MODELLING THE VEGETATION AND SOIL CHARACTERISTICS OF IMO RIVER BASIN MANGROVE ECOSYSTEM, AKWA IBOM STATE, NIGERIA.

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ABSTRACT

Modelling vegetation and soil characteristics was carried out in Imo River Basin of Akwa Ibom State, Nigeria. Systematic sampling method was used in sampling soil and vegetation using a quadrat of 10 m × 10 m. The floristic composition revealed a total of nine species from five families. *Nypa fruticans* and *Acrostichum aureum* recorded a higher frequency of 75% each while *Rhizophora mangle, Laguncularia racemosa, Pandanus candelabrum* and *Phoenix reclinata* were the least (25%) occurring species. Similarly, *Nypa fruticans* was the most abundant species recording a density of 541.78±155.90 stems/ha while *Laguncularia racemosa* had the least density (25.00±0.00 stems/ha). The tallest species was *Rhizophora mangle* (8.33±1.25 m) whereas *Laguncularia racemosa* was the shortest species (3.00±0.00 m). The most extensive crown cover value was recorded for *Avicennia africana* (2.56±1.57 m^2/ha). Basal area was widest in *Phoenix reclinata* (0.836±0.10 m^2/ha) whereas the least value was associated with *Laguncularia racemosa* (0.0032±0.00 m^2/ha). Particle size analysis followed this decreasing order: sand (56.20±2.30 %) > silt (11.82±1.40 %) > clay (31.98±5.81 %). The soils were acidic with mean pH value of 4.65 ±0.02. Also, the concentration of electrical conductivity was 3.340±0.62 ds/m while organic matter had a value of 12.82 ±2.31 %. Total nitrogen and available phosphorus had values of 0.33±0.001 % and22.83 ±1.71 mg/kg, respectively. The mean values for basic cations recorded were as follows; Ca (11.00 ±2.0 cmol/kg), Mg (3.62±1.14 cmol/kg), Na (0.49±0.01 cmol/kg) and K (0.33 ±0.02 cmol/kg). Regression modeling revealed that while *Machaerium lunatum* was dependent on electrical conductivity and pH, the existence of *Terminalia superba* was predicted by sand and total nitrogen concentration, *Phoenix reclinata* was responsive to calcium and potassium concentrations whereas *Acrostichum aureum* was associated with available phosphorus and magnesium. These results have practical implications in biodiversity conservation and wetland management.

INTRODUCTION

Mangroves are saline coastal habitats in the tropics and subtropics, occurring as an interface between land and sea (Schwarz, 2003). These ecosystems consist of single to multi tree and shrub species highly adapted to a fine sediment substrate from periodical tidal flood depositions, rich in organic matter, with varied salinity and low oxygen (Griffihs *et al*., 2008). The soils in mangrove forests are complex systems resulting from various intricate interactions between abiotic (tides and physiography) and biotic (activities of plants, microbes and invertebrates) factors, that may be altered within short distances. Soil attributes such as salinity, iron sulfide concentrations, soil redox potential, nutrients, organic matter and physiographical position are the key factors in determining mangrove flora species composition and structure (Otero *et al*., 2009). The accumulation and degradation of toxic compounds (Ke *et al*., 2002) and the mobilization and availability of trace elements also significantly influence the zonation of mangroves (Machado *et al*., 2004). Studies have revealed significant variation in the composition of mangrove soils at different depths, clay mineralogy, total organic carbon content and carbon stock (Ferreira *et al*., 2010).

The use of modelling in ecology deals with the construction and analysis of a mathematical representation of an ecosystem (ranging from population to ecological community to an entire biome (Hall and Day, 1990). On the basis of quantitative research on the relationship between vegetation and environmental factors, scholars have developed series of predictive mathematical models on both regional and global scales. These ecological models are very useful for simulating and analyzing the long-term dynamics of a complex ecosystem.

Since wetlands are among the most productive ecosystems on earth, protection of threatened natural wetlands and preservation of its biodiversity have received increasing attention globally. Wetlands and their resources in Nigeria are still facing many problems such as high population densities within the catchments areas of coastal regions. This has resulted in series of deleterious trends, in particular those arising from the clearance of vegetation for agriculture and overgrazing. Despite their importance to maintenance of biodiversity, wetland vegetation in Imo River Basin, Akwa Ibom State is less investigated and their related documentation are extremely limited. This has resulted in a dearth of information on the vegetation ecology, species composition and diversity of these wetlands. Also, a lacuna exist in modelling of vegetation and soil characteristics in wetland ecosystems in Akwa Ibom State. If these are available, understanding the pedological variables influencing the vegetation dynamics of wetlands would be possible and this would have formed the basis for sustainable management of the wetland.

