UNIVERSITY OF CAPE COAST

ASPECTS OF THE ECOLOGY OF ETSE LAGOON: IMPLICATIONS FOR SMALL SCALE FISHERIES MANAGEMENT AT ABANDZE, GHANA

BY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: ………………… Date ………………………………

Name: Georgina Atawa Tibu

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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ABSTRACT

Aspects of the ecology and spatial context of Etse Lagoon at Abandze, in the Central Region of Ghana were studied from April 2014 and March 2015. Water temperature ranged from 24.0 ^{0}C to 36.6 ^{0}C (mean = 29.43 ± 0.12 ^{0}C). Salinity varied from 0.72 ‰ to 22.30 ‰ (mean = 13.42 ± 0.30 ‰), pH from 4.6 to 8.9 with a mean value of 7.6 ± 0.03, DO from 1.65 mg/l to 11.15 mg/l with a mean value of 5.08 ± 0.08 mg/l and conductivity from 7.35 mS/cm to 43.3 mS/cm with a mean value of 18.58 ± 0.44 mS/cm. Eighteen fish species comprising 15 fin fish and 3 shell fish were sampled in the lagoon. The dominant fish species, *Sarotherodon melanontheron* comprised 74 % of the total catch and ranged in length from 7.0 cm to 7.9 cm standard length. The following characteristics were estimated for the population: growth constant K = 0.93 yr^{-1}; asymptotic length $L\infty$ = 14.25 cm of SL; longevity t_{max} = 3.2 years; theoretical length at age zero t_0 = -2.23 cm and the growth performance index, Φ' = 2.28. The total mortality rate Z was estimated at 5.09 yr^{-1}, natural mortality M at 2.15 yr^{-1}, fishing mortality, F at 2.95 yr^{-1} and the exploitation rate E as 0.58. Recruitment occurred throughout the year with two peaks representing minor and major recruitment seasons. Shannon-Wiener index H' ranged from 0 to 2.15 and the mean was 0.76 ± 0.17, Margaleff index d, 0 to 2.28 (mean = 1.07 ± 0.21) and Simpson's dominance D, 0 to 1.80 (mean = 0.64 ± 0.13). The fringe mangrove forest at Etse Lagoon can be described as having an intermediate structural development. Geographic information system information shows that the surface area of the lagoon has decreased about 2.86 % between 1973 and 2012.

KEY WORDS

Catchment

Coastal lagoons

Condition factor

Environmental parameters

Length-weight

Mangroves

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DEDICATION

To my parents, Mr Emil K. Tibu and Mrs. Felicia A. Tibu.

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LIST OF ACRONYMS

1.	ANOVA	Analysis Of Variance
2.	BL	Body length
3.	BW	Body weight
4.	CF	Condition factor
5.	CH	Carapace height
6.	CL	Carapace length
7.	Cl^-	Chloride
8.	CO_3^-	Carbonate
9.	DO	Dissolved oxygen
10.	ELEFAN	Electronic Length Frequency Analysis
11.	HCO_3^-	Bi-carbonate
12.	LWR	Length-weight relationship
13.	NH_4^+	Ammonium ion
14.	NO_3^-	Nitrate
15.	pH	Hydrogen ion concentration
16.	PO_4^{3-}	Phosphate
17.	ppt	Parts per thousand
18.	SL	Standard length
19.	SO_3^-	Sulfite
20.	TL	Total length

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CHAPTER ONE

INTRODUCTION

Background to the Study

Coastal lagoons are resources that provide a range of valuable services and goods. They are ecotones between terrestrial, freshwater and marine ecosystems (Basset & Abbiati, 2004). They are highly dynamic and unpredictable systems and considered distinct from other coastal systems such as estuaries (Kjerfve, 1994).

Coastal lagoons and their adjoining coastal wetlands are one of those marine habitats with the highest biological productivity. They have exceptional ecologic, economic and recreational values (Kennish & Paerl, 2010, pp. 6). Ecologically, they provide diverse habitats, serve as nursery and feeding areas for numerous aquatic and terrestrial organisms, and trap and transform nutrients (Entsua-Mensah et al., 2000, 2004; Kennish & Paerl, 2010). Coastal lagoons and their associated wetlands play an important role in the economy of coastal inhabitants by serving as a source of livelihood (Entsua-Mensah et al., 2004). Also, coastal lagoons serve recreational purposes.

Globally, coastal lagoons have innate differences in geomorphology, water quality and biodiversity. Water quality is the outcome of numerous landscape factors in the catchment area. The land use, soil deposits bedrock and topography are important in predicting water quality. There is a strong link between pH and water colour on the one hand, and bedrock and surfical ground material (quaternary soil deposits) on the other hand (Sanna et al., 2014). Biodiversity also largely depends on water quality and seasonal changes and geographical areas. Water quality is defined in terms of the chemical, physical and biological contents of water. Water temperature is probably the most important environmental variable in determining biodiversity in the temperate regions whiles salinity is the most important environmental variable in determining biodiversity in the tropics. They affect metabolic activities, growth, feeding and reproduction, solubility of gases in water and ultimately the migratory behaviour of aquatic organisms. This means that, some aquatic organisms are better suited for one set of physicochemical parameters pertaining in one particular ecosystem than others. Thus globally, there will be slight to wide variations in the biodiversity in different ecosystems based on natural selection and adaptability of organisms to these ecosystems.

Tropical lagoon ecosystems are closely associated with mangrove swamps. The productivity of lagoon ecosystems depends on the health of the associated mangrove forest. The mangrove forest serves as breeding, spawning, hatching and nursery grounds for many marine species. They also act as physical barrier to protect human settlement from the ocean. When mangrove forests in the catchment area of a lagoon are threatened, and have undergone significant changes as a result of natural and anthropogenic disturbances, it leads to the reduction in the productivity of the coastal ecosystem and the provision of valuable ecosystem services.

In order to assess how these disturbances have affected the health of a coastal lagoon, baseline information on the ecosystem structure and function is required. Some ecological indicators such as water quality, abundance and diversity of fish fauna and mangrove flora can be used to determine the ecological health of a lagoon and the services it provides.

Statement of the Problem

Etse Lagoon is endowed with valuable aquatic resources. It is one of the most important coastal lagoons in the Central Region of Ghana. It provides some critical goods and services such as fish and mangroves to the Abandze and Kormantse communities. It serves as roosting and feeding grounds for migratory birds and also an important habitat for some commercially important fish species. The fish and mangrove products are exploited by the fishermen and the people from the two communities throughout the year. It also serves a recreational purpose and provides a good scenic view to the Abandze Beach Resort.

Apart from Yankson and Obodai (1999) who identified the Etse Lagoon as a 'classical' closed lagoon and Essumang et al. (2009) who determined the pesticide levels in the water and lagoon tilapia, no other scientific research has been conducted on this lagoon.

Justification

Coastal lagoons are usually among those marine habitats with the highest biological productivity (Allongi, 1998). They function as nurseries and feeding grounds for opportunistic marine-estuarine fish and sustain important fisheries (Clark, 1998; Yan˜ez-Arancibia & Nugent, 1977). Consequently, these environments are of great social concern and constitute one of the main priorities in the integrated management of coastal areas due to their susceptibility to human impacts and the intensification of competing uses (Pe´rez-Ruzafa et al., 2006).

Lagoons in Ghana are deteriorating at an alarming rate due to increased urbanization, excessive pollution, over exploitation of resources, destruction of mangrove flora, land use change in the catchment of lagoons and climate change (Badu-Borteley, 2014). The consequences are poor water quality, reduction in productivity, diversity and loss of aesthetic value of these lagoons. In view of the increasing rate of degradation of lagoon habitats in the country, it is imperative to study the biotic as well as abiotic factors of lagoons to highlight the current conditions in them to assess their ecological status. Understanding the ecology of coastal lagoons is essential for the effective management of these ecosystems.

More so, lagoons in Ghana have a good potential for fisheries development. Mensah (1979) have observed that in Ghana, although these fisheries are not highly developed, they play an important role in the economy of some coastal inhabitants, especially during the marine fishery off-season (Blay & Asabere-Ameyaw, 1993). Not much is known about the state of the fish stocks and their levels of exploitation in coastal lagoons in the country even though they are exploited throughout the year. The status of a fishery is useful in the management of aquatic ecosystems. The proper management of fishery resources of coastal lagoons in Ghana is necessary if they are to make significant impacts on the socio-economic life of fishing communities. For this reason it is necessary to assess the status of the fishery of Etse Lagoon for its sustainable exploitation.

The mangrove forest is also under threat and the fishery resources may be over exploited and the productivity of the lagoon may be heavily affected. The Etse Lagoon contributes to the livelihood of the communities around it. The populations of the communities around the Etse Lagoon are fast growing with their attendant disturbances such as the encroachment of settlements within its natural boundaries and the water body could also act as a sink for materials washed in from these settlements since the lagoon is located between Abandze and Kormantse at a topographic low point. This could lead to heavy pollution of the lagoon. It is therefore important to do an ecological study of the lagoon to assess the current status of the lagoon in terms of its water quality, fishery resources, its mangrove forest and the current boundary and land use pattern within its natural boundary. This would serve as a baseline for future ecological studies. The study therefore assessed the water quality, the faunal and mangrove compositions of the lagoon, the status of the fishery and its level of exploitation and the current boundary and land use pattern within the natural boundary of the lagoon so as to give a better knowledge of the current ecological status of the lagoon.

