Chapter 2

Mangrove Species Distribution and Composition, Adaptive Strategies and Ecosystem Services in the Niger River Delta, Nigeria

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79028

Abstract

Mangroves of the Niger River Delta grade into several plant communities from land to sea. This mangrove is a biodiversity hot spot, and one of the richest in ecosystem services in the world, but due to lack of data it is often not mentioned in many global mangrove studies. Inland areas are sandy and mostly inhabited by button wood mangroves (*Conocarpus erectus*) and grass species while seaward areas are mostly inhabited by red (*Rhizophora racemosa*), black (*Laguncularia racemosa*) and white (*Avicennia germinans*) mangroves species. Anthropogenic activities such as oil and gas exploration, deforestation, dredging, urbanization and invasive nypa palms had changed the soil type from swampy to sandy mud soil. Muddy soil supports nypa palms while sandy soil supports different grass species, core mangrove soil supports red mangroves (*R. racemosa*), which are the most dominant of all species, with importance value (I_v) of 52.02. The red mangroves are adapted to the swampy soils. They possess long root system (i.e. 10 m) that originates from the tree stem to the ground, to provide extra support. The red mangrove trees are economically most viable as the main source of fire wood for cooking, medicinal herbs and dyes for clothes.

Keywords: adaptation, deforestation, ecosystem services, west African mangroves

1. Introduction

1.1. Global mangrove species distribution and composition

Mangroves are one of the world's most productive ecosystems. This is because they enrich coastal waters and serve as supermarket of the sea. They are globally distributed and occupy

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more than 150,000 km^2, occur in over 123 countries and are made up of more than 73 species and/or hybrids [1–3]. Mangroves are divided into the Indo-West Pacific (IWP) and the Atlantic East Pacific (AEP) groups [4, 5]. They originated from a hot environment [6] and their distribution is influenced by meteorological events [7] such as temperature [8] and precipitation [9]. These climatic parameters influence their distribution to different habitat [10]. Although, tolerance to warm conditions dictates their distribution, they sometimes drift to temperate regions where intense cold weather threatens their survival [11]. Global warming causes mangroves to spread beyond their latitudinal limit [12]. Mangroves are largely restricted to latitudes between 30° north and 30° south. Northern extensions of this limit occur in Japan (31° 22′N°) and Bermuda (32° 20′N); southern extensions are in New Zealand (38°03′S), Australia (38° 45′S) and on the east coast of South Africa (32°59′S) [2]; while there are robust mangrove population on the western coast of Africa with mangroves in Nigeria as one of the most dominant.

Tropical conditions are the best for mangroves, but excessive heat cause rapid evaporation leading to increase in salinity [13], which triggers the succession of salt tolerant mangrove species (e.g. *Avicennia germinans*) over less salt-tolerant species (e.g. *Rhizophora* species) [14]. Increase in temperature affects water body [15]. Temperature greater than 35°C affects root structure, seedling establishment and photosynthetic activity in mangroves [16]. Unrestricted increase in temperature can lead to the migration of species into subtropical salt marsh areas [17] and Arctic pole [18]. Precipitation regulates nutrient up-take and affects productivity [19] and survivability [20] of mangroves. Moderately warm and wet equatorial areas with high rainfall have rich supply of mangrove populations [21]. However, increase in sea level [22] can drown fringe mangroves [13]. In the same vein, global cooling and warming [23, 24] can lead to range shifts and the extinction of organisms [25, 26]. Mangrove propagules are dispersed by tidal currents, but land barriers prevent their free movement [4] leading to a discontinuous distribution. This discontinuity causes intra-specific, morphologic and genetic variation in Rhizophora species [27], which is one of the most dominant mangrove species in the world.

1.2. Ecosystem services of Niger Delta mangroves

The mangrove trees conserve water resources and serve as wind breaks in many communities. Specifically, in the Niger Delta, there are several uses of mangroves by the indigenous people, these include; fire wood, building materials, medicinal products, food baskets and fishing tools etc.

1.2.1. Cooking

Fire wood is a major means of cooking and heating. The firewood is got mostly from the red mangrove tree stems (i.e. Rhizophora species). The trees are first cut into 0.6 m stumps and thereafter chopped into smaller pieces of wood and sold. Fire wood is the preferred cooking method in most rural areas in Nigeria. This is because the wood retains heat for long. Pieces of the wood numbering about 3–5 are gathered and placed under metal tripod stands, and lighted to cook food. The wood ash that comes out after the burning of the wood is used as soil enhancer and disease destroyer in farms when it is spread on the soil surface or on the leaves of crops. It prevents biting and chewing insect pest (grasshoppers and locust) from

chewing the leaves. The fire wood is also useful in bakery, where larger wood stumps are placed underneath large ovens for baking bread.

1.2.2. Charcoal manufacture

The wood is burnt completely in kiln to form charcoal that is used for outdoor cooking. Charcoal industry is a lucrative business embarked upon by many people in the Niger Delta. The charcoals is measured, put in bags and sold in the market. It is used by a large number of people for outdoor cooking especially during occasions and festivities. It is also used by road side food vendors to roast food items such as plantain, corn, bean balls, pan cakes etc.

1.2.3. Building

The mangrove stems are cut to make stakes. They are also used for construction and building of scaffold. The wood is sawed into different sizes and used as ply wood for building houses. The wood is tough and can be used as roofing boards for houses. However, the use of mangrove for building is restricted because of its high combustibility. Other examples of industrial building materials derived from mangrove include: thatches, bamboo, poles, boats and wooden bridges in local communities. The wood is also used as support pillars and reinforcements for locally built houses and bridges across small rivers or canals. Poles from mangrove are used to connect electric wires, which supplies electricity from one part of the town to another.