MATERIALS AND METHODS

Study Area

The study was carried out in the mangrove swamp forest of Imo River Estuary at Utaewa Village in Ikot Abasi Local Government Area of Akwa Ibom State. The mangrove is located at longitude 7º 31' 40"E and latitude 4º 35' 52" N (Figure 1). The swamp serves as an intertidal zone separating the riparian communities with the sea.

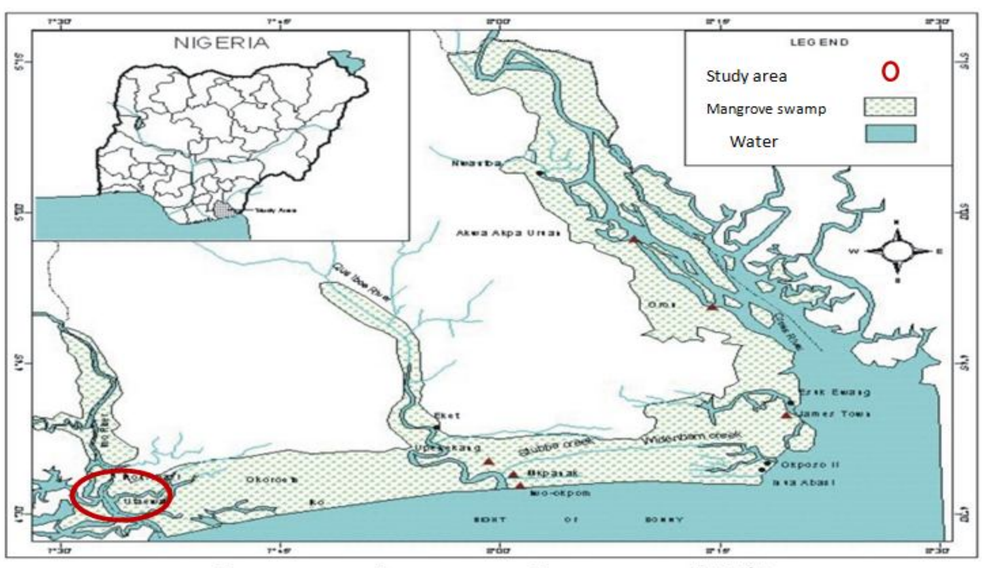

Figure 1. Coastal zone of Akwa Ibom showing the Imo River Estuary mangrove ecosystem at Utaewa, Ikot Abasi L.G.A.

Vegetation and Soil Sampling

A total of five plots in each wetland site were used for this study. In each plot, 5 belt transects were laid and in each transect, vegetation and soil were systematically sampled at regular intervals with a 10 m x 10 m quadrat. In each quadrat, plants were identified to species level and their frequency and density were obtained by enumeration. The parameters of the vegetation measured were frequency of plant species, height, density, basal area, and crown cover. Soil samples were excavated at different rooting depths (0 – 15 cm and 15 – 30 cm) using a soil auger. Two soil samples were collected in each quadrat, bulked, stored in labelled Ziploc bags and taken to the laboratory for physicochemical analyses.

Measurement and Determination of Vegetation Parameters

(a) Density

The density of the individual species was calculated using the method of Cochran (1963)

(b) Frequency

The frequency of each species occurrence was calculated thus:

$$\text{Frequency} = \frac{\text{Number of occupied quadrat for a species}}{\text{Total number of quadrats thrown}} \times 100$$

(c) Height

The heights of woody species were measured using a Haga altimeter (43913 model). The reading was taken 15 m away from the base of the woody plant from where the crown was sighted through the eye piece of the altimeter and the upper reading taken. The base of the woody plant was similarly sited and the lower altimeter readings taken. The height of each species was calculated using the relation:

Height (m) = Algebraic sum of the reading of the top and bottom of each plant × horizontal distance from observer to each species divided by scale factor used on the altimeter.

(d) Basal Area

This was calculated using the relation:

$$\text{Basal Area} = \frac{C^2}{4\pi}$$

Where $4\pi = 4 \times 3.142 = 12.568$

C = girth size of the species at breast height

(e) Crown Cover

The crown cover of woody plant species was determined by the crown cover diameter method (Muller- Dombios and Ellenberg, 1974).

