DEPARTMENT OF MARINE AND FISHERIES SCIENCES

UNIVERSITY OF GHANA

COMPARATIVE STUDY OF THE MANGROVE ECOSYSTEMS OF DOUALA-EDEA RESERVE (CAMEROON) AND SONGOR RAMSAR SITE (GHANA) USING PARAMETERS OF ECOLOGICAL VALUE

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DECLARATION

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA: Analysis of variance
BA: Basal Area
CEPFILD: Circle of Forest promotion and initiative local development
CERECOMA: Research Centre for Coastal and Marine Sciences Cameroon
CWCS: Cameroon Wildlife Conservation society
DBH: Diameter at Breast Height
DFA: Discriminant Function Analysis Rhizophora stand in Cameroon
EC: Electrical Conductivity
ECEC: Effective Cation Exchange Capacity
ECOLAB: Ecology Laboratory Centre
FAO: Food and Agriculture Organization
GAEC: Ghana Atomic Energy Commission
GLOMIS: Global Mangrove Database and Information System
ITTO: International Tropical Timber Organization
IRAD: Institut of Agricultural Research for Development
LSD: Least Significant Difference
MCL: Maximum Contaminant Level
NGO: Non Governmental Organization
NUE: Nutrient Use Efficiency
PSR: Paraíba do Sul River
PCA: Principal Component Analysis
PCQM: Point-Centered Quarter Method
SECAM: Symposium des Conférences Episcopales d’Afrique et de Madagascar
TS: Targeted sampling
UNEP: United Nations Environment Programme
WCMC: World Conservation Monotoring Centre
WRC: World Rainforest Conservation

ABSTRACT

In most tropical countries including Ghana and Cameroon, knowledge of ecological importance of mangrove ecosystem in terms of litter production, structural characteristics, water and soil properties, has been qualitatively well documented and recognised. However, there is scanty quantitative scientific data to back this up. The purpose of this research dissertation was to study and compare the mangrove ecosystems of Cameroon and Ghana two contrasting coastal zones, using parameters of ecological value and to have a better understanding of their interrelationships within mangrove ecosystem as well as the impact of their values or roles to the global ecosystem (marine and coastal) within the West and Central African ecoregion.

The study was conducted within the period of two years for both countries (One year in each country), Two major sites were chosen in Ghana (Songor Ramsar site) and Cameroon (Douala Edea Reserve). In each site, three mangrove stands: 1) *Avicennia*, 2) *Rhizophora* and mixed (*Rhizophora* and *Avicennia*) were selected and marked out, and parameters like litterfall, structural characteristics, water and soil properties were assessed.

This research on mangrove ecosystem addressed four objectives: (1) assessment of the structural parameters; (2) assessmentof litter production; (3) determination of physicochemical and climatic factors affecting mangrove structure and productivity; (4) Show the interrelationships between mangrove resources in both countries.

The results in both countries showed that, (1) Leaves, twigs, flowers and fruits were present in litter samples all over the study period with highest peak mainly in the dry season, and leaf production accounted for more than 80% in each country; (2) High values of most of the major nutrients (N, P, K, Mg, Ca) investigated and used in evaluation of mangrove ecosystem

importance were recorded between March and October for Cameroon mangroves and in December for Ghana mangroves.

(3) The mean highest species density was observed in *Rhizophora* for Cameroon and *Avicennia* and mixed in Ghana. The mangrove of Cameroon showed greater heights than their Ghanaian counterparts. (4) The values of Physical parameters (DO, BOD, EC, TDS, TSS), and nutrients were most often high in Cameroon, compared to Ghana. Mangrove waters were also found more alkaline in Cameroon than in Ghana. (5) It was observed that in both countries, *Avicennia* had the highest percentage of silt. In addition to that nitrogen ,phosphorus, leaves (Litterfall), nitrate, Biochemical Oxygen Demand, pH, Phosphate, salinity, Conductivity (Mangrove Water), percentage organic nitrogen, electrical conductivity, acidity, Exchangeable magnesium, ECEC Effective Cation Exchange Capacity, and available phosphorus Av P (Mangrove Soil), height, basal area and density (Structural characteristics) were the major discriminatory ecological features of the mangroves of Ghana and Cameroon. Correlations with litterfall, structural, water and soil variables indicated that mangrove ecosystem within and across the countries respond differently to environmental conditions.

The combination of rainfall, temperature and salinity was a good predictor of variability in the production of litterfall in both countries.

This study contributes to a better understanding of how mangrove ecosystems function. Additional work in other geographic areas within the West and Central African ecoregion is needed to provide a broader perspective on the ecological importance of mangrove ecosystem and their impact on the nearby marine and coastal areas.

CHAPTER 1

1.0 INTRODUCTION

1.1 Statement of the research Problem

Mangroves are woody plants, which grow in loose wet soils of brackish-to-saline estuaries and sheltered low-wave energy shorelines in the tropics and sub-tropics (Joshi and Ghose, 2003). Mangrove wetlands are prominent coastal features of the intertidal zone in tropical estuarine ecosystems (Twilley *et al.*, 1998; Mendelssohn *et al*., 2000). There are about 80 species of mangroves found throughout the world (Saenger *et al*., 1983), with total global mangrove coverage estimated to be about 180,000 km^2 (Tam and Wong, 2000), distributed circumtropically in 112 countries and territories. Mangroves occupy 75% of the tropical coastlines in the world, an estimated area of 22 million hectares. Spalding *et al*. (1997) estimated mangrove forest cover in the African continent to be about 19% of global coverage. This is an equivalent of 34200 km^2, covering 34 countries of the three African Ecoregions (West and Central, East, and South including Ghana and Cameroon targeted by this study.

The total area of land occupied by mangroves along Ghana's coastline of about 550 km long, is estimated to be around 137 km^2 (Saenger and Bellan, 1995; Armah *et al.*, 2009). For Cameroon the area occupied by mangrove vegetation is 1957 km^2 along the coastline of about 402 km (UNEP, 2007; Ajonina, 2008).

Mangrove forests are made up of diverse, salt-tolerant trees and other plant species which have adapted to inter-tidal zone of sheltered tropical shores, "overwash" islands, and estuaries. The mangrove forests of the world are extremely important habitats for a number of other reasons.

They offer refuge and nursery grounds for juvenile fish, crabs, shrimps and mollusks, and are prime nesting grounds and migratory sites for hundreds of bird species. A wide variety of organisms utilize mangrove habitats, including many endangered species (Ramsar-Mava- UNEP, 2012). An estimated 75 percent of fish caught commercially spend some time in the mangroves and are dependent on food chains which can be traced back to these coastal forests (UNEP, 2007; Spalding *et al*., 2010). Most of the studies focussed on the ecological importance or value of mangrove ecosystem all over the world, but still there is a strong need to deeply address ecological topics or aspects in the tropical coastal zone (Twilley *et al*., 1998; UNEP, 2007 Ajonina, 2008; Egnankou, 2009; Spalding *et al.*, 2010; Conchedda *et al*., 2011; Dahdouh Guebas, 2011).

Ecology broadly describes the myriad of abiotic and biotic mechanisms and interrelations involved in the moving of energy and nutrients, regulating population and community structure and dynamics (Kormondy, 1969; Hogarth, 1999). The concept of 'ecological value' or importance of a given ecosystem , is sometimes used to describe the internal functioning of the ecosystem (e.g. maintenance of energy fluxes, nutrient (re)cycling, food-web interactions), which relates to the benefits derived by humans from the properties and processes of ecosystems (e.g. food production and waste treatment) (de Groot *et al.*, 2003; Alongi, 2008 ; Bosire and Kairo, 2009). Ecosystem functions or values are then defined as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (Crona, 2006; Radhika, 2006). Many goods and services have been attributed to mangroves as they: 1) provide food to consumers, 2) modify the water quality of adjacent estuaries, 3) regulate important processes of estuarine chemical cycles, 4) contribute to shoreline protection, and 5) produce a variety of forest products (Banus, 1975); Tam *et al*., 1998; Piersman and Ntiamoa, 1995; Crona, 2006; Radhika, 2006).

To assess the importance of mangrove ecosystems from a scientific perspective, it is quite necessary to attempt to determine some key parameters of ecological value such as litterfall, structural characteristics, water and soil properties (Crona, 2006; Ajonina, 2008; Spalding *et al.*, 2010). Moreover, Gong and Ong (1990); Twilley *et al.*, 1997 and Wafar *et al*. (1997); (Gary, 2004); Conchedda et *al.*, 2011; Aheto *et al.*, 2011) in terms of mangrove ecosystem, considered the knowledge of forest productivity (litterfall), structural characteristics, water and soil properties as crucial factors or parameters in understanding the importance and role of mangrove forests and their impact on the adjacent aquatic systems.

Considering their high ecological importance or value as stated above, those parameters (Litterfall, structural characteristics, water and soil properties) have been selected in this study to get a better understanding of mangrove ecosystem function and their impact on marine ecosystem stability.

Many scientists have conducted extensive research on different aspects of mangrove forest ecology. Some studies, have focused on the ecological function of mangrove forest and the strong relationship with the socio- economic values of those mangrove ecosystems (Crona, 2006) Research in Ghana and Cameroon contrast too much of the rest of the world and the ecology of the mangrove ecosystems in Cameroon and Ghana has received a relatively little attention.

In Ghana the studies of mangrove ecology has not been as well quantitify as the lowland forest and savanna, judging by the rather few publications available. Taylor (2003) has some information on the phenology and silviculture of *Rhizophora* and *Avicennia*; White (1983), Lawson, (1986) and Agyepong *et al*. (1990) provide some descriptive information on the mangrove vegetation and environment, while Sackey *et al.* (1993) showed that over-cutting and pollution from industrial and domestic waste are responsible for the poor state of the mangroves and studied broadly some ecological aspects of mangrove at Korle Lagoon. Agyepong *et al.* (1990) have reported a general paucity of information on the fauna of the mangrove ecosystem. Gordon *et al.* (2009) presented some descriptive information on the economic importance of mangrove in the Lower Volta.

From the studies available about the mangrove forests of Ghana, the issue of ecological importance has been slightly tackled. Armah *et al*. (1997) stuying about mangrove forest structure, noticed that among the mangrove species, *Rhizophora* and *Avicennia* are the most common. A mature forest of *Rhizophora* and *Avicennia* species may grow to a height of 20 m to 30 m and individuals may attain a diameter at breast height (i.e. 1.3 m) of between 30 cm to 120 cm. Sackey *et al.* (1996) have provided some information on mangrove regeneration and productivity and demonstrated that regeneration of seedlings is good where there is a high leaf litter production and litter production is high, where there is no pollution and water exchange is quite good. Amatekpor (1997) showed that soils of the mangrove swamps are liable to acid sulphate formation. The mangrove vegetation, especially its dense fibrous roots, in the swamps facilitates the accumulation of organic and inorganic elements and helps in the building up of sediments by trapping mud and controlling erosion.

Fiagbedzi (2001) noticed that, soils used in nursing *Avicennia.germinans* may be utilized preferentially in the order of silty clay (at 0‰ freshwater application), sandy loam at (0‰

freshwater application), silty clay loam (5‰ saline water application), sand (5‰ saline water application) and clay loam (5‰ saline water application), for optimal biomass production. Armah *et al*. (2009), while evaluating reforested mangrove in the Obane community of Ada, showed that in the *Rhizophora* stand, densities of trees and seedlings are respectively 3,800 stems/ha and 15,000 seedlings/ha. While for *Avicennia, d*ensity of seedling is 2,400 seedlings/ha. He also demonstrated that nutrients concentrations (nitrate, phosphate and sulphate) were generally higher for the *Rhizophora* site and lowest in the river, except phosphate for which the least concentration was recorded at the *Avicennia* site. In addition, TDS and conductivity are higher in *Rhizophora* than in *Avicennia* and the river.

In Cameroon there are relatively few publications on mangrove forest ecology. Din (1993) and Abata (1994), have some information on the phenology, systematic, silviculture and ecology of mangrove in Cameroon; Angwe and Gabche (1997); Din and Blasco (1998) provide some descriptive information on the mangrove vegetation, climatology, biodiversity structure and environment, while Ajonina and Usongo (2001); Din and Ngollo (2003) showed that over-exploitation of mangrove forest and sometimes pollution by industrial and domestic waste strongly affect climate change. Din (2001) showed that, mangroves have a high ecological importance in terms of growth rate, population and dynamics, community structure and patterns of primary productivity. Ajonina and Usongo (2001), Din and Ngollo (2003) have given some scarce information on the growth and yield of mangrove stands. Ajonina and Usongo (2001) then observed the stocking rates of 1,247.5 stems/ha; 42.38 m^2/ha basal area and 558.20 m^3 of standing volume in Douala- Edea Reserve. They noticed also that, variation in the growth characteristics of trees occurs between ecosystems, habitats and even within species. Ajonina

(2008), showed that estuarine mangrove in Cameroon attain maximum height of 59 m and diameter of 131,7 cm. Stand density, basal area, volume and total trees above ground biomass in undisturbed stands varied from 400-20100 trees/ha. The standing biomass values, are then among the highest in the world mangrove. He demonstrates also that, mangrove trees are really important ecologically and need to be well preserved and exploited in a sustainable manner.

Din (2001), by studying the general ecological status of mangrove in Cameroon, noticed that the litterfall production is higher in *Avicennia* stand compared to *Rhizophora* stand. Mangrove salinity in Cameroon is between 0-20‰. In the rainy season the salinity is always less than 10‰ and in the dry season it is varied between 4-20‰. He also observed that sulphide and salinity are stress environmental factors that affect the growth of mangrove trees. Ajonina (2008) and Din (2001) acknowledged the high ecological value of mangrove trees and link this value to their economical importance, by proposing a model of sustainable exploitation of mangrove forest woods.

Fundamentally it appears that, Ghana and Cameroon are truly contrasting zones within the West – Central African landscape.

It clearly appears that, the ecological importance or value of mangroves in most tropical countries including Ghana and Cameroon have been qualitatively well documented and recognised. However, there is little quantitative scientific data to back this up. Most of the evidence is observational and anecdotal (FAO, 2006; Ajonina, 2008; Wang, *et al*., 2010); Dahdouh-Guebas, 2011). In Ghana and Cameroon, numerous scientific articles have been published, but none have properly examined and compared mangrove ecological value or importance in terms of litter production, structural characteristics , water and soil properties, how those crucial parameters or aspects interact and the link with marine ecosystem stability in each country and, the interrelationships of the ecological importance of those parameters in both countries, in the coastal zones of Cameroon and Ghana in the West- Central African Ecoregion. This study is therefore intended to contribute scientifically in this regard.

1.2 Justification of the study

Mangroves constitute a unique tropical ecosystem, occurring most extensively along the protected coastal shores with muddy to sandy bottoms, which are alternately covered and uncovered by tidal fluxes. In general geography, coastal topography (including geomorphology), and tidal regime determine the presence or absence and extent of the mangroves. Structure, physical properties and chemical composition, salinity, acidity of the soil and sediments, the nature of the substratum as well as the climate, determine the development growth and productivity of the mangrove ecosystem. (FAO, 1994; Din *et al.*, 2008). Ecologically, mangroves represent a rather sharp transitional gradient between the marine and fresh water environments. Thus, only flora and fauna that have broad physiological tolerance can survive (IITO, 2002). Mangroves of the Cameroon and Ghana coasts still have enormous potentials, despite the destruction of their areas (Gabche and Smith, 2006) and (Armah *et al.*, 2009). Because of the importance of mangrove forests, many scientists have conducted extensive research on Floristic composition and distribution of species, ecology productivity, econonomic utilization and regeneration strategies of the main species. (Tomlinson, 1986; Kjerfve *et al.*,1997; Sarayudh, 2001; Din *et al.*, 2002; Kairo *et al*, 2002; UNEP,2007; Ajonina *et al*,2008; Armah *et al*, 2009)

In terms of mangrove productivity, biomass and nutrient cycling, some basic studies have been carried out as follows: In 1974, Lugo and Snedaker developed a classification scheme for mangroves based on tidal and hydro-period characteristics. Implicit in their scheme, was the assumption that this environmental factor was the most important component of the energy signature of a mangrove forest (Lugo and Snedaker, l974). This classification system, further modified by Cintron *et al*. (1980), serves to identify some common patterns of mangrove response, to varying environmental conditions and it remains a useful framework for the first-approximation in classification of mangrove stands. As amended, it recognized three general forest types: riverine, fringe and overwash and basin. As a general rule, riverine forests exhibit the highest level of structural development, followed by basin, and finally by fringe and over-wash types.

Kathiresan (1997), Metcalfe (1999) revealed that productivity is a concept used to describe the ecological value or function of a vegetation community. Some studies have used the collection and measurement of leaf litter fallen from a mangrove area over a particular period of time, as a guide to productivity. These studies have shown that mangrove ecosystems have the ability to produce large quantities of litter, ranging from 10,000 to 14,000 kg dry weight ha-1 year-1 (Hamilton and Snedaker, 1984). Specific work in this area has been undertaken in the Darwin Harbour with research indicating that, Darwin Harbour mangroves have an average rate of leaf litter production estimated to be 7,680 kg dry weight ha-1 year-1 (Metcalfe, 1999).

The mangrove ecosystems in Ghana and Cameroon have not been well studied, that is why only some few research publications are available. Some scientists have just provided some descriptive information on: phenology and silviculture of *Rhizophora* and *Avicennia* (Lawson, 1986; Agyepong *et al*., 1990; Din *et al*, 2008; Ajonina *et al*, 2008; Nfotabong, 2011). There is little information about productivity (Sackey *et al*., 1993; Ajonina *et al.*, 2008; Din *et al*., 2008), ecological character, inventory of mangrove resources (Din, 2001; World Bank, 2003; Ajonina, 2008, Nfotabong, 2011).

This study is therefore expected to contribute scientifically to increase ecological knowledge, to our current understanding of the essence of the high value or importance attributed by scientists to the ecological functions and processes of mangrove ecosystem parameters such as litter production, structural characteristics, water and soil properties, in both countries within the West-Central African Ecoregion. In addition to that, the interrelationships of those values in these two contrasting ecosystem within the West and Central African Ecoregion, will be established and definitely additional information generated, will contribute to the consolidation and increase of the knowledge in terms of ecological value of African mangrove ecosystems in the Global Mangrove Database and Information System(GLOMIS).

1.3 Study Objectives

1.3.1 General Objective

This research aims at studying and comparing key mangrove ecological values or importance of selected parameters (Structural characteristics, litter production, water and soil properties) in the coastal zones of Cameroon and Ghana, to have a better understanding of the interrelationships of the selected parameters of mangrove ecosystem as well as the impact of their values to the global ecosystem (marine and coastal ecosystems) in both countries within the West -Central African Ecoregion.

1.3.2 Specific Objectives

- To assess the structural parameters of mangrove ecosystem
- To assess litter production of mangrove ecosystem
- To determine physicochemical and climatic factors affecting mangrove structure and productivity
- To show the interrelationships between mangrove resources as well as the ecological function of the mangrove ecosystem in both countries (Ghana and Cameroon).

CHAPTER 2
2.0 LITERATURE REVIEW

This chapter presents summaries of studies that have been done on mangroves, portraying the global distribution, taxonomy, zonation, ecological importance and factors favouring and explaining scientifically the determination of the ecological role of mangrove in terms of litter production, structural characteristics, w ater and soils properties. A review of identified threats and services is carried out, with current mangrove management efforts around the world. A brief review on the concept of sustainable management is also presented. Finally, a brief review of some researches carried out in the Western and Central Ecoregion globally and specifically in Ghana and Cameroon was done in order to facilitate the present study.

2.1 Description of Mangrove Ecosystem

According to FAO, 2007 “mangroves” are coastal forests found in sheltered estuaries and along river banks and lagoons in the tropical and subtropical regions with intertidal gradients, mudflats, and sediment. The terms ‘mangrove forest’ and ‘mangrove swamp’ are used to describe areas with a profuse community of plants such as trees, shrubs, palms, and ground ferns (Duke, 1992; Mendelssohn and McKee, 2000), that can adapt to anaerobic and saline conditions and grow into the intertidal zone. The term mangrove, originated from the Portuguese word “mangue” meaning “tree”, and in English, the word “grove” means “a stand of trees” (Dawes, 1981; Mitsch and Gosselink, 2000). The word “mangrove,” or ‘manggi’ in Malaysia, has been used to describe two genera of *Rhizophora* (i.e. *Rhizophora acupilata and Rhizophora mucronata*). These species live in the muddy shores of the tropical regions, where they distribute their seeds and emit aerial roots that fasten into the saline mire, to eventually become new stems. Their seeds, also establish a root system while still being attached to the parent plants (Mendelssohn and McKee, 2000).

The term ‘mangrove’ describes both the ecosystem and the plant families that have developed specialized adaptations, to live in this tidal environment. In a dense mangrove forest, lights and shadows reflect on the water and fish and crabs hide among the submerged roots and trunks. Moving forward, may sometimes be possible only by climbing on giant roots or using small boats (FAO, 2006). They have unique plants that have evolved to survive in the interface, between land and ocean in the humid climate of the tropics and subtropics. They are variously described as coastal woodland, tidal forest and mangrove forest and grow as trees up to 40 meters high or as shrubs below the high-water level of spring tides. They have evolved clever mechanisms, to enable them to cope with the high concentrations of salt and regular inundation of their root systems by incoming tides. They require freshwater inflow, which brings silt with it as substrate for support and nutrients from upstream (Rezende *et al*., 1990). Mangrove forests consist of true mangroves and mangrove associates. True mangroves need, intertidal gramudflats and sediments to develop and can be recognized by dominant structure in the intertidal gradient. Mangrove associates do not need, the same environmental conditions to develop and can grow in a wide range environmental conditions (Loi, 2008). According to Tomlinson (1986), the following criteria are required of a species to be designated a “true or strict mangrove”: 1) Complete fidelity to the mangrove environment, 2) Plays a major role in the structure of the community and has the ability to form pure stands, 3) Morphological specialization for adaptation to the habitat, 4) Physiological specialization for adaptation to their habitat, 5) Taxonomic isolation from terrestrial relatives.

Mangrove is a non-taxonomic term used to describe a diverse group of plants that are all adapted to a wet, saline habitat. Mangrove may typically refer to an individual species. In ecological terms, mangrove community, mangrove ecosystem, mangrove forest, mangrove swamp, and mangal are used interchangeably to describe the entire mangrove community (Mitsch and Gosselink, 2000) or to describe specific individual plants, that can adapt to saline environments (Mitsch and Gosselink, 2000) or to indicate salt-tolerant trees and shrubs that are native to the intertidal zones (Mendelssohn and McKee, 2000). Duke (1992) described mangroves, as a biodiversity of trees and shrubs that pre-dominate the tropical region and, in general, exceeds one half meter in height and normally grows above the mean sea level in the intertidal zone of the marine coastal environment or in the estuarine margin, where the environment is harsh restrictive, and dynamic. Therefore, mangrove forests or mangrove swamps are easily recognized not only by the congregation of a specific community of species, but also by the characteristics of the region in which these species prosper.

2.2 Distribution and zonation of mangroves in the World

2.2.1 Distribution of Mangrove Ecosystems

Mangrove forests are generally distributed, along the tropical and subtropical coastlines between latitudes 32° N and 28°S. However, mangrove distribution is mainly concentrated from 25° N to 25° S (Mitsch and Gosselink, 2000) because local climate conditions, such as air and water temperature, allow for it (Mendelssohn and McKee, 2000;Mitsch and Gosselink, 2000). Frequent and extreme frost is also a major factor preventing mangrove extension, into tropical and subtropical regions (Twilley, 1998). Mangroves develop prosperously on fine-grained sediment and in active deltaic plains, with abundant fresh water supply. However, they can also grow on a variety of substrates including sand, volcanic and carbonate sediments (Taal, 1994). Mangrove forests in the sub-tropical region can develop on loamy or sandy soil where they are protected by sand banks. In the delta, red mangrove forests grow best along the river bands and creeks where there are intertidal gradients and salt or brackish water. Mangroves can also survive in fresh water. About 15 to 30 million ha of the earth are occupied by mangrove forests (Saenger *et al.*, 1983; Lacerda *et al.*, 1993; Mitsch and Gosselink, 2000).

Mangrove forests can be divided into two groups: the Old World and the New World mangrove (Mitsch and Grosselink, 2000). The greatest number of mangrove species, belong to the Old World. They are concentrated in Asian countries such as Indonesia, Malaysia, Vietnam, and Thailand and in the Indo-West Pacific region, which includes Australia and East Africa. Only a small number of mangrove species are found in the New World, which includes the north and south coasts of America and the west and central coast of Africa (Taal, 1994). With respect to the limits of mangrove distribution, extensive development of mangroves has occurred in the estuaries of large rivers flowing over shallow continental shelves, such as the Ganges in Bangladesh, Fly River in Papua New Guinea, and the Mekong Delta in Vietnam. The Amazon and Congo, the two largest rivers in the world, do not have extensive stands of mangroves, primarily because of the huge outflow of freshwater.

The following factors are considered to be the major determinants of mangrove distribution:

1. *Climate:* Mangroves are tropical species and are not tolerant of freezing temperatures. Their latitudinal limits worldwide vary depending on air and water temperatures (Tomlinson, 1986; Waisel, 1972; Sherrod *et al.*, 1986; Sherrod & McMillan, 1985; Spalding *et al.*, 2010). The abundance of mangroves is also affected by aridity, and development is much greater along coasts that have high inputs of rainfall (Macnae, 1968; Golley et *al.*, 1975; UNEP-WCMC, 2012).
2. *Salinity:* Salt is generally not a requirement for growth, since most mangroves can grow in freshwater (Tomlinson, 1986; Ball, 1988). However, they do not develop in strictly freshwater habitats because of competition from freshwater species. Salinity, is thus important in eliminating other vascular plant species that are not adapted for growth in a saline habitat.
3. *Tidal fluctuation: Tidal influence is als*o not a requirement, but plays an important indirect role for :
    - inundation with saltwater helps exclude most other vascular plants and reduces competition,
    - tides bring saltwater up estuaries against the outflow of freshwater and extend mangrove development inland,
    - tides transport sediment, nutrients, and clean water into the mangrove environment and export organic carbon and reduced sulphur compounds.
    - where evaporation is high, tides help flush soils and decrease salinity.

    The effect of this "tidal subsidy" can be seen on two landscape scales:

- a regional or geographic scale-mangroves reach their greatest development, around the world in low-lying regions with large tidal ranges (Tomlinson 1986; Macnae 1968; Golley *et al*., 1975; Adjonina, 2008).
- alocal scale- trees closest to the edges of land masses, which are subject to the largest fluctuations of the tide, are obviously larger and more productive than trees in the interior (Mendelssohn & McKee, 2000).

4. *Sediment and wave energy:* Mangroves grow best *in a depo*sitional environment, with low wave energy according to Tomlinson (1986). High waves prevent propagule establishment, expose the shallow root systems, and prevent accumulation of fine sediments (Spalding *et al*., 2010).

2.2.2 Zonation of Mangrove Ecosystem

Zonation refers to the natural succession phenomenon of mangroves, in which pioneer species (*Avicennia germinans*, *Laguncularia racemosa*, *Rhizophora mangle*) are established and develop in a new environment, followed by the other associate mangrove species (e.g. in the genera *Caesalpinia*,Mora,and *Thespesia*). Environmental changes such as changes in elevation and varying of the tidal regime, form new exposed mudflats, allowing for the establishment and development of pioneer mangrove species (Thom *et al.*, 1975). Strong zonation of mangrove species varies depending on local conditions, species composition, and recurring patterns. Each mangrove species forms a mono-specific band along the coastlines (Tomlinson, 1986). The band's characteristics are a direct response to the individual species, variation in tidal inundation, salinity, freshwater input, and sediment composition (Spalding *et al*., 2010). Different species or groups of species of mangroves can be found at different elevations and locations (Davis, 1940;

Gary, 2004 and Crona, 2006). The interaction between the different species and individual trees or the competition between interspecific and intraspecific species plays an essential role in mangrove species zonation (Ellison, 2008).

The zonation ability of different mangrove species can be predicted by observing the environmental stress factors and the species competition (Kathiresan, 1997). Mangrove zonation further depends on the shape, size, and the buoyancy of the propagules (Koch and Snedaker, 1997). For example, the propagules of *Avicennia germinans*, *Avicennia bicolor*, and *Lumnitzera racemosa* in Panama are carried further inland and establish themselves in higher elevations, because of their high buoyancy and small size. In contrast, *Rhizophora mangle* and *Rhizophora harrisonii's* propagules are larger and less buoyant, so they are found mainly in the lower intertidal zones (Chapman, 1976; Spalding *et al*., 2010). However, in the Old World, *Rhizophora apiculata* are populated in the high intertidal zones, while *Avicennia* spp. and *Sonneratia* spp. are found in the low intertidal zones.

Seed predation is another important factor, determining mangrove zonation (Mendelssohn and McKee, 2000). There are negative correlations, between propagule predation rates and same species domination in some mangrove forests, and mangrove communities form where there is less floristic diversity (Lugo and Snedaker, 1974; Seanger and Bellan,1995; Kathiresan, 1997;). Definitely, mangrove zonation is determined by the climatic and tidal environment of a specific region. Land surface history, geomorphic and pedogenic processes have to be considered in studying mangrove zonation (Thom, 1982). Mendelssohn and McKee (2000), suggest four basic processes to species zonation in mangrove ecosystems. The first process includes the dispersal and establishment of seeds or propagules. The next process involves the attraction of seeds or propagules to predators. Seeds or propagules that are not consumed by predators have a greater chance to establish and develop. The third process takes into consideration the ability of species to tolerate different types of stress. High tolerance of stress increases the survival of a species and increases zonation; and finally, the last process focuses on the interspecies and intraspecies competition. Less competition will also increase mangrove zonation (Hegazy, 1998; Gary, 2004; FAO, 2007; FAO, 2009 ; Conchedda *et al.*, 2011; UNEP-WCMC, 2012).

2.3 Propagules Predation by crabs

Alongi (1996), Alongi *et al.* (2005); Bosire *et al.* (2006); Mark McGinley (2007) Lamptey and Armah (2008) emphasized on the predation of propagules by the fauna associated with the mangal community. It has also been observed that predation varies with position on the shore, predation being low in the lower intertidal and highest in the high intertidal where greater populations of crabs are normally found. Predation also varies biogeographically, with highest predation in the Indo-Pacific and decrease across the Pacific (Smith, 1998).

Predation on seeds has been recognized as an important process in a variety of ecosystems. Watson (1928), Gary (2004) and Spalding *et al.* (2010) commented on the role of crabs (Grapsidae family) as consumers of mangrove propagules, particularly in the managed forests of west Malaysia. This group is a ubiquitous feature of mangrove forests, especially in the Indo-Pacific region. Crabs are the dominant macrofauna of mangrove forest soils in terms of both numbers and biomass. Consumption of mangrove propagules by grapsid crabs greatly affects natural regeneration and influences the distribution of certain species across the intertidal zone.

Lugo (1999), Bosire *et al.* (2005) and Spalding *et al.* (2010) in their studies on mangrove ecology, pointed out that predation on propagules by graspid crabs played an important role in diminishing the relative abundance of certain species whose propagules were preferred, thus maintaining species dominance. There are a number of different ways in which graspids and other predators affect the zonation of mangrove species within a forest. Differential predation on propagules across the intertidal zone was proposed by Smith (1987a) as a determinant of mangrove zonation. Smith (1998) observed that an inverse relationship existed between predation rate and dominance in the canopy in four out of the five species studied.

In other studies Smith (1998) and colleagues have reported that crabs often consume 100% of post-dispersal propagules in Australian forests, especially the genus *Avicennia*. It is reported by Mendelssohn and McKee (2000) that *Avicennia* propagules are preferred by graspids due to their small size (facilitating burial in crab burrows), a higher nutritive content, and lower amounts of defensive chemicals such as tannins. He found also that in forests in Belize predation on propagules of *Avicennia germinans* and *Rhizophora mangle* were highest in areas where these species dominated the canopy and that predation on *R. mangle* was lowest in areas of forest dominated by *Avicennia germinans*. Bosire *et al.* (2006) found that the planting of propagules (to mimic establishment) strongly influenced the reduction of predation intensity. These findings concur with the findings of Dahdouh-Guebas *et al.* (1997) and Chen *et al.* (2008) who found propagules dispersed in the mangrove ecosystem to have higher mortality rate. The mangrove providing a suitable habitat for the crabs and the crabs predating the propagules of the mangroves competitors. With a variety of factors influencing predators' choice of propagules, various models have been proposed in support of propagule predation, as summarized by Bosire *et al.* (2005):

1. The dominance-predation model, which postulates that an inverse relationship exists between the rate of predation of a particular species and the conspecific dominance in the canopy.
2. The canopy-gap mediated model.
3. The flooding regime model. Predation of propagules is certainly an important factor in determining mangrove zonation but as has been made clear already no one factor can be held exclusively responsible (Smith, 1998; Mendelssohn and McKee, 2000; Spalding *et al.*, 2010).

The conclusion was that crabs consumed virtually 100% of the *A. marina* propagules that were dispersed into middle intertidal forests; hence, propagule predation was an important determinant of the forest species' composition and structure (Smith, 1992). Subsequent studies indicated that propagule predation was important over a much larger geographic region than northeast Queensland (Smith *et al.*, 1989). Data from Malaysia and Florida revealed high levels of predation on the propagules of *Avicennia* spp in Malaysia and in Florida. For *Rhizophora* sppand *Bruguiera* spp, propagules are consumed but not in the manner predicted. The predation hypothesis thus explains only a portion of the observed patterns of mangrove forest zonation (Day *et al*., 1987; Clough, 1992; Dahdouh- Guebas, 2011).

2.4 Mangrove flora and fauna in the world

2.4.1 Global mangrove vegetation

The knowledge on floristic composition of mangrove is still limited (Jayatissa *et al*., 2002; FAO, 2007; Spalding *et al*., 2010). Information as to the exact existing number of mangrove species in the world is very conflicting. In 1984, Hamilton and Snedaker reported 60 species with 20 associated species. Hong (1998) reported 68 species worldwide of which 51 are found in Vietnam. Spalding *et al.* (1997) reported 9 orders, 20 families, 27 genera and roughly 70 species of mangrove worldwide. Acoording to Tomlinson (1986); Kathiresan (1997); Hellier (1988) ; Dahdouh-Guebas and Koedam (2006), there are 52 mangrove species distributed worldwide grouped into 15 families. They are further grouped into two majors blocks based on their supposed centres of genetic diversity, into the eastern block (East Africa, Madagascar, Red Sea, India, South East Asia, Australia and the Western Pacific) and the Western block (West and Central Africa, Atlantic South America, Caribbean, Florida, Central America and Pacific North and South America). There is a great deal of segregation between the eastern and the western block mangroves; for instance, *Rhizophora* and *Avicennia*, two primary mangrove genera contain identical species in the Western and Eastern worlds (Enyankou *et al*., 2009). This suggests independent speciation in each region, though the Eastern block has been suggested to be the centre of origin for mangroves. Generalised reports by researchers and the lack of clear-cut definition of the mangrove ecosystem and its constituents are the origin of these diverse species publication (Ajonina, 2008 and Spalding *et al*, 2010).

2.4.2 Animals in mangrove ecosystem

Mangrove forests form the interface between marine and terrestrial environments. Consequently, animals from these two environments can be found in the mangroves. Few animals use mangroves as their only habitat. Some live primarily in the mangroves, while others move in and out of the mangroves seasonally, at different stages of their life cycle or even depending on the tide. Saltwater crocodiles are one of the most infamous inhabitants of mangrove areas. They do not generally nest in mangroves but are found nesting in vegetation fringing mangrove areas and vegetation where rivers adjoin coastal flood plains. On the rising tide these reptiles come into the mangroves to feed. Young crocodiles feed on crabs, prawns, mudskippers and other small fish. As they mature their diet changes to include large mud crabs, birds and mammals (Alongi,1996; Alongi *et al.*, 2005; FAO, 2006). Sea snakes are common visitors to mangrove forests as are terrestrial snakes. Pythons tend to be occasional visitors to the mangroves, while the Little File Snake, the Mangrove Snake and the White-bellied Mangrove Snake tend to use the mangroves as their primary habitat. The Mangrove Monitor and the Rusty Monitor, which feed on insects, fish, crabs and sometimes birds, also use the mangroves as their primary habitat. Mudskippers are one of the few animals which are restricted to mangrove environments. They burrow into the soil and can swim like fish, but, using their pectoral fins, can also climb tree roots and move across the soil. In contrast, most other fish species which inhabit mangrove creeks are also found in the coastal seas, entering the mangroves during a particular stage of their life cycle. For example, Barramundi spawn and spend their juvenile phase in mangrove creeks (Sackey *et al*.,1996; Lamptey and Armah, 2008; Spalding *et al*., 2010) .

Sea Mullet also inhabit the mangroves as hatchlings. Crustaceans (sea lice, barnacles, shrimps, prawns and crabs) are abundant in mangrove forests. One of the most distinctive crustaceans is the Mud Lobster which builds large mud towers at the entrance to its burrow. Pistol Shrimps are responsible for the loud clicks often heard in mangrove forests. There are also around 60 species of crabs which inhabit the mangroves (UNEP-WCMC, 2007). One of the most conspicuous species is the Fiddler Crab which has an enlarged orange claw. Molluscs, like the Common Mud Whelk and the Mangrove Oyster, are often visible on the muddy soil around the base of mangrove trees. In addition to these largely surface dwellers is a fauna associated with rotting wood such as Shipworms, which are not really worms but highly adapted bivalve molluscs (Dahdouh-Guebas and Koedam, 2006; Mendelssohn and Mckee, 2000).

The crabs constitute the most important and abundant crustaceans, in mangrove forest and consequently have a significant role in mangrove ecosystems. They are recognized as propagule or seedling predators, some crab species are predominantly leaf eaters while others feed mainly on algae and detritus on the soil surface, scooping the material into their mouthparts and discarding the inedible material as round pellets. Definitely, Crabs can influence mangrove forest structure. Crabs and snails, important components of the detritus food chain, help break down leaf litter through grazing. Shrimp, an important fisheries resource, find food and shelter in mangrove forests. Likewise, commercially important bivalves such as oysters, mussels and clams are commonly found in and around mangrove roots. Mangroves are also recognized as essential nursery habitat for a diverse community of fish, which find protection and abundant food in these environments, especially during their early stages. Many animals found within mangroves are semi-aquatic or derived from terrestrial environments (Kairo and Bosire, 2009; Spading *et al*., 2010).

Many species of birds also depend seasonally on mangrove environments for food and shelter. Honeyeaters and lorikeets visit the mangroves for nectar during the plant flowering season. Other species, such as the Torresian Imperial Pigeon, inhabit the mangroves during breeding. Mangroves are important habitats during annual migrations and can become important refuges during droughts and when adjacent terrestrial forest is destroyed (Sackey *et al*., 1996; Allen, 1998; Lovelock *et al*., 2005).

Water birds that visit the mangroves on a more regular basis include the Jabiru, egrets and the Mangrove Heron while the Mangrove Robin, White-breasted Whistler, Mangrove Honeyeater and Mangrove Kingfisher are woodland birds that are considered mangrove specialists. Flying foxes (fruit bats) often form large colonies in the mangroves and can be seen roosting during the day. Other mammals are not often seen in mangroves, however, wallabies, rats, possums and bandicoots visit the mangroves, as do feral pigs, cattle and water buffalo (Gary, 2004; Bosire e*t al*., 2006; Ajonina, 2008; Spalding *et al.*, 2010).

2.5 Mangrove of West and Central Africa Ecoregion

The West and Central African mangrove ecoregion is located in Western and Central Africa, and encompasses mangrove areas along the coastlines of Ghana, Nigeria, Cameroon, Equatorial Guinea, Gabon, Democratic Republic of Congo (DRC), and Angola (to 19°18' S). Climatic conditions are primarily humid and tropical, but change to more temperate conditions towards Angola. Off the coast of DRC, mangrove development is inhibited by the presence of the coldwater Benguela Current, but some stands are found where high river water temperatures counteract this current (UNEP, 2007).

Annual rainfall varies from a mean of 750 milimeters (mm) in Angola to 6,000 mm in Cameroon (McGinley, 2007; UNEP-WCMC, 2012). Mangrove occurs in the intertidal coastal plains of West Africa between 12°30'S and 19°50'N. Its optimal development is attained under rainforest climate (mean annual rainfall = more than 1200 mm year'), out of direct influence of swell and sea-water currents, at the mouths of large rivers such as the Niger, where it benefits from both dilute sea-water and large muddy areas (Marius, 1985). Sea surface temperatures average 25°C (e.g. min 24°C, maxi 38°C off Lagos) (Diop and Barrusseau, 1994) in the Gulf of Guinea and decrease toward the north to 23°C off Senegal (min. 18°C, max. 28°C) in relation with local "coastal" upwelling, while salinity averages 30 to 35%o all along the coast except for more equatorial areas as in Cameroun where values below 20%o are recorded. The structure of the mangrove areas varies considerably, from the lagoon systems found in the western part of this Ecoregion to systems modified by complex patterns of sediment deposition, at river mouths in the Central and Southern portions.

In Ghana, and the Western part of Nigeria, mangroves are primarily associated with extensive lagoons. These are enclosed part of the year by sediments, when rainfall is lower and freshwater outflow is not sufficient to counteract ocean swells. In the remainder of the region, mangroves are primarily associated with river mouths, the largest of which is the Niger River Delta, which may discharge up to 21,800 m^3 per second at peak flow in mid-October. The sediment load flowing from the Niger River has been estimated to be 20 million m^3 a year, most of which is captured in the mangrove swamps. Sediment deposition and channel erosion have created a network of river creeks, estuarine swamps and barrier islands. Soils range from recently deposited unconsolidated, soft dark mud containing silt, clay and peaty clay, to transitional swamps, all of which are associated with different types of vegetation (UNEP, 2007)..

The key factors that influence these mangrove ecosystems are river floods and the tidal range. Tidal range increases from West to East, reaching a maximum of 2.8 meters in Eastern Nigeria. This allows flood tides to penetrate up to 40–45 kilometers into the interior. The large inputs of freshwater create a low-salinity zone offshore where salinity fluctuations range between 0 and 0.5 percent during the rainy season, and 30 to 35 percent during the dry season. Farther south in Cameroon, annual rainfall reaches 6,000 milimeters, but it is highly changeable because of variation in topography and coastal types. These high freshwater inputs, together with a convergence of the Guinean counter-current, the Benguela current, and an equatorial subsurface current, creates a "piling up" of water that results in an increase in mean sea level of 1.2 m and creates an unusual circulation pattern. It also results in the formation of sandbars and the deposition of large amounts of suspended sediment, in the mouths of estuaries (McGinley, 2007, Spalding *et al.*, 2010).

Five species of mangroves in three families are found in this region, including the red mangroves, *Rhizophora racemosa*, *R. mangle*, and *R. harrisonii*, and the white mangroves *Avicennia germinans* and *Laguncularia racemosa*, as well as an introduced species, *Nypa fruticans*. *Rhizophora racemosa* is the primary colonist in the open lagoon systems, whereas *Avicennia germinans* is the primary colonist in closed systems. Vegetation varies depending on whether the soils consist of sandy troughs or muddy hollows. In the back swamps*Nypa fruticans* is replacing red mangroves because it is a quicker colonizer and has shallow roots which destabilize river banks (;Trochain, 1980; White, 1983; Maley, 1991; Anne-Marie, 1997; Gary, 2004 Ajonina, 2008; Spalding *et al.*, 2010). This is occurring rapidly from the western shores of Nigeria to the interior creeks of the Niger Delta. *Rhizophora racemosa* is dominant in the tidal and more inundated areas of Cameroon, where mangroves are found concentrated in two locations to either side of Mount Cameroon. Farther south in DRC where mangroves are found around lagoons, the dominant species is *Rhizophora mucronata*. In Angola, large mangrove communities occur at the mouths of the Cuvo, Longa, Cuanza, Dande, and M'Bridge Rivers, though they are not as extensive as the vast mangrove swamps at the mouth of the Zaire River. The dominant trees are *Rhizophora racemosa, Rhizophoramangle, Rhizophoraharrisonii and, Avicennia germinans*, the former two species reaching heights of approximately30 meters (m) (Hellier, 1988; Kathiresan, 1997; Kairo and Bosire, 2009).

West and Central African mangrove populations are mainly composed of *Rhizophora*, *Avicennia*, *Laguncularia*, and *Conocarpus* These genera are mostly distributed according to a gradient in water depth (frequency and duration of flooding by sea-water) and salinity (White, 1983; Crona, 2006; Spalding *et al.*, 2010).

2.5.1 Mangroves of Ghana

In Ghana, mangroves cover an estimated area of 100 km² with a coastline of about 550 km long. They are mainly limited to stands around lagoons, on the West coast of the country and bordering the lower reaches and Delta of the Volta River. They are best developed on the West coast between Cote d'Ivoire and Cape Three points (Sackey *et al*., 1996; Aheto et al., 2011)

The mangrove vegetation of Ghana is composed of three main genera belonging to threefamilies: *Rhizophora* (Rhizophoraceae), *Avicennia* (Avicenniaceae) and *Laguncularia* (Combretaceae).

The species represented are *Rhizophora racemosa*, *R. mangle*, *R. harrisonii*,*Avicennia germinans* and *Laguncularia racemosa* associated with these typical mangrove speciesare *Conocarpus erectus*,*Acrostichum aureum*, *Phoenix reclinata*, *Sesuvium portulacastrum*,*Hibiscus tiliaceus*, *Thespesia populnea*, *Canavalia rosea*, *Ipomoea pes-caprae*, *Dalbergia escastophyllum*, *Drepanocarpus lunatus*,*Cardiospermum grandiflorum*, *Paspalum vaginatum* andsometimes *Terminalia catappa* (Armah *et al*., 2009; Gordon *et al.*, 2009;).

A mature forest of *Rhizophora* and *Avicennia* species may grow to form a canopy of height 20 to 30 m and individual individuals may attain a diameter at breast height (i.e.1.30 m) of between 30 and 50 cm.

With severe disturbance, the vegetation appears shrubby, the trees hardly grow beyond a heightof 5 m and there is invasion by mangrove associates such as *Acrostichum aureum*,*Paspalum vaginatum* and *Phoenix reclinata*.

In a mixed mangrove forest, *Rhizophora* species occupies the wetter, softer areas that are regularly inundated whereas Avicennia species prefer the drier back-swamps (Armah *et al*., 2009; UNEP-WCMC, 2012). Open lagoons, are often dominated by *Rhizophora*, while closed lagoons, which have an elevated salinity, contain *Avicennia germinans*, *Conocarpus erectus*,*Laguncularia racemosa* and *Acrostichum aureum*, *Laguncularia racemosa* and *Rhizophora racemosa* are found on the seaward side of lagoons in saline conditions. *Avicennia germinans*(syn *A. nitida*) occurs on the landward side of the swamps (FAO, 2006; UNEP-WCMC, 2007).The mangrove fauna is composed of birds, molluscs, fishes, reptiles and mammals. The fishes include *Periophthalmus papilio* (the mudskipper), *Caranx hippos, Liza* sp, *Tilapia guineensis* and *Sarotherodon melanotheron.* The molluscs include *Ostrea rhizophorae* and *Littorina angulifera.*

The crustaceans include *Cardiosoma armatum, Sesarma sp., Uca tangerii* (crabs).

The birds include several species of terns, waders, herons, plovers and egrets. The turtles *Cheloni a mydas*, *Dermochelys coreacea* and *Caretta caretta* are also known to be associated with mangr oves (UNEP-WCMC, 2007; Spalding *et al*., 2010).

The local populations, who live in the mangrove areas, have traditionally used mangrove products and the mangrove environment over the years. They have mainly exploited it for wood, fish, crabs and oysters. Nevertheless, mangrove areas in the country have received virtually no attention in terms of conservation and sustainable management. Mangrove ecosystems support a wide array of biodiversity in Ghana. The ecosystems and their associated wetlands provide habitat for high concentrations of birds, mammals, reptiles, amphibians, fish and invertebrate species. Thousands of waterfowl, many of them migratory, visit Ghana during the northern winter. Mangroves serve as sanctuaries and nestling grounds for most of these birds.

Despite the ecological and economic importance of mangroves, they continue to be over exploited on a daily basis with little or no control. In most coastal communities in Ghana, mangrove ecosystems are used in a variety of ways such as fishponds, salt pans, sugarcane fields, human settlements and other agricultural uses. The mangrove stands from the forest are cutting for firewood which serves variety of purposes, including domestic fuel, fish smoking and distillation of akpeteshie (local gin). In Ghana, a large quantity of the mangrove wood is also used for constructional purposes and for fishing (Amatekpor, 1997; Armah *et al.*, 2009). Moreover, coastal areas are one of the most favored sites for settlements in Ghana, as in West Africa as a whole, because of the opportunities they offer. They provide fertile lands for agricultural production, marine resources and access to external markets through water transport. These economic activities in turn, have attracted a high concentration of population to places like Keta, Ada, Accra, Winneba, Takoradi and Axim. Mangrove exploitation intensified, particularly in the Volta Basin, following the construction of the Volta dam in 1964 and the consequential loss of fishing and farming opportunities for downstream communities. In all, about 76% of the mangrove forest of the country has been lost through deforestation (UNEP-WCMC, 2007). Mangroves in Ghana, represent 0.5% of African mangrove cover and 1.5% is within protected areas.

2.5.2. Mangroves in Cameroon

In Cameroon, Mangroves cover about 1957 km² and distributed along major creeks and estuaries with a coastline of roughly 402 km bordering the Atlantic Ocean and extending from latitude 2° 20' N at the boundary, with Equatorial Guinea to latitude 4° 40' N at the border with Nigeria. The annual rainfall ranges between 2000 and 6000mm. Mangroves in Cameroon represent 6% of African mangrove cover and 7.1% falls within protected areas. The estimated rate of degradation is around 72% (UNEP-WCMC, 2007). Mangrove estuarine complexes in Cameroon occupy approximately 30% (3,500 km²) of Cameroon's coastal zone and mangroves in Cameroon estuary in the centre extend over a surface area of 1100 km² (Din *et al*., 2008).

Mangroves are significant in Cameroon and predominately found in three regions: (i) The border with Nigeria in the "Cirque" (rivers are Akwayafe, Ndian and Meme); (ii) The Cameroon Estuary, at the mouths of the Bimbia, Mungo, Wouri, Dibamba and Sanga rivers; (iii) Smaller stands at the openings of the Sanaga Nyong, Lokoundje and Ntem rivers. There are six species of mangrove growing in Cameroon. The dominant mangrove species is the red mangrove *Rhizophora racemosa*, which accounts for over 90 per cent of all mangroves, followed by *Avicennia germinans*. Stands of *Rhizophora racemosa* have been found to grow up to 40–60 meters on the coastal zone, and when found in the interior they only grow 4–8 meters in height (FAO, 2005; Oumarou *et al*., 2009). Other mangrove species are only poorly represented but include: *Conocarpus erectus, Languncularia racemosa , Rhizophora mangle and Rhizophora harrisonni.* Besides, invasive mangrove fern *Acrostichum aureum* and theexotic Palm, *Nipa fructicans* are also present in mangrove ecosystem. Mangrove associates include*: Annona glaba, Coco nucifera, Machaerium lunatum, Elaeis guineensis, Eremospatha wenlandiana,Phoenis reclinata, Raphia palma-pinus, Guiborutia demensei, Alchornea cordifolia, Dalbergia ecastaphylum, Athocleista vogeli, Pandanus candelabrum, Hibiscus tilaceus, Bambusa vulgaus, Paspalum vaginatum Bambusa vulgaus, Paspalum vaginatum, Sesuvium portulacastrum, e*tc. (Ajonina, 2008;Ajonina *et al*., 2009; UNEP-WCMC, 2012).

Two key patterns of zonation of mangroves have been observed (Fomete and Tchanou, 1998): (i) In the Region of Cirque, the succession of species from the sea to dry land is as follows: *Rhizophora racemosa – Avicennia germinans – Pandanus candelabrum – Acrosticum aureum – Pandanus candelabrum – Rhizophora racemosa; (ii) In the Cameroon Estuary, around Douala, the sequence is as follows: Rhizophora racemosa – Rhizophora harrisonni – Rhizophora mangle*

– *Avicennia germinans –Avicennia* associated with *Laguncularia*. These mangrove forests are generally poor in plant species, but contain a wide spectrum of fauna including insects, crabs, molluscs, amphibians, reptiles and large mammal species such as monkeys, the West African manatee (*Trichechus senegalensis*) and Atlantic humpbacked dolphins (Ajonina and Usongo, 2001). Other important wildlife species found in the region include dwarf crocodile, slendersnorted and freshwater turtles. Mangroves serve as a nursery grounds to marine organisms, water birds and migratory birds. Recent surveys of the coastal wetlands by the Cameroon Wildlife Conservation Society in collaboration with Wetlands International (Ajonina *et al*, 2004) in April 2004 showed that numerous waterbirds species abound in mangrove areas where over 30 000 birds representing 60 species were recorded.

2.6 Importance of Mangrove

To assess the importance of mangrove ecosystems from a scientific perspective, it is quite necessary to attempt to determine their values. Notably, these values can be divided into social and cultural, habitat, educational, economic and ecological values (Crona, 2009; Ajonina, 2008; Spalding *et al*., 2010; Aheto *et al*., 2011).

2.6.1 Ecological importance of mangrove forest

Although early workers regarded mangrove forests as unimportant, transitional communities with a low productivity, most ecologists today view them as highly productive, ecologically important systems. Four major roles of mangrove swamps are recognized:

1. Mangroves contribute to soil formation and help stabilize coastlines.

2. Mangroves act as filters for upland runoff.

3. Mangrove systems serve as habitat for many marine organisms such as fish, crabs, oysters, and other invertebrates and vertebrates wildlife such as birds and reptiles.

4. Mangroves produce large amounts of detritus that may contribute to productivity in offshore waters.

In addition to these ecologically important roles, mangrove forests possess attributes that are specifically important to humans:

1. Mangrove forests serve as protection for coastal communities against storms such as hurricanes. It has been suggested that the large loss of life (between 300,000 and 500,000 lives) in Bangladesh in 1970 caused by typhoon was partly due to the fact that many of the mangrove swamps protecting those populated coastal regions had been removed and replaced by rice paddies.
2. Mangrove forests serve as nurseries and refuge for many marine organisms that are of commercial or sport value. Areas where widespread destruction of mangrove has occurred usually experience a decline in fisheries.
3. Many threatened or endangered species reside in mangrove forests.
4. Mangrove forests are also important in terms of aesthetics and tourism. Many people visit these areas for sports fishing, boating, bird watching, snorkeling, and other recreational pursuits. They are also considered to be highly productive tropical ecosystems (Clough, 1992; Crona *et al*., 2009; Spalding *et al*., 2010).