1.2.4. Food

The red mangrove propagule is succulent and rich in nutrients and is eaten by crabs (*Goniopsis pelii*). In the Niger Delta people feed on products of animals and insects that live in mangrove forest such as honey combs built by bees in thick mangrove forest. The following organisms are also found in the mangrove forest: mammals, birds, reptiles, insects, roots, stem, flower, honey resins, gum, silk, fabrics, rope, animal oil, and cosmetics. The mangrove forest serves as source of water from streams and lakes. The red mangrove sepal has an enclosure that contains a sweet tasting liquid that is sucked. The tree bark is cut into small bits and used as spices for cooking. The sweet smelling aroma is also used in the manufacture of creams and perfumes; and also bathing soaps that are produced locally.

1.2.5. Medicinal herbs

Tree barks and roots are mixed with other components to produce medicinal herbs that are used to treat some ailments. The bark is chopped into small pieces and put in locally made alcohol to dissolve; lemon is added and left for some time after which it is consumed as medicinal herb for curing several ailments. The mangrove tree bark is boiled with other herbs and used to treat malaria.

1.2.6. Fishery

The mangrove swamps serve as natural fish ponds. The site is dug and surrounded by soil like an embankment with a passageway. During high tides water carrying fishes flows into

the ponds, during ebb tide the water leaves and the fishes get trapped and remain in the embankment. The advantage of this fish pond is that there is a natural exchange of water from the sea, without the use of tap water. The need for external water supply is minimized because of the adjoining water body that supplies constant water to the pond.

1.2.7. Forest products

This includes timber and non-timber products. The timber products are used by the furniture and building industry. Several furniture products are derived from trees cut from the rain forest. Non-timber products include medicinal herbs and pharmaceutical products used locally to treat certain ailments.

1.2.8. Recreation and tourist attraction

Mangrove forests are relaxation points for many citizens who visit the area on site seeing trips. The mangrove forest has a sweet smelling aroma that is therapeutic when one spends time in it. The sea breeze that blows and serenades the trees is a soothing balm that calms a restless nerve. Scientific research is also carried out in the area to identify numerous species found within the forest. The mangrove forest of the Niger Delta contains numerous unidentified species. The forest is a living laboratory that requires further scientific work to identify and classify the species.

1.2.9. Spiritual purpose

The mangrove forest serves as sites for libation and ancestral activities by natives who visit the area to derive some spiritual powers. Big trees are usually not cut, but allowed to grow and serves as points for libation by people that practices African traditional religion. The mangrove forest also serves as hiding place for natives during local wars.

1.2.10. Production of dyes

The tree bark when boiled produces dye used by the clothing industry. The red mangrove tree bark is boiled in hot water to bring out dyes made of red to brown coloration. This is then used to dye fishing net, which help to disguise and attract fishes for higher catch by fishermen.

The mangrove forest is also a region rich in crude oil and gas, which has made Nigeria the largest producer of crude oil in Africa and the sixth largest in the world [28].

1.3. Threats to Niger Delta mangroves

The major threats to mangroves in the Niger Delta are oil and gas exploration, deforestation, dredging, urbanization and Invasive Nypa palm species. Oil exploration began when the first oil well was struck in Oloibiri in the Niger Delta in 1956. Since the striking of this oil well thousands of other oil wells had been drilled resulting to millions of crude oil spillages [28]. The oil spillages had lead to the constant pollution of the mangrove forest leading to the death of numerous mangrove stands [29, 30]. Additionally, the exploratory process involves different stages such as deforestation activities aimed at creating a right of way passage (ROW) for oil pipelines, building

of boot camps for seismic workers within the forest, etc. leading to the truncation of wildlife activities [31]. Similarly, the use of explosives such as dynamites during exploration for crude oil also led to the death of organisms and the destruction of the forest. Indiscriminate sand dredging is high in the area and had led to the disappearance of many coastal communities because of their conversion from aquatic to a terrestrial environment for the purpose of land expansion to establish residential and industrial quarters. The mangrove forest once destroyed takes up to 15 years or more to re-vegetate as compared to the rain forest that takes 5 years to re-grow. This shows that all aspects of oil exploration are inimical to the mangroves right from the pre-exploratory, exploratory and post exploratory stages. This is because each stage of oil and gas exploration involves hydrocarbon pollution and physical destruction of the mangrove forest. Pollution impacts flora and fauna, for instance oils from spillages clog the roots of mangroves causing outright death through the suffocation of the lenticels, leaf yellowing and defoliation [31, 32]. Pollution has effect on mollusk, crustaceans, echinoderms, polychaetes, cnidarians, oysters, scallops, periwinkles and different species of fishes that inhabit the mangrove forest. Similarly, the immobility of benthic organisms predisposes them to death from pollution. Different species of crabs such as *Callinectes pallidus*, *Uca tangeri*, *Ostrea tulipa* and *Goniopsis pelii* are also affected by pollutants.

Urbanization is also a major threat to the mangroves, this is because population explosion in Nigeria, which is the most populous country in Africa, had led to the migration of a large number of people numbering over 20 million [33] into coastal regions of the Niger Delta to establish houses. Industrialization of wetland areas leads to the urbanization of rural areas that were formerly a habitat for mangroves. Increase in anthropogenic activities around mangrove forest had resulted to the invasion by opportunistic nypa palms (*Nypa fruticans*) and other alien species. The nypa palms were intentionally introduced in 1906 for the purpose of fighting coastal erosion [34]. The palms were originally not a threat to the mangroves, but within the last 30 years due to unabated anthropogenic activities they have become a major threat to mangroves after hydrocarbon pollution [35]. They have currently displaced 5% of the entire mangrove forest in the last 20 years [35] caused mainly by oil and gas exploration, urbanization and deforestation [36], which had opened up the forest to further exploitation. Despite the impacts of the aforementioned factors, mangroves are still resilient to environmental perturbations [37] and have robust growth in the Niger Delta. However, the current threat to mangroves that can lead to their extinction is the interaction of all the factors. It is found that mangroves can survive hydrocarbon pollution by adapting to the contaminated environment through the activities of increased soil fertility via hydrocarbon utilizing bacteria. They can also survive some forms of selective deforestation aimed at harvesting firewood for human use. They can also survive invasion by nypa palm propagules as long as their soil quality is not reduced as a result of the actions of solid and liquid waste. But they would hardly survive when all the aforementioned factors combine and overwhelm them.