Physical and Chemical Analysis of Soil

Soil particle sizes (sand, clay and silt), organic carbon, total nitrogen and available phosphorus were determined using the Hydrometer method, Walkey Black wet oxidation method, Micro-Kjeldahl method and Bray No 1 method (Jackson, 1962). pH, electrical conductivity, and exchangeable acidity were determined using a Beckman's glass electrode pH meter (Mcclean, 1961), conductivity meter (Jenway Pcm 128723 model) and titration with 1N KCL (Kramprath, 1967), respectively. Total exchangeable bases were determined by EDTA titration method while potassium and sodium were determined by photometry method. The Effective Cation Exchange Capacity (ECEC) was calculated by the summation method (that is summing up of the Exchangeable Bases and Exchange Acidity (EA). Base Saturation was calculated by dividing total exchangeable bases by ECEC multiplied by 100.

Statistical Data Analysis and Modelling

Statistical Package for Social Sciences (SPSS, Version 20.0) was employed for descriptive statistics (mean and standard error). Stepwise multiple regression using SPSS was also used for parametric modelling of soil characteristics in relation to species attributes.

RESULTS

Floristic Inventory of the Mangrove

The floristic composition of the Imo River Basin is presented in Table 1. A total of nine species belonging to five families were encountered. *Nypa fruticans* and *Acrostichum aureum* were common with frequency value of 75% while *Rhizophora mangle, Laguncularia racemosa, Pandanus candellabrum* and *Phoenix reclinata* were the least (25%) encountered. *Nypa fruticans* was the most abundant species with a density of 541.78±155.90 stems/ha. The tallest species was *Rhizophora mangle* (8.33±1.25 m) while the shortest was *Laguncularia racemosa* (3.00±0.00m). The most extensive crown cover (2.56±1.57m^2/ha) was recorded for *Avicennia africana* while *Machaerium lunatum* had the least (0.701±0.074m^2/ha) crown cover. Basal area value was widest in *Phoenix reclinata* (0.836±0.10m^2/ha) whereas the least area for tree volume was associated with *Laguncularia racemosa* (0.0032±0.00 m^2/ha).

Physicochemical Properties of the Soil

Table 2 shows the mean values for the soil properties of the river basin. The proportions of the particle size class were as follows; sand (56.20±2.3 %), silt (11.82±1.40 %) and clay (31.98 ±5.81 %). Soil was acidic with a mean pH value of 4.65 ±0.02. However, the value for electrical conductivity was 3.34 ±0.62 ds/m while the organic matter had a value of 12.83±2.31 %. Total nitrogen and available phosphorus had a value of 0.33 ±0.001 mg/kg and 22.83 ±1.71 mg/kg, respectively. The concentrations of the basic cations recorded were as follows; Ca (11.00 ±2.00 cmol/kg), Mg (3.62 ±1.14 cmol/kg), Na (0.49 ±0.01 cmol/kg) and K (0.33 ±0.02 cmol/kg). The levels of exchange acidity, effective cation exchange capacity and base saturation were 3.10±0.41 cmol/kg, 17.99 ± 3.00 cmol/kg and 82.73 ±10.40, respectively.

Modelling of Vegetation and Soil Characteristics

The models of the vegetation and soil characteristics are presented in Tables 3 – 6.On site assessment of the wetland revealed a vegetation mix comprising nine species. In modeling species response to gradient, only four species were sensitive to the synergistic influence of specified pair of predictor variables. The models relate that while *Machaerium lunatum* was dependent on electrical conductivity and pH (Model 1), *Terminalia superba* was predicted by sand and total nitrogen concentration (Model 2), *Phoenix reclinata* was responsive to calcium and potassium concentrations (Model 3) whereas *Achrostichum aureum* aligned with available phosphorus and magnesium (Model 4).

Model 1: The regression of density of *Machaerium lunatum* with 15 soil variables yielded a prediction model equation of this form: Y = 31.45 – 24.47 log EC -1.27 log pH. Analysis of variance for the regression gave an F- ratio of 395162.3 which was significant at p = 0.05. EC and pH completely accounted for 100% of variations in species abundance values (Table 3).

*Model 2***:** The regression of density of *Terminalia superba* with 15 soil variables yielded a prediction model equation of this form: Y = -39.802 – 16.25 log Tot N + 5.41 log Sand. Analysis of variance for the regression gave an F- ratio of 39084.2 which was significant at p = 0.01. Total nitrogen and sand completely accounted for 100% of variations in species abundance scores (Table 4).