Mangrove areas are ecologically sensitive and provide physical protection for communities, more importantly they are believed to play a major role, in supporting tropical estuarine and coastal food webs (Din *et al*., 2008; Spalding *et al.,* 2010). It is a fact that, the mangrove forests represent an important carbon and nutrient source to the adjacent lagoonal and coastal systems (Odum and Heald, 1972; 1975; Twilley, 1988; Wattayakorn *et al*., 1990; Robertson *et al.*, 1992; Dahdouh- Guebas, 2011).

Mangrove trees play a major role in ecological services in mangrove ecosystems. They contribute to the stabilization of the shoreline and prevention of shore erosion. The dense network of support roots, breathing roots and stilt roots give mechanical support to the trees and trap the sediments. The mangrove trees produce litter by shedding their foliage: foliage drop is a mechanism to remove salt crystals accumulated in it. This foliage enters the mangrove water and produces detritus which in turn is colonized by heterotrophic microorganisms, thus enhancing its nutritive value. This detritus is consumed by the hatchlings of a variety of bivalves, shrimps and fishes, which migrate into the mangrove environment for better feeding and protection. Mangrove trees provide nesting sites for many shore birds and serve as home for crab-eating monkeys, proboscis monkeys, fishing cats, lizards, sea turtles, bats, and many more animals. Therefore, mangrove trees are very important since they conserve and maintain mangrove ecosystems (Kairo and Bosire, 2009; Alongi, 2011).

In terms of Structural characteristics, Mangrove forests ecologically in addition to zonation are also characterized by attributes such as species richness, canopy height, diameter, basal area, tree density, age/size class distribution, and understory development (Snedakar, 1993; Spalding et al., 2010; Aheto *et al*., 2011).Structural characteristics of forest such as stand height, tree density, and biomass accumulation may be influenced, primarily by climatic factors such as rainfall and by nutrient input (Smith *et al*., 1998; FAO, 2009; Nfotabong Atheull, 2011). Areas characterized by high rainfall typically have tall canopies, high basal areas, and low tree densities. Similarly, larger, more productive trees typify mangrove forests receiving high inputs of nutrient for example, those areas used as bird rookeries. Competition has been studied in a variety of wetland plant communities, but few studies have examined the role of competitive interactions in mangrove forests. Stand structure in mangrove forests is relatively simple when compared to that of other forest types, such as tropical rainforests (Twilley *et al*., 1997; Crona et al., 2006; Dahdouh- Gueba, 2011).

Complex stands, characterized by tall canopies, high basal areas, and lower stem densities, were common in wet, high rainfall areas. Complementary results that are based on different methods are available from the Indo-Pacific region. Rainfall and freshwater runoff appear to be major determinants of stand structure. The floristics and structural features of terrestrial forests when integrated with the number of species, stand density, basal area and height of the trees reflect their course of development (Holdridge, 1967; Smith *et al*.,1998 ; Crona et al., 2006; FAO, 2009; Bernini and Rezende, 2010; Dahdouh- Guebas, 2011).

Concerning the ecological importance of mangrove litter production, leaves, wood, propagules, flowers, bracts, and other organic materials fall continuously to the intertidal forest floor. These leaves and other litter cannot be digested by herbivores and are thus unavailable nutrient sources for higher trophic levels. When bacteria and fungi metabolize the leaf litter, however, it releases nutrients via a pathway that has been called the detrital food loop. The detritus is eaten by shrimp, mullet, and myriad smaller organisms within the mangrove prop root community and thus passed into the food web (Egnankou, 2009; Dahdouh-Guebas, 2011). Litter in the form of fallen leaves, branches and debris contributes to the addition of organic matter after decomposition (Hossain *et al*., 2008). Clough (1992) reports that the amount of litter produced in the mangrove is negatively correlated with latitude because the local fluctuations of litterfall are related to stress which is habitat specific.

2.6.2 Educational value of mangrove

Mangrove ecosystems are also a valuable educational resource. They support a wide range of animal species including birds, bats, lizards, crabs, and fish. In no other ecosystem can such an array of animals be found living together (UNEP, 2007). The plants found within mangrove communities are also distinctive. Most of them cannot be found within any other environment. They have adapted to quite unique environmental conditions, including high salinities, regular inundation and low soil oxygen conditions. No other large flowering plants could survive these conditions (Spalding *et al*., 2010; Conchedda *et al*., 2011). The uniqueness of these plants and animals, along with the role that mangroves play in adjacent marine and terrestrial food chains make them ideal locations for educational activities. Through studying mangrove communities and the interactions that take place within them, students can gain a better understanding of the natural environment.

2.6.3 Economic value of mangrove

The economic potentials of mangrove stem from three main sources: forest products, marine products and tourism (Hamilton and Snedaker, 1984). Mangroves host natural resources including timber for construction, fuel wood for cooking, fishing gear, non-timber forest like tannins, thatching materials for roofing and raw materials for indigenous medicine. As a forest ecosystem, it provides edible products like honey, wax, game, fish, fruits and drinks. Hegazy (1998) has also reported the use of certain mangrove species as fertilizer in farms and practice of agriculture inside mangrove areas. However considering soil pH, salinity levels, mangrove soil is marginal for agriculture (Tomlinson, 1986; Ajonina, 2008). This is due to acid sulphate conditions caused by oxidation of the typical hydrogen sulphide thriving in anaerobic conditions under disturbance to toxic sulphuric acid.

2.6.3 Social and cultural Importance of mangrove

Mangrove ecosystems have traditionally been sustainably managed by local populations for the production of food, medicines, tannins, fuel wood, and construction materials. For millions of indigenous coastal residents, mangrove forests offer dependable, basic livelihoods and sustain their traditional cultures. Mangroves play an important role in preventing coastal erosion. Throughout the world mangrove forests have been cleared leaving low-lying coastal areas more susceptible to damage from cyclones and storm surges. By reducing current speed and trapping sediments, the tangled roots, pneumatophores and trunks of the mangroves help to reduce siltation in adjacent marine habitats. Similarly, river-borne nutrients (including the agricultural chemicals present in many Queensland Rivers are likely to be trapped and recycled within mangroves. The protective mangrove buffer zone helps minimize damage to property and losses of life from hurricanes and storms. In regions where these coastal fringe forests have been cleared, tremendous problems of erosion and siltation have arisen, and sometimes terrible losses to human life and property have occurred due to destructive storms. Mangroves have also been useful in treating effluent, as the plants absorb excess nitrates and phosphates thereby preventing contamination of nearshore waters (Clough, 1992; Ajonina, 2008; Din *et al.*, 2008).

2.6.4 Importance of Mangrove and habitat

Mangroves often occur in environmental settings that include a predictable period of landform and physical processes that are responsible for sediment transportation and deposition (Woodroffe, 1992; Spalding *et al*., 1997). Continuous landform and physical processes, create several geomorphologic settings dominated by waves, tides, and rivers including: 1) protected shallow bays, 2) protected estuaries, 3) lagoons, 4) the leeward sides of peninsulas and islands, 5) protected seaways, 6) behind spits and 7) behind off shore shell or shingle islands (Joshi and Ghose, 2004). All of these geomorphologic settings indicate that mangroves need sufficient protection from waves to thrive. However, mangroves can also develop behind dunes at bare coasts and shallow barriers where there is no protection from waves (Chapman, 1976; Loi, 2008). Mangroves also provide important permanent and temporary habitats for a large number and range of marine and terrestrial fauna. Marine fauna commonly found in mangroves includes molluscs, crustaceans (such as crabs and prawns), a wide range of fish and of course, the saltwater crocodile. Research has shown that the abundance and diversity of marine fauna found throughout mangrove areas is quite high (Hellier, 1999; Hogarth, 1999; Spalding *et al*., 2010).

2.6.5 Mangrove importance and Shoreline stabilization and protection

Located along the coastline, mangroves play a very important role in soil formation, shoreline protection, and stabilization. The mangrove forest's extensive, above-ground root structures act as a sieve, reducing current velocities and shear, and enhancing sedimentation and sediment retention. Not only do mangroves trap sediments—they also produce sediment through accumulated, mangrove-derived organic matter. By enhancing sedimentation, sediment retention, and soil formation, mangroves stabilize soils, which reduce the risk of erosion, especially under high-energy conditions such as tropical storms. They also form a buffer zone against storms thus protecting not only the shores from erosion, but also the habitats behind the mangroves but also the human settlements. Their importance in contributing to risk reduction is considerable (Carlton, 1974; Augustinus, 1995; Gary, 2004; Crona *et al*., 2009).

Mangroves are best developed on tropical shorelines where there are active intertidal gradients bringing in a substantial amount of fine grain sediments which provides an optimal environment, for mangrove development. These fine grain sediments are usually delivered by river flow from the inland to be deposited in the sea or they come from the adjacent eroding shorelines. However, mangroves also grow on substrates that are made up of sands, volcanic lava, and where sand mixes with silt or organic matter. Carbonate material, covered by calcareous skeletal material from reefs or by organic peat from mangrove root production, also provides a suitable environment for mangrove growth. Mangroves are also very versatile, in that they can grow in soil with organic matter ranging from 10% to 90% of the total soil composition (Chapman, 1976; Mendelssohn and McKee, 2000; Crona *et al.*, 2009).

2. 7 Productivity of mangrove (litterfall)

In general, litterfall is heavier during dry seasons when thinning of the canopy results in reduced transpiration (Lewis, 1997). Reports of varying ranges on litter production are habitat dependent. Saenger and Snedaker (1993) found litter production to be largely related to local conditions and species composition in addition to Individual mangrove productivity. However production of heavy litter varies from species to species. Litter production in *Avicennia marina* in India is reported to be high In post-monsoon period and low in pre-monsoon period

(Ghosh *et al*., 1990; Conchedda *et al*., 2011). Mangrove leaves are useful contributors of nutrient mass in a mangrove environment.

It has been reported by Egnankou (2009) that mangrove leaves contain sufficient amounts of minerals, vitamins and amino acids, which are essential for the growth and nourishment of marine organisms and livestock. Microbial degradation of the litter in addition to kaching process is mainly responsible for the recycling of nutrients.

Litter can represent up to one third of mangrove primary production (Robertson *et al*., 1992), and may be remineralized by decomposition, accumulated in the sediment and/or exported to adjacent areas (Pool *et al*., 1975). The export level of dissolved and particulate materials from the litter depends on geomorphology and tidal amplitude, thus tends to be larger in mangroves located in coastal areas dominated by tides or under strong river influence (Woodroffe 1992, Twilley *et al*. ,1997; Twilley & Day,1999). However, import of organic material in this ecosystem is possible as described by Rezende *et al*. (1990) and Dittmar & Lara (2001). Litter production has been variously reported as of 0.01 t/ ha/ ya in the mangroves of Kenya, of 9.4 t/ ha/ ya in the mangroves of Bermuda and of 23.69 t/ ha/ ya in the mangroves of Australia (Kathiresan and Bingharn, 2001). Twilley *et al*. (1986) estimated the leaf fall in basin mangroves in Florida to be 0.4-1.4g/m2/d and according to Day *et al*. (1996) in Mexico it is 0.6- 1 Sg/m^2/d Steinke and Ward (1990) reported the estimated litter production for Gazi Bay of Kenya to be 4.50 t/ ha/ ya. However the litter production from *Avicennia marina* in Australia was estimated by Clarke (1994) as 3. t/ ha/ yr and by Bunt (1995) to be 15.98 t/ ha/ ya. In India, the litter production from a mixed forest of Andaman Islands is 7.10 to 8.50 t/ ha/ yr (Maley *et al*., 1991).

In general, leaves are the main components of litter accounting for more than 50% of the total production. Although there are regional differences in its fall and variations in exchange with the ocean, the annual global production rate of this component is estimated at 92 x 10 12 g C, of which 25% accumulates in the sediment, 25% is recycled within the ecosystem and 50% is exported to the coastal zone (Robertson & Daniel, 1989). The export of organic matter and dissolved nutrients is important for the productivity of coastal waters, since it has a recognizable effect on food chains (Odum & Heald, 1975, Jennerjahn & Ittekkot, 2001, Dittmar *et al*., 2006). According to Dittmar *et al*. (2006), approximately 10% of dissolved organic carbon transported from the mainland to the ocean is from mangroves, although this ecosystem occupies less than 0.1% of the continents' surface. Litter production of mangrove forests usually presents seasonal variation because it is influenced by several factors mainly related to the chemical and physical environment (for example: air temperature, solar radiation, rainfall,type of substrate, nutrient concentration, freshwater availability) (Clough, 1992; Twilley & Day , 1999). On a global scale, litter production varies between 1.0 and 20.3 t/ ha/ yr , and in spite of regional and local variations, the values tend to decline with increase in latitude (Saenger & Snedaker, 1993, Mehlig, 2001). Riverine forests are the most productive, followed by fringe and basin forests (Twilley & Day, 1999). In Brazil, where mangroves cover about 1.4 million hectares (Spalding *et al.*, 1997), studies on litterfall are numerous, but there are no report data on forests subjected to a strong river influence, compare to mangrove of the estuary of the Paraíba do Sul River, located in southeastern Brazil.

Litterfall, which provides an idea of the amount organic matter and carbon available for turnover and export, is the most common estimate of above-ground production in mangrove forests.

Based on this information, global and local patterns of above-ground dynamics have been described. Above-ground biomass and litterfall correlate positively with forest development, but decrease with increasing latitudes (Saenger and Snedaker, 1993).

Generally, aboveground biomass of mangrove forests have been reported to range between 6.8 - 436.4 t/ ha/ yr (Saenger and Snedaker, 1993; Kairo and Bosire, 2009), 'and the litter fall to range from 1.3 - 18.7 t/ ha/ yr. Twilley *et al*. (1992), report the estimation of total global mangrove biomass to be approximately 8.7 gigaton dry weight (4 gigatons of Carbon). According to Clough (1992), mangrove forest biomass may reach 700 t/ ha/ yr elsewhere. Sukardjo and Yamada (1992) report that the above-ground biomass in an Indonesian mangrove measures to 93 7 t/ ha/ yr. In a mixed forest, the above-ground biomass was estimated to be 94.4 t/ ha/ yr that estuarine mangrove of South Africa.

In tropical coastal regions, mangrove occupies the second position in terms of gross productivity, only being exceeded by coral reefs (Qasim and Wafar, 1990; Duarte and Cebrián, 1996). Because it is logistically and economically viable, litter production has been widely used to evaluate the productivity of mangroves (Putz & Chan 1986, Hegazy 1998, Silva *et al.*, 1998, Aké-Castilho *et al.*, 2006, Nascimento *et al*., 2006, Ramos e Silva *et al*., 2006; Fernandes *et al*., 2007), although there is no evidence of correlation between this compartment and the primary production of the ecosystem (Clough, 1992). Besides being used as an indicator of productivity, litter can also provide indirect evidence about plants phenology (Proctor, 1983).

2.7.1 Below-ground biomass

The few studies that estimated below-ground biomass of mangrove forests suggest that it is high in comparison to other tropical, temperate (Golley *et al.*, 1975), and freshwater forested wetlands (Lugo *et al.*, 1988) and marshes. High values of below-ground biomass suggest an important allocation of carbon under-ground, and a fine root contribution of 69% (Mokolensang, 1998). Also, the reported data of below-ground biomass suggest a high spatial variability, that may be controlled by global and local factors (Clough, 1992), as described for the above-ground component (Saenger and Snedaker, 1993). Studies of allocation patterns to above or below-ground components in 22 herbaceous species supported the hypothesis of balanced growth, i.e., under nutrient limiting conditions, more biomass was allocated to roots, and under limited irradiance, more biomass was allocated to leaves (Hossain *et al.*, 2008). Mangrove studies under controlled conditions have found that when resources such as light and nutrients are limited, plants allocate more biomass to leaf area and to roots to maximize uptake. However, species differ in their responses according to specific abilities to cope with resource limiting environments (Mehlig, 2001). Further studies are needed to understand controls on biomass partitioning in mangrove forest in response, especially to flooding and nutrient regimes.

Jane Rogers (1996) provided the first direct estimates of root production rates in basin mangrove forests (natural and restored) of Florida. They found that root production varied from 0.05 to 3.14 $g/m^2/d$, suggesting that C input by roots was 60-70% of litter fall. These estimates of below-ground production in mangroves are similar to values for marshes in the Louisiana Gulf Coast in saline and less saline habitats dominated by S. alterniflora and S. patens, respectively (1.60 and 3.84 g m-2 d-1), but higher than values reported for temperate forests (0.44-1.62

g/m²/d ; Nadelhoffer *et al*., 1985) and lower than estimates in Phragmites australis marshes in the Po delta, Italy (8.5-9.7 g/m²/d). These data further indicate the need to quantify below-ground processes in mangroves to better understand the contribution of mangroves to global net primary production and carbon cycle (Alongi, 2011).

2.8 Mangrove and water quality improvement

Mangrove habitats maintain water quality. By trapping sediments in the mangrove root system, these and other solids are kept from offshore waters, thereby protecting other coastal ecosystems such as oyster beds, sea grasses, and coral reefs from excessive sedimentation. This process can also remove agrochemical and heavy-metal pollutants from the water, since these contaminants adhere to sediment particles. Mangroves also improve water quality by removing organic and inorganic nutrients from the water column (Lawson, 2011).

Through denitrification and soil-nutrient burial, mangroves lower nitrate and phosphorus concentrations in contaminated water, preventing downstream and coastal eutrophication (Ewel *et al*., 1998; Kairo and Bosire, 2009). However, the potential of mangroves to “clean” water is limited and depends on the nature of the inputs, and the surface area and nutrient biochemistry of the mangrove forest. Mangroves have also been used as a tertiary wastewater treatment). Even though this practice may increase mangrove productivity by providing nutrients, it should be conducted under carefully designed and monitored conditions. This will reduce negative impacts, such as contamination of adjacent waterways or introduction of invasive species (Twilley, 1998; Alongi, 2011).

2.8.1 Physico-chemical parameters of surface and soil water

A dominant theme in vegetation ecology is the idea that a species adapts physiologically to physico-chemical gradients in the environment. Two forms of the "gradient" hypothesis exist: the distinct-preference hypothesis and the same-preference hypothesis. The distinct-preference hypothesis states that, each species has its optimum along the gradient which controls where that species occurs. An alternate view is that all species share the same optimum and that other factors (e.g., competition, seed dispersal, and predation) cause zonation. The idea of physiological adaptation has been used to explain the zonation patterns observed in a variety of plant communities, including mangroves. Many environmental parameters vary across the intertidal zone. The most obvious of these and most often cited, is the frequency of tidal inundation. Low intertidal areas are inundated much more frequently than high intertidal regions. Tidal action introduces two other gradients: soil porewater salinity and soil water logging. These two gradients may not vary in the same way as frequency of inundation. The pattern of soil pore-water salinity across the intertidal is influenced by the salinity of the flooding tidal water, rainfall, and freshwater runoff and seepage. (Spalding *et al*., 2010; Conchedda *et al.*, 2011).

Porewater salinity in the lowest intertidal area tends to approximate the salinity of the flooding water: 35‰ near the ocean and <1‰ at the upstream end of riverine mangrove systems. The pattern of salinity variation in the high intertidal zone is complex. In arid regions, pore- and surface-water salinities in the high intertidal may exceed 90‰. In regions with abundant rainfall and freshwater runoff and seepage, high intertidal salinities are often lower than that of the flooding water. Other factors that vary across the intertidal zone include nutrients such as nitrogen and phosphorus, oxidation-reduction potential, and soil texture. These gradients are often correlated. For example, fine-grained, clay sediments are usually the most highly reduced, whereas coarser sands are more oxidized (FAO, 2007). Salinity is one of the most investigated gradients in mangrove distribution ecology. Mangroves, however, are not obligate halophytes. They are fully capable of growing in freshwater. Propagules are capable of survival, but with less than optimal growth, over a broad salinity range (0-100‰ depending on species). Maximum seedling growth for a variety of species occurs between 8-15‰ based on laboratory culture studies. Seedling establishment by *A. germinans* in Texas was not related to salinity. Survival of experimental seedlings was 100% for salinities 0-57‰, 80% at 65 ‰ and 10% at 75‰. Detailed comparisons between the observed seedling distributions of *Ceriops tagal* and *Ceriopsaustralis* (two Australian mangroves) in the field and their survival and growth performance along a laboratory salinity gradient have been made. The studies conducted to date clearly demonstrate that, many mangroves can grow over the broad range of conditions found across the intertidal zone. Data relating species distributions to soil salinities suggest that two groups of mangroves exist. The first has very broad tolerances and can grow and survive in salinities two to three times that of seawater. The second group appears to be restricted to salinities less than 40‰. This latter group is composed of species that have predominantly upstream distributions in river-dominated estuaries (e.g., *Rhizophora. mucronata*) or those restricted to geographic areas of abundant rainfall (e.g., *Pelliciera rhizophoreae*) (UNEP, 2007).

2.9 Mangrove soil characteristics and sedimentation

Soil or sediment is a substrate in the mangrove systems. The term “soil” is used to describe materials that show pedological structure, horizontal texture, and a relationship with the parent material. While sediment consists of materials that can be produced in situ or come from outside of the mangrove systems, it does not have a relationship with the underlying parent material (Mendelssohn and McKee, 2000; Conchedda *et al.*, 2011). Even though mangroves colonize sedimentary environments, excessive sediment deposits can damage them. Moderate sedimentation is beneficial to mangroves as a source of nutrients and to keep up with predicted increases in eustatic sea level rise. When excessive, sudden sedimentation can reduce growth or even kill mangroves. Complete burial of mangrove root structures (aerial roots, pneumatophores) interrupts gas exchange, killing root tissue and trees. Excessive sedimentation can result from natural phenomena such as river floods and hurricanes, but also from human alterations to the ecosystem. Road and dam construction, mining, and dredge spoil have buried and killed mangroves (Akegbejo, 2009; Crona *et al*., 2009). Mangrove sediments are mainly anaerobic in nature with only a thin aerobic sediment layer overlying it. Often the organic matter is available in dissolved form and the nutrients get recycled both within the mangrove as well as in adjoining habitats (Kathiresan , 1997; FAO, 2009). Degradation of organic matter in the aerobic zone occurs predominantly through aerobic respiration whereas in the anaerobic layer decomposition occurs mainly through sulphate reduction (Davis ,1993; Sherman *et al*., 2003; Jane Rogers, 2006). However studies on large number of coastal ecosystem indicate that much of the energy flow through these ecosystems is mediated through anaerobic microbial metabolism, especially by the sulphur cycle (Day *et al*., 1996; Kathiresan, 1997; Alongi *et al.*, 2005; Dittmar *et al.*, 2006; Hossain *et al*., 2008).

2.10 Mangrove and Nutrients

2.10.1 Nutrients in Soils

Nutrients in mangrove forest soils are controlled by various biogeochemical processes including tidal regime, litter accumulation, and litter decomposition. Geographical location, elevation, soil properties, and microbial activities collectively affect the amount of nutrients in the mangrove soil (Boto and Wellington, 1984; Lacerda *et al*., 1993). Nutrients are abundant, further inland and in locations where freshwater input is high. Soil in high elevation usually contains more nutrients than soil in low elevation due to increased organic matter accumulation. Physical and chemical properties of soil, especially the redox potential, are factors that also significantly affect nutrients on both the macro and micro levels (Lugo, 1999; Gary, 2004).

Nitrogen availability is limited in the mangrove ecosystem (Boto 1982, Mendelssohn and McKee, 2000) due to high levels of sodium and the denitrification process. In wetland soils, ammonium is the main form of inorganic nitrogen. However, high levels of sodium in most mangrove soils displace ammonium, which is then washed away from the soil by heavy rain, water runoff, or tidal flushing (Alongi, 1996). The remaining ammonium interacts with oxygen and is oxidized to nitrate (Ponnamperuma, 1972). Through denitrification and leaching, nitrogen become limiting in the mangrove ecosystem. Organic phosphorus and dissolved inorganic phosphorus are low in the water currents of mangrove forests, and they often occur mainly in the form of HPO42- at seawater pH (Krauss *et al.*, 2008). Similar to nitrogen in the wetlands, dissolved phosphorus concentration is also affected by salinity concentration in that dissolved phosphorus decreases with increasing salinity (Alongi *et al*., 1996; FAO, 2009). Several reseachers like Odum and Heald (1975), Macintosh and Ashton (2003), Kairo and Bosire (2009), Spalding *et al.* (2010); Conchedda *et al*. (2011) report that the concentration of nutrients like the nitrogen is increased during decomposition and energy- rich microbial biomass, proteins and humic substances are entering into the ecosystem in dissolved form.

In estuary regions, phosphorus concentration is dependent on the amount of rainfall. The lowest concentration is found in the dry season when primary production is optimal (Spalding *et al*., 2010). Inorganic phosphorous is especially limited for plants in sandy soil environments (Alongi, 1996). Limited amounts of available phosphorus have been known to slow the growth of mangrove forests (UNEP, 2007; Spalding *et al*., 2010). Organic phosphorus concentration, conversely, is often higher near the soil surface (0-25cm) and affects the uptake of phosphorus by roots (Alongi, 1996; FAO, 2009). Phosphorus concentration varies by season, temperature, rainfall, oxygen availability, sediment type, and plant uptake, whereas the amount of ammonium is lower in reduced sediments, the amount of available phosphorus is often higher in reduced sediment. As mentioned above, inorganic phosphorus in mangrove sediment is bounded by calcium, iron, and aluminium phosphates, and the inorganic phosphorous proportion increases with increasing in depth (Alongi, 1997; Mendelssohn and McKee 2000; UNEP, 2007).

2.10.2 Nutrient cycling

Nutrient dynamics is an important function of mangrove ecosystem in terms of biogeochemical cycling of elements in the coastal zone (Jennerjahn and Ittekkot, 2001), Twilley (1988) elucidated how nutrient recycling is an important process that determines whether a mangrove system functions as a nutrient sink or a nutrient source to adjacent aquatic 13 systems like estuarine or coastal ecosystems. Rogers (1996) pointed out that assessment of biogeochemical functions in a mangrove ecosystem should involve the evaluation of complex processes that control soil condition, carbon movement, recycling of nutrients including other primary interactions (Sherman *et al*., 2003; UNEP, 2007).

2.11 Mangrove and pollution

Human-caused pollution in mangrove ecosystems includes thermal pollution (hot-water outflows), heavy metals, agrochemicals, nutrient pollution (including sewage), and oil spills. Thermal pollution is not common in the tropics but, when present, reduces leaf area and causes chlorotic leaves, partial defoliation, and dwarfed seedlings. Seedlings are more sensitive than trees, showing 100% mortality with a water temperature rise between 7 and 9 ºC (Conchedda *et a.l*, 2011).

Mining and industrial wastes are the main sources for heavy metal pollution (especially mercury, lead, cadmium, zinc and copper). When heavy metals reach a mangrove environment, most are already bound onto suspended particulates (sediments) and in general do not represent an ecological threat. Although the accumulation of heavy metals in mangrove soils has not been studied in detail, they may decrease growth and respiration rates of mangroves, and will also negatively impact associated animals. Concentrations of mercury, cadmium, and zinc are toxic to invertebrate and fish larvae, and heavy metals cause physiological stress and affect crab reproduction. Runoff from agricultural fields represents the main source of organic chemical contamination in mangrove ecosystems. Little is known about the effects of pesticides in mangroves and associated fauna, although chronic effects are likely. As with heavy metals, many of these compounds are absorbed onto sediment particles and degrade very slowly under anoxic conditions. Despite the possibility of burial, heavy metals and pesticides may bioaccumulate in animals that use mangroves (especially those closely associated with mangrove sediments), such as fish, shrimp, and mollusks (Krauss *et al.*, 2008; Spalding *et al.*, 2010)

Nutrient pollution in mangroves can have various effects. Sewage disposal under carefully managed conditions can enhance tree growth and productivity as a result of added nutrients, especially nitrogen and phosphorus (Twilley, 1998; Spalding *et al.*, 2010; Dahdouh-Guebas, 2011). This causes excessive algae growth, which can obstruct mangrove pneumatophores and reduce oxygen exchange. Algae mats can also hinder growth of mangrove seedlings. Excessive microbial activity accompanies high levels of nutrients, and depletes oxygen in the water, which is harmful for mangrove-associated aquatic fauna (Gary, 2004; Alongi, 2011).

2.12 Current Research on Ecological characteristics of world and African Mangrove forest

Mangroves play an extremely important role in maintaining high productivity and rich biotic diversity of coastal waters and are of interest from economic, scientific as well as wildlife management point of view (Spalding *et a.l.*, 2010). The ecological characteristics of mangrove can be truly assessed by evaluating their forest structure, litterfall production, nutrients input, water and soil qualities (Aheto *et al*., 2011 and Ramsar-Mava-UNEP, 2012).

2.12.1 Ecological characteristics of selected parameters (structural characteristics, litter production, water and soils qualities of mangrove)

Structural characteristics of mangrove forest

Fernandes (1999) conducted a research on the structural properties and the environmental parameters that characterize the three types of mangrove forests dominated by Rhizophora, *Avicennia*, and *Laguncularia* in Brazil. The aim was to determine the forcing function that influences their development and architecture.Vegetation structural measurements included trunk diameter, total height, and crown diameter. From these data a number of indices (relative frequency, relative density, relative dominance, and importance value) were calculated. The results showed that relative dominance provided the best description of the stands in terms of the contribution of each component species. DBH (Diameter at breast Height) along with height appeared to influence the density and spatial distribution of the individuals. *Avicennia* dominates the most developed stands followed by *Rhizophora*. The relative frequency of Rhizophora had similar values at each study site. It appeared that mangrove area is basically dominated by *Rhizophora mangle*, although *Avicennia germinans* is also present in this mixed stand.

Ajonina (2008) studied the possibilities of developing appropriate models to facilitate the assessment, monitoring and sustainable management of mangrove forest in order to understand the dynamics and resilience of mangrove systems to various disturbance regimes. The study was carried out in the Cameroon Estuary (Douala Edea Reserve); the focus was mainly on allometric studies and slightly in the role of the structural parameters of mangrove pure and mixed stands. From the results, it was realised that, the mean stand height for Avicennia (15.4m) was lower compared to *Rhizophora* (17.2m). On the contrary, density (4139 stems/ha) and basal area (5.18 m^2/ha) in Avicennia stand was higher than in *Rhizophora* stand (2850 stems/ha; 4.86 m^2/ha).

Mangroves exhibit different resource stock and flow (dynamic) characteristics. Tolerant forest disturbance levels generally encourage growth and recruitment processes, while extremes levels favour mortality and degradation. The study pointed to the fact that, more research, including modelling techniques, need to be focused on the description of a large range of pure, or mixed, mangrove stands. This would allow a better understanding of the effects of species composition and their architecture on the reliability of sampling distances and quadrants methods within mangrove forest.

Armah*et al.* (2009) conducted a research on the evaluation of a reforested mangrove at Obane near Ada in the Songor Ramsar site in Ghana in which they identified the structure and the forest. In addition to that, they made a socio- economic assessment of the mangrove ecosystem. For this study structural characteristics of Rhizophora and Avicennia stands were analysed respectively for height, 8.17± 1.91 m (The tallest individual was about 12 m) and 6.5 ± 1.32 m (The tallest individual was about 8 m); for regeneration, no natural recruitment into lower girth class or poor regeneration capacity and poor natural regeneration and recruitment into the higher classes (i.e. 10-15cm and above); for seedlings density, 150 stems/ha and

Nfotabong (2011) studied the impact of anthropogenic activities on the vegetation structure of mangrove forest in Cameroon estuary and Nyong and River at Kribi in Cameroon. One aspect of this study was mainly focused on the structural characterization of *Avicennia germinans*. This study broadly focused on the impact of anthropogenic activities on the vegetation structure and specifically on the structural characteristics of pure *Avicennia germinans* stands. The multi-disciplinary approach employed in this study has allowed a better understanding of the direct and indirect impacts of anthropogenic activities on the mangrove vegetation structure in Cameroon.

Aheto *et al.* (2011) worked on the analysis of mangrove forest structure and standing biomass around the Kakum Estuary of Ghana. This research aimed at evaluating the structural dimensions and biomass of the mangrove forest. The most significant conclusion from this study is that even though *R. mangle* was found to be the principal species and significantly larger in terms of mean height, basal area and standing biomass, they are of generally low structural development, as applied to the other species as well.

Litter production

Slim *et al.* (1996) assessed biomass and litterfall of *Ceriops tagal and Rhizophora mucronata* in the mangrove in the forest of Gazi in Kenya in the East African region.The study showed that, the highest above-ground biomass was observed in the *Rhizophora mucronata* stand, in which leaf litter production showed the highest value. There was a distinct seasonal pattern in litterfall in both stands, with lower litterfall values in the wet season. Chloride concentrations were relatively high in senescent leaves, compared with those in green leaves. The decreased litterfall during the wet periods may be related to a reduced accumulation of chloride in the leaves. The difference in inundation frequency between the *R. mucronata* and *C. tagal* stands is expected to cause a more substantial tidal export of fallen leaves from the *R. mucronata* stand. As nitrogen resorption before defoliation was similar for *C. tagal* (50.9%) and *R. mucronata* (50.1%), tidal flushing may cause larger nitrogen losses from the *R. mucronata* stand.

Mokolensang and Tokuyama (1998) worked on litter production of mixed mangrove forest at Ryukyus. Okinawa in Japan in the Indo-Pacific region. The results showed that Leaf production was found to be continuous throughout the study period, which suggests that the environmental conditions are favourable for leaf emergence all year round and the stress does not appear to limit the leaf production. Litterfall rate in the Gesashi mangrove forests is seasonal. It is generally low in winter and high from spring to summer. Total weight of litterfall was 1190 $g/m^2/yr$ or 11.9 t/ha/yr in the mixed mangrove forests.

Navarrete and Rivera (2002),studied litterfall production of *Rhizophora mangle* at bacalar Chico, Southern Quintana Roo, Mexico.In order to know the litter fall of the red mangrove, *Rhizophora mangle*, samples were collected from July 1996 to July 1997 in the channel of Bacalar Chico in Southern of Quintana Roo state. Four mangrove species were present in the study area, but *Rhizophora mangle* dominated widely. Leaf production comprised 99.8% of total litter fall biomass, being the highest in July and September 1996 (0.27 g/dry wt/m²/ day and 0.28 g·dry g/dry wt/m²/ day respectively). Although, the flowers and the fruits represented less than 1% of total litter production, it was clear that the reproductive season was coincident with the highest values of temperature and precipitation, both occurring in September. Mangrove in Quintana Roo produced a total litter fall of 2.61 t dry wt / ha / year.

Wang'ondu *et al*. (2010) studied Phenology of *Avicennia marina* (Forsk.) Vierh. in a disjunctly-zoned Mangrove Stand in Kenya in the East African ecoregion. The main objective of this study was to investigate the phenology of *Avicennia marina*, while observing also peaks in leaf fall, in the disjunctly zoned stands by direct shoot observation. Vegetative and reproductive phenology of *Avicennia marina* was studied from January 2005 to December 2006. The results showed that, fruit fall peaked in April and May during the wet season. The major peak leaf fall occurred between the months of July to September at these sites, whereas in 2006 leaf fall peaks occurred in September to November.

Bernini and Rezende (2010) assessed or estimated the litterfall production of a forest dominated by *Avicennia germinans, Rhizophora mangle andLaguncularia racemosa* in the mangrove estuary of the do Paraíba do Sul River (PSR), in Southeastern Brazil. The amount of litter produced was measured over a two year period (2005- 2006).The purpose of this study is: (1) quantify and compare litter production in riverine forests of *Avicennia germinans* (L.) Stearn., *Laguncularia racemosa* (L.) Gaertn. f. and *Rhizophora mangle* L. and (2) evaluate the influence of environmental factors on the productivity of the mangrove in this estuary. It was observed that, total litter production was higher in the *R. mangle* forest, followed by *A. germinans* and *L.racemosa* and did not vary between years. For the three species, the leaf fraction was the main component of the litter, followed by fruit, wood, flowers and miscellaneous. Litter production was seasonal, with higher values in the rainy season. There was no relation between litter production and vegetation structure. The environmental variables, rainfall, mean air temperature and wind speed explained little of the seasonal litter variability. The environmental variables, rainfall, mean air temperature and wind speed explained little of the seasonal litter variability. This study showed that the mangrove estuary of the PSR has as high production values of litterfall and no interannual variation, probably because it is an environment dominated by the river, which receives a high influx of nutrients and freshwater to be an environment dominated by river.

Forest structural characteristics and litter production

Sackey *et al.* (1996) also carried out a research onmangrove regeneration and productivity in the Korle Lagoon and Iture mangrove stands in Ghana in the West and Central African ecoregion. The research revealed that there is seasonal flooding of the mangrove stand and the consequent destruction of the seedlings and saplings. In Iture estuary, about 68.5% of the total litter production of 3881.7 kg dry wet/ha measured in 7 months consisted of leaf litter. Overall stand density of mangrove seedlings and saplings was 18401 stems/ha indicating good regeneration from seedlings. Soils of the estuary are liable to acid sulphate formation. Mortality of *Rhizophora* and *Avicennia seedlings* in 8 months was 30% and 36% respectively. Factors of seedlings mortality were crab damage, trampling and physical uprooting of seedlings by pigs, and trampling by human.

Arreola-Lizárraga (2004) studied Structure and litterfall in an *Avicennia germinans* mangrove stand in an arid zone on the Gulf of California, México in South America. The results revealed that, the density and basal area were more characteristic of a fringe-type mangrove stand, while average height of, and complexity index were closer to those of a dwarf-type mangrove. Structure is jointly influenced by a high rate of evaporation, scarce rainfall and a brief period of tidal flooding (also only in the summer). Litterfall averaged 1.75 t ha−1 per year, placing it even lower than the lowest value reported so far for mangrove litterfall (2–16 t ha−1 per year). Litterfall showed a unimodal seasonal pattern, with higher values in summer. Rainfall, sea level and the ratio rainfall/evaporation explained 86% of the seasonal litterfall variability.

Chen *et al.*, (2009) studied Litter dynamics and forest structure of the introduced *Sonneratia caseolaris* in themangrove forest in Shenzhen, China. The litter fall and forest structure of this *S. caseolaris* forest in Shenzhen City, Guangdong Province were monitored from 1996 to 2005. The results showed that, the mean annual total litter production during 1998–2005 was 15.1 t/ ha/ yr, among which, leaves and reproductive materials contributed more than 80% of the total. During the ten years of study, the DBH (diameter at 1.30 m from ground level) and tree height of *S.caseolaris* increased from 5.2 cm to 18.3 cm, and from 4.5 m to 13.4 m, respectively. The litter fall production was strongly correlated with forest structure parameters, such as DBH, tree height, and crown area. The R value (the ratio of the maximum total litter fall to the minimum in the same community during the investigation periods) of *S. caseolaris* in the present study was 1.98, indicating a low annual variation of litter fall during these ten years.

Hernandez *et al*. (2011)studied forest structure, productivity and species phenology of mangroves in the La Mancha lagoon in the Atlantic coast of Mexico.They described, through a vegetation profile, the forest structure (density, basal area, tree height, and species composition), the productivity dynamics (based on litterfall) and the species phenology of distinct physiognomic types of mangroves in three locations of the La Mancha lagoon system in Veracruz, Mexico, during a complete annual cycle. They also evaluated the microtopography and ground water salinity along the profile and their relationship with forest structure and productivity.

Water quality and pollution

Alkarkhi *et al.* (2008) assessed mangrove surface water through multivariate analysis in two rivers, Juru and Jejawi of Malaysia in the state of Penang.The sites are located adjacent to industrial areas which were reclaimed from mangrove.Multivariate statistical techniques such as factor analysis (FA) and Discriminant analysis (DA), were applied for the evaluation of spatial variations and the interpretation of a large complex water quality data set of those two rivers, monitoring 10 parameters at 10 different sites each, over one year (2006). Factor analysis resulted in two factors explaining more than 82% of the total variance in water quality data set. The factors indicate that the possible variances in water quality may be due to either source of anthropogenic origin or to different biochemical processes that are taking place in the system. The first factor known as pseudo anthropogenic factor explained 59.29% of the total variance. The second factor called anthropogenic explained 23.03%. DA gave the best result to identify the relative contribution for all parameters in discriminating (distinguishing) the two rivers affording 100 % correct assignations.

Nazli *et al*. (2010) studied Heavy Metal Concentrations in an Important Mangrove Species, *Sonneratia caseolaris*, in Peninsular Malaysia as mangroves receive heavy metal pollution from upstream areas and the sea. The main purpose of this study was to analyze the uptake of selected heavy metals (cadmium, chromium, copper, lead and zinc) by an important mangrove species, *Sonneratia caseolaris*.

For the results it was found that, the total concentrations of Cd, Cr, Cu, Pb, and Zn in the sediments were below the general critical soil concentrations, which are, 8, 100, 125, 400,400 respectively (Allotey *et al*., 2008). However, the total concentrations of Cu and Pb in both the roots and leaves of *Sonneratia caseolaris* exceeded the normal upper range in plants.

Lawson (2011) assessed physico-chemical parameters and heavy metal contents of Water from the Mangrove Swamps of Lagos Lagoon in Nigeria, in the West and Central African ecoregion. The study was aimed at assessing its suitability for fish production and as well as its safety for drinking purpose . In all, eleven (11) physical and chemical parameters and six (6) heavy metals were investigated for water quality assessment of the lagoon between January and December 2001. This study is therefore a baseline data toward future ecological study, conservation and management of the resources of this economically important wetland in Nigeria.

Kumara and Kumar (2011) evaluated the water quality of mangrove ecosystems of Kundapura, Udupi district, Karnataka in the Southwest coast of India. The purpose of the study was to evaluate the physico-chemical parameters of four selected sites of mangrove ecosystem, located at Kundapura, of Udupi district, Karnataka, Southwest coast of India, for a period of one year between August, 2010 and July,2011.

Soil's characteristics

Ansa *et al.* (2007**)** conducted a baseline study to determine the basic physical and chemical characteristics of the sediment in Niger Delta in Nigeria in the West and Central African ecoregion. From the results it was noticed that sediment characteristics studied are prone to changes which could arise from human activities such as removal of mangrove vegetation for domestic fuel and sand filling.

Allotey *et al*. (2008) assessed physico-chemical properties of three salt-affected soils in the Lower Volta Basin in Ghana in the West and Central African ecoregion. The aim was to contribute to the elaboration of management strategies for sustainable utilization. The results showed that, low pH of the soils, attributed to the presence of pyrite, ranged from moderately acidic to extremely acidic. The electrical conductivity of all the three pedons was more than 4 dS/m but less than 8 dS/m. They are, therefore, moderately saline.Exchangeable sodium percentage (ESP) of all the three pedons were lower than 15. The Organic carbon varied from 0.8 to 2.9%. The carbon to nitrogen ratio (C: N) was higher than the common range 8:1–15:1 for arable soils as proposed by Brady (1990). Exchangeable Ca content is comparatively the highest among the exchangeable bases in the three pedons. Exchangeable bases within the similar generic horizons in the three pedons were in the order Ca > Na > K > Mg. hence, the soils were rated saline.

Effiong *et al.* (2010) conducted a research on six representative soil profiles in the Niger Delta of Nigeria. The aim was to characterize and assess the constraints and management of mangrove soils for sustainable crop production in the Niger Delta of Nigeria. Results indicate soil texture varied widely from sandy to predominantly silty loam and sandy clay loam) with a mixed clayey/silty loam texture. In summary, the characteristics of mangrove soils indicate silty loam texture (high silt and clay contents), colour value was dominantly dark grayish to black, high total N and organic C level. The major constraints identified included high acidity (low pH < 4), high soluble salts (EC), low CEC and P levels as well as poor drainage.

The study was more focussed on the fertility aspects and not on the ecological role of soil properties in the dynamic of mangrove ecosystem.

Rambo *et al*. (2010) conducted a research based on the comparison of selected soil chemical properties of two different mangrove forests in Sarawak in Malaysia. The study attempts to obtain preliminary database of mangrove forest soil chemical properties and to compare the forest health from two different mangrove forest locations. The results showed that, the soil acidity, total N, total P, CEC and humic acid of both locations were significantly different while in terms of total carbon and organic matter were similar.

Mangrove Carbon sequestration

Sheetal and Madhuri (2010) undertook a study to assess the carbon sequestration potential of two different mangrove species (*Avicennia marina* and *Sonneratia apetala*) found in the area of Thane Creek, Maharashtra in India. They used PVC pipes as sediment cores to collect samples of different cm depth. The samples were collected monthly from Nov 2009 to Oct 2010. The results showed that, the pH ranged between 6.76 and 8.08 with an average of 7.63; On an average moisture content ranged between 47% to 48 %; the organic carbon in the sediments of Thane creek showed variations from 0.56% to 4.89 %;Sediment Organic Carbon beneath *Avicennia marina*,showed high sediment organic carbon at the top layer 2.53% and then the decline 1.406% followed by increase of 1.997%; The organic carbon content in dry leaves i.e. litter fall was 12.90 % to 13.05 %. Thane creek is therefore rich in organic carbon due to natural and anthropogenic sources of organic matter accumulated and stored in the ecosystem for some time before it is released and recycled back to the atmosphere.

Nutrient dynamic

Mohammed *et al*. (1998) studied the role of mangroves in the nutrient cycling and with productivity of adjacent seagrass communities, Chwaka Bay, Zanzibar in Tanzania. The impact of mangrove-derived particulate organic matter (POM) on nutrient dynamics and the productivity of an adjacent seagrass community were investigated. Analysis of the C:N ratio of POM in the water ebbing from the forest produced values ranging from 2 to 11 which is the same range of values as that of the mangrove plant materials on examination of the carbon and nitrogen contents of the sediment reveals a gradient of concentrations from the site closest to the forest outwards, with the site adjacent to the mangroves enriched with both total organic nitrogen (TOC) and total nitrogen (TN).

Kumar *et al.* (2011) carried out a research to determine the nutrient budget of plants, sediments and nutrient dynamics in an *Avicennia marina* (Forsk.) Vierh. dominated forest in Vamleshwar near Narmada estuary, West Coast of Gujarat for a period of one year from November 2008 to October 2009. The results of the research showed that, average tree height of the mangrove is 1.5 to 2 m without much vertical stratification.

Flow coefficients, which reveal the dynamic processes of nutrients between mangrove plants and sediments, were also explained. The present study concluded that *A. marina* a dominated mangrove plantation was more efficient in nutrient use, and conservation.

Nutrients and forest structure

Ronghua and Twilley (1999), studied patterns of mangrove forest structure and soil nutrient dynamics in the Shark River estuary at the southwest Florida coast.

These soil values indicate that abiotic stress cannot explain the decrease in forest structure along this estuarine gradient. Concentrations of nitrogen (N) and phosphorus (P) are more closely related to patterns of forest development, with higher soil fertility at the mouth of the estuary as indicated by higher concentrations of extractable ammonium, total soil P, and available P, along with higher ammonium production rates.

2.13 Threats to mangrove

2.13.1Natural Threats

It is recognized that global warming has contributed to sea level rise (Church *et al*., 2001), and increases in precipitation and the frequency and magnitude of extreme weather events in many areas (Spalding *et al*., 2010). Related disasters have had severe economic impact (UNEP, 2007). Sea level rise in Ghana and Cameroon is predicted to lead to permanent connections between the sea and lagoons; increased saltwater penetration into estuaries, lagoons and coastal freshwater aquifers, increased coastal erosion and beach recession; and decrease in coastal water table depth. Severe beach erosion on either side of the Volta and Cameroon estuaries is flooding areas such as Keta and Wouri. Lower than normal rainfall and increased use of water for irrigation in upstream areas of the Volta River have reduced water levels downstream, leading to blockages of tidal water channels, drought and reduced fish abundance (Armah *et al*., 2005; 2009; Ajonina, 2008).

2.13.2 Anthropogenic Threats

Throughout the world, humans have degraded coastal ecosystems, suggesting undervaluation of their contributions to human livelihoods. Anthropogenic interference in mangrove areas has caused substantial changes in both physiognomy and species composition within this ecosystem (Dahdouh-Guebas, 2001; Zuleiku *et al.*, 2003). Globally, this ecosystem is subjected to increase anthropogenic stress and to lesser extent natural stress (Hamilton and Snedaker, 1984). Current threats to this ecosystem stems from the difficulty in placing monetary value in all mangrove components, and lack of ecological knowledge and holistic approach among those performing the evaluation and the focus on short term returns rather than long-term ecological returns from the system (Babier *et al*.,1999; WRM, 2001).

Population growth has led to overexploitation and unregulated use of mangrove and mangrove forest goods and services for saltpans, sugarcane production, clearing for building, fuel, fish processing and construction. In most areas, mangroves are degraded due to intensive wood use. The bark of *Avicennia germinans* is used for tanning fish nets as well as for firewood for fish processing. Increased population has led to conversion of lands, development of urban centres and industries, conflicting land use, and pollution (World bank, 2003).

Mangrove depletion resulting from the activities of man leads to climatic changes. Predicted sea rise as a result of global warming is expected to affect mangroves and cause them to occupy new localities because they cannot sustain prolong inundation by fresh water or salt water (Dahdouh-Guebas, 2001; Ajonina, 2008; Armah *et al*., 2009). Major factors that seriously jeopardise the existence of mangrove worldwide include: human habitation and population increase; higher short term benefits, lack of appropriate government attention and environmental awareness and education on mangroves, inefficient restoration techniques, and pollution from crude oil, sewage and other effluents, timber and fuel wood extraction.

2.14 Sustainable Management of Mangrove

With regard to management and conservation of mangrove resources in Cameroon and Ghana coastal zones, not many scientific studies have been done. Few documents available on this subject sometimes include limited analyses. The lack of scientific database for effective wetland management and the inadequacy of in-country technical expertise, for wetland management are common to the countries in the sub-region (World Bank, 2003).

This insufficient knowledge and skills in most third world developing countries, has brought much doubts and scepticism in the management and conservation of these mangrove resources. However, in the coastal zone mangroves provide many functions such as coastal stabilization, erosion prevention, biological filtering, and serve to produce many economic benefits to local populations (World Bank/ISME/Center, 2004; UNEP, 2007).

In those zones there are sometimes many protected areas rich in biodiversity, but some of those areas are presently subjected to massive destruction, regardless of the ecological importance of mangrove resources due to existing inappropriate governance system. In Cameroon for example, this is the case of the Campo and Edea-Douala Reserves (Gabche and Smith, 2006). The high population pressure in the coastal areas has also led to the conversion of many mangrove places to other uses including infrastructure, field extension, aquaculture, rice and salt production. In that case, mangroves are being fragmented and degraded due to over exploitation of resources.

The planning of sustainable forest management at the local and national levels depends largely on this information, and the lack of data on the distribution and the ecological importance of mangroves, makes it difficult to prepare successful plans for their conservation. Regular monitoring evaluation is thus necessary and may contribute to their conservation, but also to sustainable use of mangroves as a source of wood, food, income and recreational areas for present and future generations. Results from this study will be very useful for mangrove forest managers in understanding the role played by mangroves through their ecological functions in the coastlines of Cameroon and Ghana and effectively, to establish the ecological relationship in both countries within the West and Central African Ecoregion (FAO, 2009; Spalding *et al*., 2010).

2.14.1 Forest Policy development for mangrove resources management

In many African countries and particularly in Cameroon and Ghana, there are currently no effective mangrove forest policies, legislation and institutions that responseto actual realities of collaborative natural resources management, but some countries are in the process of policy review to adapt to current context. In some other countries, good policies suffer from lack of implementation (Ajonina, 2008 and Armah *et al.*, 2009; Spalding *et al.,* 2010).

CHAPTER 3
3.0 MATERIAL AND METHODS

3.1 Description of the Study Area and Site selection

3.1.1 Songor Ramsar site in Ghana

Ghana is one of the states in West Africa with access to the Atlantic Ocean and lies along the Gulf of Guinea, 5.5 degrees north of the Equator, within longitudes 30 5' W and 1010' E and Latitudes 40 35'N and 110 N. It covers an area of about 239,000 km² and has a coastline of about 550 km., which is generally low lying and not more than 200 m above sea level (Spalding *et al.*, 2010). The total population is estimated at about 23 million inhabitants (FAO, 2009; Armah *et al.*, 2009). The coastal area is drained by four major rivers and dotted with over 90 coastal lagoons. Most of the lagoons are very small and less than 5 km² in surface area. The largest lagoon, the Keta Lagoon however covers an approximate surface area of 350 km². The coastal area represents about 6.5% of the total area of Ghana, but houses over 60% of industries in the country (Armah and Amlalo, 1998).

The coverage of mangrove vegetation is unknown but it is believed to be in the region of 20 – 100 km^2 (Chidi Ibe, 1998; UNEP, 2007; Spalding *et al.*, 2010). The Volta River Basin is located in West Africa and covers an estimated area of 400,000 km². It stretches from approximately latitude 5° 30' N in Ghana to 14° 30' N in Mali. The widest stretch is from approximately longitude 5° 30 W to 2° 00 E but the basin becomes narrower towards the coast of the Gulf of Guinea. The Volta basin is spread over six West African countries (43% in Burkina Faso, 42% in Ghana, and 15% in Togo, Benin, Cote d'Ivoire and Mali) (World Bank, 2003; FAO, 2009).

The study area is located at Ada (Figure 1). Songor Ramsar site at Ada-Foah (5°45´-6°00N, 0°25´-0°35´) lies in the Dangme East District of the Greater Accra Region and distanced about 79 km from the national capital, Accra. It is the second largest Ramsar site along the coast of Ghana and covers an area of 53.33 hectares (ha) and the only natural point where the Volta River enters the sea. The mangrove in this area covers 28.740 ha comprises mainly the Red mangrove (*Rhizophora*) and the black mangrove (*Avicennia*).

The climate of the region is controlled by two air masses: the North-East Trade Winds and the South-West Trade Winds. Three types of climatic zones can be identified in the region: the humid south with two distinct rainy seasons; the tropical transition zone with two seasons of rainfall very close to each other; and, the tropical climate, north of lat 9° N, with one rainfall season that peaks in August. Average annual rainfall varies across the basin from approximately 1600 mm in the south-eastern section of the basin in Ghana (Boubacar *et al*., 2005; FAO, 2009).