1.4. Mangrove species composition in the Niger Delta

There are several species of mangroves in the Niger Delta, but the most dominant ones are the red (*Rhizophora racemosa*), black (*Laguncularia racemosa*) and white (*Avicennia germinans*) mangroves [38]. Button wood mangroves (*Conocarpus erectus*) are also prominent but less studied and is not too common around core mangrove forest. They are mostly found in

inland areas that have sandy soil. They have green leaves and hairy round seeds (**Figure 1c**). The mangroves are mainly fringe forests [39]. This is because they are found at the fringes of the coastlines facing the river. Oil palm trees (*Elaeis guineensis*), mangrove fern (*Acrostichum aureum*) and grass species such as vines, sedges etc. (**Figure 1I**) are found around sandy or disturbed parts of the forest in inland locations. A major factor for their distribution pattern is the nature of the soil, which is less fertile and less saline. Non-mangrove species perform better in soils with low salinity unlike mangrove soil that thrives in highly saline environment [7, 40]. Human activities such as sand filling, reclamation and dredging (**Figure 2**) change the soil from muddy to sandy soil leading to the intrusion of non-mangrove species in mangrove forest.

The white mangroves (*Avicennia germinans*) on the other hand, are the next most dominant after the button wood in sandy areas. The red mangroves are the closest to the seashore whereas the black and white mangroves are more adapted to disturbed soils. They are often found on the edges of shorelines where waste are deposited. In contrast, the red mangroves are mostly found in undisturbed pure swampy soils than mixed or contaminated soils. This is because presence in soils contaminated by waste impairs the growth of red mangroves. An example of a disturbed soil is the sand filled mangrove forest in Buguma, Niger Delta, Nigeria. This area was sand filled in 1984, and since then no mangrove had ever grown on it. Rather the dominant species found

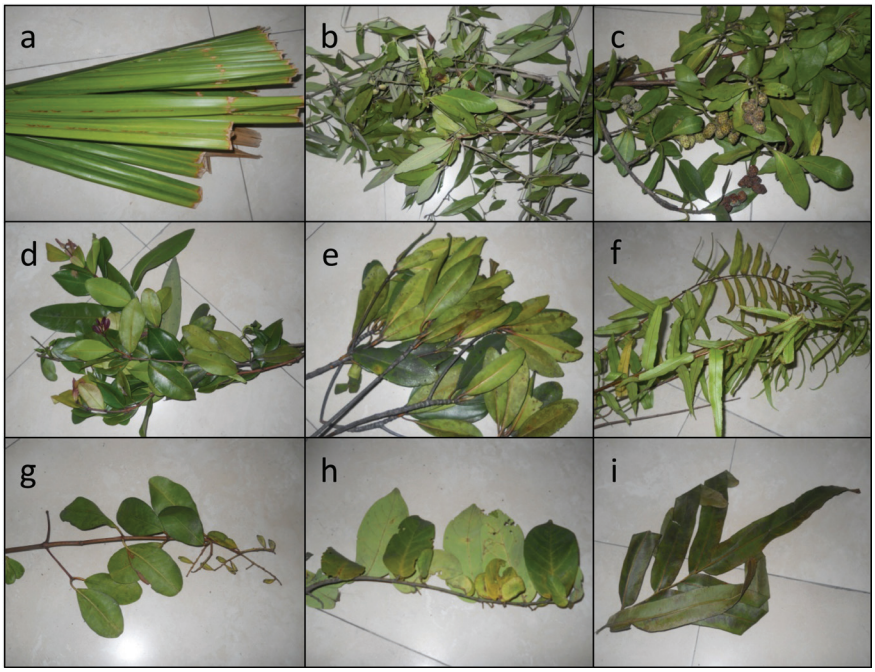

Figure 1. Different mangrove and non-mangrove species found in mangrove swamps affected by anthropogenic activities (dredging and sand filling). (a) Nypa palm (*Nypa fruticans*), (b) black mangroves (*Laguncularia racemosa*), (c) button wood (*Conocarpus erectus*) (d) herb (e) red mangrove (*Rhizophora racemosa*) (f) mangrove associated fern, (g) white mangrove (*Avicennia germinans*), (h) *Heritiera littoralis* (I) mangrove fern (*Acrostichum aureum).*

Figure 2. Dredged and sand filled mangrove forest in Buguma, Niger Delta, Nigeria. There are still some mangroves that can be seen at the foreground. On the left of the picture is the fence of a secondary school. No mangrove tree has ever grown in this area since the sand filling in 1984. The area is now occupied by weeds and other alien plant species.

are a variety of non-mangrove species in both the seaward and landward areas. The landward area has sandy soil that has large percentage growth of grass species such as corn vine (*Dalbergia ecastaphyllum*), coco plum (*Chrysobalanus icaco*) etc. Because of the proliferation of anthropogenic activities around mangrove forest some grass species had taken over the area. Examples of other species present include carpet grass (*Axonopus compressus*), elephant grass (*Pennisetum purpureum*), guinea grass (*Panicmum maximum*), goose grass (*Eleusine indica*) and goat weed (*Ageratum conyzoides*). A major observation during field work is that mangroves when cut never grow back rather the area from where they are cut is over taken by weeds [28] which forms gradients around the wetland soil. Oil and gas exploration also affect species composition in mangrove forests [35]. For example, industrial activities had led to a permanent change in soil and species composition, which accelerates the proliferation of weeds and other alien species. The weed when they grow becomes the hiding place for foreign insects and rodent pest, which later invade the mangroves.

