Freshwater Swamp Forest Ecosystem in the Niger Delta: Ecology, Disturbance and Ecosystem Services

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This thesis is dedicated to my wife and son (Chimdiebube), who was born on the day of my Ph.D. viva

Thesis Abstract

Freshwater swamp forests are wetland ecosystems of global importance, especially because they provide very valuable ecosystem services such as regulation of flood and maintenance of water quality, and provide suitable habitat for the conservation of wetland ecosystems (flora and fauna). Though they are hosts to important biodiversity as in other tropical ecosystems, their ecology, function and contribution to ecosystem services are poorly understood. With poor baseline data on this threatened ecosystem across the Niger Delta region and the entire West African region, this thesis explores its ecology, biogeography and the capacity to which this ecosystem sequester carbon, in a bid to better prioritize and inform effective conservation and management.

Floristic compositions of the ecosystem were varied in density, diversity and rarity across undisturbed, disturbed and transition (mangrove-freshwater) zones. A total of 138 species within 100 genera and 41 families of taxa were identified across the 24 one hectare forest plots; with variations in dominance according to each of the zones. With a stem density which ranged from 94 – 506 stems ha^{-1}, the ecosystem was seen to be comparable with other tropical forest ecosystems, but were poorer in species richness as a result of the environmental constraints associated with the swamp. Though disturbance (local factors) influenced the pattern of species distribution to a great extent, environmental (regional factors) equally contributed to this variation.

Above ground carbon estimates (AGC) were also similar to other African forest ecosystems, with the estimates varying at the plot level mainly due to disturbance gradients. Other variables that contributed to AGC variations included the floristic composition (which were found to be more carbon dense towards the transition zones), tree structure and climatic variables. Other ecosystem services derived from the ecosystem (timber and non-timber forest products) were found to be a major source of sustenance and income generation at varying levels. Household usage and dependence on the forests were mainly influenced by the degrees of remoteness of each community, and whether each of the households had other alternative sources of livelihood. With a poor perception of decline in ecosystem services with usage, the forests has steadily shrunk and degraded.

The future of this disturbance-prone and disturbance-determined ecosystem to continually remain viable and provide a wide range of ecosystem services at the global, regional and local scales are dependent on the conservation and management measures adopted by its people and government. Forest friendly and effective management policies (such as joint forest management strategies) and alternative sources of livelihood are advocated across the tropics, in a bid to forestall efficient conservation of the biodiversity and the services derived from such forest ecosystems.

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Author's Declaration

I hereby declare that this thesis represents my work and has not been submitted at any time for any degree, diploma or other qualification in this University or any other institution. I carried out the study design, data analysis, interpretation and writing of the thesis.

"Ultimately, the future of a natural ecosystem depends not on protection from humans but on its relationship with the people who inhabit it or share the landscape with it"

William R. Jordan III

Chapter 1 – Introduction

1.1 Overview of thesis

Freshwater swamp forests belong to a broad delimitation of forested wetlands which occupy more than 330 Mha globally (Matthews and Fung, 1987) and like other forms of the tropical forest ecosystem, are epicentres of biodiversity (Lewis, 2006). These forests are periodically inundated with mineral rich water from streams (Whitmore, 1984) and are very useful in the regulation of flood and maintenance of water quality (Asthana and Asthana, 2003). This ecosystem is delimited according to their hydrological factors, nutritional factors and geomorphology (Lugo et al. 1988). The hydrological factors include the kinetic flow of energy, the predominant direction of water flows and the hydro-period. Nutritional factors defining the freshwater swamp forests include the nutritional quality of the sediments and water. Their geomorphological delimitation includes the riverine, basin and fringe types. Even though their ecology, function and mechanism are distinct, they have not received much attention as other tropical forest ecosystems (Lugo, 1984).

Nigeria's freshwater swamp forest is an extensive biome that covers some 12,000km^2 (NDES, 1997) and found between the lowland forest and mangrove forest ecosystems. The ecosystem is found in the Niger Delta, which is a region that has been of global importance (through the slave trade, palm oil trade and fossil fuels more recently) since 1600, but has not been closely investigated biologically (Blench and Dendo, 2007). The limited surveys have revealed many species which were not known to occur in the delta notably the Niger Delta red colobus (*Procolobus badius epieni*) which was new to science (Blench and Dendo, 2007). The almost extinct abura (*Hallea ledermannii*), considered to be Nigeria's second most important timber tree, since the late 1950's, more broadly attests to the threats facing the biodiversity of the ecosystem. The demise of the abura tree coincided with the discovery of crude oil in the delta in the 1950's.

Since many of the locations in the delta were made accessible through the construction of various transportation networks (for crude oil exploration), it aided in a further decline of the biodiversity of the ecosystem. Oil activities which grew in proportion over the years have also been instrumental to massive forest loss and degradation of the ecosystem through oil spills, gas flares and forested land conversion to other uses for the advancement of crude oil exploration. Agricultural activities, especially oil palm production, root and tree crops, led to the conversion of the forest lands into plantations since the colonial days. Furthermore, increasing population growth in the region has contributed to a serious decline in the ecosystem. All these are points of concern especially because the conservation of the freshwater swamp forest ecosystem depends on forest reserves, community and/or private forest management in host communities.

This chapter provides a general introduction to the thesis, exploring the ecology, composition, determinants and dynamics of the freshwater swamp forests in Nigeria and further quantifies the use and ecosystem services, including carbon storage.

1.2 Forest classification

According to Kimmins (1997), “vegetation classification attempts to identify discrete, repeatable classes of relatively homogenous vegetation communities or associations about which reliable statements can be made. It assumes either that natural vegetation groupings (communities) do occur or that it is reasonable to separate a continuum of variation in vegetation composition and/or structure into a series of arbitrary classes”. Achieving this categorization for forest ecosystems is beneficial as it provides a foundation for forest management and conservation planning. The different approaches of forest classification can be summarized as environmental, physiognomic and floristic approaches accordingly.

1.2.1 Environmental approaches to forest classification

Environmental factors are responsible for the growth form, physiology, metabolic and resource availability of different plants and forest cover. They provide insights about the tolerance limits of plants and are responsible for the variations in the composition, structure and features of forest ecosystems. They are thus distinguished as climatic and topographic or physiographic (edaphic) variables as follows:

1.2.1.1 Climatic influences and approaches to forest classification

Climate is a major factor influencing the distribution of vegetation and is primarily defined in terms of temperature and precipitation. It influences the distribution of plant species by imposing physiological constraints which in turn affects their growth and reproduction directly and then indirectly by mediating competitive interactions (Gavin and Hu, 2006). Climatic variables affect the production of pollen, flowers and nectar (Scaven and Rafferty, 2013), size of flowers (Hoover et al. 2012), plant height (Liu et al. 2012) and also plant-pollinator interactions (Scaven and Rafferty, 2013). As climatic variables affect the photosynthesis, growth and reproduction of plants, they influence the population dynamics and distribution at local and global scales, and delineate the world into different biomes. Starting from the early bioclimatic classification by Koppen since 1900, and the modifications that followed, other notable works have been done, such as that of Thornthwaite (1933) and Holdridge (1967), who further contributed to the understanding of the influence of climatic variables in forest classification.

Climatic variables have indeed been one of the oldest methods used in empirical classification and prediction of broad physiognomic vegetation (Prentice et al. 1992). While Koppen’s work classified climatic patterns, the boundary lines coincided approximately with vegetation boundaries and were used to determine climatic variables that were relevant to plants, among which, seasonality was the strongest. Holdridge’s Life Zone Classification is the most commonly used bioclimatic classification and again related potential natural vegetation to climate. The boundaries in his work were defined by annual precipitation and growing season temperatures. Both works were developed by others over the years, and applied in understanding the impact of climate change on natural vegetation at a global scale (Prentice et al. 1992; Solomon and Kirilenko, 1996; Steffen et al. 1996; Yates, 2000). More recently, Blasco et al. (2000) have contributed to this classification by using annual rainfall, seasonality and mean temperature of the coldest month in the bioclimatic classification of the global forest ecosystems. These works have been useful in understanding forest classification at a global scale, however, classifications are still lacking at the local scales for most regions, where it is needed for effective conservation and management.

1.2.1.2 Landform or Edaphic influences and approaches to forest classification

Landform or edaphic influences have been used to delimit agro-ecological zones and vegetation boundaries, for example, differentiating between Sahel and Sudan zones in Mali using boundaries that cross major geomorphologic and geologic zones (ITC, 1977). This method of classification is normally used in vegetation classification at the regional scale, mainly because data at global scales are often lacking as is also often the case at regional scales. It was applied in the Interim Biogeographic Regionalization of Australia (Thackway and Cresswell, 1995), which used climatic, substrate and soil variables. Edaphic variables unlike climatic factors normally influence vegetation patterns with the association of other environmental factors. This could be seen from the example of Nigeria, where the major soil types are related to factors such as: climate, vegetation, lithology and topography (Areola, 1982). Since the distribution of soils is mainly due to variations in parent rock (which influences soil depth, texture, stoniness, moisture condition, nutrients and minerals) (Areola, 1982), the vegetation covers that they support equally varies across these scales. Hence, with the soils of Nigeria broadly distinguished as ferruginous tropical soils, ferralitic soils, ferrisols, weakly-developed soils and hydromorphic soils (Areola, 1982), the vegetation is equally varied due to differences in parent rocks, chemical compositions, soil horizon differentiations, nutrient status, texture, structure, organic contents and drainage. Among these soils, the hydromorphic soils are characterized by seasonal and permanent waterlogging due to their location around marine and riverine valleys and flood plains, and consequently, these dominate the Niger Delta region where swamp forests, freshwater and mangrove ecosystems are concentrated.

1.2.2 Physiognomic approaches to forest classification

The physiognomic approach to classification is mainly based on the growth form of dominant plants and their general external appearance. Most physiognomic classification is based on a ‘community type defined by dominance of a given growth form in the uppermost stratum of the community, or by a combination of dominant growth forms’ (Whittaker, 1962). Application of the physiognomic approach has mostly been on continental or global levels for mapping of vegetation. A good example is the widely recognized global vegetation classification by UNESCO (1973), which produced the world’s vegetation maps at a scale of 1:1 million or smaller. They have equally been applied in natural resource inventory, management and planning; based on assessments of vegetation attributes that may change during stand development and disturbance (Jennings et al. 2003). Other applications include the classification of redwood ecosystems based primarily on their variable physiognomy and canopy (Eyre, 1980; Fox, 1989).

1.2.3 Floristic approaches to forest classification

Floristic approaches of vegetation classification use the composition of taxa to describe vegetation types. They normally achieve this by describing the dominant (taxa) or the total floristic composition. Using dominance involves assessing the most common taxonomic entities, for example, the biomass, density, height, or canopy cover of forest ecosystems (Kimmins, 1997). Floristic classification has been used in aerial photo mapping and inventory because of its ease of interpretation, as well as the use of space borne and airborne remote sensing over large areas (Jennings et al. 2003). Its limitations notwithstanding, is been used mainly because it provides a simple, efficient approach for inventory and mapping (Jennings et al. 2003).

Total floristic composition on the other hand is used in community classification applications. This approach has found its main application through the works of Braun-Blanquet (1928) and Daubenmire (1952). Both dominance and total floristic approaches are based on the concept of 'association' which was defined by Flahault and Schröter (1910) as "a plant community type of definite floristic composition, uniform habitat conditions, and uniform physiognomy" (Jennings et al. 2003). While Braun-Blanquet (1928) based his work on the definition of association as 'a plant community characterized by definite floristic and sociological (organizational) features', Daubenmire (1952) focused on least disturbed and oldest plant communities (near climax); and hence based his premise on the view that a classification 'based upon climax types of vegetation best expresses the potential biotic productivity of a given combination of environmental factors'. Though both schools of thought had some distinctness and differences, they still have underlying similarities; and have been applied in vegetation classification ever since. Notable works include: the use of leaf retention and leaf size in defining high hierarchical orders in northern hemisphere (Dansereau, 1951) and the dominant plant species life forms-which has gained mass usage in vegetation categorization throughout the world (Raunkiaer, 1934).

These approaches represent direct methods of forest classification which have been developed from antiquity and modified over the years in a bid to categorize vast forest ecosystems into relatively homogenous units for better conservation, management and understanding of the processes. Other indirect methods of achieving the same objective have involved the use of remote sensing techniques in mapping the forest ecosystems.

1.3 Tropical forest ecosystem, distribution and ecology

Tropical forests are rich biodiverse forests that occur near the equator (within the area bounded by latitudes 23.5^{o}N and 23.5^{o}S), characterized by distinct wet and dry seasons. Even though they cover only ca. 10% of the earth's land surface, they are global epicentres of biodiversity, regulators of global biogeochemical cycles, modulators of climate change, and storehouses of large quantities of carbon (Lewis et al. 2013; Lewis, 2006; Myers et al. 2000; Houghton, 2005; Malhi et al. 2014). Tropical forests are found on different soil types, but are predominated by infertile soils from an agricultural perspective (Vitousek and Sandford, 1986; Malhi et al. 2004; Lewis, 2006). That notwithstanding, they are highly productive ecosystem that supports a large concentration of flora and fauna (Jermy and Chapman, 2002; Malhi et al. 2004).

Tropical forests are a diverse array of forests which includes both the moist forests and dry forests and also wooded savanna systems (Lewis, 2006). Tropical forest ecosystems are found in various locations: 49% in tropical America, 34% in tropical Africa and 16% in tropical Asia (FAO, 2001). They are the most species rich ecosystem on earth (Gentry, 1992), host at least two-thirds of the earth's terrestrial biodiversity (Gardner et al. 2009) and constitute 17 out of the 25 areas identified as global biodiversity hotspots (Myers et al. 2000).

Africa's tropical forests represent 13% of the world's forest area and include rainforest: evergreen forests and semi-evergreen forests dry forests, mountain forests and dry forests, mangrove swamp forest and freshwater swamp forest. (Whitmore, 1984; Grainger, 1993; Jermy and Chapman, 2002). While mangrove swamp forests are characterized by saline water and comprise trees with buttresses, stilt-roots and pneumatophores, freshwater swamp forests are fed with fresh water from streams, and periodically inundated with mineral rich water from streams (Whitmore, 1984).

1.4 Swamp forest ecosystem, characteristics and types

Swamp forests are found in different climatic regions across the globe and exist as coniferous swamp forest, boreal swamp forest, peat swamp forest, mangrove swamp forests, and freshwater swamp forest. In tropical or sub-tropical areas, swamp forests are classified as mangrove forests, peat swamp forests and freshwater swamp forests. Mangrove forests are found in brackish or salt water environments, with > 30% canopy cover, low floristic diversity and specialized roots that are inundated with saline water (FAO, 1998). Peat swamp forests and freshwater swamps are both typically flanked by lowland rainforests farther inland and mangrove forests near the coast. Peat swamp forests are found in parts of Sumatra, Borneo, Indonesia, New Guinea and Malaysia. They grow on deposits of thick peat (which may be up to 13m thick) and are significant carbon sinks (FAO, 1998). Freshwater swamp forests are found in the tropics on fertile alluvial, predominantly waterlogged soils with an average soil pH of ≥ 6.0 (Whitmore, 1990).

1.5 Freshwater swamp forest ecosystem, global and regional distribution

Freshwater swamp forests cover about 2.1% of the earth's surface (Raven and Johnson, 2002). Swamp or flooded forests, inundated with freshwater, either permanently or seasonally, occur along the lower reaches of rivers and around freshwater lakes. Freshwater swamp forests are usually associated with rivers or streams that flow into the sea (Keay, 1989), as well as a very irregular ground with frequent patches of open water in the dry season. The frequent inundation of the ecosystem by river water results in high soil nutrients which come from the transportation and deposition of mineral rich sediments and debris. Though this flood activitiy is responsible for the natural disturbance of the ecosystem, they on the other hand help to replenish the soil and enhance rapid tree growth (Thomas and Baltzer, 2002). Mounds and ridges in freshwater forests form numerous intricate narrow channels which provide a drainage network from the forest to surrounding rivers and streams, thus regulating coastal water flow and eliminating silt, sediment and pollutants from moving water (Asthana and Asthana, 2003).

In Nigeria, freshwater swamp forests are found inland beyond the reach of tidal waters on generally low-lying areas. They occur in an intricate network of creeks and lagoons which dominate the area and form dense forest vegetation in the region. The annual floods inundate the forest areas and result in siltation and soil fertility augmentation of the ecosystem during the rainy and flooding months. *Raffia* palm dominates the swampy parts of the ecosystem, while the better drained areas support *Elaeis guineensis* (oil palm trees) and trees like *Milicia excelsa* (Iroko). The main canopy of the forest is rather open and in gaps and has an almost impenetrable undergrowth (Keay, 1959). Fauna like Hartlaub's duck (*Pteronetta hartlaubi*), as well as families like heron (*Ardeidae*), ibis (*Threskiornithidae*), pelican (*Pelecanidae*), kingfisher (*Alcedinidae*) and the near threatened raptor-fish eagle (*Heliaetus vocifer*) also breed and hunt for food in the ecosystem (Isikhuemen, 2012). Seasonally flooded swamp forests (chiefly inundated during the wet season) are dominated by *Anthocleista vogelii, Carapa procera, Chrysobalanus orbicularis, Grewia coriacea, Garcinia* spp., whereas permanently flooded swamp forests (usually inundated throughout the year), are characterized by species such as *Alstonia* spp*. Hallea ledermannii* and *Raphia* spp. (Hughes and Hughes, 1992) (Fig 1.1). Since the ecosystem traverses large spatial scales, the species composition is expected to vary markedly in relation to environmental conditions.

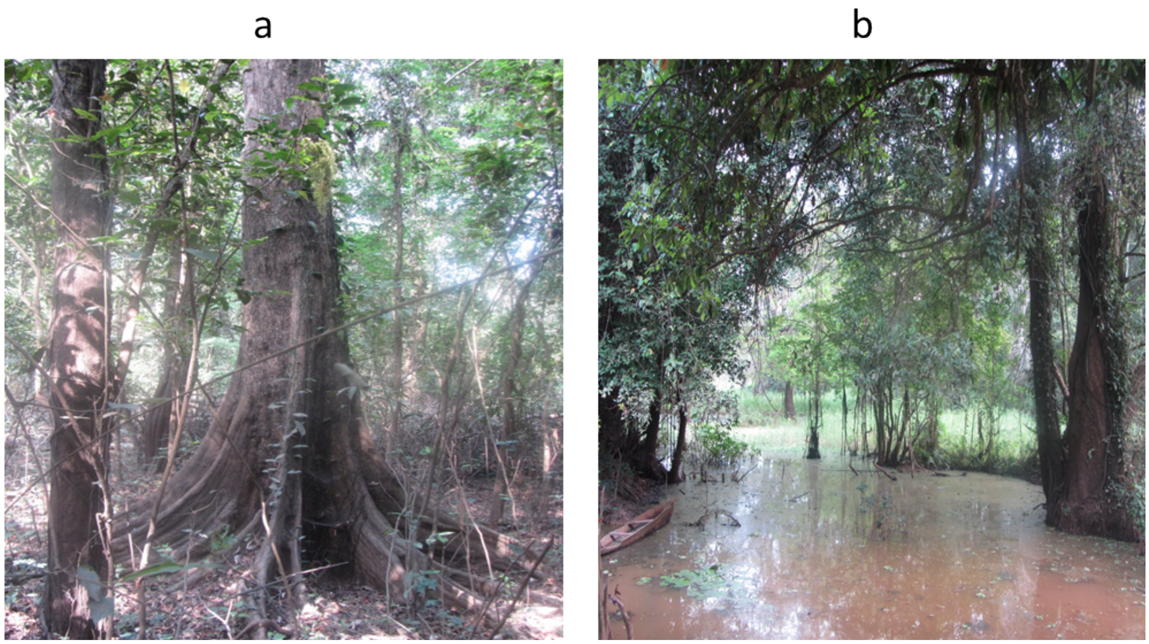

Figure 1.1 Photographs of freshwater swamp forest in the Niger Delta showing (a) seasonally flooded forest which was dry during the field-work, (b) permanently flooded forest, for which the water was at its lowest annual level during the field-work (being at the peak of dry season experienced in the month of February).

The freshwater swamp forest in Nigeria was initially protected from deforestation because of its relative inaccessibility, but is now being destroyed (Omokhua and Koyejo, 2008). The Nigerian freshwater swamp forest is concentrated in the Niger Delta where over 30 million people including 40 ethnic groups live (NPC, 2006; Spalding et al. 2010).

1.6 Forest disturbance, loss and degradation

Forest disturbance is a major feature of forest ecosystems and a fundamental reason for the variations in species composition across forest landscapes. This “relatively discrete event in time” is responsible for the disruption of the community or population structure of forest ecosystems (Pickett and White, 1985), and important for the renewal and maintenance of forest ecosystems. Disturbance occurs over a varied range of spatial scales, viz, individual tree level, stand level and landscape levels (Gong and Xu, 2003; Coops et al. 2009), duration and intensities. Hence, while some of these disturbance events occur slowly such as infestation, others are more rapid in occurrence (such as deforestation) and are more easily detected.

Natural disturbances are characterized by endogenous and exogenous causal factors that lead to tree mortality and operate over wide ranges of frequency, intensity, size, predictability and timing; and are mainly as a result of insect outbreaks, wildfire or strong winds (Attiwill, 1994; Seidl et al. 2014). These occurrence or disturbance regimes inherent in tropical forests termed “gap-phase dynamics” (Brokaw, 1985), are responsible for the cycle of tree mortality and replacement found in forest ecosystems. Gap dynamics is based on the assumption that with sufficient time periods, forest canopies are disturbed or open up in closed forest ecosystems. As these gaps are created, light tolerant species takes advantage of the micro-environmental conditions (light, moisture and temperature) to establish in the forest floor (spaces provided by such gaps). These pioneer species are sooner or later substituted with other slower growing tree species which may live for longer periods (say decades or centuries) before falling and creating gaps for subsequent replacements (Watt, 1947; Whitmore, 1978; Asner, 2013).

With this cycle and successional processes ongoing in the forests, the species diversity and adaptive capacity of the ecosystems are enhanced (Gutschick and BassiriRad, 2003). Besides the endogenous gap-phase dynamics found across tropical forests, the freshwater swamp forests are on other occasions faced with other natural exogenous disturbance incidents that are very destructive in patterns like long lasting flooding events. Such cycles or trends of disturbance (especially with only short intervals between the disturbance cycles) however affect the health of the ecosystem and its ability to both replace pioneer species and facilitate the establishment of a climax community.

Anthropogenic factors have on the other hand contributed mostly to large disturbances and consequential forest cover losses and degradation in freshwater swamp forests. Even though some of the forest areas could recover and eventually become forested landscapes, most of such anthropogenic alterations have led to a steady decline, degradation of forest ecosystems and a modification of such landscapes to other land uses. Forest loss has been attributed to factors like population increases, dependence on the forests for subsistence, food, fuel and forest products and quest for other land uses (Geist and Lambin, 2002; Diaz et al. 2006; Ferretti-Gallon and Busch, 2014). Forest ecosystems loss has been estimated to be as much as

1.8 billion hectares over the past 5,000 years (Williams, 2002) and have varied across the different ecosystems- temperate, boreal and tropical forests. With much of the tropical forest loss occurring from the beginning of the twentieth century (Morris, 2010), its capacity as an epicenter of biodiversity and carbon sink are steadily lost. More recent estimates puts the rate of loss in the ecosystem far ahead of other climatic domains (subtropical, temperate, boreal); 2101 km^2 per year, > 50% of tree cover loss (2000 – 2012; Hansen et al. 2013). These losses have not only reduced the forest extent, but has led to fragmentation of the ecosystem; which leaves some of the forested areas too small for species persistence, too far apart for migration of species and the introduction of edge effects (Fahrig, 2003; Ewers and Didham, 2006; Martin and Blackburn, 2010; Morris, 2010).

Forest loss could be caused by direct factors (which could be natural or anthropogenic), or indirect factors like market failures, weakness in governance, political and socioeconomic factors and poor policy (Contreras-Hermosilla, 2000). The dominant feature(s) that leads to loss in forest cover is a combination of both direct and indirect factors. Geist and Lambin (2002) succinctly categorized them as proximate factors: agricultural expansion, wood extraction, infrastructure extension and other factors like predisposing environmental factors, biophysical drivers, social trigger events; and underlying causes: demographic, economic, technological, policy and institutional, and cultural factors. The forest ecosystem in the Niger Delta region of Nigeria is threatened by deforestation and degradation; that have turned most of the forest landscapes into forest mosaics across the entire region. Annual forests loss across the region is at the rate of 0.95% (through deforestation); while its annual rate of change in forest cover showed a decline of – 0.13% (1986 – 2007; Onojeghuo and Blackburn, 2011). As there are no established guidelines on management of these forests at the community level, poor management of the forest reserves at the state levels and an ever increasing quest for available (forest) land space; forest losses are expected to continue across the region. As a lot of transformations (such as loss of biodiversity, fragmentation, extinction and degradation) are experienced in the ecosystem, there is a critical need to understand the patterns of these anomalies and threats through a comprehensive, up-to-date assessment and monitoring of the ecosystem.

1.7 Agents of freshwater swamp forest decline

Freshwater swamp forests in Nigeria are reducing as a result of the following factors:

1.7.1 Urbanization, industrialization and wetland reclamation

Urbanization may affect freshwater swamps through loss of extensive areas, through drainage modification and ecosystem fragmentation (Weller, 1998). The discovery of the crude oil in the Niger Delta affected the urban morphology of the entire landscape. Most of the towns and cities across the region suddenly rose to prominence by becoming the 'centers of oil production or associated industrial activities', and were equally accompanied by rapid and uncontrolled urbanization across the region (UNDP, 2006). Furthermore, the demand for land, wood and building materials like sand and the allure for fast money-making (which influenced many of the people to sell their forest lands), have ever since then impacted the environment and the forest ecosystem. As roads, waterways and rail lines were constructed across the landscape, it altered the topography and hydrology of the ecosystem, fragmented most of the forests, provided inlets of sea water into the freshwater ecosystem and consequently, impacted the local freshwater forest species.

Construction of oil and gas refineries as well as other industries has led to loss of forested lands. Reclamation of marginal swampy lands in addition to few dry portions leads to more forest and biodiversity losses and fragmentation across the ecosystem. The construction of the Nigerian Liquefied Natural Gas (NLNG) Plant in 1999 required the reclaiming of approximately 2.27 km^2 of this forest in Finima, Bonny Island (Rivers state, Nigeria); and provides a suitable example to the extent of loss ongoing in the freshwater swamp forest. Since the Delta has become a focal hub, multinational companies and the government have barely given thought to the ecological imbalance such activities result in, and as a result, the freshwater forest ecosystem has steadily been lost, degraded and modified over the years. While there is no doubt that the aforementioned anthropogenic activities contributes to the wealth of the Nigerian state and a suitable place for accommodating a growing population, forest friendly and ecosystem resilient strategies that would ensure a continuity in ecosystem function and existence should be equally be adopted.

1.7.2. Population growth and pressure

In most of West Africa, rapid and uncontrolled population growth has caused social, economic as well as environmental problems, in the face of the rapidly diminishing forest and related natural resources (Dykstra et al. 1996). The increase in the population of the Niger Delta could be attributed primarily to the migration into the region following the 'oil boom'. While the majority of the people that thronged the region were concentrated in the cities, the rural fringes supported farmers, laborers, traders, fishermen and job seekers.

The population of the Niger Delta increased from 11.3 million to 19.3 million to 31.2 million in 1963, 1991 and 2006 respectively (NPC, 2006; Onojeghuo and Blackburn, 2011) and predicted to rise to 45.7 million by 2020 (UNDP, 2006). The region constitutes 25% of Nigeria's population and its average population density is 265 persons per square kilometre (NPC, 2006; UNDP, 2006). About 62% of the entire population is below the age of 30 (Francis et al. 2011). With increased demand for food, housing and infrastructure following such increased population, the forest ecosystem continues to decline (Geist and Lambin, 2002; Pan et al. 2007; Gardner et al. 2009) due to overharvesting, degradation and land use modifications.

Table 1.1 States of Niger Delta region, land area and population. Source: National Population Commission (NPC, 2006).

States	**Land area (km^2)**	**Population**
Abia	4,877	2,833,99
Akwa Ibom	6,806	3,920,208
Bayelsa	11,007	1,703,358
Cross River	21,930	2,888,966
Delta	17,163	4,098,391
Edo	19,698	3,218,332
Imo	5,165	3,934,899
Ondo	15,086	3,441,014
Rivers	10,378	5,185,420
Total	112,110	31,224,587

1.7.3. Agriculture

As the population of the region continues to grow, more pressure is put on the ecosystem through an increase in aquaculture, plantation agriculture, commercial agriculture and subsistence agriculture; in order to meet the increasing demands for sustenance and livelihood. With the support of rich alluvial soils across the freshwater swamp ecosystem, agricultural activities were not only practiced by individuals and households, but also the government, who utilized it as a source of income for the regional and national economy. Since the soils of the ecosystem supported the cultivation of crops like plantain, banana, rubber and oil palm, individuals and government alike have used its cultivation as their economic mainstay long before the advent of crude oil in the region.

The contribution of a crop like oil palm was quite significant that “between 1865 and 1910, the export of palm produce doubled from West Africa as Nigeria took the lead; and by 1900, palm produce constituted 89% of Nigeria’s total export” (Stillard, 1938; Helleiner, 1996; Aghalino, 2000). While its prominence has declined as a major source of government revenue for the Niger Delta region and the Nigerian state (following crude oil exploration), it has however remained a major source of income (together with other crops) for the rural population who mostly depend on it as sources of livelihood. Agriculture has equally thrived across the region with the cultivation of root crops like cassava and vegetables; and these have all contributed to forest degradation in various ways. These agricultural practices are carried out on dry lands and in marshy portions (that are first of all drained) and are responsible for a significant forest cover change across the entire region (Momodu et al. 2011; Enaruvbe and Atafo, 2014).

1.7.4. Oil exploration and gas flaring

The Niger Delta is home to most of Nigeria’s vast reserve of oil and gas, and hub to her government revenue and national wealth. However, as this resource has been associated with spills and flares for decades, it has brought mixed blessings of wealth to the nation and degradation to the fragile environment. As these spills have repeatedly occurred over the years, a large part of the land, vegetation and wetlands are already affected, and groundwater contamination has equally occurred due to its penetration to the soils (Linden and Palsson, 2013). Statistics from the Department of Petroleum Resources, Shell, Nigerian National

Petroleum Corporation (NNPC) and the World Bank, on the extent and volume of spills from the inception till date are quite huge (Moffat and Linden, 1995; NDES, 1997; UNDP, 2006; Steiner, 2010) and depict the level of contamination such events introduce into the ecosystem. A suitable example of the extent and impact of such spills on the environment, could be seen from the Ogada-Brass pipeline oil spillage (near Etiama, Nembe, Bayelsa state) that occurred in February 1995; and spilled approximately 24,000 barrels of oil that spread over the freshwater swamp forest and into the brackish swamp (Kadafa, 2012); causing an unquantifiable damage to the ecosystem. Spills of such great magnitudes, which are estimated to be between 9 million and 13 million barrels (1.5 million tons), have continued over the past 50 years across the region (Obot et al. 2006), and have adversely affected and destroyed an undocumented array of plant and forest landscapes.

Oil spills impact the biodiversity of forest ecosystems- flora and fauna alike; reduces mobility of biodiversity; directly impact them through toxicity; damage cell membranes in roots and eventually lead to their death. More worryingly is the fact that cleaning up wetlands that are already contaminated are not only difficult but may not be done without additional harm to such habitats (NRC, 2003; Chan and Baba, 2009; Linden and Palsson, 2013). As the surface of the delta is dissected by a dense network of rivers and creeks, which creates a condition of delta-wide hydrological continuity, disasters such as oil spills in one part of the delta can readily be felt in other parts. This has grave implications for the ecosystem, as environmental problems like this can hardly be limited in an ecological boundary (Abam, 2009).

Gas flaring has been part of the oil industry in the Niger Delta from its inception. With as much as 70.8 million cubic metres of gas associated with crude oil flared everyday across the Delta (Environmental Rights Action, 2005), Nigeria is not only a major contributor to the global estimate of 150 billion cubic metres of gas flares each year (Farina, 2011), but also key to the challenging energy and environmental problems ravaging the globe. These activities releases large amounts of toxic components such as methane, benzene and carbon dioxide to the atmosphere and contribute to climate change and global warming across the region. They also affect the local and regional microclimate, cause greenhouse effects, acidification, retardation and destruction of plants (Isichei and Sanford, 1976; Odjugo and Osemwenkhae, 2009; Julius, 2011; Ite and Ibok, 2013). Since the gas flares generate high heat intensities, they directly burn up or destroy vegetation cover that they have contact with and destroy other biodiversity in the ecosystem. Channeling such (wasted or flared) resources for domestic and industrial use will not only benefit the Nigerian state, but also help to preserve the biodiversity of the (freshwater swamp forest) forest ecosystems in the region.

1.8 Ecosystem services

Ecosystem services have been a subject of discussion for a long time (Whitford, 1923; Pearson, 1937), although the last decade has witnessed a large amount of inquiry into this concept from stakeholders across different disciplines: scientists, policy makers, economists, environmental educators and managers (Fisher et al. 2009), who have all broadened society's understanding on the issue. Very significant among these is the work by more than 1300 scientists into the Millennium Ecosystem Assessment that provided insights on the varied categories of ecosystem services (Table 1.2), and highlighted the need for additional research on their measurements, mapping and assessments, especially as a majority of the services were found to be diminishing across the globe (MA, 2005). The ability of forests to continually deliver ecosystem services such as climate regulation, carbon sequestration, water supply and biodiversity richness, are greatly impaired due to the changes in the forest cover being experienced at different scales globally (Foley et al. 2005; Hansen et al. 2013).

Table 1.2 Categories of ecosystem services and examples. Source: De Groot et al. 2010

Ecosystem service	Example
Provisioning	Food
	Water
	Fiber, fuel and other raw materials
	Genetic materials: genes for resistance to plant pathogens
	Biochemical products and medicinal resources
	Ornamental species and/or resources
Regulating	Air quality regulation: e.g. capturing dust particles
	Climate regulation
	Natural hazard mitigation
	Water regulation
	Waste treatment
	Erosion protection
	Soil formation and regeneration
	Pollination
	Biological regulation
Habitat or Supporting	Nursery habitat
	Genepool protection
Cultural and amenity	Aesthetic: appreciation of natural scenery (other than through deliberate recreational activities)
	Inspiration for culture, art and design
	Cultural heritage and identity: sense of place and belonging
	Spiritual and religious inspiration
	Recreational: opportunities for tourism and recreational activities
	Education and science opportunities for formal and informal education and training

As tropical forests are continually altered and lost, its central role in furnishing the world with ecosystem services and functions at landscape, regional and global scales are reduced and eventually lost. Such losses have interconnected impacts on the ecosystem, since the use of one ecosystem function may influence the availability of other functions, and the good and services they provide (Limburg et al. 2002). Harvesting forest resources on the other hand, is an inherent societal trade-off which is not totally bad or evil, as it offers some positive outcomes like: the provision of forest resources (such as timber and food), employment, as well as other economic and social benefits. However, since it has the capacity to degrade other ecosystem services especially those ones that have strong ties to the functioning of the ecosystem (Foley et al. 2007; DeFries et al. 2004), it should be practiced sustainably by ensuring that there is a balance between the societal benefits (which are short termed) and long term existence and ecological functioning of the ecosystem.

Ecosystem services have been utilized in varied ways in ensuring human well-being long before and after the concept attracted scientific inquiry. More recently, its role in carbon sequestration and regulation of the global climate processes has not only been widely recognized and acknowledged, but has also been at the center of international debates and forums (Houghton, 2005; Grainger et al. 2009; Gardner et al. 2012). This has led to the assessment of forest carbon at the global, regional and local scales, and to the formulation of organizations and policies that addresses such concerns; notable among which is the recent REDD and REDD+ initiatives (Houghton, 2005; Gorte, 2009; Pan et al. 2011; Saatchi et al. 2011).