Hypotheses

1. The environmental parameters of the Etse Lagoon are suitable for healthy fish growth.
2. The fish are in good condition and are not over-exploited.
3. The mangroves are well developed structurally.
4. The natural boundary of the Etse Lagoon has been encroached upon.

Objectives

The primary objective of the study is to assess aspects of the ecology and spatial context of Etse Lagoon. The specific objectives were to:

1. determine the environmental parameters such as temperature, salinity, pH, dissolved oxygen (DO) and conductivity of the lagoon
2. ascertain the relationship between environmental parameters and the abundance and the diversity of fish species within the lagoon
3. determine the relative abundance of fish fauna caught from the lagoon
4. determine the community structure of fish fauna occurring in the lagoon
5. determine the length-weight relationships and condition factors of the most dominant fin fish and shell fish species from the lagoon
6. determine from length-frequency data, the growth and mortality parameters, and exploitation rate of the most dominant fish population
7. estimate the level of development of mangrove tree species along the lagoon
8. determine the current boundary and land-use patterns within the natural boundary of the lagoon
9. state the implications of the results on small scale fisheries management at Abandze.

CHAPTER TWO

LITERATURE REVIEW

Coastal Lagoons

Coastal lagoons can be defined as shallow aquatic ecosystems that develop at the interface between coastal terrestrial and marine ecosystems and can be permanently open or intermittently closed off from the adjacent sea by depositional barriers (Kjerfve, 1994; Gönenç & Wolflin, 2004). Coastal lagoon water can span the range of salinities from hypersaline to completely fresh depending on the relative strength of the particular drivers of their hydrological balance, such as local precipitation, watershed inflow, evaporation and sea-water intrusion by percolation through, or overtopping of, the sand barrier (Bird, 1994; Smith, 1994).

Physical characteristics of coastal lagoons

Coastal lagoon ecosystems are a particular type of estuarine system where seawater mixes with fresh water from their continental catchments. They are formed and maintained through sediment transport processes (Kennish & Paerl, 2010) and are modified by erosion and deposition (Lamptey, 2011) but the process of sedimentation can eventually fill in lagoons (Nichols & Boon, 1994). However, lagoon barriers are constantly eroded by waves and wind, and so require continuous sediment deposition to maintain them (Bird, 1994). Coastal lagoon systems vary greatly in size from as small as less than 0.01 km^2 to more than 10,000 km^2 (e.g., Lagoa dos Patos, Brazil) (Bird, 1994), and also differ considerably in morphological, geological and hydrological characteristics (Kennish & Paerl, 2010). Whiles Bird (1994) and Kjerfve (1994) reported that they are typically less than 5 m deep, Kennish and Paerl (2010) noted that they generally average less than 2 m in depth, although deeper waters may be encountered in channels and relict holes.

Distribution of coastal lagoons

Coastal lagoons generally occur on low-lying coasts and are usually oriented parallel to shores, and are often much longer than they are wide. They occupy only approximately 13% of the coastal areas worldwide, and they are present on every continent except Antarctica. They are most extensive along the coasts of Africa (17.9% of the coastline) and North America (17.6%), and less so along the coasts of Asia (13.8%), South America (12.2%), Australia (11.4%), and Europe (5.3%) (Kennish & Paerl, 2010). In Ghana, there are 98 coastal lagoons (Yankson & Obodai, 1999) along the 550 km stretch of the coastline.

Classification of coastal lagoons

De Wit (2011) noted that there are different types of lagoons based on the nature of contact between the lagoon and the adjacent sea and salinity ranges. Salinities have been used since 1958 to classify the lagoons and other brackish or estuarine waters according to the Venice system. Accordingly, a lagoon with salinities below 5 ppt is oligohaline; mesohaline waters have salinities between 5 and 18 ppt and polyhaline between 18 and 30 ppt. Lagoons with salinities above 30 ppt but below that of seawater are termed mixoeuhaline (De Wit (2011).

Kjerfve (1986) sub-divided coastal lagoons into three geomorphic types according to water exchange with the coastal ocean. They are choked, restricted and leaky lagoons. These are further explained as follows:

Choked lagoons: Choked lagoons usually consist of a series of connected elliptical cells, connected to the sea by a single long narrow entrance channel, along coasts with high wave energy and significant littoral drift. Although lagoons experience tides that co-oscillate with tides in the coastal ocean, the entrance channel serves as a dynamic filter which largely eliminates tidal currents and water level fluctuations inside the lagoon. The tidal oscillations in choked lagoons are often reduced to 5 % or less as compared to the adjacent coastal tide. Choked coastal lagoons are characterized by long flushing times, dominant wind forcing, and intermittent stratification events due to intense solar radiation or runoff events. Choked lagoons are mostly oriented shore-parallel but are sometimes also found associated with river deltas and the occasionally oriented shore-normal.

Restricted lagoons: Restricted lagoons consist of a large and wide water body, usually oriented shore-parallel, and exhibit two or more entrance channels or inlets. As a result, restricted coastal lagoons have a well-defined tidal circulation, are influenced by winds, are mostly vertically well mixed and exhibit salinities from brackish water to oceanic salinities. Flushing times are usually considerably shorter than for choked coastal lagoons.

Leaky lagoons: Leaky lagoons are elongated shore-parallel water bodies with many ocean entrance channels along coasts where tidal currents are sufficiently strong to overcome the tendencies by wave action and littoral drift to close the channel entrances. Leaky lagoons are characterized by numerous wide tidal passes, unimpaired water exchange with the ocean on wave, tidal and longer time scales, strong tidal currents, and salinities close to that of the coastal ocean.

Bernard (1937) and de Rouville (1946) identified two types of lagoons that fringe the West African coast. These are the ‘open’ and ‘closed’ lagoons. The ‘open’ lagoon (often referred to as an estuary) has sufficient volume of water at all seasons to maintain a permanent outflow from its mouth into the sea. In Ghana, such lagoons occur more in the Western part of the coastline where rainfall is heavy (mean of about 1250 mm per annum) and the lagoons are continuously fed by rivers.

The ‘closed’ lagoons in Ghana are fed by seasonal rivers and streams. They usually lie behind a sand barrier which separates them from the sea and are normally opened for one or two months a year during the rainy season (May to September) (Kjerfve, 1994). Most of these lagoons are located on the eastern coastal region where rainfall is low.

Kennish and Paerl (2010) noted that coastal lagoons may be partially or wholly enclosed, depending on the extent of the land barrier, which impedes water exchange between the basin and ocean and tends to dampen wave, wind, and current action. Yankson and Obodai (1999) identified 98 lagoons on the coastline of Ghana and classified them into (a) open (classical and man-made) (b) closed (classical, spring tide-fed and isolated)

(a) **Open Lagoons**

1. Classical open lagoons are lagoons which are usually open to the sea but seldom barred from it by a sand bar.

2. Man-made open lagoons are lagoons which maintain a permanent contact with the sea as a result of human intervention. Yankson and Obodai (1999) encountered 20 open lagoons of which 75 % are classical open and the rest 25 % are man-made open lagoons.

(b) **Closed Lagoons**

1. Classical closed lagoons are those which get cut off from the sea by a sand bar for greater part of the year, but open for a short period during the rainy season.
2. Spring tide-fed closed lagoons are those in which the sand bar is low enough, even at the peak of the dry season, to permit sea water spillage at high spring tides. There is no obvious reverse flow of water from such lagoons except during the rainy season when the sand bar is breached.
3. Isolated closed lagoon are those non-brackish, small sized coastal water bodies which lie permanently behind a sand bar and are possibly equivalent to freshwater coastal lakes or ponds (Barnes, 1980). Such lagoons may have resulted from previously existing brackish water lagoons which have become isolated from the sea due to consolidation of the sand bar. There is no obvious interchange of water between them and the sea except perhaps during prolonged heavy rains when a lagoon-sea outflow may occur.

Importance of coastal lagoons

Economic importance of coastal lagoons

Lagoons and their associated mangrove ecosystems are one of the important coastal communities in Ghana. They have a great influence in the socio-economic wellbeing and health of communities that live close to the lagoons. They are used in artisanal fisheries and play an important role in the economy of some coastal inhabitants, especially during the off-season for marine fishing (Entsua-Mensah et al., 2004). Coastal lagoons and their mangrove ecosystems are used for aquaculture. The lagoons are used in the production of salt; examples are the Songhor, Benya and Densu Lagoons. The mangroves are harvested and sold for firewood, building materials, the barks of *Rhizophora* species are used as dye for fishing nets while the branches are used as fish aggregating device and used in apiculture (Personal communication with some fishermen at Abandze).

Social importance of coastal lagoons

Lagoons serve as sanctuaries in certain areas for endangered species such as crocodiles and hippopotami (Day & Yańez-Arancibea, 1985). Inspirational activities such as landscape paintings as well as settings for films, literature, songs and other artistic expressions are other values associated with coastal lagoons (Badu-Borteley, 2014). In Ghana, most coastal lagoons are believed to be female gods and there are days set aside where there are no activities in these lagoons (non–fishing days) (Badu-Borteley, 2014). Lagoons also serve recreational purposes. Some resorts in Ghana are sited near lagoons in Ghana an example is the Abandze beach resort that is located near Etse Lagoon, Abandze in the Central Region.