1.5. Data gaps

Combinations of biotic and abiotic factors had made the mangroves one of the most unique, but less studied systems in the world. The problem of data gap in Africa is often cited in many literatures with little done to correct this trend. This work therefore, brings to fore the distribution and composition of mangroves and non-mangroves species in two locations in the Niger Delta to enable scientist in other regions of the world to have a better understating of the largest mangrove forest in Africa. The emphasis of mangrove study in the past has been the effect of pollution on mangrove forest, but no mention was made of species composition and distribution. This is the reason why this study is embarked upon to help bridge the data gap. This study thus intends to achieve the following objectives;

1.5.1. Objectives

1. To determine the distribution, composition and structural characteristics of mangroves
2. To evaluate the adaptive strategies of mangroves vis-a-vis their significance to the environment.

2. Materials and methods

2.1. Study area

The Niger Delta region is situated in the southern part of Nigeria and bordered to the south by the Atlantic Ocean and to the East by Cameroon. It occupies a surface area of about 112,110 km^2. It represents about 12% of Nigeria's total surface area and it is predicted that by the year 2020 its population would have exceeded 45 million inhabitants, which is almost two third of the entire population of Nigeria (i.e. 200 million). The region is made up of nine of Nigeria's constituent states (i.e. 37) (**Table 1**):

States	Land area (km^2)	Population	City capital
Abia	4877	5,106,000	Umuahia
Akwa Ibom	6806	5,285,000	Uyo
Bayelsa	1107	2,703,000	Yenagoa
Cross River	21,930	4,325,000	Calabar
Delta	17,163	5,681,000	Asaba
Edo	19,698	4,871,000	Benin
Imo	5165	5,283,000	Owerri
Ondo	15,086	4,782,000	Akure
Rivers	10,378	7,679,000	Port Harcourt
Total	112,110	45,715,000	

Source: Adjusted from [41].

Table 1. Land area and population of people in different states of the Niger Delta, Nigeria.

The Niger Delta region makes up 4% of Nigerian population. There is an annual growth rate of 3.5% The population of youths below 30 years (62%) far exceed that of adults of 30–69 years (36%) and older adults above 70 years (2%). The life expectancy is about 50 years. There is resurgence in population of people migrating into the mangrove forest areas to seek for habitation in the last 20 years. The consequence of this situation is the clearing of more mangrove forests.

2.2. Climatic conditions

Mangroves in the Niger River Delta, Nigeria are the largest in Africa, and the third largest in the world. It is estimated to cover between 5000 and 8500 km^3 [42]. It has a tropical monsoon climate and rainfall occurs almost all throughout the year, except November, December and January. Mean annual rainfall ranges from over 4000 mm in the coastal towns, and decreases inland to 3000 mm in the mid-delta area; and slightly less than 2400 mm in the northern parts of the region. In the north western portions including Edo and Ondo States, annual rainfall ranges from 1500 to 2000 mm, respectively. The two seasons that prevail in the Niger Delta are the wet (February–October) and the dry (November–January) seasons with a break in August,

known as the "August break". During the dry season harmattan winds also called the North East Trade winds blow particles of dust from the Sahara Desert to the coastal maritime regions in the Niger Delta. The monthly temperature ranges between 26 and 30°C. Temperatures are generally high in the region and fairly constant throughout the year. Average monthly maximum and minimum temperatures vary from 28 to 33°C and 21 to 23°C, respectively. The warmest months are February, March and early April in most parts of the Niger Delta Region. The coolest months are June through to September during the peak of rainfall during the wet season. The soil is swampy and grades from red to brown as a result of iron deposition [38]. The soil compaction ranges from 0.25–0.75 tonnes/cm, while the pH ranges from 5.0–7.0.

2.3. Sample collection

A study on species distribution was conducted between seaward and landward sites in Buguma. Along a 20 m transect running across the middle of the plot, eight equally spaced points were identified and soil samples collected and species composition and diversity indices estimated from seaward to landward locations. The soil samples were collected with a hand held augur (Germany) and placed in a black cellophane bag. Leaf samples were collected at each point and placed in an ice cooler, and sent to the laboratory for physico-chemical analysis. The different plant communities were identified by a plant taxonomist.

2.3.1. Species occurrence and stand structure

Floristic diversity, which is the percentage occurrence of mangrove species present around the forests, was determined within a 5 × 5 m^2 sub-plots within a 20 × 20 m plot in Buguma and Okrika in the Niger Delta. The dbh for trees with small girth were measured with a vernier caliper at an accuracy of 0.01 cm while the stems of larger girth were measured with tapes (Forestry suppliers Inc., Jackson, MS). The tree heights were randomly measured within the plot with EC II Haglof clinometers at an accuracy of 0.1 m.

2.3.2. Stand structural characteristics

The stand basal area, which is the summation of all individual basal areas per unit ground area, was calculated as described by [43]. The area of the main plot, 400 m^2 (i.e. 20 × 20 m), and the area of the sub-plots, 25 m^2 (i.e. 5 × 5 m) were used as the conversion factor of 1 hectare [44]. The outcome of this calculation is in [45].

The importance value (I_V) of the mangroves was calculated using the equations of [43]:

The importance value is a quantitative parameter used to show the significance of each species within a stand, and it includes the summation of relative density, relative frequency and relative dominance.