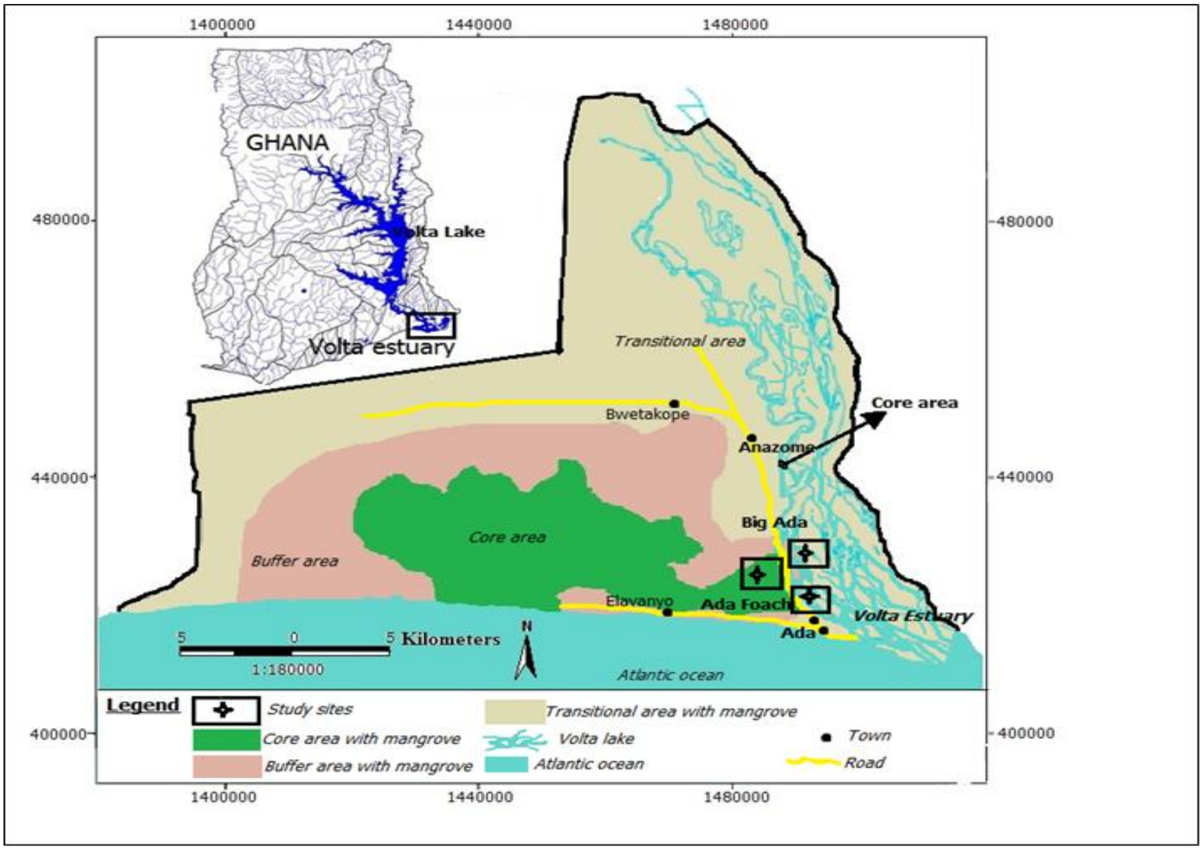


Figure 1: Map showing the Research Area at Ada Songor Ramsar site in Volta Estuary (Source: modified from EPA/UNOPS, 2004)

3.1.2 Douala- Edea Reserve in Cameroon

Cameroon is located at the extreme north-eastern end of the Gulf of Guinea and lies in the Bight of Biafra between longitudes 8° and 16° E and latitudes 2° and 13° N (Figure 2). The country has an approximate area of 475 000 km² of land, constituting about 1.47 % of the African Continent. The total population is estimated at about 19 million inhabitants (Saenger and Basco, 2008)

The Cameroon coastline is approximately 402 km long. It borders the Atlantic Ocean and extends from latitude 2° 20’ N at the boundary with Equatorial Guinea to latitude 4° 40’ N at the border with Nigeria. Cameroon has an inter-tropical climate which is characterized by generally hot, moist and dry conditions in the coastal zone. However, local factors, including proximity to the sea, may greatly affect the climate at various locations. Thus the south-western coastal area is greatly influenced by Mount Cameroon (a peak reaching 4070 m) and is characterized by abundant rains Up to 2 000 mm annually in Douala) and temperatures generally above 25° C. Mangrove estuarine complexes in Cameroon occupy approximately 30% (1,800 km²) of Cameroon's coastal zone and the Cameroon mangroves in Wouri estuary in the centre extend over a surface area of 1100 km (UNEP, 2007; Din *et al.*, 2008).

The Cameroon coastal zone contains an extensive river network which, together with supplies from groundwater and rainfall, constitute the major source of freshwater into the continental shelf which covers an area of about 15 400 km².These huge freshwater inputs also bring a variety of materials (including various pollutant substances) into the coastal zone. Indeed, this is thought to be the main source of nutrients into a coastal zone where upwelling phenomena are almost completely absent (Gabche and Smith, 2006). Prominent features of the coastal zone are beaches, coastal plains, river deltas and estuaries with extensive mangrove vegetation, and coastal forest (Gabche and Smith, 2006; UNEP, 2007).

The study area has been described (see Figure 3) by Ajonina and Usongo (2001). Douala Edea Reserve (9°31'-10°05'E, 3°14'-3°53'N) is one of the largest and biologically rich mangrove reserves of Cameroon. It is situated within the Kribi-Douala Basin of the coastal Atlantic Ocean and covers a greater part of the coastal plains of the Cameroon Coast (160.000 ha). The Area has a very dense hydrological network being a meeting point of estuaries of Cameroon largest rivers (Rivers Sanaga, Nyong, Dibamba and Wouri). The Reserve is limited in the North by the rivers

Wouri and Dibamba; East by rivers Sanaga, Dipombe and Kwakwa; the South by river Nyong; and the West by the Atlantic Ocean for some 100 km coastline from river Nyong to the Cameroon Estuary. The climate is equatorial type characterized by abundant rains (3000-4000 mm) and generally high temperatures with monthly average of 24-29 °C with a dry season spanning November to April.

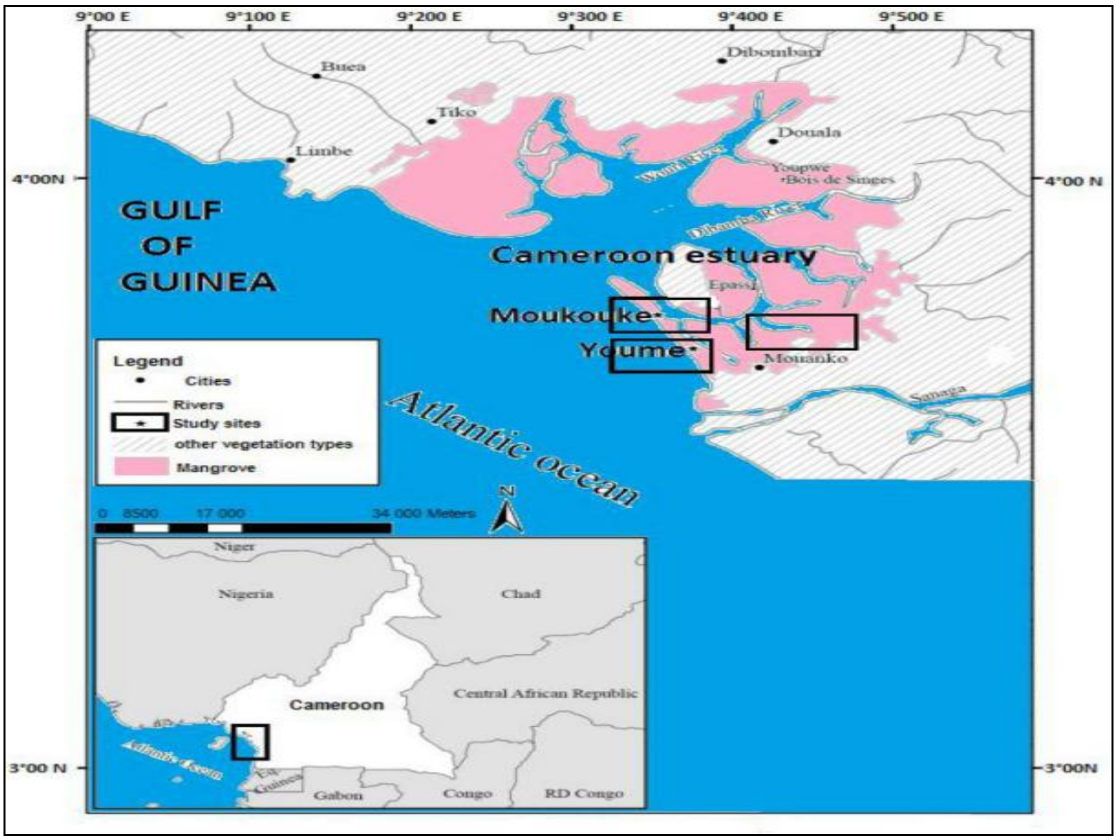


Figure 2: Map showing the sampling stations at Douala Edea Reserve in Cameroon Estuary (Source: modified from UNEP, 2007 and Nfotabong, 2011)

Prior to site selection, a preliminary survey was conducted in all of the existing mangrove ecosystems, in Ada estuary complex in the Greater Accra Region in Ghana, and in Cameroun estuary (Douala –Edea Reserve) in Cameroon. Both sites are protected areas and among the largest reserves, with a relatively high mangrove cover. The mangrove ecosystems were evaluated and identified based upon their main plant species (*Rhizophora racemosa*, *Avicennia germinans*) and their stability (very little degradation). Three study sites were then identified, based on the type of mangrove ecosystem vegetation: i) Pure red mangroves (*Rhizophora racemosa*); ii) Pure black mangroves (*Avicennia germinans*); and iii); mixed stand (red and black mangroves). These two Reserves in both countries were selected for investigation because the mangrove ecosystems are relatively well conserved.

3.2 Experimental Design and data collection

3.2.1 Survey and sampling design

Combinations of sampling approaches were used to achieve a nested design. Targeted sampling (TS) method was used to select areas of species agglomerations where three study sites representing the various species agglomerations (stands of pure *Rhizophora*, pure *Avicenina* and a mixture of them in equal proportion) were retained. This was followed by a three stage multistage sampling approach to subdivide the plots to a desired measurement level corresponding to the point-centred quarter method (PCQM) revised and described by Dahdouh-Guebas and Koedam (2006). That is at each site, each of the plots (20 m x 20 m = 400 m^2) corresponding to one species or mixed, were marked out. Each plot was further divided into four 10 m x10 m (100 m^2) subplots and each subplot into hundred 1m x 1m sampling quadrats, and forty of them were randomly selected for some measurements. Therefore, for this research in each country, a total of 3 plots and 12 subplots covering an area of 0.24 ha were established (Plate 1). Plots and subplots were then used, for some of the parameters as tree inventory, litterfall production, water and soil measurements. (Dahdouh-Guebas and Koedam, 2006; Armah *et al.*, 2009; Kairo and Bosire, 2009). After selecting and laying out the plots (Figure 3), they were monitored for 26 months selected ecological indices between November 2008 to November 2010 (Ghana and Cameroon).

Plate 1: Demarcation of sampling plots in Cameroon study site

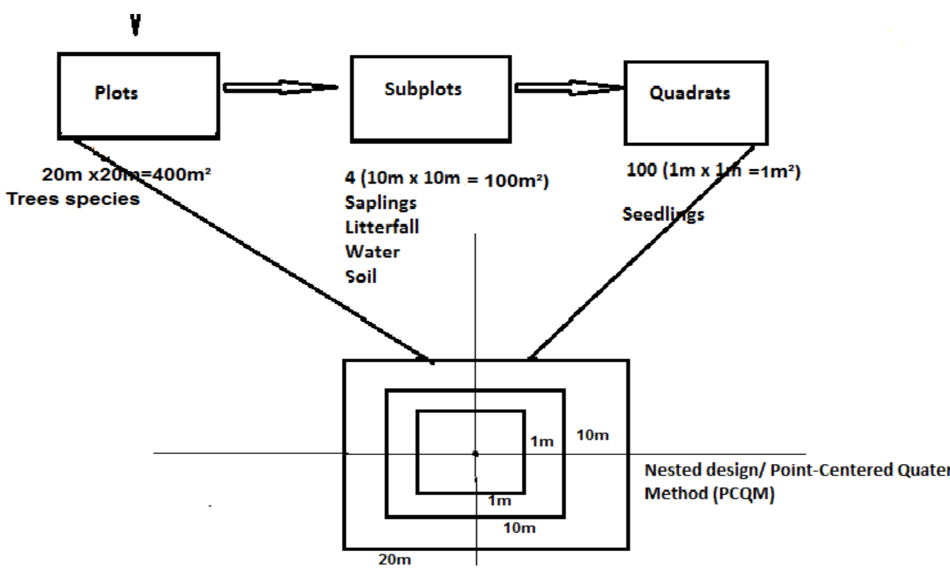


Figure 3: Sampling Design

3.2.2 Measurement of tree and stand parameters for forest structure

In each country, the structural parameters of mangrove forest, were estimated, in twenty four (24) 10 m x10 m plots where all trees with a height greater than 4 m were counted, and measured for diameter at breast height (DBH) and height. These counts were then used to estimate the same parameters (i.e., species composition, diameter, tree density, height, basal area, and importance value). The diameter and height of each tree were respectively recorded by measuring the diameter of the tree using a flexible tape measure and by using clinometers (Kathiresan, 1997; English *et al*., 1997; Armah *et al*., 2009). The diameter of each sapling or seedling was recorded using calipers. Some Sapling height was recorded using clinometer. During the inventory, red mangrove, the most abundant species, with prop-roots and multiple stems, had their DBH measured above the highest Stilt where the root no longer influences the diameter of the stem (Plate 2).

The abundance of Seedlings (DBH close to 0 cm) and saplings (DBH less than 5 cm) was recorded, in two hundred forty (240) 2 m x 2 m sampling plots selected randomly among the total number of six hundred (600) 2 m x 2 m quadrats established in each country (Cintrón and Schaffer-Novelli,1984;Kathiresan, 1997; Radhika, 2006; Ajonina, 2008; Dadhouh- Gueba, 2011).

Plate 2: Measurement of sapling in *Rhizophora* stand in Ghana and Measurement of tree in *Rhizophora* stand in Cameroon

3.2.3 Measurement of stand productivity (litterfall)

Litterfall was collected in $1m^2$ litter traps constructed of fiberglass screening (1mm mesh) and installed at about 1 m, above ground to prevent loss from flooding (Plate 3). At each study area per country (0.24 ha), twenty four traps were randomly placed in the subplots (10m x 10 m). Litter collection was carried out, on monthly basis using the method described by Day *et a.l.* (1996) and Brown (1997). At each period, all loose material of recognizable identification was collected within the traps.

Plate 3: Collection of litterfall in pure Rhizophora stand in Cameroon

3.2.3.1 Carbon stocks in litterfal

To determine the carbon pool of Litterfall (aboveground components), the method designed by Kauffman and Donato (2012) was used. Carbon pools of aboveground biomass are then assessed by multiplying the biomass of individual components by their specific carbon concentration (percentage).

3.2.4 Collection of water and soil samples

3.2.4.1 Mangrove surface water and porewater

Water samples were collected monthly, in six (6) plots for sampling of surface water and in twenty four (24) subplots, for porewater. For porewater or soil water, holes of 10 to 15 cm of diameter were dugat low tide in each of the subplots, at a depth of 50 cm in each study site. Porewater was then collected 10 minutes after the hole had been dug. The soil samples collected, were put into labelled, airtight, plastic bags and kept in an ice box and brought back to the laboratory for chemical analysis.

Samples were mainly collected, for determination of parameters such as: (salinity, pH, temperature, Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Conductivity, turbidity (bicarbonate, Chloride, sulphate, phosphate, nitrate, sodium and potassium). Fixing of DO samples (Dissolved Oxygen) was carried out in the field, where 100 ml of water were measured into clean oxygen bottles and flushed several times until all air bubbles escaped. Two (2) millimetres of Winkler's solution I ($MnSO4$ solution) and another 2 ml of Winkler's solution II (KI + NaOH solution) were added to each bottle respectively The bottles were closed and thoroughly shaken to ensure proper mixing. A brown precipitate formed at the bottom of each bottle after this process. The bottles were then, transported to the laboratory for further analysis. Data on rainfall for Ghana and Cameroon were obtained respectively from the Ghana Meteorological Agency at Legon in Accra, and the Cameroon Meteorological Agency at Douala.

3.2.4.2. Mangrove Soil properties
Soil sampling

Within each plot, Four 0.5 x 0.5 m quadrats were ramdomly laid and soil samples taken from the middle of each quadrat, sediments were then sampled at three depths: 0-20 cm, 20-40 cm, 40-60 cm using a soil auger (Eijkelkamp Agrisearch Equipment BV, Giesbeek, The Netherlands). At each depth, about 200 g of soils were collected. At a random point along the perimeter of each plot, a soil pit of 60 cm deep (about 2 m long and 1.5 m wide) was dug to collect the soil samples at the three depths (Plate 4).

All collected field soil samples were brought to the laboratory of the Department of Soil Sciences within at the University of Ghana, Legon, registered and each given a serial number for easy identification. Soil samples collected on the field at low tide from depths of 0-20 cm, 20-40 cm and 40-60 cm in each 10 m x 10 m using a soil corer were put into labelled, airtight, plastic bags and taken to the laboratory for analysis. The samples were weighed before and after oven drying (on aluminium foil at 80 °C for 24 hours), to determine the physical (texture of soil, bulk density) and chemical (pH, EC, Ca, Mg, P, K, acidity, ECEC(Effective Cation Exchange Capacity), OC (Organic Carbon), OM (organic Matter) and Nitrogen (N)) properties.

Plate 4: Collection of soil at different depths with a soil Auger in *Avicennia* stand in Cameroon

3.2.4.3. Field monitoring of other physico-chemical parameters

Physico-chemical parameters monitored monthly in the field for water include salinity level, pH, temperature, BOD, DO, TDS, TSS, Conductivity, turbidity, bicarbonate, chloride, sulphate, phosphate, nitrate, sodium and potassium. The measurements of the physical parameters, (salinity, pH, temperature, conductivity, TDS, turbidity, and TSS) were carried out using the HACH 2010 machine, while the ELE-conductivity probe was used to measure the electrical conductivity (EC) and TDS. A portable pH meter and a Gel-Plast electrode which was calibrated with pH 4 and 7 standard buffers, was used to measure pH and temperature (Macintosh *et al*, 2003). Salinity was also measured using an optical refractometer (Atago, Japan). Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) were determined, by a modification of Winkler method (Chen *et al*., 2000 ; Fiagbezi, 2001).

3.3. Sample analysis

3.3.1. Laboratory Analyses

Field sampleLaboratory analyses in Ghana were mainly done, at Ghana Atomic Energy Commission (GAEC) at the Chemistry Department, and at the University of Ghana (Ssoil Department of the Ecology Laboratory Centre). In Cameroon, laboratory facilities of IRAD institute and University of Buea were used for analyses of the samples.

3.3.1.2. Physico-chemical parameters on Water and Soil

For the laboratory procedures, each sample was analyzed for the hydrochemical parameters such as total alkalinity and acidity, salinity, Dissolved Oxygen (DO), and Biological Oxygen Demand (BOD), Total Suspended and Dissolved Solids (TSS and TDS), were determined in the laboratory following methods of APHA (2005).

For cation determination, the flame photometer was using for potassium and sodium while for nutrients and anions, the UV spectrophotometer was used for phosphate, nitrate, sulphate bicarbonate and chloride determinations (Din, 2001; World Bank, 2003; Armah *et a*l., 2009).

3.3.1.3. Soil analyses

Before analysis, the samples were air-dried at room temperature and then sieved through a 2 mm mesh. The pH of soil was measured using a mixture of 10 g of soil with 25 ml of deionized water. Readings of the pH meter were taken only after the mixtures were stirred for one hour. The electrical conductivity (EC) measured in soil -water ratio of 1:5, and acidity were also determined. Particle size was measured on the sodium dithionite and sodium citrate treated soil. Mixture of 4 g of soil with 2 g of sodium dithionite, 22 g of sodium citrate and 100 ml of deionized water were shaken overnight and then allowed to settle for 12 hrs. The liquid was decanted and 100 ml deionized water with 1 g of calgon were added. The mixture was again shaken for one hour before being introduced to the particle size analyzer (Coulter LS 230, Coulter Electronics Limited). For the physical analyses, the proportions of clay, silt, sand, and the median value of particle size for each soil sample were determined. The document on International Society of Soil Science size classes for the soil/sediment particle size classification was used as follows: particle size <0.002 mm was classified as clay; ≥0.002 mm and <0.02 mm was classified as silt; and >0.02 mm was classified as sand (Brady & Weil 1999). Bulk density was field-determined. A sample of weight (Wi) and volume (V) was driven into the soil. The soil around was excavated and the excess removed from the ends. The sample was dried at 105 ^{o}C to constant weight and re-weighed (W2). Four of such samples were taken per plot and averaged. The bulk density was calculated in grams per cubic centimetre according to the procedure of Anderson and Ingram (1989) (Amatekpor, 1995; Allotey *et al*., 2008).

(1) $Bulk\ density = W_2 - W_1 / V$

For the chemical analyses, soil samples from the respective study plots were analysed for their moisture content (%), cation exchange capacity (Cmolckg-1), organic carbon (gkg-1), total nitrogen (gkg), available phosphorus (mgkg-1) and exchangeables Ca, Mg and K as follows:

Percentage Soil Moisture:

Gravimetric soil water content of each study plot was estimated. An empty metal tin of weight (W1) was driven into the soil. The soil around the tin was excavated and the excess removed from the opened end and weighed (W2). Four of such samples were taken per plot averaged. The soil so sampled were emptied into soil bags and labelled for laboratory analyses. Each soil sample was dried at 105° C to constant weight in free air circulation oven, at the laboratory and reweighed (W3). The percentage soil moisture was calculated as:

(2) Percentage Soil moisture = $(W_2 - W_3) / (W_3 - W_1) \times 100$

After determining the percentage moisture content of all collected soil samples, they were air-dried, ground in a mortar sieved through a 1 mm mesh sieve and used for the chemical analyses (Amatekpor, 1995; Asiamah, 1995).

Percentage Organic carbon:

Percentage organic carbon content of soil samples, was determined using the Wet digestion method. Organic matter in each soil ample was oxidized with a mixture of standard potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4). The excess dichromate was then titrated with ferrous sulphate (Fe_2SO_4), using barium diphenyl-4-sulphate as indicator. The percentage organic carbon content in sample was subsequently computed as follows:

(3) *Percentage Carbon in Sample* = $M (V2 - V1) \times 0.39$ *Weight of soil sample (g)*

Where M is the molarity of the ferrous sulphate solution (mol dm^3); $0.39 = 3 \times 10^{-3} \times 1.3$ (where 3 is equivalent weight of carbon and 1.3 is the factor due to 77% carbon recovery, $V2$= Volume of Fe_2SO_4 required for the blank (cm^3); *V*1= volume of Fe_2SO_4 required for the sample (cm^3). The percentage carbon in sample was converted to g/kg of soil by multiplying by a factor stock of each plot was then computed and expressed in $kgCha^{-1}$ (Spalding *et al.*, 2010).

Available Phosphorus:

The Olsen ($NaHCO_3$) method was used for available phosphorus (Kevin, 2009). The available phosphorus in the soil sample, was extracted with 0.5M sodium hydrogen carbonate (pH 8.5) solution. To lower the pH of the $NaHCO_3$ to about 5.0 and to remove cloudiness due to the presence of organic matter in the soil sample, 1.0 ml of 2.5M sulphuric acid was added to the mixture. To develop colour for the extracts, a solution (labelled A) was prepared by mixing thoroughly solutions of 12 g ammonium molybdate in 250 cm^3 of distilled water and 100 cm^3 of 5 N sulphuric acid. The whole mixture was topped to 2000 cm^3 volume with distilled water. From solution A, another solution (labelled B) was prepared by dissolving about 1.056 g ascorbic acid in 200 cm^3 of solution A and used for colour development.

A 15 cm^3 aliquot of the extract containing about 20 µg of orthophosphate was pipetted into a 50 cm^3 volumetric flask, and its pH was adjusted by adding a few drops of p- nitrophenol indicator and a few drops of 4N – NH_4OH until the solution turned yellow. About 8 cm^3 of solution B was added to the yellow solution developed above and topped with distilled water to volume, and left for some time for colour development. Also, a 50 cm^3 blank solution was prepared with distilled water and 8 cm^3 of solution B.

A standard phosphorus solution containing 25 µg phosphorus was also prepared by pipeting 5 ml of a standard phosphorus and blank solution into a volumetric flask and made up to 50 ml with distilled water. This was also left for some time to develop colour. The standard phosphorus and blank solutions were used to calibrate the colorimeter at 712 nm wavelength (Quesada, 2009). After the calibration of the spectrophotometer (Spectronic 301) with standard solutions, the available phosphorus in the extracts were measured and calculated as:

(4) Phosphorus in soil sample (µg/g) = RxE / AxW

Where *R* = colorimeter reading in (µg/g), *E* = volume of extractant (cm^3), A = volume of aliquot (cm^3) and W = weight of soil (g).

Total Nitrogen

The Kjeltec Auto 1030 Analyzer (distillation) method (also called the Kjeldahl procedure) was used. In this method, NH^{+4}-N is liberated by distillation of the soil digest with 40 % NaOH solution and absorbed in unstandarddized boric acid to form ammonium borate. The borate was then titrated against 0.01M hydrochloridric acid (HCl) using a mixture of bromocresol green and methyl red solutions as indicator.

About 2 grams of soil sample were weighed into Kjedahl flask and a few drops of distilled water were added to moisten the soil. A scoop of digestion accelerator mixture and later 5 ml of concentrated sulphuric acid were added to the moistened soil in the flask. The result mixture was digested to obtain a clear solution; after which it was cooled with distilled water and transferred into a 50 ml volumetric flask and topped up with distilled water.

An aliquot of 5 ml was taken into a Markhan distillation apparatus. About 2 ml of 40% sodium hydroxide was added and distilled. The distillate was collected into a flask containing 5 ml of 2% boric acid. Three drops of a mixture of bromecresol green and methyl red solutions were added to the distillate; as indicator and titrated against 0.01M HCL. A change from green to pink end point was observed (Amatekpor, 1997; Kevin, 2009). The procedure was repeated twice and the average titre computed was used to calculate the percentage nitrogen:

(5) %N in Soil= (Vs – Vb) x Molarity of Standard HCL x 1.401/ Weight of sample digested

Where Vs = Volume (ml) of standard HCl for titration of sample and Vb = Volume (ml of standard HCl for titration of blank. The percentage nitrogen was converted to gkg by multiplying by a factor of 10 (Rayment and Higginson, 1992; Amatekpor, 1997).

Cation Exchange Capacity (CEC)

After leaching out the exchangeable bases, excess ammonium acetate was removed with ethanol. The exchanged ammonium salts were leached out with 0.1M calcium chloride ($CaCl_2$) and the excess ammonium in the leachate titrated against standard hydrochloric acid (HCl). The CEC was then calculated as follows:

(6) CEC = V x M x 250/ 100 x 100/W

Where V= Volume of HCl for titration in millilitre, M = Molarity of HCl for titration,

W = sample weight in grams.

Exchangeable cations

The concentrations of calcium (Ca), potassium (K), and magnesium (Mg) in the sediment samples were determined by using a single extraction with silver-thiourea for measuring exchangeable cations. The exchangeable cations were extracted for 4 hrs from 5 g samples by 30 ml of silver-thiourea reagent, and analysed by inductively coupled plasma optical emission spectrophotometer (Optima S300 DV, Perkin Elmer) (Kelvin *et al*., 2000).

3.3.1.4 Litterfall analysis

Litterfall collected from each subplot, was placed in an oven set at 70°c constant weight sorted leaves, flowers, fruits/seeds and twigsand weighed to determine the weight remaining (Barb Tope, 2003; Arreola-Liz´arraga, 2004). Litter samples were ground into fine powder and subsamples collected for chemical analysis after thorough mixing (Chiambeng, 1989; Arreola-Liz´arraga, 2004; Gary Eugene, 2004; FAO, 2009). The leaf litter was analyzed for extractable (N, P, K, Mg, Ca) and total (N, P, C). Carbon pools in litterfall were determined mainly by using Kauffman and Donato (2012) method, where carbon concentrations (ranged from 0.46-0.5) are multiplied by the biomass of litterfall in both countries.

Leaf litter nutrient Analysis

For data processing of mangrove litterfall production, material from each sub-plot was dried as 60°c to constant weight and then, separated into fractions (Leaves, flowers, fruits, seeds and twigs) and weighed to determine the mass remaining (Hegazy, 1998 ; Arreola-Liz´arraga, 2004).

For nutrient analysis, sub-samples of the litterfall were ground then re-dried at 105°C and wet-digested in a mixed acid (H_2SO_4-$NaSO_4$-Se, 1000:100:1). Nitrogen was determined by the

Kjeldahl method, phosphorus by the vanadomolybdate yellow color. Potassium was determined by flame photometer. Calcium and magnesium were determined by atomic absorption spectrophotometry (Sarayudh, 2001; Smith *et al*., 1998; Gary, 2004).

3.3.2 Stand structural analysis

Forest structural classification was done based on tree diameter measurements at breast height (DBH) into eight tree size classes as: Seedling (< 1cm), small saplings (≥1cm to< 3cm), medium saplings (young plants less than 5 cm; ≥3 cm to < 5 cm), large saplings (≥ 5 cm to < 7 cm, small trees or posts (≥7 cm to < 10 cm), medium size tree or poles (≥10 cm to<30 cm), Large tree or veterans (≥ 30 cm to < 50 cm) and giant tree (≥50 cm) categories (Ajonina, 2008). Secondary tree and stand parameters were estimated using standard forest inventory and mensuration procedures (Loetsch *et al*., 1973; Husch *et al*, 2003; Spalding *et al.*, 2010) also with adaptations to mangrove forests (Ajonina, 2008; Dahdouh-Guebas, 2011).

Structural paramaters such as: Density (Di), basal area (BA), average diameter, average height and volume were determined using the methods and formula worked out by Cintron & Novelli (1984) and Kathiresan (1997) as follows: Density is measured species wise and total in each plot as follows:

- Density of each species (no/ha)= no. x 10,000 m^2 / area of plot in m^2
- Total density of all species = sum of all species densities

➢ Basal area (A) is measured species wise and total in each plot as follows:

- Basal area (m^2) of each species = 0.7857 x $(DBH)^2$ cm^2

- Total basal area of all species (m^2/ha)= sum of all species basal area / area of plot in m^2 x 10,000 m^2 individuals of all species x100

- (7) Volume (V)= 0.6 BA x H Volume (V)= f x BA x H where f = form factor (Ajonina and Usongo, 2001)

3.4 Statistical data analysis

For this study all statistical tests were performed using the statistical packages from, PRIMER-E (Plymouth routines in multivariate ecological research) version 6 (PRIMER-E, Ltd., UK), SPSS version 18 (Statistical Package for Social Sciences), STATISTICA 6.0 (Statsoft), MINTAB 15 and Microsoft OfficeExcel 2007 softwares . Analysis of the data was mainly carried out using univariate, bivariate (descriptive and correlation analyses) and multivariate techniques (multivariate statistical and regressions analyses).

3.4.1 Descriptive and inferential statistics

For this study, two types of statistics were mainly used: descriptive and inferential. The descriptive statistics were used to assess the strength of a relationship between two variables (bivarite analysis) or among a set of variables (Multivariate analysis) as measures of association or correlation. The inferential are measures of the significance of the relationship between two or more variables. Analysis for this research was then carried out through statistical techniques and visual analysis of graphs. This included a comparison of means using a 95% confidence Interval. Latitudinal rate of change among variables was computed by comparing percent change of variable means among sites. Bar graph analysis identified latitudinal changes to mangrove litterfall, structural characteristics, water and soil properties. Histogram analysis was done for an examination of mangrove litterfall production, structural characteristics, water and soil properties, trends within each individual site. The analysis of variance (ANOVA) test statistics was used to test if more than 2 population means were equal. ANOVA of mangrove litterfall, water, soil and structural parameters was done and the differences between and within groups assessed. For data gathered once (e.g., chemical and physicals parameters, tree density, height, Basal area, litterfall, water and soil characteristics.), means, standard deviations and coefficient of variation were calculated separately for those parameters recorded on the field in each site (*Rhizophora, Avicennia* and mixed stands) per country, and monthly, annual and site means were compared using One-way ANOVA.

Data were tested for homogeneity of variances; no transformations were necessary. Analysis of Variance (ANOVA) was applied to assess significant differences of Physico-chemical parameters, nutrients and heavy metals content in water and soil in addition to structural characteristics between mangrove forest types (*Rhizophora*, *Avicennia* and mixed stands). The same ANOVA was used to assess seasonal changes in litter production and nutrientconcentration, between litterfall types and mangrove sites. After performing the analyses, linear contrasts were used to assess differences in selected variable among sites on each sampling date.

To determine which variables are different from the others in each site or country, two main Post hoc tests LSD and Tukey HSD were used in this study. Significant differences between means, were determined by Post Hoc Least Significant Difference (LDS) test at 0.05 probability level to test main effects (sites, seasons, and where applicable, species) and all interactions. Comparisons within countries and between countries were based on Tukey's Honestly Significant Difference (HSD) method.

Tests were then run, to examine differences between the three sites (Pure *Rhizophora* sp vs Pure *Avicennia* sp vs. Mixed *Rhizophora sp* and *Avicennia sp*). The similar tests have been later run to examine the differences between Ghana and Cameroon stations.

The mean and standard error (S.E.) of three sites in each country, were calculated for monthly and annual litterfall, water and soil quality. Annual litterfal of leaves, branches/twigs, flowers and fruits/seeds, and water and forest structure Characteristics were analyzed using one-way ANOVA following two main post hoc tests (Fisher LSDand HSD.

To quantify significant relationships between different parameters recorded for mangrove forest structure, litterfall, water and soil quality, correlation analyses were run and specifically, Pearson correlation coefficients were calculated and multiple linear regressions added to all were also used to study relationships between environmental and response variables (Joshi and Ghose, 2003; Gary, 2004;; Lamptey and Armah, 2008). Pratically, the relationships between Litterfall products and water, soil and structural characteristics in the selected mangrove stands within and between the two countries were analyzed using bivariate correlation, following the Pearson method where the results of significant associations ($P \leq 0.05$) enabled identification of causal factors.

Monthly average were computed for the times series data and similar multiple regressions were carried out to determine the proportion of variability in seasonal litterfall, accounted for by predictor variables. The data used in correlation and multiple regression analyses were log10 (x+1) transformed to improve normality (Wiafe, 2002; FAO, 2009; Spalding *et al*., 2010). For cross sites/country analyses, Hierarchical Cluster Analysis (HCA), Principal Component Analysis (PCA) and Discriminant Functions Analysis (DFA) were run to assess differences in variables collected across sites and countries during the study period.

Hierarchical cluster analysis, used in this study, assisted in identifying relatively homogeneous groups of variables, using an algorithm that starts with each variable in a separate cluster and combines clusters until only one is left. As the variables have large differences in scaling, standardization was performed before computing proximities, which can be done automatically by the hierarchical cluster analysis procedure. A dendrogram was constructed to assess the cohesiveness of the clusters formed, in which correlations among elements can readily be seen.

Principal Component Analysis (PCA) is designed to transform the original variables into new, uncorrelated variables (axes), called the principal components, which are linear combinations of the original variables.The new axes lie along the directions of maximum variance. PCA provides an objective way of finding indices of this type so that the variation in the data can be accounted for as concisely as possible (Dahdouh- Guebas, 2011) . PC provides information on the most meaningful parameters, which describes a whole data set affording data reduction with minimum loss of original information (Fourqurean *et al.*, 2012; FAO, 2009). PCA is widely used to reduce data (Nfotabong, 2011 ; Spalding *et al*., 2010) and to extract a small number of latent factors (principal components, PCs) for analyzing relationships among the observed variables (Deborah, 2008; Nfotabong, 2011). For each Principal Component, different factor loadings are displayed. The terms “strong”, “moderate”, and “weak” were applied to factor loadings of PC and refer to absolute loading values as >0.75, 0.75-0.50 and 0.50-0.30, respectively, following the approach of (Liu *et al*., 2003; Mohammad *et al*., 2011).

Differences among the variables and stations related to mangrove litterfall, structural characteristics, water and soil properties were tested using a two-way crossed analysis of similarity (ANOSIM) without replication (a multivariate non-parametric analogue of ANOVA), which is a permutation-based test between a priori defined groups (stations) where generated R statistic values are indicative of how similar the groups are (the closer to 1, the greater the differences; 0 indicates no difference among groups).

Discriminant Function Analysis (DFA) was also done. Discriminant analysis is a multivariate technique used for two purposes, the first purpose is description of group separation in which linear functions of the several variables (discriminant functions (DFs) are used to describe or elucidate the differences between two or more groups and identifying the relative contribution of all variable to separation of the groups (Muzilla *et al*., 2011). Second aspect is prediction or allocation of observations to group in which linear or quadratic functions of the variable (classification functions (CFs) are used to assign an observation to one of the groups. Discriminant analysis is very similar to analysis of variance (ANOVA). When given a group of variables, F tests are conducted to decide which variables are significant to differentiate between groups. The analysis derives lineaires combinations of the discriminating variables which provide maximum separation between the groups (Kovacs *et al*., 2011). These linear combinations are termed as discriminant functions and have the form: D1= di1Z1 + di2Z2 +..... + dinZn’, where Di is the score of a discriminant function i, d’s are weighting coefficients, and the

Z’s are the standardized values of the discriminating variables (Singh and Suraj, 2012).The first discriminant function was inclined such that it represented the dimension along which the maximum group differentiation occurred. The second function was independant of the first and inclined along the largest group differences not represented by the first function. Two quantities measured the relative importance of a given discriminant function.

When discriminant function was plotted as an axis, then we observed a negative coefficient of variable strongly associated with a movement in the negative direction along this axis and a positive coefficient with movement in the positive direction. Plots of the group centroids (means) along the discriminant function or axes allow a ready comparison of the degree of separation of these groups along the plotted functions. Significant tests (assuming multivariate normality) were used to examine the total separation of the groups in multivariate space (Kovacs *et al.*, 2011; Singh and Suraj, 2012).

CHAPTER 4

4.0 RESULTS

The results of this academic research are presented in four sections. The first section presents the litterfall and phenology of the mangrove ecosystem, the second deals with the structural characteristics, the third, the water quality and the fourth the soil quality. The assessments of qualities of water and soil consider also the pollution aspects of mangrove forest. Results are presented mainly in tables and graphs and greater details or supplementary information are shown in appendices.

4.1 Climatological parameters

During the study period, variations of temperature and Rainfall were observed in the sampling areas of Ghana and Cameroon, from November 2008 to November 2010. The mean air temperature varied between 26 to 30.1 º C in Ghana and 26.80 to 29.5 º C in Cameroon with higher values from January to March. Generally in both countries, most rainfall occurred between the months of July and October for Cameroon and May and June for Ghana. The lower values were between December and February in Ghana and Cameroon. The mean rainfall varied between 50 mm to 300 mm in Ghana and 100 mm to 620 mm in Cameroon, with higher values in August and September for Cameroon and May and June for Ghana (Figure 4).

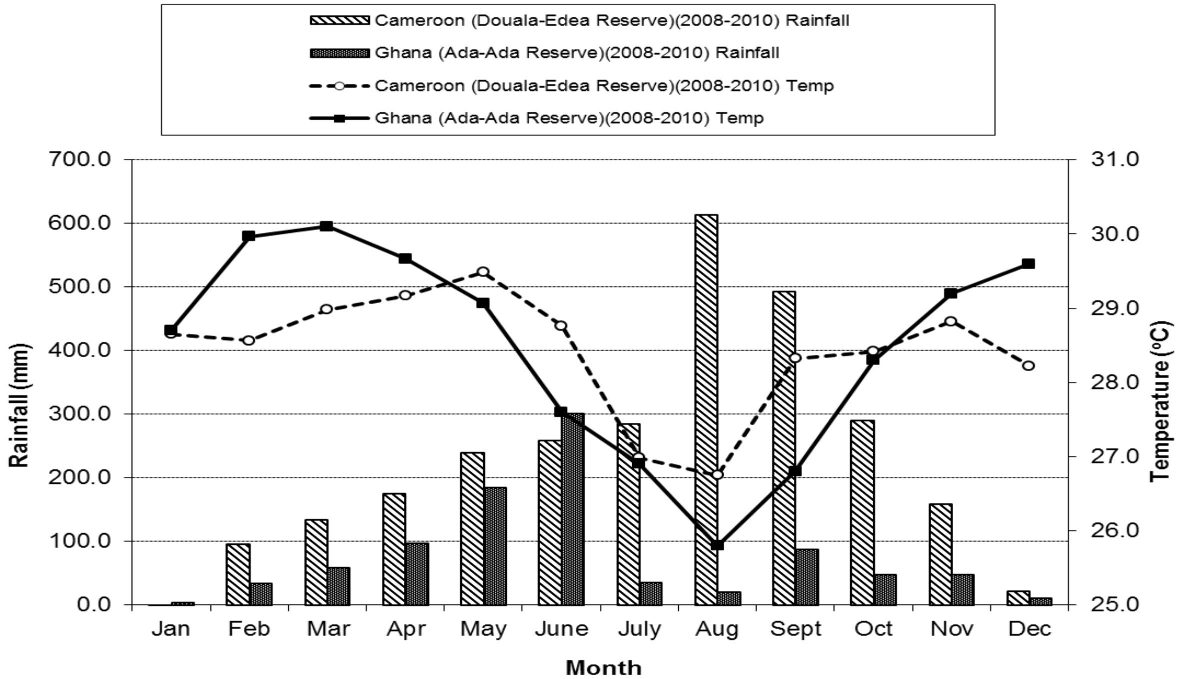


Figure 4: Annual rainfall and temperature variation in Cameroon and Ghana from November 2008 to November 2010

Data source: Ghana Meteorological Agency at Accra Legon and Cameroon Meteorological Agency at Douala.

4.2 Mangrove litterfall

4.2.1 Phenology and seasonnal patterns in litter production

The litterfall studied, Figures 5 and 6 showed that leaf production was relatively high in Ghana and Cameroon compared to other litterfall components (Twigs, Fruit/seed and flowers), but the total value of mangrove leaves in Cameroon was higher than that of Ghana. However, the response to environmental conditions was similar in all of them, since all tend to shed greater amount of litte during dry season than rainy season. Relatively low amount of leaf litterfall of mangroves in Ghana was observed in June and, in Cameroon from June to September and October in *Avicennia and Rhizophora*, and April to October in mixed mangrove (Figures 5 and 6).

According to the rainfall variation in Ghana and Cameroon, the leaf and twig/branch litterfall of *Avicennia*, *Rhizophora* and mixed stands increased with the decreasing of rainfall (Figures 5), in the dry season. The major flowering and fruiting season of *Rhizophora racemosa* and *Avicennia germinans* in Ghana and Cameroon was mainly in the dry season **(**except forfruits of *Avicennia* in Ghanaand Cameroon, and flowers in mixed mangrove in Cameroon where the production did not show any seasonal pattern).

Mean monthly total litterfall of the mangrove in Ghana and Cameroon sites' (mg/m^2), were respectively for *Avicennia*, 69.5 ±14.4 and 111.6 ± 21.3; *Rhizophora*, 123.1 ± 27.0 and 160.5 ± 14.7; mixed (*Avicennia* and *Rhizophora*), 60.3 ± 12.4 and 178.8 ±21.5 (Table 1). The leaf litterfall comprised largest component, i.e. 81.28 and 85.1% respectively in Ghana and Cameroon studies sites (Figures 5 and 6). In both countries, litterfall was observed in throughout the year. Monthly total litterfall showed a seasonal trend with the highest litterfall in the dry season and the lowest in the rainy season.

Multiple regression analyses selected average rainfall and average air temperature as independent variables which were important in explaining temporal litterfall variability over the period of study in both countries. The equation that best describes Litterfall variability is: $Y= 364 – 8.5 (X1) + 0.0780 (X2)$; $R^2 = 0.80$, where X1 is Air temperature and X2 is rainfall ($p< 0.001$).

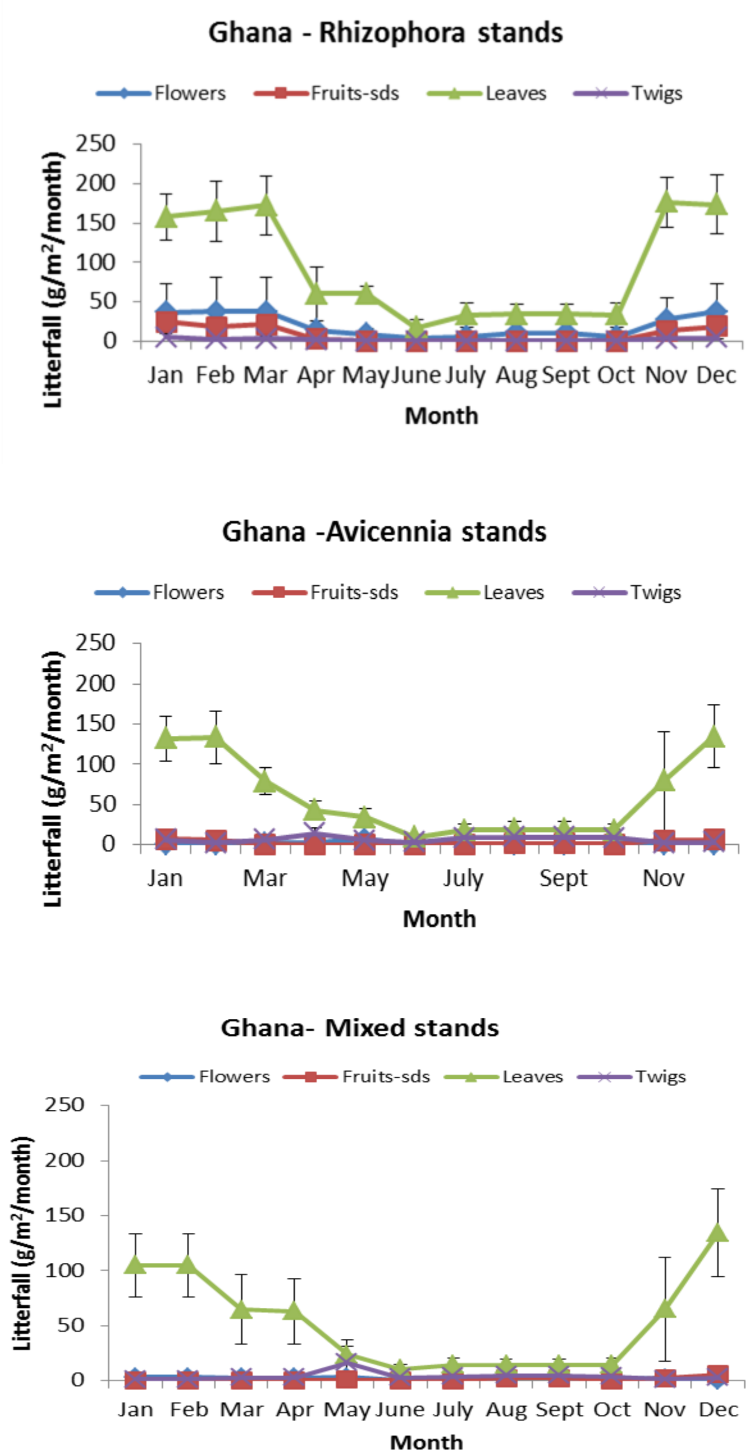


Figure 5: Seasonal variation of monthly litterfall in Ghana

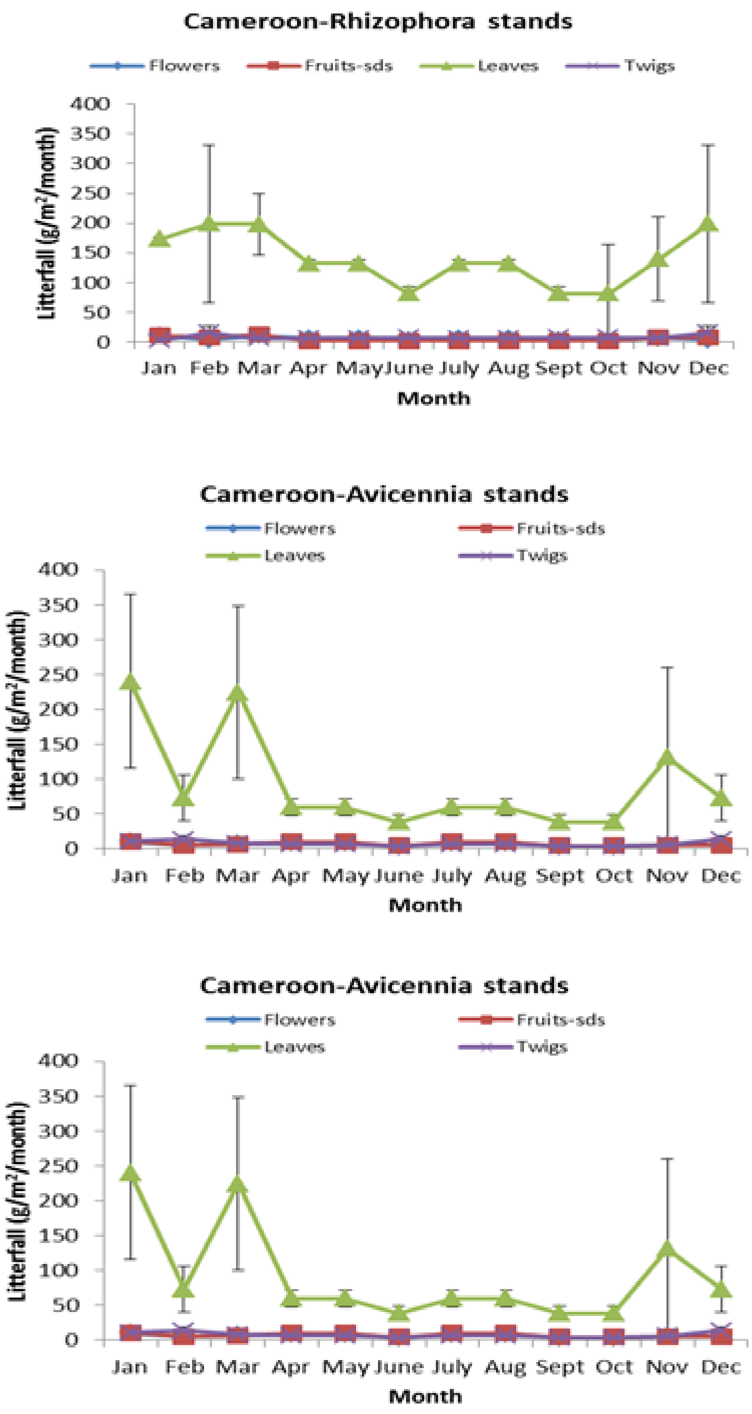


Figure 6: Seasonal variation of monthly litterfall in Cameroon

Fruits- sds= Fruits-seeds

In terms of vegetative phenology, leaf fall showed a seasonal pattern: for *Rhizophora* stands, the highest peak occurred in November in Ghana and December in Cameroon. For *Avicennia* stands, the highest peak occurred in December in Ghana and January in Cameroon (Figure7**).** The maximum production of leaf litterfall in mixed mangrove was observed in December in Ghana and in earlier March in Cameroon. In Ghana, the December peak (*Avicennia* and mixed) and the November peak (*Rhizophora)* corresponded respectively to temperatures of 29.8°C and 29.5°**C (**Figure 7**)**. It appeared that, in both countries all the leaf litterfall high peaks were observed in the dry season characterised by high temperature.

Branch/ twig litterfall in Figure 7 showed a seasonal pattern: for *Rhizophora* stands, the highest peak occurred from November to January in Ghana, and February and December in Cameroon. For *Avicennia* stands, the highest peak occurred in April in Ghana and December in Cameroon. The maximum production of branchlitterfall in mixed mangrove was observed in early May in Ghana and February and December in Cameroon. It appeared that for vegetative litterfall, relative high peaks were mainly observed in the dry season in both countries. All the parts collected as twig/branch were relatively small (Figures 7). This Figure 7 showed also that, leaf fall was at relative maximum during the study period. There was a significant variation in time for every component ($P< 0.05$).