*Model 3:*The regression of density of *Acrostichum aureum* with 15 soil variables gave a prediction model equation of this form: Y = 16.03 – 30.95 log Av. P + 6.47 log Mg. Analysis of variance for the regression gave an F- ratio of 27166.59 which was significant at p = 0.05. Soil available phosphorus and Mg concentrations completely accounted for 100% of variations in species abundance scores (Table 5).

*Model 4:*The regression of density of *Phoenix reclinata* with 15 soil variables generated a prediction model equation of this form: Y = 71.73 – 28.12 log Ca + 3.93 log K. Analysis of variance for the regression gave an F- ratio of 7657.28 which was significant at p = 0.05. Soil calcium and potassium contents accounted for 100% of variations in species abundance scores (Table 6).

Table 1: Floristic inventory of Imo River Basin mangrove ecosystem

Species	Family	Frequency (%)	Density (st/ha)	Height (m)	Crown cover (m^2/ha)	Basal Area (m^2/ha)
Achrostichum aureum	Pteridaceae	75	108.00± 47.14	-	-	-
Avicennia africana	Rhizophoraceae	50	100.00± 50.00	6.38± 0.18	2.56± 1.57	0.0839± 0.01
Laguncularia racemosa	Rhizophoraceae	25	25.00± 0.00	3.00± 0.00	0.785± 0.00	0.0032± 0.00
Machaerium lunatum	Fabaceae	50	150.00± 50.00	7.50± 0.50	0.701± 0.074	0.0306± 0.01
Nypa fruticans	Arecaceae	75	541.78± 155.90	4.78± 3.12	2.01± 0.89	0.391± 0.09
Pandanus candelabrum	Arecaceae	25	50.00± 0.00	4.00± 0.00	0.785± 0.00	0.064± 0.001
Phoenix reclinata	Arecaceae	25	250.00± 10.00	7.50± 3.20	5.64± 2.41	0.836± 0.10
Rhizophora mangle	Rhizophoraceae	25	75.00± 0.00	8.33± 1.25	1.897± 0.97	0.059± 0.01
Terminalia superba	Combretaceae	50	75.00± 25.00	4.55± 1.50	0.711± 0.074	0.4040± 0.01

± = Standard error

Table 2: Soil characteristics of Imo River Basin mangrove ecosystem

Parameter	Mean Value
Sand %	56.20±2.3
Silt (%)	11.82±1.40
Clay (%)	31.98±5.81
pH	4.65±0.02
Electrical Conductivity (ds/m)	3.34±0.62
Organic Carbon (%)	12.83±2.31
Total Nitrogen (%)	0.33±0.001
Available Phosphorus (mg/kg)	22.83 ± 1.71
Calcium (cmol/kg)	11.00±2.0
Magnesium (cmol/kg)	3.62±1.14
Sodium (cmol/kg)	0.49±0.01
Potassium (cmol/kg)	0.33±0.02
Exchange Acidity (cmol/kg)	3.10±0.41
ECEC (cmol/kg)	17.99±3.6
Base saturation (%)	82.73±10.4

± = Standard error; ECEC = Effective Cation Exchange Capacity

Table 3: Summary of Regression Analysis: *M. lunatum* and soil predictor variables.

Predictor variable	b Coeff.	Standard error of b	Multiple R	Level of explanation	Increase in level of explanation.	t-value	F-ratio
EC	- 24.47	0.04	0.998	99.80	-	- 607.57	395162.3*
pH	-1.27	0.04	1.00	100.0	0.20	- 31.63	

EC = Electrical Conductivity; Where intercept = 31.45; * Significant at 5% level

Table 4: Summary of Regression Analysis: *T. superba* and soil predictor variables.

Predictor variable	b Coeff.	Standard error of b	Multiple R	Level of explanation	Increase in level of explanation.	t-value	F-ratio
Total Nitrogen	- 16.25	0.094	0.90	90.00	-	- 173.09	39084.2*
Sand	5.41	0.075	1.00	100.0	10	72.121	

Where intercept = - 39.802; * Significant at 1% level

Table 5: Summary of Regression Analysis: *A. aureum* and soil predictor variables

Predictor variable	b Coeff.	Standard error of b	Multiple R	Level of explanation	Increase in level of explanation.	t-value	F-ratio
Av. P	- 30.95	0.163	0.855	85.5	-	- 190.05	27166.59*
Mg	6.47	0.089	1.00	100.0	14.5	72.554	

Av. P = Available Phosphorus; Where intercept = 16.03; * Significant at 5% level

Table 6: Summary of Regression Analysis: *P. reclinata* and soil predictor variables