While tropical forests are acknowledged to contain the highest concentration of carbon in its biomass (Pan et al. 2011), the assessment of this ecosystem service has received greater inquiry in south America and Asia, compared to the amount of inquiry in Africa (Lewis et al. 2013). Existing estimates for Nigeria are derived from global carbon assessments (Baccini et al. 2008; Ruesch and Gibbs, 2008; Scharlemann et al. 2011), which neither gives the estimates for specific forest ecosystems nor provide baselines for understanding the variations across the ecosystems and disturbance gradients. With varied floristic composition and disturbance regimes evident between the freshwater swamp forests and other forest ecosystems in the Niger Delta, there is need to establish baselines for the ecosystem, as this could be used for the calibration and validation of the estimates from satellite remote sensors and for comparison with other ecosystems as well.

Forest ecosystems are very vital for the sustenance and livelihood of people across different forest landscapes. Besides its role in carbon sequestration, it provides economic goods, raw materials, food and shelter for humanity at local, regional and global scales (Lewis, 2006; Gardner et al. 2009). In sub-Saharan African communities, it is known to supply over 50% of the cash income of most farmers, provides over 80% of the health needs of the entire population and as much as 80% of domestic energy needs (FAO, 2004; Babalola, 2009; Tutu and Akol, 2009). In the Niger Delta, the utilization of forest resources pre-dated the pre-colonial and colonial eras and has characterized the general livelihood pattern of the region. Before the advent of crude oil, the region has been known as a resource rich zone that produced products ranging from fishes and other sea foods like periwinkles, oysters, crabs, prawn, crayfish; honey, salt, mushroom, snails, wild fruits, nuts, biochemicals and bushmeat. Some of the resources in the locality had regional importance so much so that they were exchanged for slaves and livestock with people from the hinterlands (Irikana, 2011); and were sold in other parts of Nigeria and as far as Tripoli in North Africa (Enemugwem, 2001). It has indeed been a source of sustainability for many households and to a great extent maintained the local economy of the region till date. While the trees are used as timber for varied purposes, they are also used for other non-timber purposes across the region (Table 1.3).

Table 1.3 Some selected plant species and their uses in the Niger Delta. Adapted from Obute and Ebiare (2008); Okunomo (2010) and Ubom (2010).

Plant species	Uses
Mitragyna ciliate	Construction, furniture and mat weaving
Alstonia boonei	Furniture and construction, ship building, decking
Ceiba pentandra	Construction, lintel and concrete work; edible leaves
Guarea cedrata	Timber
Uapaca heudelotti	Boat building, door and picture frames, very desirable firewood
Lophira alata	Railway sleepers and electrical poles
Piptadeniastrum africanum	Boat building
Pycnanthus angolensis	Ceilings
Elaeis guineensis	Palm oil, leaves as thatch, logs for building, brooms
Raphia spp	Thatch for building, wine, weaving mats and baskets
Nauclea diderrichii	Electric poles, door frames and construction
Staudtia stipitata	Paddle
Khaya ivorensis	Furniture
Chlorophora excelsa	Furniture
Rhizophora racemosa	Salts extracts, tannins
Diospyros mespiliformis	Timber, furniture and sculpture
Musanga cecropioides	Floaters and shoe heels
Treculia africana	Edible seeds
Xylopia aethiopica	Edible seeds
Dacryodes edulis	Edible seeds
Tectona grandis	Decoration, veneer and plywood, furniture
Monodora myristica	Medicinal
Tetrapleura tetraptera	Medicinal
Chrysophyllum albidum	Fruits/Edible
Zanthoxylum zanthoxyloides	Edible
Myrianthus arboreus	Building materials

1.9 Study region- The Niger Delta

1.9.1 Setting and Ethnography

Situated on the coast of West Africa, it is Africa's largest delta. It is a vast sedimentary basin covering about 75,000km^2. The region is a flat area criss-crossed by a large number of meandering streams, rivers, creeks that drain the river Niger into the Atlantic Ocean at the Bight of Biafra. Based on the hydrology and human geography of the region, the Niger Delta was initially made up of the three states namely, Delta, Rivers and Bayelsa states (Fig 1.2). However, for more administrative and political benefits and governance, it currently covers all the nine oil producing states: Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers states. It is a region of vast hydrocarbon stores, economic and ecological importance, and is ethnically and multi-culturally diverse. The territory is home to Nigeria's economic hub, and is made up of more than 40 ethnic groups that speak more than 250 dialects and has a rich cultural heritage (Jike, 2004). They can be broadly classified into five major linguistic categories: the Ijoid, Yoruboid, Edoid, Igboid and Delta Cross and each of these categories embraces an enormous mix of ethno-linguistic communities (Watts, 2004).

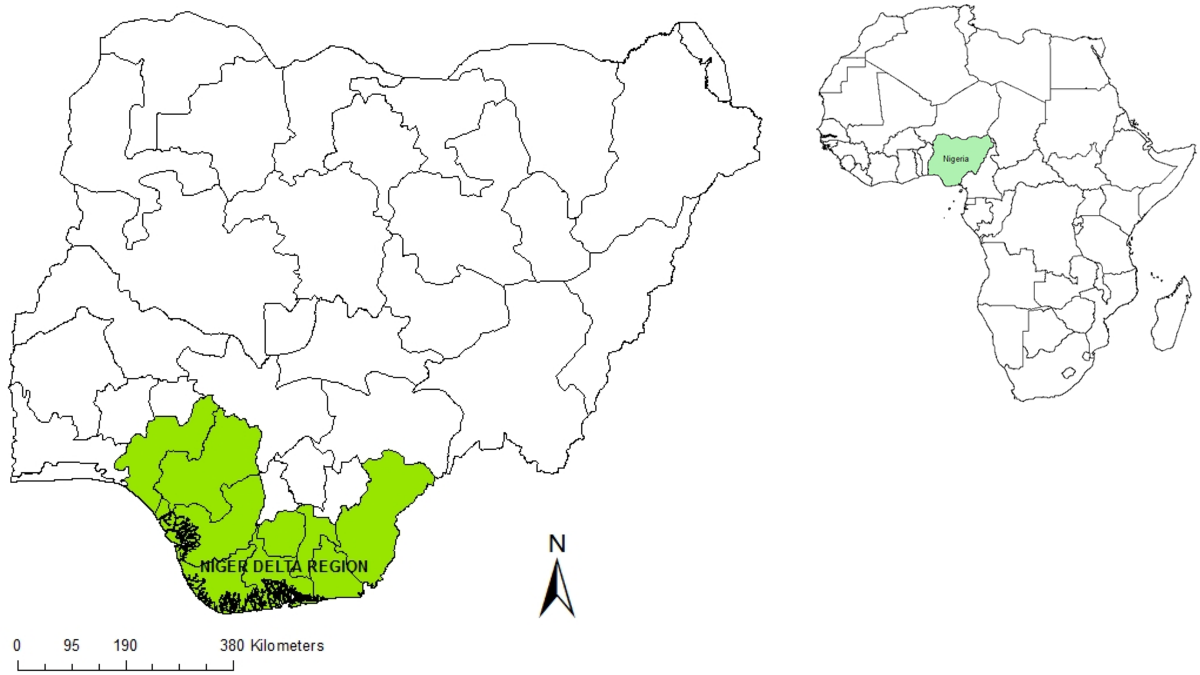

Fig 1.2 Map of Nigeria showing the Niger Delta region and the map of Africa showing the location of Nigeria (black bits on the map represents the creeks, stream and river networks that crisss-cross the region).

1.9.2 Geology and Soils

The Niger Delta is the product of both fluviatile and marine sediment build-up since the upper Cretaceous, and its low relief is responsible for the meandering and frequent shifting of the Niger and its tributaries (NEDECO, 1961). The sediments responsible for this process are derived from the Niger and Benue basins, the Volta River basin, and minor rivers within Nigeria (Allen, 1964). Broadly, the region is made up of marine sedimentaries of Lower and Upper Cretaceous age (Akintola, 1982); comprises a lower unit (Akata formation), a middle unit (Agbada formation) and an upper continental sequence (Benin formation) (Allen, 1965; Akpokodje, 1987). They are typically filled by a succession of thinly bedded silts and clays that are interbedded with sands (Allen, 1965; Amajor, 1991; Akpoborie, 2011).

The soils of this ecoregion are all of fluvial origin, except for the Coastal Barrier islands that consist of marine sand overlain with an organic surface area; characterized by a mosaic of soil types (WWF, 2008). Areola (1982) broadly categorized it as hydromorphic soils which are described as seasonally or permanently waterlogged soils; and are whitish or greyish in colour due to the reduction of oxides in the soils (an influence of their poor drainage). The permanently waterlogged soils show little horizon differentiation, the profile being largely uniformly coloured; while the extent of profile development for the seasonally waterlogged ones are limited by the depth of the permanent water table.

1.9.3 Climate and Hydrology

The climate of the region like any other part of West Africa is controlled principally by the seasonal movement of two air masses (Ojo, 1977). From September to February, the Tropical Continental Air Mass spreads southwards from the Sahara to about latititude 5^{o}N, accompanied by the hot, dry and dusty north-easterly wind known as the Harmattan. From March to August, the Tropical Maritime Air Mass, associated with rain-bearing south-westerly winds, moves northwards to about latitude 21^{o}N. The two air masses are separated by the Inter-Tropical Convergence Zone (ITCZ). Movement of the ITCZ northwards is thus associated with the rainy season while its southward movement brings the dry season.

The region has a tropical climate with long rainy season mainly from March/April to October. Precipitation increases from the north of the delta (with an average of 2,500 mm y^{-1}) to the coastal area where mean annual rainfall averages around 4,000 mm y^{-1}, making it one of the wettest areas in Africa. The wet season lasts nearly throughout the year, but more pronounced between eight and eleven months across space and time. The wet season peaks in July and the dry months are mainly between Decembers to February (with an average monthly rainfall of 150 mm) (Hughes and Hughes, 1992). Relative humidity rarely dips below 60% and fluctuates between 90% and 100% for most of the year, with average monthly maximum and minimum temperatures varying between 28^{o}C to 33^{o}C and 21^{o}C to 23^{o}C respectively (NDES, 1997; James, 2008).

The hydrological regime of the region comes from the Atlantic Ocean's tidal movements and the Niger River flood. The flood begins toward the end of the rainy season in August, peaks in October, and tapers off in December. Some fluctuations in flow is determined by the yearly variation in rainfall, but after the completion of the Kainji dam on the Niger at Bussa in 1968, the timing and level of flooding is also determined by the opening and closing of the dam's sluices (WWF, 2008). As the region's diversity is mainly varied due to its hydrology, three zones are evident: the flood forest (with seasonal variations); the second zone flanks the delta in the east and declines westwards; and the third is a relatively stable delta fringes and associated creeks barring the flood and tidal influences (NEDECO, 1996; Powell, 1997; Were, 2000).

1.9.4 Forest ecosystems across the Niger Delta

The forest ecosystem in the Niger Delta differs from each other on the basis of varied floristic composition, hydrology, soil and topography. These forest ecosystems are mainly classified as lowland rain forest, freshwater swamp forest and mangrove swamp forest. The lowland rainforest belt is the least swampy and highest in elevation among all the other ecosystems in the region. It shares or has boundaries with the freshwater swamp forest and is found in the northern part of the freshwater ecosystem. The freshwater swamp forest ecosystem is a flooded forest located in the landward side of the mangrove ecosystem. Varied by its hydrology, three zones are found in the ecosystem: the flood forest- which has large sand river channels and creeks- both permanent and seasonal; the marsh forest- which flanks the delta in the east and declines westwards, permanently swampy and under the influence of 'black flood' from the rains; and the relatively stable delta fringes which is associated with creeks that bar the flood and tidal influences (Powell, 1997; NEDECO, 1996; Were, 2000; James, 2008).

The ecosystem is located between the lowland rain forest to the north and the mangrove swamp forest to the south; providing a transition zone between the two ecosystems and a corridor for the migration of flora and fauna. The mangrove swamp forest ecosystem is the swampiest of all the other forest ecosystems and has the lowest elevation (less than one meter). The freshwater system meets the tidal salt water intrusion from the Atlantic Ocean in this zone- hence the brackish characteristics of the zone (James, 2008). Characterized by saline water and an understory of salt-tolerant plant species and flora with buttresses, stilt-roots and pneumatophores; it has a transition zone with the freshwater swamp forest which is located in its northern part.

1.9.5 Forest resources, use and management

The region has a long history of human existence (Nzewunwa, 1985) and an old account of forest resources use and exploitation. Notable among such is the use of tree species in the freshwater swamp forest for the production of plywood and other timber products. Since the region had a lot of trees, it led to the establishment of sawmills in the region with the largest in Sapele, established in 1936. The town Sapele which is a confluence location of three rivers- the Benin, Jameson and Ethiope became almost synonymous with timber production; and has ever since been a timber port due to its access (through a network of waterways) to the major forests in the country (Buckle, 1959). Mangrove species are equally dominant across the forests in the region- at the transition zones between freshwater swamp forests and in mangrove swamp forests as well. These tree species have been used for a variety of purposes: fuel wood, construction materials, dyes, tannins for fishing, medicines and timber. They equally provide habitats, spawning grounds, nutrients, nurseries and a crucial role in marine food chain (FAO, 2007). With the raffia and oil palms found across most of the forests in the region, the region is known for tapping of the sap from the palms; which are eventually used for local wine and gin.

Other forest uses include: sources of fresh water supply for both domestic and industrial purposes, fishing ground, brooding grounds and nesting sites for a host of birds and other fauna. As both the black and whitewater rivers flow into the highly productive Niger Delta, it supports an extremely rich freshwater fauna and includes the highest concentration of monotypic fish families in the world (WWF, 2008). Classified as a hot spot (Myers et al. 2000), it is home to a lot of endemic, rare and threatened plant and animal species: white throated guenon (*Cercopithecus erithrogaster*), Chimpazee (*Pan troglodytes*), Manatee (*Trichecus senegalensis*), spotted-necked otter (*Lutra maculicollis*), Crested genet (*Genetta cristata*) and Sclater's guenon (*Cercopithecus sclateri*) (Happold, 1987; Sayer et al. 1992; Hilton-Taylor, 2000).

Forest ecosystems across the region, like in other parts of Nigeria, are managed at the state levels, community levels and family or private levels. The state ministry of forestry in each of the Niger Delta states is laden with the responsibility of managing government forest units (mostly in forest reserves). At the community level, the forest units found on communal lands are managed by the host community of such forests; mostly with the paramount rulers in charge, while community leaders and youth groups support them. Family units and individuals equally own and manage most of the remaining forest lands in the region and transfer the ownership of such forest lands to either their offspring or non-relatives by inheritance or sale. Other forest units found in sacred groves, burial grounds and shrines are managed by their respective owners (either a community or family).

1.10 Thesis overall aims

Freshwater swamp forest is a poorly understood ecosystem found within the Niger Delta. Its ecology and floristic composition (chapters 2 to 6) are sufficient to distinguish it from other ecosystems, mainly mangroves. With the high rate of losses and degradation of forest ecosystems across the Nigerian state and the African continent, the study will provide a baseline for the ecosystem, but furthermore contribute to understanding the processes, functional dynamics and resource utilization of the ecosystem. This thesis is aimed at documenting the varied floristic composition of the ecosystem, its biodiversity index patterns and the varied ecosystem service values and utilization. These will be achieved through the following objectives:

1. Document and update the floristic composition of the freshwater swamp forest
2. Determine the environmental variables that are responsible for the distribution of the flora
3. Measure the carbon storage of the swamp forests
4. Determine the drivers of forest loss and degradation across the ecosystem
5. Determine the swamp forest human use and dependence across the Niger Delta region

1.11 Outline of chapters

This thesis is structured as scientific publications (from chapter 2 to 6) and then a summary of the findings and further discussions provided in chapter 7. With this style of presentation some of the chapters will overlap each other.

Chapter 2- Floristic composition and diversity of freshwater swamp forests in the Niger Delta

With poor baselines on the ecosystem across the Niger Delta, the study sought to document and updates the floristic composition of the ecosystem. It sought to elucidate how species rich or diverse the ecosystem is and compare the findings with the more studied swamp forests in other parts of the world. Furthermore, the patterns of abundance of the different taxa were elucidated for each of the forest zones. These data can better inform the conservation and management of this threatened ecosystem.

Chapter 3- Determinants and patterns of freshwater swamp forests

The study sought to explain the variables responsible for the variations in the species composition of the ecosystem. Indicator species analysis was used to characterize the ecosystem, while each of the taxa was grouped according to their associations. This aimed at providing more detail for biogeographic classification and in elucidating the extent environmental factors and disturbances shaped the ecosystem. Furthermore, the study was used to ascertain the validity of the intermediate disturbance hypothesis to swamp forests and highlight the extent to which the ecosystem could be impacted by changes in the environment.

Chapter 4- Above ground carbon storage in freshwater swamp forest ecosystems

Tropical forests are known as storehouses of carbon and important for modulating the climatic influences across the globe. With little or no baselines for the freshwater swamp forests across Nigeria and the West African region, this chapter highlights the estimates of the ecosystem in providing this ecosystem service. Utilizing the varied flora across the ecosystem, the study examined the extent to which the above ground carbon for each forest zone was determined by its composition. Furthermore, since the ecosystem is rife with disturbance, it provided a basis for estimating the relative carbon store of disturbed forests versus intact forests, in order to effectively assess its conservation value.

Chapter 5- Patterns of freshwater swamp use and degradation

Tropical forest ecosystems in Africa are vital for household sustenance and income generation; however, the extent to which this is harnessed in freshwater swamp forests across West Africa is largely unknown. This study assessed the use of this ecosystem across the Niger Delta and the extent livelihoods depended on the ecosystem. How the people used the forest was highlighted since it served as a good basis for understanding the underlying issues of utilization in the ecosystem, and could provide insights on effective management and conservation guidelines suitable for the ecosystem. These issues are vital for ensuring a sustainable livelihood for the rural poor across the region and continual existence of the ecosystem.

Chapter 6- Ecosystem services at the cross-roads

Forest use affects the viability, composition and ultimately, the extent to which forest ecosystems could provide vital services. With variations in the ownership and management of the ecosystem differing across the forest communities as in most African landscapes, this chapter focuses on assessing how these patterns influences the carbon potentials of the ecosystem. Since most of the forest landscapes across the region are being modified and its capacities as potential carbon stores dwindling, deciphering effective and realistic forest management policies for the privately owned and community owned forest units (that dominate the landscape) has become more crucial than ever. This will not only help to ensure that the carbon sequestration in the ecosystem is maintained, but also help to preserve its unique biodiversity.

Chapter 7- Summary discussion

This chapter summarizes the findings and discussions of the study, provides insights on effective management structures and presents the need for further work. Furthermore, it highlights the importance of additional baselines, data improvements and updating. These are viewed as essential steps to achieving more applied ecological studies in the future.

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Chapter 2- Floristic composition and diversity of freshwater swamp forests

2.0 Floristic composition and diversity of freshwater swamp forests in the Niger Delta

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2.1 Abstract

Freshwater swamp forests are very valuable ecosystems with poorly understood ecology. With increasing degradation and loss of the ecosystem in the Niger Delta region of Nigeria, there is need to improve the understanding of the ecosystem and provide ecological and environmental baselines. This study assessed the floristic composition and diversity across 24 one hectare forest plots comprising 138 species within 100 genera and 41 families. Species and family importance values were used to summarize the floristic composition and patterns of abundance for each of the sites. Analysis of variance (ANOVA) using Tukey's post-hoc test was used to see how the sites varied in diversity, stem density and basal area. The number of species found in each of the disturbed sites was generally higher than in the intact forest sites, which was not diverse but comprised many trees with higher basal area. While the stem density of 94 – 506 stems ha^{-1} was comparable with that of other tropical forest, species richness was low, but consistent with other freshwater swamp forests across the globe. Diversity was higher in the disturbed sites than in the intact location and the number of species with single occurrence was equally more in the disturbed forest plots/sites. This emphasizes the huge importance of disturbed swamp forests for conservation.

Keywords: biodiversity indices, forest disturbance, species rarity, stem density, transition forests

2.2 Introduction

Tropical forest ecosystems are host to a rich assemblage of biodiversity which are varied in composition across spatial scales. While several attempts have been made to document this array of flora across the tropics (Keay, 1949; White, 1983; Gentry, 1988) , a lot still remain to be explored especially with reference to their patterns of abundance at the landscape level (Boubli et al. 2004). Such understanding and inventory are not only vital for providing an updated database for such ecosystems, but furthermore, help to provide veritable insights on the varying mechanisms inherent in such ecosystems. On the other hand, such in-depth understanding of the biodiversity of tropical forest ecosystems is needed for an adequate conservation of the ecosystem (van Andel, 2003). Among the different vegetation types that make up the tropical forest ecosystem, the freshwater swamp forests have received little inquiry and are poorly known even though that it constitutes about 2.1% of the earth surface (Raven and Johnson, 2002). These forests (freshwater swamp forests) are wetland ecosystems associated with low-lying areas along the lower reaches of rivers and around freshwater lakes. Being periodically inundated by river water, their soils are high in nutrients and its trees grow rapidly, particularly where flooding results in physical disturbance of the forest (Thomas and Baltzer, 2002).

Although ample work have been conducted on the floristic composition of freshwater swamp forests (Ivanauskas et al. 1997; Scarano et al. 1997; Marques et al. 2003; Scarano, 2006; Teixeira, 2008; Teixeira et al. 2008; Teixeira and Assis, 2011; Kurtz et al. 2013), it has been dominated by studies from the Neotropics. The studies on the ecosystem in the neotropics have focused mainly on understanding the diversity, phytosociological structure of the tree layer of the ecosystem, general floristic patterns and the floristic similarities the ecosystem shared with other surrounding ecosystems. Generally, the species richness and diversity of the ecosystem were reported to be low, their species mostly had high local densities and were monodominant (Koponen et al. 2004; Teixeira and Assis, 2011; Kurtz et al. 2013). Their studies revealed that the ecosystem was mostly restricted to hydromorphic soils and characterized by natural fragmentation and exposed borders (Ivanauskas et al. 1997; Teixeira and Assis, 2011). As a result, species found in other surrounding ecosystems were noted to occur in the ecosystem (Teixeira and Assis, 2011; Kurtz et al. 2013).

There is need to understand the ecosystem better in other parts of the tropics, document its varied floristic composition and fill the gaps that may be existing as well. This lack of information about the ecosystem is more pronounced in Africa and Nigeria as a whole, with no baseline information and understanding since the initial rapid assessment on the composition and control of the ecosystem by Keay (1959). Documenting the biodiversity of this ecosystem through forest surveys and taxonomic inventories have become more necessary than ever, particularly in the Niger Delta region of Nigeria where the ecosystem has a vast extent and covers up to half of the delta (NDES, 1997). Though this ecosystem has been a source of timber for most other parts of the Niger Delta for a long time (UNDP, 2006), its relative inaccessibility has on the other hand not permitted over exploitation of its varied tree populations. However, with the development of the region and opening of its forest interiors mainly through crude oil exploration and prospecting, more of the ecosystem's flora was lost at astronomical scales, without being captured in the taxonomic database for the region/ecosystem. Such continual degradation of the ecosystem affects not only the species composition of the ecosystem, but also reduces the capacity to which it could inform conservation prioritization.

This study is hence aimed at improving the baselines of the freshwater swamp forests at the landscape level across the Niger Delta. To achieve this, the objectives are to: 1) document the existing composition of the ecosystem and show their varied abundance at the species and family levels; 2) show the variations in species richness, diversity and density of the ecosystem; 3) to determine the variations that exist in the biodiversity indices within and across the sites and 4) to compare the findings with other studies conducted elsewhere and determine the global importance of the region and priorities for conservation management.

2.3 Materials and methods

2.3.1 Study area

The study was conducted in the Niger Delta region of Nigeria, which is a vast low lying sedimentary basin crisscrossed by a large number of meandering streams, rivers, creeks that drain the river Niger into the Atlantic Ocean at the Bight of Biafra. Areola (1982) broadly categorized the soils of this region as hydromorphic. These soils are seasonally or permanently waterlogged and are whitish or greyish in colour due to the reduction of oxides. The region has a tropical climate with long rainy season mainly from March/April to October. The flood regime begins in August, peaks in October and tapers off in December. The the wet season peaks in July and the dry months are mainly between December and February (Hughes and Hughes, 1992). Relative humidity rarely dips below 60% and fluctuates between 90% and 100% for most of the year, with average monthly maximum and minimum temperatures varying between 28^oC to 33^oC and 21^oC to 23^oC respectively (NDES, 1997; James, 2008).

The survey was conducted in four locations across the region (Fig 2.1). The first two sites: Akarai-Obodo (site 1) and Akili-Ogidi (site 2) are secondary freshwater swamp forests, while the third site (Akoloma) which is equally a secondary forest, is found in a freshwater-mangrove transition zone. The fourth site (Otuwe), named after Lake Otuwe, the most inaccessible of all the sites, is a primary freshwater swamp forest. Forest plots were only set up in the seasonally flooded part of the ecosystem during the dry months when the floods had subsided. Distance of forest site to the communities or settlements was used as a proxy in determining how disturbed each site was. The coordinates of each of the locations was taken with a GPS in the field and the distance were eventually determined using Google earth pro.

2.3.2 Vegetation data collection

Following Phillips et al. (2003) a standard plot-based method with 24, 1 ha square plots (across four locations) was established between December 2013 and April 2014. Plots were placed 500m apart to ensure variation in floristic composition. All the 4 – 8 plots per site were placed along transects spaced 1km apart rather than random placement. This was to ensure that consistency in enumeration was maintained across the sites. All stems ≥ 10cm diameter at breast height (130cm) within each of the plots were identified and documented, while the voucher specimen for the unidentified ones were collected and taken to the herbarium of the Forestry Research Institute, Ibadan for identification. Species identification was conducted with the assistance of taxonomists (Oladimeji Michael and assited by Ige Peter) from the Forestry Research Institute, Ibadan. Sites in Akarai-Obodo and Akili-Ogidi had 4 plots each (two transects), while the plots at Akoloma and Otuwe were 8 each (four transects). The size of the forests in each of the communities accounted for the variation in the number of plots per site.

Tree measurements and setting of the plots were conducted by Nwabueze Igu, with the assistance of Cyril Mama and Ifeanyi Iwegbue.

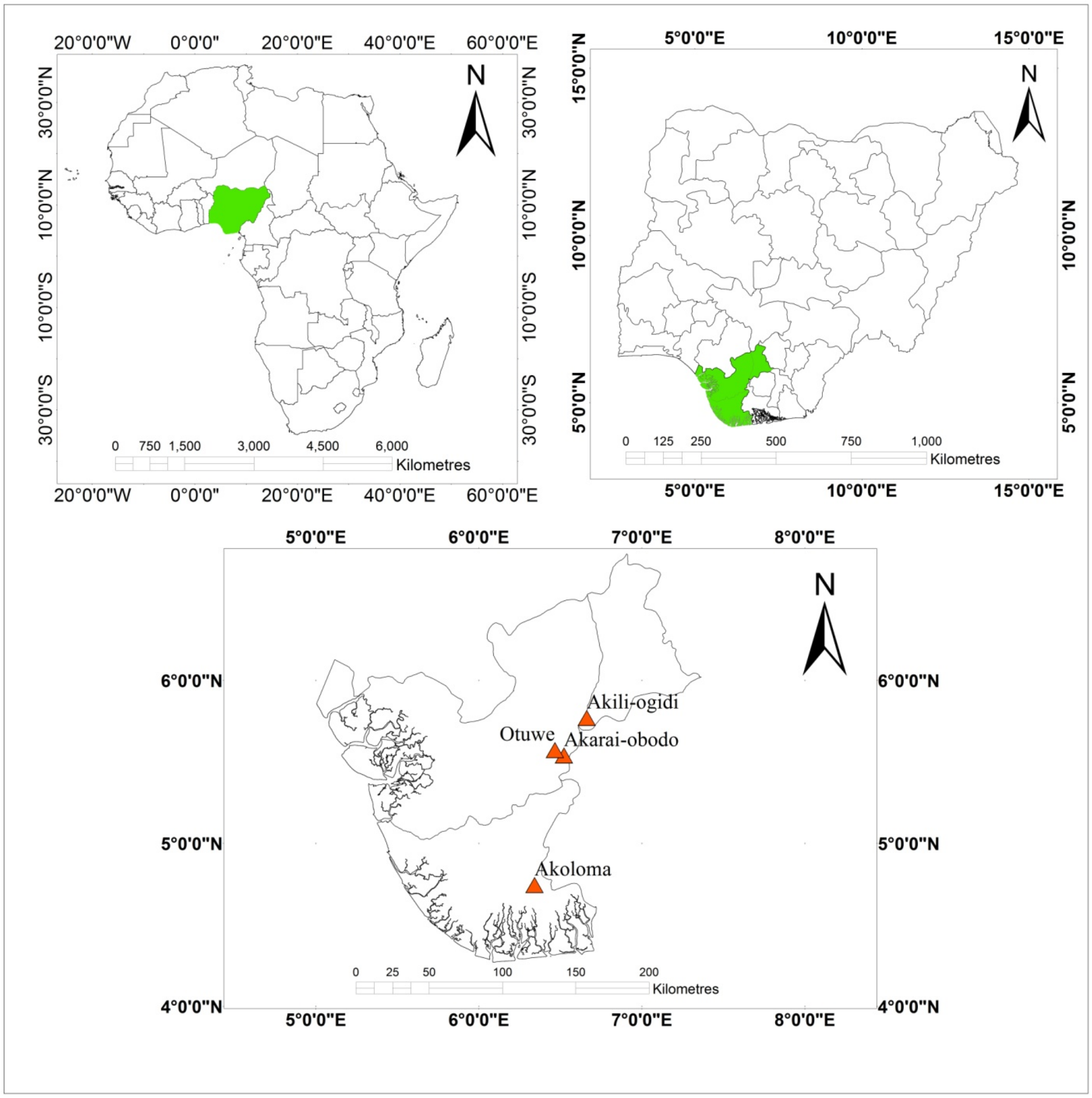

Fig 2.1 Map showing the four study locations

2.3.3 Data analysis

Stem frequency, density, basal area and species dominance were calculated. Species and family importance values (SIV and FIV) and biodiversity indices were also calculated to characterize the forest sites and summarize variation across different forest locations (Equations 1-5). The importance values ranged from 0 (no dominance) to 300 (monodominance); dominant species or families were defined as those with values ≥ 10 (Adomou et al. 2009).

Species importance values (SIV) = Relative density + Relative frequency + Relative dominance (Cottam and Curtis, 1956)………………………………. Equation 1

The family importance values were calculated as follows:

Family importance values (FIV) = Relative density + Relative dominance + Relative diversity (Mori et al. 1983)…………………………………… Equation 2

Where:

$$\text{Relative Density} = 100 \times \frac{\text{Number of stems of a species}}{\text{Total number of stems}}$$

$$\text{Relative frequency} = 100 \times \frac{\text{Frequency of a species}}{\text{Sum of all species}}$$

$$\text{Relative dominance} = 100 \times \frac{\text{Total basal area of a species}}{\text{Total basal area of all species}}$$

$$\text{Relative diversity} = 100 \times \frac{\text{Number of species in a family}}{\text{Total number of species}}$$

Basal Area (BA) = $\left(\frac{dbh}{2}\right)^2 \times \pi$

Shannon-Wiener index (Kent and Coker, 1992)…………………Equation 3:

$$H^{'} = -\sum_{i=1}^{s} pi \ln pi$$

Where H^{l} is the Shannon-Weiner index, s is the total number of species, pi is the proportion of individuals in the ith species, and ln is the natural logarithm. This measure of diversity was used because it is a commonly used and acceptable form of biodiversity assessment that is not affected by sample size.

Pielou's evenness index (Magurran, 1998)……………………….. Equation 4:

$$E = \frac{\sum_{i=1}^{s} pi \ln pi}{\ln (S)}$$

This measure of evenness is used due to its general acceptability and use

Margalef's species richness index (Magurran, 2004)……………………………… Equation 5:

$$M = \frac{(S-1)}{lnN}$$

This measure of richness assessment is suitable as it is independent of sample size

Analysis of variance (ANOVA) (at 95% confidence level) using Tukey's post hoc test was used to show the variations in basal area, diversity and stem density of the different forest locations. Hochberg corrected alpha values (Hochberg, 1988) were used to correct for multiple testing. Statistical analyses were performed in R version 3.1.0 (http://cran.r-project.org).

2.4 Results

The survey recorded a total of 138 species within 100 genera and 41 families (Appendix 1) across the 24 plots. As these hectares were from 4 different forest locations or sites, the results are thus presented according to the different forest sites below.

2.4.1 Species composition and dominance across the forest sites

Akarai-Obodo (Site 1)

This location had the highest number of plant species (80) compared to all other sites. While many species are found here, they are composed of four abundant species: *Elaeis guineensis*, *Cleistopholis patens* Engl. & Diels, *Sterculia oblonga* and *Hallea ciliata* J. F. Leroy. (Fig 2.2); with species importance values of 52, 29.4, 28 and 9.63, respectively (Appendix 2). Malvaceae with the highest family importance value of 43.41 dominated the remaining 32 families that constitute the forest site. Other dominant families within the site includes: Rubiaceae, Arecacea and Leguminosae, in decreasing order (Appendix 3).

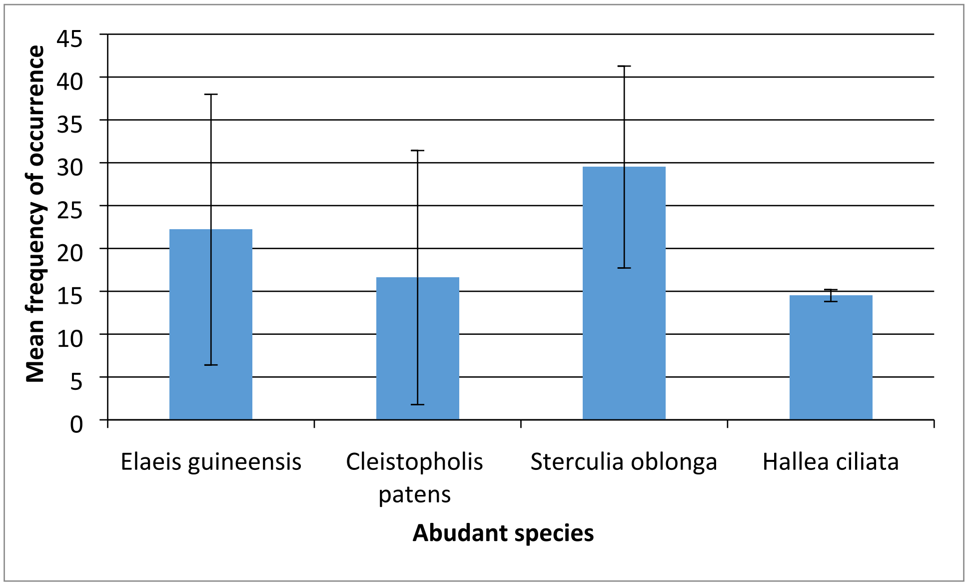

Fig 2.2 Mean species abundance across site 1, including 95% confidence intervals

Akili-Ogidi (Site 2)

This forest location is made up of 58 plant species and 23 families. The species in the location are however dominated by *Elaeis guineensis*, *Hexalobus crispiflorus* A. Rich, *Spondias mombin* Jacq and *Hylodendron gabunense* Taub. (Fig 2.3); with species importance values of 129.65, 13.91, 10.74 and 9.22, respectively (Appendix 2). While most species' occurrence in the forest is less than 1%, *Elaeis guineensis* had a 42.2% occurrence in the forest. The Arecaceae family had the highest family importance value of 111.7 in the forest, while other abundant families include: Malvaceae, Leguminosae and Annonaceae in decreasing order (Appendix 3).