2.3.3. Above ground biomass (AGB)

The allometric method was used to estimate the plot AGB, since biomass was an indicator of the productivity of a mangrove stand [45, 46]. This method is used for estimating tree weight from field verifiable structural indices such as diameter at breast height (dbh) and tree height (h) [46]. The amount of standing biomass in mangrove forest is a function of the systems productivity

[45]. The development of site and species specific allometric relationship is best done using harvesting method [47]. But this method was not used because of its negative effect on the environment. The above ground biomass was therefore, calculated following the equations developed by [48] and presented in 4 studies of [45].

This equation is the Model 1 (diameter-height-wood density) mangrove biomass regression model. The wood specific density (ρ) for African mangroves from the Global Density Database was used in the calculation [49–51]. A total of five dominant mangrove species were taxonomically identified in the study locations and their wood specific densities (ρ) recorded as follows: *R. racemosa* (0.96 g cm^{-3}), *R. mangle* (0.98 g cm^{-3}), *A. germinans* (0.90 g cm^{-3}), *R. harrisonii* (0.86 g cm^{-3}) and *L. racemosa* (0.61 g cm^{-3}). These specific densities were put into the Model 1 mangrove regression model to calculate the plot AGB.

2.4. Soil sample analysis

A comprehensive physicochemical analysis of soils collected from Buguma and Okrika was done at the laboratory where standard methods were observed to analyze the parameters.

2.4.1. Soil organic carbon (Walkley-Black method)

A representative soil sample was collected and grinded into fine particles, such that it can pass through 0.5 mm sieve and air dried. Soil samples were weighed in duplicates of 75 g and transferred to 250 ml Erlenmeyer flask. 10 ml of $K_2Cr_2O_7$ solution was accurately pipetted and dispensed into each of the flasks and swirled gently to disperse the soil. 20 ml of concentrate H_2SO_4 was added rapidly and directing the stream into the suspension. The soil and the reagents were mixed by swirling the flask gently for 1 min. The beaker was rotated again and the flask was allowed to stand on a sheet of asbestos for about 30 min, thereafter, 100 ml of distilled water was added. Then, 3–4 drops of indicator were added and titrated with 0.5 ml of ferrous sulphate solution. As the end point is approached, a greenish caste was observed which later changed to dark green. Thereafter, ferrous sulphate was added, drop by drop until the color changed sharply from blue to red (maroon color) in reflected light against a white background. The blank titration was prepared in the same manner using the above mentioned steps but without soil to standardize the dichromate.

The result was obtained using the formula of [52].

$$\%\text{Organic Carbon in Soil} = \frac{\text{Blank Titre Value-Sample Titre Value}}{\text{Weight of Air-dried Soil (g)}} \quad (1)$$

2.4.2. Soil pH and conductivity

pH meter was used to check the acidity and alkalinity of the soil in situ. Conductivity was measured in field using conductivity meter.

The KH_2PO_4 Extraction Method was used to analyze sulphate content of the soil.

2.4.3. Sulphate and phosphorus analysis

The KH_2PO_4 Extraction Method was used to analyze sulphate content of the soil. 2 g of soil with one tea spoon of carbon black and 40 ml of extracting solution were added into 125 ml of

Erlenmeyer flask, and mechanical shaker was used to shake the mixture for 30 min. The suspension was later emptied into a funnel containing Whatman No. 40 Paper to obtain a clear filtrate. The solution was stored and phosphorus was determined using Calorimetric Method [53].

2.4.4. Metal analysis

A portion of 0.25 g of air dried sediment samples were weighed into a Teflon inset of a microwave digestion vessel and 2 ml concentrated (90%) nitric acid (Sigma-Aldrich, Dorset, UK) were added. The metals were extracted using a microwave accelerated reaction system (MARS Xpress, CEM Corporation, Matthews, North Carolina) at 1500 W power (100%), ramped to 175°C in 5.5 min, held for 4.5 min, and allowed to cool down for 1 h. The cool digest solution was filtered through the Whatman 42 filter paper and made up to 100 ml in a volumetric flask by adding de-ionized water.

For the water samples, 2 ml concentrated (90%) nitric acid (Sigma-Aldrich) was added to 0.2 ml water and the volume was made up to 10 ml with de-ionized water (X 5 dilution). Metal concentrations were analyzed by inductively coupled plasma mass spectrometry (ICP MS: model X7, Thermo Electron, Winsford-Cheshire, UK).

All chemicals and reagents used were of analytical grade and of highest purity possible. Analytical blanks were prepared with each batch of the digestion set and analyzed (one blank for every set of six samples) in the same way as the samples. The analytical methodologies were confirmed using certified reference materials for sandy clay (CRM 049-050, Sigma-Aldrich RTC, Salisbury).

3. Results

3.1. Species composition and diversity indices

Most locations in the Niger Delta have similar mangroves species composition. Some mangrove species found include: *Rhizophora harrisonii* and *Laguncularia racemosa*. The three most commonly found mangrove species are: *Rhizophora racemosa*, *Rhizophora mangle*, and *Avicennia germinans*. Species diversity indices indicates that among the mangroves *Rhizophora racemosa* had the highest abundance and species diversity (**Table 2**) while for the palm species, the nypa palm dominated (**Table 3**) and for the grass species, *Dalbergia ecastophylum* had the highest diversity (**Table 4**).

3.2. Species distribution

Species distribution from seaward to landward areas indicates that core mangrove species were found in the seaward side, whereas the non-mangrove species were found in the landward direction.

3.3. Heavy metal and nutrient concentrations distribution along a transect

There was gradation of heavy metal concentration along the established 20 m transect. It shows that the concentration of metals from landward to seaward directions remained unchanged while Zinc (Zn) concentration along transect fluctuate.