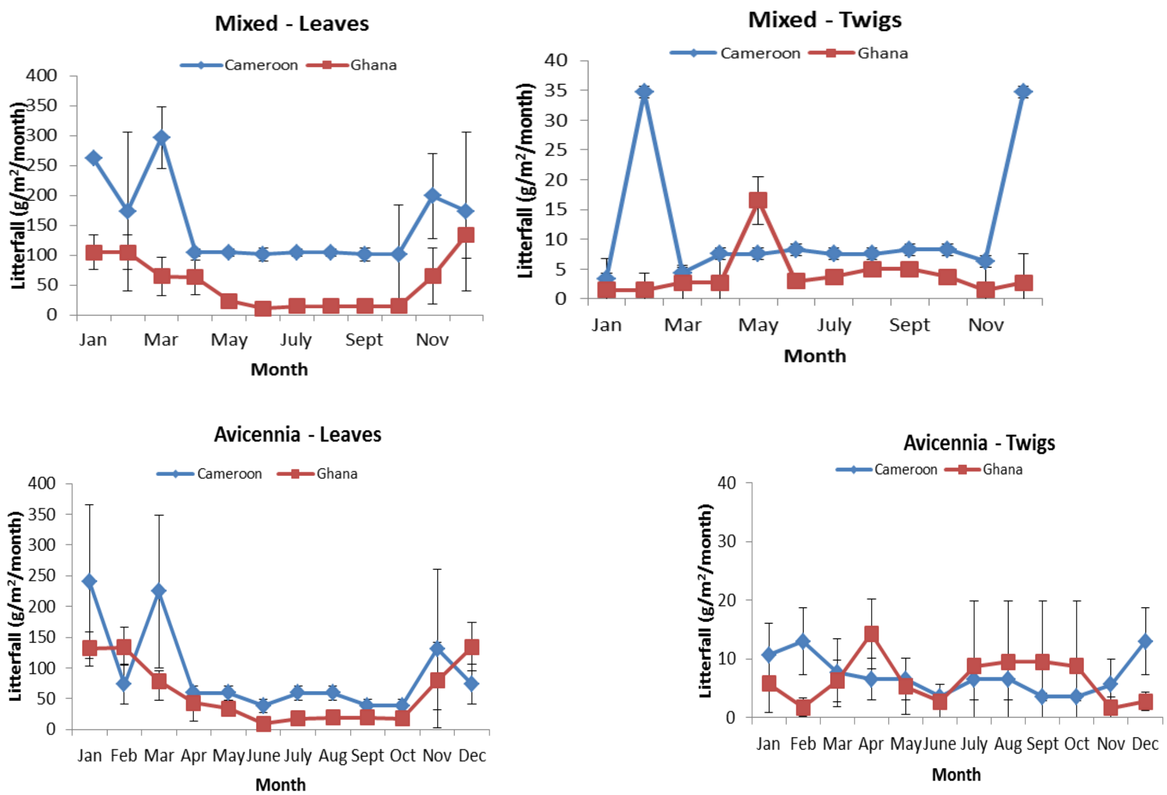


Figure 7: Seasonnal variations in vegetative phenology for mangrove types in Cameroon and Ghana

In terms of reproductive phenology, flowers fall in Figure 8, showed a seasonal pattern: for *Avicennia* stands, the highest peak occurred in early May for Ghana, and January for Cameroon. For *Rhizophora* stands, the highest peak occurred in December for Ghana and January for Cameroon. The relative maximum production of flowers litterl in mixed mangrove was observed in early May for Ghana and December for Cameroon. The total monthly flower litterfall in both countries during the study period showed notable peaks in early May for *Avicennia* and mixed stands, and December for *Rhizophora* in Ghana. For Cameroon, the highest peaks were in January for *Avicennia* and *Rhizophora*, and December in mixed stands.The flower fall peaks were mainly observed in the dry season or high temperature in both countries.

In Ghana, the early May peak (*Avicennia* and mixed) and the December peak (*Rhizophora*) were corresponded respectively to a relatively high temperature of 29°C and 29.8°C (Figure 8). In Cameroon, the January peak in Avicennia and *Rhizophora*, and December peak in mixed stand was corresponded respectively to a relative high temperature of 28.5°C and 28.1°C (Figure8).

Fruits fall in Figure 8 showed a seasonal pattern: for *Avicennia* stands, the highest peak occurred in January and December for Ghana, and January for Cameroon. For *Rhizophora* stands, the highest peak occurred in January for Ghana and March for Cameroon. The maximum production of fruits litterfall in mixed mangrove was observed in December for Ghana and February and December for Cameroon. All the parts collected as fruits were relatively small compared to flowers (Figures 8). These figures showed also that, leaf fall was maximum during the study period. There is significant variation in time for every component.

In both countries, vegetative and reproductive materials were present in litter samples all over the year in the study sites. Leaves, branches/twigs, flowers and fruits showed mainly the highest peak in the dry season, but sometimes the peak was extended to the early rainy season. *The Avicennia*, *Rhizophora* and mixed stands showed statistically significant ($P< 0.05$), leaf litter variation over time in the two countries.

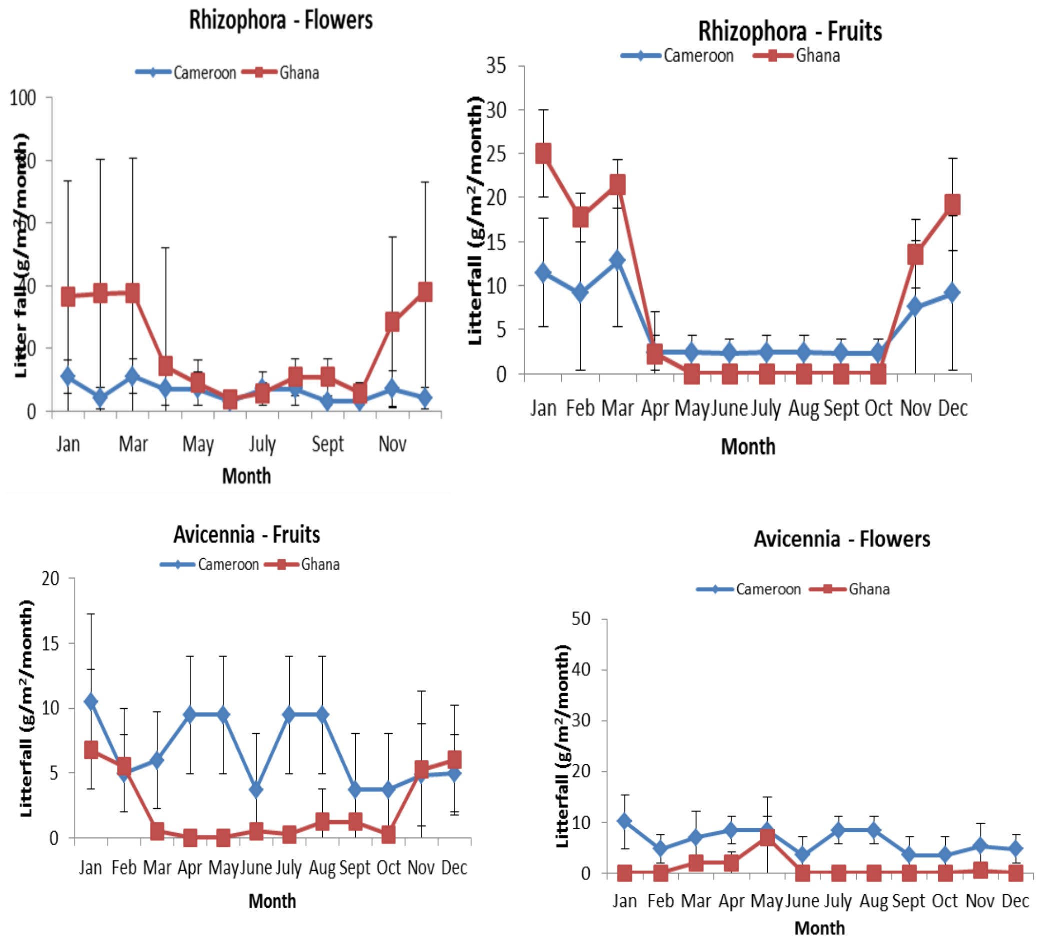


Figure 8: Seasonnal changes in reproductive phenology in Cameroon and Ghana

It was observed that, no significant differences existed between mixed and *Avicennia* stands for Ghana (P> 0.05). For mixed and *Rhizophora* stands, significant differences were found only for flower and fruit (P< 0.05). Between mixed stands in Ghana and Cameroon, significant differences were found only for Leaf and twig. For *Avicennia* (Cameroon) and mixed (Ghana), and *Rhizophora* in Cameroon and mixed stand in Ghana, significant difference was mainly found for leaf. Significant changes in litter components production in both countries were therefore observed at all sites.

According to the rainfall variation in Ghana and Cameroon, the leaves and twigs/branches litterfall of *Avicennia*, *Rhizophora* and mixed stands increased with the decreasing of Rainfall in the dry season (Figures 7 and 8). An analysis of variance (ANOVA) of vegetative and reproductive litterfall showed very significant differences ($p \leq 0.0001$) in twigs/branches, leaves and flowers in Ghana and Cameroon between sites.

4.2.4 Total annual litterfall

For Ghana sites, the total annual litterfall was 3035 g/m²/year or 30.3 t/ha (average value, 2.5t/ha/yr) constituted of *Avicennia* (27. 47%), *Rhizophora* (48. 66%) and Mixed (23.85%) (table2). Leaf litterfall comprised the largest component (81.28%). For Cameroon sites, the total annual litterfall was 5410 g/m²/year or 54.1 t/ha (average value: 4.5 t/ha/yr) made up by Avicennia (24.75%), *Rhizophora* (35.60%) and Mixed (39.64%) **(**Table1**).** Leaf litterfall comprised the largest component (85.17%). The total litterfall of the 2 countries within the West and Central African ecoregion was 8445 g/m²/year or 84.4 t/ha (average value:7 t/ha/yr), with a high percentage of leaf litterfall (83.77%).

Table 1: Mean total annual litterfall (g/m^2)

Country	Mangrove forest Stand composition	Litter component	Total annual production (g/m^2)	% of total production	Mean monthly production (g/m^2) ± sd
Cameroon (Douala-Edea Reserve)	*Avicennia*	Flowers	76	5.68	6.3±0.7
		Fruits-seeds	80	5.97	6.7±0.8
		Leaves	1097	81.93	91.4±20.3
		Twigs	86	6.42	7.2±1.0
		Total	1339	**15.86**	111.6±21.3
	Rhizophora	Flowers	75	3.89	6.2±0.8
		Fruits-seeds	67	3.48	5.5±1.2
		Leaves	1685	87.49	140.4±12.8
		Twigs	99	5.14	8.2±1.1
		Total	1926	**22.81**	160.5±14.7
	Mixed	Flowers	80	3.73	6.7±0.5
		Fruits-seeds	100	4.66	8.3±2.5
		Leaves	1826	85.13	152.2±20.0
		Twigs	138	6.43	11.5±3.2
		Total	2145	**25.40**	178.8±21.5
Ghana (Ada Ada Reserve)	*Avicennia*	Flowers	12	1.44	1.0±0.6
		Fruits-seeds	28	3.36	2.3±0.8
		Leaves	718	86.09	59.8±14.4
		Twigs	77	9.23	6.4±1.1
		Total	834	**9.88**	69.5±14.4
	Rhizophora	Flowers	238	16.11	19.8±4.2
		Fruits-seeds	99	6.70	8.3±2.9
		Leaves	1119	75.76	93.3±19.7
		Twigs	20	1.35	1.7±0.5
		Total	1477	**17.49**	123.1±27.0
	Mixed	Flowers	28	3.87	2.3±0.3
		Fruits-seeds	16	2.21	1.3±0.5
		Leaves	630	87.02	52.5±12.6
		Twigs	50	6.91	4.1±1.2
		Total	724	**8.57**	60.3±12.4
				100	

In the studied areas it wasobserved that, in Cameroon and Ghana the highest peaks in total litterfall production occurred, in January for *Avicennia*, early March and November *for Rhizophora* and March and December for Mixed stands in Cameroon. In Ghana, peaks were

Avicennia (December), *Rhizophora* (March and December) and Mixed (December). The highest peaks in Cameroon and Ghana were observed in the dry season (Figure 9).

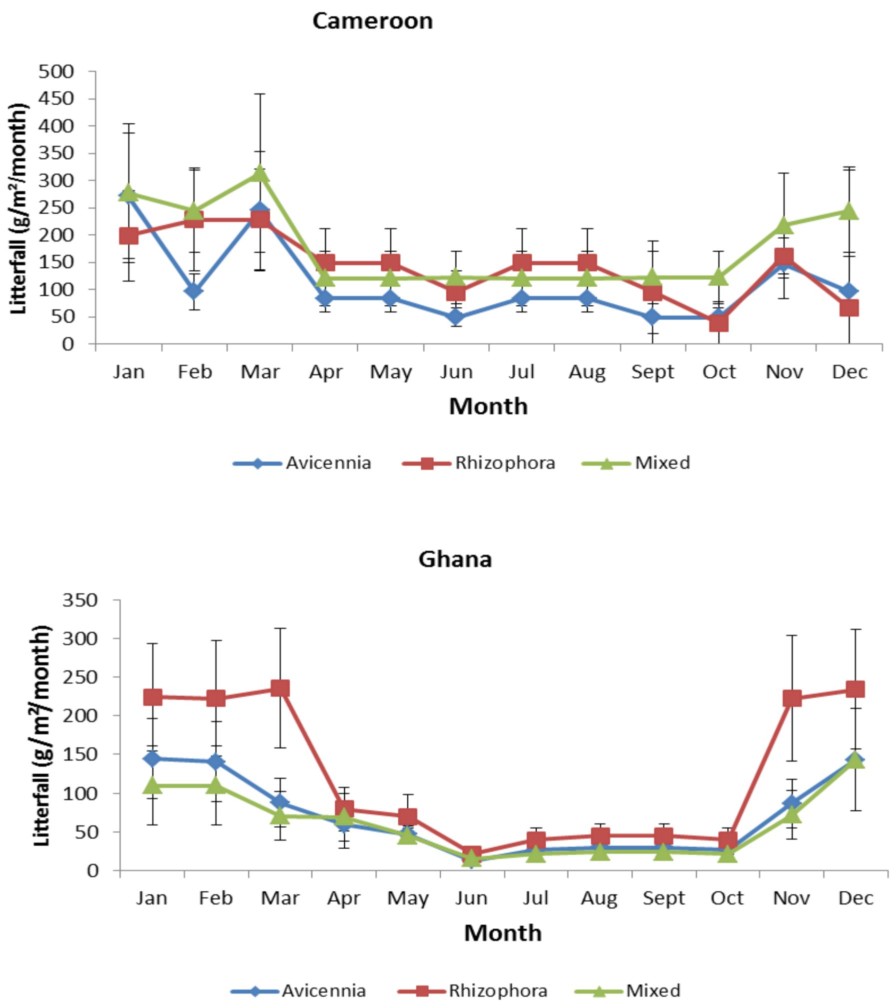


Figure 9: Changes in monthly total litterfall for mangrove stands in Cameroon and Ghana

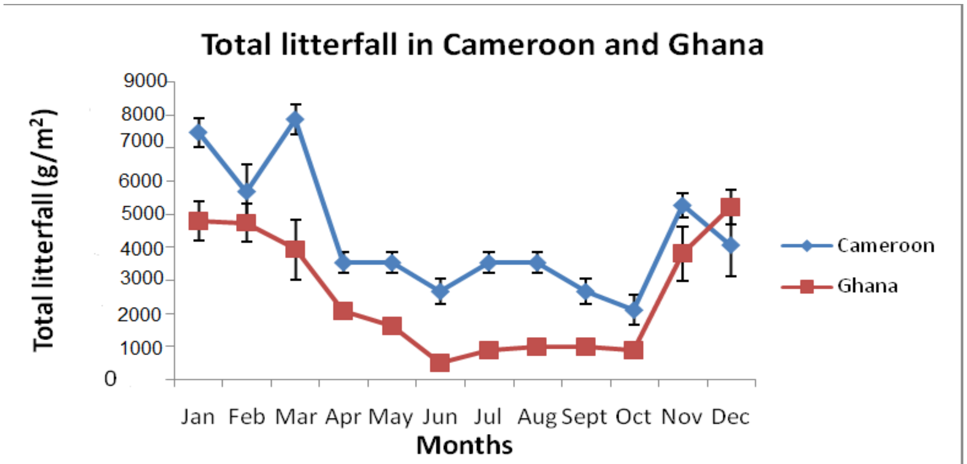


Figure 10: Changes in total litterfall in Cameroon and Ghana

4.2.5 Leaf litterfall nutrients inputs

In Ghana, the concentration of N, P, K, Ca, and Mg in leaf litter in various mangrove stands are shown in the Table 1. The variations in monthly nutrient concentrations during the period under investigation were considerable (Figure 15). The amount of N, P, K, Ca, and Mg in leaf litter (mg/m²/year) obtained from the study, Table 2 indicated that,. The total amount of N, P, K, Ca, and Mg in the various stands were decreased in the order Ca>Mg>P>K>N. The highest content of total Ca and N were observed in the *Rhizophora* and *Avicennia* stands, and the lowest in the *Avicennia* and *Rhizophora* stands. A negative correlation between Ca and N was then observed in the study areas of Ghana (Table 2). It appeared that, the amount of N was rather low in all the mangrove stands in Ghana;

The production of Mg was high in *Rhizophora* and mixed stands, while in *Avicennia* Ca is rather very high (Figure 15). In the study areas in Ghana, it was was observed that, the highest values in nutrient content were observed in December for N, P, K, Mg and in March for Ca (Figure 15). The high values of nutrients in Ghana were mainly observed in the dry season.

Nutrient content seemed to have strong relation with the monthly rainfall variation (Figure15). Leaf nutrients showed respectively significant differences in P, K ($p \leq 0.05$) and Ca, Mg ($p \leq 0.0001$) production between the sites.

There were very significant differences between *Avicennia* and *Rhizophora* in P, K ($p \leq 0.05$) and Ca, Mg ($p \geq 0.0001$) production among site, but not Monthly leaves and twigs fall was significantly different ($p \leq 0.001$) between sites, but not significantly different ($p \geq 0.05$) within sites. There was no significant difference in Nitrogen (N) among the sites ($p>0.05$). Between *Avicennia* and *Rhizophora* there was no significant difference ($P>0.05$) in the total annual input of N. However, the amount of Mg and Ca was significantly different ($p<0.0001$) (table 3).

In Cameroon, the highest amount of N, P, K, Ca and Mg in leaf litter in various mangrove stands are shown in Table 3. The variations in monthly nutrient concentrations during the period under investigation were also significant (Figures11 to 15). The amount of N, P, K, Ca and Mg in leaf litter ($mg/m^2/year$) obtained from the study sites are shown in table3. The total amount of N, P, K, Ca and Mg in the various stands were in the order Mg > N > K > P >Ca. The highest content of total Mg and Ca was respectively observed in the mixed and *Rhizophora* Stands, and the lowest in the *Rhizophora* and mixed stands.

In the studied areas in Cameroon, it was observed that, the highest values in nutrient content were observed in December for N, P, K, Mg and in early March for Ca (Figures11 to 15). Nutrient content seemed to have no relation with the monthly rainfall variation (Figures11 to 15). It was observed that, the amount of Ca is relatively low in all the mangrove stands in Cameroon, this may be due to the lower rate of leaching of Ca from the decomposing of the litterfall into the soil. Leaf nutrients showed respectively significant differences in N, P ($p \leq 0.0001$) and Mg ($p \leq 0.05$) production between the sites.

There were no significant differences ($p>0.05$) in Ca and K production between the sites. There were more strongly significant differences between *Avicennia* and *Rhizophora* in N production between sites, but not significantly different ($p \geq 0.05$) within sites. There were significant differences between *Avicennia* and mixed (*Avicennia+ Rhizophora*) and *Rhizophora* and mixed ($p \leq 0.05$). Between *Avicennia* and *Rhizophora* there was no significant difference ($P>0.05$) in the total annual input of Ca. however the amount of Mg and N was significantly different ($p<0.0001$) (Table 2).

Table 2: Annual Litter production and Nutrient input in Cameroon and Ghana sites

parameter	**Cameroon**			**Ghana**		
	Avicennia	***Rhizophora***	**Mixed**	***Avicennia***	***Rhizophora***	**Mixed**
Total Annual leaf litterfall (g/m^2)	1097 ***	1685*	1826**	718**	1119***	630*
Total annual N	138.82**	78.94*	124.76 ***	29.73 **	29.06 **	29.55
Total annual P	95.28***	40.53*	91.36 **	230.56**	254.41 ***	238.96*
Total annual K	116.63***	48.54*	110.36**	128.60*	161.18**	161.40. ***
Total annual Ca	11.25**	126.27**	33.13**	243.56*	364.84 ***	274.37**
Total annual Mg	109.4**	92.54	151.97***	281.89**	185.02**	301.59 ***

Significant values in Cameroon and Ghana of one-way following a Least Significant Difference test (LSD) (F-values) for comparisons in annual litterfall and nutrients input of *Avicennia*, *Rhizophora* and mixed stands. Levels of significance are shown as:*$P \leq 0.05$. **$P \leq 0.01$. ***$P \leq 0.0001$.

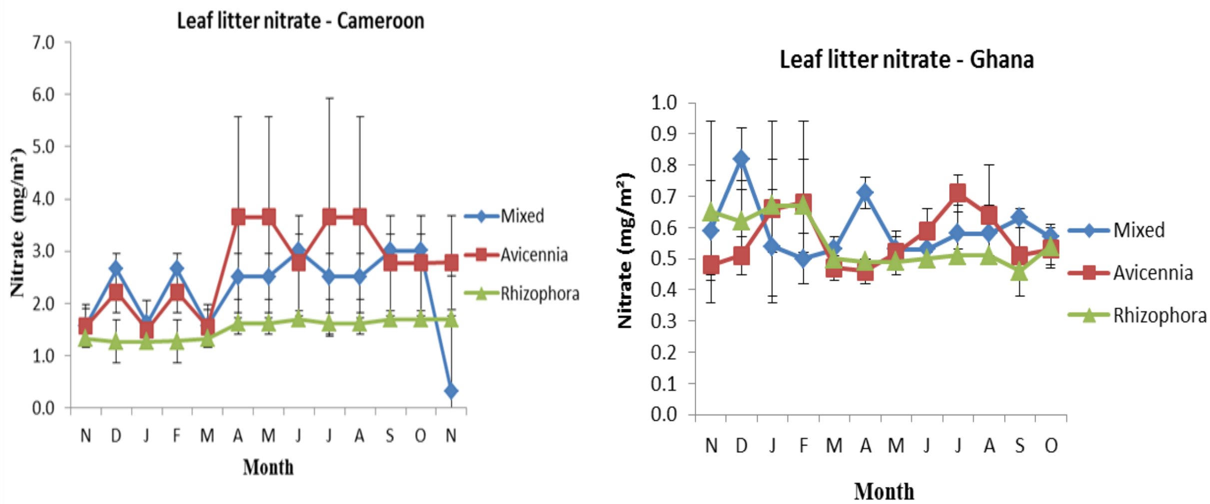


Figure 11: Mean monthly variation in leaf litter nitrate contents of Avicennia, Rhizophora and mixed stands in Cameroon and Ghana

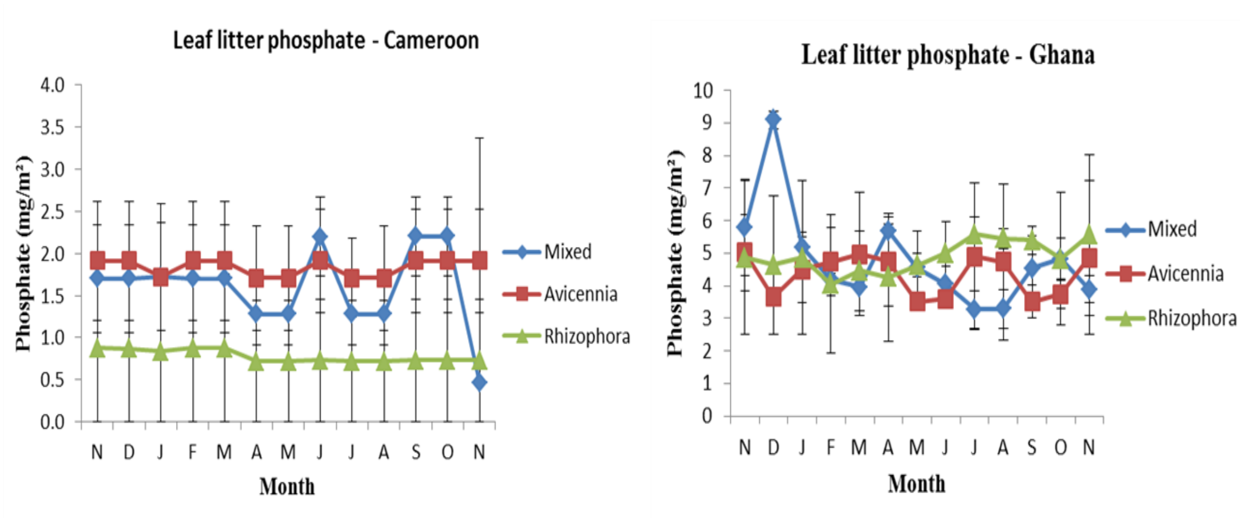


Figure 12: Mean monthly variation in leaf litter phosphate contents of Avicennia, Rhizophora and mixed stands in Cameroon and Ghana

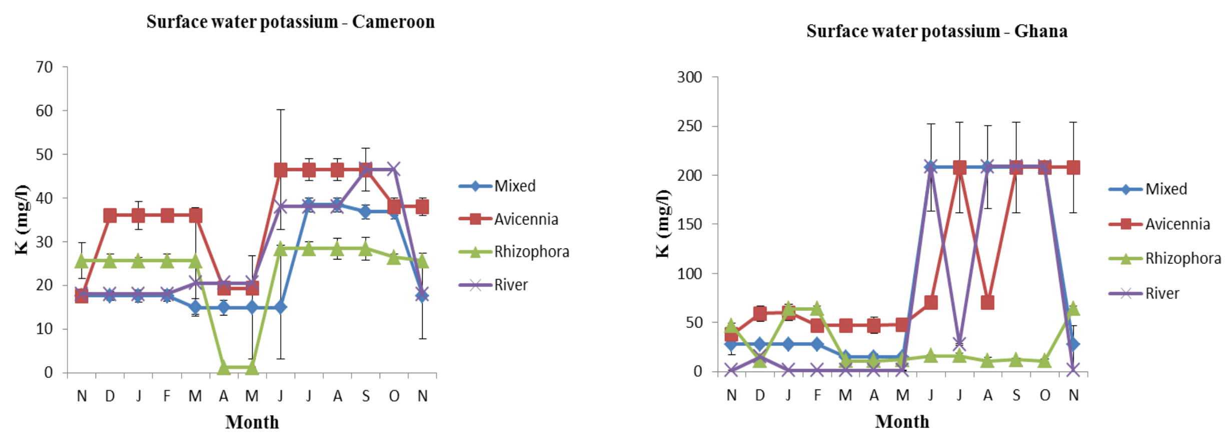


Figure 13: Mean monthly variation in leaf litter potassium contents of Avicennia, Rhizophora and mixed stands in Cameroon and Ghana.

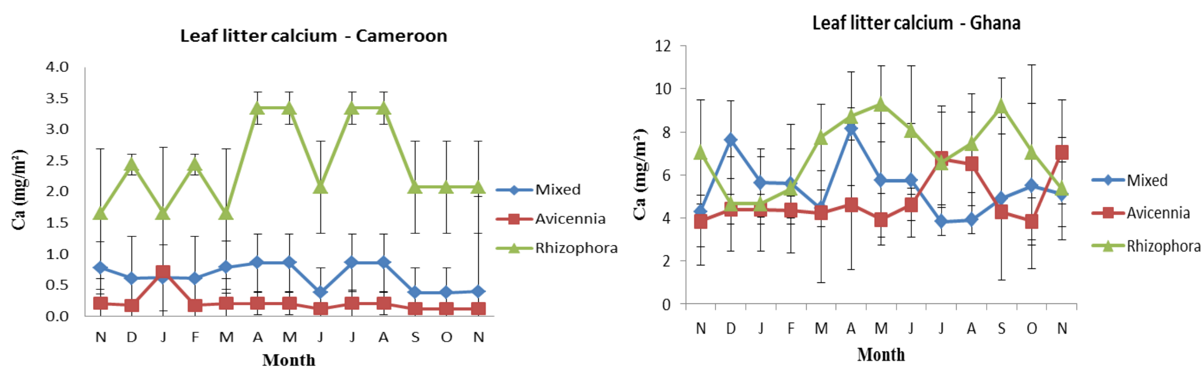


Figure 14: Mean monthly variation in leaf litter calcium contents of Avicennia, Rhizophora and mixed stands in Cameroon and Ghana.

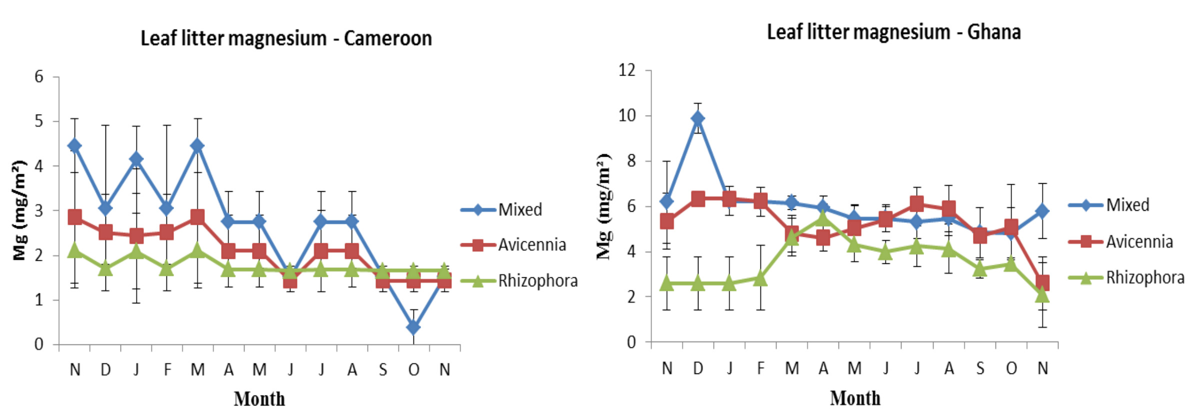


Figure 15: Mean monthly variations in leaf litter magnesium contents of *Avicennia*, *Rhizophora* and mixed stands in Cameroon and Ghana.

In terms of leaf nutrients, Ghana had the highest mean concentrations of P, K,Ca and Mg and a low level of leaf litterfall mass compared to Cameroon with high value of leaf litterfall mass and low nutrients content (Tables 2). Cameroon had at least a very high concentration of N compared to Ghana.

4.2.6 Carbon stocks in total litterfall in Cameroon and Ghana

It appeared that, in the Ghana sites the total mean carbon stock was 3410.98g/m²/yr (34.10 t/ha/yr) in *Avicennia*, 6067.33 g/m² g/m²/yr (60.67 t/ha/yr) in *Rhizophora* and 2975.84g/m²/yr (29.75 t/ha/yr) in mixed stand; While in Cameroon the carbon stocks were 5329.73g/m²/yr (53.29 t/ha/yr) in *Avicennia*, 7582.52 g/m² in *Rhizophora* and 8529.36 g/m² yr (85.29 t/ha/yr) in mixed stand. It was also clearly showed in Figure16 that, significantly higher content ($P < 0.05$) of Carbon stocks were recorded in the dry season and Cameroon had the highest content of carbon in litterfall.

Table3: Carbon concentration of litter in mangrove protected areas of Cameroon and Ghana.

Country	Mangrove forest Stand composition	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
Cameroon	Avicennia	47.7	47.8	47.8	47.7	47.7	47.8	47.7	47.7	47.8	47.8	47.8	47.8	47.8± 0.0
	Rhizophora	47.3	47.3	47.3	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.3	47.3	47.2± 0.0
	Mixed	47.7	47.7	47.7	47.5	47.5	48.0	47.5	47.5	48.0	48.0	47.8	47.7	47.7± 0.1
Ghana	Avicennia	49.1	49.0	49.5	49.6	48.7	48.7	49.4	49.4	48.6	48.6	49.0	49.1	49.0± 0.1
	Rhizophora	49.3	49.3	49.1	48.9	49.2	49.2	49.7	49.7	49.6	49.6	49.5	49.2	49.4± 0.1
	Mixed	49.5	49.0	48.9	49.8	49.2	48.9	48.5	48.5	49.2	49.2	49.4	49.8	49.2± 0.1

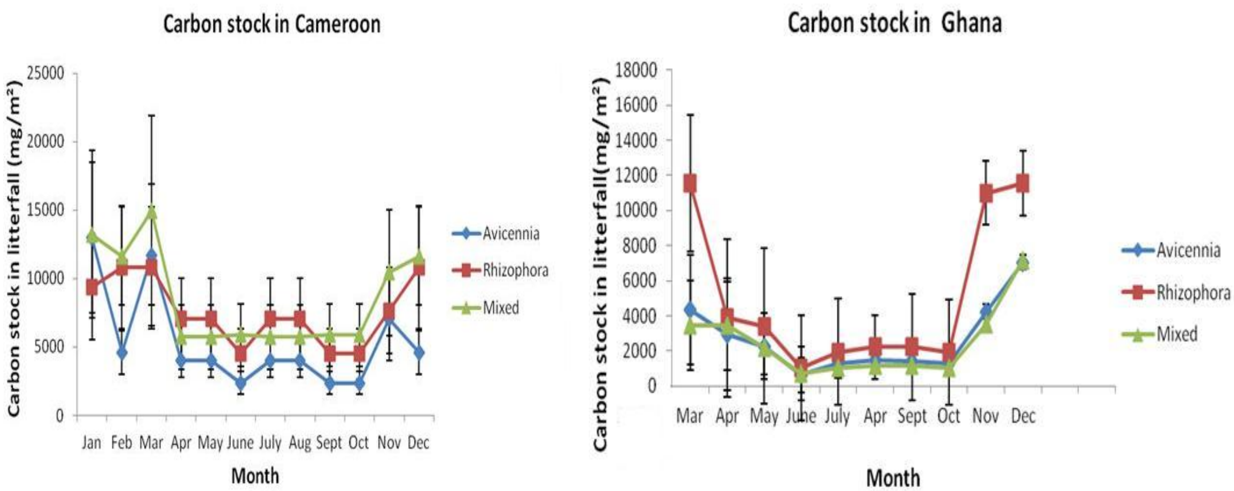


Figure 16: Changes in carbon stocks in litterfall in Cameroon and Ghana

4.2.7 Relationships among variables for litterfall and Phenology in Cameroon and Ghana

Cluster analysis with Similarity Proficiency (SIMPROF) test for litterfall characteristics of the mangrove stands revealed that all mangrove stands from Cameroon and Ghana (*Rhizophora* Cameroon (RhCA), AVCA, mixed Cameroon (MxCA), *Rhizophora* Ghana (RhGH), *Avicennia* Ghana (AVGH) and mixed Ghana (MxGH) are significantly different from each other at a 50% Euclidean distance (Figure 17). However, at a Euclidean distance of about 7, two groups of mangrove stands could be seen, with the two groups made up of a mixture of stands from Ghana and Cameroon each. These groups were further explained by the principal component analysis.

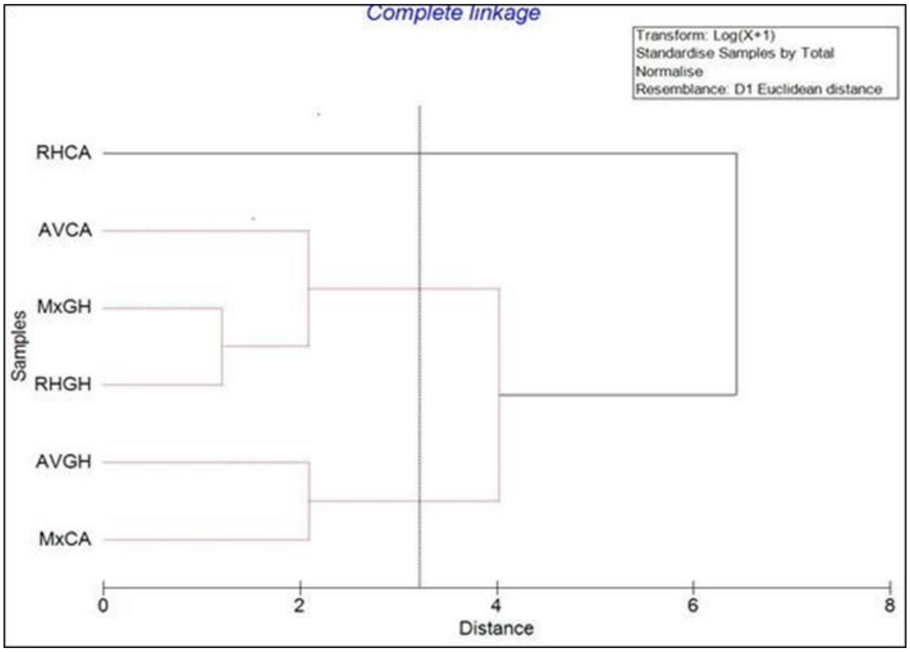


Figure 17: Dendrogramm showing the clustering of Sampling sites for litterfall parameters

Principal Component Analysis (PCA) for litterfall production (Figure 18) indicated that five principal components (PCs) explain 100 % of the variability in the data, with PC1 and PC2 contributing to 66.4% and 24.8%, respectively (Annexe 3). Parameters that are strongly distributed on PC1 included flower, fruit, twigs, N, P, Ca and Mg. On the other hand, leaf, N, and K were observed to be strongly loaded on PC2. Using PC1 and PC2, which contribute to a total of 91, 2 % of the variability in the data, it was observed that litterfall from mixed Cameroon (MxCA) and *Avicennia* Ghana (AVGH) contributed to the variability by flower and fruit while those from *Avicennia* Cammeroon (AVCA), mixed Ghana (MxGH) and *Rhizophora* Ghana (RHGH) were mainly contributed by leaves, N and K, and *Rhizophora* Cameroon (RHCA) by twig, Ca and Mg.

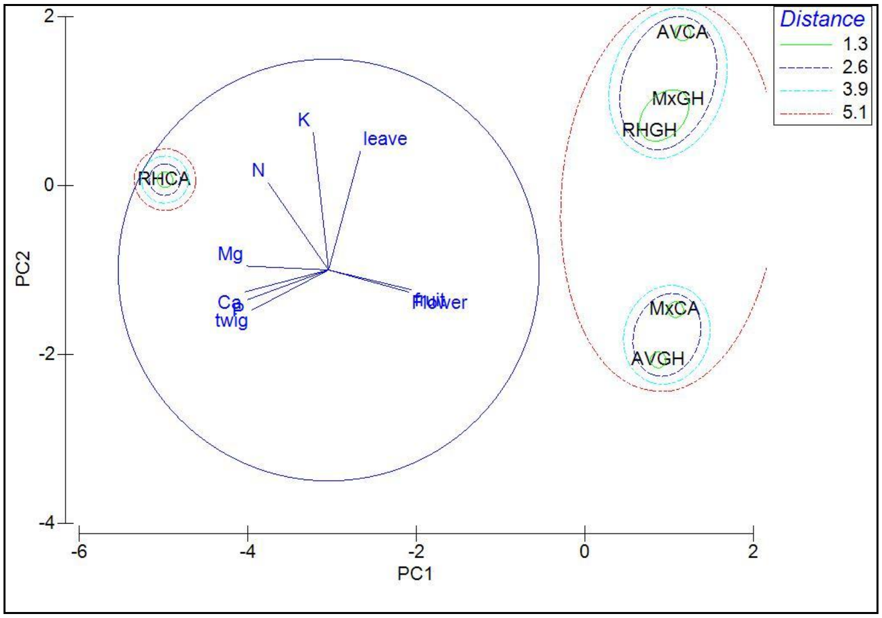


Figure 18: Principal component analysis (PCA) ordination plot of sampling stations based on litterfall.

A One-way Analysis of Similarity (ANOSIM) performed for litterfal parameters indicated a Global R of 0.674 at a significant level of 0.1% (P= 0.001), indicating high dissimilarity among the mangrove stands from Ghana and Cameroon. A Parewise test indicated higher similarity between mangrove stands in Ghana, as well as mangrove stands in Cameroon, but high dissimilarity between those of Ghana and Cameroon (Appendix 3).

In order to explain the disparate patterns of litterfall production and nutrients concentrations within and between the two countries, Discriminant Function Analysis (DFA) was performed The group centroids of the six sites representing, Avicennia GH, Rhizophora GH, Mixed GH, *Avicennia* CA, *Rhizophora* CA and Mixed CA, were significantly different from one another (Wilks' lamba =0.04667, P<0.00001).

For the first two axes, Mixed GH group overlapped with those of *Avicennia* GH and *Rhizophora* GH. Mixed CA group overlapped with those of *Avicennia* CA and *Rhizophora* CA. Within each country the separation of the groups was bad, and good between the countries (Figure 19). A total variation (85%) was expressed by the 1st canonical variate axis (Root1), whereas 15% of the total variance was explained by the 2nd axis. The first canonical variate axis tended to discriminate with a high score Mixed GH from the five others groups (*Avicennia* GH, *Rhizophora* GH, Mixed CA, *Avicennia* CA and *Rhizophora* CA). Character- axis correlations (Appendix 4) indicated that N, P, Mg, K and Ca were the variables that most negatively correlated with this axis (r= -0.54, -0.51, -0.50,-0.46 and -0.45, respectively).

The second canonical variate axis discriminated the group *Avicennia* GH from the five others (Mixed GH. *Rhizophora* GH, Mixed CA, *Avicennia* CA and *Rhizophora* CA) with low canonical scores. This canonical variate axis was most negatively correlated with the variables flowers, Fruits/seeds and leaves (r=-0.67,-0.31 and -0.24 respectively). This discriminant analysis clearly showed discrimination between the different groups in both countries: Mixed GH, *Avicennia* GH, *Rhizophora* GH, Mixed CA, *Avicennia* CA and *Rhizophora*. Nitrogen (N), Phosphorus (P), Magnesium (Mg) Potassium (K) and Calcium (Ca) exhibited strong contribution in distinguishing the two countries and account for most of the expected variations in nutrient content, while other parameters flowers, Fruits/seeds and leaves showed less contribution in explaining the variation between Ghana and Cameroon.

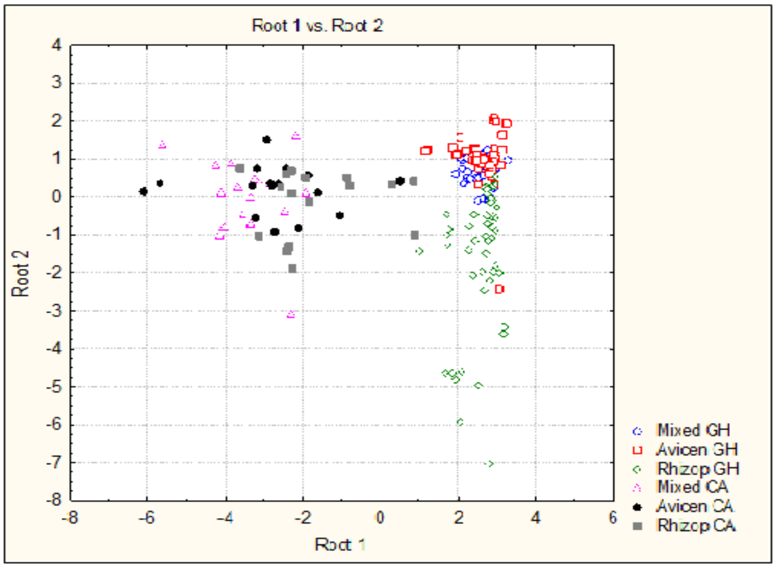


Figure 19: Scatter plot for litterfall production to indicate the six groups of Ghana (GH) and Cameroon (CA).

4.2 Mangrove Forest structure

4.2.1 Diameter Class Distribution of mangrove species

For *Rhizophora* stands in Ghana and Cameroon, analysis of the size class distribution of the trees showed very few individuals in the upper diameter-classes (from class 5 to 8) and a preponderance of individuals in the lower classes. (Figure 20). Pure *Rhizophora* stand had a lot more saplings (small, medium and large) followed by seedlings. The figure 20 showed that, there has been high natural recruitment into the lower diameter-classes in these stands of *Rhizophora.* The relatively high saplings and seedling density under the canopy implied great natural regeneration capacity of the stands. In both countries, it was observed also that the densities of species were very higher in Cameroon, compared to Ghana.

For *Avicennia* stands, analysis of the size class distribution of the trees showed very high density of seedling in Ghana and none in Cameroon. Saplings in the other hands were found in

Cameroon, but not in Ghana. There were no small trees (class 5) in both countries; from medium size to giants trees, the density was relatively low in both countries. There has been high natural recruitment into the lower diameter-classes since the establishment of these *Avicennia s*tands (Figure 20).

For a mixed balanced stand (*Rhizophora* and *Avicennia*), analysis of the size class distribution of the trees showed that Cameroon had the higher value of seedlings' density compared to Ghana (2600 stems/ha). Ghana on the other hand hada very high density of saplings compared to Cameroon a density of small saplings. Most of the trees (small to giant) were observed to be sparsely distributed in the upper diameter- classes (class 5 to 8) in Cameroon while none of them were seen in Ghana (Figure 20). It was shown that there had been high natural recruitment into the lower diameter-classes in these mixed stands in both countries (Figure 24).

In the mangroves of both countries, the number of saplings, seedlings and trees ranges respectively from 200 to17100, 5500 to 7100 and 175 to 400 stems/ha in Cameroon, and 7600 to 23600, 1900 to 5500 and 225 to 575 stems /ha in Ghana (Figures 20). Generally in both countries, high natural recruitment into the lower diameter-classes was observed in all the mangrove stands studied. ; A Great number of seedlings was observed in *Rhizophora* and mixed stands in Cameroon and in *Avicennia* stand in Ghana **(**Figure 20).

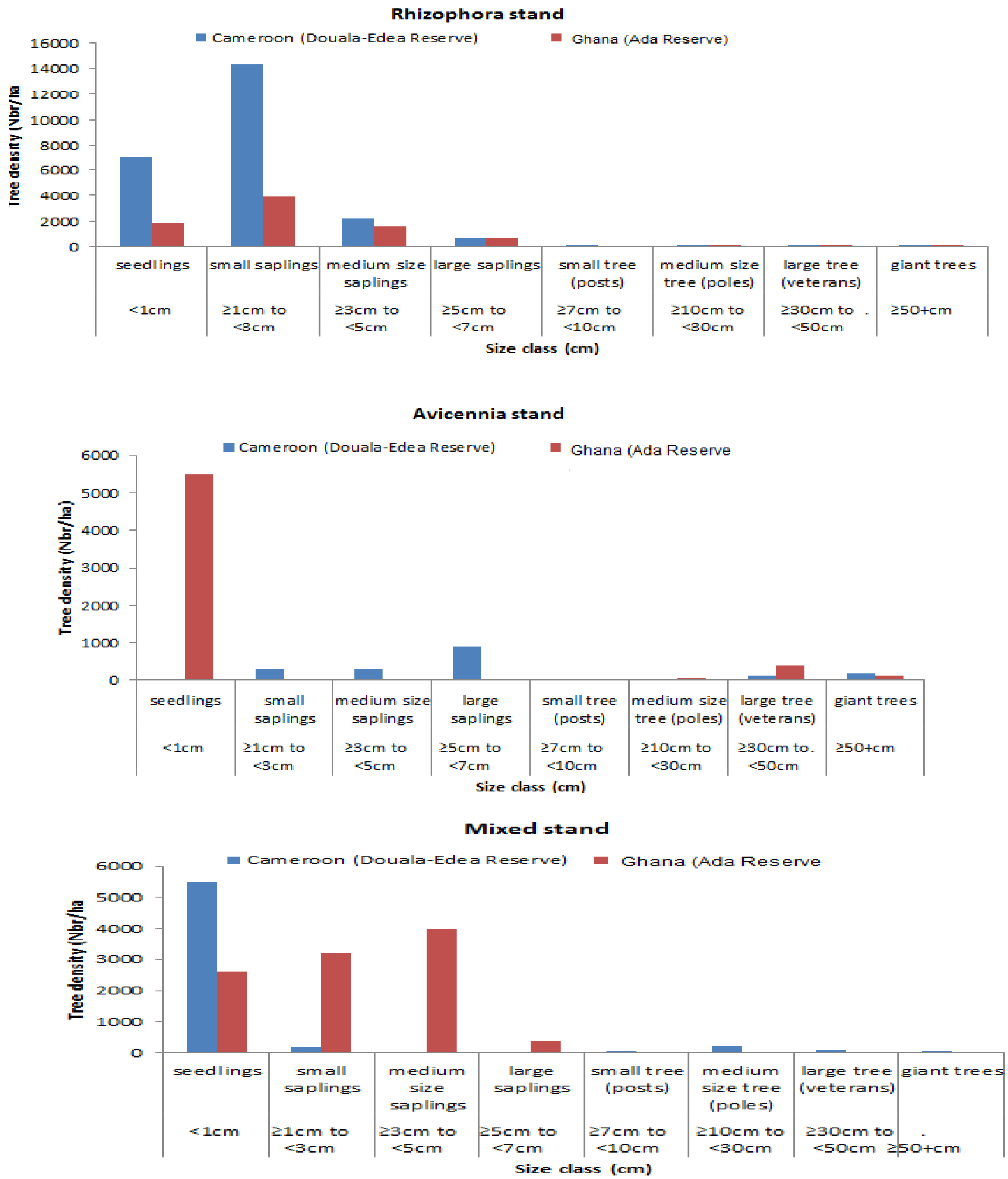


Figure 20: Distribution of mangrove tree in pure *Rhizophora* stand, pure *Avicennia* stand and mix of *Rhizophora* and *Avicennia* (Mixed stand).

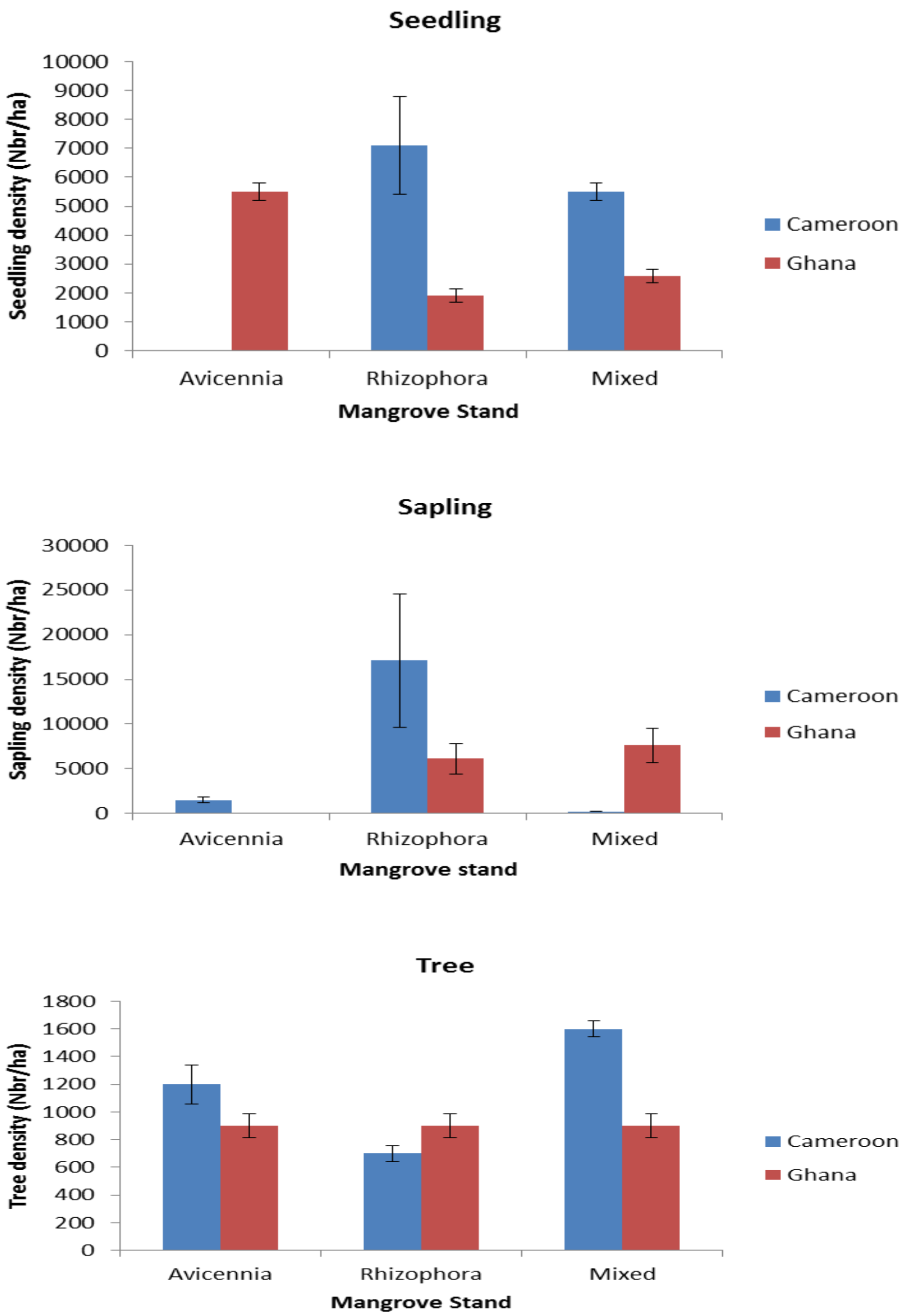


Figure 21: Stems density of seedling, saplings and trees in Cameroon and Ghana.

4.2.2 Structural Characteristics of mangrove forest

4.2.2.1 Pure *Rhizophora* Stand

The data about structural attributes of pure *Rhizophora* stands indicated that, the forest structure shown mainly by the mean values of density, basal area volume and dominant height in both countries was respectively 46.7 m, 24375 stems/ha, 37.35 m^2/ha and 836.18 m^3 in Cameroon and 14 m, 8225 stems/ha, 44.21 m^2/ha and 279.66 m^3 in Ghana (Figures 22). *Rhizophora* in Cameroon was significantly larger in terms of mean height (46.7m), mean density (24375stems/ha) and mean volume (836.18 m^3) than in Ghana. *Rhizophora* in Ghana was only significantly larger ($P< 0.05$) in terms of mean basal area (44.21m^2/ha).

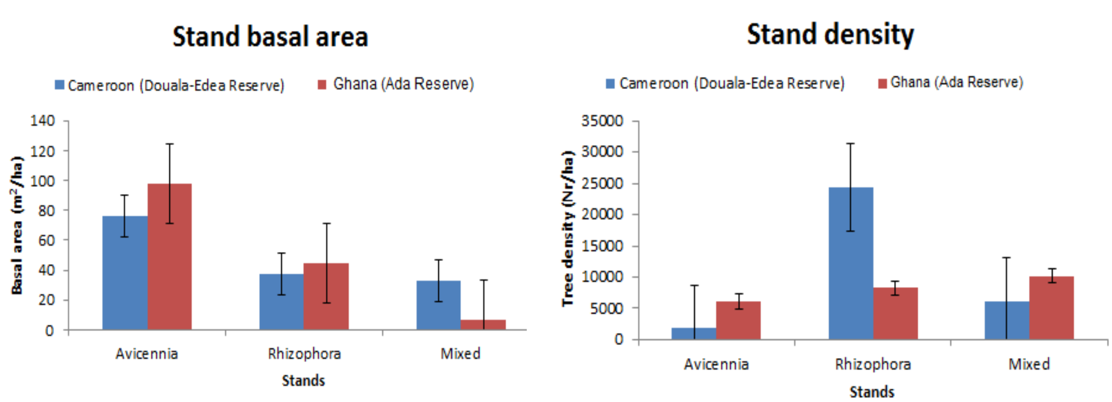
From this study, it has been shown that Cameroon had a higher mean *Rhizophora* density of 24375 stems/ha (Figure 22). Ghana had lesser density (8225 stems/ha) of smaller size (BA=44.21m^2/ha). The highest average canopy height was in Cameroon (46.7m), while the lowest 14m was in Ghana (Figure 22). Although *Rhizophora s*tand in Ghana had the highest basal area (44.21 m^2/ha); it was noted that the average height was only 14 m.