Predictor variable	b Coeff.	Standard error of b	Multiple R	Level of explanation	Increase in level of explanation	t-value	F-ratio
Ca	- 28.12	0.288	0.971	97.1	-	- 97.622	7657.28*
K	3.93	0.229	1.00	100.0	2.90	17.127	

Where intercept = 71.73; * Significant at 5% level

DISCUSSION

The vegetation attributes of the wetland plots revealed low species diversity, reduced abundance and a marked heterogeneity in terms of species composition within the basin. However, the species composition in this ecosystem conforms to the vegetation typologies reported by earlier researchers in freshwater swamp forest (Ubom *et al.*, 2012). The spatial variation in floristic variables (density, frequency, height, basal area and crown cover) of the wetland is a true reflection of the different levels of biomass production in these habitats. This view is also in synchrony with the report by Ubom *et al.* (2012). These variations may be ascribed to the fact that plant species adapt differently to changes in topographic, anthropogenic and edaphic factors within their environment. The dominance of *Nypa fruticans* over other species may be due to its efficient reproductive strategies and good dispersal capabilities in the ecosystem. Also, the gap observed in numeric quantification of species points to niche differentiation among species in the mangrove wetlands. Similar findings were reported by Offiong *et al.* (2012) and Ukpong (1997).

The role of stepwise multiple regression technique in enabling the synthesis and derivation of predictive equations which serve as illustrative models, based on the responses of selected species along environmental gradients has been established. The technique also identified those independent (soil) variables having strong relationship with vegetation. Similar observations have earlier been reported by Ogbemudia (2014). Regression modeling confirmed that species differed in their nutrient requirements while highlighting the preferential ranking of soil variables by plants. This ranking is the basic principle governing the retention or exclusion of the predictor variables in the species density equations. For instance, in each model, 15 predictor variables were fitted into the equation while only two were retained. *Machaerium lunatum* was sensitive to electrical conductivity and pH. These two predictor variables are related in that the pH of any medium decrease with an increase in H^+ ions and conductivity and vice versa with an increase in the concentration of OH^- ions. Model one leaves the notion that *Machaerium lunatum* were abundant in soil with lower pH. Mbong (2013) reported same and, this verifies the negativity in the regression coefficients associated with this model. *Terminalia superba* showed strong affinity for nitrogen and sand. This is not unprecedented in that Pandey and Sinha (2007), emphasized the role of nitrogen in the constitution of different plant proteins, nucleic acids and many other essential molecules like chlorophyll, hence, its relevance in plant growth and development. Sand on the other hand, is necessary in muddy wetland substrate due to the fact that it helps in loosening muddy substrate, facilitates aeration and rapid water movements (Ita, 2017). This study has shown that in the river basin investigated, the distribution of *Acrostichum aureum* was dependent on the concentration of phosphorus and magnesium. This is clearly understood because while phosphorus is essential to plants in the formation of genetic materials (ATP, DNA and RNA), formation of stem and roots, seed and fruit formation, magnesium plays pivotal roles in co-enzymes activation, synthesis of chlorophyll and is critical to cell division process (Umeh, 2010). Similarly, the existence of *Phoenix reclinata* was also dependent on the concentration basic cations (Ca and K). The role of calcium in plants is very essential especially in wetlands with reduced pH such as this. According to Verma and Verma (2007), Ca plays essential roles of providing a base for the neutralization of organic acids and is concern with the growing root apices and proper cell wall development. This could be related to its relevance and thus confirms the species dependency as earlier reported by Ubom (1992) and Mbong (2013). Potassium (K) on the other hand, plays a major role as a cationic inorganic element in the soil and is therefore regarded as an essential element to all plant life (Mengel, 2007). According to Zlatev and Lidon (2012), K is also linked to many physiological processes which aid in enzyme activation, water relations, photosynthesis, assimilates, transportation, as well as growth and development of plants.

CONCLUSION

This study has revealed the existence of an intricate relationship between vegetation and soil in Imo River Basin mangrove ecosystem. A marked spatial heterogeneity in the concentration of physical and chemical parameters was observed in the wetland. Stepwise multiple regression provided a suitable option for deriving models which provided reliable information on soil parameters controlling the various vegetation blocks. Important soil factors included nutrient cations (calcium, potassium and magnesium), pH, soil texture, electrical conductivity, total nitrogen and available phosphorus. The interactions existing between plant species with soil properties thus indicate their importance in these ecosystems. The results of this study have practical implications in biodiversity conservation and sustainable management of wetlands.

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