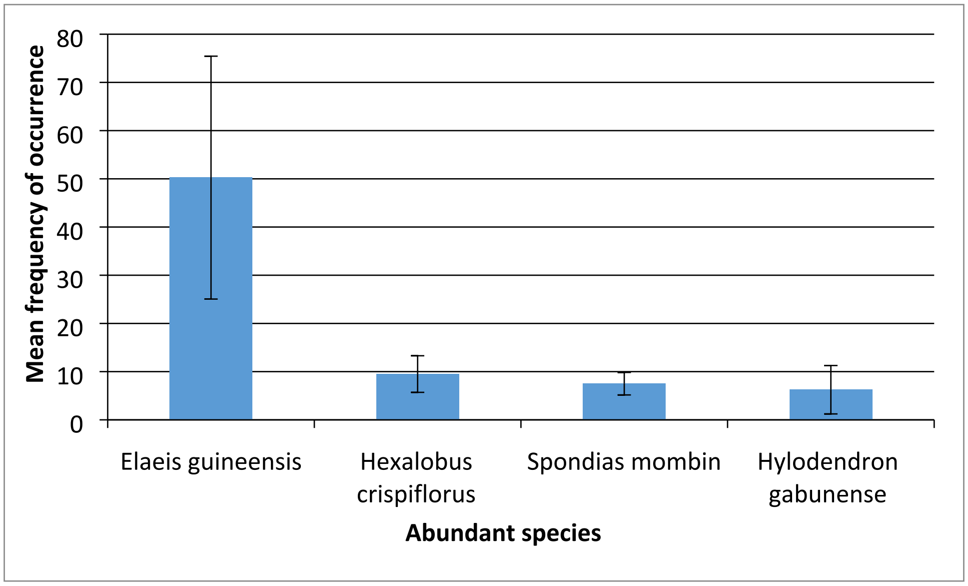

Fig 2.3 Mean species abundance across site 2, including 95% confidence intervals

Akoloma (Site 3)

This location/site is made up of 55 plant species and 30 families. The abundant floristic composition of the forest are: *Rhizophora racemosa*, *Elaeis guineensis, Raphia* spp, and Lannea welwitschii Engl. (Fig 2.4); with species importance values of 72.94, 64.22, 18.17 and 8.35, respectively (Appendix 2). The Arecaceae family had the highest family importance value of 89.84 and was followed by Rhizophoraceae, Leguminosae and Annonaceae, respectively across the forest site (Appendix 3).

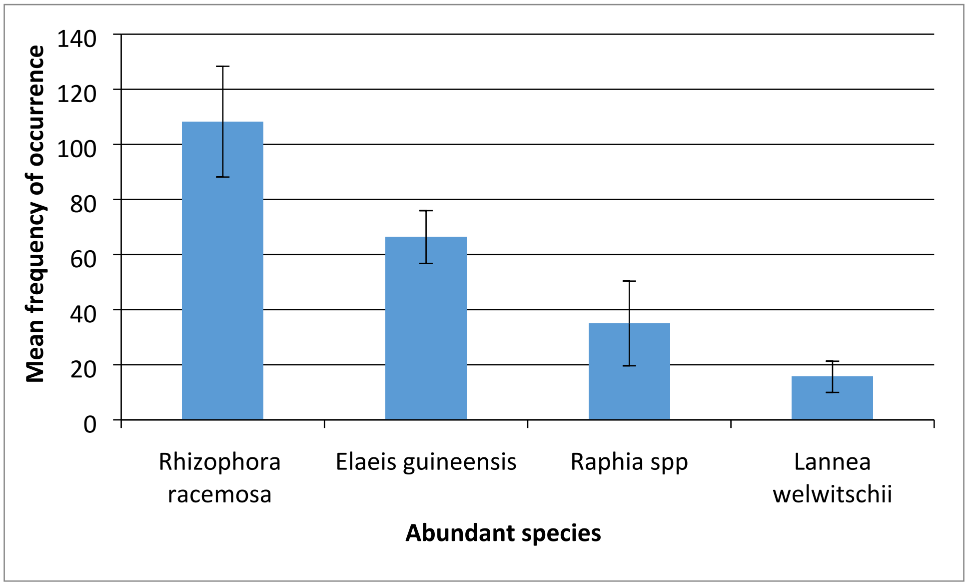

Fig 2.4 Mean species abundance across site 3, including 95% confidence intervals

Otuwe (Site 4)

This forest location had the lowest number (35) of species and family (18) occurrence among other forest locations. The abundant species includes *Diospyros mespiliformis*, *Sterculia oblonga, Sterculia rhinopetala* K. Schum and *Celtis zenkeri* Engl., (Fig 2.5); with species importance values of 83.61, 66.29, 35.51 and 26.32, respectively across the site (Appendix 2). Malvaceae recorded the highest family importance value of 106.93, while the remaining three abundant families were Ebenaceae, Leguminosae and Cannabaceae, respectively (Appendix 3).

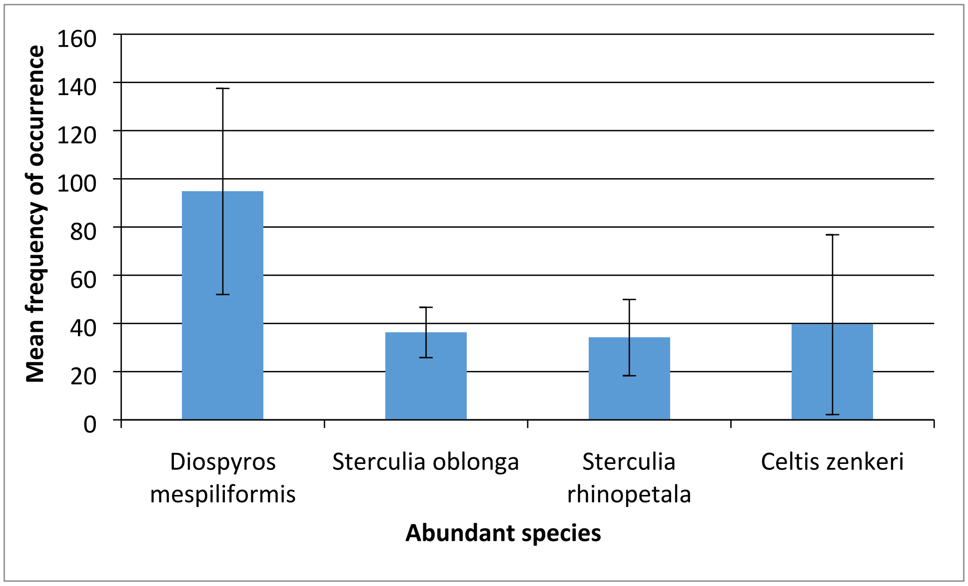

Fig 2.5 Mean species abundance across site 4, including 95% confidence intervals

2.4.2 Biodiversity indices, tree abundance and stem sizes

The species richness varied from the highest index of 8.65 in the first forest location to the least value of 0.52 in the last site (Appendix 4). The mean values of the different sites ranged from 6.74 ± 1.37, 5.49 ± 1.69, 5.16 ± 0.50, to 1.92 ± 1.20 in Akarai-Obodo, Akili-Ogidi, Akoloma and Otuwe respectively. The evenness across the plots and sites varied from the highest index of 0.88 in site 1, to its least value of 0.55 seen in site 4 (Appendix 2). Mean values are across the forest sites ranged from 0.84 ± 0.04, 0.75 ± 0.06, 0.70 ± 0.03, to 0.75 ± 0.09 in Akarai-Obodo, Akili-Ogidi, Akoloma and Otuwe respectively. The forest plots differed in their species diversity across the sites. The highest Shannon diversity index of 3.38 was recorded in the first forest site (Akarai-Obodo), while the last site (Otuwe) had the least value of 0.98 (Appendix 4). Leguminosae and Malvaceae families recorded the highest number of species across the forest sites while others varied across the sites (Table 2.2). About 60% of the other families only had a single species in occurrence.

Table 2.1 Species rich families (with occurrence ≥ 4 species)

	Number of species per forest site			
Family	Site 1	Site 2	Site 3	Site 4
Annonaceae	4	5	5	-
Apocynaceae	6	4	-	-
Leguminosae	11	6	6	9
Malvaceae	7	10	4	5
Meliaceae	4	5	-	-
Moraceae	6	5	-	-
Rubiaceae	7	-	-	-

The number of tree stems varied across the plots and locations. The number of trees per plot ≥ 10 DBH ranged from a least value of 94 to the highest value of 506 (Table 2.3). The pattern of stem abundance across the sites showed mean values of 193, 138, 388 and 255 tree stands ha^{-1} (dbh ≥ 10 cm) in site 1, 2, 3 and 4 respectively (Table 2.3). *Khaya ivorensis* A. Chev had the highest stem size in site 1 (112 cm); *Entandrophragma utile* Sprague had the highest size of 185 cm in the second site; *Irvingia gabonensis* Baill. Ex Lanen had the highest size for the third site (252 cm); and the highest overall size of 448 cm was accounted by *Celtis zenkeri* in site 4.

Stem abundance, density and diversity were varied across the sites (Table 2.3; Fig 2.6, 2.7 and 2.8) due to the different disturbance state of each site.

Table 2.2 Mean values of basal area, diversity and stem density across the forest locations

Forest location	Number of plots (ha)	Average basal area (m^2 per ha) [a]	Average diversity per ha [b]	Average stem density per ha [c]
Akarai-obodo	4	204861.5± 51382.02	4.00 ± 0.34	193.75 ± 74.79
Akili-ogidi	4	179904.7 ± 39781.25	3.34 ± 0.34	138 ± 43.61
Akoloma	8	234557.3 ± 55579.01	3.52 ± 0.22	388.63 ± 72.49
Otuwe	8	421830.5 ± 164251.2	2.66 ± 0.35	255.13 ± 88.16

One way ANOVA: [a]$F = 7.17$, $p = 0.001$, DF = 3; [b]$F = 19.74$, $p < 0.001$, DF = 3; [c]$F = 12.16$, $p < 0.001$, DF = 3. Hochberg adjusted alpha = 0.25

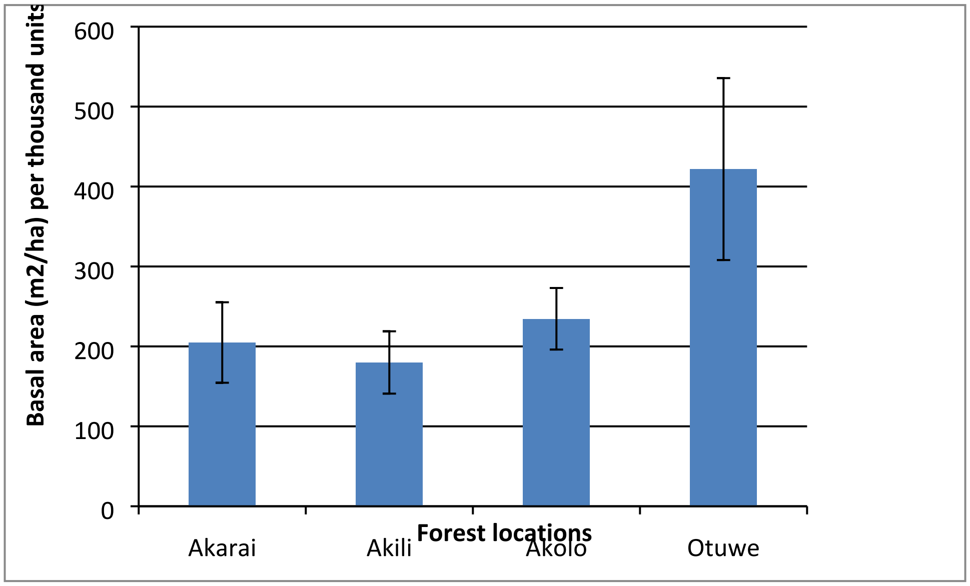

Fig 2.6 Mean basal area of the forest locations, including 95% confidence intervals

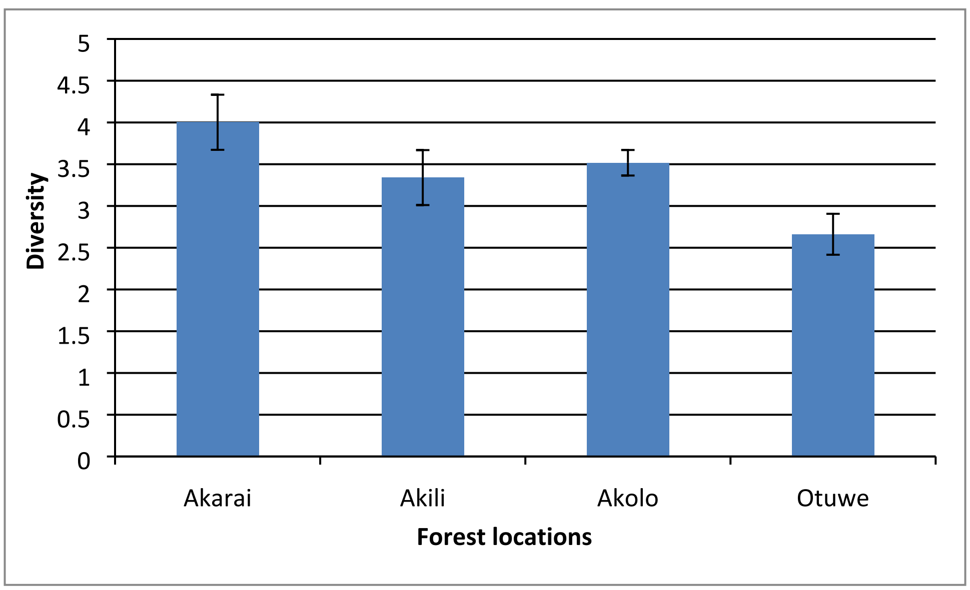

Fig 2.7 Mean diversity of each of the forest locations, including 95% confidence intervals

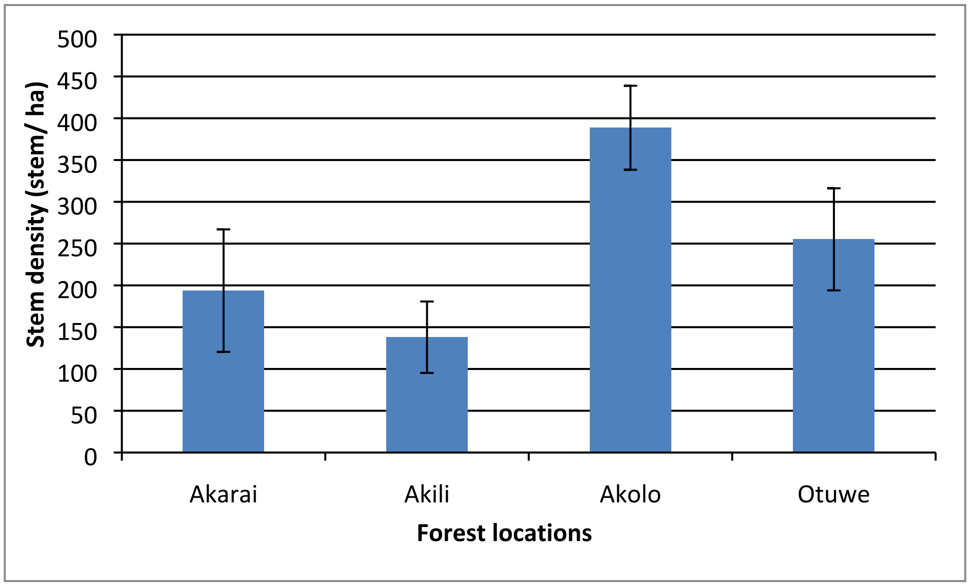

Fig 2.8 Mean values of the stem density of the forest locations, including 95% confidence intervals

The variations in basal area, diversity and stem density all contributed to the variations in the species compositions. Differences in the basal area were mainly from the Otuwe-Akili locations, with the highest difference of 241925.75, p adj = 0.0065. Diversity varied across the locations mostly from Otuwe-Akarai locations with highest difference of 1.34, p adj = 0.0000038 and stem density which varied mostly in Akoloma-Akili locations (highest difference of 250.63, p adj = 0.00014).

2.5 Discussion

The species composition across the sites and plots differed in their patterns of dominance. The dominance of Malvaceae across the ecosystem was mainly from the genus *Sterculia,* which occurred in all the forest locations. The genus has distributional range in tropical areas of Africa and Asia and particularly in the West African countries of Nigeria, Benin, Cote d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Togo and Sierra-Leone (Burkill, 1985; Keay, 1989; Nussinovitch, 2010); and not restricted to the freshwater swamp forest ecosystem only. Though the dominance of *Elaeis guineensis* has been reported in other swamp forests (Keay, 1959; Ubom et al. 2012), it is however a reflection of the extent of the degradation, mainly from anthropogenic factors ongoing in the ecosystem. Being a secondary forest species which requires an open canopy to thrive, it dominates the freshwater swamp ecosystems that have undergone series of anthropogenic and natural disturbances. As such, it is a main flora of the first three sites which are more degraded than the fourth site where it only had a single stem/tree occurrence out of 2,041 stems ≥ 10 DBH.

The Leguminosae family being another notable dominant family in the ecosystem recorded the highest number of species among all the families in the ecosystem. Being a major feature of the tropical (or Neotropical) rainforest ecosystem (Gentry, 1995; 1988; Duran et al. 2006; Romero-Duque et al. 2007; Fonty et al. 2011), it maintains its dominance through its multiple species presence. As such, the constraint associated with the ecosystem which limits the number of plant presence does not affect it in the same proportion with the other families with poorer species diversity. The Rhizophoraceae (mainly from *Rhizophora racemosa*) is a main feature of the ecosystem especially where the ecosystem has transition with the mangrove ecosystem (site 3). The genus *Rhizophora* was also found in plots (especially, in site 1 and site 4) associated with creeks and rivulets where disturbances have opened up spaces for them to thrive and where the degree of salinity (associated with the creeks) permits or is suitable for them to coexist with other freshwater swamp flora. It was not found in site 2 which even though was similar in terms of wetness but does not have the tiny creeks and inlets like other locations that permits the transportation of both their seeds and saline water for the facilitation of their propagation and coexistence. However, the Rhizophoraceae are floristic features of the freshwater swamp ecosystem but the patterns of their coexistence and dominance are varied from site to site.

The freshwater swamp ecosystem is a floristically variable forest whose dominance is varied across different geographical scales. As such, the main feature that is found or dominates one location is not consistently the same across a landscape or region. In the Indo Malayan region for example, dominant species like: *Melaleuca leucadendron, Ficus* sp., *Erythrina* sp, *Memecylon* sp. have been reported (Wikramanayake et al. 2002); in the neotropics, dominant species like *Tabebuia cassinoides*, *Tovomitopsis paniculata*, *Symphonia globulifera*, *Pterocarpus officinalis* and families like: Clusiaceae, Bignoniaceae, Burseraceae, Arecaceae and Annonaceae were reported (Scarano et al. 1997; van Andel, 2003; Fickert and Grüninger, 2010; Teixeira et al. 2011). This pattern is unlike other ecosystem like the lowland forests in the tropical and neotropical regions which are dominated by the Leguminosae family (Gentry, 1995; 1988; Duran et al. 2006) and the lowland (rainforest) forests of southwestern Nigeria which is dominated by Moraceae family (Adekunle et al. 2013). The freshwater swamp forests in the Niger Delta are made up of floristic composition which occurs in other ecosystems; however its pattern of dominance and coexistence are varied and site specific.

Species diversity varied from site to site and from forest to forest, with some forest or sites being composed of large trees and diverse composition, while others have less (Table 2.3; Fig 2.7) . The variation in the species diversity of the forest sites is mainly a function of disturbance, which was equally varied across the sites. This come out clearly in the Tukey's test, which showed the highest difference in diversity between the intact forest site and the most disturbed site, which incidentally had the highest diversity as well. While the extent of disturbance, as well as land use and biogeochemical factors are undoubtedly responsible for the variations seen in forest landscapes, understanding they apply to the local environment and particular ecosystem like the freshwater swamp forest is very vital. This variation in the number of species found across the forest sites especially among the disturbed sites shows that the freshwater swamp forest ecosystem does not have uniform or consistent flora across large geographical scales, but are site specific and very variable. Even though the diversity of the forest sites increased with disturbance and the species richness improved with disturbance as well, such landscape's resilience reduces on the other hand since functional attributes such as invasion resistance tends to become more endangered (MacDougall et al. 2013).

The results of the patterns of stem abundance across the sites (Table 2.3) could be compared with the results from other tropical forests. Studies from tropical forests in Asia have shown tree densities of 349-627 stems ha^{-1} and 9-14 species in a dry tropical forest of Mirzapur district, Uttar Pradesh, India (Singh and Singh, 1991); 217-292 stems ha^{-1} in a dry tropical forest sanctuary in Raipur district, Chhattisgarh (Bijalwan, 2010); 428 stems ha^{-1} in 95 species in a rainforest of Xishuangbana, China (Lu et al. 2010). African tropical forests have shown densities of 434 stems (≥ 10 cm dbh) in mixed tropical forest, and 340 stems in a monodominant forest in Cameroun (Lewis et al. 2013); 387 stems in 94 species in a strict nature reserve in southwest Nigeria (Adekunle et al. 2013). The stem densities are indeed similar and comparable with that of other tropical forests across the globe. These densities vary across the sites mainly due to the variations in disturbance regimes and capacities of each landscape to regrow after disturbance cycles. This on the other hand is responsible for the variations in basal area of the stems in each site.

Species richness of the ecosystem though varied, were generally low. However, this is not strange with the freshwater swamp forests which are characterized by low species richness (Lugo et al. 1988; Scarano et al. 1997; Teixeira et al. 2011; Kurtz et al. 2013) due to environmental constraints which the ecosystem responds to sensitively. The flooding regime that is associated with the ecosystem which inundates the soil exerts selective pressure on the composition and the structure of the ecosystem (Kurtz et al. 2013). As trees require flood free environments to facilitate reproduction and shallow water to prevent water-logging of seedlings or gas exchange (Lugo et al. 1998) which are not guaranteed for the ecosystem regularly, species with higher tendencies of adaptation to such conditions are found more in the ecosystem; hence making the ecosystem to display tendencies of monodominance. Similar studies (Kurtz et al. 2013) reported lower species richness of the forests compared to the drier adjacent soil or forest locations; as was seen in the study. This further explains why the permanently flooded sites (were observed) have lower species richness and stem density than the seasonally flooded sites and then the adjacent lowland rain forests (which has transition zones with the freshwater swamp forests) in the region.

As the ecosystem continues to undergo regimes of natural and anthropogenic disturbances, they provide gaps in the canopies of the forests and provide basis for regeneration and species diversity across the landscape. Such events go on to create opportunities for the addition of new species to the ecosystem and in turn facilitate the reinforcement and maintenance of the tree diversity in the ecosystem (Nakagawa et al. 2013).

2.6 Conclusion

The study documented an array of composition found across the ecosystem according to their respective abundance in the ecosystem. Their stem densities were similar with that of other tropical forest ecosystems, while their diversity increased with disturbance across the ecosystem. The ecosystem is characterized by general low species richness, as in other freshwater swamp forests in the Neotropics. This implies that the loss of any single species in the ecosystem poses a great threat to the ecosystem as there are not many species for which the ecosystem is known for and puts the ecosystem at the risk of ecosystem collapse. Furthermore, as the species diversity and rarity of the ecosystem are more associated with disturbed locations more than the intact zones, effective conservation of the ecosystem should not only be focused on the intact forest locations with higher basal area per hectare, but also the disturbed locations whose higher species value are vital for the stability of the ecosystem.

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Chapter 3 – Determinants of freshwater swamp forests distribution

3.0 Determinants of freshwater swamp forests distribution in the Niger Delta

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3.1 Abstract

Global understanding of the biogeography of freshwater swamp forests are shaped and dominated by studies from the neotropics, with little or no baselines from (west) Africa to compare with. This study seeks to provide insights about these factors as well as the species therein across the Niger Delta and West African region. To understand the determinants of species distribution in the Niger Delta, forest plots were set up in four locations and were used to assess the tree species (DBH ≥ 10 cm). In total, 138 species within 100 genera and 41 families were the taxa identified across the forest plots. Cluster analysis (Ward's agglomerative cluster) was used to classify the forest plots distributed across the four forest locations into three zones: intact, transition and disturbed. Indicator species analysis was used to decipher the key taxa (indicator species) that represented each of the forest classes. Among the 47 species identified as indicator species, 40 of them occurred (had single associations) only once across the zones, while the remaining 7 coexisted in disturbed freshwater and transition zones. The mangrove-freshwater zone had the highest occurrence of indicator species (25) and was followed by disturbed freshwater zone and intact zone with ten and five species occurrences respectively. The variation in the distribution of the species was found to be mainly as a result of disturbance (local factors) and the varied climate of the locations. Indicator species identified for each of the forest zones both serve as indicators for deciphering the state (disturbed or intact) of the forest and for assessing forest restoration. Employing such insights (indicator species) will not only help to understand the biogeography of tropical forest ecosystems, but furthermore inform better restoration capacities for its degraded landscapes.

Keywords: ecological niche, ecosystem resilience, environmental gradients, floristic composition, forest transitions

3.2 Introduction

The floristic composition and species distribution of plants within a region or geographical delimitation are structured according to environmental (Tuomisto et al. 2003; Gole et al. 2008; Costa et al. 2009; Homeier et al. 2010), ecological (Holt, 2003; Clarke et al. 2007; Chave, 2008) and historical factors (Von Holle and Motzkin, 2007; Blach-Overgaard et al. 2010; Eiserhardt et al. 2011); and constrain or permit plant species to occur and coexist with others in different environments. While these patterns and processes have varied spatial scales (Eiserhardt et al. 2011), their role in determining the floristic composition have mainly been attributed to climatic factors (Pyke et al. 2001; Parmentier et al. 2007); soil and topography (Phillips et al. 2003; Chain-Guadarrama et al. 2012; Bueno et al. 2013; Mwakalukwa et al. 2014); and natural and anthropogenic disturbances (Lugo and Scatena, 1996; Motzkin et al. 2002). Even though the role of climatic and edaphic factors has been established in defining the gradients of the tropical forests, their patterns have however varied across the tropics. While studies from South America have emphasized soil gradients (soil fertility) as the main determinant for defining species composition, West African forests' composition have been correlated mostly with climatic gradients (rainfall) (Toledo et al. 2011).

As the biodiversity of tropical forests are products of their biogeography, habitat and disturbance regime (Whitmore, 1998), understanding the role of disturbance in shaping tropical ecosystems, alongside other factors, have been understudied in the west African region, particularly the freshwater swamp forest which is characterized by different disturbance regimes. Studies in West Africa have attempted to use the environmental variables of climate and soil in the zonation of the forest ecosystem into phytogeographical units: Hall and Swaine (1981) in Ghana; Ern (1979) in Togo; Adomou et al. (2006) in Benin and Keay (1949) in Nigeria. While these studies provide background for understanding the patterns of the forest ecosystem, they are focused on categorizing the whole forest ecosystem and not specifically aimed at understanding how these affect the individual ecosystems. As plants are more consistent indicators than other taxa, (Toledo et al. 2011; Bakker, 2008) they could be used as bioindicators of their environment especially when their frequencies within a particular habitat is high (Dufrêne and Legendre, 1997). This study aims to determine the variables that are responsible for the floristic distribution across the ecosystem. Specific objectives include: 1) to determine the species that are indicators of each of the forest groups; 2) to examine how variations in disturbance and environmental variables contributed to the distribution of the floristic composition across the ecosystem and 3) relate the insights to that of other ecosystems and provide biogeographic insights for the ecosystem.

3.3 Materials and methods

3.3.1 Study area

The study was carried out in the Niger Delta region; a vast sedimentary area characterized by low relief and crisscrossed by a network of rivers, streams and creeks (Fig 3.1). Forest sites used for the study were communally owned forests located in Akarai-Obodo, Akili-Ogidi and Otuwe and Akoloma (Fig 3.1). The two sites in Akarai-Obodo and Akili-Ogidi are disturbed freshwater swamp forests that are only accessible during the dry season months due to poor terrain and flooding. Both forests are secondary forests regrowing from anthropogenic disturbances and owned by nearby villages that are composed mainly of local farmers, artisanal fishermen and few civil servants; who all depend on the environment for their sustenance. The site at Otuwe is an intact freshwater swamp forest with a nearby lake where fishing camps are established and used seasonally by the surrounding communities. With no form of accessibility, it is the most intact of all the forest sites with no signs of anthropogenic disturbances (stumps and cut stems) and characterized by large stems and tall trees. The site in Akoloma is a freshwater-mangrove transition forest zone not too far from a creek (Kolo creek); which has tiny rivulets into the forests and owned by a neighbouring hamlet. It is a secondary forest with dense undergrowth and tree species that have buttresses and close to each other. Seismic activities and logging contributed to the disturbance in the past; while being encroached currently by plantain farms. With no access road linking it to other communities, it is made up of few household units that engage in farming, oil palm processing, artisanal fishing and hunting.

The soils of the region are of fluvial origin which is characterized by a succession of thinly bedded silts and clays interbedded with sands. Soils are classified as hydromorphic soils which are either temporarily or permanently flooded (Areola, 1982). The hydrological regime comes from the Atlantic Ocean’s tidal movements and the Niger River flood. It’s flooding starts toward the end of August, peaks in October, and tapers off in December. It is characterized by a long rainy season which lasts nearly throughout the year; mainly from March/April to October, while the dry months (with an average monthly rainfall of 150mm) are experienced between Decembers to February. Relative humidity rarely dips below 60% and the average monthly maximum and minimum temperatures vary between 28°C to 33°C and 21°C to 23°C respectively (NDES, 1997; James, 2008).

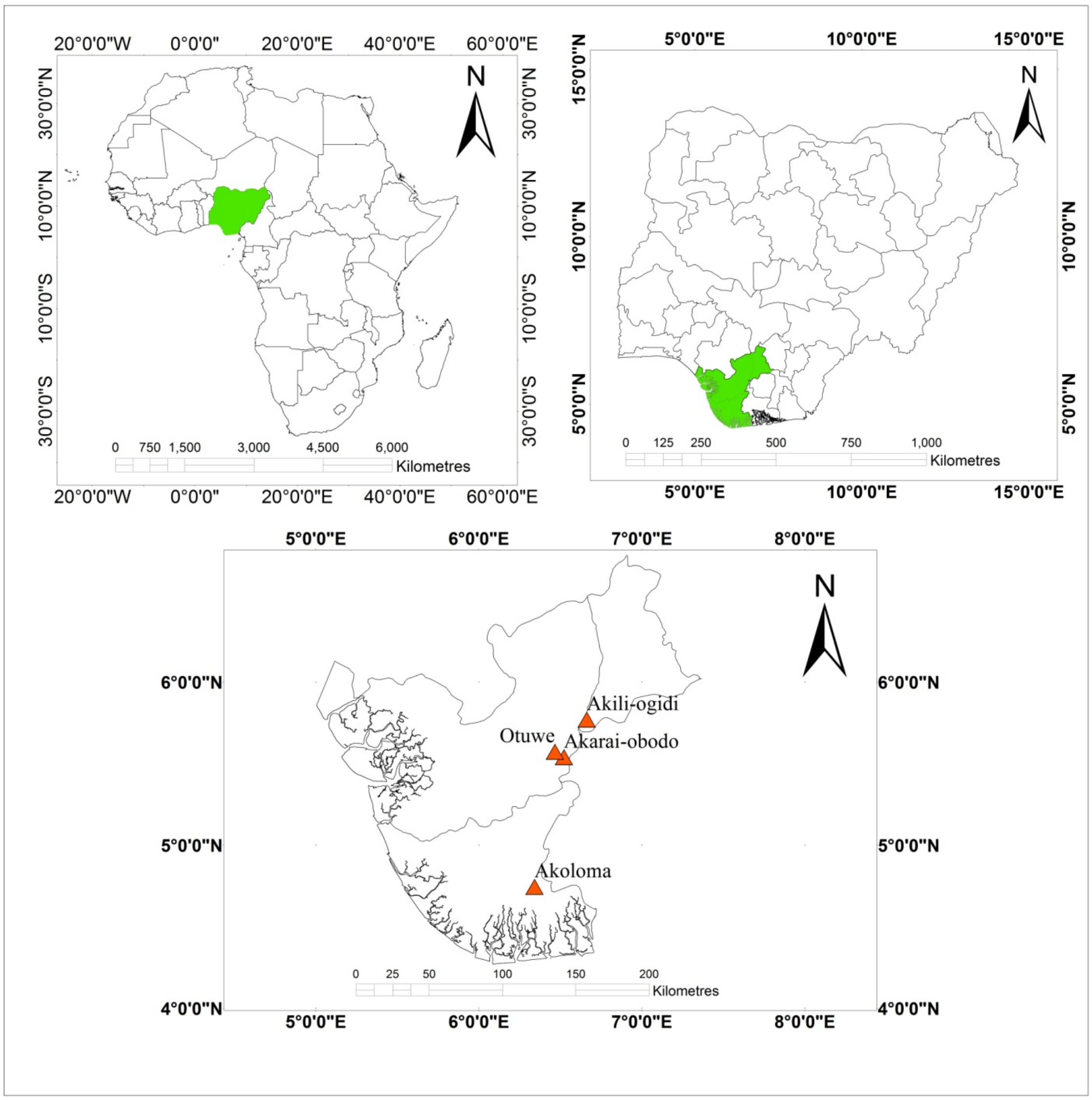

Fig 3.1 Map of the study locations

3.3.2 Data collection

The forest survey employed a standard 1 hectare (ha) square plot method established along transects (Phillips et al. 2003) between December 2013 and April 2014. Plots were placed 500m apart to ensure variation in floristic composition. All the 4 – 8 plots per site were placed along transects spaced 1km apart rather than random placement. This helped to ensure that consistency in enumeration was maintained across the plots. Sites in Akarai-Obodo and Akili-Ogidi had 4 plots each (two transects), while the plots at Akoloma and Otuwe were 8 each (four transects). Each of the forest plots were used for the enumeration and identification of all tree stems ≥ 10cm in diameter. Tree species were identified in the field with the assistance of botanists from the Forestry Research Institute of Nigeria, Ibadan; while voucher specimen for species that could not be identified in the field was taken to the herbarium of the Forestry Research Institute for identification. The forest plots were only set up in the seasonally flooded part of the freshwater swamp forests during the dry months when the water had subsided. Species identification was conducted by Michael Oladimeji, a taxonomist from the research institute and assisted by Peter Ige. Tree measurements and setting of the plots were conducted by Nwabueze Igu, with the assistance of Cyril Mama and Ifeanyi Iwegbue. The climatic data used for the work were highest resolution ($30^{''}$ minute) WorldClim data (Hijmans et al. 2005). Elevation was measured in the field with a GPS. Distance of the forest to the nearest settlement was used as a proxy for determining disturbance across the sites. A GPS was used to collect the coordinates of the locations and was converted to distance in kilometres in Google earth pro.

3.3.3 Data analysis

To understand how the species composition compared among the plots, quantitative (abundance data) and qualitative (presence/absence data) matrices were generated using Non-metric Multidimensional Scaling Ordination (NMDS) in Community Analysis Package (CAP) version 4.0 (Pisces Conservation Limited, 2007); with default setting of PCA rotations and Bray-Curtis distance similarity measure (McCune and Grace, 2002). This method of ordination is suitable as it summarizes the data into two axes dimensions unlike other indirect ordination methods. To understand the plot resemblance based on their community composition, a cluster analysis based on Ward's agglomerative cluster using Bray-Curtis dissimilarity coefficient (Clarke and Warwick, 2001) was performed in Community Analysis Package (CAP) version 4.0. (Pisces Conservation Limited, 2007).

Indicator species analysis (ISA) was used to understand the species associations or preferences of certain key taxa across the study region. This method characterizes the environmental preferences of target species (De Cáceres et al. 2010) by combining the abundance of specific group and the occurrence of species in a specific group (McCune and Grace, 2002). This method of analysis is preferred to TWINSPAN in identifying indicator species, as it treats each species separately, unlike TWINSPAN where the value of one species depends on the abundance of other species in a data set (Dufrêne and Legendre, 1997; McGeoch and Chown, 1998). The indicator species analysis combines species mean abundance and frequency of occurrence in each group. The resulting indicator values ranges from 0 to 1. A high indicator value occurs when a species is both abundant ("specificity") and occurs in most sites ("fidelity"), with the IndVal value of 1 seen as a perfect indicator species with reference to specificity and fidelity.

The summarized axes dimension in NMDS was used in the multivariate analyses of variance (MANOVA) to show how the species compositions were varied across the forest locations. Multiple-response permutation procedures (MRPP), a nonparametric procedure for testing difference between groups of entities (Mielke and Berry, 2001), was used to verify if clusters of vegetation type identified by the NMDS were statistically different. To show how varied disturbance and climatic variables were in contributing to the distribution of the composition, a one way ANOVA with Tukey's HSD post hoc test (95% confidence level) was conducted. Hochberg corrected alpha values (Hochberg, 1988) was used for the adjustment due to multiple testing. All analyses were performed using R statistical software version 3.1.0 (http://cran.r-project.org).