4.2.2.2 Pure *Avicennia* Stand

Concerning the structural characteristics of *Avicennia* stands, the forest structure presented mainly by the mean values of density, basal area, volume and dominant height in both countries was respectively 50.1 m, 1800 stems/ha. 76.07 m^2/ha and 2246.87m^3 in Cameroon and 7.3 m 6075 stems/ha, 98.11 m^2/ha and 412.82m^3 in Ghana (Figure 26). *Avicennia* was significantly larger in terms of mean height (50.1m) and mean volume (2246.87 m^3) in Cameroon and density (6075 stems/ha) and basal area (98.11 m^2/ha) in Ghana. From this study, it was revealed that Ghana had the mean higher *Avicennia* density with 6075 stems/ha (Figure 22). Cameroon has lesser density (1800) stems/ha) of smaller size (BA=44.21m²/ha). This zone before had been designated as protected area where large mangrove trees were cut as construction materials and firewood for bakeries resulting in denser trees of smaller size being left (BA= 76.07m²/ha). The highest average canopy height was in Cameroon (50.1m), while the lowest of 7.3m in Ghana (Figure 22). Although *Avicennia* stand in Ghana had the highest basal area (98.11m²/ha) it was noted that the average height was only 7.3 m.

2.2.3 *Rhizophora* and *Avicennia in* balanced mixed Stand

In mixed stands the mean values of density, basal area, volume and dominant height in both countries were 25.1m, 6100 stems/ha, 32.76 m²/ha and 466.22 m³ in Cameroon and 4.7 m, 10200 stems/ha, 6.62 m²/ha and 14.78m³ for Ghana (Figure 22). Mixed stands in both countries is are significantly larger in terms of mean height (25.1 m), average basal area (32.76 m²/ha) and mean stand volume (466.22 m³) in Cameroon, but stand density (10200 stems/ha) in Ghana was higher (Figure 22).



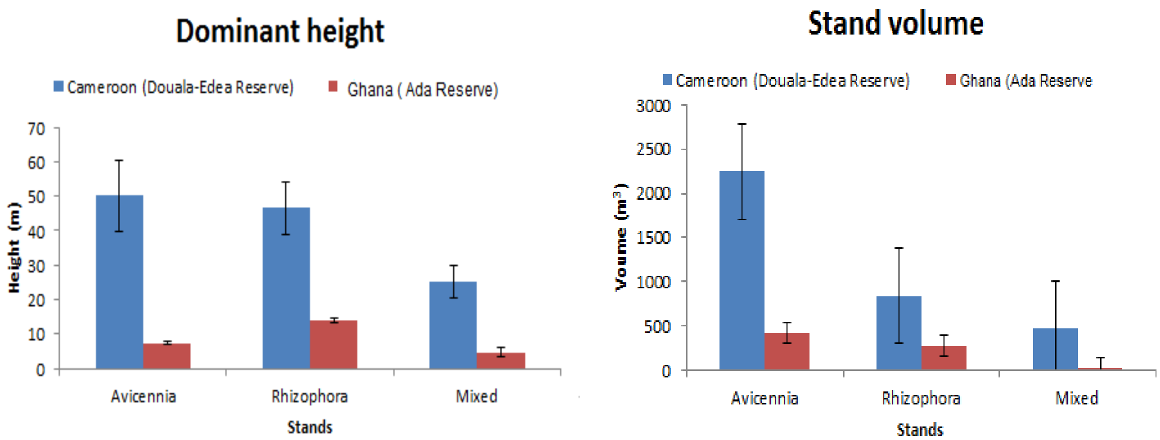


Figure 22: Changes in the structural parameters of mangrove species in Cameroon and Ghana.

4.2.2.4 Comparing pure and mixed forests in Cameroon and Ghana

Generally in both countries, high natural recruitment into the lower diameter-classes was observed in all the mangrove stands studied, that implied great natural regeneration capacity of the stands. A Great number of seedlings was observed in *Rhizophora* and mixed stands in Cameroon and in *Avicennia* stand in Ghana (Figure 21). It was observed that mangrove forest stands had their number of stems decreased with increasing size classes (Figures 20, 21 and 22). However, the mixed forests had significantly more trees of DBH ≥10cm to < 30cm, and fewer trees of DBH≥ 7cm to<10cm and DBH >30 cm than the pure mangrove stands consisting of *Avicennia* and *Rhizophora* (Figures 20).

The proportion of trees in different DBH classes was not significantly different between mangrove stands in both countries, except for the mixed forest in Cameroon with relative great proportion of trees DBH ≥10cm to<30cm (medium size tree) and low proportion in small, large and giant trees **(**Figures 20, 21 22**)**. The density was higher in *Rhizophora* stand in Cameroon compared to Ghana (Figure 22**).** The densities in *Rhizophora* mangrove forest in both countries seemed to be more stable. The basal area was higher in pure mangrove (*Avicennia* and *Rhizophora*) compare to mixed stands in both countries (Figure 22**).** The dominant height was higher in pure mangrove (*Avicennia* and *Rhizophora)* compared to mixed stands in both countries **(**Figure 22**).** It was observed that volume was higher in *Avicennia* stand in Cameroon (Figure 22**).** From this research, it has been also observed that in general, Ghana has the mean highest species density with 10200 stems/ha (Figure 26). Cameroon has lesser density (6100 stems/ha) of smaller size with a larger basal area (BA= 32.76m²/ha).

In both countries, an analysis of variance (ANOVA) on structural characteristics of the mangrove forest over the study period in both countries, showed no significant difference between the sites ($P > 0.05$) in mean density. There was significant difference in mean basal area, dominant height and volume ($P > 0.05$) in both countries **(**Table 4 **).**

Table 4: Analysis of variance of structural characteristics of the mangrove forest in Cameroon and Ghana.

Parameters	**F value**	**Significance (P< 0.05)**
Mean density	3.32	0.064
Basal area	9.587	0.002
Mean Dominant height	7.41	0.006
Mean volume	4.57	0.028

4.2.9 Relationships among variables for Structural Characteristicsof mangrove forest in Cameroon and Ghana

Cluster analysis with Similarity Proficiency (SIMPROF) test for structural characteristics of the mangrove forest revealed that all mangrove stands from Cameroon and Ghana (RhCA, AVCA, MxCA, RhGH, AVGH and MxGH) were significantly different from each other at a 50% Euclidean distance (Figure 23). However, at a Euclidean distance of about 6, two groups of mangrove stands could be seen with one group of a mixture of stands from Ghana and Cameroon and the other group comprising only a stand from Ghana (MxGH). These groups were further explained by the principal component analysis.

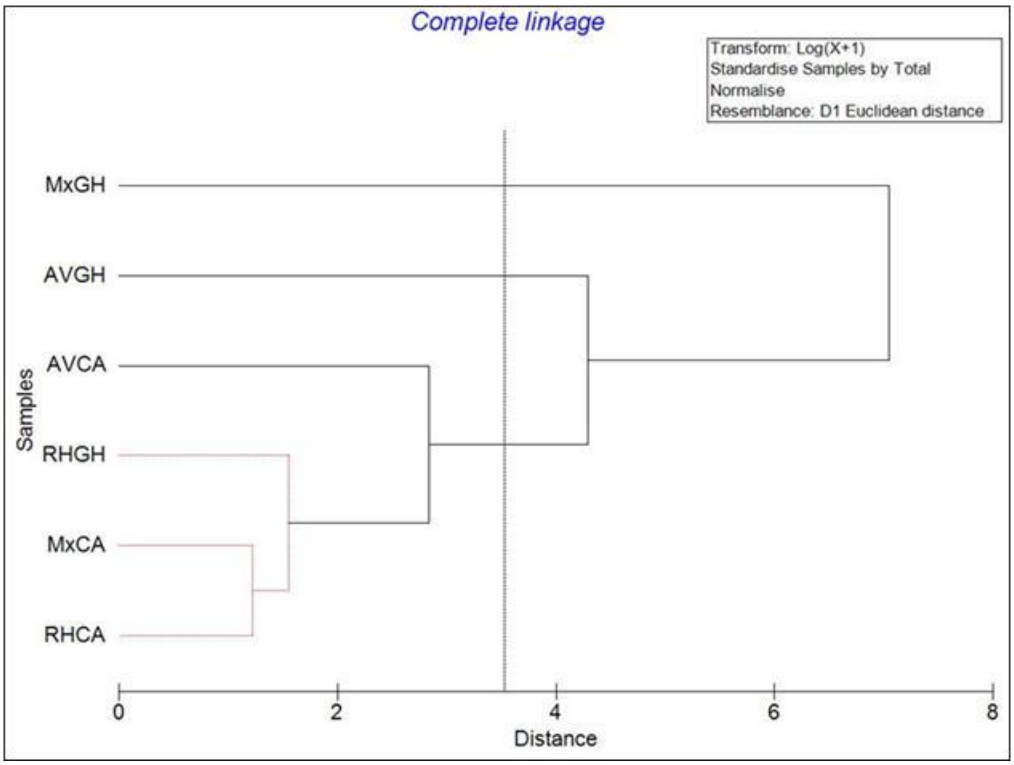


Figure 23: Dendrogramm showing the clustering of sampling sites for structural characteristics.

Principal Component Analysis (PCA) for structural characteristics (Figure 24) indicated that five principal components (PCs) explain 100 % of the variability in the data, with PC1 and PC2 contributing to 68.1% and 29.8% respectively (Annexe 5). Parameters that are strongly distributed on PC1 included Number of species (Nbsp), Mean height (MnH), total basal area (Tot

BA), Total volume (Tot vol), Mean height per hectare (MnHha), density (Dsty), (Basal area (BA) and Volume (Vol). On PC2 rather MnH, Tot BA, BA and density were well represented. Using PC1 and PC2, which contributed to a total of 97,9 % of the variability in the data, it was observed that structural parameters from mixed Ghana (MxGH) are contributed to the variability by Dsty and Nbsp, while those of AVGH(*Avicennia* Ghana) mainly contributed by TotBA and BA and *Avicennia* Cameroon (AVCA), mixed Cameroon (MxCA), *Rhizophora* Cameroon (RHCA) and *Rhizophora* Ghana contributed by MnH,, MnHa, Tot Vol and Vol.

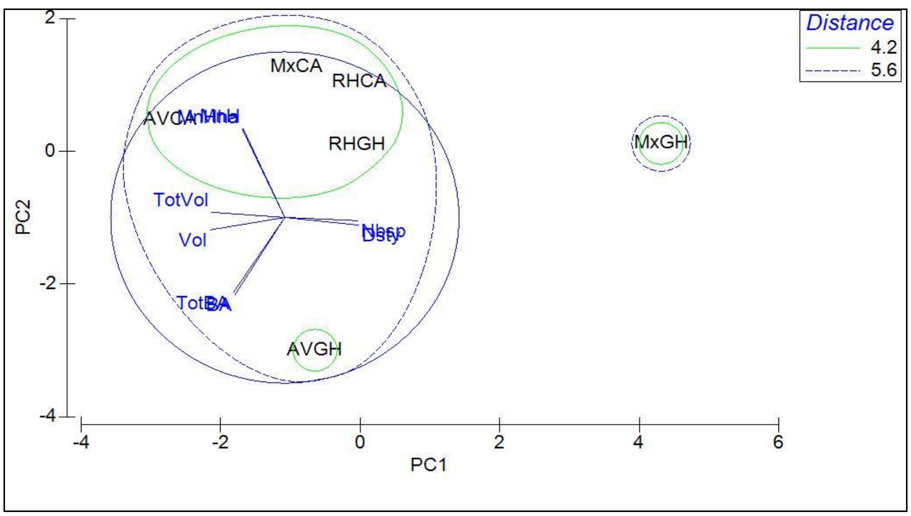


Figure 24: Principal component analysis (PCA) ordination plot of sampling stations based on structural characteristics.

In order to explain the disparate patterns of mangrove forest structure within and between the two countries Discriminant Function Analysis (DFA). The group centroids of the six sites, representing *Avicennia* GH, *Rhizophora* GH, Mixed GH, *Avicennia* CA. *Rhizophora* CA and Mixed CA. were significantly different from each other (Wilks' lamba =0.12718; P<0.00001). For the first two axes, Mixed GH group overlapped with those of *Avicennia* GH and *Rhizophora* GH, Mixed CA group overlapped with those of *Avicennia* CA and *Rhizophora* CA.

A total variation (86%) was expressed by the 1st canonical variate axis (Root1), whereas 14% of the total variance was explained by the 2nd axis. The first canonical variate axis tended to discriminate with a high score Mixed GH from the five othergroups (*Avicennia* GH, *Rhizophora* GH, Mixed CA, *Avicennia* CA and *Rhizophora* CA). Character- axis correlations (Table15) indicated that Mean height (MnHha), MnH (dominant height), BA (Basal area) and Tot BA (total basal area) were the variables, that were most negatively correlated with this axis (r= -0.90, -0.97,-0. Nbsp (number of species), Dsty (density) 99 and -0.98) respectively). The second canonical variate axis discriminated the group Avicennia GH, from the five others (Mixed GH, Rhizophora GH, Mixed CA, Avicennia CA and Rhizophora CA).This canonical variate (Root2) axis was negatively correlated with variables Nbsp (number of species) ,Dsty (density) (r= -0.95, 0.99). This discriminant analysis clearly showed discrimination between the different groups in both countries: Mixed GH, *Avicennia* GH, *Rhizophora* GH, Mixed CA, *Avicennia* CA and *Rhizophora* CA).

It appeared that, Mean height (MnHha), MnH (dominant height), BA (Basal area) and Tot BA (total basal area) exhibited strong contribution in discriminating the two countries and accounted for most of the expected variations in the structural characteristics of mangrove forest, while the other parameters Nbsp (number of species),Dsty (density) showed less contribution in explaining the variation between Ghana and Cameroon.

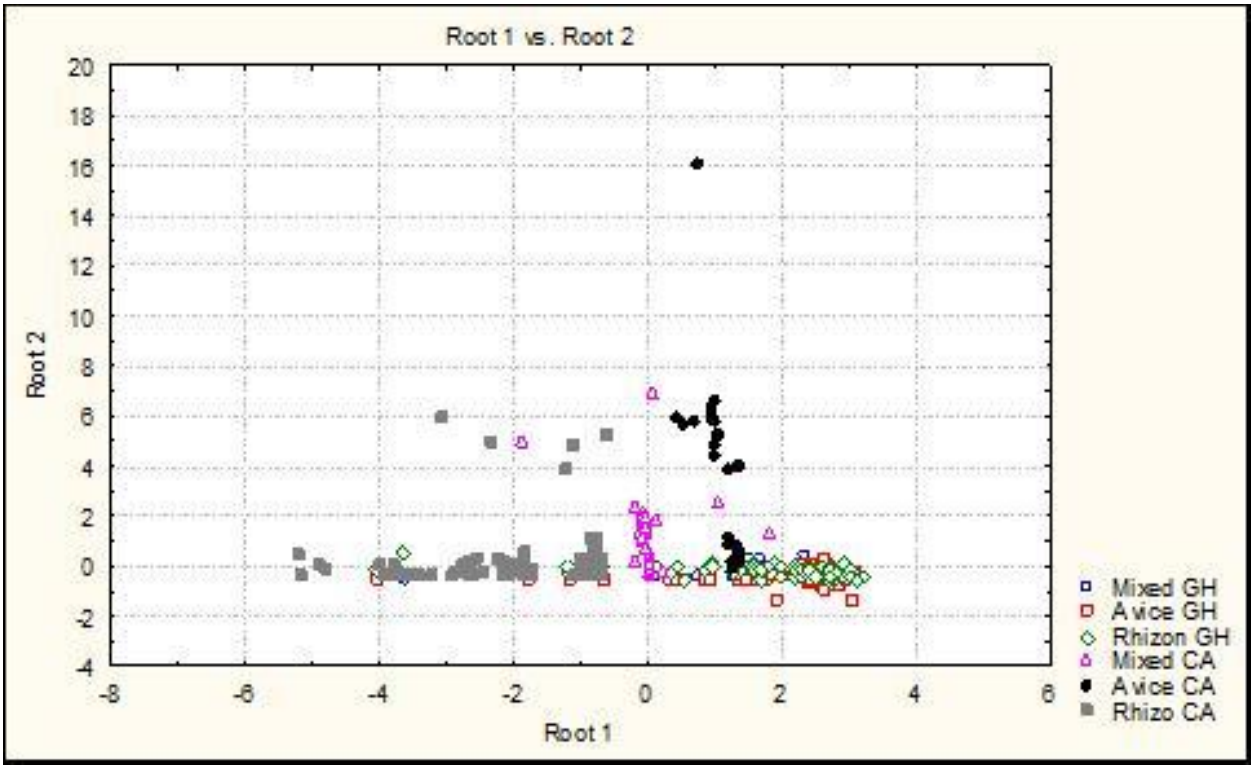


Figure 25: Scatter plot for structural characteristics to indicate the six groups of Ghana (GH) and Cameroon (CA).

4.3. Water quality on Mangrove Ecosystem

4.3.1. Physico-chemical parameters in surface water

The physico-chemical characteristics of mangrove areas in Ghana and Cameroon are presented from Figure1 to Figure 8. The parameters are discussed based on the variation in both sites and countries as well as variations during the sampling months.

pH

For Cameroon, minimum average of pH values in River (June to August), *Rhizophora* (June to August), *Avicennia* (September and October) and mixed stands (June to August) were respectively: 6.92, 7.26, 7.05 and 7.21 **(**Figure 26**).** The maximum average of pH was 7.29 for *Rhizophora* (February, March, September and October), 7.37 for *Avicennia* (July), 7.39 for mixed stands (November and December) and 7.39 for River (November, December, January and February). Thus, lower values were recorded in the rainy season and higher values were observed in the dry season for River and Mixed stand. However, in *Rhizophora* stand It was observed that higher values were recorded in both the dry and rainy season. For *Avicennia*, the higher value was recorded in the rainy season.

In Ghana, water pH recorded was more or less similar only for *Avicennia* and mixed, the others fluctuated rather widely **(**Figure 26**)**. The pH for the water samples, in the four sites varied between 6.42 and 7.2 and these values ranged from a minimum average of 6.42 in *Rhizophora* stands (November, December, February, March and April) to a maximum average of 7.2 in River site on November and December. In the mangrove stands, the high value of pH was recorded respectively on August for *Rhizophora*, June to August for Mixed and November, February, March, April for *Avicennia* and November and December for River. In general, the high value of pH (7.2) was mainly observed in the rainy season and the least value in the dry season.

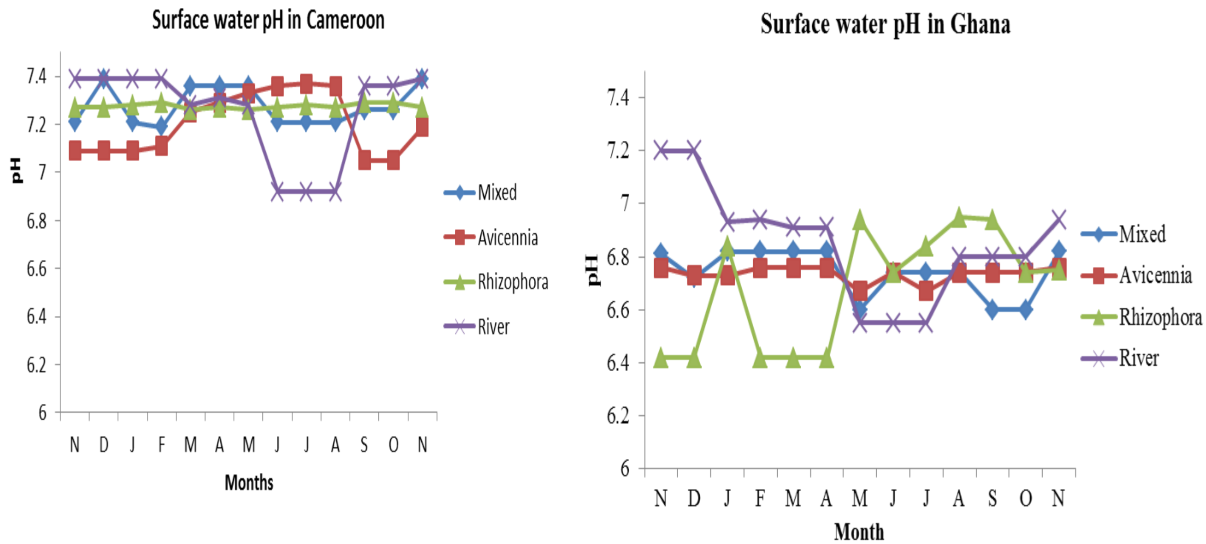


Figure 26: Seasonal changes in surface water pH in mangrove stands in Cameroon and Ghana.

Temperature

Water temperature for Cameroon during the sampling period varied from 22.3 to 26.3 ºC. The maximum temperature was observed in April 2009 in mixed stand and the minimum was recorded in March, April and May 2009 in the River (Figure 27). Water temperature showed the highest peak in: *Avicennia* (March), *Rhizophora (*July- October), mixed stands (April) and River (September- November). Seasonal variation of the temperature values presented higher values during dry season (In March for Avicennia (25.8 ºC) and in April for mixed stand (26.3 ºC) and during rainy season (In July for *Rhizophora* (24.6 ºC) in september- October for and River (25.8 ºC) (Figure27).

In Ghana, water temperature during the sampling of different seasons varied from 25.2 to 30 ºC (Figure 27). The maximum temperature was observed on November 2009 in *Rhizophora* stand and the minimum was recorded in November and December, 2008 in the *Rhizophora* stand and from January to April and November 2009 in the River. Water temperature showed the highest peak in: *Avicennia* (May and July), *Rhizophora (*November), Mixed (November) and River (August, September and October) and mixed stands (November-December on 2008 and September – October, 2009).

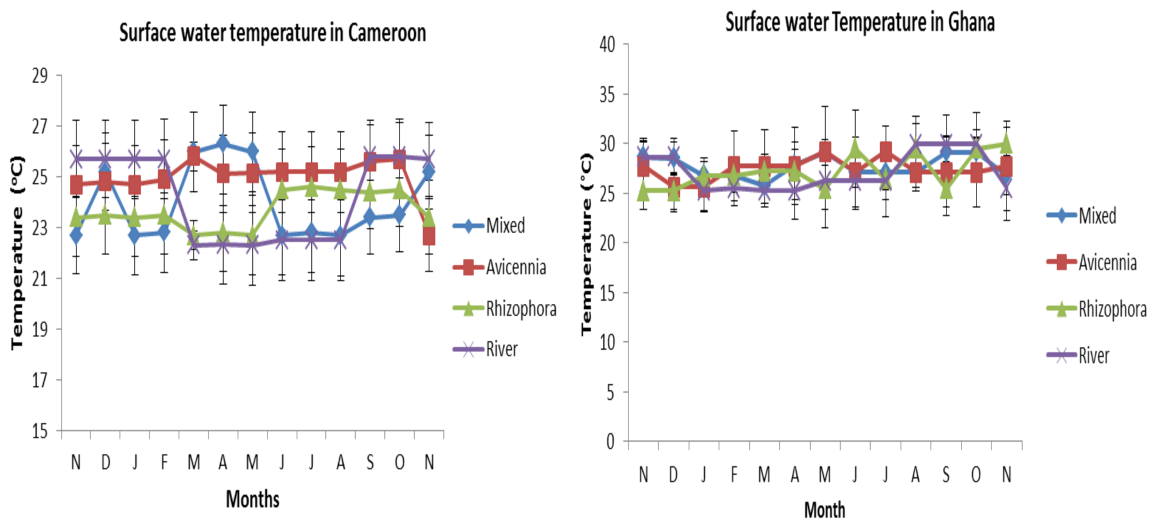


Figure 27: Seasonnal change in surface water temperature in mangrove stands in Cameroon and Ghana.

Electrical conductivity (EC)

For Cameroon, EC showed relatively great fluctuations in all the sites as well as seasons. The EC values varied between 220 µs/cm and 2550 µs/cm. The maximum value was recorded in the *Rhizophora* stand and the minimum in the *Avicennia* (Figure 28). Electrical conductivity showed the highest peak in: *Avicennia* (1852 µs/cm, from March to August), *Rhizophora* (2550 µs/cm, from March to May), mixed stands (2290 µs/cm, from March to May) and River (1313 µs/cm from March to May).

Also in Ghana, EC showed relatively high oscillations in all stations as well as seasons. The EC values varied between 284µs/cm and 4750 µs/cm. The maximum value was recorded in the *Avicennia* stand and the minimum in the mixed stand. Electrical conductivityshowed the highest peak in: *Avicennia* (4750 µs/cm, in June and July), *Rhizophora (*4002 µs/cm, March- May), mixed stands (1583 µs/cm in March) and Volta river (609 µs/cm, in May, June, July). The seasonal variation of the EC values was showed higher values during rainy season (May, June and July for *Avicennia* and Volta river) and during dry season (November, December and March for *Rhizophora* and Mixed (Figure 28).

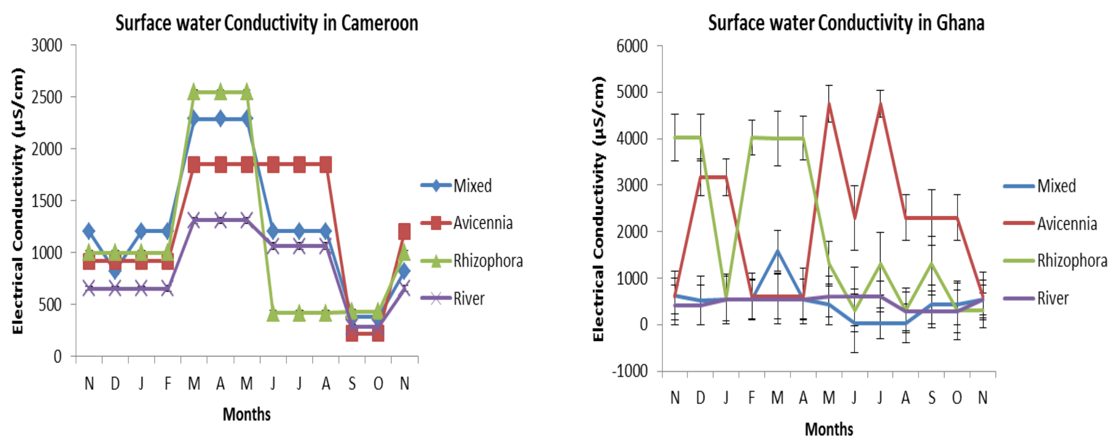


Figure 28: Seasonal changes surface water conductivity in mangrove stands in Cameroon and Ghana

Total dissolved solids (TDS)

The TDS varied between 303 and 2600 mg/l (Figure 29) for Cameroon. The maximum TDS was recorded during the months of March, April and May, in the *Rhizophora* stand and the minimum was observed during the month of September and October in the mixed and *Avicennia* stands . Total Dissolved Solids showed the highest peak in: *Avicennia* (2180 mg/l in

March, April and May), *Rhizophora (*2600 mg/l in March, April and May), mixed stands (2350 mg/l in March, April and May) and River (2180 mg/l in March, April and May).

For Ghana, the TDS varied between 296 and 2220 mg/l (Figure 29). The maximum TDS was recorded during the month of June to July, in the *Avicennia* stand the minimum was observed during the month of May to July in the River. Total dissolved solids showed the highest peak in: *Avicennia* (2220 mg/l in June and July), *Rhizophora (*1675 mg/l in February, March, April), mixed stands (1112 mg/l in July) and River (296 mg/l in May, June, July). The seasonal variation of the TDS values was showed higher values during rainy season (*Avicennia* and River) and during dry season for *Rhizophora* and Mixed (Figure 29).

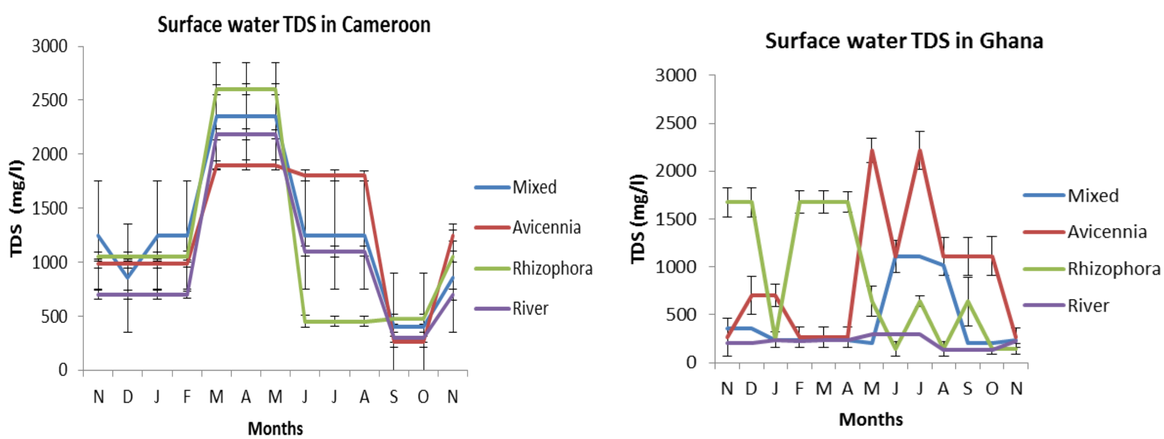


Figure 29: Seasonal variations in surface water TDS in mangrove stands in Cameroon and Ghana.

Total Suspended Solid (TSS)

In Cameroon, TSS showed relative great changes in all sites as well as seasons. The TSS varied between 20 and 294 mg/l (Figure30). The maximum value was recorded in the *Avicennia* stand and the minimum in the *Rhizophora* stand. Total Suspended Solids showed the highest peak in: *Avicennia* (294 mg/l in May, July to September), *Rhizophora* (49 mg/l in May, July and

September), mixed stands (103 mg/l in July) and River (51 mg/l from June to October). The seasonal variations of the TSS values in all sites showed higher values during rainy season (49- 294 mg/l, from june to October) and lower values mainly on the dry season (15-23 mg/l, from November to February) (Figure 30).

Similarly, in Ghana, TSS showed relative great changes*Avicennia* and Rhizophora. The TSS varied between 16 and 289 mg/l (Figure 30). The maximum value (289 mg/l) was recorded in the *Avicennia* stand and the minimum (16 mg/l) in the *Rhizophora* stand. Total Suspended solids presented the highest peak in: *Avicennia* (289 mg/l in June, August, September and October), *Rhizophora* (46 mg/l in July and September), mixed stands (98 mg/l in July) and Volta river (46 mg/l from June to October). The seasonal variations of the TSS values in all sites were showed higher values during rainy season and lower values during the dry season (46-289 mg/l, from November to February) (Figure 30).

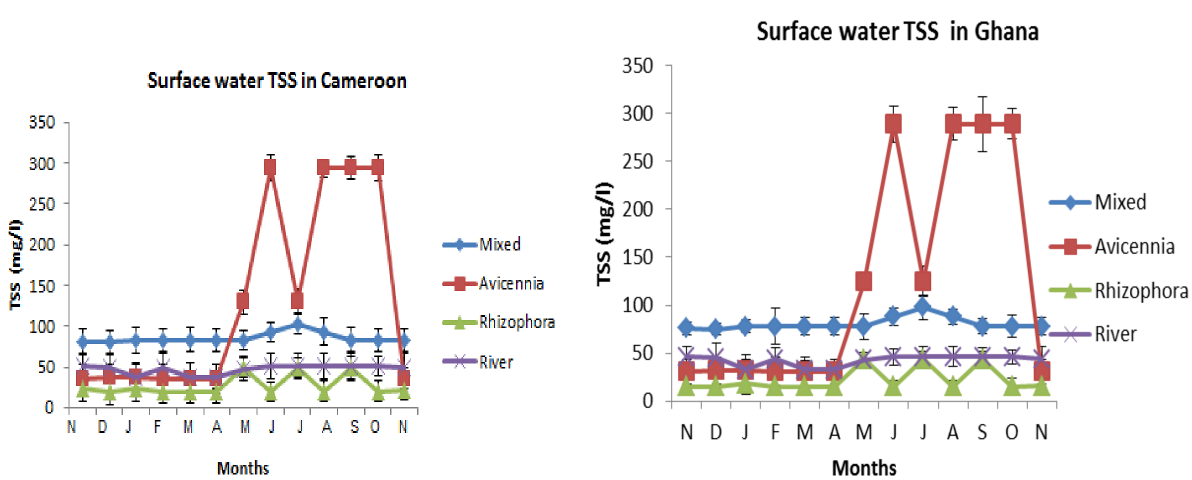


Figure 30: Seasonal variations in surface water TSS in mangrove stands in Cameroon and Ghana.

Turbidity

In Cameroon, the turbidity in the mangrove swamp varied between 23 to 255 NTU (Figure31). The maximum value (255 NTU) was observed in the *Avicennia* stand and the minimum (23 NTU) in the *Rhizophora* stand. The Turbidity showed the highest peak in: *Avicennia* (255 NTU in June, August, September and October), *Rhizophora* (42-62 NTU in May, July, September and October), Mixed stands (135 NTU in August) and River (62 NTU in February, May and November).

In Ghana, the turbidity in the mangrove swamp varied between 18 to 250 NTU (Figure 31). The maximum value was recorded in the *Avicennia* stand and the minimum in the *Rhizophora* stand. Turbidity showed the highest peak in: *Avicennia* (250 NTU in June, August, September and October), *Rhizophora* (42- 57 NTU in May, July and September). Mixed stands (130 NTU in August) and River (57 NTU in February, May and November). The seasonal variations of the Turbidity values in all sites were showed higher values during rainy season for all the mangroves stands and during the dry season (November to February) for Volta river. The seasonal variations of turbidity values in all sites, was showed higher values during rainy season (May to October) and lower values particularly during the dry season (November to February) (Figure 31).

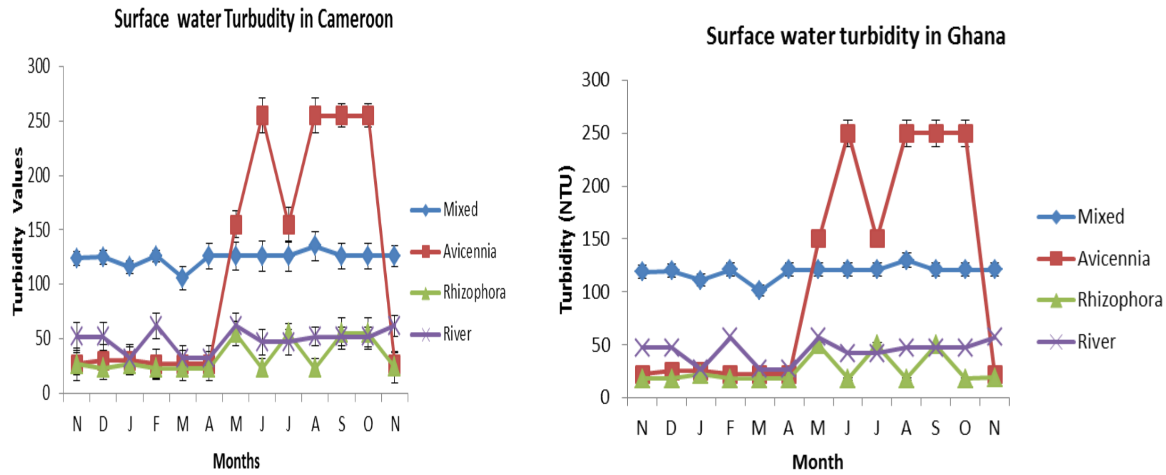


Figure 31: Monthly variations in Surface water turbidity in mangrove stands in Cameroon and Ghana.

Alkalinity

Alkalinity values for Cameroonian mangrove swamps ranged from a minimum of 35.13mg/l in June in the *Rhizophora* to a maximum of 1583.78 mg/l in March, April and May in *the* River, Alkalinity showed the highest peak in: Avicennia (70.17 mg/l from March to June), *Rhizophora* (167.75 mg/l from March to May), mixed stands (185.5 mg/l from June to August) and River (242.48 mg/l in July). The seasonal variations of the Alkalinity, values in all sites showed higher values during rainy season (May to August) for mixed stands and Wouri river (Figure 32).

Alkalinity values for Ghanaian mangrove swamps ranged from a minimum of 39.01mg/l in August. September and October in Volta river to a maximum of 287.72 mg/l in May and July in *Avicennia* Stand. Alkalinity showed the highest peak in: *Avicennia* (287.72 mg/l in May and July), *Rhizophora* (51 mg/l in June and July), mixed stands (85.34 mg/l in October).

The seasonal variations of the Alkalinity values in all sites was showed higher values during rainy season (from July to October) and lower values during the dry season (November to February) (Figure 32).

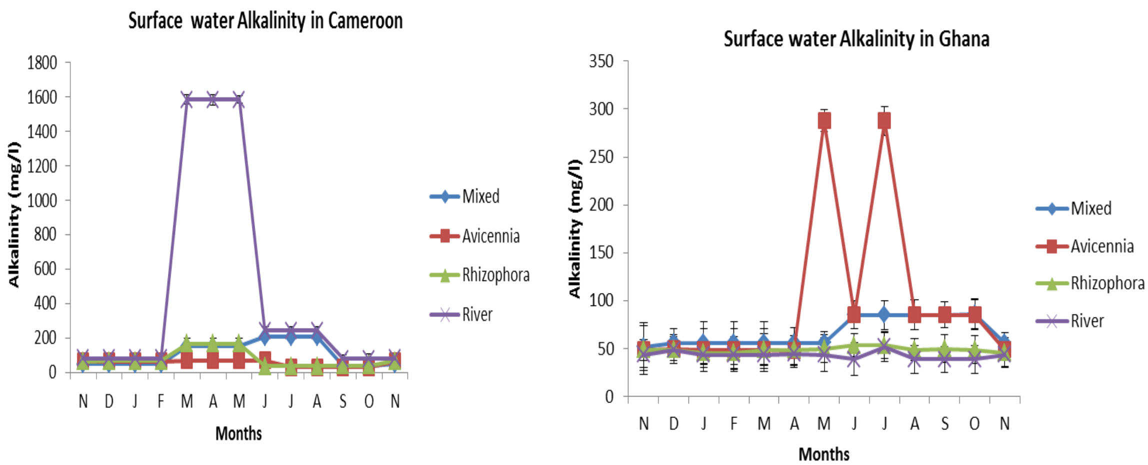
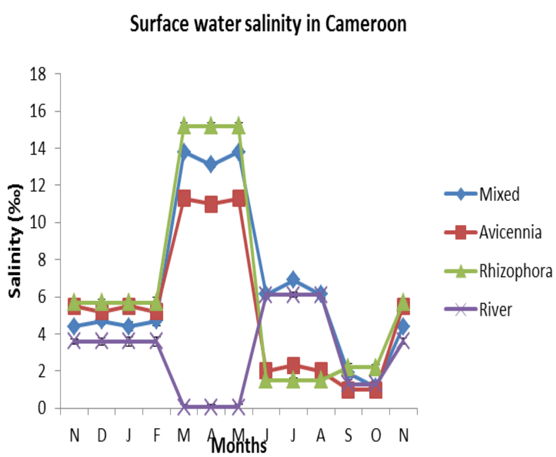


Figure 32: Seasonal changes in surface water alkalinity in mangrove stands in Cameroon and Ghana.

Salinity

Salinity in all sites for Cameroon varied between 0.04and 15.2 ‰ (Figure 35). The maximum salinity was recorded during the months of March, April and May in *Rhizophora* and the minimum was observed also during the months of March, April and May in River. Water salinity showed the highest peak in: *Avicennia* (11.3‰ in March and May), mixed stands (13.8‰ in March and May) and River (6.1‰ in June, July and August). The seasonal variations of the salinity values in all sites were showed little dependence on seasons (Figure 33).

In Ghana, salinity in at all sites varied between 0.13 and 2.6 ‰ (Figure33). The maximum salinity was recorded during the months of May and July and the minimum was observed during the months of November and December for River Salinity showed the highest peak in: *Rhizophora* (2‰ in November, December, February, March and April), Mixed stands (0.7‰ from June to August) and River (March, May, June, August, Sept and October). The seasonal variations of the Salinity values in all sites were showed higher values mainly during rainy season and lower values during the dry season (Figure 33).



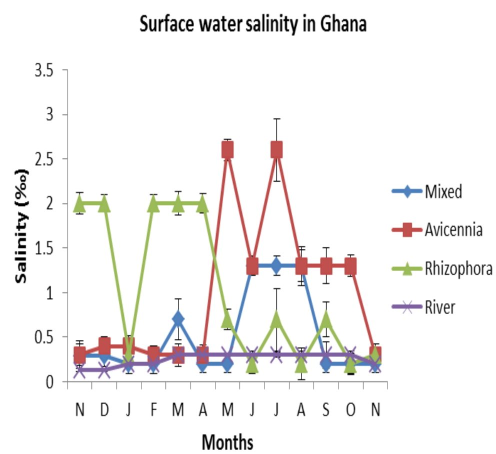


Figure 33: Monthly variations in Surface water salinity in mangrove stands in Cameroon and Ghana.

Dissolved oxygen (DO)

The Dissolved Oxygen content of Cameroonian mangrove swamps varied from 7.52 in *Avicennia* to 10.53 mg/l in *Rhizophora*. The seasonal maximum Dissolved Oxygen content in *Rhizophora* occurred in August. For *Avicennia*, the maximum value (9.5 mg/l) occurred in October. For mixed stands the maximum value (10 mg/l) occurred in October and River (9.92 mg/l) in December, January and November). The variations of the DO values among sites seasonal did not follow seasonal patterns (Figure 34).

The Dissolved Oxygen content in Ghanaian mangrove swamps varied from 2.52 to 5.53 mg/l. The maximum DO (5.53 mg/l) observed in *Rhizophora* occurred in February, May, July and September (Rainy season) and the minimum (2.52 mg/l) was observed inNovember in *Avicennia* (Dry season). The DO, showed the highest peak in: *Rhizophora* (5.53 mg/l) in February, May, July and September, *Avicennia* (4.1 mg/l) August to October in mixed stands (4.88 mg/l) from September to October and River (4.92 mg/l) from November to March The seasonal variations of the DO values among sites was showed higher values in *Rhizophora* and *Avicennia* stands mainly during rainy season and in mixed and River during dry season (Figure 34).

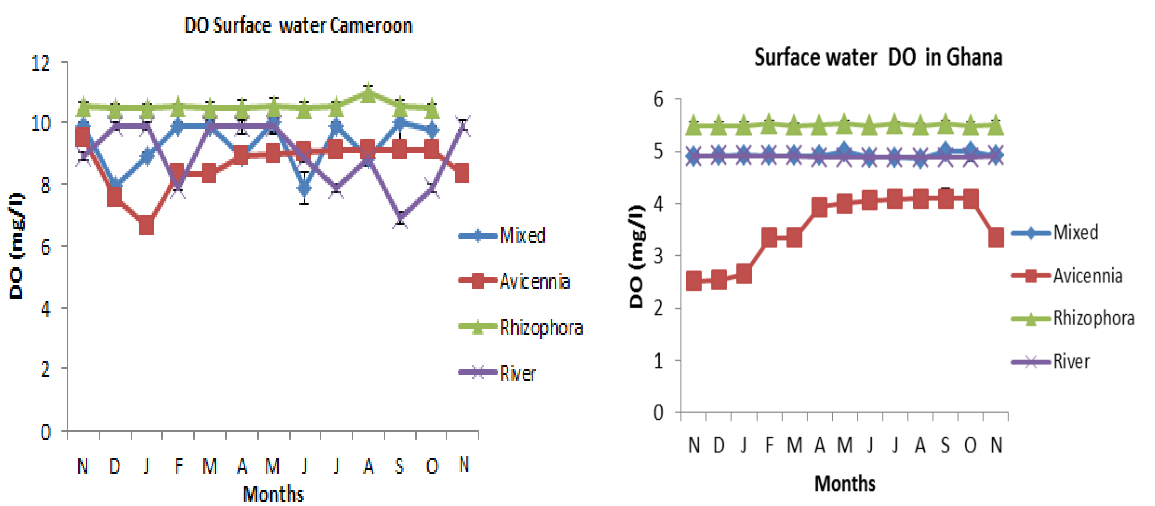


Figure 34: Surface water DO in mangrove stands in Cameroon and Ghana.

Biological Oxygen Demand (BOD)

In all sites in Cameroon, BOD values ranged from a minimum of 5.81mg/l in *Avicennia* in December, February March and to a maximum of 11.04 mg/l in *Rhizophora* in January. The BOD showed the highest peak in: *Avicennia* (9.04 mg/l) in October, Mixed stands (9.95 mg/l) in

November and River (9.04 mg/l) in October. The seasonal variations of the BOD values among sites showed higher values in *Avicennia*, mixed stands and Wouri river in the rainy season and in *Rhizophora* in the dry season (Figure 35).

In all sites for Ghana, values ranged from a minimum of 0.81mg/l in *Avicennia* in November, February and March and to a maximum of 2.5 mg/l in *Rhizophora* on November. The BOD, showed the highest peak in *Avicennia* (2.04 mg/l) from August to October, mixed stands (2.02 mg/l) from June and Julyand River from April to October. The seasonal variations of the BOD values among sites was showed, higher values in Avicennia , mixed stands and Volta river mainly in the rainy season and in *Rhizophora* in the dry season (Figure 35). The lower values were particularly recorded in the dry season.

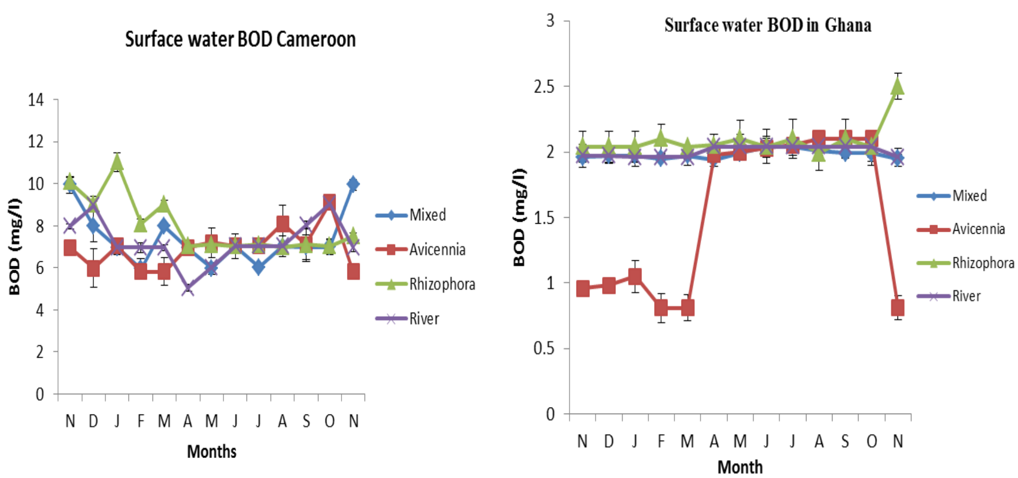


Figure 35: Monthly variations for surface water BOD in mangrove stands in Cameroon and Ghana.

Sulphate

In Cameroon, sulphate concentrations ranged from a minimum of 184 mg/l in to a maximum of 1445.58 mg/l in mixed stand from March to June. The Sulphate, showed the highest peak in: *Rhizophora* (755.22 mg/l) in April and May), *Avicennia* (583.8 mg/l) in April and May), and River (713 mg/l from July to August). The seasonal variations of the sulphate values among sites showed, higher values in *Rhizophora* and Mixed stands in the dry season. The variation of the content of sulphate in *Avicennia.Rhizophora* and Mixed stands did not relate to the seasonal patterns (Figure 36).

Sulphate concentrations for Ghana ranged from a minimum of 6.73 mg/l in River in November to a maximum of 808.956 mg/l in *Avicennia* from February to May and *Rhizophora* in November. The sulphate, showed the highest peak in: mixed stands (31.55 mg/l) in February) and River (39.82 mg/l in July). The seasonal variations of the sulphate values among sites showed higher values in *Rhizophora* and Mixed stands on the dry season. The variation of the content of sulphate in *Avicennia* and Volta river did not relate to the seasonnal patterns (Figure 36).

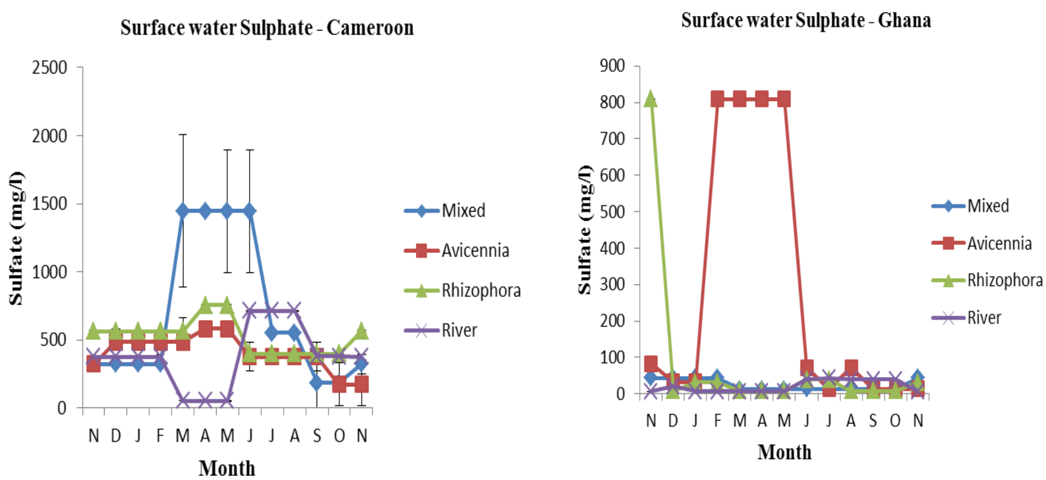


Figure 36: Seasonal changes in surface water sulphate concentrations in mangrove stands in Cameroon and Ghana.

Phosphate

The concentration of phosphates in Cameroonian mangroves varied from 0.05 to 0.256 mg/l. The maximum value was observed in *Rhizophora* in June and July and the minimum in the mixed stand in September to October and in *Rhizophora* from November to March (Figure 37). The Phosphate showed the highest peak in: *Avicennia* (0.083 mg/l) from November to January), mixed stands (0.083 mg/l) from November to February) nd0.083 mg/l River (July). The seasonal variations of the Phosphate values among sites were showed higher values in in *Rhizophora* and River in the rainy season.

The concentration of phosphates in Ghanaian mangroves fluctuated among the sites as well as between the seasons (Figure 37). The phosphate values varied from 0.002 to 0.206 mg/l. The maximum value was observed in *Rhizophora* in June and July and the minimum in the *Avicennia* stand in December. The Phosphate showed low values for the rest of the year.

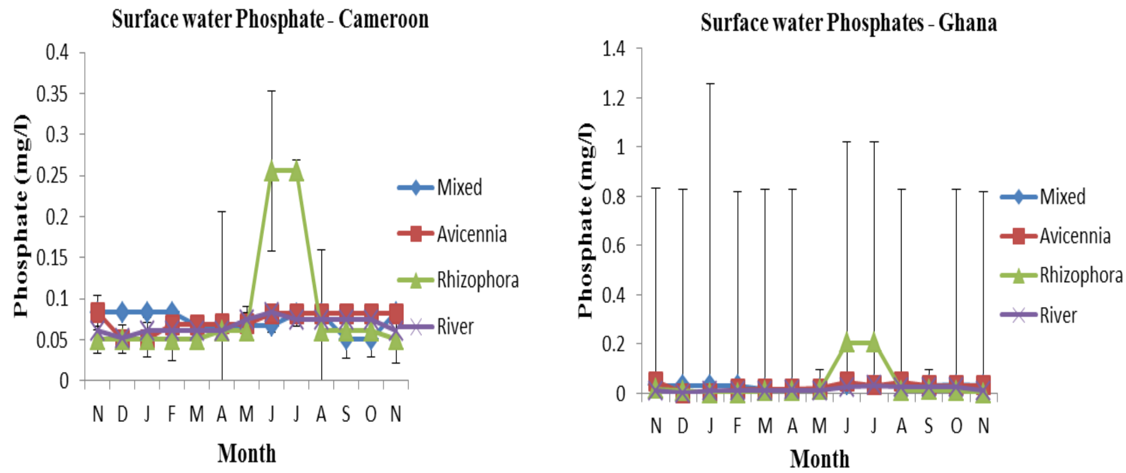


Figure 37: Seasonnal variations in surface water phosphate concentrations in mangrove stands in Cameroon and Ghana.

Nitrate

Nitrate concentrations in Cameroon also fluctuated between the sites as well as the seasons (Figure38). The nitrate values varied from 1.48 to 114.38 mg/l. The maximum values were observed in March, April, Mayon the River and the minimum values were recorded on April and March in the *Avicennia* stand.. Mixed stands had a peak of 13.38 mg/l from March to June and River from November to January. The variation of nitrate content in mixed stand and River did not show any seasonal patterns.

In Ghana, nitrate concentrations fluctuated among the sites as well as between the seasons (Figure38). The nitrate values varied from 0.047 to 0.595 mg/l. The maximum and minimum values were observed in the *Avicennia* mixed stands had highest nitrate peak (0.233 mg/l) in June, August and October) and River (December). The seasonal variations of the Nitrate values among sites showed higher values in the dry season and low values in the rainy season.