Threats to coastal lagoons

Coastal lagoons are highly susceptible to human activities, and many now rank among the most heavily impacted aquatic ecosystems on earth

(Kennish & Paerl, 2010). They are affected by natural habitat alteration both in adjoining coastal watersheds and in the water bodies themselves (Kennish & Paerl, 2010). Most of the anthropogenic stressors can be linked to rapid population growth and overdevelopment of the coastal zone (Vitousek et al., 1997). Although anthropogenic stressors on coastal lagoons have received the greatest attention, some natural phenomena or stressors such as global warming and climate change, *El-Niño* Southern Oscillation (ENSO) and rainfall can have more profound consequences (Esteves et al., 2008). However, such natural events often occur less frequently than many anthropogenic stressors which typically result in insidious impacts (Paerl et al., 2006a).

In Ghana, most urbanized coastal lagoons such as Korle Lagoon in Accra have historically been the most heavily impacted systems because they lack government regulatory controls or have less stringent (government and traditional) controls.

Anthropogenic threats

According to Esteves et al. (2008) local stressors such as watershed threats, eutrophication, and pollution by chemical and physical contaminants, heavy metals and pesticides, introduction of non-indigenous species, fishery overexploitation and artificial sandbar openings lead to habitat loss and alteration, and put the functioning and conservation of coastal lagoon biodiversity at risk. Kennish and Paerl (2010) categorized anthropogenic stressors into 3 groups; whether they degrade habitat, compromise water quality, or alter biotic communities. Stressors that degrade habitat are mainly physical factors (e.g., dredging, shoreline modification, and wetland reclamation). Those impacting water quality are primarily chemical and biological in nature (e.g., nutrient enrichment, organic carbon loading, pathogens, heavy metals, and other chemical contaminants). Biotic stressors include significant changes in biological components caused by human activities (e.g., overfishing and introduced/invasive species).

Watershed threats are probably prevalent around the world and are mostly associated with activities related to water quality and quantity and sediment delivery (Esteves et al., 2008). Agriculture and silviculture are often the most important controllers of the quality and quantity of water exported from the watershed (Alexandridis et al., 2007). They increase concentration of nutrients, pesticides and suspended sediments. Industrial activities such as mining also increase concentrations of metals and toxic chemicals, add suspended sediment, increase temperature and lower dissolved oxygen in the water (Lawson, 2011). According to Esteves et al. (2008) the entrance and maintenance of chemical contaminants are becoming extremely common in coastal lagoons, and in some cases their levels are above the predicted toxic effects to aquatic organisms. Heavy metals and compounds originating from pesticides are problematic toxic agents in coastal areas around the world. Some substances tend to bio- accumulate in aquatic organisms and, in some cases, bio- magnify in food chains, reaching high concentrations in the upper trophic levels. The coastal lagoons more impacted by chemical contaminants are those located in the vicinity of urban regions and agricultural lands. Each of these effects can have a negative impact on the aquatic ecosystem and or make it unsuitable for established or potential uses (Lawson, 2011) that coastal lagoons can offer to local communities and their accumulation in fishes causes serious health problems for people consuming them (Esteves et al., 2008). An additional watershed alteration is the construction of dams and channels on the shores of permanent sea-connected lagoons to enhance salt extraction. Such habitat modifications promoted by salt works alter both the inflow of freshwater from the watershed and the runoff, thus directly affecting the water salinity (Esteves et al., 2008).

The cultural eutrophication process is undoubtedly the most common problem affecting the biodiversity and functioning of coastal lagoons. The negative consequences of nutrient enrichment by phosphorus and nitrogen on inland aquatic ecosystems are multiple and are known to occur worldwide (Vitousek et al., 1997; Carpenter et al., 1998). These impacts can drastically affect the composition, trophic structure and size or biomass patterns of community organization from algae to fish (Jeppesen et al, 2000). Regime shifts from clear to turbid water states are also expected, when such human-mediated stressors cause phytoplankton communities to be more prone to outcompeting aquatic macrophytes, changing shallow aquatic systems from a clear-water high-diversity state to a turbid-water low-diversity state (Scheffer et al., 1993). Esteves et al. (2008) noted that eutrophic waters are also more susceptible to dissolved oxygen depletion, which can lead to the production of H_2S in the sediment and to high fish mortalities, as in the Rodrigo de Freitas lagoon (Esteves et al., 2008).

The introduction of non-indigenous species is another considerable threat for coastal lagoons, given the fact that this impact is one of the top 5 causes of changes in biodiversity on a global scale (Sala et al., 2000). Esteves et al. (2008) stated that the intentional introduction of *Tilapia* spp. and

Oreochromis spp. into coastal lagoons in order to increase local fishery has however, become a serious problem, diminishing the abundance of native species and possibly causing local extinctions. For instance, McCrary et al. (2007) reported that tilapia have become widely established and have been responsible for reducing the size and abundance of native species as well as eliminating native species as a food source in local fish markets in aquatic systems in Nicaragua.

Innovation in fishing technologies and overfishing affect the structure and diversity of fishing resources, destroy nursing habitats, capture smaller fishes and shrimps, and reduce natural stocks (Seixas & Troutt, 2004). Two common features of coastal lagoons make these systems especially appreciable for fishing: the relatively small area and the high productivity rates (Esteves, 1998), allowing large fish stocks and a better fishing-efficiency (Esteves et al., 2008). Overfishing has direct negative consequences on coastal lagoon biodiversity and proper functioning, by reducing natural stocks and altering the patterns of the trophic structure. Reduced natural stocks make populations more vulnerable to stochastic extinctions, alter the energy flux in the food chain and reduce the strength of biotic interactions (Esteves et al., 2008). Recovery from such disturbances may be slow, especially for marine species in closed coastal lagoons, as dispersion and recolonization is more difficult. To facilitate this process, fishermen choose to artificially open the sandbar, allowing fish and fish larvae to enter the coastal lagoons, though this profoundly affects many other natural features (Esteves et al., 2008).

Closed coastal lagoons can be naturally connected to the sea when the lagoon fills up and overflows its banks or they can be opened artificially. The various reasons for artificial sandbar openings include: 1) fishery improvement; 2) water-level reduction to avoid inundation of residences and roads constructed near the shoreline; 3) water-quality improvement by exporting nutrients to the ocean; and 4) hypoxia risk reduction, among others (Esteves et al., 2008). In these cases, the impacts of such disturbances are promptly reflected in the aquatic communities, especially due to water level reduction and increased salinities. A decrease in species richness and diversity is commonly observed for a variety of aquatic communities, in addition to changes in the biological composition, which may then show marine and estuarine characteristics (Saad et al., 2002; Santangelo et al., 2007). In addition, the areas most influenced by marine intrusions may show the highest UV penetration, as observed in Rocha coastal lagoon, Uruguay (Conde et al., 2000). Salinity is key factor acting on the osmoregulation of individuals (Remane & Schlieper, 1971). According to Esteves et al. (2008) changes in the primary production rates due to increased salinities could represent an extra factor contributing to alterations in the trophic structure and patterns of biodiversity. Artificial sandbar openings have shown little efficiency in controlling eutrophication in coastal lagoons since internal load by sediment phosphorus regeneration quickly enhances phosphorus concentrations in the water column (Esteves et al., 2008). Also, the death of submerged macrophytes upon exposure to air increases dissolved and total nutrients, and primary production can shift from being macrophyte to phytoplankton-dominated (Esteves et al., 2008). According to dos Santos et al. (2006), the decay of *Typha domingensis* stands due to the sandbar opening contributed to an increase in phosphorous in the water column at the Imboassica Lagoon. In conclusion, dos Santos et al. (2006) stated that water level variation plays a fundamental role in the biology of emergent aquatic macrophytes in coastal lagoons, regulating biomass, net primary productivity and nutrients among other biological attributes.

Natural threats

Coastal lagoons in general, are highly vulnerable to some natural phenomena. Natural stressors such as global warming and climate change, and rainfall can adversely impact on coastal lagoons. Under these scenarios, the biotic communities and productivity of coastal lagoons are likely to undergo a variety of changes, depending on whether and how a particular system's characteristics, such as its littoral area, freshwater flows and salt intrusion, are affected (Nicholls et al., 2007).

Coastal lagoons probably experience higher temperatures and increased salinities. Warmer waters will directly or indirectly mediate extinctions of those species less adapted to higher temperatures. At the same time, they may increase the chance of invasions by exotic species, as already reported for arid terrestrial systems (Smith et al., 2000), thus changing the neotropical coastal lagoon biodiversity (Esteves et al., 2008). The same effects are predicted to occur via salinity alterations. Schallenberg et al. (2003) noted that climate-induced salinity increases can drive coastal systems to a state of depleted zooplankton biodiversity and altered ecosystem functioning. The interactive effects of multiple stressors, such as higher temperatures and increased salinities, under natural conditions are not yet understood, but laboratory experiments show a lower tolerance to salinity as temperature increases for some freshwater zooplankton (Hall & Burns, 2001; 2002).

Rainfall patterns can also be modified by climate change and this can have both negative and positive consequences on coastal lagoons (Esteves et al., 2008). According to Lawson (2011) rainfall is an important factor in aquatic environment. It is an important regulator of the hydrologic balance, and determines the salinity ranges in the coastal lagoons (Esteves et al., 2008). It modifies the euphotic zone depth, the heat distribution in the aquatic system, the water pH and the primary productivity (Esteves et al., 1988; Farjalla et al., 2002; Steinberg, 2003; Suhett et al., 2007). Rainfall is also a key mechanism regulating the rates and concentrations at which substances such as organic matter, dust, volcanic gases, natural gases such as carbon dioxide, oxygen and sulphur dioxide, nutrients such as nitrogen and phosphorus, sediments, animal wastes, petroleum products and road salts, toxic chemicals enter coastal lagoons. Also, total suspended and dissolved solids which affect metabolism and physiology of fish and other aquatic organisms are the products of run offs. The dissolved solids directly influence water conductivity; the higher the dissolved solids the higher the conductivity. The dissolved solids also increase with increased rainfall and have adverse effects on dissolved oxygen and carbon dioxide (Lawson, 2011). According to Esteves et al. (2008) rainfall 1) modifies the system's productivity and alters the carrying capacity of populations; 2) interferes in visual-based predatory interactions, modifying species interaction strength; and 3) changes the abiotic environment, affecting the physiology of individual plants and animals.