3.4 Results

3.4.1 Overview

The ecosystem is composed of 138 species within 100 genera and 41 families distributed across 24 hectares. *Elaeis guineensis* Jacq, *Sterculia oblonga* Mast, *Diospyros mespiliformis* Hochst and *Rhizophora racemosa* G. Mey recorded the highest number of stems across the forest region. Malvaceae and Leguminosae families had the highest number of species (13 each), while 60% of other families has single species in occurrence across the ecosystem. The stem density ranged from 94 – 506 stems ha^{-1}.

3.4.2 Patterns and cluster of forest species

The results of the cluster analysis divided the forest into three main clusters: plots 1-8, which are termed disturbed freshwater swamp forests; plots 9-16, termed, the freshwater-mangrove transition zone; and then plots 17-24, which are the intact freshwater swamp forest zone (Fig 3.2).

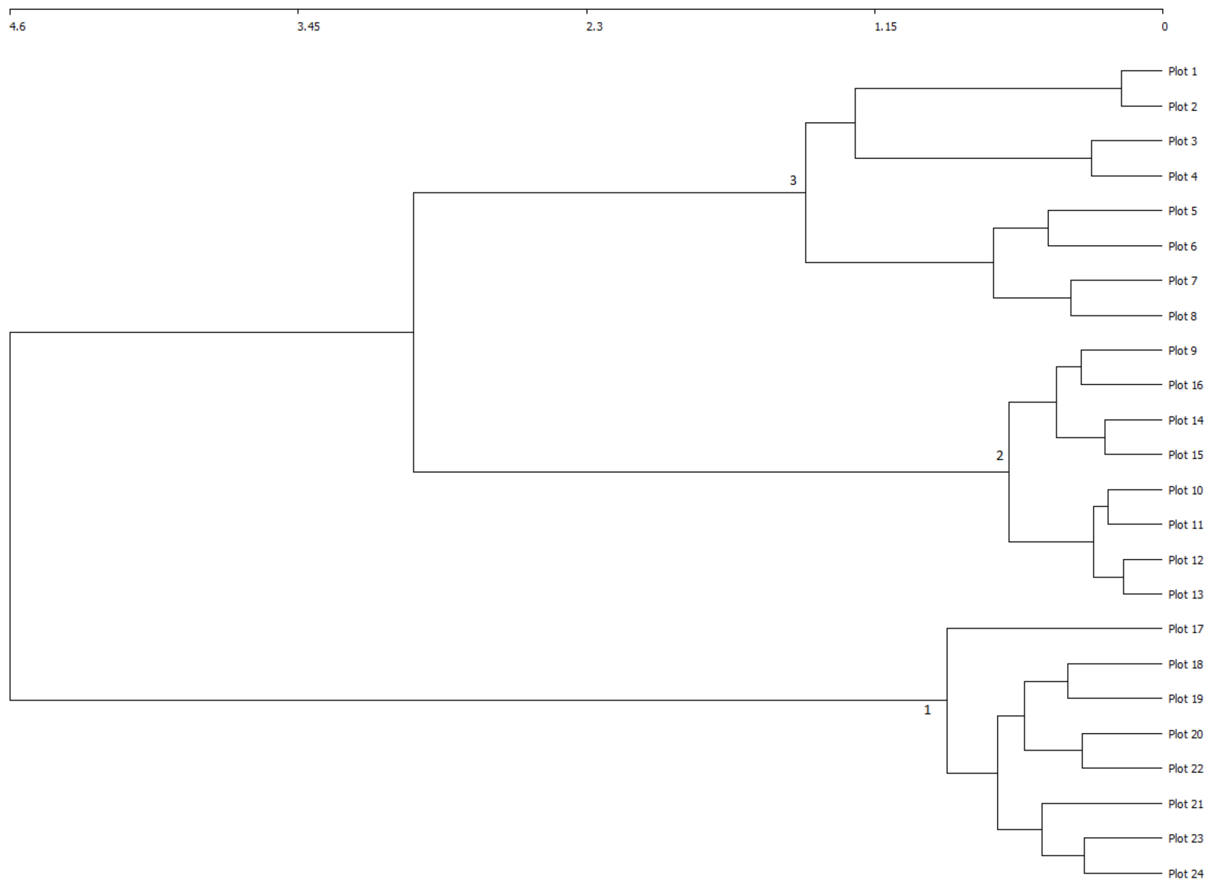

Fig 3.2 Ward's Cluster Analysis of 24 forest tree plots showing groups 1 (Intact forest zone), 2 (Transition forest zone) and 3 (Disturbed forest zone)

3.4.3 Indicator species analysis

The results of the analysis showed that out the 138 species, 47 were selected and presented in two groups: the number of species associated to group 1 was 40 (and made up of species with single occurrence across the groups), while the species associated to group 2 were 7 (being composed of species that coexisted in more than one group). Further details are given below:

A total of 10 species were found in group 1 (disturbed forest locations) with different significance (with 1 as the highest value) and p values. Among them, *Treculia africana* Decne. ex Trécul had the highest statistical significance of 1.000, with 0.001 p values; followed by *Spondias mombin* L. and *Ceiba pentandra* Gaertn with 0.935 and 0.897 statistical significance (Appendix 5).

Group 2 (transition forest zone) was characterised by 25 species: *Abarema floribunda* Benth, *Erythrina indet., Lannea welwitschii* (Hiern) Engl *, Raphia indet* and *Staudtia stipitata* Warb, which recorded the highest statistical significance of 1.000, with p values of 0.001. These were followed by *Rhizophora racemosa* G. Mey and *Monodora myristica* Dunal with 0.984 and 0.959 values respectively and p values of 0.001 (Appendix 5).

Group 3 (intact forest zone) had a total of 5 species that were associated with the cluster. Among the significant species: *Diospyros mespiliformis* Hochst. ex A. DC had the highest statistical significance of 0.987, and was followed by *Sterculia rhinopetala* K. Schum*, Sterculia oblonga* Mast and *Celtis zenkeri* Engl with 0.975, 0.912 and 0.861 values respectively, with 0.001 p values (Appendix 5).

Among the combination groups (1+2 groups), *Elaeis guineensis* Jacq had the highest significance of 0.968 and was followed by *Hylodendron gabunense* Taub (0.901) with 0.001 p values (Appendix 5).

The results of the Multiple Response Permutation Procedure (MRPP) test showed that the a priori groups were different as regards their species composition (MRPP: A = 0.3659, p = 0.001).

3.4.4 Determinants of variation in floristic composition

The results of the multivariate analysis of variance (MANOVA) showed how varied the composition was across the forest locations: $F = 35.25$, $DF = 3$, $p\ adj < 0.001$ (95% family-wise confidence levels). These variations in composition were contributed by the variation in disturbance: $F = 1.743 \times 10^{31}$, $DF = 3$, $p\ adj < 0.001$ (95% family-wise confidence levels) which was mostly between Otuwe and Akoloma sites (difference = 13.66); mean annual temperature: $F = 2.84 \times 10^{28}$, $DF = 3$, $p\ adj < 0.001$ (95% family-wise confidence levels), mostly between Akoloma and Akarai-Obodo sites (difference = 11) and annual precipitation: $F = 2.203 \times 10^{29}$, $DF = 3$, $p\ adj < 0.001$ (95% family-wise confidence levels), mostly between Akoloma and Akili-Ogidi (difference = 352).

3.5 Discussion

3.5.1 Patterns of community variation

Tree species composition of tropical forest ecosystems are not only biodiverse, but differ widely within the same forest ecosystem and across the different forest types within the tropics. As its concerns the freshwater swamp forests, the nature of this variation in flora followed three main distinct community patterns. While most of the species (85.1%) were seen in only one group out of the three clusters, others were captured in two clusters (14.9%). Malvaceae and Leguminosae were the most dominant families, recording six species each across the community clusters. As their species were found in all the forest clusters, disturbed freshwater swamp forests, intact freshwater swamp forests and mangrove-freshwater transition zone, it shows that they are widespread and are dominant features or flora of tropical forests (Gentry, 1988). The Malvaceae family, which has not received wide documentation as a main feature of tropical forests, was seen occur across the forest locations and share a good coexistence with the mangrove swamps following its representativeness in the transition zone community.

Since plant species respond differently to ecological niches (Chase and Myers, 2011; Wiens, 2011; Heino, 2005), the pattern of distribution of the species expectedly varied across the forest clusters. The disturbed forest groups (both the disturbed freshwater and transition zones) were seen to have higher indicator species frequencies as a result of their great number of ecological niches, compared to the intact forest group with a lower ecological diversity and consequently, fewer species occurrence. However, with reference to the two disturbed groups, more species were found to coexist in the transition zones than in the disturbed freshwater zone. This ongoing community facilitation in the transition zone enables the realized niches of the species to be larger than the fundamental ecological niches within the disturbed freshwater zone (Bruno et al. 2003; He and Bertness, 2014; He and Cui, 2015). Conversely, since the populations in the regional pool of the intact zone are few and it's rare species (low relative abundance) are limited in their recruitment due to limited dispersal or fecundity (Chase and Myers, 2011); its homogeneity will remain low. This is however not so for the other groups (1 and 2) which are more disturbed and have limited physical barriers to dispersal, and as such their community composition will not be structured by such stochastic factors like colonization history (Chase and Myers, 2011).

The distribution of the indicator species across three groups (Appendix 5) shows the different environmental preferences of the species across the ecosystem. Hence, they (indicator species) could be used to understand the environmental (due to the existing species-environment relationships) conditions of the ecosystem (Diekmann, 2003; Toledo et al. 2011) and will be suitable for informing more precise classification and sustainable management of the ecosystem. A greater part of these indicator species (85.1%) had single species distribution across the forest sites and are suitable for understanding the habitat conditions of the forest categories they represent (Baker, 2008). While this is equally similar for the remaining smaller fraction (14.9%) which occurred in more than one group or cluster (both group 1 and 2), they are however species that could indicate disturbed freshwater and mangrove-freshwater ecosystems. Though the results of the multiple response permutation procedure (MRPP) showed that there was a difference in the different forest categories, the significant value was weak. This is mainly due to the weak environmental gradients within and between the communities (same geology and ecological zonation shared by the sites) and the close proximity of the plots.

3.5.2 Ecological characteristics and determinants of indicator species

The freshwater ecosystems in the Niger Delta are generally found in low-lying areas and composed of alluvial soils whose fertility are replenished on regular basis through the deposition of silt and soil nutrients following the annual inundation (flooding) of the forest floor. Unlike other West African forests which are generally poor in their soil fertility (Hall and Swaine, 1976; Swaine et al. 1996; Toledo et al. 2011), the freshwater swamp forests in the Niger Delta are characterized by rapid tree growth and dense vegetation. With similar geological history, geomorphology and relief across the region, edaphic factors were not seen to be responsible for the variations in the composition of the different locations. Though the forest floor across the region is characterized by ridges, mounds and some pockets of depressions (with marshes or pools of stagnant water that generally limits tree growth and shapes the ecosystem at the landscape scale), it however contributes to the gap dynamics of the ecosystem. Such features are not only responsible for the gaps found in the forest structure of freshwater swamp ecosystems, but furthermore presents the ecosystem as mosaics of forest patches even when anthropogenic disturbances may not be ongoing.

Climatic factors contributed to the variations in distribution of the ecosystem's composition. Both the mean annual rainfall and temperature were needed to sustain the humid, warm and swampy environment suitable for the ecosystem's flora. Their variations contributed to the differences in the duration of waterlogging of the soil (and micro climate of the forest clusters), their ecological processes (distribution, productivity and reproductive biology) and their floristic/vegetative formations of the ecosystem (Megonigal et al. 1997; Ferreira et al. 2014). These climatic factors impose habitat selection on the ecosystem, contribute to the variation in the stem and species abundance across the forest clusters and create different climatic niches (gradients) and stand structure within the ecosystem. While both the mean annual rainfall and temperature are vital in ensuring that the climatic conditions necessary for the swamp environment is maintained, other climatic variables also contribute in determining the patterns of their heights and their general life history traits (Moles et al. 2009).

The pattern of disturbance across the forest clusters are varied and are significant indices in the biogeography of the ecosystem. Being a dynamic determinant for species richness of different landscapes (Wohlgemuth et al. 2002); it (disturbance) is responsible for the variations seen in the species abundance as well as the structure of forest clusters. Disturbed forest clusters are characterised by more species than the intact clusters (Appendix 5): a character found in other forest ecosystems and best explained by the intermediate disturbance hypothesis (Connell, 1978). Although disturbances may have destroyed certain tree species, it equally creates opportunities for propagules to arrive in the open spaces and colonize the ecosystem, thereby increasing the diversity of the disturbed area. As the time between disturbances increases, their diversity will also increase as more species invade the area, while the slower growing species and those with low dispersal capabilities will then have the capacity and opportunity to reach maturity.

3.6 Conclusion

Variation in disturbance and climate were both responsible for the varied distribution of their flora. With differences existing in the ecological niches of the species in the ecosystem, their indicator species were equally seen to occur at different frequencies. Even though the relative abundance of species is higher in disturbed locations due to their higher fecundity, ensuring that their rate of disturbance is managed will help to ensure that their ecological thresholds are not exceeded. To achieve this, efforts that encourage community forest conservation should not only focus on preserving the biodiversity of the freshwater ecosystems, but also the environmental conditions of the region and in turn, the viability of the ecosystem.

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Chapter 4 – Above ground carbon storage in freshwater swamp forest ecosystem

4.0 Above ground carbon storage in freshwater swamp forest ecosystem in the Niger Delta

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4.1 Abstract

Tropical forests are important stores of carbon but the contribution of freshwater swamp forests to this store is largely unquantified. This study quantifies the above ground carbon (AGC) store of Freshwater swamp forests and the transition zones into mangrove forests in the Niger Delta and the results used to explore the role of forest structure, floristic composition and climatic variables to this store. Taxonomic data were derived from tree stems ≥ 10 cm diameter at breast height (DBH) in 24 one hectare plots established across different disturbance gradients and transition zone to mangrove and terrestrial forest. An allometric equation was used to estimate the AGC of forest disturbance categories and multiple regressions used to verify the determinants of the carbon stores, including climatic influences. Future climate projections were also used to model expected change. AGC was typical of other African forests, and ranged from a mean of 228 t ha^{-1} (bootstrapped 95% CI: 168 - 288) in intact forests, to 104 t ha^{-1} (64 - 144) in disturbed forests and 100 t ha^{-1} (60 - 141) in disturbed freshwater-mangrove transition. Basal area was seen as the most important variable, hence showing the role of disturbance in distinguishing areas of higher carbon stores from lower zones. Though the disturbed forests contained less carbon, conserving them alongside the intact forests was seen to not only contribute to increasing the long-term carbon budget of the region, but also its biodiversity and other ecosystem services. Variations in temperature and precipitation across the sites contributed to their varied AGC. Expected temperature rise (following the climate change scenarios) are equally expected to contribute to the AGC of the different forests. Our study suggests that the variation in AGC of the swamp forests is largely related to historical use and current management of the forest resources. Efforts to ensure that forest degradation is reduced are advocated in order to enhance carbon storage by 228 t ha^{-1} or more for the whole Niger Delta freshwater swamp ecosystem.

Keywords: biomass, carbon budget, climate change, forest structure, Nigeria

4.2 Introduction

Tropical forests are store houses for vast quantities of carbon and modulators of climate change (Houghton, 2005; Lewis, 2013). Containing as much as 30% of global carbon stocks (Keith et al. 2009), tropical forests are estimated to store a greater proportion of carbon in its above ground biomass (70-90%) depending on its climate, soil, disturbance and topography (Saatchi et al. 2011), as well as threats from deforestation and forest degradation. Since forests have a significant role to play in carbon mitigation, understanding the drivers that determine the carbon potentials of the ecosystem are vital for effective management and will in turn help to optimize and potentially increase carbon stocks for sustained mitigation benefit.

Estimating the quantity of carbon stored in the biomass of tropical forests, with high-resolution remote sensors like light detection and ranging (LiDar) and radio detection and ranging (radar) have been produced (Saatchi et al. 2011). However, despite the importance for climate change mitigation, baseline information from field studies on estimates of the forest carbon are still lacking in many parts of the tropics and for whole ecosystem types. This 'basic' foundation information is vital as it is used for calibration and validation of remote sensing methods and models used to produce carbon estimates that policies such as Reducing Emissions from Deforestation and Degradation (REDD+) are based upon. While most of the studies on forest carbon have been concentrated in the Americas, the (West) African forests (especially Nigeria) have been relatively poorly studied. Furthermore, with varied determinants and patterns of distribution of forests across the region, establishing carbon baselines for the different forest ecosystems in the region is the first step towards understanding how the varied ecosystems, and the associated carbon store, could respond to changes in the environment.

Freshwater swamp forests are ecosystems whose biogeography and biogeochemical processes differ from other tropical forest ecosystems, notably with adjacent lowland rainforest and mangrove swamp forest ecosystems. With such inter-ecosystem variation in biodiversity indices, environmental determinants and disturbance regimes, understanding the carbon storage or capacity of the freshwater ecosystem will furthermore enhance a better appreciation of the importance of swamp forests. The Nigerian freshwater forest ecosystem which is concentrated in the Niger Delta (Fig 4.1) and covers some 12,000 km^2 (NDES, 1997), is threatened by forest degradation and land use changes. As this ecosystem is threatened by an escalating deforestation and degradation mainly due to agricultural expansion, population growth, urbanization and crude oil exploration, quantifying the carbon stores of the remaining intact and disturbed forest mosaic are steps towards ensuring a correct future referencing point for the ecosystem. Accurate assessments of carbon are imperative to establish a good national data and baseline for the ecosystem, and furthermore, contribute to reducing the high uncertainty associated with global forest carbon assessments (Grainger, 2008; Baker et al. 2010).

This research is aimed at assessing the estimates of above ground carbon store of the freshwater swamp ecosystem across the Niger Delta. Specifically, the objectives includes: 1) to quantify AGC and compare the estimates to that of other tropical forests in Africa, 2) to analyze the extent to which forest structure and floristic composition influences the carbon store, 3) to show the relationships between diversity, stem density, basal area and AGC across the sites, 4) to show how varied the AGC were based on their climatic variables and 5) to discuss the carbon implictions of improved forest management.

4.3 Materials and methods

4.3.1 Study area

The Niger Delta is a vast sedimentary basin in southern Nigeria located in the lower reaches of the River Niger and the River Benue (Fig 4.1). Formed by the accumulation of sedimentary deposits derived from the Niger and Benue basins, the Volta River basin, and minor rivers within Nigeria (Allen, 1964), it has undergone three major depositional cycles (Short and Staeuble, 1967) and is broadly made up of marine sediments of Lower and Upper Cretaceous age (Akintola, 1982). Areola (1982) classified the soils of this region as hydromorphic soils which are either seasonally or permanently waterlogged. The region is characterized by a tropical climate with long rainy season from March/April to October. The flood regime starts in August, peaks in October and tapers off in December. The wet season lasts nearly throughout the year; the wet season peaks in July and the dry months are mainly between December and February (Hughes and Hughes, 1992). Relative humidity rarely dips below 60% and fluctuates between 90% and 100% for most of the year, with average monthly maximum and minimum temperatures varying between 28^{o}C to 33^{o}C and 21^{o}C to 23^{o}C respectively (James, 2008; NDES, 1997). The Niger Delta is the third largest wetland in the world (Uluocha and Okeke, 2004), has the most extensive mangrove and freshwater ecosystems in Africa (Ajonina et al. 2008) and is the most biodiverse area in Nigeria (Ebeku, 2004).

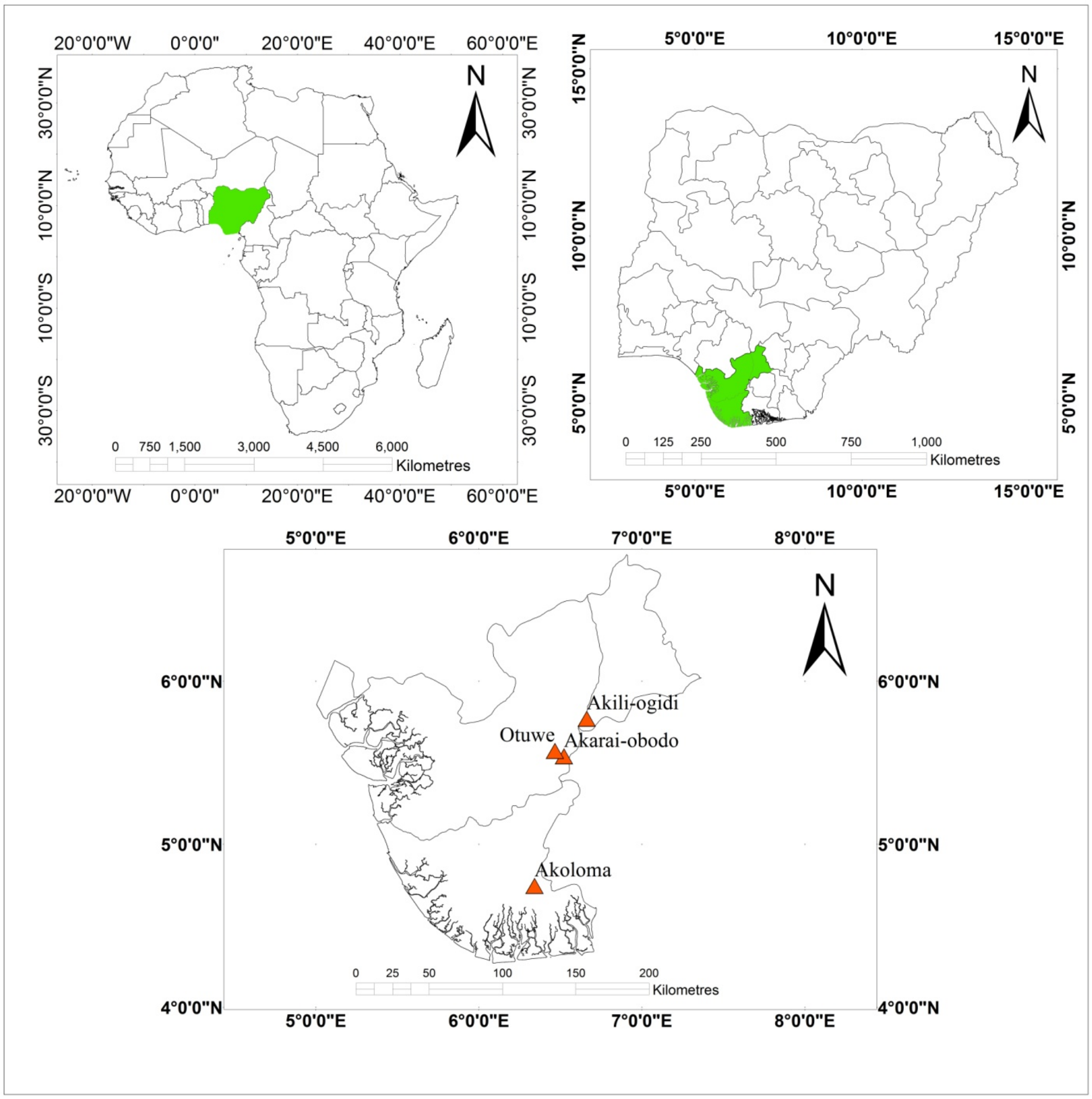

Fig 4.1 Map of the study sites

4.3.2 Data collection

The vegetation survey was conducted in four locations across the region (Fig 4.1). The first two sites: Akarai-Obodo (site 1) and Akili-Ogidi (site 2) are disturbed freshwater swamp forests, the third site (Akoloma) is a (secondary forest) freshwater-mangrove transition forest and the fourth site (Otuwe) is an intact freshwater swamp forest. Distance of the forest sites to the communities were used as a proxy for assessing the degree of disturbance for each of the study sites. A GPS was used to get the coordinates of the forest locations and that of the communities and was converted to distance in kilometres with Google earth pro. Palms were included in the survey as taxa since they occupied a great amount of space in forest locations and by implication, stored carbon in their biomass.

Twenty four, one hectare forest plots used for the survey were set up in the seasonally flooded part of the ecosystem between December 2013 and April 2014, when the flood water had subsided. Plots were placed 500m apart to ensure variation in floristic composition. All the 24 plots (4 – 8 plots) per site were placed along transects spaced 1km apart rather than random placement. This helped to ensure that consistency in enumeration was maintained across the plots. Sites in Akarai-Obodo and Akili-Ogidi had 4 plots each (two transects), while the plots at Akoloma and Otuwe were 8 each (four transects). The forest plots were then used for species identification and measurements across the ecosystem. All stems ≥ 10 cm diameter at breast height (DBH) were enumerated and identified to species level in the field with the assistance of taxonomists from the Forestry Research Institute Ibadan, Nigeria. Voucher specimens were collected for unidentified species and verified at the Forestry Research Institute Ibadan (Nigeria). Smaller tree stems were omitted in the inventory as they contained approximately 5% of above ground carbon (Lewis et al. 2009). Tree diameters were measured at DBH or above the buttresses if present. Stem heights were measured from the base of each tree to its highest point with a laser rangefinder and with a graduated pole where the tree was less than 10m, for which the rangefinder could not measure. Species identification was conducted by Michael Oladimeji, a taxonomist from the research institute and assisted by Peter Ige. Tree measurements and setting of the plots were conducted by Nwabueze Igu, with the assistance of Cyril Mama and Ifeanyi Iwegbue. The climatic data used were derived from WorldClim at the highest available resolution of 30^{ll} minute (Hijmans et al. 2005), while the data for future climatic scenarios were from AFRICLIM (Platts et al. 2015).

4.3.3 Quantifying above ground carbon

To calculate the above ground carbon of each of the stems enumerated, the taxon-specific average values of wood specific gravity (WSG) were first extracted from a global wood density database (Zanne et al. 2009). In situations where the WSG were not available for any species, the mean values of the genus or family of the closest taxonomic unit was used. Where these were not available, the average known WSG of the current plot was used. The WSG for palms is problematic because of their exceptionally dynamic structures (very large radial and longitudinal gradients in tissue density) (Rich, 1987; Baker et al. 2004) and so were calculated differently. To ensure consistency in the protocol of the sampling methods as well as to avoid overestimating the biomass, the mean WSG of Arecaceae across the tropics (0.55 g cm^{-3}) was used (in the absence of any available data from Africa) for all the palms. The biomass for each taxon was calculated using the WSG, height and DBH of each stem (Equation 1), according to Chave et al. (2014) pantropical equation. Equation 1 is given below as:

$$AGB = 0.0673 \times (\rho D^2 H)^{0.976}$$

Where AGB is the above ground biomass; ρ is the wood specific gravity (WSG; g cm^{-3}); D is the diameter at breast height (DBH; cm) and H is the height (m). Above ground carbon was calculated by multiplying the biomass by 0.5 with the assumption that 50% of biomass is carbon (Brown and Lugo, 1982; Chave et al. 2005; Kalaba et al. 2013).

4.3.4 Determinants of variation in AGC estimates

Multiple regression analysis was used to verify the different influences or contributions of the floristic composition (WSG) of the forests and their basal area to the total AGC of the ecosystem. In order to ascertain the relationship between the floristic composition of the ecosystem and the carbon storage, a linear regression was done. A two-way ANOVA was used to verify how the carbon storage of each forest category varied based on their diversity and stem density. Analysis of variance (ANOVA) was used to see how the AGC varied according to climatic influences: mean annual temperature and rainfall. Forest structural classes were classified as: smaller (10–20 cm DBH); medium (21-50 cm DBH); large (51-100 cm DBH) and largest (> 100 cm DBH) (Adekunle et al. 2013). Hochberg corrected alpha values (Hochberg, 1988) were used to correct for multiple testing (alpha [H] = 0.025). Confidence intervals (95%) were calculated through bootstrapping with (10,000) iterations. Statistical analyses were performed in R version 3.1.0 (http://cran.r-project.org).

4.4 Results

4.4.1 Above ground carbon estimates

The carbon assessments varied across the ecosystems, with the intact forest stands recording higher amounts than the disturbed forest stands/plots: intact forests (mean value of 228.28 t ha^{-1}); disturbed freshwater forests (mean value of 104.53 t ha^{-1}) and disturbed mangrove-freshwater forests (mean value of 100.69 t ha^{-1}). Bootstrapped confidence intervals (95% CI) which show the pattern of spread, hence provides a summary of the above ground estimates per forest category (Fig 4.2). The number of stems across the plots totaled 6477 trees and ranged from 94 – 506 trees ha^{-1} across the entire plots, while the number of species ranged from 4 – 46 ha^{-1} across the forest plots.

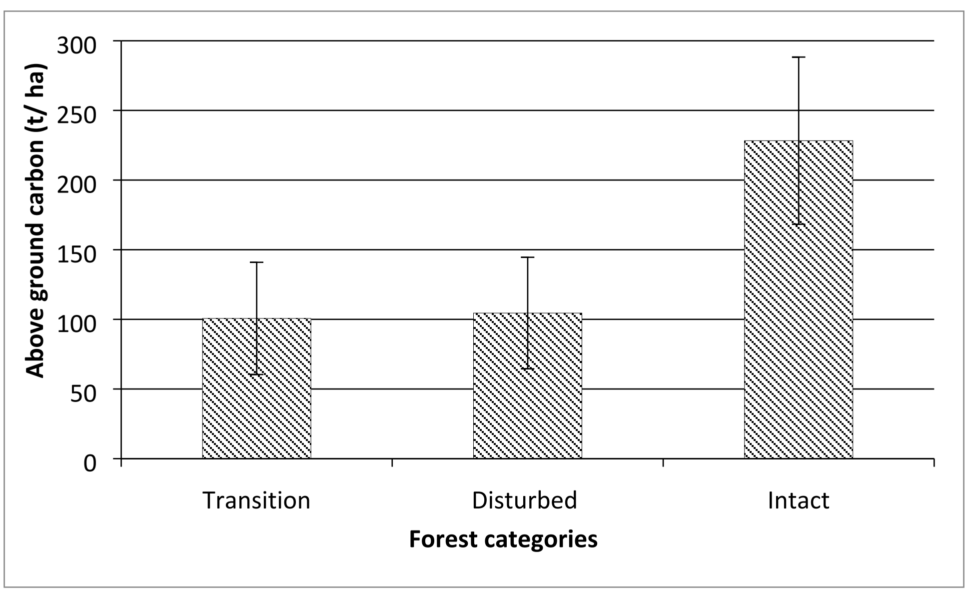

Fig 4.2 Mean ± 95% CI bootstrapped AGC of transition, disturbed and undisturbed (intact) forest categories

4.4.2 Determinants of AGC across the ecosystem

Estimates of AGC were different across the plots and forest categories as a result of the variations in the biodiversity, forest structure and climatic variables. Basal area of the stems and floristic composition were the main deteminants of the total AGC across the ecosystems: (F = 77.04 (2, 21), p adj < 0.001, Adj R^2 = 0.87). Though the floristic composition (t = 0.00989) of each forest group contributed to its total AGC, it was not as significant as that of the basal area (t = 4.32 x 10^{-11}). On the other hand, since the disturbance state of the forests (seen through their variations in basal area or stem size) had stronger influence, their composition were not seen to directly determine their carbon storage (F = 0.22 (1, 22), p = 0.65, Adj R^2 = -0.04, t = 0.47). The carbon storage of each forest category was varied due to their diversity (F = 20.86, p adj < 0.001; Fig 4.3) rather than according to their stem density (F = 0.58, p = 0.45). Climatic variables varied across the forest sites (F = 20.9, p adj < 0.001; 95% family-wise confidence levels): mean annual temperature range and mean annual rainfall range were 257- 268 ^{o}C and 2096 - 2448 mm, respectively. This was mainly from the mean annual temperature (F = 10.57, p = 0.004) rather than from the mean annual rainfall (F = 0.57, p = 0.46). Expectedly, the different forest categories varied in their AGC contributions (Fig 4.2), due to the varied basal area of the forest locations (F = 11.17, p adj < 0.001; 95% family-wise confidence levels) as well as their different structural class contributions (Fig 4.4). This variation in structural class contributions to AGC was most pronounced between the large and small stem intervals, being the highest and least contributors, respectively (Fig 4.5).

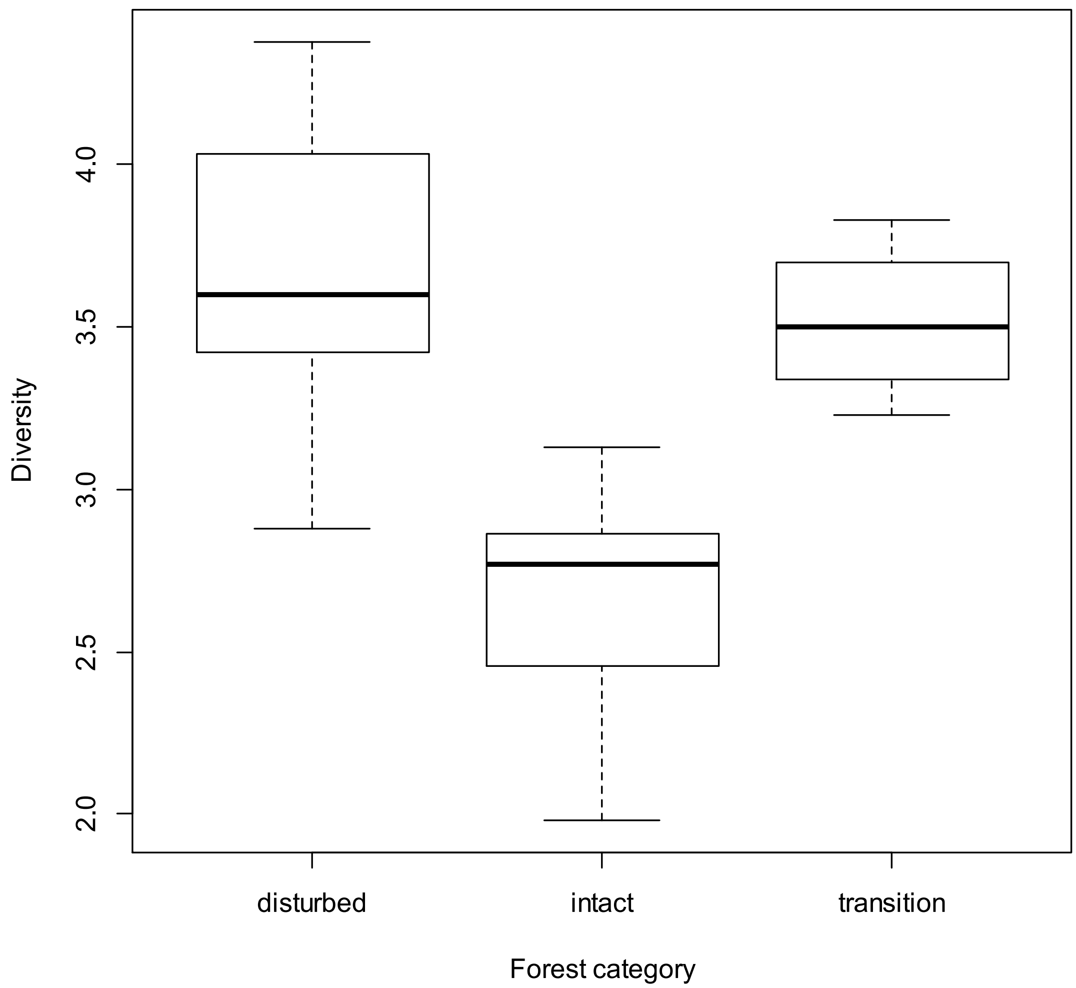

Fig 4.3 Diversity variations of the forest categories

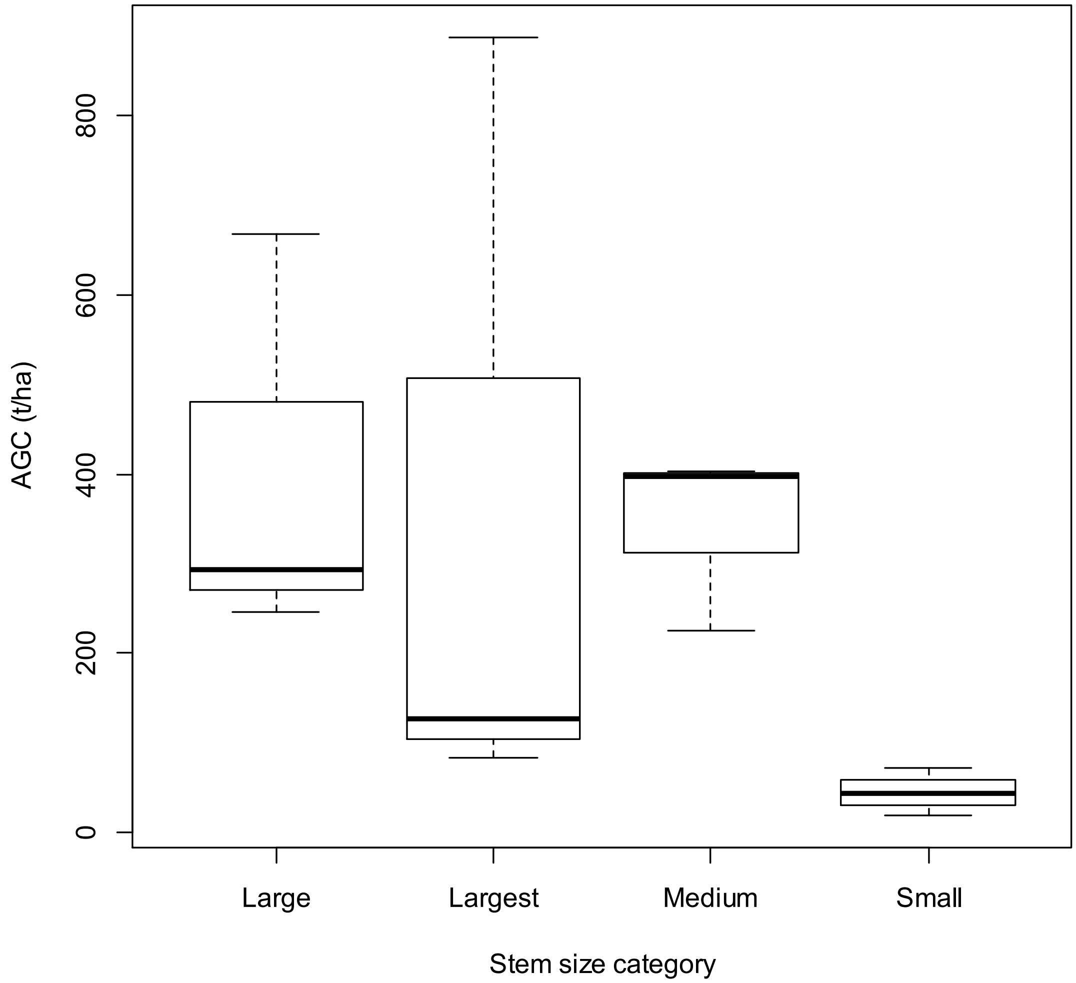

Fig 4.4 Variation in stem size contributions to total AGC across the entire ecosystem, where the stem sizes: small, medium, large and largest categories, represents DBH sizes, 10-20, 21-50, 51-100 and > 100 cm, respectively.