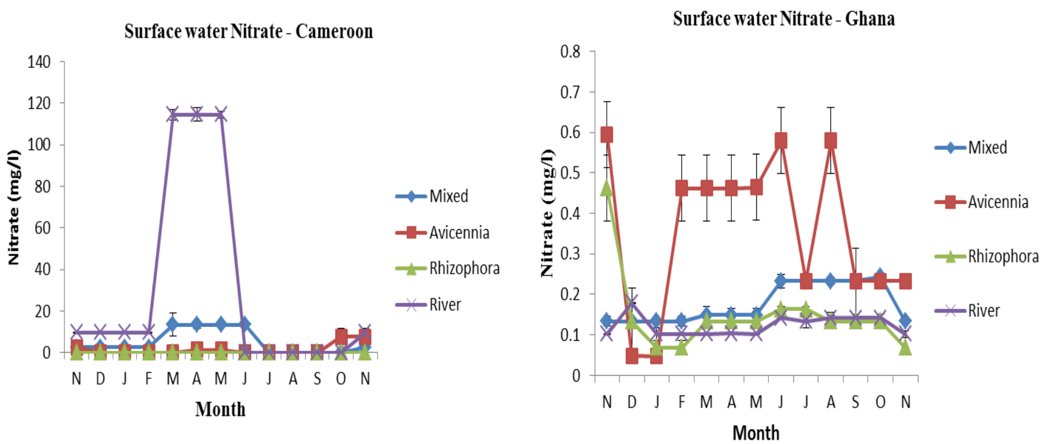
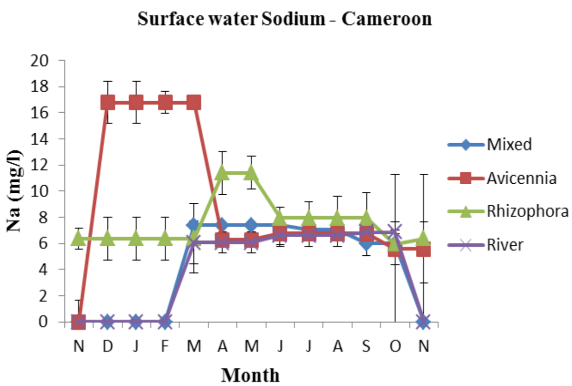


Figure 38: Seasonal changes in surface water nitrate concentrations in mangrove stands in Cameroon and Ghana.

Sodium

In Cameoon, sodium ion concentrations varied from 6 to 16.78 mg/l. The maximum value was recorded in the *Avicennia* from December to March and the minimum value was observed in the mixed stand in December – February and November (Figure 39). The Sodium, showed the highest peak in , *Rhizophora* (11.38 mg/l in April and May), mixed stands (7.37 mg/l from March to June) and River (6.86 mg/l in October). The seasonal variations of the Sodium values among sites showed higher values in the dry season. The fluctuation of Sodium content in *Rhizophora* Mixed stand and River did not depend on the seasonal patterns.

In Ghana, sodium ion concentrations fluctuated among the sites as well as between the seasons (Figure 39). The Sodium values varied from 111.4 to 2670 mg/l. The maximum value was recorded in the *Avicennia* in June and August and the minimum value was observed in River in December. The Sodium showed the highest peak in: *Rhizophora* (958 mg/l) in November), Mixed stands (356 mg/l in October) and River (354 mg/l June, August and October). The seasonal variations of the Sodium values among sites showed higher values in *Rhizophora* stands on the dry season and in *Avicennia*, mixed Stands and River on the rainy season.



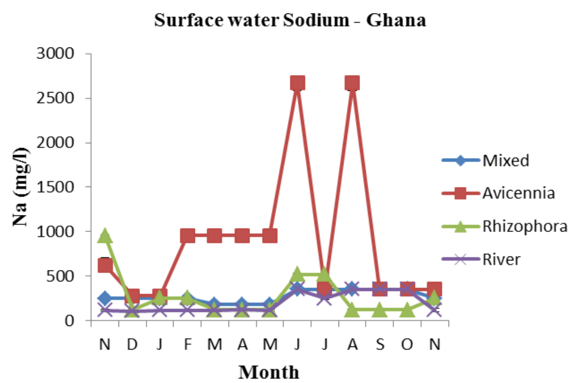


Figure 39: Seasonal changes in surface water sodium concentrations in mangrove stands in Cameroon and Ghana.

Potassium

In Cameroon, the levels of potassium in surface water fluctuated between the sites as well as the seasons. The potassium values varied from 1.19 to 46.6 mg/l. The maximum values were observed in the River (September and October) and *Avicennia* (June to September). The minimum value was recorded in the *Rhizophora* stand, in April and May (Figure 40). The Potassium showed the highest peak in: *Rhizophora* (28.4 mg/l from June to September), mixed stands (38 mg/l in July and August) and River (38 mg/l in September and October). The seasonal variations of the potassium values among sites were showed higher values in all the sites sampled in the rainy season and relatively low values in the dry season.

The levels of potassium in Ghanaian surface waters also fluctuated among the sites and in the seasons. Potassium levels varied from 1.2 to 209 mg/l. The maximum and minimum values were observed in the River respectively on June, July to August and November, January to March (Figure 40). The Potassium showed the maximum peak in: *Avicennia* (June and September), *Rhizophora* (64 mg/l) in January and February), mixed stands (208 mg/l from June to October) and River (209 mg/l June, August to October). The seasonal variations of the Potassium values among sites showed higher values in *Rhizophora* in the dry season and in mixed stand and River in the rainy season.

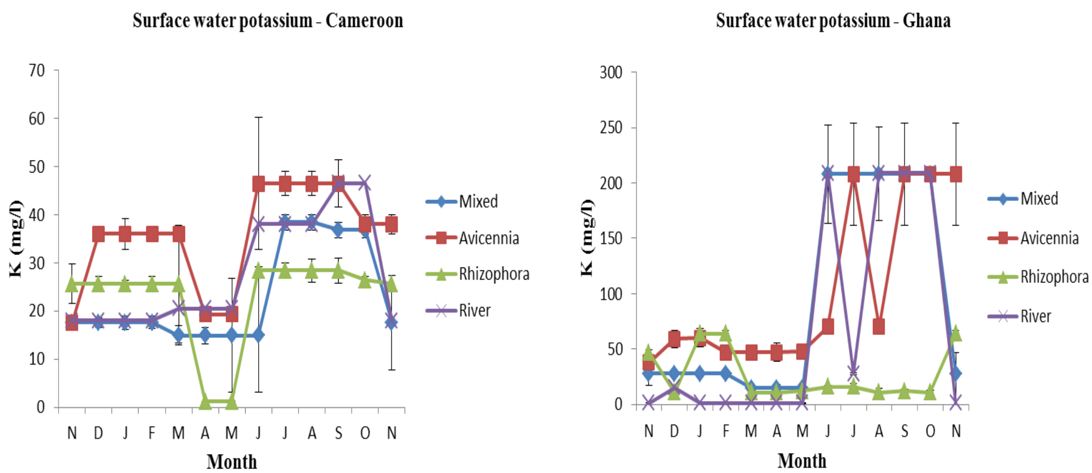


Figure 40: Seasonal changes in surface water potassium concentrations in mangrove stands in Cameroon and Ghana.

Chloride

In Cameroonian surface waters, chloride ion concentrations ranged from a minimum of 23.3 mg/l from March to April in the River and a maximum of 691.28 mg/l from October to November in the *Avicennia* stand. The Chloride showed the highest peak in: *Rhizophora* (193.2

mg/l from November to March). Mixed stands (226.88 mg/l from September to October) and River (109.9 mg/l in September and October). The seasonal variations of the Chloride values among sites showed higher values in mixed stands and River in the rainy season. In the *Rhizophor*a stand the high values were recorded in the dry season and in both seasons for *Avicennia* (Figure 41).

In Ghanaian surface waters, chloride ion concentrations ranged from a minimum of 1.5 mg/l in November in *Rhizophora* and from February in *Avicennia* stand to a maximum of 1699.43 mg/l in June and August in *Avicennia*. The Chloride alsoshowed the high peak in: *Rhizophora* (398.99 mg/l in June and July), mixed stands (1699.43 mg/l in June and August) and River (999.69 mg/l in December). The seasonal variations of the Chloride values among sites showed higher values in *Rhizophora* in the dry season and in mixed and River in the rainy season (Figure 41).

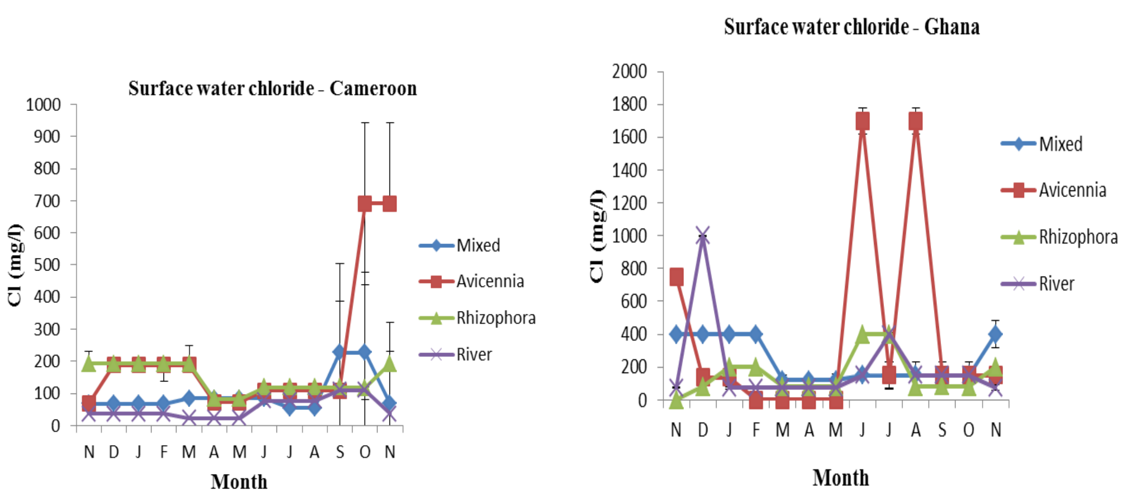


Figure 41: Surface water chloride concentrations in mangrove stands in Cameroon and Ghana.

It were observed that, no significant differences existed between mixed and *Avicennia* stands in Ghana for T°, P, K and Cl (P> 0.05), while the other paramaters presented significant differences (P<0.05). For mixed and *Rhizophora* stands in Ghana, only Cond, TSS, DO, Turb and K showed significant differences (P<0.05). Between mixed stands in Ghana and Cameroon, significant differences (P<0.05) were only found for T°, Cond, TDS, Sal, N, DO, DBO, P, and K. For *Avicennia* (Cameroon) and mixed (Ghana), significant differences (P<0.05)., were found only for T°, E.C and TDS, Sal, DO, BOD, K, P and Nand *Rhizophora* in Cameroon and mixed stand in Ghana, no significant difference were found for Alk, Sul, and Cl. Significant Changes in soil water characteristics in both countries were therefore observed at all sites.

4.3.3 Physico-chemical parameters in porewater

pH

The pH values in porewater for Cameroonian mangroves ranged from a minimum of 6.68 in March, April and May in the *Rhizophora* stand and a maximum of 7.43 from June to August in the mixed stand and River (September- November) **(**Figure 42**)**. The pH showed high peak in: *Avicennia* (7.40) in October, November, December, January and February, *Rhizophora* (7.16) from June to August, mixed stands (7.43) from June to August and River (7.39) in November and February. The seasonal variations of the mean pH values among sites showed higher values in *Rhizophora* and mixed stands in the rainy season and *Avicennia* and River in the dry season.

The mean pH values in porewater for Ghanaian mangroves ranged from a minimum of 4.81 inMarch in the mixed stand to a maximum of 7.2 from November to December in the River **(**Figure 42**)**. The pH, was just below the neutral in: *Avicennia* (6.54) in October, November, December, January and February, *Rhizophora* (6.40) on July, August, September and October, mixed stands (6.54) from July to October and River (7.2) in November and December. The seasonal variations of the mean pH values among sites showed higher values in *Rhizophora* and mixed stands on the rainy season, River in the dry season and *Avicennia* in both seasons.

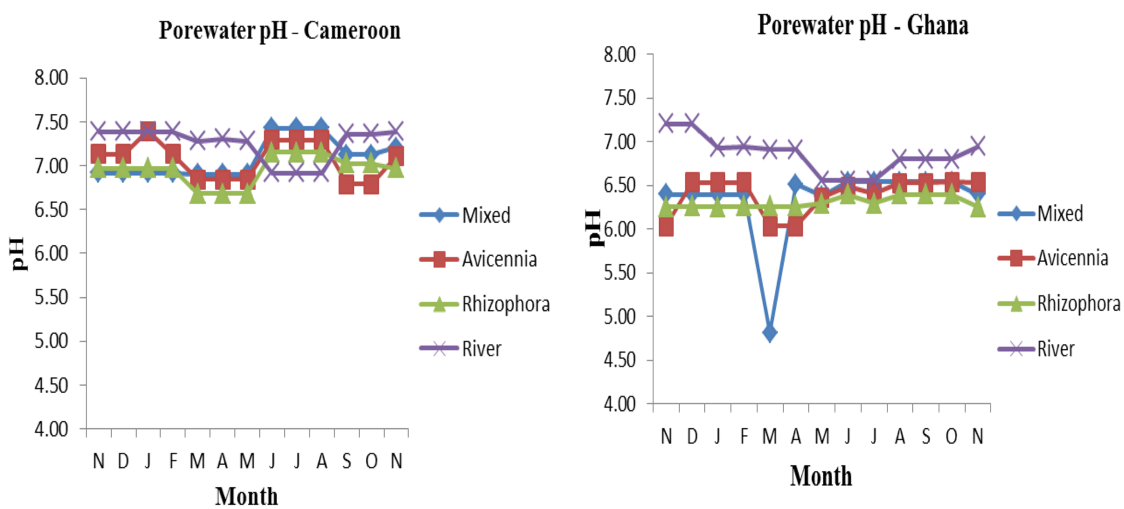


Figure 42: Seasonal changes in Porewater pH in mangrove stands in Cameroon and Ghana.

Temperature

The mean water temperature value during the sampling period in different seasons ranged, from 22.04±0.75 to 26.03±0.33ºC (Figure 43). The maximum temperature was recorded from November to December in the mixed stand and the minimum was observed from June to August in the *Avicennia* stand. Mean water temperature showed the highest peak in: mixed (24.88± 0.91 ºC) from November to February. *Rhizophora* (25.25±0.91 ºC) from November to February and River (25.7 ºC) from November to February. The seasonal variations of the mean temperature values among sites showed higher values in dry season in all the studied sites.

The mean water temperature value during the sampling period in different seasons fluctuated between 20.74± 13.79 and 29.9 ºC (Figure 43).

The maximum temperature was recorded from August to October in the River and the minimum was observed on March in the mixed stand. Mean water temperature showed the highest peak in: *Avicennia* (29.03± 0.10 ºC) in March, mixed (28.70±2.27 ºC) on May, *Rhizophora* (28.85±0.31 ºC) on June to August and River (29.0 ºC) 0n September to October. The seasonal variations of the mean Temperature values among sites showed higher values in *Rhizophora* , mixed and Volta river in the rainy season and *Avicennia* in the dry season (Figure 43).

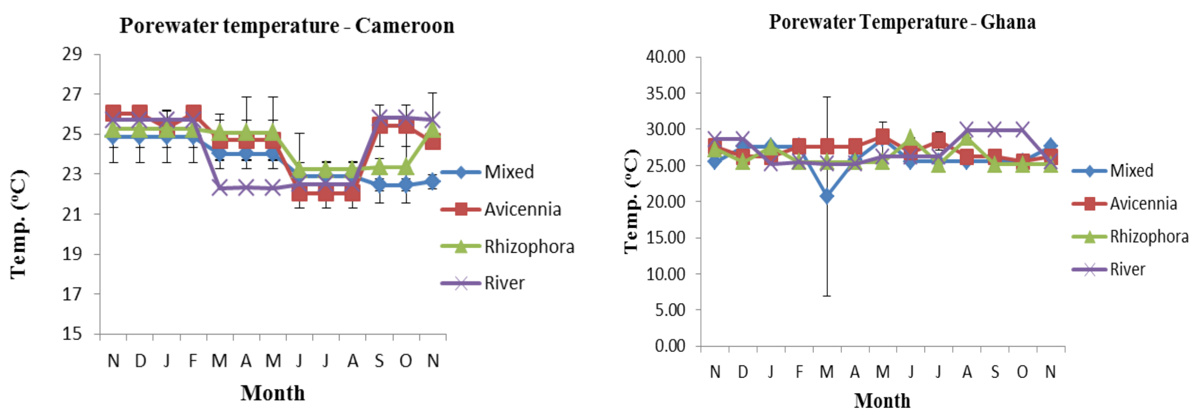


Figure 43: Seasonal variations in porewater temperature in mangrove stands in Cameroon and Ghana.

Electrical conductivity (EC)

The mean EC values for porewater in Cameroon during the sampling period fluctuated between 27.75± 1.22 and 3672.50 ± 958.88 ms/cm (Figure 44). The maximum EC was observed from March to May the mixed stand and the minimum was recorded in March to May in the *Avicennia* stand. Mean EC values showed the highest peak in: *Avicennia* (1680.75 ± 379.82 ms/cm) November, December and February, , *Rhizophora* (2642±193.31ms/cm) in September to October and River (1310 ms/cm) from March to May. The seasonal variations of the mean EC values among sites showed higher values in *Avicennia* in the dry season and River in the rainy season and *Avicennia*, Mixed *Rhizophora* and River in the rainy season.

In Ghana, mean EC value for porewater during the sampling period oscillated between 86.75 ± 76.15 and 10622.50 ± 3347.27 µs/cm (Figure 44). The maximum EC was observed in November, March and April in the *Avicennia* stand and the minimum was recorded in May in the mixed stand. Mean EC values showed the highest peak in: *Avicennia* (10622.50 ± 3347.27 µs/cm) November to March and April, mixed (2975.75±1649.51 µs/cm) from November to February, *Rhizophora* (4345±685.78 µs/cm) on May and River (609 µs/cm) from May to July (Figure 44). The seasonal variations of the mean EC values among sites showed higher values in *Rhizophora* and River in the rainy season and *Avicennia* and mixed in the dry season.

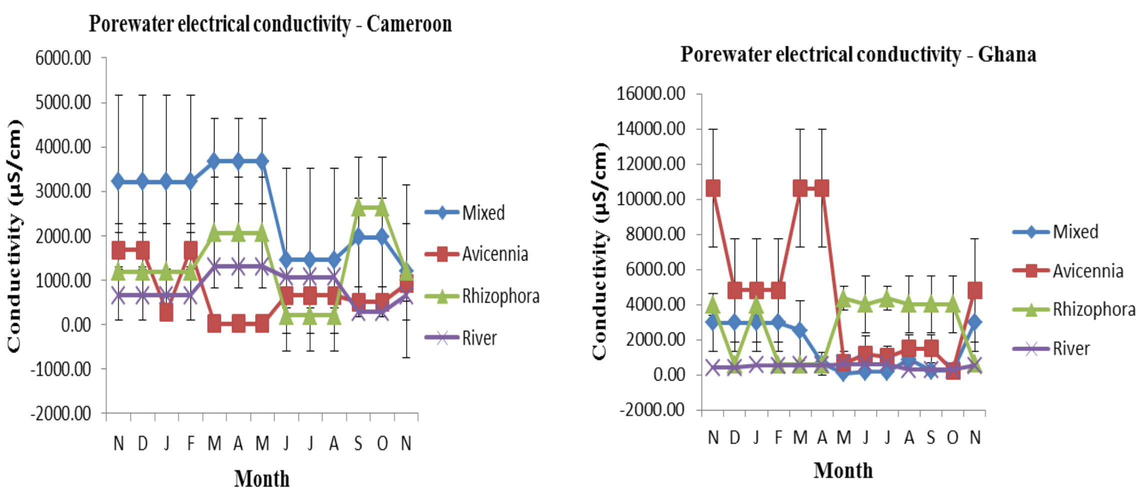


Figure 44: Monthly variations in Porewater electrical conductivity in mangrove stands in Cameroon and Ghana.

Total dissolved solids (TDS)

In Cameroon, mean porewater TDS values during the sampling period varied from 28.20 ±1.30 to 2807.50 ± 425.31 g/l (Figure 45). The maximum TDS was recorded from March to May in the *Rhizophora* stand and the minimum was observedfrom March to May in the *Avicennia* stand. Average TDS values presented the high values in: *Avicennia* (1737.75± 363.46 g/l) on November, December and February, mixed (2052.82±2095.28 g/l) from June to August and river (2180 mg/l) from March to May. The seasonal variations of the mean TSS values among sites presented higher values mainly in the rainy season for *Rhizophora*, mixed stands and River all the studied sites and in the dry season for *Avicennia*.

Mean porewater TDS values for Ghana during the sampling period were varied from 0.22 to 5875 ± 4830.67 mg/l (Figure 45). The maximum TDS was observed from in August and September in the *Avicennia* stand and the minimum was recorded on February in the River. Mean TDS values presented the highest peak in: mixed (1275.50±710.36 mg/l) from November to February, *Rhizophora* (2069.25±329.34mg/l) from May to October and River (296 mg/l) from May to July. The seasonal variations of the mean TDS values among sites presented higher values in *Rhizophora*, *Avicennia* and Volta river in the rainy season and Mixed in the dry season.

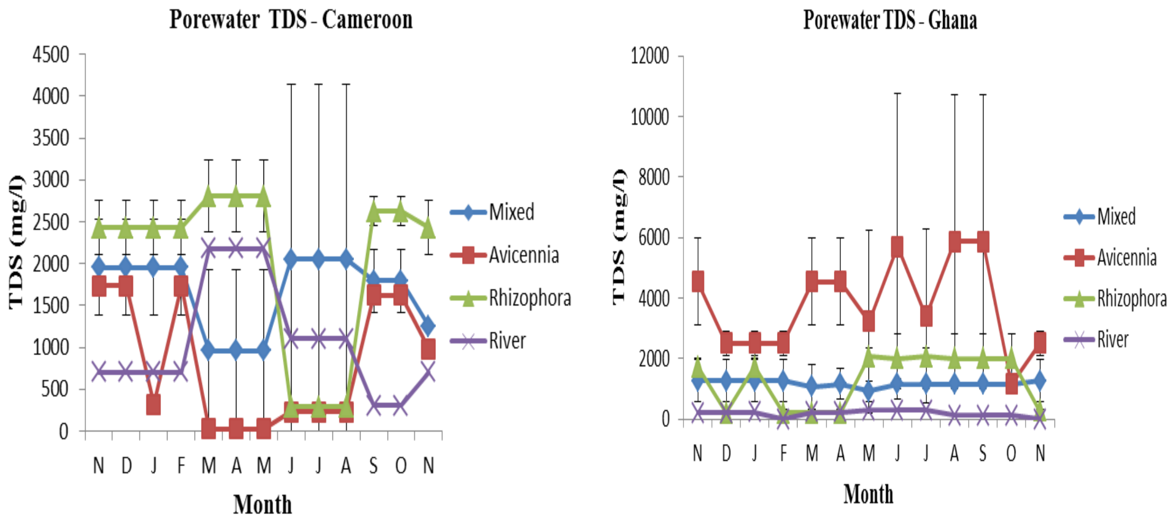


Figure 45: Seasonal variations porewater TDS in mangrove stands in Cameroon and Ghana.

Total Suspended Solid (TSS)

In Cameroon, mean TSS values during the sampling period were varied from 20.75 ± 6.24 to 68.50±20.49 g/l (Figure 46). The maximum EC was observed in June in the mixed stand and the minimum was recorded from November to April in the *Rhizophora* stand. The mean TSS values presented the high values in: *Avicennia* (68 ± 21.04 g/l) in October, *Rhizophora* (49.25±0.96 g/l) in June, August to October and River (51 g/l) in Nov, June to October. The seasonal variations of the mean TSSvalues among sites were presented, higher values in mixed mainly in the dry season and Rhizophora, Avicennia *and* River mainly in the rainy season.

The mean TSS values in Ghana for porewater varied from 15.75± 0.96 to 63.50 ± 20.49 mg/l (Figure 46). The maximum TSS was recorded from June to July in the mixedstand and the minimum was observed from November to April in the *Rhizophora*.Mean TSS values presented high values in: *Avicennia* (63 ± 21.04 mg/l) in October, mixed (63.50 ± 20.49 mg/l) from June to July, *Rhizophora* (44.25 ±0.96 mg/l) from August to October and River (46 mg/l) in November and June to October. The seasonal variations of the mean TSS values among sites were presented higher values mainly in the rainy season for all the studied sites.

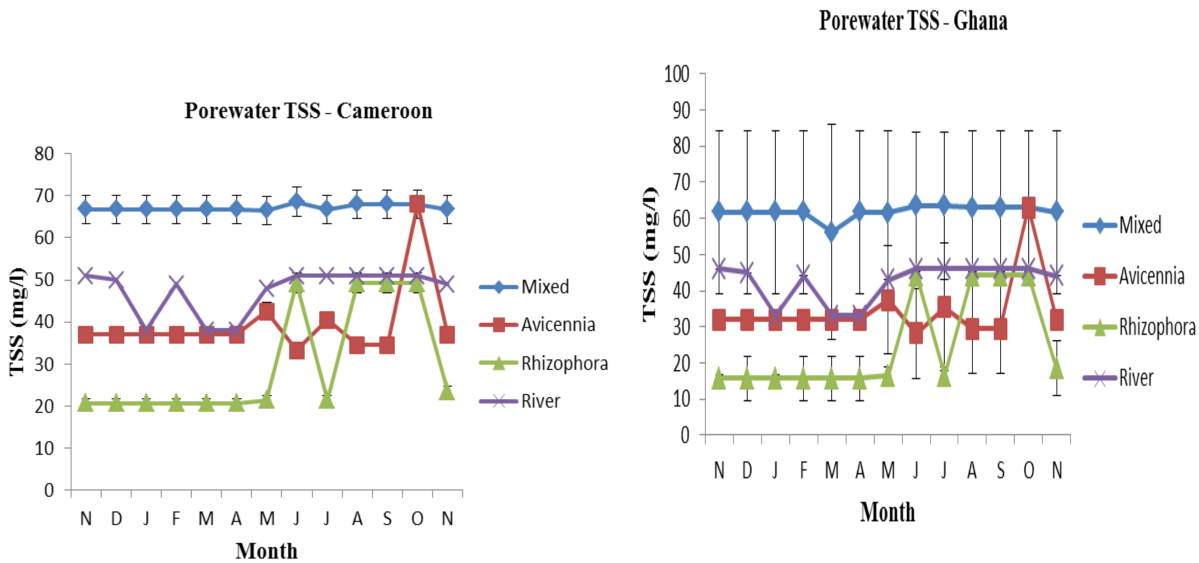


Figure 46: Seasonal variations in porewater TSS in mangrove stands in Cameroon and Ghana.

Turbidity

The mean Turbidity value for Cameroon during the sampling period varied from 22.72 ±2.22 to 118±13.13 NTU (Figure 47). The maximum Turbidity was recorded in January in the mixedstand, and the minimum was observed on December, February to April in the *Rhizophora* stand. The mean Turbidity values presented the high values in: *Avicennia* (116 ± 37.47 NTU) in October, , *Rhizophora* (56 ±2.71 NTU) in June, April to October and River (62 NTU) in November, February and May. The seasonal variations of the mean Turbidity values among sites were presented, higher values in *Avicennia* and *Rhizophora* stands in the rainy season and mixed stand and River in the dry season.

Mean porewater Turbidity values for Ghana during the sampling period varied from 18± 2.45 to 107.25 ± 11.70 NTU (Figure 47). The maximum Turbidity was recorded on November. December andJanuary in the Mixedstand and the minimum was observed in November in the *Rhizophora*. Mean Turbidity values presented the high values in: *Avicennia* (111 ± 37.47 NTU) in October. *Rhizophora* (51 ±2.71 NTU) in June, August to October and River (57 NTU) in, November, February and May. The seasonal variations of the mean turbidity values among sites presented, higher values in *Avicennia* and *Rhizophora* stands in the rainy season and mixed stand in the dry season.

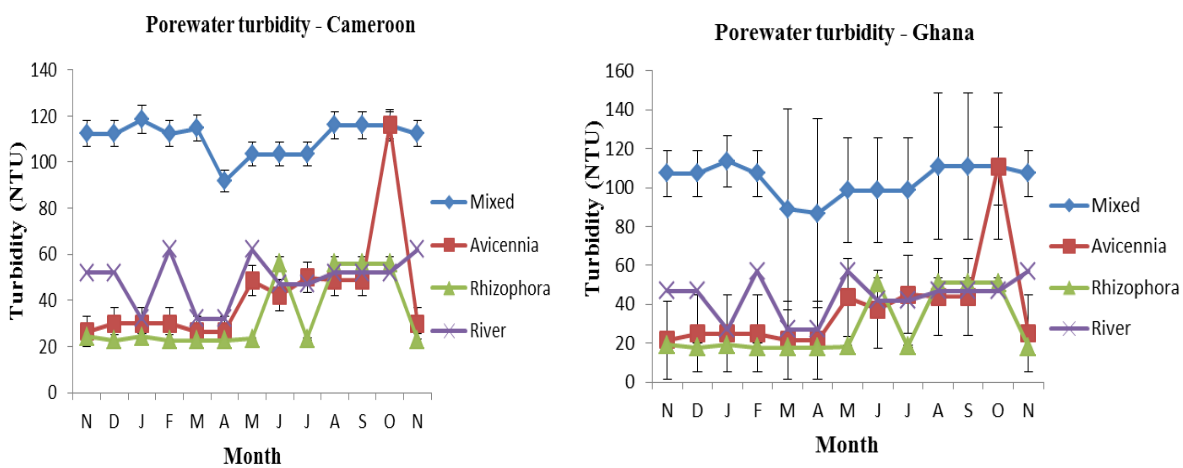


Figure 47: Seasonal changes in porewater turbidity in mangrove stands in Cameroon and Ghana.

Alkalinity

In Cameroon, the mean Alkalinity values during the sampling period varied from 77.78 to 1834± 444.33 mg/l (Figure 48). The maximum Alkalinity was observed from November to February in the mixed stand and the minimum was observed from September to October in the

River. Mean Alkalinity values showed the high values in: *Avicennia* (361.43± 208.32 mg/l) in November to February. *Rhizophora* (767.08± 228.80 mg/l) from September to October and River (1583.78mg/l) from March to May. The seasonal variations of the mean Alkalinity values among sites were presented higher values mainly in the rainy season for *Rhizophora* and River and in the dry season for *Avicennia* and mixed stands.

In Ghana, mean Alkalinity values varied from 39.01 to 307.07±191.78 mg/l (Figure 48). The maximum Alkalinity was observed from June to October in the mixed stand, and the minimum was recorded from August to October in the River. Mean Alkalinity values showed high values in: *Avicennia* (287.11 ± 236.32 mg/l) on May, June and September. *Rhizophora* (304.15 ±27.52 mg/l) in June, August to October and River (52.08mg/l) in July. The seasonal variations of the mean Alkalinity values among sites presented higher values in the rainy season for all the studied sites.

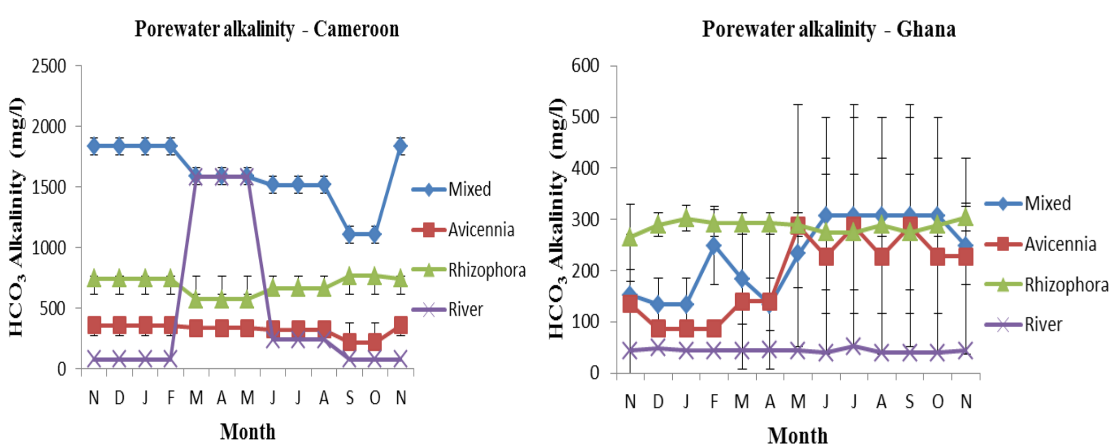


Figure 48: Seasonal variations in porewater alkalinity in mangrove stands in Cameroon and Ghana.

Salinity

In Cameroon, mean porewater salinity values during the sampling period varied from 3.6 to 28.03± 6.51 ‰ (Figure 49). The maximum mean salinity was observed From June to August in the mixed stand, and the minimum was observed from March to May in the River.Mean salinity values showed the high values in: *Avicennia* (17±0.80 ‰) from March to May,.*Rhizophora* (17.43± 3.73 ‰) from June to August and River (6.1 ‰) From June to August. The seasonal variations of the mean salinity values among sites showed higher values in the rainy season for all the studied sites.

In Ghana, mean porewater salinity values varied from 0.13 to 20.95± 20.84 ‰ (Figure 49). The maximum mean salinity was observed in December in the *Avicennia* stand and the minimum was observed from November to December in the River. Mean salinity values showed the stated values in: mixed (1.48 ± 0.88 ‰) from November to February, *Rhizophora* (3.30 ± 0.88 ‰) on November 2009 and River (0.3 ‰) from March to October. The seasonal variations of the mean salinity values among sites showed higher values in the dry season for all the mangrove stands. The variation of the salinity in the River did not follow seasonal patterns.

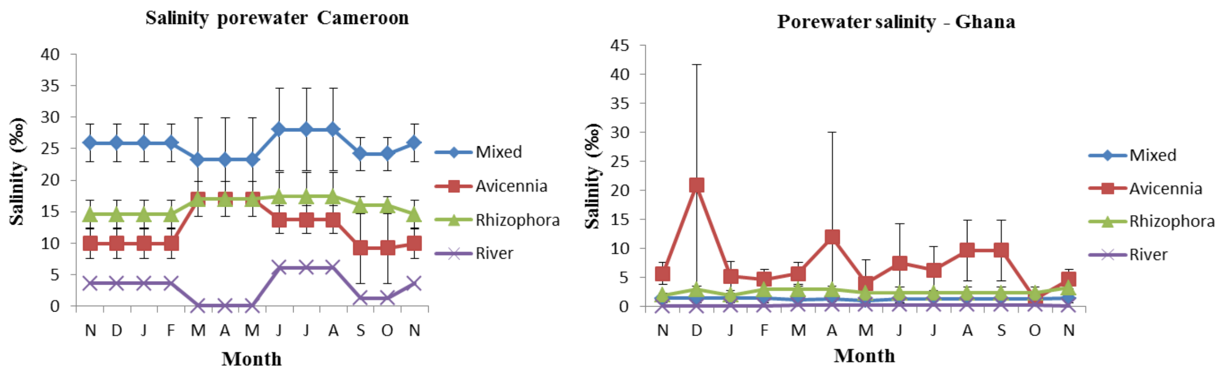


Figure 49: Porewater salinity in mangrove stands in Cameroon and Ghana.

A relatively strong relationship were established between soil water salinity, air temperature, rainfall and litterfall in both countries. Multiple regression analysis selected average rainfall, average air temperature and soil water salinity as independent variables which were important in explaining temporal litterfall variability over the study period. The equation that best describes litterfall variability in both countries is: Y= 232 –5.07 (X1) - 0.197 (X2) + 5.95 (X3) ; $R^2 = 0.66$, where X1 is Air temperature ($p < 0.001$) and X2 is rainfall ($p < 0.001$) and X3 is soil water salinity.

Dissolved oxygen (DO)

Mean DO concentrations in porewater from Cameroon during the sampling period, varied from 7.52 to 10.5 mg/l (Figure 50). The maximum mean value was recorded from March to April in the *Rhizophora* stand the minimum in November in the *Avicennia* stand. The mean DO values showed the highest peak in: *Avicennia* (9.09 mg/l) from June to September. Mixed (9.92 mg/l) from December to April, *Rhizophora* (10.5 mg/l) from March to April and River (9.92 mg/l) on December. The seasonal variations of the mean DO values among sites were shown higher values mainly in the dry season in mixed stand and River in the rainy season mainly in the *Rhizophora* and *Avicennia* stands.

Mean DO concentrations in porewater from Ghana during the sampling period varied from 2.52 to 5.53 mg/l (Figure 50). The maximum mean value was recorded on November, June to July in the *Rhizophora* stand the minimum in November in the *Avicennia* stand.The mean DO values showed the highest peak in: *Avicennia* (4.86 mg/l) in October. Mixed (4.97 mg/l) on May, and River (4.92 mg/l) on December. The seasonal variations of the mean DO values among sites were showed higher values in the dry season in *Avicennia* and River in the rainy season in the mixed stand. The highest values were shown in both seasons in the *Rhizophora* stand.

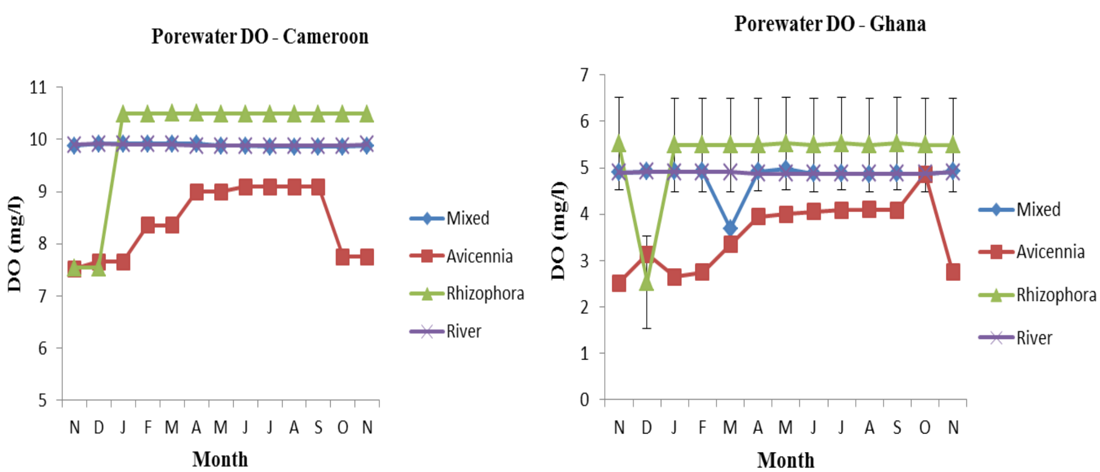


Figure 50: Porewater DO in mangrove stands in Cameroon and Ghana.

Biological Oxygen Demand (BOD)

Mean BOD values for Cameroon porewater during the sampling period varied from 5.81 to 7.05mg/l (Figure 51). The maximum BOD mean value was recorded from March to April in *Rhizophora* and *Avicennia* stands. The mean BOD showed the following values in: Mixed (7.04

mg/l) from March to July and River (7.04 mg/l) from July to October. The seasonal variations of the mean BOD values among sites were shown higher values mainly in the rainy season for all the studied sites.

Mean BOD values for Ghana porewater during the sampling period varied from 0.98 to 2.10 mg/l (Figure 51). The maximum BOD mean value was recorded in May and July to October in *Rhizophora* and *Avicennia* stands. Mixed (2.04 mg/l) in June to July and and River (2.04 mg/l) from April to October. The seasonal variations of the mean BOD values among sites showed higher values in the rainy season in *Avicennia* and mixed. The *Rhizophora* and River did not show any seasonal patterns.

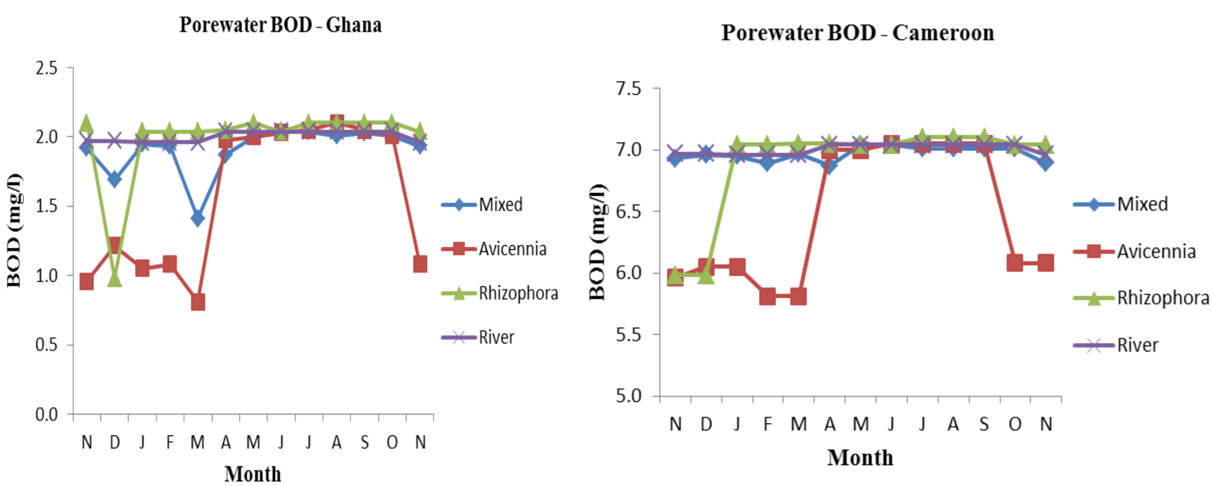


Figure 51: Seasonal changes in porewater BOD in mangrove stands in Cameroon and Ghana.

Sulphate

In Cameroon, mean sulphate concentrations recorded during the data collection period, fluctuated from 53.18 to 917.70 ± 205.30 mg/l (Figure 52). The maximum mean Sulphate value was observed in July to August in the *Rhizophora* stand and the minimum was observed from March to May in the River. Mean Sulphate values showed the high values in: *Avicennia* (808.59 ± 81.59 mg/l) in June to August, mixed (496.18±167.58 mg/l) in September, , and River (713 mg/l) in July to August. The seasonal variations of the mean Sulphate values among sites showed higher values, in the rainy season for all the studied sites.

In Ghana, mean sulphate concentrations recorded in porewater during the data collection period fluctuated from 6.73 to178.33 ± 66.89 mg/l (Figure 52). The maximum mean Sulphate value was observed on January in the *Rhizophora* stand and the minimum was observed on November and January to May in the River. Mean Sulphate values showed other values in: *Avicennia* (154 ± 102.91mg/l) in March and April, mixed (125± 33.20 mg/l) in December, January and April and river (43.52 mg/l) in July. The seasonal variations of the mean Sulphate values among sites presented higher values in the dry season for *Rhizophora*, *avicennia* and mixed stand and river in the rainy season.

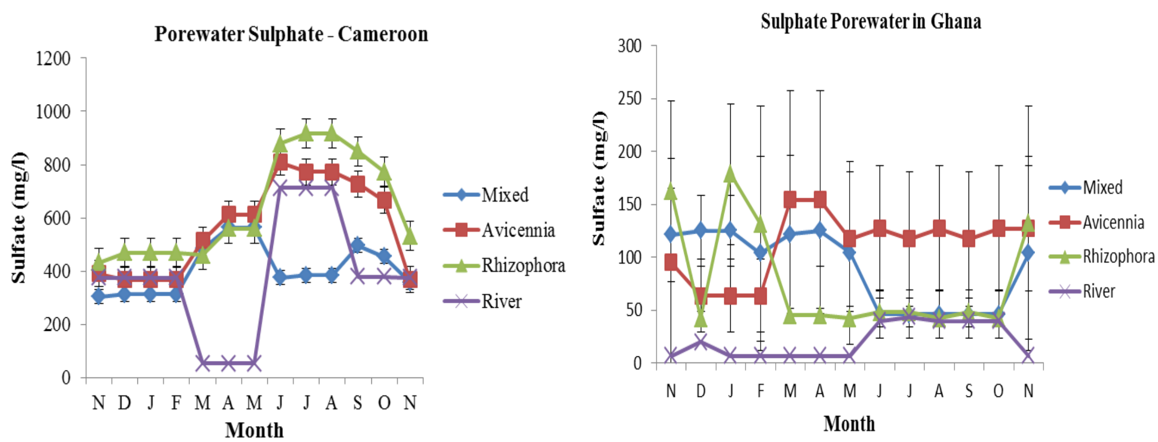


Figure 52: Seasonal changes in Porewater sulphate concentration in mangrove stands in Cameroon and Ghana.

Phosphate

Mean porewater phosphate concentrations in Cameroon during the data collection period varied from 0.052 to 0.23 ± 0.14 mg/l (Figure 53). The maximum mean phosphate value was observed in November 2009 and January in the *Rhizophora* stand and the minimum was observed in December in the Wouri river. Mean phosphate values showed other values in: *Avicennia* (0.12 ± 0.08 mg/l) in November, June, August and October; in Mixed (0.21±0.06 mg/l) from July to October, and Volta river (0.083mg/l) in July. The seasonal variations of the mean phosphate values among sites were presented, higher values mainly in the rainy season for mixed *Avicennia* and Volta river and in the dry season for *Rhizophora*.

In Ghana, mean porewater phosphate concentrations recorded during the data collection period, varied from 0.002 to 0.20± 0.02 mg/l (Figure 53). The maximum mean phosphate value was observed in November in the *Rhizophora* stand, and the minimum was observed on December in the River. Mean phosphate values shown elsewhere were in: *Avicennia* (0.07± 0.08 mg/l) on November 2009, May, July, September to October, mixed (0.16± 0.04 mg/l) from June to September, and River (0.024 mg/l) from August to October. The seasonal variations of the mean phosphate values among sites presented higher values mainly in the rainy season for *Avicennia* and mixed stand and River, *Rhizophora* in the dry season.

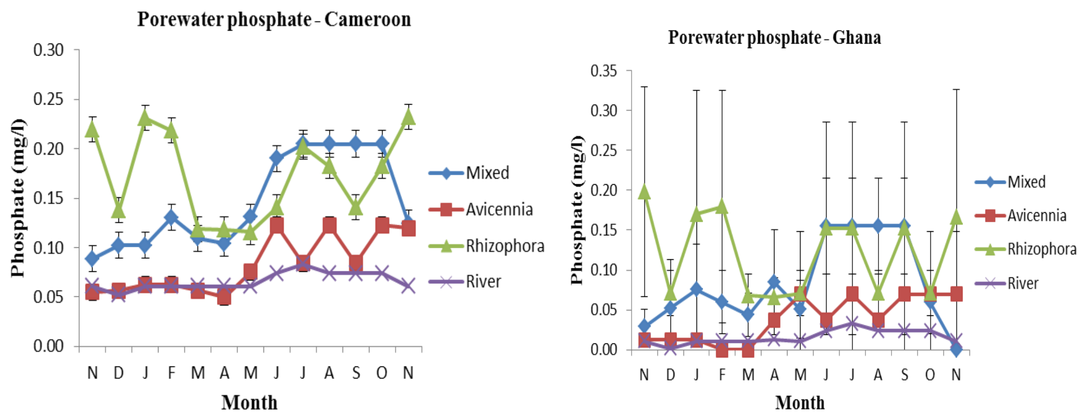


Figure 53: Seasonal changes in porewater phosphate concentration in mangrove stands in Cameroon and Ghana.

Nitrate

Mean nitrate concentrations for Cameroon porewater during the data collection period, fluctuated between 0.16 ± 0.32 to 114.38 mg/l (Figure 54). The maximum mean nitrate value was observed from March to May in the River and the minimum was recorded in October in the mixed stands. Mean nitrate values showed other values in: *Avicennia* (1.38 ± 1.68 mg/l) from December to February, Mixed (4.93± 9.87 mg/l) from June to August, *Rhizophora* (4.46± 8.91 mg/l) from July to September. The seasonal variations of the mean nitrate values among sites presented higher values mainly in the rainy season for mixed, *Rhizophor*a and River and in the dry season for *Avicennia*.

The average nitrate concentrations for porewater in Ghana during the data collection period varied from 0.102 to 2.18± 1.84 mg/l (Figure 54). The maximum mean nitrate value was recorded on November in the mixedstand and the minimum was observed in November, January to March and May in the River. The mean nitrate values elsewhere wereshowed the highest peak in: *Avicennia* (0.87± 0.17 mg/l) on April. June and August, mixed (2.18± 1.84 mg/l) in November, *Rhizophora* (0.97± 0.59 mg/l) on February and River (0.179 mg/l) on December, The seasonal variations of the mean nitrate values among sites presented, higher values mainly in the rainy season for, *Avicennia* stand and for River, *Rhizophora* and mixed in the dry season.

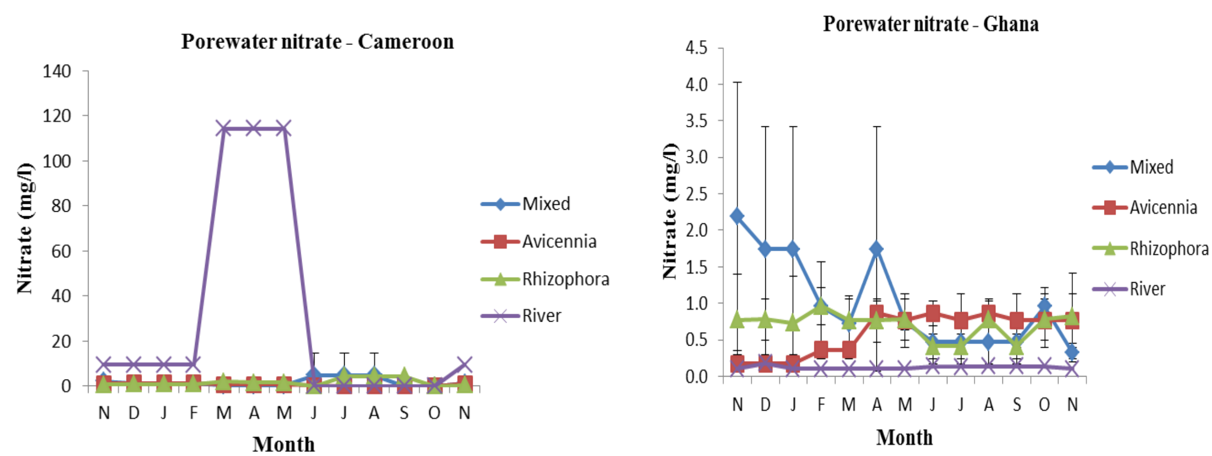


Figure 54: Variation in porewater nitrate concentration in mangrove stands in Cameroon and Ghana.

Sodium

Mean porewater sodium ion concentrations for Cameroon during the data collection period, varied from 1.75± 0.49 to 54.31± 18.94 mg/l (Figure 55). The maximum mean Sodium value was observed from April to June in the mixed stand and the minimum was recorded on November 2009 in the *Avicennia* stands. From November 2008 to February 2009, no values of

Sodium were observed in the *Avicennia* stand. Mean Sodium values elsewhere were in: *Avicennia* (9.72± 4.67mg/l) in September, Mixed (54.31± 88.94 mg/l) from April to June, *Rhizophora* (13.31±7.06 mg/l) from December to February and River (6.86mg/l) from September to October. The seasonal variations of the mean Sodium values among sites were presented higher values mainly in the rainy season for *Avicennia*, mixed, and River and in the dry season for *Rhizophora.*

Mean porewater sodium ion concentrations for Ghana during the sampling period, oscillated from 111.4 to 4235 ± 1182.50 mg/l (Figure 55). The maximum mean Sodium value was recorded on February to March in the *Avicennia* stand and the minimum was observed on December in the River. The mean Sodium values showed the highest peak in: *Avicennia* (4235 ± 1182.50 mg/l) in February to March, mixed (3449.50± 3176 mg/l) on May, *Rhizophora* (2267.50 ± 1032.84 mg/l) in June, July and September and River (354 mg/l) in June, August to September. The seasonal variations of the mean Sodium values among sites showed higher values in the rainy season, for *Rhizophora* and River and *Avicennia* mixed in the dry season.

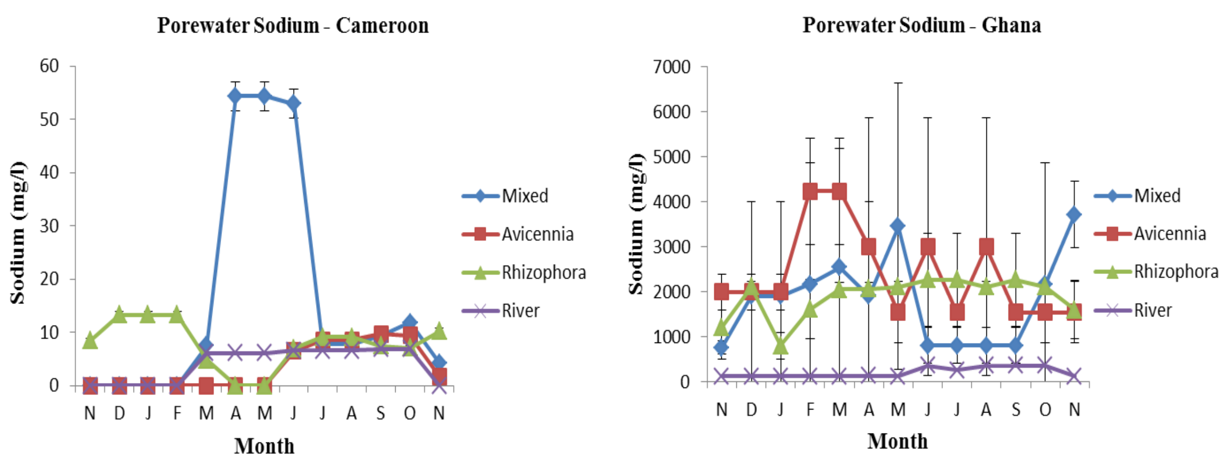


Figure 55: Seasonal changes in porewater sodium concentration in mangrove stands in Cameroon and Ghana.

Potassium

Mean potassium ion concentrations for Cameroon recorded during the sampling period varied from 20.53 to 112.25 ± 22.85 mg/l (Figure 56). The maximum mean Potassium value was recorded from July to August in the *Rhizophora* stand, and the minimum was recorded March to May in the River. Mean Potassium values elsewhere were in: *Avicennia* (66.05± 7.04 mg/l) from July to August. Mixed (57.15± 17.16 mg/l) from July to August, and River (20.53mg/l) from September to October. The seasonal variations of the mean Potassium values among sites indicated high values mainly in the rainy season for all the studied sites.