Scientific name	Common name	Abundance	Proportion (P_i)	Ln (P_i)	P_i Ln(P_i)
Rhizophora mangle	Red	5	0.21	−1.561	−0.328
Rhizophora racemosa	Red	8	0.33	−1.109	−0.366
Rhizophora harrisonii	Red	2	0.08	−2.526	−0.202
Avicennia germinans	White	6	0.25	−1.386	−0.347
Laguncularia racemosa	Black	3	0.13	−2.040	−0.265
Total		24		H	1.508

Table 2. Shannon wiener diversity indices (H) of major mangrove species in the Niger Delta, Nigeria.

Scientific name	Common name	Abundance	Proportion (Pi)	Ln (P_i)	P_i Ln(P_i)
Nypa fruticans	Nypa palm	5	0.83	−0.186	−0.154
Elaeis guineensis	Date palm	1	0.17	−1.772	0.366
Total		6		H	0.52

Table 3. Diversity indices (H) of palm species commonly found around most mangrove forest in the Niger Delta, Nigeria.

Scientific name	Common name	Abundance	Proportion (P_i)	Ln (P_i)	P_i Ln(P_i)
Dalbergia ecastophylum	Corn vine	6	0.24	−1.427	−0.343
Chrysobala musicaco	Coco plum	4	0.16	−1.833	−0.293
Paspalum	Silt grass	2	0.08	−2.526	−0.202
Scleria verrucosa	Bush knife	1	0.04	−3.219	−0.129
Combretum racemosum	Christmas tree	3	0.12	−2.120	−0.254
Osbeckia tubulosa	Melastomataceae	1	0.04	−3.219	−0.129
Mariscus longibracteatus	Sedge	1	0.04	−3.219	−0.129
Acrostichum aureum	Aquatic fern	1	0.04	−3.219	−0.129
Scleria naumanniana	Bush knife	1	0.04	−3.219	−0.129
Lycopodium cernuum	Fern	1	0.04	−3.219	−0.129
Alchornea laxiflora	Christmas bush	1	0.04	−3.219	−0.129
Syzygium guineense	Myrtaceae	3	0.12	−2.120	−0.254
Total		25		H	2.249

Table 4. Shannon wiener diversity indices (H) of weed species commonly found around mangrove forest in the Niger Delta, Nigeria.

Nutrient contents varied along the 20 m transect from seaward to landward directions. There was an increase in sulphate (SO_4) and potassium (K) content while there was a decrease in Calcium (Ca), Magnesium (Mg), Manganese (Mn) and Phosphorous (P) contents.

http://dx.doi.org/10.5772/intechopen.79028

Study location	Conductivity µs/cm	pH	TOC (%)	P (mg/kg)	SO_4^{2-} (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Ca (mg/kg)	K (mg/kg)	Mg (mg/kg)
OK1	1133	5.94	1.989	0.07	25	0.06	6.21	4.86	1.26	1.52	33.28	54.95	229.48
OK2	783	6.4	1.716	0.03	28	0.001	0.001	1.26	0.001	0.44	45.17	38.31	143.73
OK3	9920	5.97	3.315	0.09	60	0.001	0.001	2.6	0.001	4.71	36.95	334.8	513.2
Mean	3945.33	6.10	2.34	0.06	37.67	0.02	2.07	2.91	0.42	2.22	38.47	142.69	295.47
SD	5177.17	0.26	0.86	0.03	19.40	0.03	3.58	1.82	0.73	2.22	6.09	166.58	193.37
SE	2989.04	0.15	0.49	0.02	11.2	0.02	2.07	1.05	0.42	1.28	3.52	96.18	111.64

Table 5. Soil physico-chemical characteristics of different mangrove forest in Okrika, Niger Delta, Nigeria. OK refers to Okrika.

Study location	Conductivity µs/cm	pH	TOC (%)	P (mg/kg)	SO_4^{2-} (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Ca (mg/kg)	K (mg/kg)	Mg (mg/kg)
BG1	308	6.53	2.808	0.15	18	1.34	19.14	83.97	19.28	51.84	1149.1	133.85	737.35
BG2	186	6.83	2.145	0.1	15	0.93	22.82	88.55	38.85	62.55	1156	157.05	715.49
BG3	19,280	6.58	3.939	0.24	240	0.001	0.001	8.4	0.001	4.77	282.85	407.4	794.61
Mean	6591.33	6.65	2.96	0.16	91.00	0.76	13.99	60.30	19.38	39.72	862.65	232.77	749.15
SD	10988.9	0.16	0.91	0.07	129.05	0.69	12.25	45.01	19.43	30.74	502.13	151.68	40.86
SE	6344.43	0.09	0.52	0.04	74.51	0.40	7.07	25.99	11.21	17.75	289.91	87.57	23.59

Table 6. Soil physico-chemical characteristics of different mangrove forest in Buguma, Niger Delta, Nigeria. BG refers to Buguma.

A detailed physico-chemical analysis of the study locations is presented in **Tables 5** and **6**.

3.4. Stand structure and above ground biomass

Stem diameter of the mangrove trees ranged from 0.01 to 16 cm. *Avicennia germinans* had the largest diameter among species. Tree height ranged from 0.02 to 6.71 m. The average diameter and average tree height for most locations are not significantly different from each other.

4. Discussion

Rhizophora racemosa was the most dominant species in all locations. This is in line with the outcome of previous studies done in the Niger Delta [40]. The importance value (I_v) of *R. racemosa* (i.e. 52.02) was the highest for all locations. It is similar to the value derived by [54] in south-eastern Nigeria (i.e. 55.6). The next most dominant species of mangroves are *R. mangle* followed by *A. germinans* [45].