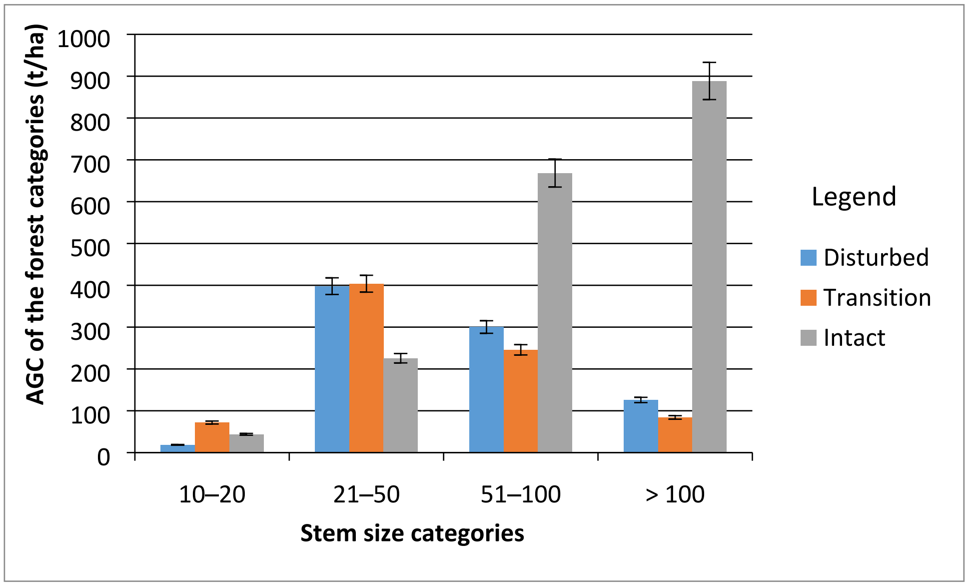

Fig 4.5 Contributions of the stem size categories to the AGC of the ecosystem per forest category

4.4.3 Floristic contributions to the total AGC of the forest categories

The variations in the floristic composition across the forest categories were assessed to document the contributions of each taxon to the carbon storage of the forest categories. *Elaeis guineensis* Jacq. had the highest AGC of 143 t and was followed by *Irvingia gabonensis* Baill. Ex Lanen*, Hylodendron gabunense* Taub. and *Treculia africana* Decne. ex Trécul (50.7t, 49t, and 44.5t respectively) (Fig 4.6) in disturbed forest category. In transition forest category, *Rhizophora racemosa* G. Mey had the highest total AGC (206 t) and was followed by *Elaeis guineensis* (165.8t), *Cordia* millenii Baker (87.7t) and *Irvingia gabonensis* (58t) respectively (Fig 4.7); while in the intact forests, the *Sterculia oblonga* Mast contributed the highest total AGC (898t), followed by *Sterculia rhinopetala* K. Schum (379t), *Diospyros mespiliformis* Hochst (201t) and *Celtis zenkeri* Engl. (106t) respectively (Fig 4.8).

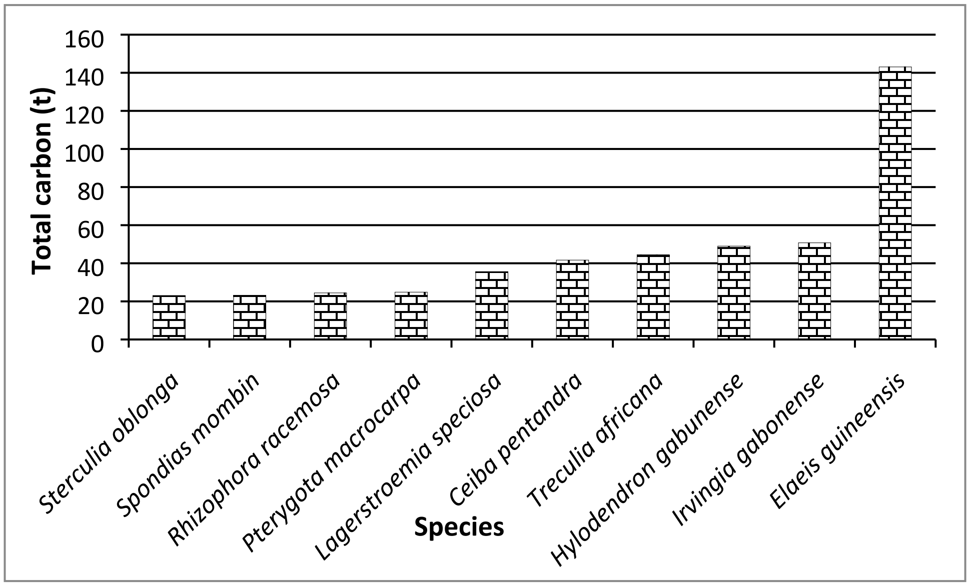

Fig 4.6 Ten species with the highest total AGC in disturbed forests

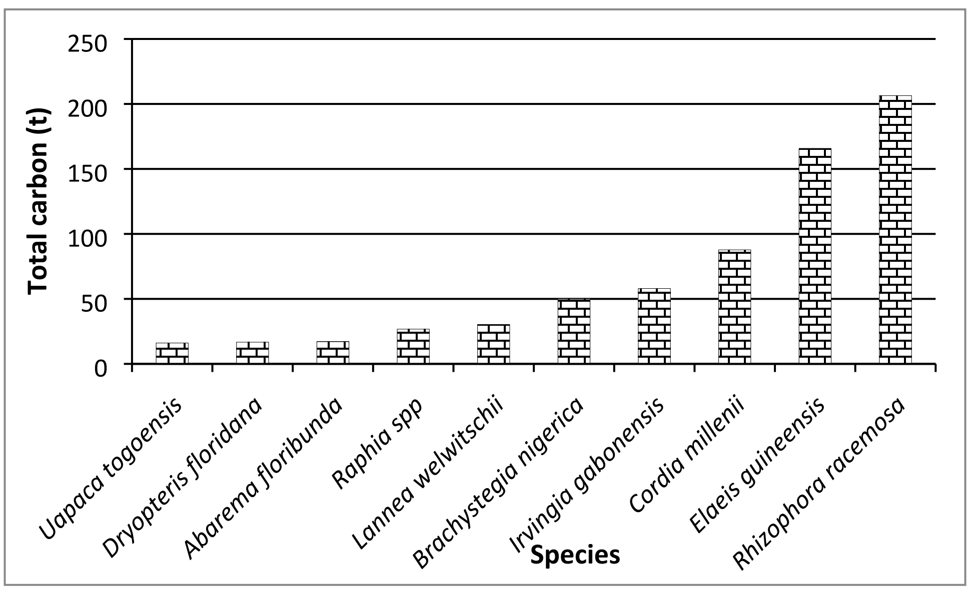

Fig 4.7 Ten species with the highest total AGC across the transition forests

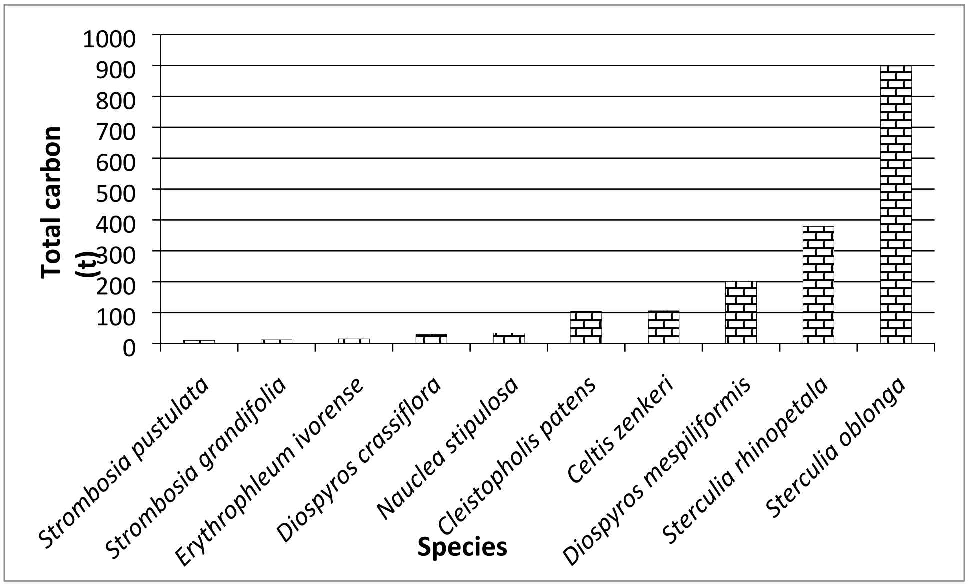

Fig 4.8 Ten species with the highest total AGC in intact forests

4.5 Discussion

4.5.1 AGC and its determinants

The results of the AGC estimates across the ecosystem for intact freshwater ecosystems showed that this ecosystem stores quantities of carbon that are comparable with the results from other intact forests in Africa: 202 t ha^{-1} (174–244) (Lewis et al. 2009) and 395 t ha^{-1} (Lewis et al. 2013). The degree of degradation of carbon stocks in tropical forests are dependent on the type of disturbance (logging, edge effects), the intensity and frequency of the disturbance regimes, as well as the time lag between the occurrences (Aragão et al. 2014; Berenguer et al. 2014). Since these ultimately affect their capacity to store carbon, the disturbed plots were seen to have significantly lower carbon stores compared to the intact plots. The disturbed freshwater forests and disturbed transition forests varied in their degrees of disturbance, with the latter being more disturbed, and recording a lower AGC. Though the pressures associated with the destruction of trees through biotic influences (from big animals such as elephants) seems reduced for the ecosystem, the disturbances associated with annual floods and selective logging still curtails the capacity to which the ecosystem could act as carbon store. In order to secure this important ecosystem service, forest disturbances should be tackled adequately across the ecosystem.

4.5.2 Climatic influences on AGC

Climatic variables (mainly temperature) explained the variations of AGC across the ecosystem. Since temperature affects a host of biological processes (Dillon and Frazier, 2013) and can determine to a large extent the survival, reproduction and persistence of species in certain locations (Angilletta et al. 2006; Sexton et al. 2009; Sheldon et al. 2015), as well as their physiology, life history and consequently their ecology (Sheldon and Tewksbury, 2014), it was seen to influence the AGC more than the moisture variables. However, the moisture regime was equally seen as an important factor, since rainfall patterns, timings, and amounts are vital determinants and drivers of ecological processes (Schwinning and Sala, 2004; Zeppel et al. 2008; Zeppel et al. 2014). Furthermore, the moisture variables and their varied patterns affect the plant growth patterns, mortality rates, local climatic patterns as well as soil-biogeochemical processes, carbon and water fluxes and the general land-surface feedbacks between vegetation, hydrology and climates (Adams et al. 2011; Zeppel et al. 2014).

Expected rise in mean annual temperature for the study sites for the (RCP4.5 pathway (for 2055 – 2085) scenarios and RCP8.5 pathway (2055 – 2085) showed an increase of 1.9 – 2.4 ^{o}C and to 2.6 – 4.1 ^{o}C, respectively. Furthermore, the temperature seasonality are expected to rise up to 0.15 – 0.18 ^{o}C (RCP4.5 pathway (for 2055 – 2085 scenarios) and a further rise of up to 0.18 – 0.28 ^{o}C (under the RCP8.5 pathway (2055 – 2085 scenarios)) are expected (Platts et al. 2015). The carbon sequestration capacity of the ecosystem is likely to be affected by such predicted climate shifts, even though there are huge uncertainties surrounding the interactions with the carbon sequestration of the ecosystem (Friedlingstein et al. 2006; Cox et al. 2013; Doughty et al. 2015). Since the temperature of the region will likely increase over the coming years and may result in saturation of the carbon sinks and eventual conversion of the ecosystem into a carbon source as seen in some tropical forests of Costa Rica (Levy, 2007), this could however be mitigated across the region (at the local scale) if effective forest-management strategies are designed and implemented. With varying models and debates still surrounding the issue of future forest carbon balance and magnitude (Bellasen and Luyssaert, 2014), attention should be given to developing effective region-specific and ecosystem resilient forest management strategies that would be suitable for the changes in the environment.

4.5.3 Floristic composition and structural influences on AGC

The forest locations were varied in their diversity (Fig 4.3) and their floristic composition at the plot and regional levels. However, this did not determine the capacities to which they stored carbon in their biomass. This further explained why plots and forest categories that had trees with higher WSG (example, the genus *Rhizophora*; mean WSG = mean 0.93 g cm^{-3}) did not necessarily have higher AGC t ha^{-1} stores. Since this was the case, the transition forest category which was dominated by such taxa did not have the higher carbon storage. It instead recorded the least AGC t ha^{-1} compared to the mean values found in intact forest locations and disturbed freshwater forest locations, which were dominated by the genus *Sterculia* (mean WSG = 0.60 g cm^{-3}) and *Elaeis guineensis* (mean WSG = 0.56 g cm^{-3}) respectively. The variation in the basal area across the forest sites and regions were the main reason for the varied mean AGC of the different forest categories instead of the WSG of the sites. The basal area of the forest plots differed among and between each of the forest categories due to the varied disturbance gradients of each of the sites. While edge effects and natural disturbances from the annual flooding of the ecosystem were responsible for the variations in basal area of the intact forest sites and in effect the total AGC ha^{-1}, selective logging and land use changes were the main issues for lower basal areas (AGC) of the disturbed forests.

Forest structure determines the net primary productivity and turnover of ecosystems (Marvin et al. 2014) and was found to be a major determinant of the AGC across the swamp forest ecosystem. Evidence from the study showed that the frequency of species occurrence were not the main determinants of total AGC of the forests, but their structural configurations. As a result, though the number of species of the smaller structural classes outnumbered those with larger structures as would be seen in most tropical forests, yet the fewer bigger structured trees contributed mostly to the AGC of each of the forest categories. This pattern whereby larger stems contribute mostly to the estimates of AGC across most of the forest ecosystems have been reported in other studies (Rutishauser et al. 2010; Baraloto et al. 2011; Marshall et al. 2012) and may explain the underlying focus of carbon estimation and conservation in intact forests.

4.5.4 Implications for carbon budget, forest conservation and climate change

Tropical forests are affected by a wide range of environmental and anthropogenic factors which directly and indirectly influence their carbon budget and potential as a global carbon store. While these influences affect the above ground carbon in inter-related ways and spatial scales, it has increasingly affected the carbon sinks due to human modifications which have degraded the ecosystem. As the rate of forest degradation through selective logging increases throughout the tropics (Asner et al. 2005) with a consequential loss in the biodiversity, it has become imperative to understand the carbon budget of different regions and ecosystem types. With the apparent decline of the forest cover and land use changes in the tropics, concentrating conservation and management efforts only on the intact forests which no doubt have larger biomass and carbon budgets seems elusive, as tangible alternative sources of livelihood are not yet at sight for the vast majority of the forest-poor dependent populace.

Even though the capacity of forests to store large quantities of carbon are higher when undisturbed, and losses much greater carbon when the forests become disturbed (Luyssaert et al. 2008), the potential for such disturbed ecosystems to still act as carbon sinks and stores of biodiversity are substantial. This potential could be further realised through reforestation and forest restoration (Silver et al. 2000; Sasaki et al. 2011) of such disturbed ecosystems. Although the effectiveness of such strategies depends to a large extent on the management of such forest lands, supporting such techniques with alternative sources of livelihood and fuel will enable greater carbon biomass accumulation for such landscapes to become a reality. Efforts towards effective forest conservation and stronger management regime have become imperative, particularly as most of the remaining intact forests in the Niger Delta are owned and managed by individuals. Such measures will help to ensure that the rate at which such forest landscapes are exposed to edge effects, fragmentation, degradation from adjacent agricultural activities, land tenure and population pressure becomes reduced.

With the total net carbon emission from tropical deforestation and land use at 1.0 Pg C yr^{-1} (2000–2010; Baccini et al. 2012) and an ever increasing degradation of tropical forests (Asner et al. 2005; 2009), efforts towards increasing the carbon sink of tropical forests should not be targeted only on primary forests. Since secondary and degraded forests equally contribute to the overall carbon budget, their potentials should be harnessed as well. The analyses demonstrates the wide margin (more than 50%) between the amount of carbon from intact forests and that from disturbed forest tracts. With this in mind, there is then every need to conserve the remaining intact forests not just in the Niger Delta, but generally across the tropics, since forest degradation not only affects the carbon budget of the tropical forest ecosystem, but also other important ecosystem services (Seidl et al. 2014; Lewis et al. 2006), the local climate (Chagnon et al. 2004) and the biodiversity (Reid et al. 2005) of the ecosystem.

4.6 Conclusion

Freshwater swamp forests are important carbon stores comparable to other tropical forest ecosystems. Their capacity to provide this increasingly vital ecosystem service is dependent on the disturbance regime of the forest in its intact, disturbed and transition zones. With variations in basal area as well as the floristic composition of the different zones, their capacities to store carbon were seen to vary. Climatic influences varied across the ecosystem and were responsible for the variations in the carbon store. With an expected change in the climate of the region, the capacity of the ecosystem to act as a carbon sink remains uncertain. Efforts that will promote effective forest management for the ecosystem are advocated, in a bid to both promote biodiversity conservation for the ecosystem as well as its carbon stores.

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Chapter 5 – Patterns of freshwater swamp forest use and degradation

5.0 Patterns of freshwater swamp forest use and degradation in the Niger Delta

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5.1 Abstract

Forest ecosystems are increasingly seen as vital resources and elements for the sustenance of households across rural landscapes in tropical regions. However, the dynamics surrounding the forest use and consequent degradation are poorly understood. In West Africa, these relationships are a serious challenge to the management and sustainable use of freshwater swamp forest. This study presents a detailed examination of the determinants and socio-ecological processes of forest use from 243 household surveys within 12 communities across the Niger Delta region. A socio-economic model of the levels of importance and dependence on the ecosystem for different provisioning services was produced. I also assessed variation in current and past use of the ecosystem and furthermore analyzed the influences of spatial distance (from household to forests) on their level of use. The results showed that the communities derived a major part of their sustenance from the forests and frequently used the forests for varied purposes. However, since some households had other non-forest related sources of livelihood (such as civil service), forest distance only mattered to those whose livelihood depends totally on it and who were found to defy the constraints associated with the swamp terrain to source their livelihood and income. The socio-economic status of each household influenced their degree of dependence and the importance they attached to each of the forest resources. Since the communities varied in their levels of remoteness, availability of alternative sources of livelihood and resources (crude oil presence), their use of the forests equally differed. With little or no understanding that the forests serve other ecosystem functions, they are being exploited mainly for sustenance (provisioning service) across the region, as in most other tropical regions. This explains why most tropical forest ecosystems are undergoing different scales of degradation, without user consideration of resilience, livelihood implications of resource depletion or sustainable forest use.

Keywords: ecosystem services, environmental income, livelihood, sustainability

5.2 Introduction

Tropical forest ecosystems are host to a rich assemblage of species and provide a wide range of ecosystem services such as food, medicines, building materials, shelter (Lawrence et al. 2005; Reid et al. 2005) and store houses for carbon (Houghton, 2005; Pan et al. 2011; Lewis, 2013). These enormous resources provide a wide range of benefits to the African populace whose subsistence and livelihood are to a large extent dependent on the forests (CIFOR, 2005; Norris et al. 2010; Bromhead, 2012). As these forest resources continually sustain the rural poor communities by providing an important “safety net” of food (Bromhead, 2012), they equally contribute to the economy by providing employment in the forest sector and so provide a basis for diversification in forest-based enterprises at different scales. Although rural households generate quite a lot of “environmental income” (either as cash or subsistence) from the forests, its benefits are not only used to meet their immediate needs, but helps them not to slack into (deeper) poverty (during bad harvests or between agricultural harvests (by filling the seasonal gaps) and also to step out of poverty (Angelsen and Wunder, 2003; McSweeney, 2004; Wunder et al. 2014). Hence, these forest resources have not only supported households that are mostly engaged in farming activities (as seen in most rural African setting), but also, provided platforms for continual co-existence and subsistence. Even though the African forest ecosystem is known to achieve the afore-mentioned for many households, little is known about the existing relationships between freshwater swamp forest use and degradation across the West African region.

Indeed the freshwater swamp forest ecosystems are not only poorly understood, estimated and studied, but are largely unexplored as regards their use, potentials and ecological processes. Though this fragile but beautiful landscape supports the livelihood and economy of the forest dependent communities with its high value timber, other forest products, fertile soils and vast potentials, it has largely remained unexplored and documented. With the tightly socio-ecological system and processes of forest ecosystems across the region (Norris et al. 2010), it has become imperative that how these relate to and affect the freshwater swamp forest ecosystem is explored and elucidated. As this ecosystem remains both a centre-piece and pivotal resource base for the sustenance of households across the Niger Delta region, exploring its use dynamics are both important in achieving sustainability of the ecosystem to the people and maximizing its potential in climatic regulation and ecosystem stability of the West African region. This study aims to explore the dynamics of forest use across the freshwater swamp forest ecosystem. Specific objectives include: 1) to elucidate the determinants of forest utilization across the forest region, 2) to determine the extent to which the populace depends on the ecosystem, and 3) to highlight the constraints surrounding the use of the ecosystem and how it affects their livelihoods and 4) to relate the findings to that of other (tropical) forested landscapes and provide insights on effective management strategies.

5.3 Materials and methods

5.3.1 Study area

5.3.1.1 Niger Delta environment and people

The Niger Delta is a generally flat, low-lying sedimentary basin located in southern Nigeria, drained by the Niger River and criss-crossed by a network of rivers, streams and creeks which drains into the Atlantic Ocean at the Bight of Biafra (Fig 5.1). Broadly made up of marine sedimentaries of Lower and Upper Cretaceous age (Akintola, 1982), it is a swampy region with mainly medium to coarse unconsolidated sands, silt, clay, shale and peat. The region is characterized by a tropical climate with long rainy season mainly from March/April to October. The flood regime starts in August, peaks in October and tapers off in December. The wet season lasts nearly throughout the year; the wet season peaks in July and the dry months are mainly between Decembers to February (Hughes and Hughes, 1992). Relative humidity rarely dips below 60% and fluctuates between 90% and 100% for most of the year, with average monthly maximum and minimum temperatures varying between 28^{o}C to 33^{o}C and 21^{o}C to 23^{o}C respectively (NDES, 1997; James, 2008).

The region represents about 12% of Nigeria's total land surface area and supports 31.2 million people who account for 25% of Nigeria's population (NPC, 2006; UNDP, 2006). It is made up of more than 40 ethnic groups that speak more than 250 dialects and has a rich cultural heritage (Jike, 2004). These ethnic groups are broadly classified into five major linguistic categories: the Ijoid, Yoruboid, Edoid, Igboid and Delta Cross; with each of them embracing an enormous mix of ethno-linguistic settlements (Watts, 2004). The settlement of the region is made up of predominantly rural populations who live in dispersed settlements and have cultural attachments to the environment. With the availability of dry land determining the settlement pattern across the region, many of the larger settlements are found in the better drained and accessible interior parts, while the low relief and poorly drained locations supports the vast majority of small and scattered rural settlements (UNDP, 2006).

5.3.1.2 Freshwater forest ecosystem and resources

The forest ecosystems in the Niger Delta differ from each other on the basis of varied floristic composition, hydrology, soil and topography and are mainly grouped into mangrove and coastal vegetation (brackish water swamps), lowland rain forest and freshwater swamp forest. Covering about 17,000 km^2 or about half of the delta region (UNDP, 2006), the freshwater swamp ecosystem of the Niger Delta are unique and represent an important biodiversity area (Happold, 1987; Hilton-Taylor, 2000; UNDP, 2006) not only for the local environment and the Nigerian state but also for the west African region. This important ecosystem which is concentrated in the Delta region is a flooded forest with varied ecology, biodiversity and potentials. Driven by hydrology, three zones are found in the ecosystem: the flood forest- which has large sand river channels and creeks- both permanent and seasonal; the marsh forest- which flanks the delta in the east and declines westwards, permanently swampy and under the influence of 'black flood' from the rains; and the relatively stable delta fringes which is associated with creeks that bar the flood and tidal influences (NEDECO, 1996; Powell, 1997; Were, 2000; James, 2008).

The freshwater swamp ecosystem is located between the lowland rain forest to the north and the mangrove swamp forest to the south; providing a transition zone between the two ecosystems and a corridor for the migration of flora and fauna. It is the region's main source of timber and forest products, and habitat for endangered and rare wildlife (UNDP, 2006). It has vast potentials for fishery across the region, a seasonal nursery for fishes especially during the floods and a major habitat for crayfish, prawn, crabs and crocodile. The fertile silt soils which are enriched from annual floods, have great agricultural potentials both for the region and the Nigerian state and have been a major attraction for migrant farmers long before the advent of crude oil in the zone. The region is notable for its vast quantities of oil and gas reserves of reputable quality; which has been the economic mainstay of the Nigerian state.

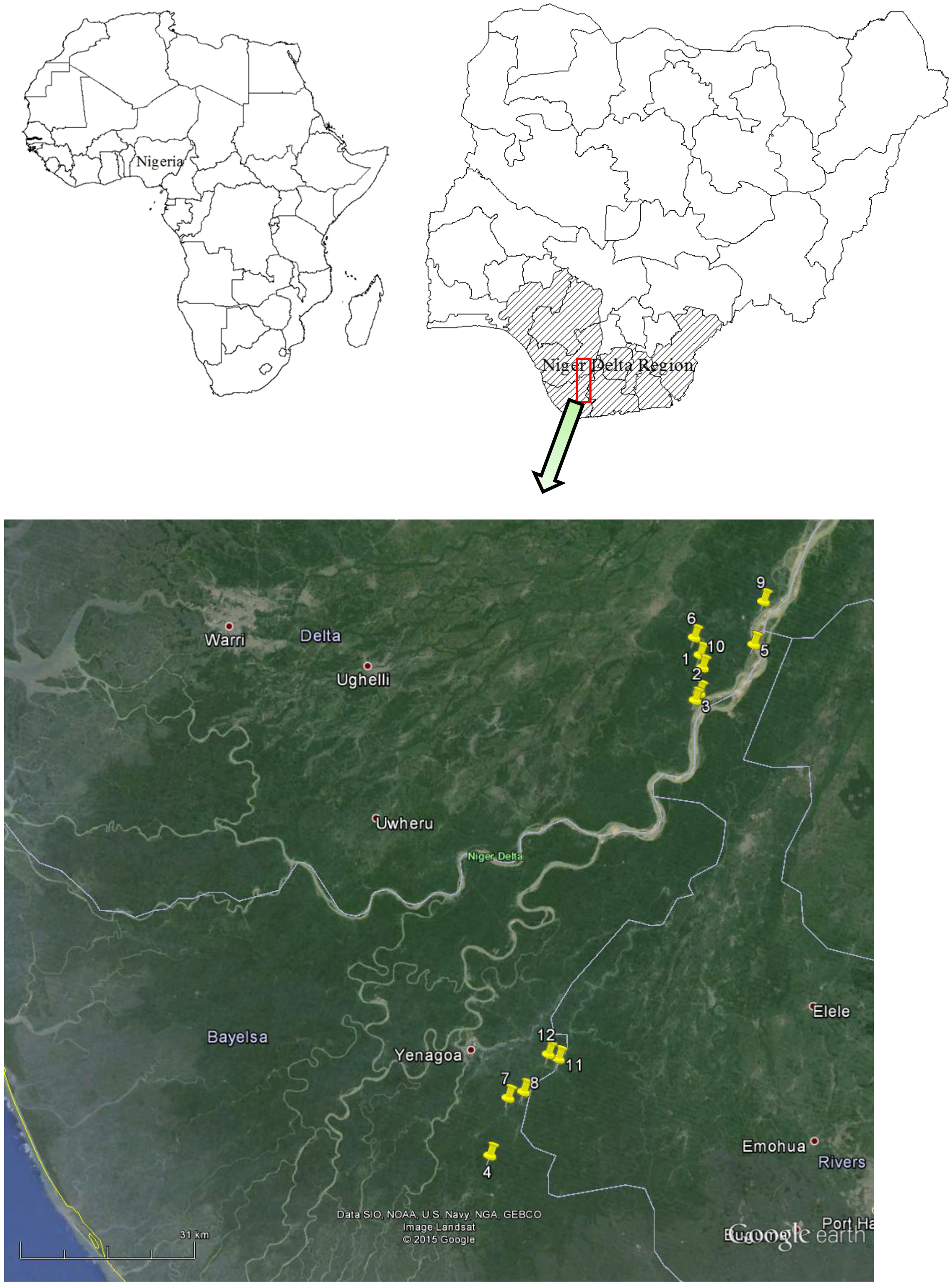


Fig 5.1 Map of the Niger Delta region showing the study settlements

5.3.2 Questionnaire design and data collection

A semi-structured questionnaire (Appendix 6) was used to gather information from households (defined as a person or group of people who live together, and depend on each other to meet their daily needs) across 12 randomly selected forest settlements in (Delta and Bayelsa states) the region (Fig 5.1). Reconnaissance survey was initially conducted across the Niger basin where the freshwater swamp forests are located/concentrated (Fig 5.1), and used to identify and note the existing rural forest landscapes. Futher consultations with the leaders of the various settlements helped in deciding on the settlements that captured a wide range of indices. The questionnaire was designed following reviews of forest ecosystem use, management and degradation across the region (World Bank, 1995; NDES, 1997; UNDP, 2006; James, 2008; Adekola and Mitchell, 2011; Irikana, 2011; Onojeghuo and Blackburn, 2011). Pilot study was initially conducted across the settlements and discussions held with key informants (community leaders, professionals and old residents) on the contents of the survey. This helped to ensure that the issues raised were both applicable to the people and understood as well. A random sampling was then conducted across the forest settlements (Fig 5.1) using households in each of the locations.

Each of the settlements were stratified into four spatially distinct clusters to enable better coverage of the localities, then for each of the clusters, the first household was visited and every fourth household used subsequently. This helped to eliminate bias of choice, and also enabled variation of views based on the socio-ecological and economic variations inherent in each of the settlements, to be captured. The different settlements used for the study were selected to capture the variations in resource availability (crude oil presence/absence), remoteness, accessibility and alternative sources of livelihood (besides forest-based activities); and how these affected or influenced forest use across the region/ecosystem. Since the sizes of the settlements (population and household units) surveyed were not even, the number of respondents from each of the settlements varied accordingly, but ensuring sufficient sample size for analysis (minimum [12] samples per settlement). The study was conducted between October 2013 and April 2014 and covered 243 households across the region.

5.3.3 Data analysis

To understand variation in forest use, I used the Kruskal-Wallis rank sum test to test variation in household (indices: ranking on the levels of importance of the forests and levels of remoteness) [between] settlements. Wilcoxon rankings were used to determine differences in the indices surrounding access to forest resources and services reduction. In order to understand the existing relationship between forests' use (number of forest visit) and distance to household units, a linear regression was conducted and how the use varied shown with the analysis of variance output. Because of our clumped study design, due to limited accessibility, forest distances were categorized into: forests within the neighbourhoods (0 – 1km); forests beyond the neighbourhoods but within the villages (> 1 – 5km) and forests far from the villages (> 5km).

To verify if the people's socio economic status influenced the extent to which each of the provisioning services of the forest ecosystem supported their livelihood, a spearmank rank correlation was conducted. The provisioning services (food [forest fruits, nuts and vegetables], fuel wood, wood [timber], grazing land, medicine/herbs, bushmeat/game, fishery, snails, and composting) were categorized using Likert scale according to their levels of importance (from its least value of 1 to its highest importance value of 5) to the people. The socio-economic status used were the people's full time occupation (which included both forest and non-forest related jobs).
All the analyses were conducted with R statistical software version 3.1.0 (http://cran.r-project.org).

5.4 Results

5.4.1 Forest use dynamics

The forests were generally very useful across the entire region, as the different communities were seen to depend on it (high levels of importance) to meet their needs on more regular occasions (Kruskal–Wallis $\chi^2 = 104.10$, $p < 0.05$; Fig 5.2).