In Ghana, mean potassium ion concentrations recorded during the sampling period, varied from 1.2 to 517.50 ± 177.27 mg/l (Figure 56). The maximum mean Potassium value was recorded on February to March in the *Avicennia* stand, and the minimum was observed on November and January to March in the River. The mean Potassium values showed the highest peak in: *Avicennia* (517.50 ± 177.27 mg/l) on February to March. Mixed (432.50 ± 145.69 mg/l) in November 2009, *Rhizophora* (168.50± 168.20mg/l) on November and River (209 mg/l) on June, August to October. The seasonal variations of the mean Potassium values among sites showed higher values in the rainy season, for River and for mixed, *Rhizophora*, *Avicennia* and mixed stands in the dry season.

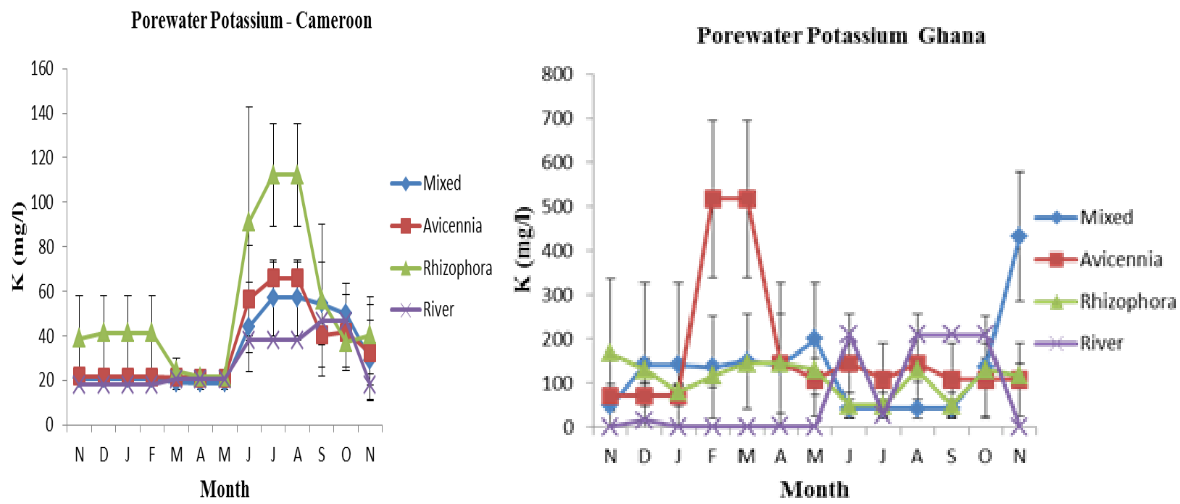


Figure 56: Seasonal variations in porewater potassium ion concentration in mangrove stands in Cameroon and Ghana.

Chloride

Concentrations of mean chloride ions recorded for Cameroon during the data collection period, varied from 23.3 to 109.9 mg/l (Figure 57). The maximum mean Chloride values was found in the River from September to October and the minimum occurred from March to May. Mean Chloride values in: *Avicennia* (85.53 ± 12.65 mg/l) in March, Mixed (99.26± 21.32 mg/l) in October, *Rhizophora* (105.91± 59.54 mg/l) on November 2009 and he seasonal variations of the mean Chloride values among sites presented higher values mainly in the rainy season for mixed and River and in the dry season, for *Rhizophora* and *Avicennia.*

Concentrations of mean chloride ions recorded for Ghana during the sampling periods, fluctuated between from 73.98 and 4323.19 ± 3417.43 mg/l (Figure 57). The maximum mean Chloride value was observed on May, July and September to November in the *Avicennia* stand and the minimum was observed in November, February, March and May in the River.

The mean Chloride values elsewhere were: mixed (2899.10 ± 962.34 mg/l) in November 2009, *Rhizophora* (1637± 160.03 mg/l) on March, April and River (999.69 mg/l) in December. The seasonal variations of the mean Chloride values among sites showed higher values in the rainy season for *Avicennia* , mixed and *Rhizophora* standsin the dry season.

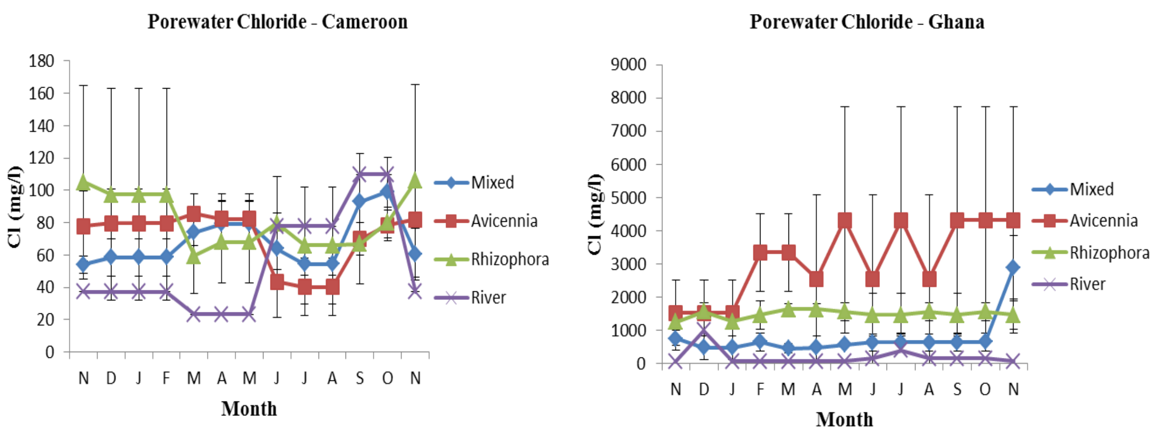


Figure 57: Changes in porewater chloride ion concentration in mangrove stands in Cameroon and Ghana.

It was observed that, no significant differences existed between mixed and *Avicennia* stands in Ghana for temperature (T°) (P> 0.05), while the other paramaters presented significant differences (P<0.05). For mixed and *Rhizophora* stands in Ghana, only TSS and Turbidity showed significant differences (P<0.05).

Between mixed stands in Ghana and Cameroon, no significant differences (P> 0.05), were only found for Cond, TSS, Turb, N and Cl. For *Avicennia* (Cameroon) and mixed (Ghana), no significant differences (P> 0.05), were found only for Cond and TSS, and for N and *Rhizophora* in Cameroon and mixed stand in Ghana, no significant differences were mainly found for N, Na and Cl. Significant Changes in soil water characteristics in both countries were therefore observed at all sites.

4.2.10 Relationships among variables for water quality in Cameroon and Ghana

Cluster analysis with Similarity Proficiency (SIMPROF) test for surface water and porewater physico-chemics properties of the mangrove stands revealed that all mangrove stands from Cameroon and Ghana (*Rhizophora* Cameroon (RhCA), *Avicennia* Cameroon (AVCA), Mixed Cameroon (MxCA), *Rhizophora* Ghana (RhGH), *Avicennia* Ghana (AVGH) and Mixed Mixed (MxGH)) are significantly different from one another at a 50% Euclidean distance (Figure 58). However at a Euclidean distance of about 7, two groups of mangrove stands could be seen, with one group comprising only stands in Ghana and the other group comprising only stands in Cameroon. These groups are further explained by Principal Component Analysis.

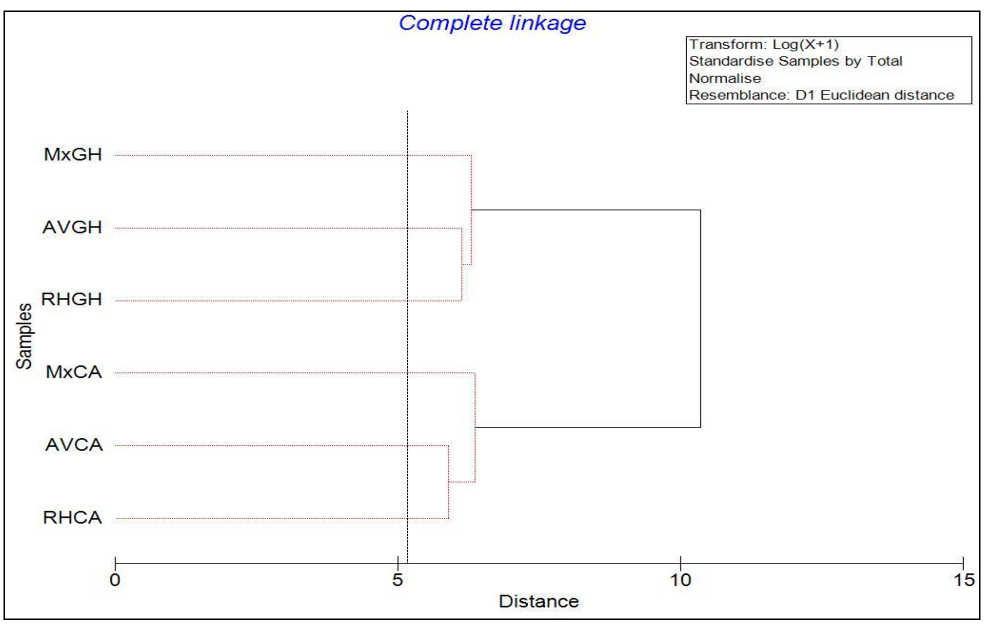


Figure 58: Dendrogramm showing the clustering of sampling sites for water quality.

Principal Component Analysis for surface water and porewater physico-chemical properties **(Figure 59)** indicates that five principal components (PCs) explain 100 % of the variability in the data, with PC1 and PC2 contributing to 53.4% and 17.5 % , respectively.

Parameters that are strongly distributed on PC1 included surface water DO (SW_DO), surface water BOD (SW_BOD), surface water sulphate (SW_Sul), surface water phosphate (SW_P), surface water sodium (SW_Na), porewater alkalinity (PW_Alk), porewater DO (PW_DO), porewater BOD (PW_BOD), porewater sulphate (PW_Sul), porewater phosphate (PW_P), porewater potassium (PW_K) and chloride (PW_Cl). On the other hand, SW_pH, temperature, SW_TSS, SW_turbidity, PW_pH and PW_temperature were strongly loaded on PC2 (Appendix 10).

Using PC1 and PC2, which contribute to a total of 70.9% of the variability in the data, it was observed that, the water and porewater physico-chemical properties from mixed Cameroon (MxCA), are contributed to the variability by SW_TSS and SW_turbidity, while those of *Avicennia* Cameroon (AVCA) and *Rhizophora* Cameroon (RHCA) mainly contributed to the variability by SW_pH, SW-temperature, PW_pH and PW_temperature. Similarly, the variability at *Avicennia* Ghana (AVGH) and mixed Ghana (MxGH) were mainly contributed to by SW_sulfate and PW_TDS, while that of *Rhizophora* Ghana (RHGH) was mainly contributed to by SW_conductivity, SW_Na, PW_sulphate, PW_K and PW_Cl.

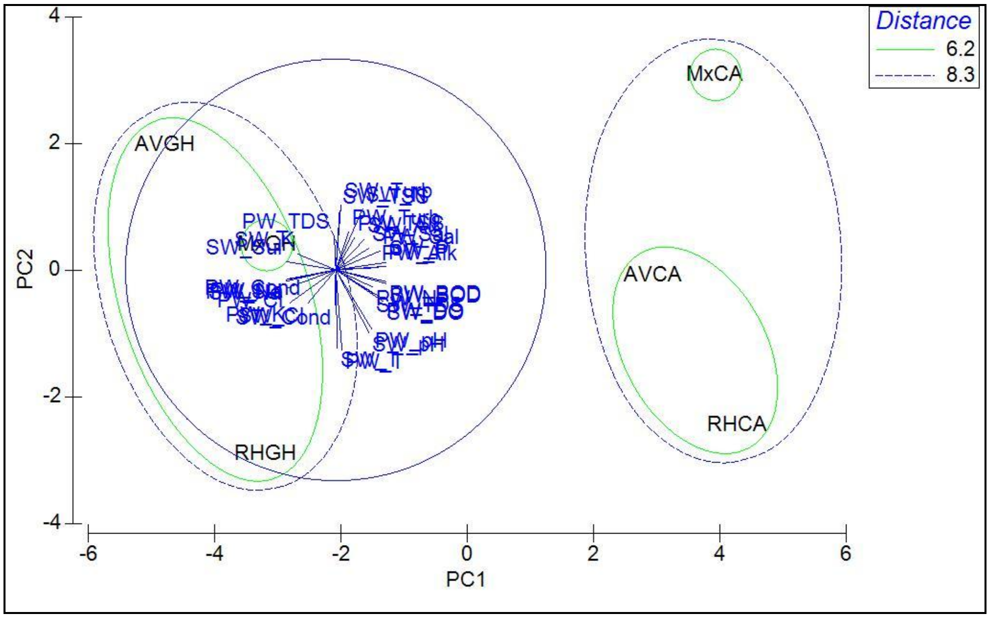


Figure 59: Principal component analysis (PCA) ordination plot of sampling stations based on water quality.

A One-way Analysis of Similarity (ANOSIM) performed for surface water and porewater physico-chemical parameters indicated a Global R of 0.729 at a significant level of 0.1%, indicating high dissimilarity among the mangrove stands from Ghana and Cameroon.

A Parewise test indicated higher similarity between mangrove stands in Ghana, as well as mangrove stands in Cameroon, but high dissimilarity between those formed by a mixturof Ghana and Cameroon sites (Appendix12).

In order to explain the disparate patterns of mangrove water quality between the two countries, Discriminant Function Analysis (DFA). The group centroids of the six sites representing, *Avicennia* GH, *Rhizophora* GH, Mixed GH, *Avicennia* CA, *Rhizophora* CA, Mixed CA, were significantly different from each other (Wilks' lamba =0.00000, P<0.00001). For the first two axes, Mixed GH group overlapped with those of Avicennia GH and Rhizophora GH. Mixed CA group overlapped with those of Avicennia CA and Rhizophora CA. Within each country, the separation of the groups was bad, and good between the countries (Figure 46). A total variation 88% was expressed by the 1st canonical variate axis (Root1), whereas 12% of the total variance was explained by the 2nd axis.

The first canonical variate axis tended to discriminate with a high score Mixed GH from the five others groups (*Avicennia* GH, *Rhizophora* GH, Mixed CA, *Avicennia* CA, and *Rhizophora* CA). The first Character- axis correlations (Table 26) indicated that Alkalinity, Sulphate, Cadmium, Chloride, Chromium, Lead, Salinity and Total Dissolved Solids were the variables the most positively correlated with this axis (r=0.75, 0.63, 0.55, 0.46,0.26 , 0.20) and turbidity and nitrate were the variables the most negatively correlated with this axis (r=-0.62 and -0.22) respectively.

The second canonical variate axis discriminated the group *Avicennia* GH, from the six others (Mixed GH, *Rhizophora* GH, Mixed CA, *Avicennia* CA and, *Rhizophora* CA) with low canonical scores. This canonical variate axis was positively correlated with the variables Dissolved Oxygen, Total Suspended Solids, Lead, water temperature, Salinity (r=0.98, 0.46, 0.33, 0.26, 0.21) and negatively correlated with Total Dissolved Solids (r= -0.27) respectively.

This discriminant analysis clearly showed discrimination between the different groups in both countries: Mixed GH, Avicennia GH, Rhizophora GH, Mixed CA, Avicennia CA, and RhizophoraCA). Alkalinity, Sulphate, Cadmium, Chloride, Chromium, Lead, Salinity ,Total Dissolved Solids, turbidity and nitrate exhibited strong contribution in distinguishing the two countries and account for most of the expected variations in the quality of mangrove water, while the other parameters, Dissolved Oxygen, water temperature, Total Suspended Solids showed less contribution in explaining the variation between Ghana and Cameroon.

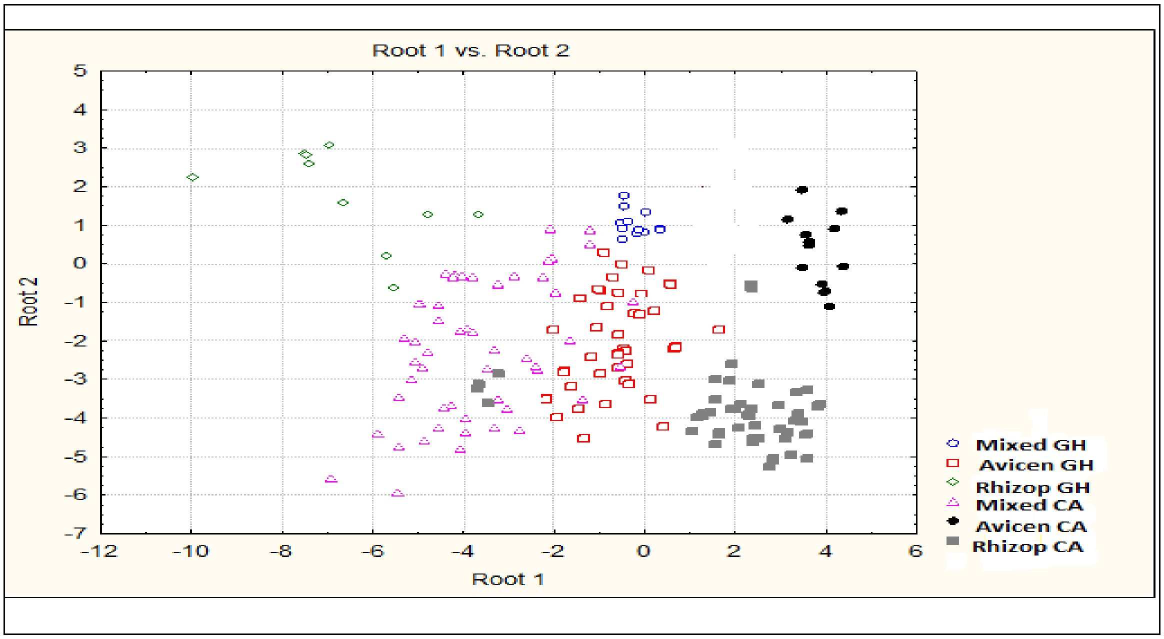


Figure 60: Scatter plot to indicate the six groups of Ghana (GH) and Cameroon (CA) for water quality.

4.4. Soil physical and chemical characteristics

4.4.1. Characteristics of mangroves' soils in Cameroon and Ghana

Soil pH

In Ghana, the values obtained varied between 4.46±0.55 in the *Rhizophora* stand and 4.62±0.52 in the mixed stand (Table 5).The soils in the *Rhizophora* stand were the most acidic. In Cameroon Soil pH in the three mangrove sites was moderately acidic. The values obtained varied between 5.02±1.09 in the*Rhizophora* stand and 6.22±0.64 in the mixed stand (Table 5).

Conductivity (mS/m)

Conductivity of soils in Ghana varied between 6.37±1.03 mS/cm in the *Rhizophora* Stand and 11.44±1.21 mS/ m in the Mixed. Mean values of conductivity in *Rhizophora* stand was relatively lower than in the *Avicennia* and mixed stands (Table 5). The soil in *Rhizophora* stand was most acidic (low pH), and had the lowest conductivity in the other hand. Soil in the mixed stand which had the highest pH value recorded also the highest conductivity.

Conductivity of soil in Cameroon varied between 1.18±0.72 mS/cm in the *Avicennia* Stand and 2.72±2.72 mS/ m in the *Rhizophora*. Mean values of conductivity in Avicennia and mixed stands were relatively lower than in the *Rhizophora* (Table 5). The soil in *Rhizophora* stand was most acidic (low pH) and had the highest conductivity, while soil in the mixed stand which had the highest pH value recorded a low conductivity.

Soil Organic Carbon and Organic matter

Mean values of organic carbon in Ghana varied between 4.32±0.25 in the Avicennia Stand and 9.11±1.02% in the *Rhizophora* stand (Table 5). The mean values of organic carbon content in the *Rhizophora*, *Avicennia* and mixed stands are high (values above 2.9%). The range of Organic Matter of the soil was between a low value of 7.42±0.42 % in the *Avicennia* stand and to a high value of 15.43±1.76 % in *the Rhizophora*.

For the mean values of Organic Carbon and Organic matter, the *Rhizophora* stand had the highest standard deviation followed by mixed stand. The variance analysis showed that the difference between those sites was statistically significant.

Mean values of organic carbon varied be`tween 2.70±0.38 in the *Avicennia* Standand 5.31±2.61%in the *Rhizophora* stand (Table 5). It appeared that, the mean values of organic carbon content in the *Rhizophora* and mixed stands are High (values above 2.9%) and in the *Avicennia* Stand the content of Organic carbon is medium (values between 1.5% to 2.9%). The range of organic matter of the soils was between a low value of 4.64±0.66% in the *Avicennia* stand and a high value of 10.43±5.79% in the *Rhizophora*.

For the mean values of organic carbon and organic matter, *Rhizophora* stand had the highest standard deviation followed by mixed stand. The variance analysis showed that the difference between those sites was statistically significant.

Total organic nitrogen available phosphorus and C/N

Mean values of Total Nitrogen content in Ghana varied between 0.69±0.48% inthe *Rhizophora* Standand 3.36±0.60%in the mixed stand (Table 5). The average values of phosphorus fluctuated between 5.75±0.61 mg/kg in the *Rhizophora* stand and 18.91±6.95 mg/kg in the *Avicennia* stand. The relative maximum value of C/N ratio was observed as 31.67±3.33 in the *Rhizophora* stand and the minimum 1.38±0.21 in the *Avicennia*.

Mean values of Total Nitrogen content in Cameroon varied between 0.07±0.04 in the *Avicennia* Standand 0.16±0.11%in the *Rhizophora* stand (Table 5). The average values of phosphorus fluctuated between 6.06±1.53 mg/kg in the Rhizophora stand and 10.46±6.33 mg/kg in the mixed stand. The Maximum value of C/N ratio was observed 47.18±26.24 in the *Avicennia* stand and the minimum 39.73±11.09 in the *Rhizophora*.

Available P levels were low in the *Avicennia* and *Rhizophora* stands with values ranging from 6.06 to 7.72 mg/kg indicating deficiency level in all the profiles.

Cation Exchange Capacity and percent base saturation

In Ghana the lowest mean value of Exchangeable Ca content was 3.14±0.29 cmol/kg and inthe *Avicennia* and the highest mean value in the *Rhizophora* stand was 3.60±1.24 cmol/kg (Table 5). The average value of Exchangeable Mg varied between 1.43±0.18 in *Rhizophora* stand and 27.72±43.26 cmol/kg in the mixed stand. The average value of Exchangeable K, varied between 0.83±0.48 cmol/kg in *Rhizophora* stand and 2.69±0.06cmol/kg in the *Avicennia* stand. The highest mean value of Effective Cation Exchange Capacity (ECEC) observed in the mixed mangrove was25.53±2.59 cmol/kg and the lowest value 6.88±1.18 in the *Rhizophora* stand.

Exchangeable Ca (3.14–3.60 cmolkg-1) Mg (1.43–27.72 cmolkg-1) and K (0.83– 0.48 cmolkg-1) values reflect the overall influence of regular replenishment by seepage and tides. ECEC values ranged from moderate to very high (6.88– 25.53 cmolkg-1) and reflect the high exchange acid conditions in mangrove swamp soil on air drying.

In Cameroon the lowest mean value of Exchangeable Ca content was 2.64±0.70 cmol/kg and 2.64±0.1.49 cmol/kg in the *Avicennia* and *Rhizophora* stands, and the highest mean value in the mixed stand was 3.07±1.29 cmol/kg (Table5)**.** The average value of Exchangeable Mg varied between 0.29±0.11 in Avicennia stand, and 1.84±0.94 cmol/kg in the mixed stand. The Maximum value of Exchangeable Mg was 0.55±0.34 cmol/kg and the minimum0.32±0.15

cmol/kg in the *Rhizophora* stand. The average value of Exchangeable K, varied between 0.32±0.15 in *Rhizophora* stand and 0.55±0.34 cmol/kg in the mixed stand.

The Maximum value of Exchangeable K was 0.55±0.34 cmol/kg and the minimum,0.32±0.15 cmol/kg in the *Rhizophora* stand. The highest mean value of Effective Cation Exchange Capacity (ECEC) observed in the mixed mangrove was, 6.62±2.35 cmol/kg and the lowest value 4.57±2.48 in the *Rhizophora* stand. Exchangeable Ca (2.64–3.07cmolkg-1), Mg (0.29–1.84 cmolkg-1) and K (0.32– 0.55 cmolkg-1) values reflect the overall influence of regular replenishment by seepage and tides.

Soil Texture

The sand fraction in Ghana for all the mangrove stands ranged between 4.14% in *Rhizophora* stand to 5.36% in the mixed **(**Table 5**).** On the other hand, Analysis of variance (ANOVA**)** **(**Table7**),** revealed that with the exception of dissolved solids, that showed significant variations at ($p < 0.05$) **(**Table 1**),** in the six sampling stations, all other parameters showed no significant variations ($p > 0.05$). Silt was relatively abundant in the *Avicennia* (61.68±0.88%) and less in the mixed stands (37.92±23.71%). The clay was most abundant in the *Avicennia* stand (17.89±1.08%) and less in the *Rhizophora* Stand (14.27±2.28). The mean of the fractions for the different classes was shown that, the combined amount of sand. Silt and clay was 28.22% in *Avicennia* stand. 26.13% in *Rhizophora* and 20.09 % in mixed stand. Soil in *Avicenna* had the highest percentage of silt (61.68±0.88%), while the other two stands had a relatively low percent silt. In addition, the tidal movement are restricted in this site. The sand fraction in Cameroon for all the mangrove stands ranged between 17.56% in the mixed stand to 41% in the *Rhizophora*

(Table 5**),** On the other hand, silt was relatively abundant in the *Avicennia* (32.80±9.93%) and *Rhizophora* stands (25.43±5.10).

The clay was most abundant in the mixed stand (52.01±5.92) and the *Avicennia* Stand (40.01±8.75). The mean of the fractions for the different classes showed that, the combined amount of sand, silt and clay was 34% in *Avicennia s*tand. 33% in *Rhizophora* and 30% in mixed stand. Soils in *Avicennia* had the highest percentage of silt (32.80±9.93%), while the other two stands had a relatively low percent silt

Table5: Soil Characteristics in Ghana and Cameroon (mean ±sd).

Variables	***Avicennia*** **Ghana**	***Avicennia*** **Cameroon**	***Rhizophora*** **Ghana**	***Rhizophora*** **Cameroon**	**Mixed Ghana**	**Mixed Cameroon**
Soil pH	5.80±0.64	4.56±0.63	5.02±1.09	4.46±0.55	6.22±0.64	4.62±0.52
EC(mS/m)	1.18±0.72	10.87±1.36	2.72±2.72	6.37±1.03	1.50±0.72	11.44±1.21
ExCa	2.64±0.70**	3.14±0.29	2.64±1.49	3.60±1.24	3.07±1.29	3.48±0.50
ExMg	0.29±0.11	13.10±0.83	1.04±0.60	1.43±0.18	1.84±0.94	27.72±43.26
ExK	0.45±0.25	2.69±0.06	0.32±0.15	0.83±0.48	0.55±0.34	2.51±0.62
Acidity	1.42±0.34	2.98±2.64	1.44±0.54	2.90±0.71	1.16±0.28	10.86±16.39
ECEC	4.81±1.05	22.48±1.11	4.57±2.48	6.88±1.18	6.62±2.35	25.53±2.59
`%OC	2.70±0.38	4.32±0.25	5.31±2.61	9.11±1.02	3.42±1.63	5.16±0.55
%OM	4.64±0.66	7.42±0.42	10.43±5.79	15.43±1.76	5.28±3.42	8.35±0.61
%ON	0.07±0.04	3.20±0.31	0.16±0.11	0.69±0.48	0.09±0.06	3.36±0.60
Av. C/N	4 7.18±26.24**	1.38±0.21**	39.73±11.09**	31.67±3.33**	40.78±15.03**	2.34±0.52**
Av. P	7.72±1.32*	18.91±6.95*	6.06±1.53*	5.75±0.61*	10.46±6.33*	11.22±1.68*
Sand	28.19±7.72*	5.10±0.83*	41.78±4.92*	4.14±0.65*	17.56±5.86*	5.36±0.89*
Silt	32.80±9.93	61.68±0.88	25.43±5.10	59.98±13.96	21.62±12.80	37.92±23.71
Clay	40.01±8.75	17.89±1.08	32.57±5.45	14.27±2.28	52.01±5.92	16.99±0.97

* p<0.05 **P<0.001

Analysis of variance (ANOVA) based on the mean values observed in Ghana and Cameroon (Table5), revealed that Exchangeable Calcium (ExCa), available C/N ratio showed strong significant variations (**) and available phosphorus and sand that presented significant variations (*) in the sampling stations of both countries, all other variables showed no significant variations ($p > 0.05$).

4.2.11 Relationships among variables for mangrove soil description in Cameroon and Ghana

Cluster analysis with Similarity Proficiency (SIMPROF) test for soil characteristics of the mangrove stands revealed that all mangrove stands from Cameroon and Ghana (RhCA, AVCA, MxCA, RhGH, AVGH and MxGH) were significantly different from one another at 50% Euclidean distance (Figure 61). However at a Euclidean distance of about 6, two groups of mangrove stands could be seen, with the two groups, one of them comprising only the stands from Ghana and the other group consisting of stands from Cameroon. These groups are further explain by principal component analysis.

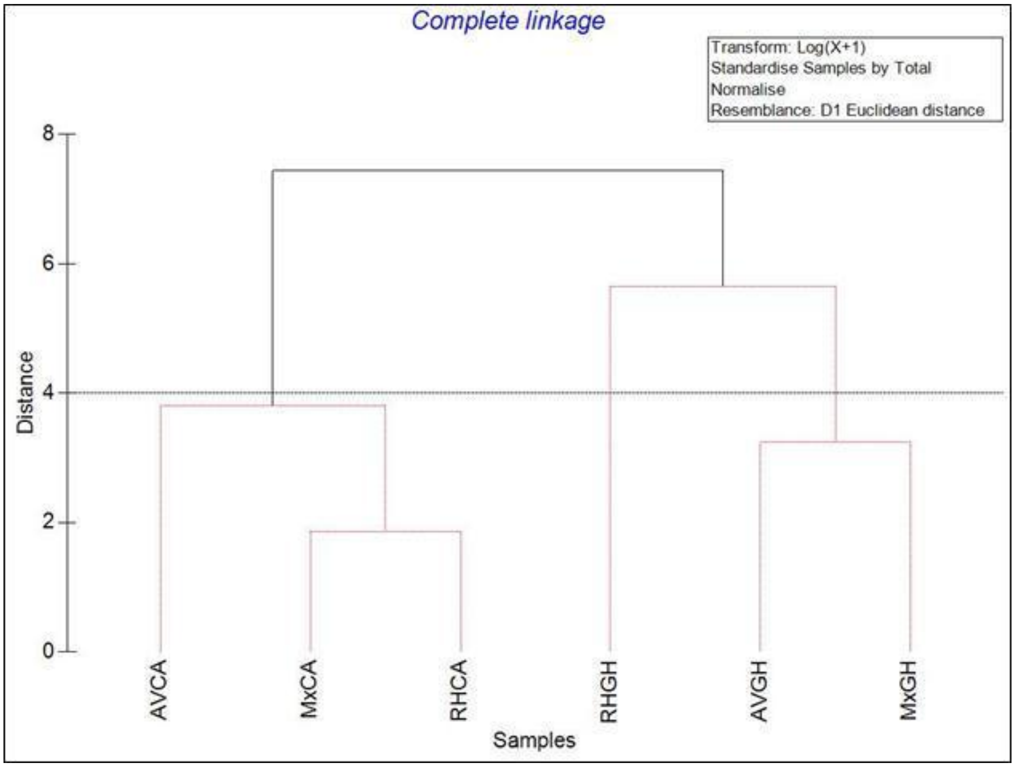


Figure 61: Principal component analysis (PCA) ordination plot of sampling stations based on soil characteristics.

Principal Component Analysis (PCA) for soil characteristics **(**Figure.62) indicated that five principal components (PCs) explain 100 % of the variability in the data, with PC1 and PC2 contributing to 62.8% and 20.1%, respectively (Appendix12.). Parameters that are strongly distributed on PC1 included pH, EC, ExCa, ExMg, ExK, acidity, ECEC, ON, AVCN, sand and clay. On the other hand, ExK, ECEC, OM, OC, AVP, Silt and Bulk density were found to be strongly loaded on PC2. Using PC1 and PC2, which contribute to a total of 82.9 % of the variability in the data, it was observed that, soil characteristics from *Rhizophora* Ghana (RHGH) were contributed to the variability by OM, OC and bulk density, while those from mixed Ghana (MxGH) and *Avicennia* Ghana (AVGH) were contributed by AVP, AV C/N, ExCa, pH, clay, sand and silt and mixed Cameroon (MxCA), *Avicennia* Cameroon (AVCA) and *Rhizophora* Cameroon (RHCA) were contributed to the variability by Mg, ExK, Acidity, ON and EC.

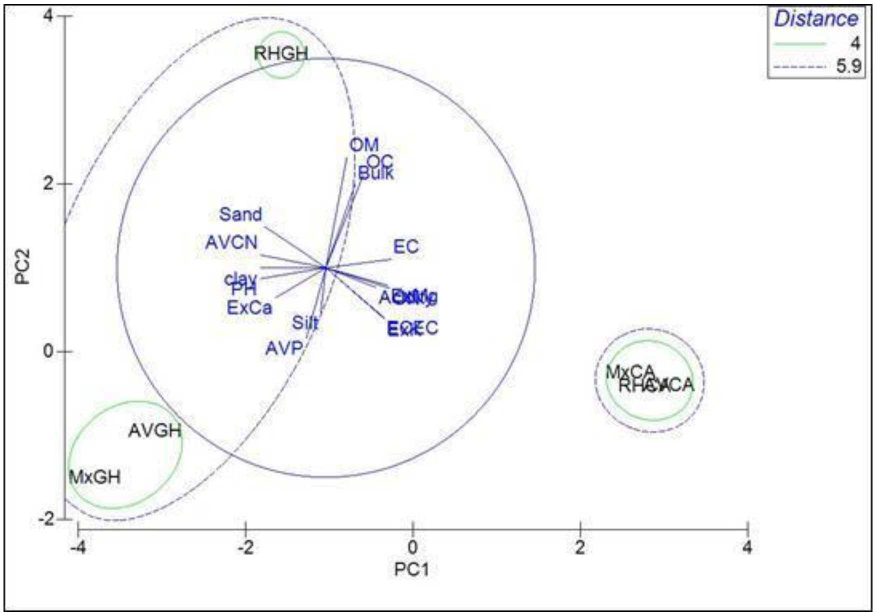


Figure 62: Principal component analysis (PCA) ordination plot of sampling stations based on soil characteristics.

A One-way Analysis of Similarity (ANOSIM) performed for soil parameters presented a Global R of 0.824at a significant level of 0.1%, indicating high dissimilarity among the mangrove stands from Ghana and Cameroon. A Parewise test indicated higher similarity between mangrove stands in Ghana, as well as mangrove stands in Cameroon, but high dissimilarity between those of Ghana and Cameroon put together **(**Appendix 14).

In order to explain the disparate patterns of mangrove soils' quality within and between the two countries, Discriminant Function Analysis (DFA) was performed. The group centroids of the six sites representing, *Avicennia* GH, *Rhizophora* GH, Mixed GH, *Avicennia* CA, *Rhizophora* CA, and Mixed CA were significantly different from one another (Wilks' lamba =0.00001, P<0.00001). For the first two axes, Mixed GH group overlapped with those of *Avicennia* GH and *Rhizophora* GH, Mixed CA group overlapped with those of Avicennia CA. *Rhizophora* CA is not mixed with one of them. Within each country the separation of the groups slightly was bad, and good between the countries (Figure 63).

A total variation of 74% was expressed by the 1st canonical variate axis (Root1), whereas 26% of the total variance was explained by the 2nd axis. The first canonical variate axis tended to discriminate with a high score Mixed GH from the five others groups (Avicennia GH, *Rhizophora* GH, Mixed CA, *Avicennia* CA, and *Rhizophora* CA). Character- axis correlations (Appendix 15) indicated that %0N, EC, acidity, Ex Mg, were the variables, the most positively correlated with this axis (r= 0.97; 0. 63;0.43, 0.24, 0.20, and respectively).

The second canonical variate axis discriminated the group *Avicennia* GH, from the five others (Mixed GH. *Rhizophora* GH, Mixed CA, *Avicennia* CA, and *Rhizophora* CA) with low canonical scores. This canonical variate axis was positively correlated with the variables, Sand, %OM, Clay, Ex Mg , acidity, pH, ECEC (r=0.99, 0.50, 0.46, 0.31 ,0.23 ,0.21, 0.20, and respectively). This discriminant analysis clearly showed discrimination between the different groups in both countries: Mixed GH, *Avicennia G*H, *Rhizophora* GH, Mixed CA, *Avicennia* CA and *Rhizophora* CA). It was found that %0N, EC, acidity, Ex Mg, ECEC, and Av P exhibited strong contribution in distinguishing the two countries and accounted for most of the expected variations in the soil characteristics of mangrove forest, while the other parameters, Sand, %OM, Clay, pH, showed less contribution in explaining the variation between Ghana and Cameroon (Appendix 15).

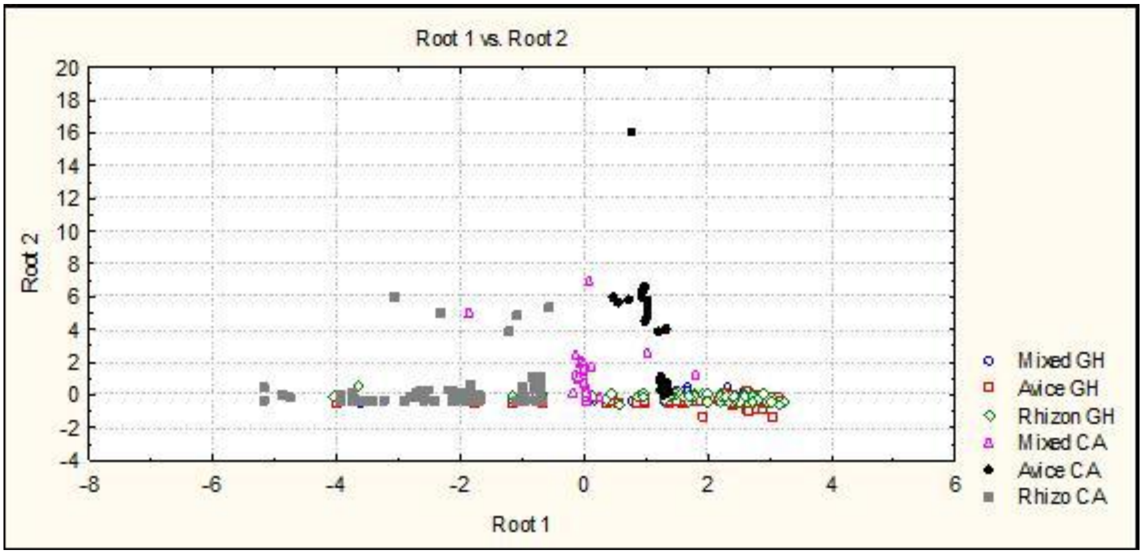


Figure 63: Scatter plot to indicate the six groups of Ghana (GH) and Cameroon (CA) for description of soil.

CHAPTER 5
5.0. DISCUSSION

Many qualitative ecological studies have been conducted on mangrove ecosystems but less quantitative information is available in Africa mainly in the West and Central African ecoregion. Few researchers have tried hard to give some insights in the ecology of mangrove ecosystems. This limits more or less the comparability of results from this study. The following discussions are carried out by comparing the results obtained with available information from mangrove ecosystem studies all over the world under the headings, i) Litterfall production ii) Forest structure, iii) water quality assessment, and iv) Soil quality assessment.

5.1. Litter production (Litterfall)

Seasonal fluctuations have been found in litterfall of several mangrove species, notably of the genera *Avicennia* and *Rhizophora* as presented in this study (FAO, 2006; Spalding *et al*., 2010). The relative maximum production of litterhas been observed mainly in the dry season. Theorically, Litterfall increases during the dry season, because water stress is linked to a complex physiological process, that leads to the death and shedding of vegetative organs, resulting in high litterfall during low water availability in seasonal forests (Kelvin, 2009; Spalding *et al*., 2010). Mokolensang *et al*.(1998) also reported a seasonal pattern of increase of leaf litter during the dry season for mixed *Avicennia germinans*, *Rhizophora racemosa* and pure *Avicennia germinans* and *Rhizophora racemosa* forests in Japan in the Indo-Pacific region. Similar to the result were obtained by Kairo and Bosire (2009) who studied a research on mangrove in Kenya in the East African ecoregion and by Engankou (2009) who studied *Avicennia* and *Rhizophora* forest in Cote d'Ivoire added to Conchedda *et al*.(2011) who studied mangrove in Senegal in the West and Central African ecoregion.

However, in terms of seasonal fluctuation, the results of some other studies seemed to indicate that litterfall peaks do not have any relation with the rainfall patterns (UNEP,2007; Luzhen Chen *et al*., 2009; Spalding *et al*., 2010). This emphasizes the need for long-term litterfall studies to confirm seasonal periodicity and establish relations between rainfall and litterfall peaks.

Litterfall has been also observed throughout the year with little (Chen *et al*., 2009; Conchedda *et al*., 2011) or marked (Day *et al*., 1996; Wafar *et al*., 1997; Bosire *et al*., 2006; Egnankou, 2009) seasonal variations. Leaf production was found to be continuous throughout the study period, which suggests that the environmental conditions are favourable for leaf emergence all year round. Similar results have been reported by Gary (2004), Krauss *et al*. (2008), Kairo and Bosire (2009); Crona *et al.* (2009); Conchedda *et al*. (2011); and Dahdouh- Guebas (2011).

It was also observed that, in *Rhizophora* and *Avicennia* stands, low temperatures generally reduce the flower and fruit (mature and immature) production. This is true with several tropical/subtropical tree species whose number of flowers is quite large as compared to fruit , because of the low conversion of flowers to fruitsin reproductive phenology it is known that, there is conversion of flowers to fruits, and fruits to propagules; immature dropping of propagules was also observed, during the collection of data (Bosire *et al.*, 2006; UNEP, 2007; Krauss *et al.*, 2008; Alongi, 2011; Dahdouh et Guebas, 2011).

Annual litter production (litterfall) from the mangrove sites of Ghana (average annual production: 2.5 t ha−1 per year) and those of Cameroon (average annual production: 4.5 t ha−1 per year) actually fall within the range documented for tropical and subtropical mangroves and are slightly higher than to those of a riverine mangrove wetland (1.7 t/ha/year) reported by Arreola-Lizárraga *et al*. (2004).

However, the estimates for *Avicennia germinans*, *Rhizophora racemosa* and mixed (*Avicennia* and *Rhizophora*) forests are higher when compared to forests of the same species in other regions including other areas in low latitudes (Fernandes, 2003; Arreola-Lizárraga *et al*., 2004; UNEP, 2007; Spalding *et al*., 2010).

The sequence of the components of total litterfall found in this study (leaves> Twigs > flowers > fruits/seeds) is consistent with data obtained in other mangroves (Kairo and Bosire, 2009; Egnankou, 2009; Conchedda *et al*., 2011). The production of leaves usually represented the largest fraction (> 50%), but in some cases can exceed 80%, regardless of latitude, weather conditions or type of forest as observed in this study (Day *et al.*,1996; Mehlig, 2001; Kairo and Bosire, 2009;). The relative contribution of the litter components is similar to data reported in the literature for mangrove ecosystems. The contribution of reproductive parts in litter in the study site is among the highest reported in the literature suggesting vegetation which is vigorous enough to allocate a great part of its energy for reproduction, while at the same time requiring frequent replacement (Bosire *et al.*, 2006; Dahdouh-Guebas, 2011).

In the present study nutrients inputs through leaf litter component (mg/ha) in the mangrove forest studied were respectively for Nitrogen (N), 88.34 and 20230.46, Phosphate (P), 723.93 and 342.52, Potassium (K), 451.18 and 227.17; Calcium (Ca), 882.77 and 275.53 and Magnesium (Mg), 768.50 and 275.53. It was observed that, nutrient inputs through leaf litterfall (mg/ha/year) are in the lower part of the spectrum of values compiled by Barbosa and Fearnside (1996) for lowland tropical forests which include mangrove forest as follows (34200-158000 N, 1900- 6700 P, 12700 - 59300 K,17400-114200 Ca, and 7200-26800 Mg).

Relative low inputs of nutrients through leaf litterfall in the studied forests was due to a combination of low rates of return of litter to the soil and low concentrations of nutrients in the fallen material. Nitrogen (N) inputs in the studied sites are quite low but it was noted that the lowest value was found particularly in Ghana, and can therefore be considered as the lowest N inputs recorded for tropical forests. This situation can be due to low rates of return of litter to the soil surface and low concentrations of nitrogen in the fallen material (Spalding *et al*., 2010).

It was observed that nutrient content of mangrove litterfall may vary between countries in the West and Central African Ecoregion as a result of the different biological and chemical processes occurring in each study area (UNEP-WCMC, 2007; Krauss *et al*., 2008; Dahdouh-Guebas, 2011).

Mean concentrations of nutrients in leaf litter in Ghana and Cameroon are in the range of other tropical forests (Crona *et al*., 2009; Spalding *et al.*, 2010; Conchedda *et al.*, 2011). Values of nutrients in Ghana sites were lower, especially those of N and P, making evident that leaf litter quality is unique to each ecosystem, according to soil properties and climate (FAO, 2009; Alongi, 2011). Leaf fall determined the seasonality of mineral return to soil in both countries (Spalding *et al.,* 2010, Conchedda *et al.,* 2011). A seasonal pattern was therefore derived from curve of litter production and not from concentration values which were quite uniform during the entire period of study.

Relatively high concentrations of N, P and Mg in the leaf litter of mangrove sites in Cameroon may be explained by the richness of those elements in the topsoils of mangrove sites. On the other hand, Ca was highly concentrated in leaves of mangroves in Ghana. In both countries, the relative great variability of results could be due to differences in the amount and quality of litter, according to edaphic and climatic conditions found in each mangrove ecosystem. Nutrients are not often quantified in litterfall studies, which restricts the possibilities for comparisons. In both countries nutrient concentrations were generally constant across the leaf fall cycle, but the values for N were greater in Cameroon especially during the dry season. This is probably due to greater accumulation of marine aerosols on the mangrove forest canopy, as rainfall is lower at that season. While comparing both countries it appeared that, the annual return of nutrients to the soil was relatively high in Ghana sites for P, K, Ca and Mg, butfar higher in Cameroon sites for N content. All those results in nutrients in both countries were within the ranges reported by Owusu-Sekyere, 2006; Krauss *et al*., 2008; Egnankou, 2009; Spalding *et al*, 2010 and Dahdouh-Guebas, 2011) for African Ecosystems.

Mangrove forest in Cameroon with a leaf litterfall mass of 46.08 t/ha presented for nitrogen, a Nutrient Use Efficiency (NUE) of 13.44, which was relatively low compared to that reported by Nelda Dezzeo for a tropical forest. Ghana mangrove forest, on the other hand, with leaf litterfall mass of 24.64t/ha and NUE for nitrogen of 27.93 was less inefficient compare to Cameroon, and showing a relative high level of adaptation to the low nutrient (nitrogen) availability (Nelda Dezzeo, 2006; Sekyere *et al.*, 2006; UNEP, 2007).

The ratio between litterfall mass and litterfall nutrient content gives the nutrient use efficiency (NUE) (Vitousek, 1982, Nelda Dezzeo, 2006). Globally, Tropical mangrove forest as observed in the present study, are more or less inefficient in the use of nitrogen although relatively great amounts of leaf litter are produced (Gary, 2004; Alongia, 2005; FAO, 2009; Conchedda *et al.*, 2011).

5.2 Diameter class distribution and structural characteristics of mangrove forest

5.2.1 Diameter class distribution

The diameter class distributions observed in this study, are similar to those obtained for mangrove forest found in in Kenya (Kairo and Bosire, 2009), and Senegal (Conchedda *et al.*, 2011) where about 70% of trees were in the smallest DBH class (small and medium trees). The decreasing curve has a reverse-J distribution typical of natural forest regenerating from seed (Dahdouh- Guebas, 2011; Nfotabong *et al.*, 2011). It suggests a stable size and age class distribution (Adjonina, 2008; Din *et al.*, 2008; Egnankou, 2009). This shape is characteristic of climax species (Whitmore, 1990; UNEP, 2007; Spalding *et al.*, 2010,). For many small individuals and few large ones, we hypothesise or assume that the most abundant species among the mangrove tolerant species of both countries are certainly at a stage of equilibrium with the climatic and edaphic conditions.

5.2.2 Structural characteristics

Rhizophora racemosa was the dominant species in the mixed stands of the studied areas with a great capacity of natural regeneration. This apparent dominance could be associated with its ability to survive inundation compared to *Avicennia germinans* and its ability to colonize substrates. Similar results were found by Gary (2004), Lovelock (2005); Krauss *et al*.(2008), Spalding *et al.* (2010).

The main structural attributes considered in the studied mangrove forest were the mean dominant height stand density basal area and volume. Generally, the structural attributes of the vegetation in the present study are in the range of the mean values calculated for dominant height, stand density, basal area and volume of species for riverine forests in the literature (Brown and Lugo, 1982; Cintron and Novelli, 1984; Lovelock, 2005; UNEP, 2007; Aheto *et al*. (2011). Gehring *et al*. (2008) and Conchedda *et al*. (2011) have confirmed that diameter at breast height (DBH) and height (H) are standard measures for investigating large mangrove plants.

According to Aheto *et al*. (2011) a mangrove forest with a maximum structural development has a DBH between 27.0 and 29.9cm and a mean height of the most-developed trees between 17.7 and 21.2 m a forest with a high structural development has a DBH between 15.6 and 22.9 cm and a mean height of the more developed trees between 11.8 and 22.7m a forest with intermediate structural development has a DBH between 4.5 cm and 14.8 cm and a mean height of the most developed trees between 5.7 and 13.7 m and a forest with low structural development has a DBH between 1.6 and 3.1cm and mean height of the most developed trees better. Based on these results, the mangrove forest in the present study could be described as being of low structural development for *Rhizophora* stands, intermediate structural developpement for mixed stands and a relative maximum developpement for *Avicennia s*tands (FAO,2009; Spalding *et al*.,2010; Dahdouh- Gueba, 2011).

The reasons for these variations in structural developpement may be attributed more or less to the prior cutting of mangrove trees before the decisions to declare the area as protected one has been made by the respective government in both countries. *Rhizophora racemosa* was then the species most devastated because, the wood was greatly used for smoking of fish in the mangrove communities (UNEP, 2007; FAO, 2009; Aheto, 2011; Nfotabong, 2011).

The contribution in basal area and volume was higher for mangrove stands recording the greater mean dominant height Similar results were found in the present study, where dominant height, volume and basal area were relatively high in all the mangrove stands in Cameroon compared to those of Ghana in the Central African ecoregion (FAO, 2009; Spalding *et al*.,2010; Conchedda *et al.,).* The increase in average volume may also be an indicator of relative high productivity of the forest. This may be due to the fact that, *Rhizophora s*pecies dominated the Cameroon and Ghana coastlines and is very suitable for making charcoal or to be burned as fuelwood (Nfotabong *et al*.. 2009; Aheto *et al*, 2011).

This species dominated also the Cameroon coastlines (Van Campo & Bengo 2004; FAO 2007) and is very suitable for making charcoal or to be burned as fuelwood (FAO, 2007; Adjonina, 2008; Armah *et al.*, 2009; Din *et al.*. 2008; Bosire, 2009; Kairo and Bosire, 2009; Nfotabong *et al*., 2009;; Spalding *et al*., 2010 ; Dahdouh-Guebas , 2011; Aheto *et al*., 2011).

5.2.3 Water Quality of mangrove forest

5.2.3.1 Physico- chemical parameters

In the present study, air temperature varied between varied between 26 to 30.1 º C in Ghana and 26.80 to 29.5 º C in Cameroon and water temperature ranged from 25.2 to 30 ºC in Ghana and 22.3 to 26.3 ºC in Cameroon.

From this study, it has been observed that, temperature values were within the acceptable levels for survival metabolism and physiology of aquatic organisms. Water temperature has some positive and negative effects on plant growth. The most suitable water temperature for plant growth is 20-35°C Temperature over 30°C can cause regression in growthand decay in plants (Krauss *et al.*, 2008; Luo *et al.*, 2010; Lawson, 2011).

The monthly rainfall recorded in this study was varied between 50 mm and 300 mm in Ghana and 100 mm to 600 mm in Cameroon. Rainfall greatly affects the dynamics of the environments transports nutrients and allochthonous materials and alters the water's visual physical and chemical characteristics (Krauss *et al.*, 2008; Conchedda *et al*., 2011).

The pH ranged from 4.81 to 7.43 in the mangrove studied. The pH values recorded in the study fell within ranges reported for rivers flowing through areas with mangrove vegetation. pH has direct or indirect effects on photosynthesis and growth of water plants. In water with low pH, solution dissociation of iron phosphate decreases and vice versa. High pH causes more carbonate and bicarbonate in water (Adriamalala, 2007; UNEP, 2007; Spalding *et al*., 2010; Lawson, 2011).

Lawson (2011) confirmed that organic acids resulting from decaying vegetation might be responsible for the low pH in most aquatic ecosystems. Drinking water pH level varies between 6.5 and 9.5. The safest pH level of drinking water would be 7 which is the pH level of pure water. Based on this, waters from the mangrove swamps studied are relatively not really suitable for drinking.

It was observed that salinity was sometimes relatively high in the present study. The values of salinity observed in this study were sometimes out of the range advisable. Higher salinities were recorded across the research stations during the dry months than wet months this may be due to dilution of the water by the increased freshwater input during these wet months (Luo *et al.,* 2010; Ramsar-Mava-Unep, 2012). This was also in agreement with reports made by Lawson (2011) on the evaluation of mangrove water quality in Lagos in the Central African ecoregion.

The values recorded for Dissolved Oxygen (DO) in the present study were similar to those reported for many other polluted Nigerian waters including 6.9 - 8.8 mg/l for Lagos lagoon, 4.00-7.50 mg/l for Luubara creek in Niger Delta and 1.20 - 9.40 mg/l documented in Victor and Onmivbori and Edokpayi and Osimen for some polluted water bodies in Nigeria (Spalding *et al*., 2010; Lawson, 2011;; Ramsar-Mava-Unep, 2012).