The dominance of the red mangroves (i.e. *Rhizophoraceae* family) is because they grow best in core mangrove soil. They are mostly old growth forest that had been growing for the past 20–30 years without disturbance. They have large diameter and grow beyond 6 m in height. The trees grow in groups and are self-sustaining and support each other. Because of the large sizes of the stem they are often used for firewood and charcoal. Constant destruction of the mangroves by humans had, however, made them to regenerate and grow afresh, making them have less significant wood for charcoals production. Clear cutting lead to renewed sprouting of fresh mangroves, which unifies regeneration [55]. Hydrocarbon pollution and selective deforestation lead to uneven growth. Nevertheless, the growth in height and stem diameter is greater in younger mangrove forest than in older mangrove forest [56]. The forest is also cut to create room for building residential and industrial quarters.

Baseline data on biomass will help to recognize importance of mangroves in Nigeria. Biomass differences among mangrove forests are indicator of healthy and unhealthy forest. Mangrove forest in unprotected areas seems to show unhealthy condition or fragmentation and degradation due to illegal logging and aquaculture [57, 58]. Thus, management effort of rehabilitating degraded forest must be done to improve carbon sequestration and productivity in unprotected mangroves forest.

Four kinds of soils found in mangrove forest in the Niger Delta include: are mud, chikoko-wet, chikoko-dry and sandy soils. Muddy soils is fine to the touch, light brown in color, wet, and mixed with litter. It can be molded into shapes because of its high plasticity and low porosity. This soil allows the growth of few weeds, and few mangrove species. The chikoko-wet is dark brown in color, rough to the touch, forms a semi mold, and often wet and has medium plasticity and low porosity. This soil is the best for the growth of red, black and white mangroves. The chikoko-dry is coffee-brown in color, rough to the touch, has particulate matter and forms no mold. It contains litter material, and has low plasticity and medium porosity. This soil does not support the growth of many plant species because of its dryness. The sandy soil is whitish to dark brown in color, rough to the touch, forms no mold, and has low plasticity, but high

porosity. This soil strictly allows only grasses and other weed species grow on it. They are often found in dredged or sand filled areas.

Mangroves have low growth in muddy soil because the soil suffocate their lenticels, which may lead to death. The case is, however, different for the weeds, which have better growth in muddy soil. A species composition study done in a sand filled area indicates that in a 20 m transect starting from the seaward to the landward direction; there was a significant difference in the number of species found. Similarly, there was a significant difference in soil physico-chemistry at eight points along the transect. The result indicates that the sandier the soil the more the number of weeds, while the swampier the soil the more the population of red mangrove trees (**Table 2**).

The breathing root system of mangrove is built for survival in anaerobic soils. That is why the mangroves thrive in areas where other species fail that soil types influence mangrove growth. For instance, results from a fieldwork I embarked on indicates that total organic content (TOC) was higher in farm (1.99 ± 0.01%) and Nypa palm (1.87 ± 0.01%) soils than in mangrove soils (1.01–1.48%). Similarly, soil types influence the height of mangrove and nypa palm seedlings ($P < 0.001$), but did not influence diameter of seedlings ($P > 0.05$). Mangrove propagules grew best in farm soils. This shows that mangrove distribution is strongly influenced by soil types. Therefore, the more the soil type changes as a result of anthropogenic activities the more it harbors foreign species, which are non-mangroves. In addition, tidal fluctuation and soil moisture content affects the amount of organic matter in sediments [59].

Changes in heavy metals and nutrients can also influence the distribution of mangroves and other plant species in a wet land area. In a study carried out in dredged and sand filled site in Buguma Niger Delta, Nigeria, the result indicates that apart from zinc, which fluctuated, other heavy metals did not vary significantly along a 20 m transect from sandy to mangrove soil ($P > 0.05$). Mangroves play environmental role by acting as a biofilter of heavy metals [60]. Lastly, maintaining high diversity of mangroves is crucial to ensure the health and productivity of coastal zones [60].

4.1. Adaptive strategies of mangroves

There are several adaptive features in mangroves [61] including some that are peculiar to the Niger Delta, Nigeria. The mangrove develops long root system that can easily be mistaken for a tree branch. They grow up to 3 m in height, and grow out from tree branches to the ground. This helps to provide extra support for the trees. The adventitious roots do not only grow from the base, but grow from the top of the trees to the ground. The giant roots support and provide extra surface area for atmospheric respiration during high tides when the ground roots are submerged in water. The branches hardly submerge during high tide or flooding because of the nature of the root system, which grow above the water level. The red mangrove trees are more dominant and more adapted to core mangrove soils. The red mangrove propagules have limited growth in sandy or mixed soils. They are mostly adapted to wet chikoko soil, which is slightly muddy.

The red mangroves (e.g. *Rhizophora mangle*) are viviparous and have spear-like propagules that germinate while still attached to the tree. This is an adaptation for quick deployment and growth especially when they fall on swampy soils. The base of the propagule contains root cells, which begin to grow immediately it touches the soil or water. However, if the propagules fall on hard surface it lies horizontal, but if it falls in water it would be carried away by tidal currents. The seeds, nevertheless survive being swept away by water current because of its buoyancy, as compared to the nypa palm seeds that are round and are partially submerged when carried by tidal currents.

The torpedo shape of the mangrove propagule enables it to float upright i.e. bottom down and heads up when submerged in water. This allows easy soil implantation and growth.

Rootlets of the white mangrove trees protrude from oxygen-depleted soils like spikes to take in oxygen. This is a way of boosting their survival in a difficult and marshy environment. This characteristic is most often exhibited by the black and white mangroves, but not the red mangroves. This is because white and black mangroves are mostly found in disturbed environments, such as dump sites and sand filled areas. The stems of the red mangroves are elastic and are adapted to wear and tear. The stems and roots form a network that prevents the free movement of animals and humans within the forest. They also restrict the movement of humans and machinery during exploratory activities.

