation cover (24.8%). The braided depositional bars have gradients < 0.05 in 500 m. Silting and permanent ponds characterise these "mangrove islands" which are flooded by all diurnal tides.

The wooded levee habitat is dominated by *Avicennia africana* in association with *Nypa fruticans*, *Rhizophora racemosa* and *Raphia vinifera*. Although *Avicennia africana* is dominant, *Nypa fruticans* and *Rhizophora racemosa* with extensive props occupy the submerged channel margins in mixed stands, while *Avicennia* sp. adapts to elevated segments. The distinguishing characteristics of the wooded levee soils are the relatively high clay (27.0±3.25%) and carbonate (8.2±1.6 mg/100 g) contents. Other soil attributes are similar to the braided channel on account of their topographic similarities. The highest levees have gradients > 0.05 in 500 m and are flooded by tides > mean low water neap (1.04 m). The low tidal mudflats are flooded by all diurnal tides.

Conclusions

Mangrove vegetation along accreting shores shows a high level of structural complexity, compared to the shrubby vegetation usually associated with erosional coastlines (Semeniuk 1980, Ukpong 1992). Forests on accreting shores correspond with the classification of Davy (1938) and Pool et al. (1977) as "tropical mangrove woodlands". These forests are found below high-tide mark in the estuaries. The tropical mangrove woodland habitat is usually estuarine mud. Comparatively, forests on eroding shores classify as "tropical littoral woodlands" which is synonymous with strand vegetation in which few species occur in pure stands along sandy beaches (Walsh 1974).

In the eroding coastal mangroves of Australia, Clarke and Hannon (1967) reported predominantly sandy (> 75%) soils. This contrasts with the result of this study where the mean sand proportion in the accreting swamp is 25.8±2.8%. In Australia CEC was extremely low, ranging from 0.38 to 0.84 meq/100 g, while in this study the mean CEC value is 34.4±2.5 meq/100 g. In South America, Moorman and Pons (1974) reported clayey texture in soils, which contracts with the dominantly loamy texture of the West African swamp. These differences are also accounted for by geogenetic factors, e.g. soils of adjacent areas or hydraulic characteristics of channels and tidal influence. Salinity is mainly of importance because it excludes competition from non-mangroves thereby enabling mangroves to be perpetuated along the shorelines.

Unless physiography habitats are differentiated in accretive swamps, the relationships between the soil and species distribution and structure may be obscured. The exchangeable cations could be important in habitat differentiation but they are also influence by location of stands relative to marine influences (Ukpong 1995c). The sedimentation pattern and consequently soil texture probably determines which species dominate on the different habitats. Hence, baseline studies for the purpose of initiating conservation should emphasise identification of habitats/forest types and the associated physical environmental variables which evolved the peculiar microtopographic/topographic variations. Conservation models should therefore take into account the dynamic mangrove habitats which are continually modified by sediment accretion.

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