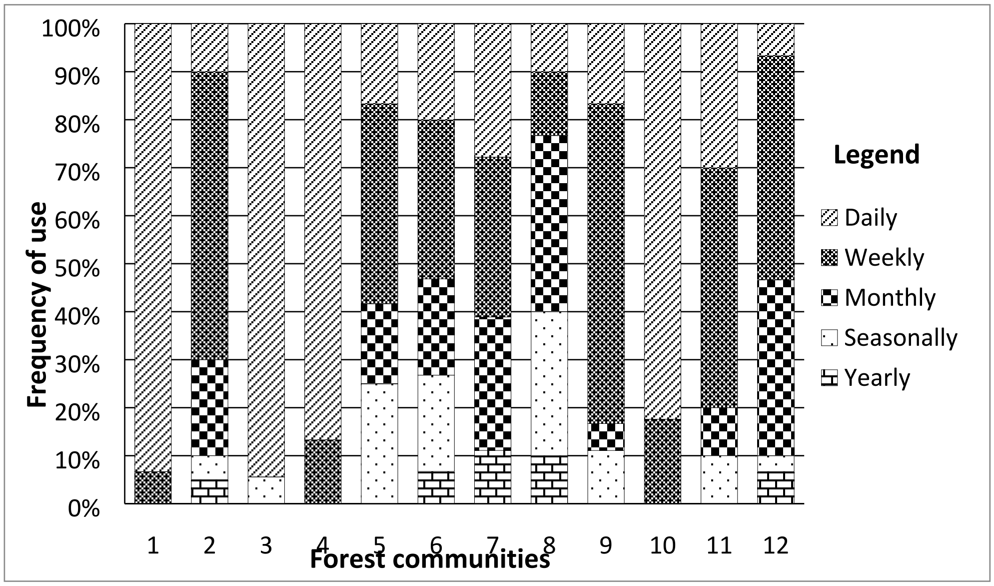
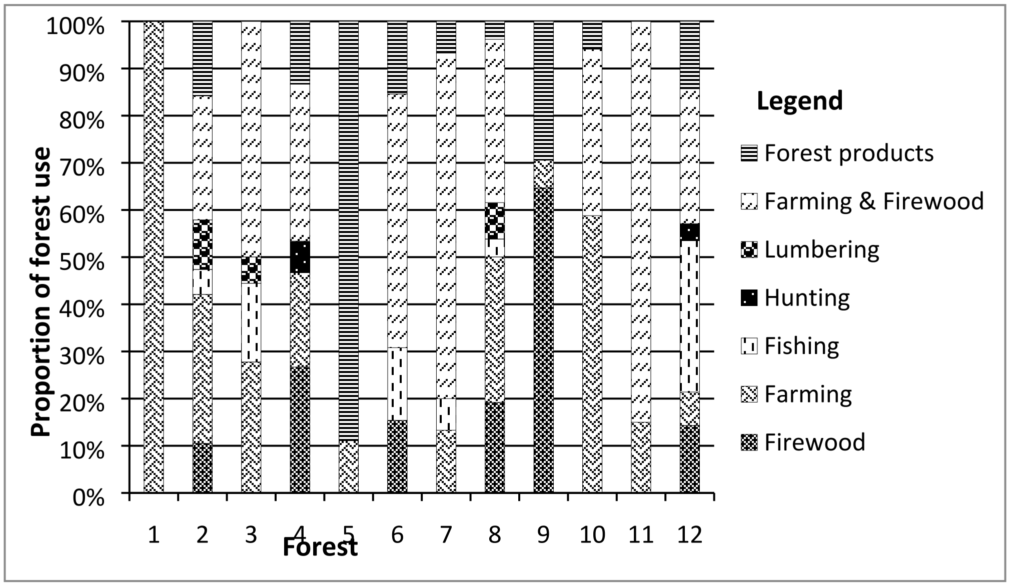


Fig 5.2 Frequency of forest use/visit

Since the communities differed in their remoteness, they equally varied in their needs for the forests (Kruskal–Wallis $\chi^2 = 43.08$, $p < 0.05$). However, since they generally depend on the forests to meet most of their needs, they visited the forests more frequently (Fig 5.2) mostly due to reasons associated with their daily sustenance (farming [22.6%]; forest products [11.9%]; fire wood gathering [11.5%]; fishing [7.8%] as well as for multiple or combined reasons (farming and fire wood collection [34.6%]; Fig 5.3). This quest to satisfy their needs for sustenance, which generally influences their current use of the forests are somehow not different from the fundamental use of the forests in their past ((Kruskal–Wallis $\chi^2 = 11.18$, $p = 0.43$; Fig 5.4).



Forest products included vegetables, fruits and nuts

Fig 5.3 Varying forest uses across the forest communities

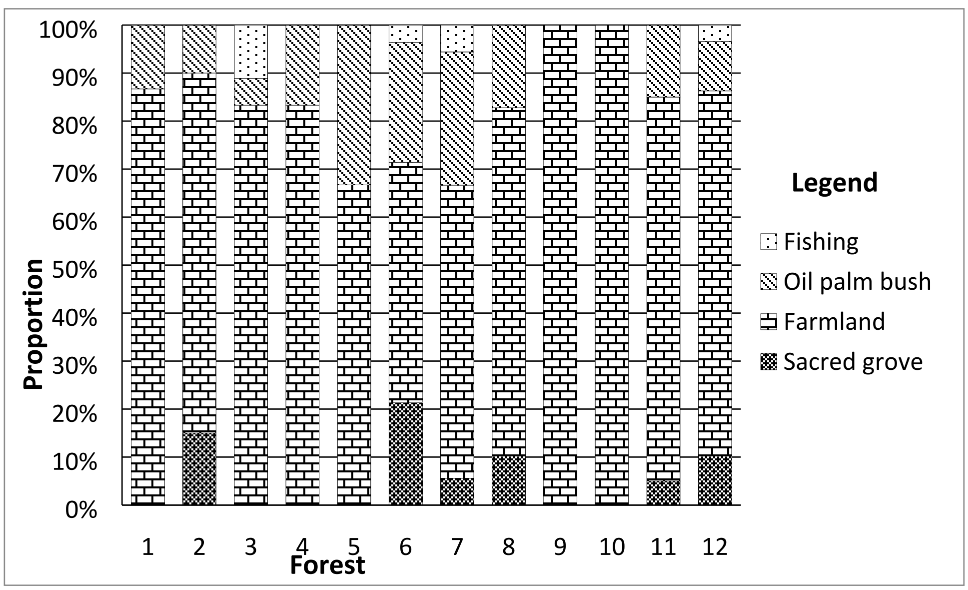


Fig 5.4 Patterns of forest use in the past across the forest communities

5.4.2 Forest products/services loss and responses

Due to the nature and myriad of activities ongoing across the forest communities, the forest products were found to be reducing drastically across the forest communities (Wicoxon W = 2820, $p < 0.05$). This reduction in resources were varied across the forest communities ((Kruskal–Wallis $\chi^2 = 33.72$, $p = 0.0004$) due to direct and underlying causes (Fig 5.5) in different proportions and furthermore, due to lack of individual commitments to the preservation of the forest resources (W = 4920, $p < 0.05$) across the region.

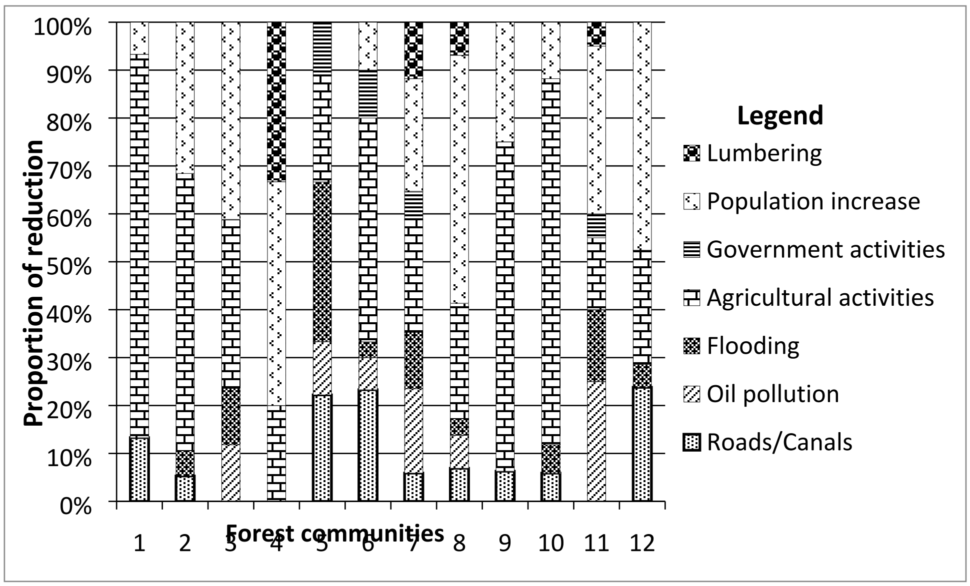


Fig 5.5 Reasons for forest products reduction across the forest communities

5.4.3 Determinants/patterns of forest use

Distances between the dwelling units and the forests were found to influence their use of forests across the region ($F(3, 239) = 8.76$, $p = < 0.05$) accordingly: forests within the neighbourhoods, within the villages and far from the villages ($F = 13.29$, $p = 0.000328$; $F = 9.15$, $p = 0.002762$; $F = 3.83$, $p = 0.051376$, respectively). Though the levels of importance differed with distance across space, the forest units were generally useful to the people from one location to the other.

Generally, the different forest resources were important to the people, as the people were found to utilize or depend on them to sustain their livlihoods. Socio economic status only partly influenced their dependence on fishery (rho = -0.19, p = 0.0029), as against other provisioning services that were not significant.

5.5 Discussion

5.5.1 Forest utilization

The Niger Delta ecosystem provided forest products (such as food, medicines, protein sources – fishes and game and building materials) as seen in most other forest-community landscapes (Lawrence et al. 2005; Lewis, 2006; Shackleton et al. 2007; World Bank, 2008). Hence, the forests were used frequently by the people for sustenance and sources of livelihood (Fig 5.2). However, with varied communal-individual preferences and needs, the uses of the forests for different purposes varied across the communities. While some of the people across the forest communities utilized the forest resources by harvesting what they needed, others were constrained to buy them from the markets due to the scarcity of the forest products or lack of time to harness them. Similarly, forest products were used as avenues for sustenance and sources of livelihood for some fraction of the populace who used proceeds from its sale in the market to meet other needs.

This quest for sustenance has remained the central focus of forest use across the region over the years and may likely remain the same since neither their lifestyle nor their economic well-being has changed. Hence, logging of forests to facilitate agricultural activities, oil palm production and fishing (Fig 5.4) were seen to dominate the forest use. With the variation in perception and dependence on the forest in absolute terms for the provision of vital services, the ecosystem's forest and rural landscapes are expected to experience degradation at different spatial scales.

5.5.2 Patterns and determinants of forest use

The freshwater swamp forests were important for the existence of the forest communities and were the mainstay of their sustenance and livelihood. This may be partly because there are no wide gaps between the wealth of the people, as those that had higher degrees and were engaged in non-forestry related jobs like civil service, still depended on the forests to meet some of their needs. Such individuals maximize the use of the forests for the provision of nutrition (fruits, vegetables and nuts), fuel and forest land for subsistence agriculture. This enables them to channel their income to meeting other needs like clothing and family maintenance and in effect augment or make up for their low earnings. Since most of the people are indigenes of the communities, they had access to family lands and either lived in their own houses or family houses. Such dwelling units equally afforded them the convenience and opportunity to process harvested forest products and to use fuel wood in cooking.

Though there are no supposed restrictions on forest use across most of the communities, non-indigenes tends to be be free and able to utilize it the longer they spend and become integrated into the society. These few migrant populations are mostly in the communities as civil servants or teachers, traders and short term contract workers (which are mostly better socio-economically than the indigenous people). Such fraction constitute the bulk of the people whose household income could afford them other sources of protein (such as meat and dairy products) apart from fishes sourced in their environment and options of buying forest products (including fishes) from the market as well. Higher levels of education are supposed to generally reduce forest dependency (Mamo et al. 2007) (by opening up other opportunities) as well as the use of fuel wood (as the time spent collecting them are both unprofitable and higher in opportunity costs) (Adhikari et al. 2004; Coulibaly-Lingani et al. 2009). However, as most of the people do not have the (better) employment which their educational status are supposed to offer them due to the high unemployment rates in the region (UNDP, 2006), it becomes difficult to absolutely depend on it as an index for socio-economic status across the region.

Households and individuals with full time occupations equally utilized the forests as sources of some of their needs, though not at the same scale with the general populace. While such households with other alternative sources of livelihood tended to use the forests at a lesser proportion, other indices such as household size and family needs also shaped their ultimate dependence pattern. Hence, as it is common to find families with so many children to feed or extended families (living with them) to take care of across the region, people that had jobs that could take care of their needs still relied on the forests to provide for their households. These additional burdens affect both the indigenous and migrant households, and have contributed to the degradation of the resources.

Forests found within their neighbourhoods were considered to be more important and useful compared to those more distant to their neighbourhoods. While this (distance to forests) may be considered a common phenomenon of forest use (Mamo et al. 2007; Brown et al. 2011), its application to the swamp forests are both contextual and specific. This is so because, the very rainy and swampy nature of the communities were found to constrain forest resource use among the people. Such scenarios lead to loss of forest resources, as the inability to harvest the vital forest products (due to longer rains and flood) leads to their rot and decay for greater times of the year. As a result, only forests locations that are easily accessible are utilized for a greater part of the year. This model of forest use is however not adhered to strictly by some of the people that depend on certain forest products to generate income and sources of livelihood for their families. As most of these resources are scarce in nearby forests, these fewer group of people for whom forest distance is not an issue, utilize short breaks in rain to access the distant forests and so act as agents of degradation in the distant (more undisturbed) forests long before the general populace.

5.5.3 Forest ecosystem services reduction and responses

The causes of loss and reduction of ecosystem services are varied at different spatial scales across the communities (Fig 5.5), mainly due to underlying factors such as agricultural activities and population increase. As the population of the region grows, efforts to harness forest resources are intensified and as a result, most of the forest products are overexploited at non-resilient scales. While this pressure and consequent depletion of forest resources are mainly as a result of varied and increased demands from a growing population (Dubey et al. 2009; Misra et al. 2014), it is equally as a result of the shallow understanding and perception of forest use and service across the region as in most African communities. As the communities know so much about what they could get from the forest ecosystem in terms of provisioning services and little or nothing about the capacities of the forests to provide regulatory and supportive services, it affects both the way they relate with and use the swamp forests. Hence, the capacity of the swamp forests to continually sequester carbon and regulate the climate of the region is continually impeded by the people who have been focused on short term and immediate benefits from the ecosystem.

On the other hand, as agricultural activities are continually seen as a better (income yielding) alternative to the forests, it has remained the major threat to harnessing the full potential of the freshwater swamp ecosystem. Such agricultural activities (which have mainly been in the form of plantain and oil palm plantations) have no doubt sustained the different households. However, it has promoted reductions in the biodiversity, led to large-scale environmental degradation, resulted in a net loss of carbon emissions and reduced the carbon storage in the ecosystem (Koh and Wilcove, 2008; van der Werf et al. 2009; Morel et al. 2011; Koh et al. 2011).

As the forest ecosystem continually becomes degraded, the associated consequences are not only seen in the loss of ecological services (such as the biodiversity and watershed protection), but equally affects the forest-dwelling people who continually lose their means of existence (Lamb et al. 2005). Since these reductions are likely to impact the livelihoods of the rural poor mostly, alternative sources of livelihood and proactive steps towards sustaining the ecosystem are advocated.

5.6 Conclusion

Swamp forest ecosystems are important in meeting the needs of people who depend on them to sustain their needs and household livelihoods. The extent to which the populace depended on the ecosystem to provide vital resources and income were shaped by the socioeconomic well-being. Since the people’s needs, household size, occupation and levels of education differed, so did their utilization of the forests. Constraints associated with the swampy terrain and distance to the forest locations only deterred those whose livelihoods were not absolutely dependent on the forests from harnessing the resources. With the intensity and trend of anthropogenic activities ongoing in the Niger Delta, the freshwater swamp forests, as well most other tropical forest ecosystems are threatened with extinctions and potential collapse. Achieving forest conservation and sustainability across most tropical regions has not been effective due to the absence of all-inclusive forest conservation strategies that considers the people’s social interests. Implementing such efficient steps will help promote forest resource management and use across the ecosystem.

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Chapter 6 – Ecosystem services at the cross-roads

6.0 Ecosystem services at the cross-roads: the carbon potential of freshwater swamp forests in the Niger Delta and its associated determinants

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6.1 Abstract

Carbon storage in terrestrial ecosystems, mostly tropical forest ecosytems are important for global biogeochemical cycles and climate change modulation. Even though tropical forests are carbon dense and its storage capacity is critical, the extent to which this is influenced by human forest use and management (especially for the freshwater swamp forests) is poorly quantified. This study utilized the results of a taxanomic inventory from 16, one hectare forest plots divided evenly across four forest sites in the Niger Delta to estimate their above ground carbon (AGC). The results were compared with results from interviews (targeted at the community leaders, aged individuals and other key informants) on forest management, use and ownership, in order to assess the linkages between AGC and forest management. The capacity to which each of the plots stored carbon in its biomass varied (and decreased) from plots found in locations with least frequency of forest use and dependence to the ones that were used more frequently (mostly on daily and weekly basis) as sources of livelihood and sustenance. Forest units under communal management had restrictions to forest use and presents possibilities of regulated resource exploitation and AGC. The forests were used across the locations for different purposes such as farming, sources of timber and non-timber forest products, hunting and fishing. While these vital needs are important components for the livelihood support of such rural landscapes, they were however exploited by its owners at the expense of other long term benefits (as potential carbon stores). Ensuring that tropical forest landscapes are jointly managed and conserved will not only assist in preserving its biodiversity, but also promote and facilitate greater carbon storage across tropical forest ecosystems.

Keywords: forest carbon, forest resources, mangrove transition, modified ecosystems

6.2 Introduction

Tropical forest ecosystems are hosts to rich biological diversity and critical for global carbon storage and climatic processes. While tropical forests are known to store as much as 40-50% carbon in its terrestrial vegetation, the contribution of the African forests to this trajectory only started receiving attention more recently (Lewis et al. 2009). Such insights will become more beneficial with more improved and specific assessment of the different forest types within the tropics, especially those ones (such as the freshwater swamp forests) for which much is not known. Freshwater swamp forests supports high levels of important biodiversity for which the Niger Delta is renowned. Located between the mangrove swamp forest and the lowland forest ecosystems in the region, freshwater swamp forests provides a corridor for the migration of flora and fauna between the ecosystems and is floristically varied from the other ecosystems. Swamp forests contributes to the provision of ecosystem services across the Nigerian state and like other tropical forests, are potential stores of carbon and important for climate regulation and biogeochemical cycling (Lewis, 2006; Keith et al. 2009; Lewis, 2013; Cavaleri et al. 2015). Supporting the majority of households across the region that depend on it for subsistence and livelihood (UNDP, 2006), swamp forest has provided a resource base over the last 400 years (Fund, 2014). However, this ecosystem has been steadily exploited, its extent has reduced, been degraded and is now confined to small pockets across the Niger Delta. As a result, its species like in most other old growth forests across the tropics, are not only threatened and fragmented, but the ecosystem services they provide are reduced (Laurance and Peres, 2006; Sodhi and Ehrlich, 2010; Laurance et al. 2011; Kessler et al. 2012; Hansen et al. 2013). These changes have impacted the forest landscape adversely and reduced the former extensive ecosystem into mosaics of forest islands.

Disturbance and degradation associated with the use of the forests are responsible for modifying the composition, their biodiversity and conservation prospects (Harvey et al. 2008; Chazdon et al. 2009; van Breugel et al. 2013). Hence, with variations in frequency and patterns of use of the freshwater swamp forests across the Niger Delta, some of the native species (such as the “abura” taxa (*Hallea ledermannii*)) have almost become extinct in many locations across the ecosystem; while some other economic trees (such as “Iroko” tree (*Milicia excelsa*)) have become very rare at the landscape levels across the region. With most of the ‘target species’ in the ecosystem continually facing harvesting pressure, maintaining stable climax species composition across most of the forest landscapes in the region has remained difficult (Joseph et al. 2009; Bisong and Buckley, 2014). As these trees are either selectively logged or cleared, they are on the other hand replaced by other (heliophilous) species such as the palms (Arecaceae family), which eventually dominate the ecosystem and in turn affect the ecosystem services derived from the forest. Since the use of the ecosystem are dependent on the management and ownership statuses of the forest lands, understanding the linkages between the management of the ecosystem and the services they provide is crucial to maximize ecosystem service potentials.

The study aims to show the extent to which forest use and management influences the AGC of the freshwater swamp forest ecosystem in the Niger Delta. Specific objectives include: to 1) estimate the AGC of the different sites, 2) show the different uses of the forests across the communities and how they were managed, 3) show the relationship between forest use, management and AGC across the sites and 4) provide insights on effective measures that will enhance adequate management of tropical forest landscapes.

6.3 Materials and methods

6.3.1 Study area

The Niger Delta is the largest river Delta in Africa (Dupont et al. 2000). With thousands of creeks dotted across the region, this unique delta supports rich floral and faunal biodiversity that is of regional and international importance (Happold, 1987; Hilton-Taylor, 2000; Abam, 2001; Ikelegbe, 2006). The region is a vast sedimentary basin found in the lower reaches of the River Niger and River Benue (Fig 6.1). They were formed from the accumulated sediments derived from the Niger and Benue basins, the Volta River basin, and minor rivers within Nigeria (Allen, 1964). Soils of the region are classified as hydromorphic soils that are either seasonally or permanently waterlogged (Areola, 1982). The region is characterized by a long rainy season that lasts nearly throughout the year (mainly between March and October) and a short dry season (with an average monthly rainfall of 150 mm).

Situated at the apex of the Gulf of Guinea and in the southern part of Nigeria (Fig 6.1), the region covers all the oil producing states of Nigeria, from which the bulk of Nigeria's oil and gas reserves, wealth and foreign exchange are sourced (Haack et al. 2000; Ite et al. 2013). The region has a rich cultural heritage and is ethnically varied; with ethnic groups such as Ijo, Efik, Ibibio, Bini, Isoko/Ukwani, Urhobo and Itsekiri found across the entire region. Settlements across the region are predominantly rural and composed of people that are culturally attached to the environment. Most of the people living in the region are quite poor and the unemployment and underemployment rates (8.8% and 26.2% respectively) across the region are higher than that of other regions in the country (Ukiwo, 2009).

6.3.2 Data collection

A standard plot based method (Phillips et al. 2003) was used to conduct a vegetation survey by establishing sixteen 1 ha plots across the ecosystem in four locations: Akarai-Obodo, Akili-Ogidi, Otuwe and Akoloma (Fig 6.1) between December 2013 and April 2014. Plots were placed 500m apart to ensure variation in floristic composition. All the 16 plots (4 plots) per site were placed along transects (two transects per site) spaced 1km apart rather than random placement. This helped to ensure that consistency in enumeration was maintained across the plots. The forest plots were then used for species identification and measurements across the ecosystem. The plot size and arrangement for the carbon assessment followed the RAINFOR protocol (Marthews et al. 2014). All tree species that were ≥ 10 cm diameter at breast height (DBH) were identified and measured. While each of these species were enumerated and identified to species level in the field, voucher specimens were collected for unidentified species that were verified at the Forestry Research Institute Ibadan (Nigeria).

Smaller tree stems were omitted as they contain approximately 5% of above ground carbon (Lewis et al. 2009). Tree heights were determined using a laser rangefinder, and where the tree height was less than 10 metres, graduated poles was used to measure the height. Species identification was conducted by Michael Oladimeji, a taxonomist from the research institute and assisted by Peter Ige. Tree measurements and setting of the plots were conducted by Nwabueze Igu, with the assistance of Cyril Mama and Ifeanyi Iwegbue. The forest sites were selected to capture variation in species composition, carbon storage potentials, as well as use and management dynamics. While Akarai-Obodo, Akili-Ogidi and Otuwe are freshwater swamp forests, Akoloma is a mangrove-freshwater transition forest (Fig 6.1). Akili-Ogidi, Akarai-Obodo and Akoloma are secondary forests that are managed by people from the nearby communities; whereas Otuwe is an undisturbed forest that is very remote and inaccessible either during the rainy or dry season. Plots were only set up in the seasonally flooded part of the ecosystem, when the water had subsided.

Information on forest use, management and ownership (Table 6.1) was collected from the forest communities using interviews and informal discussions. This was targeted at the community leaders, aged individuals and other key informants (such as youth leaders and school teachers) where possible. Each of the respondents was interviewed individually so they could comfortably express their views. This method of collecting information enabled in depth views to be garnered from respondents and also gave opportunity for follow-up questions where necessary.

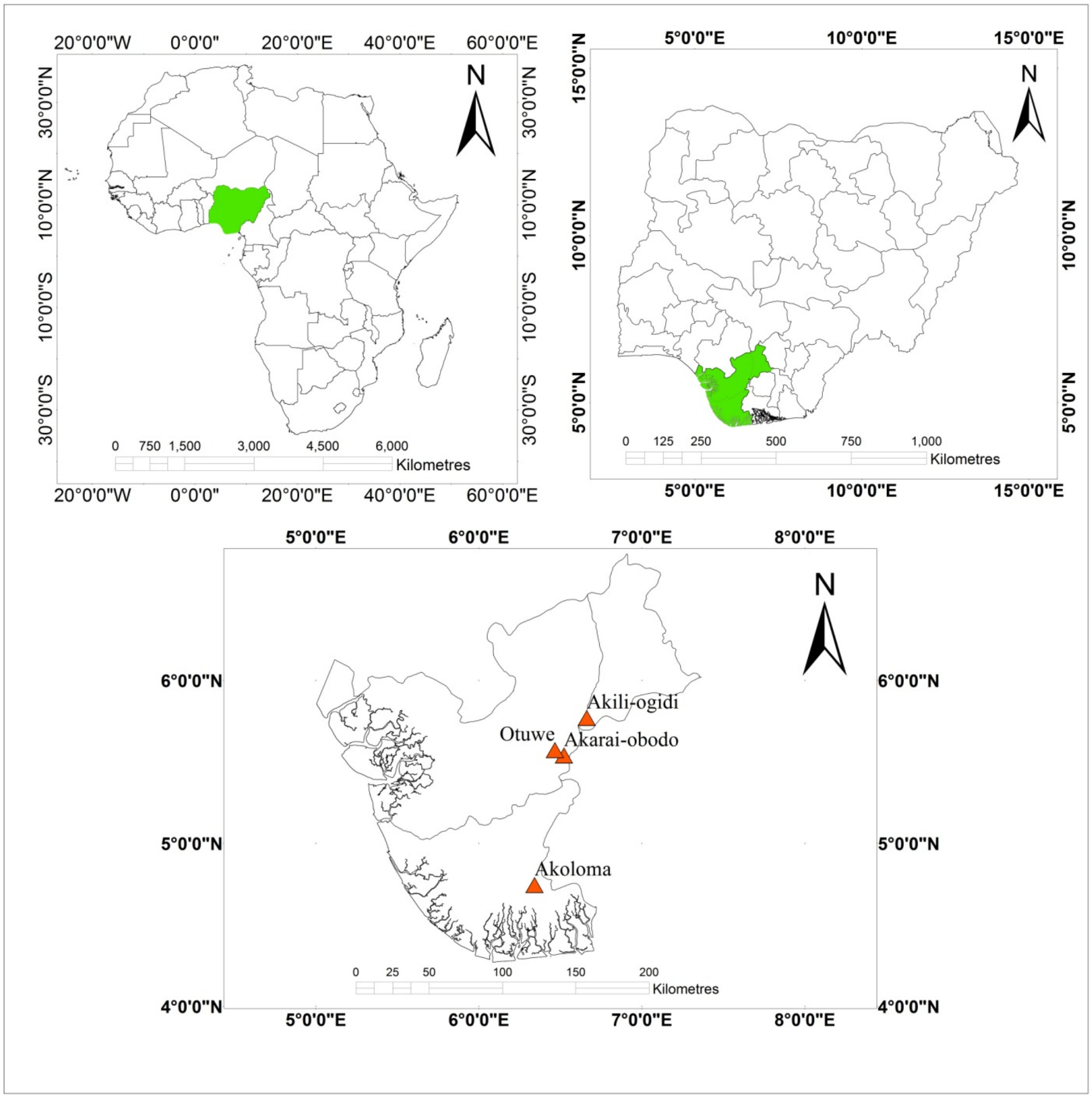

Fig 6.1 Map of the study locations.

Table 6.1 List of questions used to assess forest ownership, use and management

S/N	Questions
1	Who owns the forest(s) in your locality?
2	What are the forests used for or what are the purposes they serve?
3	What is the frequency of forest visit or use in your locality?
4	Are there any restrictions to forest use in your environment?
5	How are the forests managed/who takes care of the forests?
6	Are there any laws guiding the use of the forests?
7	Are there any tree(s) that forest users are prevented by law from harvesting or logging?

6.3.3 Data analysis

Taxon-specific average values of wood specific gravity (WSG) for each of the stems across the forest plots were extracted from the database on global wood density (Zanne et al. 2009) and used to calculate the AGC. Mean values for genus, family or current plot was used (respectively) in situations where the WSG of any of the species was unavailable. Arecaceae species were calculated with the mean WSG (0.55 g cm^{-3}) for the entire tropics, since the African mean value was absent. Each taxon's biomass was eventually calculated with (Equation 1) Chave et al. (2014) pantropical equation. Equation 1 is given as:

$$AGB = 0.0673 \times (\rho D^2 H)^{0.976}$$

Where AGB is the above ground biomass; ρ is the wood specific gravity (WSG; g cm^{-3}); D is the diameter at breast height (DBH; cm) and H is the height (m). The biomass for each taxon was estimated to contain 50% above ground carbon throughout the study (Brown and Lugo, 1982; Chave et al. 2005).

To show how the above ground carbon (AGC) estimates varied across the forest locations and across the plots within each of the forest locations, a Kruskal-Wallis test was conducted. T test was used to show if the presence/absence of palms in the forest locations (an index of forest modification) influenced the AGC. Kruskal-Wallis test further showed how varied the modified forest locations were in their occurrence of palms and an independent sample t test used to verify if there was any significant difference between the AGC estimates of the locations and their estimates when the palms were excluded. Kruskal-Wallis test was equally used to show how the AGC varied with intensities of use of the forest sites. Wilcox test was used to show the influence of management on the AGC estimates. Intensities of use and management were ranked as less frequently used = 1 and more frequently used = 2; and individual/family management = 1 and communal management = 2, respectively. Hochberg corrected alpha values (Hochberg, 1988) were used to correct for multiple testing. Adjusted alpha values were at 0.0031. The analyses were performed with R statistical software version 3.1.0 (cran.r-project.org).

6.4 Results

6.4.1 AGC estimates and influences

The AGC storage across the forest locations varied based on their degrees of modification (Figs 6.2 and 6.3). This differed across the sites (Kruskal–Wallis $\chi^2 = 10.65$, DF = 3, $p = 0.13$; Fig 6.2), with Otuwe location which is the least modified or degraded forest location, had the highest value of AGC than the other forest locations (Fig 6.2). The AGC of plots within each of the forest location were not significantly varied (Kruskal–Wallis $\chi^2 = 3$, DF = 3, $p = 0.39$), however the AGC estimates differed across the locations: 39.21, 56.36, 93.72 and 105.10 t for Akili-Ogidi, Akarai-Obodo, Otuwe and Akoloma, respectively (Fig 6.2).

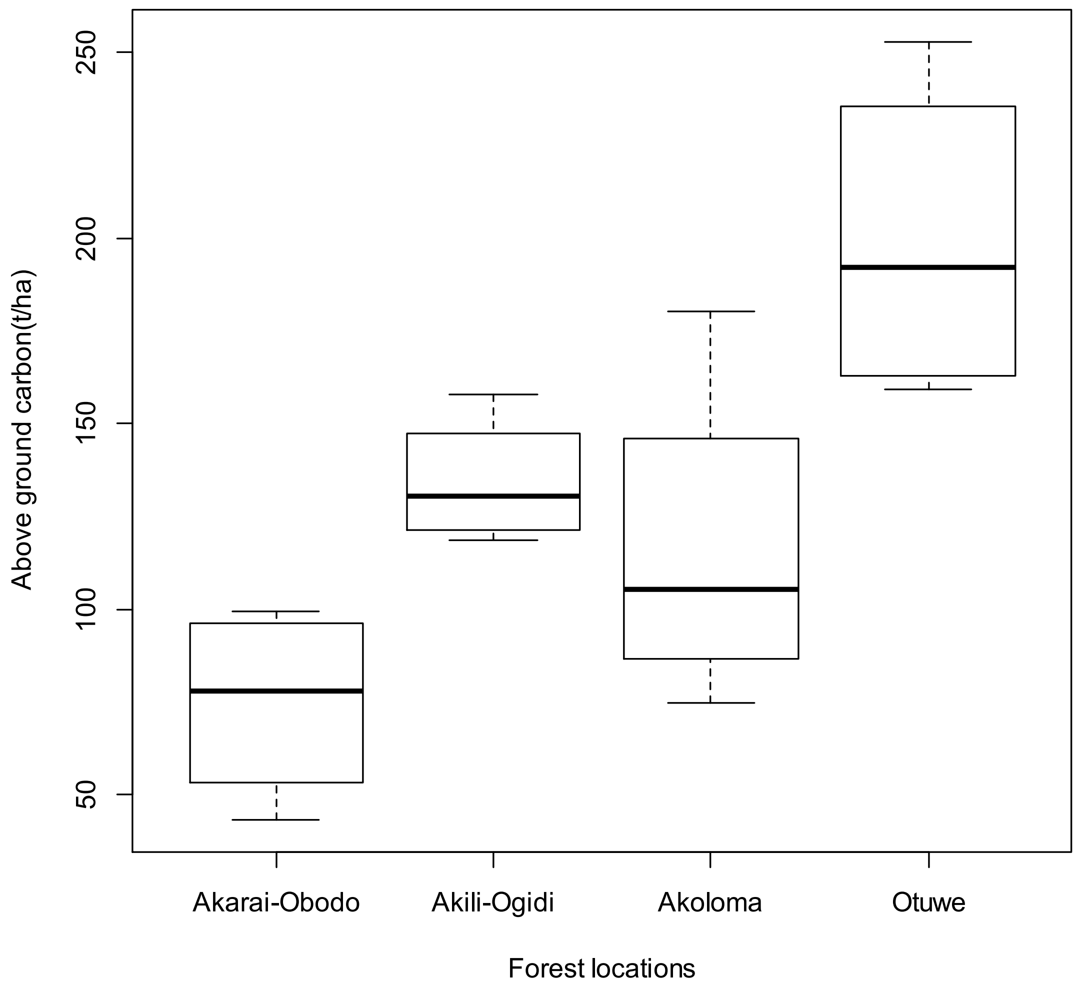

Fig 6.2 Estimates of the AGC of the forest sites

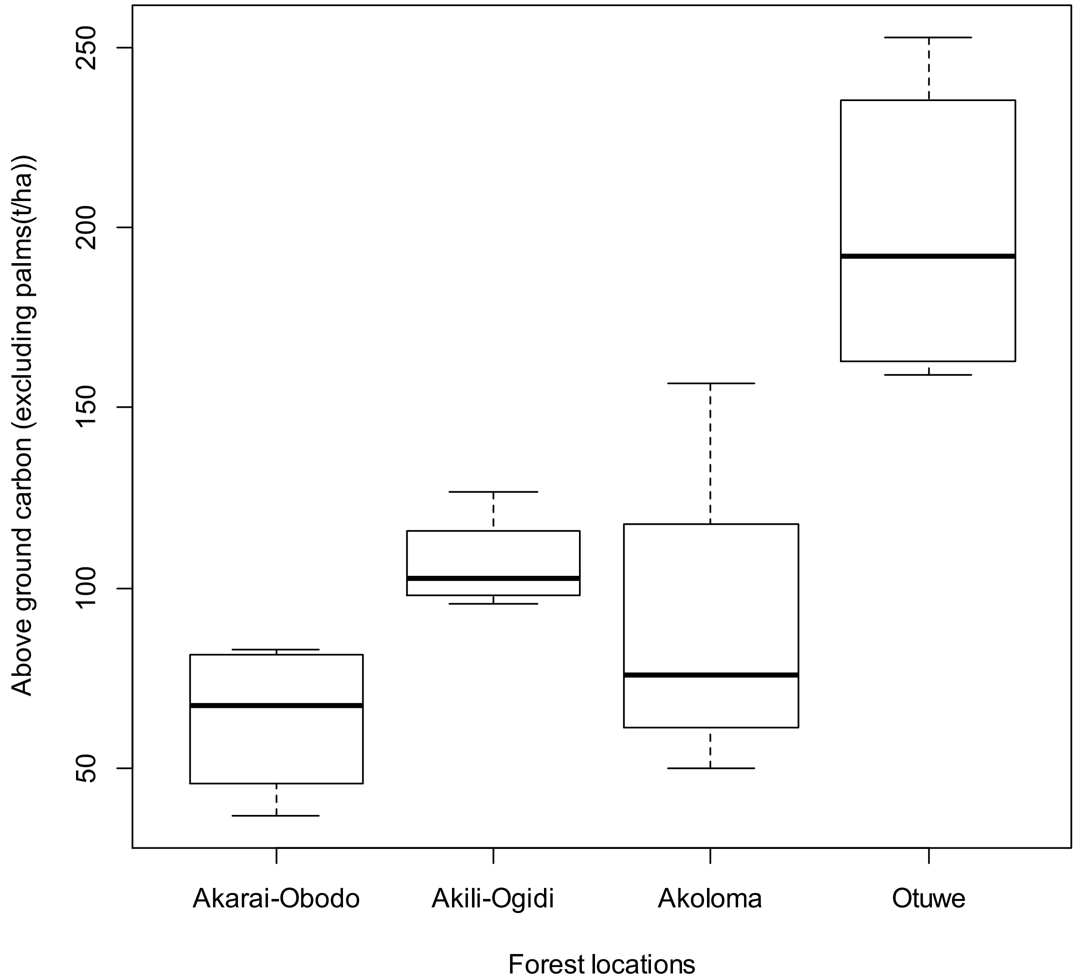

Fig 6.3 AGC estimates of each forest site (when the contribution of palms are excluded)

The presence/absence of palms in the plots were found to influence the AGC estimates of the forest sites (t = 4.64, DF = 28.59, p = 7.147e-05; Fig 6.4). Even though their presence in each plot contributed to the AGC of such location (F (14, 52.22) = 3.28, p = 0.09, R^2 Adjusted = 0.13), they were however not the main determinants of the AGC of such landscapes. There was equally no significant difference between the carbon estimates contributed by the whole taxa and the estimates when the palms were excluded (t = 0.79, DF = 29.77, p = 0.44). The varied degrees of modification (number of palms) encountered across the (forest) disturbed locations

(Akarai-Obodo, Akili-Ogidi and Akoloma) (Kruskal–Wallis $\chi^2 = 7.27$, DF = 2, $p = 0.026$; Fig 6.5), explains the wide variations of AGC across the forest locations (Fig 6.2).