Environmental Parameters

Water is the most vital substance among the natural resources and it is crucial for the survival of all living organisms. Globally, much attention is focused on this resource especially its quality. Water quality can be defined in terms of the biological, chemical and physical contents of the water (Lawson, 2011). The water quality of an aquatic ecosystem varies with the seasons, weather conditions, geographic locations and time of the day. Some water quality parameters are temperature, salinity, dissolved oxygen, pH and conductivity. Others are alkalinity, hardness, turbidity, biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Some parameters such as alkalinity and hardness are fairly stable while others like DO, temperature and pH fluctuate daily. These parameters are the limiting factors for the survival of flora and fauna component of the water body. They affect the growth, feeding, metabolism, reproduction and migratory behaviour of the organisms inhabiting the water body (Lawson, 2011; Naeema et al., 2015). Most importantly, environmental variables play important roles in determining fish assemblages (Pombo & Rebelo, 2002).

Water quantity and quality in a lagoon are influenced by the rate at which the lagoon loses or gains water from evaporation, precipitation, groundwater input, surface runoff, and exchange with the ocean (Allen et al., 1981). In addition, Koffi et al. (2014) also noted that coastal lagoons depend on freshwater supply: lagoon salinity is relatively lower when freshwater inputs are higher and lagoon salinity becomes relatively higher in the dry season when freshwater inputs are lower or during sea water intrusions. Anthropogenic activities also have remarkably influenced the quality of ecosystems in aquatic environments (Jiang et al., 2011; Pei et al., 2011; Jing & Zhiyuan, 2011; Hallare et al., 2011; Siddiqui, 2011; Feng et al., 2012). According to Chitmanat and Traichaiyaporn, (2010) poor water quality may be caused by low water flow, municipal effluents and industrial discharges. Also, lagoons receive pollutants from agricultural pesticides and fertilizers from their immediate catchment area and from flood waters of larger streams and rivers (Entsua-Mensah, 2002). These can have detrimental effects on the lagoon ecosystem and eventually alter its biodiversity.

The physical and chemical characteristics of water are important parameters as they may directly or indirectly affect its quality and consequently its suitability for the abundance, distribution, diversity and production of fish and other aquatic organisms (Moses, 1983; Ofonmbuk et al., 2014). In aquatic environments, water quality parameters help in structuring communities inhabiting them, and Badu (2007) emphasised that environmental gradients are important in structuring communities by allowing some species to survive. Most importantly, environmental conditions underlie fisheries productivity (Finney et al., 2002; Wynne & Cote, 2007) and according to Entsua-Mensah et al. (2000) fishery yields from lagoons are not uniform due to fluctuations in some water quality parameters such as salinity, conductivity, dissolved oxygen, pH and depth. More so, coastal lagoons are considered naturally stressed systems with frequent environmental disturbances and fluctuations (Barnes, 1980; Kjerfve, 1994; UNESCO, 1980, 1981) that induce immense stress on the organisms inhabiting those lagoons (Armah et al., 2005). Therefore, an adequate knowledge of the prevailing physicochemical regime in a coastal lagoon is necessary for the understanding of its ecology. The water quality parameters studied are as follows.

Water temperature

Water temperature is probably the most important environmental variable. Temperature is affected by time of the day; high temperatures may be recorded in day time and become low at night (Lawson, 2011). Temperature affects physical, chemical and biological processes in water bodies. Biological processes such as metabolic activities, growth, feeding, reproduction; distribution and migratory behaviours of aquatic organisms are affected by water temperature (Suski et al., 2006; Ramanathan et al., 2005; Mukhtar & Hannan, 2012). Woodward (1987) and Turner (2003) reported that water temperature influences DO concentrations, as well as the physiology of lagoon organisms, species' ranges, and patterns of migration (Woodward, 1987; Turner, 2003). Most importantly, fish is affected by the temperature of the surrounding water by influencing the body temperature, growth rate, food consumption, feed conversion and other functions (Houlihan et al., 1993; Britz et al., 1997; Azevedo et al., 1998). In addition, growth and livability in fish are optimum within a defined temperature range (Gadowaski & Caddell, 1991). Also, spawning and the hatching of eggs are geared more towards annual temperature changes (Coastal Resource Center-Ghana/Friends of the Nation, 2010) in most fish species. Each fish species has an ideal temperature within which it grows quickly. In warmer environments fish have a faster growth rate but tend to have a shorter lifespan than in cool water. High water temperature increases the metabolic rates, resulting in increased food demand (Badu-Borteley, 2014). Although fish can generally function in a wide range of temperature, they do have an optimum range, as lower and upper lethal temperature for various activities (Beschta et al., 1987). An increase in temperature increases the activity of digestive enzymes, which may accelerate the digestion of the nutrients, thus resulting in better growth. Feed Conversion Ratio increases with increasing temperature (Badu-Borteley, 2014). Lastly, fish migration is linked to water temperature (Lawson, 2011; Badu-Borteley, 2014). Rising water temperature may cue fish to migrate to a new location or to begin their spawning season. As temperature drops, juvenile marine fish and shrimp move from their nursery grounds in the estuaries out into the ocean, or into rivers. Tropical fishes survive best in a range of 21 $^{\circ}$C–32 $^{\circ}$C but may not survive in a temperature below 15 $^{\circ}$C (Badu-Borteley, 2014).

Salinity

It is expressed as the total concentration of electrically charged ions in water in part per thousand (‰). The ions include CO_3^- , SO_3^- , Cl^- , HCO_3^-, NO_3^-, NH_4^+, PO_4^- . It tells how much freshwater has mixed with seawater. Salinity variation in lagoons is due to the influx of saltwater during high tides and the input of freshwater when it rains. Salinity determines distribution of organisms in aquatic environments (Lawson, 2011). Changes in salinity often modify population distributions and biotic community structure (Carriker, 1967). Increase in salinity has been shown to cause shifts in biotic communities, limit biodiversity, exclude less-tolerant species and cause acute or chronic effects at specific life stages (Weber-Scannell & Duffy, 2007). Derry et al., (2003) reported that the diversity of aquatic species declines as osmotic tolerances are exceeded with increasing salinity and an inverse relation exists between salinity and aquatic biodiversity.

Hydrogen ion concentration (pH)

pH is defined as the negative logarithm of hydrogen ion concentration (Pankratz, 2000). This is usually expressed as the hydrogen concentration and measurement is done on a pH scale of 0-14. A value of 7 at 25 $^{\circ}$C indicates a neutral condition, 6.9 - 0 indicates increasing hydrogen ion (acidity); increasing values indicate decreasing ion concentration (alkalinity) (Badu-Borteley, 2014). pH of water decreases with increasing dissolved carbon dioxide. pH is influenced by acidity of the bottom sediment and biological activities (Lawson, 2011). High pH may result from high rate of photosynthesis by dense phytoplankton blooms. pH may also be affected by total alkalinity and acidity, run-off from surrounding rocks and water discharges (Lawson, 2011). pH catalyses chemical reactions in the water and sediment as well as metabolic activities in living aquatic organisms (Badu-Borteley, 2014). Abowei (2010) observed that pH higher than 7 but lower than 8.5 are ideal for biological productivity, but pH less than 4 is detrimental to aquatic life. Addy et al. (2004) also stated that each organism has an ideal pH for optimal growth and survival, but for most aquatic organisms, pH of 6.5-8.5 is the optimum whiles Alabaster and Lloyd (1981) reported that pH 5-9 is not lethal to fishes. The optimum range of pH for maximum growth and production of shrimp and carp is recommended as 6.8 - 8.7 (Ramanathan et al., 2005). The pH of a water body influences the concentration of many metals by altering their availability and toxicity. Metals such as zinc (Zn) and cadmium (Cd) are most likely to have detrimental environmental effects as a result of lowered pH (DWAF, 1996).

Dissolved oxygen (DO)

Dissolved oxygen is the oxygen that is dissolved in water and available to aquatic organisms. It is essential to all forms of aquatic life, including those organisms responsible for self-purification processes in water bodies. Dissolved oxygen affects the growth, survival, distribution, behaviour and physiology of shrimps and other aquatic organisms (Solis, 1988). It can determine whether the environment is aerobic or anaerobic (Abowei, 2010). The oxygen concentration of aquatic medium varies with temperature, atmospheric pressure, salinity, turbulence and photosynthetic activities of algae (Badu-Borteley, 2014). The solubility of oxygen decreases as temperature and salinity increases and as pressure decreases (Annang, 2000; Naeema et al., 2015). Oxygen is essential in aerobic organisms and its insufficiency at the mitochondria results in reduction in cellular energy and subsequent loss of ion balance in cellular and circulatory fluids. If this condition persists, death will ultimately occur (EPA, 2000).