The leaves of the red mangroves (*Rhizophora germinans*) are leathery and succulent and have some xerophytic [62] and schlerophyllic attributes. The epidermis has thick outer walls which enables them to withstand both dry and wet conditions. During the dry season from October to January, the leaves do not fall, and do not undergo rapid transpiration and evaporation, thus preventing desiccation. The mangroves rather look robust, fresh and evergreen in both dry and wet seasons. High litter fall usually occur in the dry season unlike in other areas where the rate of litter fall was higher in wet season. Studies had shown that seasonal changes and hydrocarbon pollution are the two major causes of litter fall and litter accumulation in the Niger Delta, Nigeria. The highest rate of litter fall was recorded in the dry season, between November and March. This is because of reproductive activity (i.e. fruiting and flowering) and harmattan winds that occur mainly during the dry season. The litter enriches the soil and supplies the raw materials needed for decomposition [63]. This leads to the constant enrichment of the soil, which makes the mangrove forest rich in biodiversity.

The mangrove soil is red in color and has life-saving gas that breathes life into the entire mangrove ecosystem. The soil has numerous fiber-like materials that hold and reinforce the soil against water erosion and tide. The combination of nutrients and red soil water with fibrous materials is what has made the mangrove a biodiversity hot spot. Therefore, if these qualities are destroyed as a result of human activities the red mangrove population will decline leading to succession [14] and entry of foreign species [64]. The surface of an undisturbed mangrove soil is slimy and facilitates the movement of creeping and swimming organisms such as mud skippers during low or ebb tides. The slimy and soft nature of the top soil also acts as a defensive mechanism to prevent the free movement of man and

animals on the forest floor. The soil has some holes, which serve as air pockets and safe sanctuaries for threatened organisms (e.g. crabs, mudskippers).

A symbiotic relationship does exist between the red mangrove trees and black ants. Large number of black ants are always found on the leaves, branches and stems of trees, which serve as a source of food for the ants while the ants in turn provide protection for the tree against intruders. Termites also build huge termitarium on the tree trunks, which further provides extra security for the plants by warding off intruders and predators. The ants are entomophagous because they feed on other insects along their path. The ants also attack humans that climb to exploit the trees.

The stems of the mangrove trees are very rigid and could withstand severe external impact or fracture during wind storm. It is also extremely difficult to cut down the trees with a machete. The trees are often cut with chain saw or brought down with bulldozers. The mangroves grow in groups, which gives them extra protection from wind storms. The closeness of the trees to each other also leads to the accumulation of large amount of ground litter materials that decompose to drive the nutrient cycle of the forest [14].

Tree climbing skill is exhibited by red mangrove crabs (*Goniopsis pelii*) to hide from ground predators and evade capture. The crabs eat mangrove leaves thereby contributing to litter fall, which help to enrich the mangrove soil.

The mangrove forest is rich in biodiversity and has organism such as monkeys, guinea fowl, periwinkle, mudskipper, crabs (*Goniopsis pelii*), birds (i.e. cranes) and insects [3]. The whole mangrove system is built to withstand stressful conditions. For example, its roots are natural air pumps that suck in oxygen from the atmosphere. The roots are also one of the largest above ground root systems possessed by any plant in the world. The roots provide extra support for growth in soft soil. The mangrove seeds are highly buoyant, which enables them to float, travel and colonize vast areas without drowning. The tenacity of their stems make their wood to be suitable for the production of charcoal and fire wood for cooking in most African communities. The wood have high combustibility and high fire retention capability. The mangrove forest serves as home for many rural dwellers, who build their houses right inside the forest because it provides protection from flood, tsunami or hurricanes.

In addition to plant and animal resources the Niger Delta mangrove forest is rich in crude oil. Most oil and gas exploration activities do occur within the mangrove forest. These exploratory activities have decimated the mangroves in many locations, which may lead to extinction if this trend is not stopped [4, 5]. Over the years the mangroves had survived many environmental disturbances such as hydrocarbon pollution, deforestation, urbanization, and invasive species by adapting to very difficult conditions.

Mangroves are adapted to hydrocarbon pollution: This is because series of studies and field observations have shown that mangroves growing in highly polluted plots had better structural characteristics, above ground biomass and species composition than mangrove trees growing in lowly polluted soil [45, 54]. It has been difficult to provide answers to the cause of this trend, but of recent it was discovered that the robust growth of mangroves in highly polluted plots is as a result of decomposition and nutrient cycling from excess defoliations as a result of oil and gas exploration. The reason is that oil spill leads to increase in litter fall, which covers the soil surface, and decomposes to enrich the soil. This condition leads

to the proliferation of hydrocarbon utilizing bacteria, which detoxifies the soil and increase the soil fertility leading to a positive feedback such as increase in nutrient turnover. This leads to the rapid growth of mangroves in highly polluted soils. This study is supported by other studies which revealed that the rate of herbivory of crabs and insects on mangrove leave was higher on trees growing in highly polluted soils than in trees growing in lowly polluted soils.

5. Conclusion

Mangrove of the Niger Delta, Nigeria is one of the most productive systems in terms of biodiversity, and ecosystem services in the world, but because of lack of data it is often not mentioned in many literatures. This chapter has brought to light the distribution of different species of mangroves between landward and seaward areas and the effect of soil physicochemistry on mangrove species distribution. *Rhizophora* species i.e. red mangroves are the most dominant species and is often found in the seaward areas whereas the white mangroves and the button wood mangroves are found in the landward locations. The positions of the different species of mangroves in the coastal areas had given them the ability to adapt to their difficult environment. The red mangrove of the Niger Delta has one of the longest above ground root systems, which it uses for support and respiration. The stem is also used for fire wood and charcoal production. The mangrove despite its usefulness to man and the environment has faced a lot of anthropogenic disturbances, which if not curtailed will lead to the final extinction of the mangroves.

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