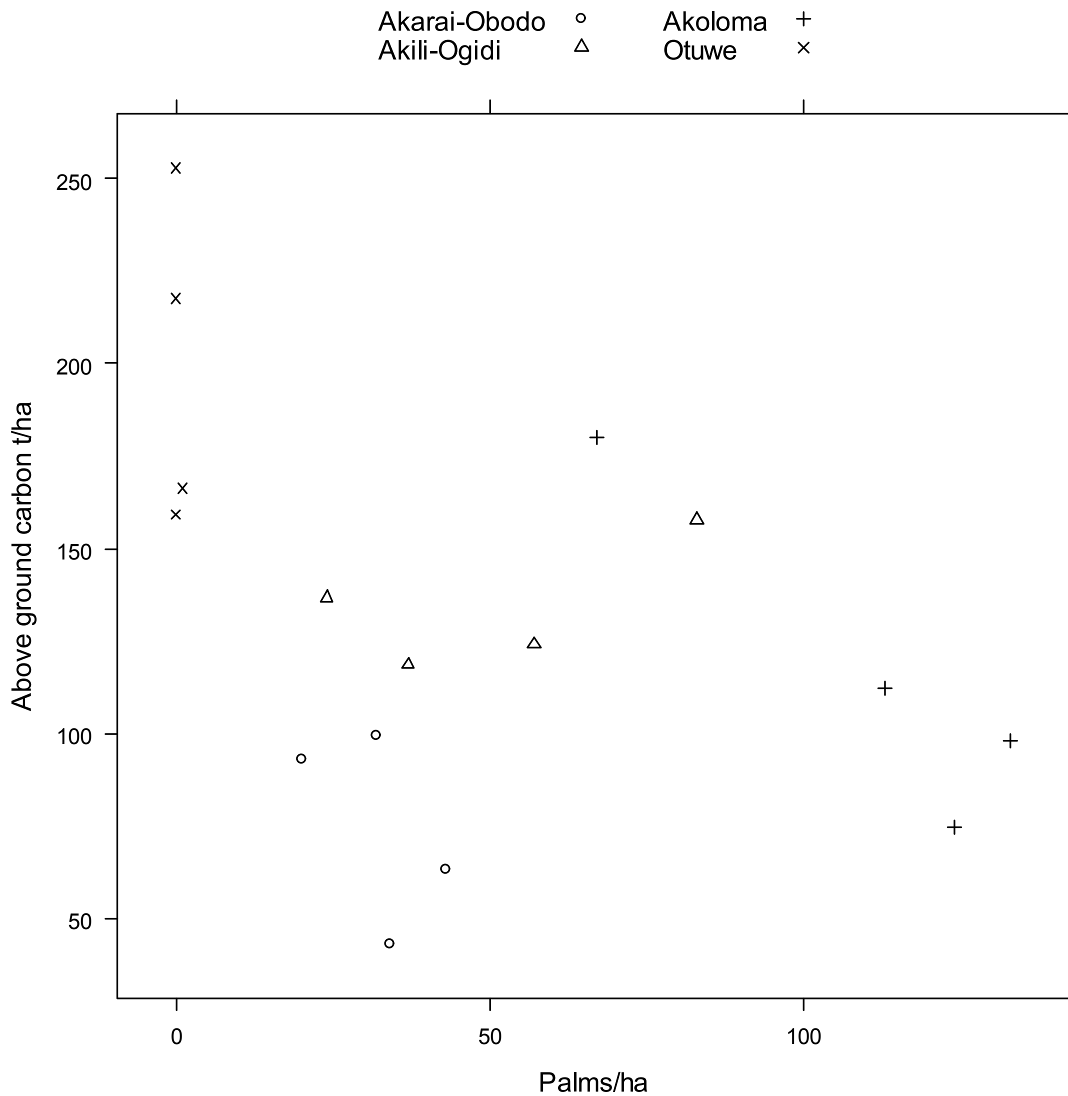

Fig 6.4 Relationship between AGC and forest modification (presence/absence of palms)

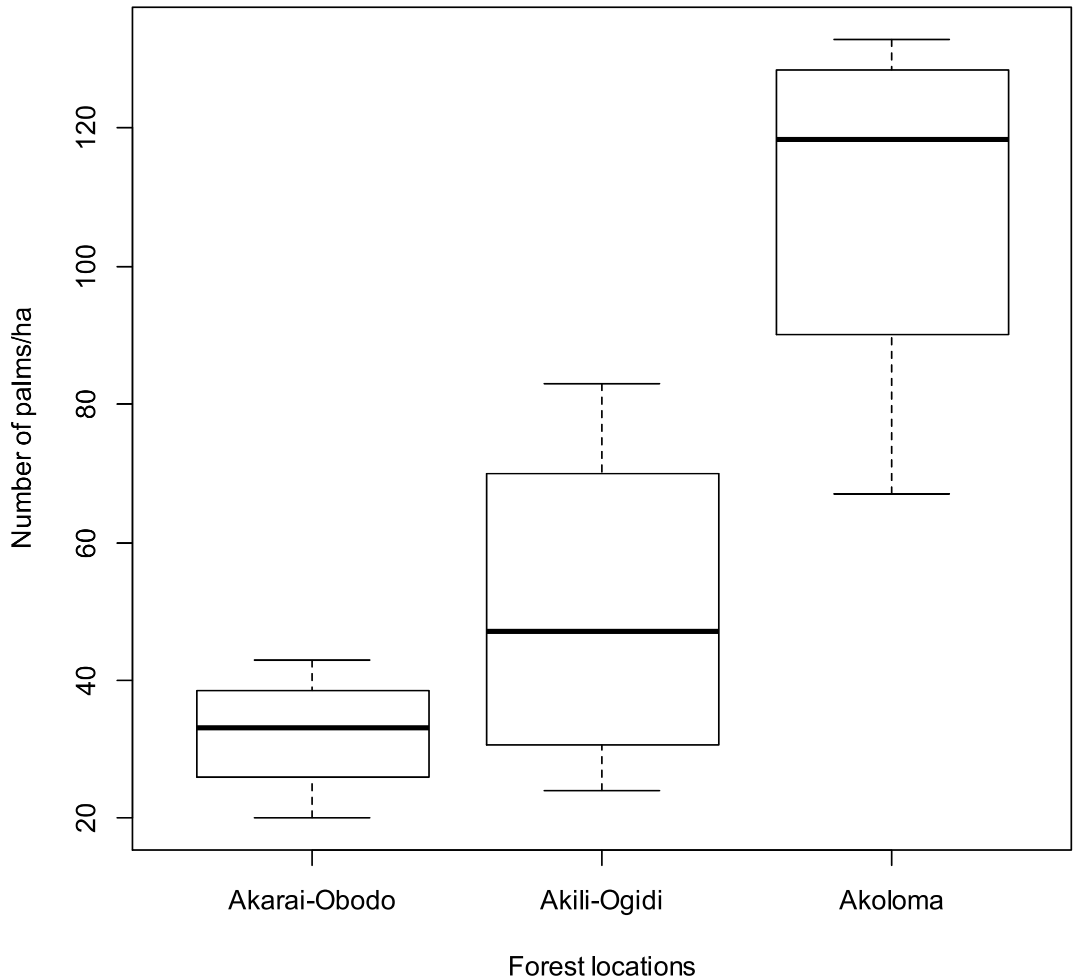

Fig 6.5 Number of palm occurrence across the modified locations

6.4.2 Forest management and use

The forests were managed by their owners: individual families and communities (Table 6.2). While the forest plots at Akarai-Obodo and Akoloma are under individual family management, the forest plots at Akili-Ogidi are managed communally. Otuwe forest site (though owned by different families from Akarai-Obodo) is very far away from the community and only used (that is the lake in its environs) for seasonal fishing activities. Akarai-Obodo and Akoloma forest locations had no forms of restrictions to forest use, as the forests served the needs of their owners (Table 6.2). Akili-Ogidi forest site is owned and managed communally. It served the community members who needed it for different purposes (such as hunting, firewood collection and non-timber forest products). Even though it was logged as in other secondary forest sites, there were guidelines and restrictions regarding its use (Table 6.2). Across the forest communities: Akarai-Obodo, Akili-Ogidi and Akoloma, the forests were used as the main sources of timber and non-timber forest products such as forest fruits, vegetables and nuts. It equally served as sources of fuel (firewood), medicine (herbs) and used for hunting game. The swamps in the forests served as fishing grounds, while the forest lands were mainly used for agricultural activities.

Table 6.2 Results of forest use and management in the different locations

Variable	Response
Forest ownership	Forest units are owned by individual families in all the locations (Akarai-Obodo, Akoloma and Otuwe) except Akili-Ogidi (communally owned)
Forest use	Non-timber forest products (such as vegetables and fruits), firewood, hunting, lumbering, farming activities in all the locations, except Otuwe (where it is only used for seasonal fishing activities)
Frequency of use	Very frequently (mostly on daily and weekly basis) in all locations, except in Otuwe that is only used seasonally
Restrictions to use	No restrictions to use in all locations except Akili-Ogidi
Forest management	Family management in all locations except Akili-Ogidi, where it is managed communally
Laws on use	No cultural laws barring forest use across all locations
Taxa prohibitions	Akarai-Obodo & Akoloma: No prohibitions Akili-Ogidi: Prohibitions on logging of *Milicia excelsa* Otuwe: Not applicable

6.4.3 Relationship between forest use/management and AGC

The AGC of the forest locations differed across the sites mainly due to the variations in intensities of use (Kruskal–Wallis $\chi^2 = 7.12$, DF = 1, p = 0.008). Hence, Otuwe site which had the least intensity of use (seasonally), recorded a higher mean AGC compared to the remaining locations (put together) that were used on more frequent occasions (Fig 6.6). Management of the forest sites influenced the AGC estimates of the ecosystem (Wicoxon W = 256, p = 7.763e-07). Furthermore, this influenced the range of carbon storage in each of the forest sites (Fig 6.2). Akili-Ogidi location had more uniform estimates due to the more organized management pattern in its plots, unlike other locations which had no form of restriction to use and lacked uniform management.

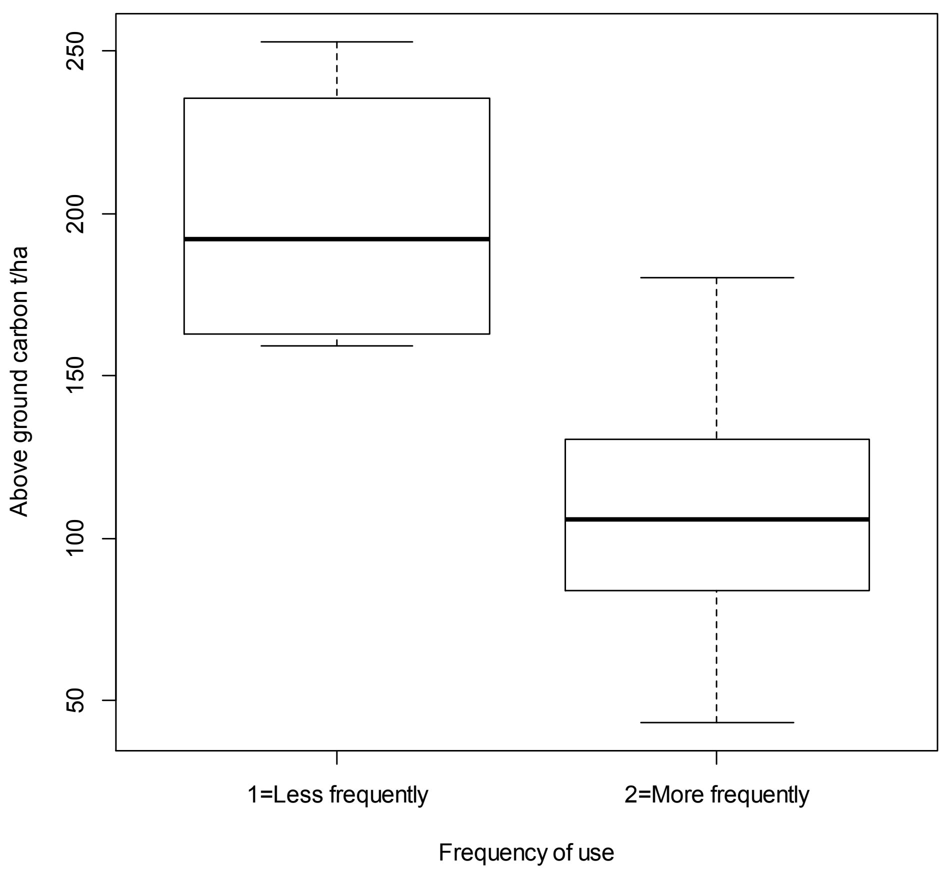

Fig 6.6 Variation in AGC with levels of human use

6.5 Discussion

Freshwater swamp forests are good stores of carbon and important for climate change mitigation across the Niger Delta region, however, the rate at which this could be realised is dependent on the state of the forest, its extent and disturbance dynamics. While the intactness of the forest ecosystem is a major feature that determines its ability to store more carbon (Fig 6.2) as seen in other forest ecosystems across the African continent (Lewis et al. 2013), the floristic composition or taxa (which has varied wood specific gravities) in each forest site determines also the potential carbon estimate of each site. This was more evident across the modified forest landscapes in the region: Akarai-Obodo, Akili-Ogidi and Akoloma, where human impacts on the ecosystem are responsible for the dominance and growth of monocots like the palms (Arecaceae family) in the ecosystem.

Even though palms could grow naturally in both pioneer and secondary forests and in swamps (Runge, 2008), they tend to grow more and dominate such forests, when their surrounding environment become hotter and drier (Luskin and Potts, 2011). Such environments are created through disturbances (mainly from anthropogenic influences) associated with forest use and land use changes across the freshwater ecosystem. This opens up the forest canopies and vegetation structure and alters the microclimate; hence, creating suitable microclimatic conditions that will promote the growth and spread of palms across the ecosystem. Such modifications in the ecosystem alters its composition, threatens forest-dependent species in the landscape, and will also act as microclimatic barriers to the growth of native species that are adapted to the moist freshwater swamp terrain (Fitzherbert et al. 2008; Luskin and Potts, 2011).

On the other hand, since the proceeds from the palms have remained the main source of livelihood for the people of the region for centuries (Aghalino, 2000), the people not only became attached to the tree and encouraged its growth, but rarely log it in the forests. With this, the composition of the freshwater swamp forests have steadily changed across disturbed forest sites in the ecosystem (Fig 6.5). While there is no doubt that such forest-agricultural landscapes have the capacity to store carbon in the above ground biomass of its taxa (like the Arecaceae), they cannot be compared with the capacities found in dominant and pioneer species in the ecosystem. Examples of such taxa includes *Sterculia oblonga* and *Rhizophora racemosa*, whose capacities to store carbon (mean genus WSG = 0.832 and mean 0.93 g cm^{-3}, respectively) are higher than that found in the Arecaceae (mean WSG = 0.55 g cm^{-3}). Ensuring that the forest ecosystem as well as their taxa is not being replaced by other land uses or less carbon dense taxa (in instances where the forests become degraded) are vital steps to ensuring a higher potential carbon sequestration for the ecosystem.

Forest use has both shaped and contributed to the biodiversity modifications of freshwater swamps and its composition at landscape levels across the region. This is mostly due to the pattern of forest harvesting as well as the purpose for such activities. Continual and unregulated harvesting of trees in the ecosystem have steadily altered the composition of the forests and equally caused species with small ranges to become scarce (Pimm and Raven, 2000). Furthermore, as such patterns of forest use have continually contributed to a reduction in the viability of the ecosystem (Vos et al. 2008; Pütz et al. 2011; Laurance et al. 2011), the extent and capacity to which such disturbed forests could store carbon in its biomass at plot levels and landscape scales have continually widened (Fig 6.2). On the other hand, as the intensity of forest use and land use changes (mainly for agricultural purposes) increases across the landscape, the services such forest landscapes initially provided will continue to be on the decline (Fig 6.6). This pressure from agricultural activities at subsistence and commercial levels are not only the main underlying causes of forest loss in a majority of the forest communities in the region (Geist and Lambin, 2002; Enaruvbe and Atafo, 2014), but a threat to long term ecosystem service provision and forest conservation. Since the rural landscapes across the region mostly engage in agro-based economies, land use changes and conversions are likely to continue its debilitating effects on ecosystem services unless alternative sources of livelihood and forest friendly initiatives are adopted.

Forest ecosystems in most forest communities in the Niger Delta region are mainly under private (family) and community ownership holdings. These management levels are responsible for the use and preservation of the forest landscapes and directly influence the composition, service provision and viability of the ecosystem. Community ownership and management of the forest lands offers viable management and use of forests through its ability to provide sutiable guidelines and enforce restrictions on forest. Hence, with the restrictions on the logging of *Milicia excelsa* in Akili-Ogidi, such high-market valued and sought after economic tree (which are very rare in forest ecosystems in the region), are preserved. Such communal management structures may be potentially useful in preserving the native species in the freshwater swamp forests in the region as well as their carbon storage capacities.

Conversely, the ownership and management of forest units under private holdings are mainly influenced by the needs and socio-economic status of the individuals or families that own them. Such ownership structures have had to grapple more with intense pressures from commercial timber operators who desire to log the high value timber trees in their forest lands. These family ownership structures span from single nuclear family ownerships to the kindred levels, depending on how united the families are and the size of forest lands to be inherited. As most family units are characterized by individuals with different socio-economic levels and interests, their forest lands have mostly been parcelized (in a bid to either ensure that each one gets his inheritance or to settle conflicting interests on forest use) over the years. Managing such extensive forest units that are owned by different individuals with varied needs have not only been complicated, but has continually made conservation prioritization of such landscapes very elusive.

In a bid to properly manage such forest ecosystems and sites (under private ownership), a more decentralized system of ownership, management and decision-making have been advocated across most African nations (Lund and Treue, 2008; Robinson et al. 2013) which are equally dominated by private ownership of forest lands. While this seems to be a likely strategy to enforce forest management and guided use of the ecosystem services across the region, the feasibility of achieving it in a region with deeply entrenched land tenure system and a family land (forest) inheritance norm seems elusive. With the bulk of forest lands and majority of the undisturbed forests under private ownership and management across the region, the future of ecosystem service provision across the region depends to a large extent on how the people use the ecosystem.

6.6 Conclusion

Forest ownership, use and management can affect forest productivity, composition and its capacity to provide vital ecosystem services. The AGC of the different sites were found to vary based on the intensities of use, management and ownership of the sites. The forest was found to be of much importance to its owners, for whom it provided vital ecosystem services such as game, firewood and timber. Forest sites were privately and publicly owned and managed, with each reflecting differences in restrictions of use and management and in turn, the capacity to which it was beneficial to the people. Awareness of forest management techniques that are harvesting friendly and sustainable are advocated across tropical forest landscapes and ecosystems, so that the services such landscapes provide could be assured.

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Chapter 7 – Summary Discussion

This thesis focused on investigating the ecology, biodiversity, potentials and threats of the poorly understood freshwater swamp forest ecosystem of the Niger Delta. The second and third chapters showed the floristic composition of the ecosystem and shed light on the variability in species dominance, diversity and richness of the ecosystem, as well as its varied indicator species. Chapter four looked at the carbon storage capacities of the ecosystem; while chapter five identified the pattern of forest use and consequent degradation ongoing in the ecosystem. Chapter six provided insights on the linkages between forest management and carbon storage in the ecosystem. The following discussion provides a summary of the findings; posits the need and guidelines for effective forest management and conservation across the ecosystem and presents issues for further work.

7.1 Biodiversity patterns and indicators of the ecosystem

The freshwater swamp forest ecosystem is unique and distinct from other tropical forest ecosystems. While the tree densities and stem abundance are similar with other tropical forest ecosystems, its species richness is lower, mainly due to the environmental constraints associated with the ecosystem (Teixeira et al. 2011; Scarano et al. 1997; Kurtz et al. 2013; Lugo et al. 1988). With variations in the dominance and the environmental features of the different forest locations or plots (Gole et al. 2008; Toledo et al. 2011), the species in the ecosystem were either constrained in some distinct locations or permitted to coexist with other species in other locations. Gaining insight into these variations were seen to be necessary for understanding the plant-environment relationships inherent in the ecosystem (Bakker, 2008; Toledo et al. 2011); explore the appropriate biogeographic categorization and provide insights on how the species may respond to changes in the environment. Furthermore, with increasing forest disturbances and degradation ongoing across the ecosystem, offsetting biodiversity losses could be achieved through forest restoration (Montoya et al. 2012; Audino et al. 2014) using the indicator species of the different forest zones. These (indicator) species could be used as consistent indicators of ongoing environmental-ecological relationships and in ascertaining the health of the ecosystem. With the knowledge of which species to expect in each of the forest categories (disturbed, undisturbed and transition zones), better and more accurate assessments of the ecosystem will result in more effective forest regeneration.

7.2 Freshwater swamp forest determinants and regimes

Forest ecosystems are all subject to different regimes of disturbance which shape and maintain their structures and ecological processes through varied and inter-related ways. Freshwater swamp forest ecosystems are to a large extent designed by the environmental factors and processes in its surrounding region; however the extent to which this influences the floristic composition of the ecosystem is dependent on the disturbance regime. While (disturbance) this “relatively discreet event in time” is responsible for the disruption of the community or population structure of the ecosystem (Pickett and White, 1985), it has on the other hand enabled patch or gap dynamics (Brokaw, 1985; Torimaru et al. 2012; Boyd et al. 2013) in the ecosystem and facilitated forest succession. Such successional processes not only enables new species to be introduced into the ecosystem, but has to a great extent influenced (improved) the diversity, species richness and adaptive capacity of the ecosystem (Gutschick and BassiriRad, 2003; Seidl et al. 2014).

As the ecosystem has the resilience to cope with the anomalies associated with the natural disturbance regime (mainly from the annual or seasonal flood), the forests have maintained their dense vegetations and luxuriant growth over the years. However, with the recent anthropogenic activities ongoing in the ecosystem, forest degradation is exacerbated at local and regional scales and the resilience capacity of the ecosystem reduced over the years. Consequently, there has been a reduction in the capacity of the ecosystem to sequester carbon and also to provide other vital ecosystem services for its forest-dependent communities. Hence, while this process (disturbance) is meant to bring about the renewal and continual growth of the ecosystem, it has been complicated by a variety of exogenous anthropogenic disturbances that has not permitted the establishment of climax communities across most of the forest locations. As a result, such forests have barely been restored, but have instead remained as shrub-lands and serve as grazing fields or open spaces (which may be used eventually as farmlands).

On the other hand, environmental variables were found to influence the floristic composition and pattern of cluster of the indicator species across the ecosystem. Such environmental variables (notably, the mean annual rainfall and temperature) not only impose habitat selection on the ecosystem, but also influence their stem and species abundance. Furthermore, they help to ensure that the climatic conditions necessary to maintain the ecological processes and species differentiation across the ecosystem is assured (Slik et al. 2003; Ferreira et al. 2014). With alterations in the forest structure (through disturbances regimes and events), the microclimate of the forests become modified and eventually necessitate variations in composition across the forest ecosystem, depending on the varied ecological niches, species pool, dispersal capacities, relative abundance of the species and the degree of physical barriers in each of the forest locations (Chase and Myers, 2011; Wiens, 2011).

7.3 Forest dependence and degradation

The rate of tropical forest loss is so enormous that the future of its species has never been more uncertain (Gardner et al. 2009). With only very few area across the whole tropics escaping human impacts (Kareiva et al. 2007), forest modifications, biodiversity losses and extinctions are fast becoming a norm. These have been attributed to varied proximate and underlying (Geist and Lambin, 2002) causes which have not only reduced the extent of the forests, but has led to the degradation of vital forest resources across the study region. With increase in the population of the region, much demand and pressures have been placed on the forests' resources beyond their resilient capacities. As a result, most of the forest resources are not only scarce, but are threatened with extinction at the landscape scale and across the region. On the other hand, agriculture has been intensified by households in a bid to meet the demands of the growing family sizes across the freshwater swamp communities. Indeed, agricultural expansion has not only been the major indicator of human footprint on the entire biosphere (Gardner et al. 2013), but has indirectly (through biodiversity losses and forest fragmentation) affected the capacity to which forest ecosystems could provide other functions such as carbon sequestration (Sasaki et al. 2011; Berenguer et al. 2014).

With the high unemployment and underemployment across the region (Ukiwo, 2009), the intensity of use of the forest ecosystem to meet the needs for sustenance and livelihood has steadily increased in the freshwater swamp ecosystem. As a result, forest degradation has not only affected forest units that are closer to community dwelling units, but has been introduced in distant forests mostly by the people whose livelihood are dependent on the forest resources, and who have defied the constraints associated with the swampy terrain to harness the forest resources.

7.4 Ecosystem services

Freshwater swamp forests are very productive ecosystems that provide a wide array of services and functions across the Niger Delta region and globally. Its potential to sequester carbon in its carbon-dense ecosystem was found to be high and comparable to other tropical forest ecosystems, but, decreasing with disturbance and poor management across the forest landscapes. Since the ecosystem is composed of different flora (with varied carbon densities), the capacities of each of the forest categories to store carbon in its biomass varied at different spatial scales. Basal area and height of each tree were found to determine to a large extent the carbon storage of each forest, as is common in forest ecosystems. As a result, though the intact forest group was not composed of carbon dense flora as in the other groups (which had more carbon dense flora like the genus *Rhizophora*); they were found to contain ample and higher stores of carbon across the ecosystem. The inability of other forest categories (disturbed freshwater forests and transition forests) to measure up with the intact category despite their carbon dense composition were strictly because of their disturbed state (lower basal area and heights). Thus, as the households across the forest ecosystem intensify their use of the ecosystem services for sustenance and livelihood, it not only leads to degradation of the forest trees but also other services they provide (such as carbon storage) (Berenguer et al. 2014).

Other ecosystem services derived from the ecosystem were seen to be the basis for the sustenance of many households across the region as in most other African communities (CIFOR, 2005; Shackleton et al. 2007; Bromhead, 2012). While a lot of households depend on the swamp forest ecosystem to meet varied needs and so have continually used the forests on regular basis, they have mostly not considered other vital aspects of ecosystem service such as regulatory and supportive functions. Since forest ecosystem and its resources have mostly been used to meet immediate needs (with little or no thought given to long term uses), the ecosystem’s capacity as carbon stores are on the decline. While there are possibilities of regulating the use of the ecosystem to achieve targeted potential stores of carbon (through community forest management) for the ecosystem, the poor management structure associated with the privately owned forest units (which dominate the landscape) still poses a challenge to realizing such targets.

7.5 Forest use and ownership

Freshwater swamp forest across the Niger Delta region are beneficial to the people in various ways as sources of livelihood, sustenance and nutrition; hence, are used for lumbering, fishing, farming, hunting and gathering of fuelwood and other non-timber forest products. While the ecosystem serves diverse functions, the extent to which they could be utilized are however constrained by the ownership status of the forest units and the environment (swampy and inaccessible terrain and/or dry accessible parts). Ownership of the different forest units determines to a great extent, the activities in terms of what the forests are used for, the values and attitudes the people have towards the forest units (Ritter and Dauksta, 2011) and the pattern of loss or degradation in such landscapes.

The variations in the ownership of forest units across the region: government (forest reserves), community forest lands and individual/family land units; determines the pattern of forest use (through restriction or access to forest units), shapes the ecosystem composition and distribution (ecology) and consequently, dictates its capacity to provide other vital functions (biophysical attributes) (Figure 7.1). With this trend, communities that are dominated by private forest ownership across the Niger Delta, which are more prone to forest modifications and fragmentation (due to unrestricted forest use), are expected to experience more intensive forest use and higher rate of degradation, unlike those that are jointly owned by more people(s) or communities. While forest units that are owned by a higher number of person(s) (such as a large extended family or community forest holdings) may not allow the weak, individualistic and unregulated use of the forest (as in private forest holdings), it may still not be effective in enhancing a better use of such forest landscapes (due to conflicts of interests that may arise) except suitable people-oriented guidelines and mutual understanding are in place.

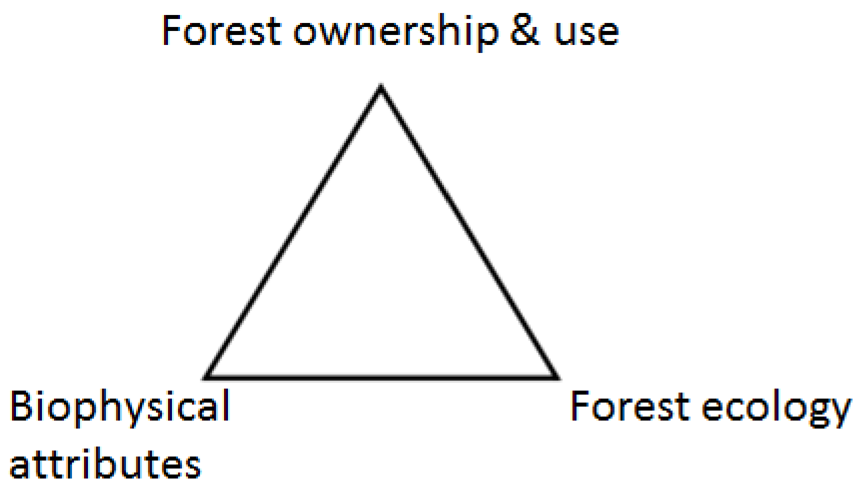

Figure 7.1 Schematic diagram of the relationship between forest ownership, ecology and biophysical attributes (ecosystem functions).

7.6 Forest management and conservation

Achieving forest conservation and management across tropical landscapes have been quite a challenge due to the ineffectiveness of long existing protocols and methods of forest management across most of the tropics. While efforts to conserve the biodiversity of forest ecosystems across the tropics have been hinged on the use of protected areas for quite some time, it has not in reality achieved much. This is mainly due to the fact that only 9.8% of the entire tropical forest biome are found within strictly protected areas (Schmitt et al. 2008; Gardner et al. 2009) and this low proportion under reserve is on the other hand encroached by human activities as well (Wittemyer et al. 2008; Gardner et al. 2009). Therefore, to ensure that forest ecosystems are effectively managed and the future of its ecological processes and services are preserved, workable and sustainable techniques of conservation should not only be advocated but also enforced. With the poor state of the reserves across Nigeria (Adekunle et al. 2013), achieving forest conservation for the freshwater swamp ecosystem using forest reserves appears to be a futile exercise. As these reserves across the Niger Delta are degraded and poorly managed in most cases, enhancing biodiversity conservation and management through such steps seems elusive. Instead, channeling such management measures towards the communally owned forest areas (where the remaining forest stands are found) are viewed as more likely steps to achieving the set goal. While it would be ideal to harness the forest resource potentials in non-government forest holdings, efforts towards reforesting the degraded forest reserves should be promoted, where possible. To maximize such strategies, plant species that are adapted to the environment should be considered, such as the ones identified as indicators of the ecosystem.

Effective and sustainable community forest management practices on the other hand should be promoted across the region. While it may not be appropriate to confiscate individual/family (forest) lands, however, in instances where such lands and those on communal holdings are procured with appropriate agreement and compensation, they should be used as reserves. Where such reserves are gazetted, they should be under the management of the donor communities, as they are more likely to ensure its sustainability. Conversely, since most of the communities in the region are characterized with land scarcity on the large scale (since most of their terrestrial spaces are swamps), establishing isolated forest reserves may not be that easy and feasible.

As such, the conservation techniques that would be suitable across most of the region are such that would take into consideration other important land uses especially agriculture. Though agriculture is viewed as a defining feature of biodiversity loss (Perfecto and Vandermeer, 2008), they are a vital necessity for the sustenance of such forest-landscapes and so should be properly managed. This reality about how modified the forest ecosystem (as a result of human actions and influences) are already, have however been accommodated by the ecological and conservation paradigms, which is moving away from the strict protection of forests in isolated reserves, to an acceptance of the coupled social-ecological dynamics inherent in modified forest lands (Liu et al. 2007; Gardner et al. 2009). Implementing such strategies for the freshwater forest ecosystem seems appropriate since in advocating for the conservation of the ecosystem, it does not on the other hand dismiss the idea that the sources of livelihood of the people across the region should be eliminated. To achieve this, the following should be considered:

7.6.1 Enhancing the implementation of agroforestry in agricultural landscapes across the region

Forest conservation could be enhanced in regions with degraded native forests and associated agricultural intensification (Perfecto and Vandermeer, 2008). This has been demonstrated in planned biodiversity environments, where trees, crops (both annual and perennials) and livestock are raised together, with up to 80 – 334 species being reported (Montagnini, 2006; Perfecto and Vandermeer, 2008). Even though similar coexistence of trees and shrubs are common features in home gardens across the forest landscapes in the Niger Delta region, it has mainly been characterized by very few trees and shrubs which are mostly edible. Since such disturbed landscapes have the potentials of experiencing an enormous number of different tree species sprouting in its landscapes, selective thinning of the trees or shrubs (with due consideration to the total surface area, and structural attributes of the plants) rather than a complete removal, should be encouraged. Furthermore, selective cultivation of tree species is advocated across the agricultural ecosystems that span the region, as they equally contribute to the biodiversity and better symbiotic interactions across the landscapes.

7.6.2 Protection and establishments of forest pools or patches across disturbed landscapes

Disturbed forest ecosystems are characterized by patches of forest trees and shrubs in different proportions. Encouraging the growth of such tree species across the region is important as they could contribute to improving the ecosystem's species pool, as well as preserving its native biodiversity. Managing such forest islands on the other hand are equally vital, in order to facilitate continual corridors for the migration of important species across the ecosystem and in turn, contribute to the ecosystem's functional biodiversity. Across the region, these forest islands are normally found on abandoned farmlands, along the creeks (in small pockets) and in locations designated as groves or shrines. Sustainable use and preservation of such small pockets by individuals and communities are essential and potential forest conservation steps that could grow from such micro scales to larger forest management commitments across the region.

7.6.3 Forest restoration

Even though restored forest ecosystems are not comparable to the natural forest ecosystems in terms of species composition and structure, they still have potentials to improve the ecosystem services and biodiversity conservation of such landscapes (Chazdon, 2008). This initiative is responsible for the increases in forest cover despite ongoing forest losses experienced the world over; though, it has not been much practiced in the study region. As the region's forest ecosystem has been lost at astronomical rates through deforestation and degradation, employing it in areas with sparse tree stands to no tree stands due to logging and pollution (mainly through crude oil spills) could be steps to enhancing the productivity of freshwater forests across the region and potentially, reclaiming oil-devastated derelict lands.