Normally, decrease in DO takes place owning to some factors such as rise in water temperatures, respiration of plants and animals and mingling of toxic materials (Naeema et al., 2015). Low DO concentrations can have negative impact on aquatic life. For aquatic animals, extended periods of DO below 5mg/l can cause adverse effects to larval life-stages (EPA, 2002). In restricted lagoons with low flushing rates and high nutrient inputs, temperature increases will increase the hypoxic events (D'Avanzo & Kremer, 1994). Chronic hypoxia leads to changes in benthic community structure characterised by a persistent shift in species composition to more hypoxia-tolerant species and an overall decrease in species diversity (Conley et al., 2007; Anthony et al., 2009). Diaz and Rosenberg (1995) observed that should DO concentrations become slightly lower, catastrophic events may overcome the systems and alter the productivity base of economically important fisheries. More so, aquatic biota exposed to low DO concentrations may be more susceptible to adverse effects of other stressors such as disease, toxic chemicals, and habitat modification (Holland et al., 1997). In addition, reduced DO adversely affects aerobic biota, with benthic communities expected to be the more severely stressed (Anthony et al., 2009) and also increase their vulnerability to predation, as they migrate above the sediment surface to obtain more oxygen (Holland et al., 1987). DO concentrations below 5mg/l may affect the functioning and survival of biological communities and below 2 mg/l may lead to death of most fishes (Chapman & Kimstach, 1992).

Dissolved oxygen distribution affects the solubility of and availability of inorganic nutrients since it helps to change the redox potential of the medium (Lawson, 2011; Naema et al., 2015). For example, in areas of very low DO levels nitrate is readily reduced to ammonia and acute toxicity of ammonia to fish increases with low dissolved oxygen concentrations. Low levels of DO can result in damages to the oxidation state of substances from the oxidized form to the reduced form, thereby increasing the levels of toxic metabolites (Lawson, 2011). The DO range for lagoons in Ghana as reported by Biney (1986) is 0.0 to 8.0 mg/l.

Conductivity

Conductivity values can become relatively high when lagoons undergo drying and salts accumulate through evaporation. Merz (2006) confirmed that during drying phases, conductivity concentrations can become high to impact on biota. During wet seasons conductivity levels decrease because most coastal lagoons refill and the salts get diluted or flushed out of the system by rainfall. Lawson (2011) also observed that suspended solids in water are directly proportional to dissolved solids which are all products of run-offs; could directly influence water conductivity, the higher the suspended and dissolved solids, the higher the conductivity. If the electrical conductivity exceeds the value of 1000 mS/cm at 25 °C, no fish could survive (Banu et al., 2013).

Fish Community Structure

Fish community diversity is a basic ecological indicator of the health of an aquatic ecosystem. The more diverse the fish community is, the healthier the aquatic ecosystem and vice versa. The knowledge of this is important for the sustainable exploitation and management of fish resources. Fish fauna and its diversity are seasonally variable in relationship with the entrance of marine waters into the lagoons (Lalèyè & Moreau (2004) and the input of freshwater which affect water quality of that lagoon ecosystem. Based on this different categories of fish inhabit coastal lagoon ecosystems. Durand et al. (1994) classified the fish communities of coastal lagoons into three categories: (1) the littoral euryhaline marine species which come seasonally or accidentally into the lagoons; (2) the estuarine species which live usually in mixohaline inland waters; and (3) the continental or inland water species which are only scarcely recorded in the lagoons as they can enter them only when the water becomes fresh when rivers flood. These can be referred to as marine, brackish and freshwater fish species respectively. Yanez-Arancibia (1978) also classified coastal lagoon fishes into three groups: (i) sedentary species: those which spend their entire life cycles within coastal lagoons; (ii) seasonal migrants: those which enter the lagoon during a more or less well-defined season from either the marine or freshwater side and leave it during another season and (iii) occasional visitors: those which enter and leave lagoon without a clear pattern within and among years.

Koffi et al. (2014), further classified lagoon fish fauna into six ecological categories. These are (1) estuarine resident fish (those that inhabit estuarine waters throughout their life cycle), (2) estuarine dependent freshwater fish, (3) estuarine dependent marine fish (marine fish which are predominantly found in lagoons at some stage of their life cycle), (4) estuarine non-dependent marine fish (species commonly found in both estuarine and coastal inshore areas and do not depend upon estuarine environment to complete their life cycles, (5) occasional marine visitor and (6) accessory marine visitor fish.

Ghana is endowed with abundant water bodies and fish resources. The fish resources are a major source of high quality animal protein. They provide socio-economic benefits and also serve as sources of job opportunities for the fringing human communities. Several fish species belonging to the above mentioned ecological categories have been reported. Pauly (1975) categorised the fish in Ghanaian lagoons as follows: (a) Fresh water fishes which swim into the lagoon through permanent or temporary rivers. (b) Those that spend most of their lifetime in the lagoon. (c) Those that have their juvenile forms washed into the lagoon from the sea after the rainy season. (d) Marine species which make short incursions into the lagoon. Aggrey-Fynn et al. (2011)

encountered 18 species belonging to 18 genera and 12 families of marine, brackish water and freshwater fishes in an unmanaged wetland in Ghana and also a total of 26 species of shellfishes and fin fishes from 18 families comprising freshwater, brackish water and marine fishes from Essei, Butuah and Whin estuary. Also, Entsua-Mensah (1998) identified 19 finfish species and 4 shellfish in Abrubi Lagoon.

Biological communities vary in time and space, as a result of differences in habitat structure (Gorman & Karr, 1978) and resource availability (Grenouillet et al., 2002). Knowledge and prediction of community characteristics in response to different environmental factors is one of the main objectives of community ecology (Yzel & Miguel (2007). The importance of environmental variables to fish communities is dependent on the scale of analysis (Yzel & Miguel (2007). On a small scale, biotic factors play an important role in community organization; however in large-scale studies, biogeography and abiotic factors are the main determinants of fish communities (Jackson et al., 2001). Lagoon systems directly support essential fisheries, with the consequences that, at present, relatively few remain unexploited (Grenouillet et al., 2002). Lagoon ecosystems face increased stress due to fishing activities and other anthropogenic disturbances and many of their habitats are being destroyed rapidly globally. In order to understand and protect these critical habitats, it is important to document the communities they support and understand the factors that naturally influence the distribution and abundance of associated species. These environments may undergo extreme fluctuations, leading to high variability in the number and abundance of fish species (Hoeinghaus et al., 2004; Hubbell 2001; Jackson & Harvey, 1989).

Several authors have reported the fish community structure of some coastal lagoons worldwide examples are Amezcua and Amezcua-Linares (2014) who studied the fish community of subtropical coastal lagoon of Santa Maria la Reforma on the continental shelf of the Central Mexican Pacific and in Ghana, Aheto et al. (2014) studied the fish assemblage in the Kakum mangrove ecosystem, Okyere et al. (2012) studied the fish communities in the salt marsh adjoining the mangroves, Entsua-Mensah (1998) studied fish population in an open and closed lagoon, and Blay (1997) studied the occurrence and diversity of fish entering the Kakum estuary. However the community structure of fish fauna of Etse Lagoon has not been studied. In order to establish a database of the community structure of fish fauna in the Central Region, a baseline study on the community structure of fish fauna of Etse Lagoon is necessary.

Length-Weight Relationship and Condition Factor of Fish

According to Pailwan (2007), fish is the most important animal of brackish water ecosystems because they contribute to an essential and beneficial food item for humans. Fishes, especially those of tropical and sub-tropical water systems are known to experience growth fluctuations due to many factors such as environmental changes, food composition changes, competition within the food chain, and changes in the physical and chemical properties of the aquatic medium (Adedeji & Araoye, 2005; Abowei & Davies, 2009). Therefore, a study of data on fish biota gives indication of state of ecosystem health (Okyere et al., 2011). More so, Obasohan et al. (2012)

emphasized that morphometric characters can be used to assess the influence of environmental factors on fish populations. In this regard, I used the total length, standard length of fin fish and shrimps, carapace length and carapace width of crabs and body weight measurements were used to assess fish habitat qualities.

Length-weight relationship of fish

Growth in fish is in length as well as in bulk (King, 1996). Bake and Sadiku (2004) also noted that growth is the change in absolute weight (energy content) or length of fish over time. Length-weight relationship of fish also known as growth index is an important management tool used in estimating the average weight at a given length growth (Abowei & Hart, 2009). It is a very important tool or index or basis or information for proper exploitation and management of the population of fish species (Anene, 2005). It also provides valuable information on the habitat where the fish lives (Oni, et al., 1983) and it is used in modelling aquatic ecosystems (Kulbicki et al., 2005). Length-weight relationships give information on the condition and growth patterns of fish (Bagenal & Tesch, 1978). Fish are said to exhibit isometric growth when length increases in equal proportions with body weight for constant specific gravity. The regression co-efficient for isometric growth is ‘3’ and values greater or lesser than ‘3’ indicate allometric growth (Gayanilo & Pauly, 1997).

Condition factor of fish

In fisheries science, the condition factor is used in order to compare the “condition”, “fatness” or wellbeing of fish (Kamelan et al., 2014). It is based on the hypothesis that heavier fish of a particular length are in a better physiological condition (Bagenal & Tesch, 1978). Condition factor is also a useful index for monitoring of feeding intensity, age, and growth rates in fish (Ndimele et al., 2010). It is strongly influenced by both biotic and abiotic environmental conditions and can be used as an index to assess the status of the aquatic ecosystem in which fish live (Anene, 2005). Koranteng (1995) noted that condition factor increases with increasing rainfall. In addition, increase in the condition factor can be attributed to seasonal variability (Mommsen, 1998; Henderson, 2005) or habitat suitability (Nieto-Navarro et al., 2010). Finally, increased values may imply the accumulation of fat and gonads during the reproductive period (Vazzoler, 1996) and it decreases as the fish increases in size.