All the values recorded fell outside the "no effect" range of 0–0.3 mg/l for drinking water However, the values fell within the 0.1–10 mg/l range for which slight adverse health effects can be expected in children and sensitive individuals. High organic content from human faeces decayed plant materials and domestic and sawmill wastes that found their ways intothe lagoon may be responsible for the low dissolved oxygen. The level of oxygen depletion depends primarily on the amount of waste added, the size velocity, turbulence of the stream and the temperature of the water. Frequent deaths of fish in water in fact do not come from toxicity of matters but from deficit of consumed oxygen from biological decomposition of pollutants (UNEP, 2007; FAO, 2009; Luo *et al*., 2010; Lawson, 2011). Various studies suggestthat dissolved oxygen in waters depends on water temperature, partial pressure of oxygen in atmosphere and salt contents in waters (Spalding *et al*., 2010; Lawson, 2011). It has been proved that higher Dissolved Oxygen concentration might be due to the cumulative effect of higher wind velocity coupled with heavy rainfall and the resultant freshwater mixing (Adriamalala, 2007; FAO, 2009; Luo *et al.*, 2010; Lawson, 2011) .

The Biological Oxygen Demand (BOD) values ranged from 0.98 to 7.03 in the present study and similar results were found for other African mangrove forest (UNEP, 2007; FAO, 2009; Spalding *et al*., 2010 ; Lawson, 2011). BOD is an indicator for the amount of the biodegradable organic substances. BOD also accounts the oxygen that is required in organic matter decomposition (Amadi *et al.*, 2010). BOD value will rise when there is more organic matter such as leaves; wood, waste water or urban storm water runoff took place at the river water (Seca Gandaseca *et al*., 2011).

Alkalinity in the present study values ranged from 39.01 to 1834 mg/l 307.07±191.78 mg/l in Ghana and 77.78 to ± 444.33 in Cameroon. Moderately alkaline water (less than 350 mg/L) in combination with hardness forms a layer of calcium or magnesium carbonate that tends to inhibit corrosion of metal piping. High alkalinity (above 500 mg/l) is usually associated with high pH values, hardness and high dissolved solids. Water with low alkalinity (less than 75 mg/l) especially some surface waters and rainfall is subject to changes in pH due to dissolved gasses that may be corrosive to metallic fittings. This study revealed that, mangrove waters were more alkaline in Cameroon than in Ghana.

The observed changes in EC values were due to fresh water influx and mix up with ebb and flow. The relatively high Electrical Conductivity in Cameroon may be due to high organic residue in the water body, as high temperature favours degradation of organic pollutants. Similar results were reported by Amadi *et al*. (2010), Gandaseca *et al*. (2011), Lawson (2011).

Total Dissolved Solids (TDS) varied between 0.22 and 5875 ± 4830.67 mg/l in Ghana and 28.20 ±1.30 to 2807.50 ± 425.31 g/l in Cameroon. The EPA Secondary Regulations advise a maximum contamination level (MCL) of 500 mg/liter for TDS. When TDS levels exceed 1000 mg/L it is generally considered unfit for human consumption. A high level of TDS is an indicator of potential concerns and warrants further investigation. Most often high levels of TDS are caused by the presence of potassium, chlorides and sodium. These ions have little or no short-term effects but toxic ions (lead arsenic, cadmium, nitrate and others) may also be dissolved in the water. Most aquatic ecosystems involving mixed fish fauna can tolerate TDS levels of 1000 mg/l (Alongi *et al*., 2011; Conchedda *et al*., 2011).

High TDS indicates hard water. High TDS results is undesirable taste which could be salty, bitter, or metallic. It could also indicate the presence of toxic minerals. Some Dissolved Solids come from organic sources such as leaves, silt plankton and industrial waste and sewage (Spalding *et al*., 2010; Ramsar-Mava- UNEP, 2012).

Others include runoff from urban areas road salts used on street and in fertilizers and pesticides used in farms; inorganic materials such as rocks and air that may contain calcium bicarbonate, nitrogen, iron,, phosphorous, sulfur and other minerals (FAO, 2009; Lawson, 2011). Many of these materials form salts which are compounds that contain both metals and nonmetals. Salts usually dissolve in water forming ions. Ions are particles that have a positive or negative charge which form the total dissolved Solids (Amadi *et al.*, 2010; Gandaseca *et al*., 2011).

Total Suspended Solid (TSS) values ranged from 15.75± 0.96 to 63.50 ± 20.49 mg/l in Ghana and 20.75 ± 6.24 to 68.50±20.49 g/l in Cameroon. It is clearly known that TSS are solid materials including organic and inorganic, that are suspended in the water. These would include silt, plankton and industrial wastes. Sources of total suspended solids include erosion from urban runoff and agricultural land industrial wastes, bank erosion, bottom feeders, algae growth or wastewater discharges (UNEP, 2007; FAO, 2009). High concentrations of suspended solids can lower water quality by absorbing light. Waters then become warmer and lessen the ability of the water to hold oxygen necessary for aquatic life. Because aquatic plants also receive less light, photosynthesis decreases and less oxygen is produced (Amadi *et al.*, 2010; Gandaseca *et al*., 2011).

The combination of warmer water less light and less oxygen makes it impossible for some forms of life to exist. Suspended solids clog fish gills reduce growth rates decrease resistance to disease and prevent egg and larval development. Particles that settle out can smother fish eggs and those of aquatic insects as well as suffocate newly-hatched larvae. The material that settles also fills the spaces between rocks and makes these microhabitats unsuitable for various aquatic insects such as mayfly nymphs, stonefly nymphs and caddis fly larva (Spalding *et al.*, 2010; Ramsar-Mava- UNEP, 2012). TSS and TDS are strongly correlated. The more salts are dissolved in the water; the higher is the value of the electric conductivity. High purity water that contains no salts or minerals has a very low electrical conductivity (Crona *et al.*, 2009; FAO, 2009).

For turbidity, Cameroon and Ghana recorded the highest values mainly in the dry season because the volume of the water was getting smaller as the dry season was reaching its peak and most of the tributaries were getting turbid because of anthropogenic activities. Lower values recorded in both countries at the end of dry and the beginning of the rainy seasons can be explained by the fact that at that time all the tributaries had dried up thus reducing the influx of suspended matter for the dry season and for the rainy season the occurrence of dilution by rainwater.

The low values recorded in May which was the beginning of the rainy season could be due to dilution by the rainwater. The turbidity values for Ghana and Cameroon (both in the dry season) were far higher than the no effect range of 0-1 NTU for drinking water use (WRC, 2003). This indicates that in the dry season the water carried an associated risk of disease transmission due to infectious disease agents and chemicals absorbed on to particulate matter. In addition turbidity was visible and had aesthetic effects on appearance (Spalding *et al*., 2010).

Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g.. whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea cramps diarrhoea and associated headaches (Singh *et al.*, 2011; Singhard Suraj. 2012).

Some of the sulphate values fell out of ''the no effect range'' of 0-200mg/l for drinking water use (WRC, 2003). This implies that no adverse health aesthetic effects were expected. Sulphate when added to water tends to accumulate to progressively increasing concentration (WRC, 2003). This could account for the high levels recorded in both countries under anaerobic conditions bacteria use sulphate as an oxygen source. The much lower sulphate values recorded in Ghana could be because sulphate easily precipitate and settles to the bottom sediment of the river (Kairo and Bosire, 2009; Conchedda *et al*., 2011).

For phosphate, all the sampling locations were above the detection limit (<0.001 mg/l) of the method used. This indicated that the farmers along the river surrounding the mangrove forest probably used N-P-K fertilizer at least during the sampling period which has the potential to being leached or washed into the river.

For nitrate, the high levels of nitrate recorded in Cameroon, may have been due to surface run-off from farms and animal pens into the river from the early rains. All the nitrate values were within the ''no effect'' range of 0-6 mg/l for drinking water in Ghana but partially in Cameroon. (WRC, 2003; Singare *et al*., 2010; Singh *et al*., 2011). This indicated that no adverse health effects were expected in Ghana, but most of the time in Cameroon during the sampling period.

The lower values of chloride in May could be justified by the fact that, there were little or no irrigation returns flows. It was just the beginning of the rainy season. Most of the values recorded were out of the ''no-effect'' range of 0-100mg/l for drinking water use (WRC, 2003; Abdul-Razak *et al*., 2009). This means that adverse health affects aesthetic effects and effects on household items were sometimes expected.

For potassium, all the sampling locations were above the detection limit (<0.001 mg/l) of the method used. This indicated that the farmers along the river surrounding the mangrove forest, probably used N-P-K fertilizer at least during the sampling period which has the potential to being leached or washed into the river. (Abdul- Razak *et al*., 2009; Singare *et al*., 2010; Lawson, 2011)

5.2.4. Soils Characteristics

It was observed that, the soils in the *Rhizophora* stands were the most acidic in Ghana and Cameroon. The relative low pH levels observed in these soils are attributable to the presence of pyrites Pyrites upon oxidation and hydration generally produce hydrogen sulphide which hydrolyses into sulphuric acid to reduce the soil pH(Amatekpor, 1989; Allotey, 2008). PH of the soil was near neutral due to the dynamic water percolation in the soil which is influenced by tides (UNEP- WCMC, 2012). The results obtained in this study corroborate the findings of other studies (MacDonald *et al*., 1987; Amatekpor, 1989; Spalding *et al.,* 2010; Ramsar-MAVA- UNEP, 2012).

The results for conductivity obtained for the sediment in the mangrove sites indicated that, the sediments can be classified as moderately saline in Ghana, and strongly saline in Cameroon. Salinity in excess of 4 ‰ has been reported to be detrimental to plant growth; Salinity is also known to cause low water permeability for roots, ion toxicity, drought stress, and non-availability of nutrients high concentrations of soluble salts are then detrimental to plant growth. Soils are definitely rated based on their degree of salinity (Flower & Imbert, 2006; Allotey, 2008; Spalding *et al*., 2010).

For Organic Matter (OM), the high content in *Rhizophora* in Ghana and Cameroon implies that the soils may have adequate supply of N, P and S among other nutrients elements. Organic matter is known to supply most of the N and S and half of P taken up by fertilizers crops (Davies *et al*., 1993; UNEP, 2007). Furthermore the role of Organic matter in soil aggregation, general improvement of physical chemical and hydrological properties of soils, and reduction of susceptibility of soils to erosion are well known (Davies *et al*., 1993; FAO, 2009; Conchedda *et al.*, 2011). The relatively high percentage of Organic Matter recorded in the mangrove sites could primarily also be attributed to input from the mangrove form of dead leaves and decaying stilt roots (Amatekpor, 1989; Ajonina , 2008; Allotey, 2008;).

ECEC and base saturation have been used to indicate the fertility status of the soils. According to FAO (1976) soils with ECEC of > 20 cmol/kg are indicative of high suitability of the soils for crops production (Edem and Ndon, 2001; FAO, 2009). From the results of this study, the soils of Cameroon are more fertile compared to those of Ghana. Values of cation Exchange capacity in both countries reflect the overall influence of regular replenishment by seepage and tides. In all the mangrove stands, the value of Exchangeable Ca content were below 4.0 cmolkg-1 regarded as critical level for fertile soils (UNEP, 2007 ; FAO, 2009; Spalding *et al*., 2010).

Available P levels were low in the *Avicennia* and *Rhizophora* stands with values ranging from 6.06 to 7.72 mg/kg indicating deficiency level in all the profiles since the mean value of 7.72 mg/l P is below the critical level of 10mg/l Bray P-1 (Effiong *et al*., 2010; Spalding *et al*, 2010; Conchedda *et al.*, 2011). The apparent acid nature of the soil, suggests that Al and iron (Fe) become very soluble and increase to toxic level, forming very insoluble phosphate compounds, and thus are unavailable to plants (Allotey, 2008; Effiong *et al*., 2010).

The soils generally have narrow C/N ratios; this implies that microbial activities which are necessary for the release of nutrient element may not be hindered. This is consonant with the report of Allotey (2008) that plant residues with C/N ratios of 20:1 or narrower have sufficient N supply micro-organisms responsible for decomposition and also to release N for plant use while residues with C:N ratios of 20:1 to 30:1 supply sufficient N for decomposition but enough to result in much release of N for plant use.

It was observed that, *Avicennia* had the highest percentage of silt, while the other two stands had relative low percent silt. This high accumulation of silt in *Avicennia* stand provides a suitable habitat for the settling of sediments and detritus from the water column to the bottom. In addition, the tidal movement are relatively restricted in this site (UNEP, 2007; Allotey, 2008; Spalding *et al.*, 2010). The silt/ clay ratio values were higher in Cameroon, compared to Ghana. According to Amatekpor (1989) and Allotey (2008), soil with silt/ clay ratio below 0.15 is of old parent materials, while soils with silt/ clay ratio above 0.15 are of young parent materials. Also Asiamoa (1973) reported that soil with silt/ clay ratios of less than 0.25 are at an advance stage of weathering, while those with ratio greater than 0.25 indicated a low degree of weathering. Generally the results showed that, the soils had silt/ clay ratios greater than 0.25 indicating that they are likely to have weatherable minerals needed for plants.

Litterfall values for mangrove forests worldwide range from 2 to 16 t ha−1 per year (Twilley and Day, 1999). It was apparent that, the values of annual litterfall production from the mangrove sites of Ghana (average annual production: 2.5 t ha−1 per year) and those of Cameroon (average annual production: 4.5 t ha−1 per year) actually fall within this range documented for tropical and subtropical mangroves and are little bit higher than those of a riverine mangrove wetland (1.7 t/ha/year) reported by Arreola-Lizárraga *et al*. (2004). However, the estimates for *A.Germinans,R. racemosa* and mixed (*Avicennia* and *Rhizophora*) forests are higher when compared to forests of the same species in other regions including other areas in low latitudes (Fernandes 2003; Arreola-Lizárraga *et al*., 2004; Aké-Castilho *et al*., 2006; Spalding *et al*., 2010).

The sequence of the components of litterfall found in this study in Cameroon and Ghana (leaves> Twigs > fruits/seeds> flowers) is consistent with data obtained in other mangroves

(Mackey and Smail, 1995; Parkinson *et al*., 1999, Ochieng and Erftemeijer 2002, Sherman *et al*., 2003). The production of leaves usually represented the largest fraction (> 50%), but in some cases can exceed 80%, regardless of latitude, weather conditions or type of forest as observed in this study (Day *et al.*,1996; Mehlig, 2001; Kairo and Bosire, 2009;).

The relative contribution of the litter components is similar to data reported in the literature for mangrove ecosystems. The contribution of reproductive parts in litter in the study sites in both countries is among the highest reported in the literature (table1) suggesting a vegetation which is vigorous enough to allocate a great part of its energy for reproduction while at the same time requiring frequent replacement (Bosire *et al.,* 2006; Dahdouh-Guebas, 2011).

A relative high litter production rate (as observed in this study) indicates optimal habitats for the mangrove allowing the primary net productivity of mangrove forests to be favourably compared with tropical forests (Clough 1992. Saenger & Snedaker 1993, Concheda *et al*., 2011). Considering the different physiographic types, the litter production ranged from 320 to 1700 g.m-2.year-1 for riverine forests, from 430 to 1.082 g.m-2.year-1 for fringe forests and 250 to 970 g.m-2.year-1 for bay forests (Lugo *et al*., 1988. Spalding *et al*. 2010).

According to Pool *et al*. (1975) and Crona *et al.* (2009) the production rate of mangrove litter is closely related to fresh water supply, which is higher in riverine forests (Lugo and Snedaker. 1974 and Spalding *et al.*.2010).

Seasonal fluctuations have been found in litter fall of several mangrove species notably of the genera *Avicennia* , *Bruguiera*, *Rhizophora*, and *Sonneratia* (Spalding *et al*., 2010). Litter fall can

also be observed throughout a year with little (Luzhen Chen, 2009; Conchedda *et al.*, 2011) or marked (Day *et al*., 1996; Wafar *et al*., 1997; Bosire *et al*., 2006) seasonal variations.
The major flowering and fruiting season of *R. racemosa* and *A. germinans* in Ghana and Cameroon was mainly in the dry season when the air temperature day length and evaporation are at their highest. The trend of total litter fall products followed the changes of flower and fruit litter fall products (Table 1). It was observed that total litter fall decreased in the rainy season (Krauss *et al*., 2008; Kairo and Bosire, 2009; Dahdouh-Guebas., 2011).

In the present study, litter fall took place throughout the year during which peak production occurred mainly in the dry season when leaf fall is greater as predicted by the production curve. This pattern is similar from most investigations conducted in tropical ecosystems, where the highest deposition of litter occurred in the dry season (Regina De Moraes, 1999; Krauss *et al*., 2008; Conchedda *et al.*, 2011). The yearly change of litter fall products increased with an increase in air temperature and decrease of rainfall (Kairo and Bosire, 2009; Spalding *et al*., 2010). It was apparent that periodicity of litterfall is largely influenced by annual climatic variations (Liu *et al*., 2003; Bosire *et al*., 2006; Spalding *et al.*, 2010; Alongi, 2011).

Mokolensang *et al*., 1998 (Japan) reported also a seasonal pattern of increase of leaf litter during the dry months for mixed *Avicennia germinans*, *Rhizophora racemosa* and pure *A. germinans* and *R. racemosa* forests in Japan in the Indo-Pacific region. Similar to the result obtained by Kairo and Bosire (2009) who conducted a research on mangrove in Kenya in the East African ecoregion and by Engankou (2009) who studied Avicennia and Rhizophora forest in Cote d'Ivoire added to Conchedda *et al*.(2011) who studied mangrove in Senegal in the West and Central African ecoregion. However, the results of some other studies seemed to indicate that litterfall peaks do not have any relation with the rainfall variation (Luzhen Chen *et al*., 2009; Spalding *et al*., 2010). This emphasizes the need for long-term litterfall studies to confirm seasonal periodicity and establish relations between rainfall and litterfall peaks.

In the present study, nutrients inputs through litterfall (mg/ha) in the mangrove forest studied in Ghana and Cameroon were respectively for Nitrogen (N), 88.34 and 20230.46, Phosphate (P), 723.93 and 342.52, Potassium (K), 451.18 and 227.17; Calcium (Ca), 882.77 and 275.53 and Magnesium (Mg), 768.50 and 275.53. It was apparent that, nutrient inputs through litterfall (mg/ha/year) at each studied forest in each country are in the lower part of the spectrum of values compiled by Alongi (1996) for lowland tropical forests which include mangrove forest as follows (34200-158000 N, 1900- 6700 P, 12700 - 59300 K,17400-114200 Ca, and 7200-26800 Mg). Relative low inputs of nutrients through litterfall in the studied forests were due to a combination of low rates of return of litter to the soil and low concentrations of nutrients in the fallen material. N inputs in the studied sites are quite low but it was noted that the lowest value was found particularly in Ghana, and can therefore be considered as the lowest N inputs recorded for tropical forests. This situation can be due to low rates of return of litter to the soil surface and low concentrations of nitrogen in the fallen material (Spalding *et al*., 2010). It was observed that, nutrient content of mangrove litterfall may vary between countries in the West and Central African Ecoregion as a result of the different biological and chemical processes occurring in each study area (UNEP-WCMC, 2007; Krauss *et al*., 2008; Dahdouh- Guebas, 2011). The results of the present study confirmed this statement.

Mean concentrations of nutrients in leaf litter in Ghana and Cameroon are in the range of other tropical forests (Crona et *al*., 2009; Spalding *et al.,* 2010; Conchedda *et al.,* 2011). Values of nutrients in Ghana sites were lower, mainly those of N and P, making evident that leaf litter quality is unique to each ecosystem, according to soil properties and climate (FAO, 2009, Alongi, 2011). Leaffall determined the seasonality of mineral return to soil in both countries (Spalding *et al.,* 2010, Conchedda *et al.,* 2011). A seasonal pattern was therefore derived from curve of litter production and not from concentration values which were quite uniform during the entire period of study.

Relative high concentrations of N, P and Mg in the leaf litter of mangrove sites in Cameroon may be explained by the richness of those elements in the topsoils of mangrove sites. On the other hand, Ca was highly concentrated in leaves of mangroves in Ghana. In both countries, the relative great variability of results was due to differences in the amount and quality of litter, according to edaphic and climatic conditions found in each mangrove ecosystem. Nutrients are not often quantified in litterfall studies, what restricts the possibilities for comparisons. In both countries nutrient concentrations were constant across the leaf fall cycle, but the values for N were greater in Cameroon especially during the dry season. This is probably due to greater accumulation of marine aerosols on the mangrove forest canopy, as rainfall is lower at that season. While comparing both countries it was appeared that, the annual return of nutrients to the soil was relatively high in Ghana sites for P, K, Ca and Mg and far higher in Cameroon sites for

N content. All those results in nutrients in both countries were within the ranges reported by Owusu-Sekyere, 2006; Krauss *et al*., 2008; Egnankou, 2009; Spalding *et al.*, 2010 and Dahdouh-Guebas, 2011) for African Ecosystems.

For The ratio between litterfall mass and litterfall nutrient content gives the nutrient use efficiency (NUE) (Vitousek, 1982; Nelda, 2006). Globally, mangrove in tropical forest are more or less inefficient in the use of nitrogen although relatively great amounts of leaf litter are produced (Alongia, 2005; Nelda, 2006).

Mangrove forest in Cameroon with a leaf litterfall mass of 46.08 t/ha presented for nitrogen, a NUE of 13.44, which was relatively low compared to that reported by Nelda Dezzeo for a tropical forest. Ghana mangrove forest on the other hand with leaf litterfall mass of 24.64 t/ha and NUE for nitrogen of 27.93 was less inefficient compared to Cameroon, and showing a relative high level of adaptation to the low nutrient (nitrogen) availability (Nelda, 2006, Sekyere *et al*., 2006, UNEP, 2007).

CHAPTER 6
6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Litter production (Litterfall)

- Generally, in Ghana and Cameroon it appeared that the leaf and twig /branch litter components of *Avicennia* , *Rhizophora* and mixed stands were relatively high in the dry season and 80% of total litterfall was made up of leaf component.

- In both countries, the production of leaf and branch/twig (Vegetative) and flower and fruit (Reproductive) components were observed all over the year and were relatively high in the dry season

- The highest values in nutrient content (N, P, K, Mg and Ca) were shown from March to October in Cameroon and December in Ghana. Nutrients content in Cameroon seemed to have no relation with the monthly rainfall variation while in Ghana there is a strong relation between nutrient content and Rainfall.

- N, P and leaves exhibited strong contribution in discriminating the two countries and account for most of the expected variations in litter production and nutrient content, while other parameters Mg, Fruits/seeds and branches showed less contribution in explaining the variation between Ghana and Cameroon.

Forest Structural characteristics

- For *Avicennia* stands it has been shown that Ghana has the mean highest *Avicennia* density, with 6075 stems/ha Cameroon has lesser density (1800) stems/ha) of smaller size (Ba=44.21m²/ha). The highest average canopy height was in Cameroon (50.1m), while the lowest was 7.3m in Ghana

- For *Rhizophora* stands it appeared that Cameroon has the mean highest *Rhizophora* density with 24375 stems/ha. Ghana has lesser density (8225 stems/ha) of smaller size (Ba=44.21m²/ha).

- In Mixed stands, it has been observed that Ghana has the mean highest species density with 10200 stems/ha (Figure 12). Cameroon has lesser density (6100 stems/ha) of smaller size with a larger basal area (Ba= 32.76m²/ha).

- Mangrove forest in Cameroon and Ghana in terms of diameter distribution, basal area, stem density, volume, mean and dominant height are very similar to many tropical forests and in particular to Central and West African ones.

Water Quality

- In the present study air temperature varied between varied between 26 to 30.1 º C in Ghana and 26.80 to 29.5 º C in Cameroon and water temperature ranged from 25.2 to 30 ºC in Ghana and 22.3 to 26.3 ºC in Cameroon.

- The Rainfall recorded in this study varied between 50 mm to 300 mm in Ghana and 100 mm to 600 mm in Cameroon. Rainfall greatly affected the dynamics of the environments transports nutrients and allochthonous materials and alters the water's visual physical and chemical characteristics

- This study revealed that, mangrove waters were more alkaline in Cameroon than in Ghana and most of the physico-chemical parameters were high in Cameroon compared to Ghana

Soil Characteristics

- In both countries sediments in *Avicennia* had the highest percentage of silt (32.80±9.93%), while the other two stands had a relatively low percent silt.
- Soil pH values in Ghana ranged from 5.02±1.09 in the *Rhizophora* stand to 6.22±0.64 in the mixed stand and in Cameroon 4.46±0.55 in the *Rhizophora* to 4.62±0.52 in the mixed stand. The soils in the *Rhizophora* stands were the most acidic in Ghana and Cameroon.

- Accumulation of silt in *Avicennia* stand provides a suitable habitat for the settling of sediments and detritus. In addition the tidal movement were restricted to this site and soils had silt/ clay ratios greater than 0.25.

- Effective Cation Exchange capacity (ECEC) valuesranged from 4.57 to 6.62 cmolkg-1 in Ghana and 6.88 to 25.53 cmolkg-1 in Cameroon. The mangrove soils of Cameroon were more fertile compared to those of Ghana.

6.2 RECOMMENDATIONS

Results from this study are very preliminary owing to the limited time of two years (One year in each country). However, they indicate encouraging insights into assessing the importance of mangrove using parameters of ecological value (Litterfall, structural characteristics, water and soil properties) in the two countries of the West and Central ecoregion. The following recommendations can be made for further studies:

- Determine the impact of litterfall on the overall productivity of mangrove forest. Monitoring of litter production must be done for at least five to ten years, for a better knowledge of the role of litterfall in the productivity of mangrove ecosystem

- Efficiently assess the growth and the structural development of a mangrove forest. There is a need to conduct a research on structural characteristics of key mangrove species (*Rhizophora* and *Avicennia*) over a longer time spans for at least five to ten years.

- Deeply address the **v**ariability of the mangrove forests in terms of soil water salinity, knowing that salinity is one of the major factors influencing and structuring life in the mangrove ecosystem. A specific study on spatial and temporal variation in soil water in the studied mangrove forest needs to be carried out, with adequate number of measurements covering the local variation in space and time.

- Integrate the local communities' knowledge or perceptions of the mangrove biodiversity functions, when studying the ecological processes. There is a need to understand and include the knowledge of how mangrove ecosystem is influenced by socio-economy and livelihoods perspectives.

- Addressthe adaptation to climate change/variability on mangrove ecosystem via a participatory action research on issues relevant to the daily life of coastal communities and on their adaptive capacity to deal with the high degree of uncertainty that characterizes African mangrove ecosystems subjected to the consequences of climate change.
- Focus on below-ground and above-ground roots carbon stocks, growth rates and carbon sequestration potentials of mangroves through lying out and periodically measuring permanent sample mangrove plots.
- Conduct a research on ecological linkages within mangrove ecosystems as well as between mangrove and other coastal ecosystems.

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APPENDICES

Appendix 1: Main contrasts in mangrove ecosystems between Ghana and Cameroon

Type of information	Ghana	Cameroon	Gaps in information	Contribution of the study
Climate and vegetation	- Savanna coastal zone - Small size of mangrove trees - Annual rainfall :625 to 1600 mm - Existence of a dam in Volta River	- Humid forest coastal zone - Big size of mangrove trees - Annual rainfall :2000 to 6000 mm - Non- existence of a dam in Wouri River	Insufficient data about the growth of seedlings -	The size of the seedlings will be determine in each mangrove stand in both countries -
General information (size, rate of degradation)	- Entire country covers about 239,000 km^2 with a coastline of 550 km long and a mangrove vegetation which varies from 20 to 167 km^2 - Rate degradation: 76% - Mangrove falling in protected areas:1.5% - Percentage of African mangrove cover:0.5%	-Entire country covers about 475,000 km^2 with a coastline of 402 km long and a mangrove vegetation which is about 1957 km^2 - Rate degradation:72% - Mangrove falling in protected areas:7.1% - Percentage of African mangrove cover:6 %	-	-
Mangrove forest structure	- Maximum height of trees : 30 m - *Avicennia*: density seedlings:2400/ha - *Rhizophora*: trees	- Maximum height of trees : 60 m -Density of trees:1,247.5 stems/ha - Basal area:42.36 m^3	Insufficient information on mangrove forest structure parameters and specifically the importance value indicator of	Complete information on mangrove forest structure parameters in terms of species (*Rhizophora*,*Avicen*

Type of information	Ghana	Cameroon	Gaps in information	Contribution of the study
	density:3800 stems/ha; seedlings density:15000/ha		mangrove trees	*nia*) and type of vegetation(trees,saplings and seedlings)
Litterfall	- Extensive Study showed that -High litter production implies good regeneration - The proportion of leaf litter is high	- Extensive Study showed that Litterfall is higher in *Avicennia* compared to *Rhizophora*	Scarce information on litterfall production in mangroves areas in both countries	Improve knowledge on mangrove litterfall production in both countries
Mangrove soil	- Sulphide and salinity are stress factors that affect growth	- Sulphide and salinity are stress factors that affect growth	Scarce soils'information on Physico-chemicals, nutrients parameters in mangroves areas	Improve knowledge on mangrove soils parameters (Physico-chemicals,nutrients and heavy metals) and their interraltionships
Mangrove water	-Nutrient(nitrate, phosphate, sulphate) in porewater and TDS and conductivity are higher in *Rhizophora than in Avicennia* and the river	-Mangrove salinity: rainy season: less than 10‰; dry season: 4-20‰	Scarce water information on Physico-chemicals,nutrients parameters in mangroves areas in both countries	Improve knowledge on mangrove water parameters (Physico-chemicals,nutrients and heavy metals)
Mangrove Management plan	Existence of a code of conduct for sustainable management	Existence of a code of conduct for sustainable management	Insufficient database for better implementation	Provide more scientific ecological information
Ecological value or importance of	Acknowledged the importance of regeneration	Acknowledged the importance of regeneration	Insufficient database	Provide more scientific ecological information

Appendix 2: Tukey Honestly Significant Difference (HSD) for ANOVA performed for Log transformed data of Litterfall and leaf nutrients parameters from Ghana and Cameroon

Number	Leave	Twigs	Flower	Fruit	N	P	K	Ca	Mg
MxGH 1 AVGH 2	.994	.750	0.985	.998	1.000	.775	.099	.551	.914
RHGH 3	.015	.750	0.000	.031	1.000	.284	.998	.000	.000
MxCA 4	.000	.000	0.322	.059	.000	.000	.000	.000	.000
AVCA 5	.046	.324	0.463	.269	.000	.000	.001	.000	.000
RHCA 6	.000	.072	0.444	.356	.000	.000	.000	.000	.000
AVGH 2 MxGH 1	.994	.750	0.985	.998	1.000	.775	.099	.551	.914
RHGH 3	.076	.074	0.000	.099	1.000	.009	.029	.000	.000
MxCA 4	.000	.014	0.075	.170	.000	.000	.341	.000	.000
AVCA 5	.180	.985	0.132	.532	.000	.000	.746	.000	.000
RHCA 6	.000	.744	0.124	.639	.000	.000	.000	.000	.000
RHGH 3 MxGH 1	.015	.750	0.000	.031	1.000	.284	.998	.000	.000
AVGH 2	.076	.074	0.000	.099	1.000	.009	.029	.000	.000
MxCA 4	.001	.000	0.000	1.000	.000	.000	.000	.000	.002
AVCA 5	.999	.010	0.000	.946	.000	.000	.000	.000	.000
RHCA 6	.049	.001	0.000	.895	.000	.000	.000	.000	.000
MxCA4 MxGH 1	.000	.000	0.322	.059	.000	.000	.000	.000	.000
AVGH 2	.000	.014	.075	.170	.000	.000	.341	.000	.000
RHGH 3	.001	.000	.000	1.000	.000	.000	.000	.000	.002
AVCA 5	.000	.095	1.000	.985	.566	.993	.988	.755	.008
RHCA 6	.887	.389	1.000	.961	.000	.000	.000	.000	.000
AVCA 5 MxGH 1	.046	.324	.463	.269	.000	.000	.001	.000	.000
AVGH 2	.180	.985	.132	.532	.000	.000	.746	.000	.000

RHGH 3	.999	.010	.000	.946	.000	.000	.000	.000	.000
MxCA 4	.000	.095	.000	.985	.566	.993	.988	.755	.008
RHCA 6	.016	.982	.000	1.000	.000	.000	.000	.000	.573
RHCA 6 MxGH 1	.000	.072	.444	.356	.000	.000	.000	.000	.000
AVGH 2	.000	.744	.124	.639	.000	.000	.000	.000	.000
RHGH 3	.049	.001	.000	.895	.000	.000	.000	.000	.000
MxCA 4	.887	.389	1.000	.961	.000	.000	.000	.000	.000
AVCA 5	.016	.982	1.000	1.000	.000	.000	.000	.000	.573

The mean difference is significant at the Alpha= 0.05 level

Appendix 3: Principal Component Analysis showing eigenvectors for litterfall

Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Flower	**0.382**	-0.105	-0.176	-0.53	0.347
fruit	**0.393**	-0.093	0.348	0.061	-0.123
twig	**-0.364**	-0.19	-0.178	0.615	0.253
leave	0.151	**0.564**	-0.575	0.001	-0.323
N	**-0.287**	**0.413**	0.487	-0.223	0.359
P	**-0.384**	-0.14	0.205	-0.281	-0.723
K	-0.072	**0.651**	0.202	0.137	0.028
Ca	**-0.396**	-0.103	-0.076	-0.339	0.151
Mg	**-0.389**	0.018	-0.399	-0.272	0.144
Eigenvalues	5.98	2.23	0.442	0.289	6.49E-02
%Variation	66.4	24.8	4.9	3.2	0.7

Appendix 4: ANOSIM pairwise test for Litterfall

Groups	R Statistic	Significance Level (%)
MxGH, AvGH	0.179	1.1
MxGH, RhGH	0.484	0.1
MxGH, MxCA	0.978	0.1
MxGH, AvCA	0.993	0.1
MxGH, RhCA	0.978	0.1
MxGH, RhCA	0.978	0.1
AvGH, RhGH	0.772	0.1
AvGH, MxCA	0.889	0.1
AvGH, AvCA	0.933	0.1
AvGH, RhCA	0.882	0.1
RhGH, MxCA	0.781	0.1
RhGH, AvCA	0.779	0.1
RhGH, RhCA	0.762	0.1
MxCA, AvCA	0.1	5.5
MxCA, RhCA	0.587	0.1
AvCA, RhCA	0.911	0.1

Appendix 5: Character axis correlations of each variable in the first two canonical variate axis for litterfall production

	CV 1	CV 2	CV 3	CV4	CV5
LFlower	0.023917	-0.674245	0.016239	-0.136453	-0.473418
Ltwig	-0.120777	0.160327	-0.273524	0.104264	-0.643217
Lfruit/seed	0.048898	-0.328362	-0.000258	-0.097074	-0.496328
Lleave	-0.150974	-0.241427	-0.402857	0.326469	-0.438915
Lnutr N	-0.541440	0.057506	0.354389	-0.636112	-0.174865
LnutrP	-0.511378	-0.014335	-0.248253	0.420892	0.355214
LnutrK	-0.463665	-0.011076	-0.040121	0.530244	0.269799
LnutrCa	-0.453523	-0.032690	-0.082875	0.507758	0.262299
LnutrMg	-0.509360	0.018054	-0.197915	0.413314	0.364969
Eigenval	7.091606	0.73983	0.24641	0.21517	0.004854
Cum.Prop	0.854629	0.94379	0.97348	0.99941	1.000000

Appendix 6: Principal Component Analysis showing eigenvectors for structural characteristics

Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Nbsp	**0.421**	-0.02	0.301	0.657	-0.424
MnH	**-0.238**	**0.536**	-0.145	-0.081	-0.263
TotBA	**-0.297**	**-0.454**	0.338	-0.437	-0.602
TotVol	**-0.419**	0.031	0.566	0.148	0.531
MnHha	**-0.243**	0.531	-0.159	-0.021	-0.253
Dsty	**0.425**	**-0.046**	-0.107	-0.461	0.193
BA	**-0.284**	**-0.463**	-0.646	0.308	0.041
Vol	**-0.425**	-0.074	0.001	0.201	-0.066
Eigenvalues	5.44	2.39	0.104	4.35E-02	2.02E-02
%Variation	68.1	29.8	1.3	0.5	0.3

Nbsp =Number of species; MnH = dominant height; Tot BA =Total basal area; Tot vol =Total volume; Mnha = Mean height/ha; Dsty = Density; BA = Basal Area ; Vol = Volume.

Appendix 7: Character axis correlations of each variable in the first two canonical variate axes

Vegetation parameters	**CV1**	**CV 2**	**CV 3**
MnHha(mean height/ha)	-0.907915	0.407089	0.099846
MnH (dominant height	-0.973894	0.010984	-0.226736
BA(Basal area)	-0.998951	-0.040281	0.021784
Tot BA (Total Basal area)	-0.988951	-0.040281	0.021784
Nbsp (number of species)	-0.040281-	-0.958951	0.021784
Dsty (density)	-0.040281	-0.998951	0.021784
Eigenval	3.80035	0.511992	0.08333
Cum.Prop	0.86457	0.981042	1.00000

Appendix 8: Tukey Honestly Significant Difference (HSD) for ANOVA performed for Log transformed data of Mangrove Surface water parameters from Ghana and Cameroon

Number	T°	Cond	TDS	TSS	Turb	Alk	Sal	DO	BOD	Sul	P	N	Na	K	Cl
MxGH 1 **AVGH 2**	.913	.000	.005	.011	.992	.033	.000	.000	.000	.000	1.000	.999	.000	.964	.524
RHGH 3	.762	.000	.152	.000	.000	.422	1.000	.000	.550	1.000	1.000	1.000	.977	.000	.747
MxCA 4	.000	.002	.000	.999	.998	.001	.000	.000	.000	.967	.000	.000	.001	.000	.066
AVCA 5	.000	.002	.000	.003	1.000	.612	.003	.000	.000	.967	.000	.056	.001	.000	.999
RHCA 6	.000	.017	.000	.001	.000	.883	.000	.000	.000	.967	.000	.999	.001	.000	.414
AVGH 2 **MxGH 1**	.913	.000	.005	.011	.992	.033	.000	.000	.000	.000	1.000	.999	.000	.964	.524
RHGH 3	1.000	.236	.848	.000	.000	.000	.000	.000	.000	.000	1.000	.997	.000	.000	.027
MxCA 4	.000	.000	.012	.035	.915	.941	.998	.000	.000	.000	.000	.000	.000	.000	.000
AVCA 5	.000	.000	.019	.999	.998	.000	.736	.000	.000	.000	.000	.137	.000	.000	.307
RHCA 6	.000	.000	.196	.000	.000	.395	.995	.000	.000	.000	.000	.978	.000	.000	.005
RHGH 3 **MxGH 1**	.762	.000	.152	.000	.000	.422	1.000	.000	.550	1.000	1.000	1.000	.977	.000	.747
AVGH 2	1.000	.236	.848	.000	.000	.000	.000	.000	.000	.000	1.000	.997	.000	.000	.027
MxCA 4	.000	.225	.000	.000	.000	.000	.000	.000	.000	.986	.000	.000	.011	.999	.727
AVCA 5	.000	.214	.000	.000	.000	1.000	.010	.000	.000	.986	.000	.040	.014	.983	.914

RHCA 6	.000	.045	.008	.999	.998	.038	.000	.000	.000	.986	.000	1.00 0	.013	.978	.995
MxCA4 MxGH 1	.000	.002	.000	.999	.998	.001	.000	.000	.000	.967	.000	.000	.001	.000	.066
AVGH 2	.000	.000	.012	.035	.915	.941	.998	.000	.000	.000	.000	.000	.000	.000	.000
RHGH 3	.000	.225	.000	.000	.000	.000	.000	.000	.000	.986	.000	.000	.011	.999	.727
AVCA 5	.001	1.000	1.000	.011	.992	.000	.931	.000	.000	1.000	.000	.000	1.000	.897	.155
RHCA 6	.886	.985	.901	.000	.000	.055	1.000	.000	.550	1.000	.428	.000	1.000	.999	.951
AVCA 5 MxGH 1	.000	.002	.000	.003	1.000	.612	.003	.000	.000	.967	.000	.000	.001	.000	.999
AVGH 2	.000	.000	.019	.999	.998	.000	.736	.000	.000	.000	.000	.056	.000	.000	.307
RHGH 3	.000	.214	.000	.000	.000	1.000	.010	.000	.000	.986	.000	.137	.014	.983	.914
MxCA 4	.001	1.000	1.000	.011	.992	.000	.931	.000	.000	1.000	.000	.040	1.000	.897	.155
RHCA 6	.000	.988	.947	.000	.000	.083	.957	.000	.000	1.000	.125	.000	1.000	.714	.645
RHCA 6 MxGH 1	.000	.017	.000	.001	.000	.883	.000	.000	.000	.967	.000	.019	.001	.000	.414
AVGH 2	.000	.000	.196	.000	.000	.395	.995	.000	.000	.000	.000	.999	.000	.000	.005
RHGH 3	.000	.045	.008	.999	.998	.038	.000	.000	.000	.986	.000	.978	.013	.978	.995
MxCA 4	.886	.985	.901	.000	.000	.055	1.000	.000	.550	1.000	.428	1.00 0	1.000	.999	.951
AVCA 5	.000	.988	.947	.000	.000	.083	.957	.000	.000	1.000	.125	.000	1.000	.714	.645

The mean difference is significant at the Alpha= 0.05 level

Appendix 9: Tukey Honestly Significant Difference (HSD) for ANOVA performed for Log transformed data of Mangrove porewater water parameters from Ghana and Cameroon

Number	T°	Cond	TDS	TSS	Turb	Alk	Sal	DO	BOD	Sul	P	N	Na	K	Cl
MxGH 1 AVGH 2	.995	.000	.000	.000	.000	.893	.000	.000	.000	.087	1.000	.942	.000	.000	000
RHGH 3	.249	.045	1.000	.000	.000	.862	.752	.037	.994	.862	1.000	.989	.634	.989	.000
MxCA 4	.000	.134	.000	.567	.875	.000	.000	.000	.000	.000	.000	.724	.000	.006	.052
AVCA 5	.000	.566	.772	.000	.000	.338	.000	.000	.000	.000	.000	.987	.000	.009	.054
RHCA 6	.000	1.000	.039	.000	.000	.000	.000	.000	.000	.000	.000	.722	.000	.128	.061
AVGH 2 MxGH 1	.995	.000	.000	.000	.000	.893	.000	.000	.000	.087	1.000	.942	.000	.000	.000
RHGH 3	.075	.010	.000	.022	.305	.234	.000	.000	.000	.002	1.000	1.000	.015	.000	.000
MxCA 4	.000	.002	.236	.000	.000	.000	.000	.000	.000	.000	.000	.189	.000	.000	.000
AVCA 5	.000	.000	.000	.567	.875	.027	.000	.000	.000	.000	.000	1.000	.000	.000	.000

RHCA 6	.000	.000	.000	.663	.931	.000	.000	.000	.000	.000	.000	.18 8	.00 0	.000	.000
RHGH 3 MxGH 1	.249	.045	1.000	.000	.000	.862	.752	.037	.994	.862	1.000	.98 9	.63 4	.989	.052
AVGH 2	.075	.010	.000	.022	.305	.234	.000	.000	.000	.002	1.000	1.0 00	.01 5	.000	.000
MxCA 4	.000	.998	.000	.000	.000	.000	.000	.000	.000	.000	.000	.32 8	.00 0	.001	.000
AVCA 5	.000	.000	.628	.000	.020	.954	.000	.000	.000	.000	.000	1.0 00	.00 0	.001	1.000
RHCA 6	.000	.030	.074	.567	.875	.000	.000	.000	.000	.000	.000	.32 6	.00 0	.024	1.000
MxCA4 MxGH 1	.000	.134	.000	.567	.875	.000	.000	.000	.000	.000	.000	.72 4	.00 0	.006	.054
AVGH 2	.000	.002	.236	.000	.000	.000	.000	.000	.000	.000	.000	.18 9	.00 0	.000	.000
RHGH 3	.000	.998	.000	.000	.000	.000	.000	.000	.000	.000	.000	.32 8	.00 0	.001	.000
AVCA 5	.016	.001	.000	.000	.000	.000	.000	.000	.000	1.000	.000	.31 3	1.0 00	1.000	1.000
RHCA 6	.045	.097	.004	.000	.000	.000	.000	.037	.994	1.000	.000	1.0 00	1.0 00	.907	1.000

AVCA 5 MxGH 1	.000	.566	.772	.000	.000	.338	.000	.000	.000	.000	.000	.987	.000	.009	.061
AVGH 2	.000	.000	.000	.567	.875	.027	.000	.000	.000	.000	.000	1.000	.000	.000	.000
RHGH 3	.000	.000	.628	.000	.020	.954	.000	.000	.000	.000	.000	1.000	.000	.001	.000
MxCA 4	.016	.001	.000	.000	.000	.000	.000	.000	.000	1.000	.000	.313	1.000	1.000	1.000
RHCA 6	.999	.657	.000	.022	.305	.000	.001	.000	.000	1.000	.098	.311	1.000	.934	1.000
RHCA 6 MxGH 1	.000	1.000	.039	.000	.000	.000	.000	.000	.000	.000	.000	.722	.000	.128	.061
AVGH 2	.000	.000	.000	.663	.931	.000	.000	.000	.000	.000	.000	.188	.000	.000	.000
RHGH 3	.000	.030	.074	.567	.875	.000	.000	.000	.000	.000	.000	.326	.000	.024	.000
MxCA 4	.045	.097	.004	.000	.000	.000	.000	.037	.994	.000	.000	1.000	1.000	.907	1.000
AVCA 5	.999	.657	.000	.022	.305	.000	.001	.000	.000	1.000	.098	.311	1.000	.934	1.000

The mean difference is significant at the Alpha= 0.05 level

Appendix 10: Principal Component Analysis showing eigenvectors for water quality

Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
SW_pH	0.159	**-0.299**	-0.068	-0.09	-0.108
SW_T	0.006	**-0.371**	-0.192	-0.084	0.163
SW_Cond	-0.005	-0.169	0.214	0.374	0.323
SW_TDS	0.178	-0.112	0.005	0.269	0.287
SW_TSS	0.018	**0.282**	-0.303	0.224	-0.033
SW_Turb	0.024	**0.307**	-0.325	0.061	0.059
SW_Alk	0.137	0.146	0.112	-0.362	-0.212
SW_Sal	0.157	0.104	0.17	0.211	-0.368
SW_DO	**0.224**	-0.149	-0.013	-0.064	0.018
SW_BOD	**0.238**	-0.064	-0.014	0.018	-0.046
SW_Sul	**-0.235**	0.039	0.059	0.007	-0.128
SW_P	**0.238**	0.035	-0.005	0.085	-0.032
SW_N	0.128	0.29	0.02	0.094	0.342
SW_Na	**-0.239**	-0.054	-0.014	-0.017	-0.065
SW_K	**-0.18**	0.075	-0.282	-0.041	-0.199
SW_Cl	-0.134	-0.16	-0.312	0.205	-0.07
PW_pH	0.17	**-0.279**	-0.085	-0.08	-0.107
PW_T	0.029	**-0.379**	-0.183	-0.089	0.095
PW_Cond	-0.15	-0.03	0.289	-0.124	0.334
PW_TDS	-0.007	0.163	0.405	-0.223	0.033
PW_TSS	0.091	0.156	-0.3	-0.284	0.213
PW_Turb	0.061	0.179	-0.253	-0.344	0.235
PW_Alk	**0.203**	0.011	0.093	-0.178	0.29
PW_Sal	0.21	0.09	0.16	0.124	-0.147
PW_DO	**0.227**	-0.138	-0.02	-0.06	0.011
PW_BOD	**0.239**	-0.055	-0.017	0.025	-0.058
PW_Sul	**-0.236**	-0.046	0	-0.098	0.04
PW_P	**0.237**	0.016	-0.021	0.102	-0.048
PW_N	0.175	-0.081	0.076	-0.325	-0.196
PW_Na	-0.23	-0.043	0.048	-0.145	0.066
PW_K	**-0.219**	-0.157	0.038	-0.053	-0.12
PW_Cl	**-0.233**	-0.087	0.076	0.001	0.034
Eigenvalues	17.1	5.6	4.19	3.24	1.87
%Variation	53.4	17.5	13.1	10.1	5.8

Appendix 11: ANOSIM pairwise test for surface water and porewater physico-chemical properties

Groups	R Statistic	Significance Level (%)
MxGH, AvGH	**0.263**	0.1
MxGH, RhGH	**0.39**	0.1
MxGH, MxCA	1	0.1
MxGH, AvCA	1	0.1
MxGH, RhCA	1	0.1
AvGH, RhGH	**0.313**	0.1
AvGH, MxCA	1	0.1
AvGH, AvCA	1	0.1
AvGH, RhCA	1	0.1
RhGH, MxCA	1	0.1
RhGH, AvCA	1	0.1
RhGH, RhCA	1	0.1
MxCA, AvCA	**0.403**	0.1
MxCA, RhCA	**0.39**	0.1
AvCA, RhCA	**0.251**	0.4

Global R of 0.729 at a significant level of 0.1%,

Appendix 12: Character axis correlations of each variable in the first two canonical variate axis for water quality

Variables	**CV 1**	**CV2**	**CV 3**	**CV 4**	**CV 5**	**CV 6**
pH	0.329	-0.35645	0.04419	0.037496	0.03368	0.07462
T°	-0.216	0.28141	0.02924	-0.172027	0.08788	-0.03724
Cond	0.088	-0.22361	0.03936	0.283610	0.05960	0.36786
TDS	-0.073	-0.04266	0.08007	0.165039	0.00540	-0.42435
TSS	-0.042	1.02088	0.43439	-0.410640	1.49832	1.95803
Turb	-0.248	-1.13344	0.21200	0.164638	-2.26186	-1.72940
HCO3(Alk)	-0.023	0.24597	0.16782	0.556619	-0.29841	0.52080
Sal	0.221	0.67014	0.11271	-0.095248	-0.16102	-0.16008
DO	-0.123	0.57465	-1.28535	0.327858	-0.46227	0.32715
BOD	0.519	-0.83507	0.49237	-0.182576	0.82772	-0.05263
Sulfate	-0.031	-0.20384	0.58104	0.039157	-0.35320	0.44337
Phosphate	0.327	0.44672	0.00397	-0.011150	-0.14621	-0.09214
Nitrate	0.853	-0.53598	0.01476	0.123313	-0.00065	0.17016
Sodium	-0.044	-0.07037	0.04572	0.133696	0.06476	0.22942
Potassium	0.021	0.13875	0.03914	0.052994	-0.10667	-0.44414
Chloride	-0.018	0.11643	0.16619	0.352588	0.43624	-0.29428
Eigenval	12.17672	8.94663	5.57742	2.070450	1.72816	0.96470
Cum.Prop	0.983	0.99048	0.99499	0.996660	0.99806	0.99883

Appendix 13: Principal Component Analysis showing eigenvectors for soil description

Variable	PC1	PC2	PC3	PC4	PC5
PH	-0.313	-0.052	0.01	0.039	-0.177
EC	0.311	0.04	0.106	-0.015	-0.213
ExCa	-0.241	-0.143	-0.314	0.338	0.653
ExMg	0.295	-0.084	-0.219	0.167	0.008
ExK	0.282	-0.245	-0.038	0.031	0.114
Acidity	0.241	-0.095	-0.438	-0.272	0.294
ECEC	0.276	-0.237	0.109	0.172	-0.143
OC	0.181	0.447	0.04	0.132	0.219
OM	0.1	0.526	0.034	-0.036	0.196
ON	0.306	-0.098	0.127	-0.015	-0.072
AVCN	-0.313	0.061	0.017	-0.056	-0.094
AVP	-0.094	-0.335	0.426	0.513	0.169
Sand	-0.292	0.196	0.02	-0.145	0.042
Silt	-0.025	-0.213	0.554	-0.578	0.442
clay	-0.313	-0.002	-0.038	0.088	-0.177
Bulk	0.139	0.396	0.357	0.321	0.142
Eigenvalues	10	3.22	1.54	1	0.195
%Variation	62.8	20.1	9.6	6.3	1.2

Appendix 14: ANOSIM pairwise test for soil description

Pairwise Tests	R Statistic	Significance Level %
Groups		
MxGH, AvGH	0.328	0.1
MxGH, RhGH	0.295	0.1
MxGH,MxCA	1	0.1
MxGH, AvCA	1	0.1
MxGH, RhCA	0.948	0.1
AvGH, RhGH	0.301	0.1
AvGH, MxCA	1	0.1
AvGH, AVCA	1	0.1
AvGH, RhCA	1	0.1
RhGH, MxCA	1	0.1
RhGH, AvCA	1	0.1
RhGH, RhCA	0.89	0.1
MxCA, AvCA	0.232	0.7
MxCA, RhCA	0.999	0.1
AvCA. RhCA	1	0.1

Appendix 15: Character axis correlations of each variable in the first two canonical variates for soil description

	CV 1	**CV 2**	**CV 3**	**CV 4**	**CV 5**
PH (1:1w)	-0.2434	0.21125	-0.616510	-0.23850	0.343433
EC (mS/m)	0.6306	-0.20477	-0.381145	0.14188	0.283907
ExCa	-0.1199	-0.67718	0.226540	0.48544	0.617090
ExMg	0.2422	0.31778	-0.093336	-1.06870	-0.333981
ExK	-0.3413	-0.23347	-0.091979	0.37658	-0.634702
Acidity	0.4324	0.23855	-0.067716	-0.05138	0.833878
ECEC	0.20 43	0.20053	-0.049980	-0.05005	0.407495
%OC	-1.0096	-0.33534	0.083483	-0.49891	-0.488990
%OM	0.0063	0.50180	0.183368	-0.10297	-0.180296
%ON	0.9725	-0.17934	0.381349	-0.07826	0.193432
Av. C/N	-0.1994	-1.35530	-0.178434	-0.28638	0.025484
Av. P	0.0334	0.09123	-0.570996	0.17517	-0.158260
Sand (2-0.05)	-0.5990	0.9944	0.700542	-0.13608	0.078700
Silt (0.05-0.002)	-0.3070	-0.12920	0.330665	-0.10192	-0.554386
Clay (<0.002)	-1.0991	0.46095	-0.492501	-0.12321	-0.205555