On the other hand, this equally has the ability to increase the carbon sequestration capacity of the ecosystem, sustain the nearly extinct species of the region (both fauna and flora) and stimulate the return and restoration of important animals that were displaced by degradation. However, it is expedient to balance ambition with reality if such projects are to be fruitful and sustained. To achieve this, long-term processes and goals should not be replaced with short-term attractive solutions, example, fast-growing and short-lived species which are low in wood density (and carbon offset) should not be favored for the long-lived, slow-growing trees with dense wood and slow turnover of woody species in carbon sequestration initiatives (Chazdon, 2008). Since forest restoration projects are not always guaranteed of success (leading to huge financial losses), efforts that will help to ensure that a positive result is achieved is hereby advocated. Such initiatives should consider very important steps such as: planting the right tree species, right timing for planting, ideal site preparation, ensuring that individuals and communities participate and are committed to the project (rather than being seen as a "government thing").

7.6.4 Forest friendly and sustainable agricultural practices

Despite the fact that agriculture is a major threat to continuous forest existence across the region, it is however, essential for human sustenance and regional coexistence. However, to ensure that the ecosystem is not completely overtaken by agricultural activities, farming practices that will reduce the pressure on forest lands needs to be adopted across the region. Techniques such as mixed cropping are advocated across the region, since it encourages multiple crops planting and in effect could reduce the portions of forest lands that are cleared for agricultural purposes. On the other hand, farmers should be made to maximize the use of agricultural extension personnel in their locality, as this will afford them the privilege of optimizing their time, resources, output and the forest lands as well. Government support and the awareness on the use of organic or inorganic fertilizers to enrich the soils are equally advocated. Such initiatives are important steps that could discourage forest loss that are as a result of a quest to farm on fertile or virgin soils.

7.6.5 Sustainable and alternative sources of energy

Fuel wood generation across the region is both a norm and a major cause of forest degradation; especially as its gathering prevents disturbed forests from achieving its climax succession. Advocating for sustainable use of wood for energy generation is necessary for continued forest existence across the ecosystem. This could be achieved by: encouraging the people to use energy saving stoves (as it only requires few logs of wood to generate energy); use of saw dust and wood chippings; harvesting of snags (dead wood) either from live trees or from fallen dead trees instead of cutting down of live shrubs (as is mostly practiced by the people). Conversely, other alternative sources of energy such as kerosene, gas and electricity should not only be advocated, but provided for the people at subsidized rates as well. Furthermore, the uses of other viable alternative sources of energy such as sawmill wastes and agricultural wastes in form of briquettes could also provide affordable options for the populace.

7.6.6 Alternative sources of livelihood and sustenance

Since a vast majority of households across the region are mostly made up of individuals that depend on the forests for their sources of livelihood, the provision of other sources of livelihood are advocated, in a bid to reduce the pressure and demand being put on the forest ecosystem. On the other hand, the populace should be encouraged to domesticate plants and animals and in effect reduce their dependence on the wild for the supply of nutrients (vegetables, fruits, spices and meat) and fuel. Such steps will not only reduce the rate of forest degradation across the region, but also ensure that the biodiversity of the ecosystem is preserved.

7.7 Further work

While the freshwater swamp forest ecosystem is poorly understood, this study has no doubt contributed to elucidating the various dynamics surrounding the ecosystem in the Niger Delta. Nevertheless, there is need to still build on what has already been done and further address other issues that have not been covered by the study. This will be briefly discussed in the subsequent sections.

7.7.1 Increased taxonomic inventories

The ecosystem's understanding will be improved with every additional inventory and survey that is conducted across the ecosystem. As such, more fieldwork are advocated in other locations (distant geographically) from the ones already studied, so as to be furnished with more updated floristic components of the ecosystem. This will not only be useful for elucidating the phytogeography of the ecosystem, but furthermore provide baselines that will shed more light on the carbon sequestration of the ecosystem and better inform conservation prioritization. As more data on the ecosystem become available, the long term dynamics would be better understood and more precise management strategies developed as well.

7.7.2 Data improvements and generation

Generally, the study was conducted based on what was available in terms of data, and what could be generated. Nonetheless, improvements in the baseline data of the region are vital in order to achieve more precision and accuracy. To better understand how the climate of the region would affect the ecosystem and its processes, ground-truthed data collected at the plot levels could be used to validate the available remote sensed climatic data. While such a data may not be easy to come by for a study as this due to the enormous resources involved, further climatic studies in the region are advocated as they could be relied on to provide these information at shorter intervals. Additionally, if more meteorological stations are established by the government at shorter distances, they could be relied on to provide more precise information. The need to provide more refined socio-economic and demographic data for the region is of utmost importance to help improve the scope of research at local and regional scales. While these data are not readily available for the region, the few ones that exist (from sources such as the World Bank and United Nations) are not available in GIS formats and so are limited in importance for studies like this. Initiatives and projects that would promote and improve the aforementioned baseline information and data for the region are necessary and timely, so that future ecological studies in the zone could be more applied.

7.7.3 Additional baselines

Understanding the carbon pathways and baselines for the freshwater swamp forests is a necessary step to effective climate change mitigation and adaptation. While more data on the above ground carbon estimates in other parts of the region not covered in the study will be steps to increasing the baselines for the ecosystem, understanding the below ground carbon of the ecosystem is very vital but remains largely unexplored. Since the carbon stored in soils is three times more than the ones in the atmosphere, and four times more than the ones in the vegetation (Jobbagy and Jackson, 2000), they remain an important and integral part of the carbon cycle that should be researched alongside. Other aspects of the below ground carbon such as the below ground biomass for the flora in the ecosystem are equally needed as they would contribute to a more wholistic understanding of the carbon potentials of the ecosystem.

In addition, inquiries into the canopy features (openness, closure, cover and Leaf area index) of the ecosystem with the use of hemispherical photographs are equally advocated. These baselines and others are very vital areas that will equally contribute to undertaking a species modelling for the ecosystem, which at the moment are lacking for the ecosystem.

7.7.4 Ecosystem dynamics and management

Present vegetation patterns of forest ecosystems are products of past events and regimes, as well as its current and evolving processes. Exploring the spatio-temporal changes in the ecosystem over a considerable historical time is needed in order to ascertain the trajectories of change in the ecosystem. This will not only help to better understand the present vegetation patterns, but will also be beneficial in providing insights to future vegetation trends. Furthermore, studies that will promote the understanding of the species-environment relationships in the ecosystem are equally needed at different scales across the ecosystem. On the other hand, there is also the need to conduct research on the climate change of the region and decipher its associated impacts on the ecosystem composition and ecological processes. Providing insights into this area of lack will help to provide the necessary information suitable for targeted decision making.

Management techniques adopted for the ecosystem not only determine the ecology of the ecosystem, but also future existence; yet adequate policies that may be most suitable for the ecosystem/region are still lacking. While this study has highlighted some aspects of management for the ecosystem/region, studies that would explore in detail suitable ecosystem and region specific management guidelines are of utmost importance. Such studies should seek to understand the suitable management techniques that would be ideal in promoting more carbon storage for the ecosystem under expected future rising temperatures, community forest management and participation effectiveness, and adequate policy for restoring and keeping the forest reserves viable; as well as other aspects of ecosystem management.

7.8 References

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Appendices

Appendix 1: List of taxa identified across the sites

Specie	Family
Abarema floribunda Benth.	Leguminosae
Albizia ferruginea Benth.	Leguminosae
Albizia sp Benth.	Leguminosae
Alstonia boonei De Wild.	Apocynaceae
Amphimas pterocarpoides Harms.	Leguminosae
Aningeria robusta A. Chev.	Sapotaceae
Anogeissus leiocarpus (DC). Guill&Perr.	Combretaceae
Anonidium mannii Engl & Diels	Annonaceae
Anthocleista djalonensis A. Chev.	Gentianaceae
Antiaris africana Engl.	Moraceae
Antiaris toxicaria Lesh.	Moraceae
Barteria fistulosa Mast.	Passifloraceae
Bombax buonopozense P. Beauv.	Malvaceae
Bosqueia angolensis Ficalho	Moraceae
Brachystegia eurycoma Harms	Leguminosae
Brachystegia leonensis Hutch. & Burtt Davy	Leguminosae
Brachystegia nigerica Hoyle & A.P.D. Jones	Leguminosae
Canthium hispidum Benth.	Rubiaceae
Ceiba pentandra Gaertn.	Malvaceae
Celtis zenkeri Engl.	Cannabaceae
Chrysophyllum albidum G. Don	Sapotaceae
Chrysophyllum perpulchrum Mildbr. ex Hutch. &Dalziel	Sapotaceae
Chytranthus sp Radlk.	Sapindaceae
Cleistopholis patens Engl. & Diels	Annonaceae
Coelocaryon preussii Warb.	Myristicaceae
Cola acuminata (P. Beauv.) Schott &Endl.	Malvaceae
Cola gigantea A. Chev.	Malvaceae

Cola glabra Brenan & Keay	Malvaceae
Cola laurifolia Mast.	Malvaceae
Cordia millenii Baker	Boraginaceae
Dacryodes edulis(G. Don) H. J. Lam	Burseraceae
Desplatsia dewevrei (De Wild. & T. Durand) Burret	Malvaceae
Dialium guineense Willd.	Leguminosae
Dichapetalum madagascariense Rowland & Irving	Dichapetalaceae
Digitaria debilis Willd.	Poaceae
Diospyros crassiflora Hiern	Ebenaceae
Diospyros dendo Welw. ex Hiern	Ebenaceae
Diospyros mespiliformis Hochst. ex A. DC.	Ebenaceae
Diospyros nigerica F. White	Ebenaceae
Discoglypremna caloneura Prain	Euphorbiaceae
Dryopteris floridana (Hook.) Kuntze	Dryopteridaceae
Elaeis guineensis Jacq.	Arecaceae
Enantia chlorantha Oliv.	Annonaceae
Entandrophragm candollei (Welw.) C. DC.	Meliaceae
Entandrophragm utile Sprague	Meliaceae
Entandrophragma angolense (Welw.) C. DC.	Meliaceae
Eribroma oblonga (Mast.) Pierre ex A. Chev.	Sterculiaceae
Erythrina sp Hurst.	Leguminosae
Erythrophleum ivorense A. Chev.	Leguminosae
Erythrophleum sp	Leguminosae
Ficus capensis Thunb.	Moraceae
Ficus exasperata Vahl	Moraceae
Ficus mucuso Welw. ex Ficalho	Moraceae
Funtumia elastica (P. Preuss) Stapf	Apocynaceae
Garcinia kola Heckel	Clusiaceae
Guarea cedrata Pellegr. ex A. Chev.	Meliaceae
Hallea ciliata J. -F. Leroy	Rubiaceae
Hallea stipulosa J.-F. Leroy	Rubiaceae
Hexalobus crispiflorus A. Rich.	Annonaceae

Holarrhena floribunda T. Durand & Schinz	Apocynaceae
Hunteria umbellata Hallier f.	Apocynaceae
Hylodendron gabunense Taub.	Leguminosae
Irvingia gabonensis (Aubry-Lecomte ex O'Rorke) Baill	Irvingiaceae
Isoberlina doka Craib & Stapf	Leguminosae
Khaya grandifoliola C. DC.	Meliaceae
Khaya ivorensis A. Chev.	Meliaceae
Lagerstroemia speciosa Pers.	Lythraceae
Lannea schweinfurthii Engl.	Anacardiaceae
Lannea welwitschii (Hiern) Engl.	Anacardiaceae
Lecaniodiscus cupanioides Planch.	Sapindaceae
Lophira alata Banks ex C. F. Gaertn	Ochnaceae
Lophira lanceolata Tiegh. ex Keay	Ochnaceae
Macaranga barteri Müll. Arg.	Euphorbiaceae
Maesopsis eminii Engl.	Rhamnaceae
Malacantha alnifolia Pierre	Sapotaceae
Mangifera indica L.	Meliaceae
Manilkara obovata J. H. Hemsl.	Sapotaceae
Margaritaria discoidea G. L. Webster	Phyllanthaceae
Melaleuca leucadendra L.	Myrtaceae
Memecylon afzelii G. Don	Melastomataceae
Memecylon sp G. Don	Melastomataceae
Milicia excelsa C. C. Berg	Moraceae
Milicia regia C. C. Berg	Moraceae
Millettia thonningii Baker	Leguminosae
Mitragyna inermis Kuntze	Rubiaceae
Mitragyna stipulosa Kuntze	Rubiaceae
Monodora myristica Dunal	Annonaceae
Morinda lucida Benth.	Rubiaceae
Morus mesozyia Stapf.	Moraceae
Musanga cecropioides R. Br. ex Tedlie	Urticaceae
Myrianthus arboreus P. Beauv.	Urticaceae

Napoleonaea vogelii Hook & Planch.	Lecythidaceae
Nauclea diderrichii de Wild	Rubiaceae
Nauclea stipulosa DC.	Rubiaceae
Nesogordonia papaverifera (A. Chev.) R. Capuron	Malvaceae
Octolobus angustatus Hutch.	Malvaceae
Parinari robusta Oliv.	Chrysobalanaceae
Patabea capitellata Wawra	Rubiaceae
Pentaclethra macrophylla Benth	Leguminosae
Pentadesma butyracea Sabine	Clusiaceae
Picralima nitida Th. & H. Dur.	Apocynaceae
Piptadeniastrum africanum (Hook. f.) Brenan	Leguminosae
Pterocarpus santalinoides L'Hér. ex DC.	Leguminosae
Pterocarpus soyauxii Taub.	Leguminosae
Pterocarpus indet	Leguminosae
Pterygota macrocarpa K. Schum	Malvaceae
Pycnanthus angolensis (Welw.) Warb.	Myristicaceae
Pycnanthus indet	Myristicaceae
Raphia indet	Arecaceae
Raphia sudanica A. Chev	Arecaceae
Rauvolfia indet	Apocynaceae
Rauvolfia vomitoria Wennberg	Apocynaceae
Rhizophora mangle L.	Rhizophoraceae
Rhizophora racemosa G. Mey	Rhizophoraceae
Rhizophora indet	Rhizophoraceae
Ricinodendron heudelotii (Baill.) Pierre ex Heckel	Euphorbiaceae
Rinorea dentata (P. Beauv.) Kuntze	Violaceae
Rothmannia indet	Rubiaceae
Spathodea campanulata P. Beauv.	Bignoniaceae
Spondias mombin L.	Anacardiaceae
Staudtia stipitata Warb.	Myristicaceae
Sterculia africana (Lour.) Fiori	Malvaceae
Sterculia oblonga Mast.	Malvaceae

Sterculia rhinopetala K. Schum.	Malvaceae
Sterculia tragacantha Lindl.	Malvaceae
Strombosia grandifolia Hook. f. ex Benth.	Olacaceae
Strombosia pustulata Oliv.	Olacaceae
Terminalia avicennioides Guill. & Perr.	Combretaceae
Terminalia glaucescens Planch. ex Benth.	Combretaceae
Terminalia indet	Combretaceae
Terminalia superba Engl. & Diels	Combretaceae
Tetrapleura tetraptera Taub.	Leguminosae
Treculia africana Decne. ex Trécul	Moraceae
Trichilia monadelpha (Thonn.) J. J. de Wilde	Meliaceae
Uapaca guineensis Müll. Arg.	Phyllanthaceae
Uapaca togoensis Pax	Phyllanthaceae
Vitex doniana Sweet	Lamiaceae
Xylopia aethiopica A. Rich.	Annonaceae
Zanthoxylum zanthoxyloides (Lam.) B. Zepernick & Timler	Rutaceae

Appendix 2: Species importance values for all the forest sites

Species	Akarai-Obodo	Akili-Ogidi	Akoloma	Otuwe
Abarema floribunda			4.438403	
Albizia ferruginea	1.688261			
Albizia spp				1.182647
Alstonia boonei	5.273127			1.134639
Amphimas pterocarpoides	1.666846			
Aningeria robusta			1.238174	
Anogeissus leiocarpus			0.531461	
Anonidium mannii		2.154593		
Anthocleista djalonensis	2.213826	1.262639	4.715954	1.182452
Antiaris africana	1.982069			
Barteria fistulosa			0.802661	
Bombax buonopozense	2.031561			
Bosqueia angolensis	4.167887		3.920141	1.182457
Brachystegia eurycoma	2.246022			3.904973
Brachystegia leonensis	1.576329			
Brachystegia nigerica	1.862433	5.379226		
Canthium hispidum	2.000241	2.151111	3.742889	
Ceiba pentandra	5.940044	6.490513	0.83738	
Celtis zenkeri	1.923731			26.32844
Chrysophyllum albidum	1.898732	1.075445		
Chrysophyllum perpulchrum		1.078215		
Chytranthus spp			2.95055	
Cleistopholis patens	29.45342	4.660224	2.207278	4.124914
Coelocaryon preussii			3.216961	
Cola acuminata		1.075155		
Cola gigantea	2.488194	2.347414		
Cola glabra		1.839652		
Cola laurifolia	0.825137	5.574301		
Cola millenii		1.258239		
Cordia millenii			7.167588	
Dacryodes edulis			3.629085	
Desplatsia dewevrei	3.51052			
Dialium guineensis	1.090339	2.344116		
Dichapetalum madagascariense	0.962355			
Digitaria debilis	0.962717			

Diospyros dendo	0.968501			
Diospyros crassiflora				4.506656
Diospyros mespiliformis	5.338611	1.074898		83.61359
Diospyros nigerica			0.803236	
Discoglypremna caloneura	3.609703			
Dryopteris floridana			2.554838	
Elaeis guineensis	52.00559	126.6598	64.22543	1.134632
Enantia chlorantha	1.273874		1.236749	
Entandrophragm candollei		1.080146		
Entandrophragm utile		2.247097		
Entandrophragma angolense	0.825435			
Eribroma oblonga	2.182032			
Erythrina spp			3.816683	
Erythrophleum ivorense	2.06397			13.31255
Erythrophleum spp				1.903386
Ficus capensis	0.825137	5.302325		
Ficus exasperata				2.317183
Ficus mucuso	8.633911	1.271621	1.500623	3.404889
Funtumia elastica	0.827792	5.028155	2.643213	
Garcinia kola		1.629011		
Guarea cedrata	1.812063	1.075882	0.433669	
Hallea ciliata	9.629677		1.20445	
Hallea stipulosa	0.828533			
Hexalobu crispiflorus		13.91045	0.467595	
Holarrhena floribunda	0.962355	1.444515		
Hunteria umbellata	0.837557			1.134745
Hylodendron gabunense	0.962355	9.223245	5.149262	
Irvingia gabonensis	0.827444	6.319821	1.95914	
Isoberlina doka		5.364762		
Khaya grandifoliola	1.172013			1.134665
Khaya ivornensis	4.094591		1.868838	
Lagerstroemia speciosa		5.930298		
Lannea schweinfurthii		1.082442		
Lannea welwitschii			8.350602	
Lecaniodiscus cupanioides	1.662038	2.342669		2.317108
Lophira alata	9.547587			
Lophira lanceolata			3.978912	
Macaranga barteri	2.196274		3.055894	
Maesopsis eminii			1.303244	
Malacantha alnifolia	0.970397	2.158558		
Mangifera indica		2.771867		

Manilkara obovata			1.804278	
Margaritaria discoidea	0.825137	1.278033		
Melaleuca leucadendra	0.833518			
Memecylon afzelii	0.825282	1.076123		
Memecylon spp			0.401347	
Milicia excelsa		3.515729	0.802707	
Milicia regia		1.075345		
Millettia thonningii		2.338638		1.134632
Mitragyna inermis	0.831446			
Mitragyna stipulosa	4.380536			
Monodora myristica	1.815984	1.474119	5.492769	
Morinda lucida		3.438922		
Morus mesozyia	0.824802			
Musanga cecropioides	1.857842		4.43895	
Myrianthus arboreus	2.23528			
Napoleonaea vogelii	2.94418			1.278873
Nauclea diderrichii		1.078215		
Nauclea stipulosa	2.884921			6.566734
Nesogordonia papaverifera				1.328563
Octolobus angustatus			6.566825	
Parinari robusta	2.266607			2.221846
Patabea capitellata	1.655753			
Pentaclethra macrophylla	0.827133			
Pentadesma butyracea			2.935735	
Picralima nitida	0.963652	2.539741	1.405406	
Piptadeniastrum africanum	2.210919		1.206158	
Pterocarpus santalinoides	3.455573	1.258704	0.802746	6.437034
Pterocarpus soyauxii				5.331148
Pterocarpus spp				4.237953
Pterygota macrocarpa		1.776064		
Pycnanthus angolensis	2.866712		4.507812	1.23056
Raphia spp			18.17869	
Raphia sudanica	2.930847			
Rauvolfia spp	1.649942			
Rauvolfia vomitoria		1.074745		
Rhizophora mangle	0.831446			
Rhizophora racemosa	7.91984		72.94143	2.317417
Rhizophora spp			2.593509	
Ricinodendron heudelotii	0.834263	1.298952		
Rinorea dentata	1.647195		4.210137	
Rothmannia spp			1.269265	

Spathodea campanulata	1.794041	3.254281		
Spondias mombin	6.178376	10.74476		
Staudtia stipitata			5.94397	
Sterculia africana		1.139104	1.204559	
Sterculia oblonga	28.07248			66.29354
Sterculia rhinopetala	4.12768	1.077231		35.51309
Sterculia tragacantha		2.933026	1.545593	1.376623
Strombosia grandifolia				3.120082
Strombosia pustulata	5.322241	1.633595	0.835205	4.291599
Terminalia avicennioides	2.516946			
Terminalia glaucescens	1.139711			
Terminalia spp				1.134634
Terminalia superba	1.42714		0.629301	
Tetrapleura tetraptera				1.134715
Treculia africana	6.577993	8.526626		
Trichilia monadelpha		6.247534	0.401355	
Uapaca guineensis		1.075345		
Uapaca togoensis	0.977829		8.209196	
Vitex doniana		3.387174		
Xylopia aethiopica	1.725525	1.074859	3.323615	1.231034
Zanthoxylum zanthoxyloides		1.074745		

Appendix 3: Family importance values of the forest sites

Family	Akarai-Obodo	Akili-Ogidi	Akoloma	Otuwe
Anacardiaceae	2.326875392	10.7531479	6.835891	-
Annonaceae	21.54616439	24.0358095	13.1688	6.327382
Apocynaceae	13.68306688	10.9453741	4.371378	5.500882
Arecaceae	31.43476464	111.73514	89.84991	2.750374
Bignoniaceae	1.647105548	2.29498454	-	-
Boraginaceae	-	-	5.486812	-
Burseraceae	-	-	2.851714	-
Cannabaceae	11.46649296	-	-	20.75239
Chrysobalanaceae	2.943130047	-	-	2.750537
Clusiaceae	-	2.45855428	2.527745	-
Combretaceae	6.697683047	-	4.060262	2.750375
Dichapetalaceae	1.513550285	-	-	-
Dryopteridaceae	-	-	2.501104	-
Ebenaceae	3.560009764	1.90604619	1.883234	72.36145
Euphorbiaceae	20.90501934	2.12362815	2.285266	-
Gentianaceae	1.793739678	2.09279409	3.531392	2.798137
Irvingiaceae	1.381257431	4.38585439	1.909408	-
Lamiaceae	-	3.30263665	-	-
Lecythidaceae	2.485428041	-	-	2.894153
Leguminosae	28.45146696	24.91781	18.26146	40.5147
Lythraceae	-	6.54819949	-	-
Malvaceae	43.41755092	31.5052189	13.05568	106.9306
Melastomataceae	1.380086734	1.90708591	1.850513	-
Meliaceae	8.583727185	16.0890486	5.944566	2.750395
Moraceae	22.47994868	19.8750625	7.260442	8.491825
Myristicaceae	1.582812675	-	10.86418	5.548783
Myrtaceae	1.384547581	-	-	-
Ochnaceae	3.758184234	-	3.541126	-
Olacaceae	2.486928279	2.46244664	1.915296	7.400022
Passifloraceae	-	-	1.88282	-
Phyllanthaceae	4.846542261	4.0216475	7.189602	-
Poaceae	2.934935178	-	-	-
Rhamnaceae	-	-	2.013734	-
Rhizophoraceae	3.985304624	-	64.42381	2.846018
Rubiaceae	34.70823489	6.52173711	6.51041	3.786145

Rutaceae	-	1.90591623	-	-
Sapindaceae	4.100367167	2.27905925	2.547453	2.845823
Sapotaceae	3.91789855	5.93279789	4.098398	-
Sterculiaceae	1.942724369	-	-	-
Urticaceae	5.119861064	-	3.944741	-
Violaceae	1.534591196	-	3.432862	-

Appendix 4: Biodiversity indices of the different forest sites

Site location	Plot number	Diversity	Richness index	Evenness
Akarai-Obodo	1	4.03	6.55	0.83
Akarai-Obodo	2	4.04	6.36	0.86
Akarai-Obodo	3	4.38	8.65	0.88
Akarai-Obodo	4	3.56	5.4	0.78
Akili-Ogidi	5	3.53	7.65	0.68
Akili-Ogidi	6	3.64	5.88	0.77
Akili-Ogidi	7	2.88	4.68	0.73
Akili-Ogidi	8	3.31	3.74	0.81
Akoloma	9	3.23	4.75	0.66
Akoloma	10	3.52	5.85	0.7
Akoloma	11	3.36	4.86	0.7
Akoloma	12	3.48	5.16	0.72
Akoloma	13	3.32	5.38	0.67
Akoloma	14	3.83	6.63	0.76
Akoloma	15	3.58	5.67	0.73
Akoloma	16	3.82	6.42	0.76
Otuwe	17	3.13	2.47	0.83
Otuwe	18	2.78	1.43	0.81
Otuwe	19	1.98	0.52	0.7
Otuwe	20	2.88	3.26	0.64
Otuwe	21	2.44	2.16	0.55
Otuwe	22	2.47	1.34	0.71
Otuwe	23	2.85	1.91	0.75
Otuwe	24	2.76	1.71	0.77

Appendix 5 Indicator species across the ecosystem

Family	Species	Group	IV	p (significance level)
Moraceae	*Treculia africana* Decne. ex Trécul	# 1	1	0.001
Anacardiaceae	*Spondias mombin* L.	# 1	0.935	0.001
Malvaceae	*Ceiba pentandra* Gaertn.	# 1	0.897	0.001
Malvaceae	*Cola gigantea* A. Chev.	# 1	0.791	0.005
Malvaceae	*Cola laurifolia* Mast.	# 1	0.791	0.007
Bignoniaceae	*Spathodea campanulata* P. Beauv.	# 1	0.791	0.006
Moraceae	*Ficus capensis* Thunb.	# 1	0.707	0.023
Leguminosae	*Isoberlinia doka* Craib & Stapf	# 1	0.707	0.025
Apocynaceae	*Alstonia boonei* De Wild.	# 1	0.685	0.047
Annonaceae	*Hexalobus crispiflorus* A. Rich.	# 1	0.681	0.025
Leguminosae	*Abarema floribunda* Benth.	# 2	1	0.001
Leguminosae	*Erythrina indet*	# 2	1	0.001
Anacardiaceae	*Lannea welwitschii* (Hiern) Engl.	# 2	1	0.001
Arecaceae	*Raphia indet*	# 2	1	0.001
Myristicaceae	*Staudtia stipitata* Warb.	# 2	1	0.001

Rhizophoraceae	*Rhizophora racemosa* G. Mey	# 2	0.984	0.001
Annonaceae	*Monodora myristica* Dunal.	# 2	0.959	0.001
Myristicaceae	*Coelocaryon preussii* Warb.	# 2	0.935	0.001
Burseraceae	*Dacryodes edulis* (G. Don) H. J. Lam	# 2	0.935	0.001
Phyllanthaceae	*Uapaca togoensis* Pax.	# 2	0.929	0.001
Myristicaceae	*Pycnanthus angolensis* (Welw.) Warb.	# 2	0.923	0.002
Gentianaceae	*Anthocleista djalonensis* A. Chev.	# 2	0.911	0.003
Violaceae	*Rinorea dentata* (P. Beauv.) Kuntze	# 2	0.875	0.001
Sapindaceae	*Chytranthus indet*.	# 2	0.866	0.001
Boraginaceae	*Cordia millenii* Baker	# 2	0.866	0.001
Dryopteridaceae	*Dryopteris floridana* (Hook.) Kuntze	# 2	0.866	0.001
Ochnaceae	*Lophira lanceolata* Tiegh. ex Keay	# 2	0.866	0.001
Clusiaceae	*Pentadesma butyracea* Sabine	# 2	0.866	0.001
Urticaceae	*Musanga cecropioides* R. Br. Ex Tedlie	# 2	0.844	0.002
Annonaceae	*Xylopia aethiopica* A. Rich	# 2	0.829	0.009
Moraceae	*Bosqueia angolensis* Ficalho	# 2	0.807	0.016
Rhizophoraceae	*Rhizophora indet*.	# 2	0.791	0.008
Euphorbiaceae	*Macaranga barteri*	# 2	0.783	0.004

	Müll. Arg.			
Sapotaceae	*Manilkara obovata* J. H. Hemsl.	# 2	0.707	0.022
Malvaceae	*Octolobus angustatus* Hutch.	# 2	0.707	0.027
Ebenaceae	*Diospyros mesipiliformis* Hochst. ex A. DC.	# 3	0.987	0.001
Malvaceae	*Sterculia rhinopetala* K. Schum.	# 3	0.975	0.001
Malvaceae	*Sterculia oblonga* Mast.	# 3	0.912	0.001
Cannabaceae	*Celtis zenkeri* Engl.	# 3	0.861	0.001
Leguminosae	*Erythrophleum ivorense* A. Chev.	# 3	0.853	0.004
Arecaceae	*Elaeis guineensis* Jacq.	# 1 & 2	0.968	0.001
Leguminosae	*Hylodendron gabunense* Taub.	# 1 & 2	0.901	0.001
Leguminosae	*Brachystegia nigerica* Hoyle & A.P.D. Jones	# 1 & 2	0.866	0.002
Rubiaceae	*Canthium hispidum* Benth.	# 1 & 2	0.829	0.008
Apocynaceae	*Funtumia elastica* (Preuss) Stapf	# 1 & 2	0.791	0.009
Irvingiaceae	*Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill.	# 1 & 2	0.791	0.007
Meliaceae	*Khaya ivorensis* A. Chev.	# 1 & 2	0.75	0.032

Appendix 6: Questionnaire

HOUSEHOLD SURVEY FOR ASSESSING FOREST USE AND DEGRADATION IN THE NIGER DELTA

Date ………………….. Village ……………………………..

Local Government Area ……………………………………….. State ………………………..

SECTION A

FOREST ECOSYSTEM, VISIT AND PURPOSE

A1. Have you ever visited the forest in your community?

1. Yes ………. 2. No …………..

A4. What is your frequency of forest visit?

1. Yearly ………. 2. Monthly …………….. 3. Weekly …………………
4. Daily …………… 5. Others (specify) ……………………………………………….

A5. Why do you visit the forests? (Can provide as many reasons as possible)

………
………
……………………………………

SECTION B

FOREST EXTENT, DISTURBANCE AND CONSERVATION

B1. Do you know what the forest was used for about 50 years ago?

1. Evil forest …………………………… 2. Sacred grove …………………… 3. Farmland …………………

4. Communal Oil palm bush …………... 5. Others (specify) ………………………………………………….

B2. What is your view about the extent of the forest for the past 10 – 40 years?

1. Decreased ………….. 2. Increased …………….. 3. Same ……………………….

B3. What are the causes of forest loss in your community?

……

B4. Suggest how the forests could be effectively conserved.

………..

SECTION C

FOREST MANAGEMENT

C1. Who owns the forest in your community?

1. Government ……………… 2. Community ……………….. 3. Households/families ………………

4. Others (specify) ………………………….

C2. Do you do anything in particular to care for or preserve the forest?

1. Yes ………………… 2. No …………………………….

C3. Are there any restrictions to forest use in your community?

………

………

…………………………………..

SECTION D

ECOSYSTEM SERVICES AND LIVELIHOOD ASSESSMENT

D1. Rank (√) the following Provisioning services in their order of importance to you and your family.

S/N	Provisioning Function	Highly important	Important	Neutral	Not important	Not at all important
1	Food (Edibles like fruits, vegetables, nuts, etc)					
2	Fuel wood (Firewood)					
3	Wood (Timber, logs)					
4	Grazing/Pasture land					
5	Medicines/Herbs					
6	Bush meat (Game)					
7	Fishery					

8	Snails					
9	Composting					

D2. Do you think that the forest products and services are reducing?

Yes ………………… 2. No …………………………..

D3. What do you think is the cause of the loss or reduction of forest products/resources?

1. Road/Canal construction ………….. 2. Oil pollution ………….. 3. Natural causes …………..
4. Agricultural activities …….. 5. Government (Policies and activities) ………………..
6. Population increase ……………
7. Others (specify) …………………………………………………………..

D4. How important are the forests at different distances from your house to your livelihood?

S/N	Distance to forest	Highly important	Important	Neither important or unimportant	Not important	Not at all important
1	Forests found within your neighbourhood					
2	Forests located some distances away from					

	your house but within your village					
3	Forests found far away from your village					

D5. What response (with reference to your livelihood) have you adopted (or will adopt) to the reduction in forest resources/products in your area?

……………………………………………………………………………………………………

……

…………………

SECTION E

SOCIO DEMOGRAPHIC VARIABLES

E1. What is your highest level of education?

1. No formal education ……….. 2. Primary ………… 3. Secondary ………… 4. Diploma/NCE …………… 5. Bachelor's degree ……………. 6. Master's degree ………… 7. Others (specify) ……………………

E2. What is your age group?

1. Less than 20 (16 – 20) ………….. 2. 21 – 30 ……………. 3. 31 – 40 ……………
4. 41 – 50 ……………. 5. 51 – 60 …………….. 6. Above 60 …………………

E3. Which of the following best describes your full time occupation? (Tick (√) only one option)

1. Farming [ ] 2. Government employee [ ] 3. Teaching [ ] 4. Fishing [

] 5. Trading [ ] 6. Craft making [ ] 7. Collection of snails and shellfish (oysters, crabs and periwinkles) [ ] 8. Labourer (Hired) [ ] 9. Unemployed [ ] 10. Others (specify) [ ]

Appendix 7 Additional data used in the work

Location	Bio1	Bio12	Axis1	Axis2	Elev	Dist
Akaria-obodo	268	2204	0.822692	1.0525454	38	7.52
Akaria-obodo	268	2204	0.896235	1.169249	15	7.52
Akaria-obodo	268	2204	1.387634	1.744988	31	7.52
Akaria-obodo	268	2204	0.880419	2.31215	30	7.52
Akili-ogidi	267	2096	1.966697	1.658542	19	3.39
Akili-ogidi	267	2096	1.778361	1.503837	12	3.39
Akili-ogidi	267	2096	1.805283	1.318352	34	3.39
Akili-ogidi	267	2096	1.6712	1.286415	14	3.39
Akoloma	257	2448	1.825542	0.561718	40	1.38
Akoloma	257	2448	1.76673	0.623516	42	1.38
Akoloma	257	2448	1.796046	0.630904	10	1.38
Akoloma	257	2448	1.797839	0.595836	12	1.38
Akoloma	257	2448	1.781981	0.647948	21	1.38
Akoloma	257	2448	1.740949	0.509546	21	1.38
Akoloma	257	2448	1.759294	0.59679	20	1.38
Akoloma	257	2448	1.775372	0.516752	23	1.38
Otuwe	266	2266	0.01166	1.415572	40	15.04
Otuwe	266	2266	-0.20467	0.9060463	18	15.04
Otuwe	266	2266	-0.32285	0.687089	43	15.04
Otuwe	266	2266	-0.08571	0.9102205	20	15.04
Otuwe	266	2266	-0.22169	0.650307	40	15.04
Otuwe	266	2266	-0.23855	0.806904	24	15.04
Otuwe	266	2266	-0.18013	0.878533	28	15.04
Otuwe	266	2266	-0.21034	1.0162423	33	15.04

Bio 1 = Mean annual temperature

Bio 12 = Mean annual rainfall

Elev = Elevation

Dist = Disturbance