Fish Growth, Mortality and Exploitation in Coastal Lagoons

Lagoon environments are highly seasonal, more so than the open marine environment to which they are connected. Thus, the food types and food consumption, and hence, the growth of lagoon fishes are bound to oscillate seasonally, whether the fish in question undertake seasonal migrations in and out of coastal lagoons or not (Pauly & Yanez-Arancibia, 1994). The growth of fishes within coastal lagoons relative to that of conspecifics growing in other habitats appears to be a function of (a) the type of lagoon and or of habitats being compared (b) the species of fish and (c) the life stage of the fish species (Pauly and Yanez-Arancibia, 1994). Also, fishing pressure can have an impact on the growth of fish in coastal lagoons and consequently the fishery. Population parameters evaluate the effect of fishing on fishery management decisions (Ogamba & Abowei, 2012). The fundamental models used are based on four parameters: growth, recruitment, natural and fishing mortality (Ricker, 1975). Age and growth are particularly important for describing the status of a fish population and for predicting the potential yield of the fishery (Ogamba & Abowei, 2012, pp. 945). It also facilitates the assessment of production, stock size, recruitment to adult stock and mortalities (Lowe-McConnel, 1987). Fish mortality is caused by several factors, which include age (King, 1991), fish predation (Otobo, 1993), environmental stress (Ogamba & Abowei, 2012), parasites and diseases (Ogamba & Abowei, 2012) and fishing activity (King, 1991).

Fish fauna in lagoons are exploited on both commercial and subsistence basis. The exploitation rate is an index, which estimates the level of utilization of a fishery (Ogamba & Abowei, 2012, pp. 945). The value of exploitation rate is based on the fact that sustainable yield is optimized when the fishing mortality coefficient is equal to natural mortality (Pauly, 1983). Significant studies have been made on growth, mortality and exploitation rates of *Sarotherodon melanotheron* by Blay (1993) from Benya Lagoon and Kakum estuary; Blay and Asabere-Ameyaw (1996) from Fosu Lagoon, Koranteng et al. (2000) from Muni Lagoon, Arizi et al. (2014) from Dominli Lagoon among many other authors, but no study was done on *Sarotherodon melanotheron* from Etse Lagoon.

The exploitation rate assesses if a stock is over-fished or not, on the assumption that optimal value E (E opt) is 0.5 (Ogamba & Abowei, 2012, pp. 951). The use of 0.5 as optimal value for the exploitation rate is based on the assumption that the sustainable yield is optimized when F = M (Gulland, 1971); 'F' represents fishing mortality and 'M' represents natural mortality.

Mangroves Associated With Coastal Lagoons

Mangroves are woody plants, which grow in loose wet soils of brackish-to-saline estuaries, creeks, backwaters, lagoons, marshes, mudflats and shorelines in the tropics and sub-tropics (Aheto et al., 2011; Swaminathan, 2002). They possess morphological, physiological, biochemical and reproductive adaptations that enable them to grow in the unstable and harsh tropic intertidal environment. Morphological and eco-physiological characteristics and adaptations of mangroves include aerial roots, viviparous embryos, tidal dispersal of propagules, rapid rates of canopy production, frequent absence of an under storey, wood with narrow, densely distributed vessels, highly efficient nutrient retention mechanisms, and the ability to cope with salt and to maintain water and carbon balance (Lebata-Ramos, 2013). The mangrove ecosystem is dominated by mangrove trees as the primary producer interacting with associated aquatic fauna, social and physical factors of the coastal environment (Melana et al., 2000). Mangrove trees have different levels of structural development based on their location and the environmental conditions of that locality.

Structural developments of mangroves

Human pressure on coastal systems, through expansion of activities such as aquaculture, agriculture, infrastructure and tourism, is the principal agent of the losses of mangrove forests (FAO, 2007). Structural characteristics of mangrove forests can be used as indicators of their natural stress level and to indicate the degree of sensitivity and vulnerability to additional man-induced stressors (Pellengrini et al., 2009). The levels of structural development of mangroves are important. The plant structure of mangrove directly influences the conditions and functioning of mangrove forests, and its alteration may influence the distribution and abundance of fauna (Soares, 1999: Cavalcanti et al., 2009). Therefore its characterization constitutes an important tool in understanding how this ecosystem responds to existing environmental conditions (Maia and Coutinho, 2012). Mangrove forest structure can be determined by measuring the adult tree heights and diameters at breast height (DBH) using pre-calibrated DBH tape measure proposed by Benfield (2002) and Defew (2003). The specially calibrated tape measure converts the girth or circumference of the tree into its diameter. This means that no post calculations are needed to determine DBH from girth or circumference measurement, since the direct measurement of diameter could be taken (Tania, 2006). Pellengrini et al. (2009) identified four categories of forest structural development: (a) Forests having maximum structural development–mean DBH between 27.0 and 29.9 cm, and mean height of the most-developed trees between 17.7 and 21.2 m; (b) Forests that have high structural development – mean DBH between 15.6 and 22.9 cm, and mean height of the most-developed trees between 11.8 and 22.7 m; (c) Forests that have intermediate structural development– mean DBH between 4.5 and 14.8 cm, and mean height of the most-developed trees between 5.7 and 13.7 m; (d) Forests that have low structural development – mean DBH between 1.6 and 3.1 cm, and mean height of the most-developed trees between 2.4 and 4.7 m.

Mangroves are distributed globally, and so these structural developments may vary from one geographical location to the other.

Distribution of mangroves

Mangroves are distributed circumtropically, occurring in 112 countries and territories (Aheto et al., 2011; Lebata-Ramos, 2013). Their distribution is determined by latitude, temperature (air temperature >20 ºC; water temperature ≥24 ºC) and coastal aridity. The richest mangrove communities occur in areas where the water temperature is greater than 24 ºC in the warmest month (Agrawala et al., 2003). Rainfall also influences mangrove distribution, largely by its effect on salinity. Mangroves are almost exclusively tropical and are confined between 30º N and 30º S latitudes. On a global scale the essential environmental prerequisites for mangrove development are temperature, mud substrate, protection, salt water, tidal range, ocean currents, and shallow shores (Lebata-Ramos, 2013). Approximately 73 species of plants, belonging to 28 genera and 21 families, are recognized throughout the world as being mangroves and the most diverse mangrove forests are found in Southeast Asia (Lebata-Ramos, 2013).

Mangroves cover about 137 km^2 (UNEP, 2007), constituting approximately 0.2% of the 81,342 km^2 of total forest area in Ghana (Gordon and Ayivor, 2003). The mangroves in Ghana are limited to very narrow, non-continuous coastal lagoons and estuaries, notably from the Ivory Coast border to Cape Three Points; and in the east, bordering the fringes of the lower reaches and delta of the Volta River (UNEP, 2007; Spalding et al., 2010; Gordon and Ayivor, 2003). There are six species of true mangroves in Ghana. These are *Acrostichum aureum, Avicennia germinans, Conarcarpus erectus,* *Laguncularia racemosa, Rhizophora harrisoni, and Rhizophora racemosa. Rhizophora racemosa* tends to dominate the open lagoons while *Avicennia germinans, Conarcarpus erectus, Laguncularia racemosa* and *Acrostichum aureum* are often associated with closed lagoons with elevated salinity (UNEP, 2007; Ajonina, 2011). All these species of mangrove are useful resources to the communities in which they occur.

Importance of Mangroves

Giesen et al. (2007) noted that mangroves are highly beneficial, as they yield many valuable products, while also performing, free-of-cost, many important functions that support the often dense coastal populations. They are very productive ecosystems, and the list of mangrove products commonly used worldwide is long and impressive. Some of the important benefits derived from mangroves are economic, ecological and social benefits.

Economic importance

Economically, they are highly important, be it at local, regional or even national level. The economies of coastal villages are often very dependent on adjacent mangroves, either directly, because of the products they derive from these habitats and are able to sell, or because of the coastal fisheries that are supported by mangroves, or the coastlines that are sheltered from storms (Giesen, et al., 2007). Wells et al. (2006), emphasized that the annual economic value of mangroves, estimated by the cost of the products and services they provide, has been pegged between $200,000 and $900,000 per hectare.

Mangrove associated fisheries

Many commercially important fish, shellfish and prawn species depend on mangroves at least during part of their life cycle (Foo & Wong, 1980; Adiwiryono et al., 1984; Sasekumar et al., 1992; Burhanuddin, 1993), and it has been demonstrated that the productivity of coastal fisheries is directly correlated with the area of mangrove: the more mangrove, the better the fisheries (Giesen et al., 2007). Aquaculture and commercial fisheries also depend on mangroves for juvenile and mature fish species (Melana et al., 2000).

Tourism, recreation and education

Mangrove areas are increasingly becoming important for ecotourism, education and study, especially in areas where they are readily accessible (Giesen et al., 2007). As a habitat for a range of organisms, both from the terrestrial and aquatic environments, mangroves themselves are unique systems with very high biodiversity (Lebata-Ramos, 2013), making them ecological destinations and field laboratories for biology and ecology students and researchers (Melana et al., 2000). In Malaysia, for example, Kuala Selangor Nature Park on the west coast of Peninsular Malaysia is a popular destination for nature lovers, birders and students. Also, in Thailand, mangrove sites such as Yaring Mangrove Education Center at Pattani are popular tourist destinations and it is much used by local schools (Giesen et al., 2007).

Shoreline protection

Mangroves play an important role in protecting shorelines from waves, winds, storms and typhoons. The roots of mangrove plants bind and stabilize the substrate and prevent coastal erosion, the crown and stem of mangroves serve as physical barriers that dissipate wave and current energy, and the vegetation as a whole can trap sediments (Davies & Claridge, 1993; Othman, 1994; Melana et al., 2000; Giesen, et al., 2007; Lebata-Ramos, 2013). Riverine mangroves reduce water velocity by adding to flood storage capacity thus mitigating flooding (Lebata-Ramos, 2013).

Support to food web

Mangroves are net exporters of organic matter, thus providing food for organisms that inhabit waters well outside the actual mangrove (Chapman, 1976; Mann, 1982; Sasekumar, 1992; Mastaller, 1997).

Carbon sequestration

According to Fujimoto, (2004) mangroves are able to sequester from 0.22- 1.24 tons of carbon per hectare per year. They produce organic biomass (carbon) and reduce organic pollution in near shore areas by trapping or absorbing 1,800-4,200 grams of carbon per square meter per year (Melana et al., 2000).

Ecological importance

Mangroves maintain estuarine water quality. Suspended matter, nutrients and heavy metals are reduced by the mangrove root system. The sediment and nutrient retention function of mangroves provide waters suitable for seagrass and coral reef development (Lebata-Ramos, 2013). Mangroves also function as a nursery habitat for fish, prawns and crabs (Melana et al., 2000). Melana et al. (2000) stated that mangroves contribute about 3.65 tons of litter per hectare per year and for every hectare of mangrove cut down, a corresponding reduction in fish catch is estimated at 1.08 tons per hectare per year. Their arched-shaped roots and finger-like roots provide hiding places for young animals and their leaf litter also provides valuable sources of food (Melana et al., 2000). However, globally, mangroves are undervalued, over-exploited and poorly managed (Ewel et al., 1998a) as evidenced by the destruction of 35% of world mangrove forests by human activities over the last two decades (Valiela et al., 2001).

Threats to mangroves

Many factors contribute to mangrove forest loss, which can be grouped into two.

a) **Natural stresses** - such as changes in topography and in the configuration of the coastline, leading to erosion in some mangrove areas and sedimentation in the mouth regions of some of the mangrove estuaries. Many of the mangrove wetlands are also affected by changes in the river course leading to reduced inflow of fresh water (Swaminathan Research Foundation, 2002). Diseases and pests also destroy mangroves, typhoons and sea level rise due to global warming cause polar ice cap to melt and inundate mangrove areas (Lebata-Ramos, 2013).

b) **Human-induced stresses** - such as felling of mangrove trees for fuel, charcoal and timber; grazing by domestic and feral cattle; diversion of land for agriculture, human settlements, salt pans and aquaculture; industrial pollution; indiscriminate fishing and diversion of fresh water flow. During the past decade, vast tracts of mangrove forests have been cleared to make way for coastal shrimp farms. Swaminathan Research Foundation (2002) has reiterated that consumer demand for shrimp has fuelled an export-oriented industrial shrimp aquaculture industry.

Land use in the Catchment of a Coastal Lagoon

The catchment of a lagoon comprises specific landscape features that feed or transmit water to the lagoon via surface and groundwater. The landscape influences its water bodies through multiple pathways and mechanisms which operate at different spatial scales (Allan & Johnson, 1997). Coastal lagoons being an embedded part of a larger landscape can be profoundly influenced by land uses in their catchment areas. Land use change is an example of anthropogenic stressors that can have profound and sudden impacts on coastal lagoons. It refers to the direct or indirect disruption of catchment structure and processes by anthropogenic activities. Land use is a kind of catchment disturbance. Some of the most important land uses affecting coastal lagoons in Ghana include agriculture, urbanization, industry, infrastructure and recreation. These anthropogenic activities lead to the alteration and degradation of most lagoon ecosystems. For example, the clearance of vegetation around lagoons and the increase in impervious surfaces which are associated with urbanization can lead to an increase in the volume and rate of runoff entering the lagoon. This can result in increased sediment, nutrient and pollutant loads (Lee et al., 2006) in the water body with the accompanying siltation, algal blooms and death of aquatic organisms, especially fish. Also, Marais (1988) noted that the size of the catchment area has been identified as an important factor governing both fish species diversity and abundance in South African estuaries. There is paucity of information on the boundary, size and land use change of the natural boundary of coastal lagoons in Ghana. Coastal Resource Center-Ghana/Friends of the Nation (2010) studied the land use or cover pattern within the natural boundaries of Whin estuary, Essei and Butuah Lagoons and identified three main categories which are built up area, industrial and vegetation with minimal encroachment into their boundaries.

CHAPTER THREE

MATERIALS AND METHODS

Study Area

Etse Lagoon is a "classical'' closed lagoon (Yankson & Obodai, 1999) located between latitude 5 °11'30'' N and 5° 11'50'' N and longitude 1° 5'25''W and 1 ° 5'15'' W (Figure 1). It has a surface area of about 27118.4 m^2 (approximately 2.7 hectares). Precipitation and runoff from the two communities and freshwater inflow from the Woraba stream (Figure 1 shows the Woraba stream) are the main sources of freshwater into the lagoon. In addition, there is some exchange of water between the lagoon and the adjacent sea in the major rainy season when the lagoon fills up and the sand bar separating the two water bodies gets breached. The vegetation around the lagoon is dominated by seashore paspalum (Family Poaceae), coastal rat-tail grass (Family Poaceae), shoreline purslane (Family Aizoaceae), date palm (Family Arecaceae), coconut (Family Arecaceae), Portia tree (Family Malvaceae), red mangrove (Family Rhizophoraceae), white mangrove (Family Combretaceae) and black mangrove (Family Acanthaceae). The lagoon's fringe mangrove vegetation at the upper and lower portions of the lagoon is luxuriant and appears undisturbed but the middle portion of the lagoon is characterised by few patches of stunted and exploited fringing mangroves. The Etse Lagoon is located on the boundary between Abandze and Kormantse communities at a topographic low point in the landscape. The two communities, Abandze and Kormantse border the western and eastern sides of the lagoon respectively, whiles the southern portion is bordered by a narrow sand bar.

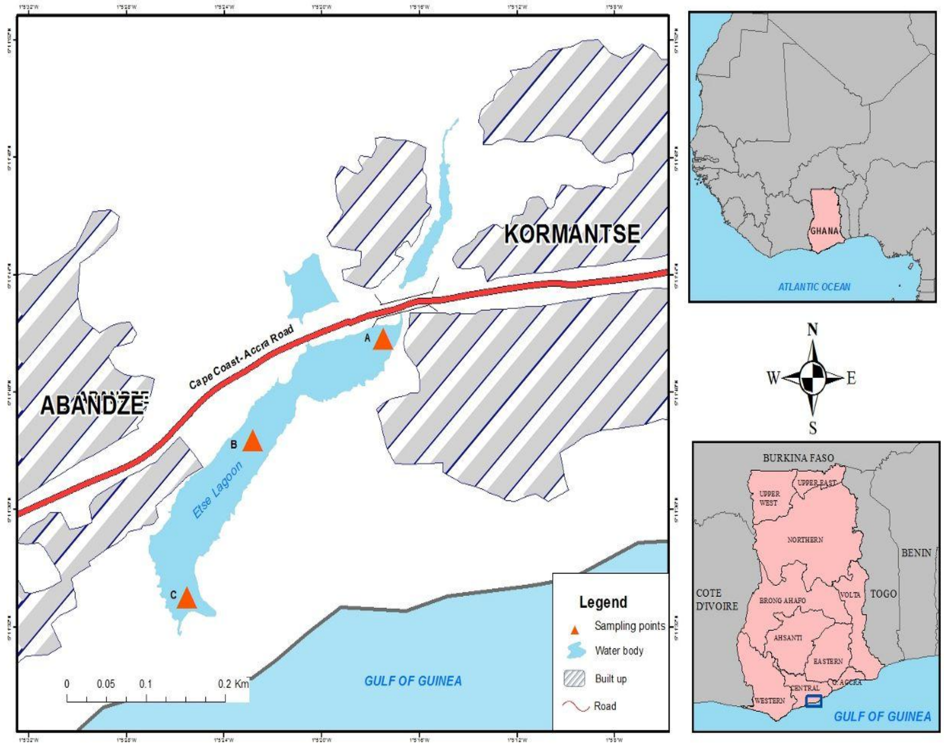

Figure 1: A map of Etse Lagoon showing the stations sampled for water quality measurement (Source: Centre for Coastal Management, University of Cape Coast).

The resources of the lagoon are exploited for various uses. The trees fringing the lagoon are exploited for fuel wood. The fish are exploited for subsistence, and the fruits of coconut trees are harvested for food and income whiles their fronds are used in fencing.

Annual air temperature around Abandze and Kormantse ranges from 24.9 ^{0}C to 28 ^{0}C while relative humidity ranges from 82 % to 91 % with the area experiencing an average annual rainfall of 100.9 mm (Ghana Meteorological Service, 2014). The lagoon is located in a coastal savannah ecosystem that is influenced by a bimodal rainfall pattern. A major rainy season occurs in May-July, and a minor season in September-October. Dry period is experienced between November and April. At the peak of the rainy season, the lagoon fills up and spills over the narrow sandbar which gets breached, creating an outlet that temporarily connects the lagoon to the sea.

Even though the Etse Lagoon provides important fisheries livelihood for Abandze and Kormantse communities and beyond, fishing in the lagoon depends on the fishing seasons at sea; there is more fishing in the lagoon during the lean season (range from 4 to 10 fishermen a day). During bumper harvest season at sea, there is little or no fishing in the lagoon. Fish catch per fishing effort of 3 hours (using cast net) from the lagoon is usually small and this also depends on the volume of water or the water depth in the lagoon. There is more catch when the depth is relatively shallow and less catch when the depth increases. Etse Lagoon also enhances the scenic view of the Abandze Beach Resort.

Data Collection and Analysis

The study was conducted from April 2014 to March 2015. Three stations were selected for sampling of environmental parameters (Figure 1). Station A was nearest the riverine part (upper portion) close to the Accra-Cape Coast highway culvert; station B was approximately the middle portion, and station C was close to the sea. The stations were about 200 m from each other.

Measurement of environmental parameters

Water quality was measured bi-weekly from 8.00 GMT to 10.00 GMT on each sampling day as shown in Figure 2. Temperature, salinity, pH, dissolved oxygen (DO) and conductivity, were recorded *in situ* from a dinghy by immersing the probe of the water quality checker (Oakton PCD 650) into the water and recording the values of each parameter (Figure 2). Three measurements of each environmental parameter were taken from the surface and subsurface from each of the three stations. Rainfall and air temperature data from April 2014 to March 2015 for the study area were obtained from Ghana Meteorological Service and analyzed to show their influence on salinity and temperature of the lagoon.

Figure 2: Measuring environmental parameters *in-situ* from a dinghy at Etse Lagoon.

Analysis of environmental parameters

The means, standard deviations and standard error of the physicochemical parameters were computed for each station and each month. Analysis of variance (ANOVA) procedure was carried out in GraphPad Prism 5 (www.graphpad .com>support>prism 5) to test for the differences in the means of the various physicochemical parameters in the different stations and months.

Fish sampling

Fish samples were obtained bi-weekly from the fishermen for a period of twelve months, from April 2014 to March 2015. Cast nets with stretched mesh size ranging from 2.5 cm to 3.0 cm were used by the fishermen who wade in the lagoon to cast their nets. Fish samples were obtained by buying all the fish caught by two to four fishermen per fishing period of three hours on the average. The samples were kept on ice soon after capture and transported to the Fisheries and Coastal Laboratory, University of Cape Coast for further examination.

In the laboratory the fish were sorted and identified to their families and species using manuals and keys on fin fishes and shellfishes in Ghana and West Africa (Paugy, Leveque & Teugels, 2003; Kwei & Ofori-Adu, 2005; Schneider, 1990; Dankwa et al., 1998). The number of individuals belonging to each species from the lagoon was also recorded.

Fish diversity determination

The relative abundance of fish fauna caught from Etse Lagoon was determined based on the number of specimens of the various fish species. The relative abundance was determined as the percentage ratio of the number of a particular species to the total number of all sampled species (Arizi et al., 2014).

Fish species diversity was determined using:

(i) Shannon-Wiener's Index (H′) of species diversity

$$H' = -\sum_{i}^{s} = 1\ Pi\ (lnPi)$$ (Krebs, 1999)

where s = number of species in the community and Pi = proportion of individuals belonging to species *i* in the community

(ii) Margalef's Index (d) was used to determine species richness

$$d=(S-1)/\ln N$$ (Krebs, 1999)

where S is the number of species in the sample and N is the number of individuals in the sample

(iii) Species dominance which measures the probability that individuals randomly selected from a sample will belong to the same species was determined using Simpsons species dominance index (D)

$$D = \sum (n - (n - 1)/N (N - 1)$$ (Krebs, 1999)

where n is the number of individuals of a particular species

Relationship between environmental parameters and biological data

Pearson's correlation analysis was used to ascertain the relationship between the environmental parameters and also between environmental parameters and biological data to establish how these parameters influence the abundance and diversity of fish fauna in Etse Lagoon. This was done using Minitab version 16 computer software.

Measurement of finfish and carapace length and weight

Records of the weight and length of individuals of each species were taken to the nearest 0.01g (using FEL500 electronic balance as shown in Figure 3) and 0.01 cm respectively (using a measuring board and a rule). The total length (TL) was taken from the tip of the snout to the tip of the caudal fin and standard length (SL) from the tip of the snout to the base of the caudal fin of finfish; carapace length (CL) was taken at the widest point of the upper part of the carapace, and carapace height (CH) from the median frontal notch to the posterior carapace margin of crab specimen (Ashkenazi et al., 2005) using a pair of vernier callipers, and body length (BL) from the rostrum to the telson of prawn specimen was measured to the nearest 0.01cm.

Figure 3: Weighing the fish samples using FEL500 electronic balance in the laboratory.

Determination of length frequency distribution, length–weight relationship and condition factor

Fish length data were sorted into classes of 1 cm intervals and plotted as length - frequency distribution histograms.

Changes in growth pattern were investigated using relationship between length and weight. The relationship between the length (L) and weight (W) of the most dominant fish species was described by the power equation: $W= aL^b$ (Pauly, 1983) where W is total weight, L is standard length; 'a' is the intercept and ‘b’ the exponent. The values of constants ‘‘a’’ and ‘‘b’’ were estimated from a linear regression of the length and weight of fish after a logarithmic transformation of equation above. The logarithmic transformation of the equation gave a straight line relationship expressed as:

$$\text{Log } W = \log a + b \log L$$

The correlation (r) that is the degree of association between the length and weight was computed from the linear regression analysis.

The condition factor (C. F.) of the most dominant fin and shell fish was estimated from the equation (Pauly, 1983):

$$C.\ F. = 100W/L^3$$

where W is weight (g) and L is standard length (cm) of the fish.

Growth and mortality parameters and exploitation rate estimation

Due to insufficient number of specimens for most fish species in monthly samples, only the growth and mortality parameters of the commonest fish, *Sarotherodon melanotheron* were estimated. The Electronic Length Frequency Analysis (ELEFAN) computer programme incorporated into FAO-ICLARM fish stock assessment tool (FiSAT) was used to estimate population parameters (growth parameters, mortality and exploitation rates) of this fish.

3.2.3.5.1 *Growth parameters estimation*

The growth parameters, $L\infty$ (asymptotic length, cm) and K (growth constant, yr^{-1}) of *Sarotherodon melanotheron* were determined using ELEFAN in the FiSAT software (Gayanilo & Pauly, 1997), while t_0 (age at length zero) was computed from the equation:

$$\text{Log}_{10}(-t_0) = -0.392 - 0.275 \log_{10} L\infty - 1.038 \text{ Log}_{10} K \text{ (Pauly, 1979).}$$

These parameters were used to describe von Bertalanffy growth function (VBGF) of the population:

$$L_t = L\infty\ [1 – e^{-K(t - t_0)}]$$

Mortality parameters estimation

Using the FiSAT programme, the total mortality coefficient (Z) was estimated by linearized length converted catch curve analysis (Sparre & Venema, 1992) and natural mortality (M) was estimated by entering data on the annual temperature of the lagoon and *K* and L∞ of the population in Pauly’s (1980) equation:

$$Log_{10}\ M = 0.0066\ Log_{10}\ K – 0.2791\ Log_{10}\ L\infty + 0.6543\ Log_{10}\ K + 0.4634 Log_{10}$$

The fishing mortality (F) that describes the rate of mortality due to fishing activities was estimated from the relationship:

$Z = F + M$ (Ricker, 1975)

Exploitation rate estimation

The exploitation rate (E), which describes the extent to which the fish stocks are exploited was also estimated from the equation:

$E = F/Z$ (Ricker, 1975)

The longevity or natural life span (t_{max}) of the stocks was estimated from the equation:

$t_{max} = 3/K$ (Pauly, 1984)

where *K* = von Bertalanfy growth coefficient

The growth performance index (Φ′) was computed using the following equation by Munro and Pauly (1983):

$$\Phi' = Log_{10} K + 2\ Log_{10} L\infty$$

Information on the annual recruitment pattern of the *Sarotherodon melanotheron* population was also provided by the programme.

Mangrove Sampling

Samples of flowers, stems, leaves, fruits, pneumatophores, prop roots and propagules from the mangrove trees and other flora were collected for identification in the herbarium at the Department of Environmental Science of the University of Cape Coast. The identification key used was Field guide to Florida mangroves, www.gofishguides.com>mangrove id.

The fringe mangrove stand at the seaward portion of the lagoon (Figure 4) was demarcated for the study. Two sites (Sites 1 and 2) were located on the banks at either side of the lagoon. Ten plots (5 m x 5 m), five on either banks of the lagoon were created at 5 m intervals and perpendicular to the banks of the lagoon to record data on the mangrove communities present. Each mangrove species occurring in a plot was identified and counted to determine its density and relative frequency. The composition of the species (relative abundance) and their relative dominance were also calculated.

Mangrove trees above 1m in height were measured using a graduated pole. The girth or circumference of each mangrove species was determined using a measuring tape and calculation (circumference/π) was later done to determine DBH from girth since direct reading of diameter at breast height could not be taken. Breast height was determined as being approximately at 1.3 m from the ground. When abnormalities such as swelling, forks or prop roots prohibited measurement to be taken at 1.3 m, a convenient height was chosen by following the rules established by English et al. (1997).

Determination of mangrove tree population and structural parameters

The density of mangrove species (D_i), their basal area (BA), their frequency of occurrence and importance values (IV) were calculated according to Cintron and Schaeffer- Novelli (1984) method:

$$\text{Density } (D_i) = \frac{\text{ni}}{A}$$

where D_i = Density of species *i*; n_i = Total number of species *i* and A = sampling area.

$$\text{Basal Area of trees (BA)} = \pi r^2$$

where $r = \frac{D}{2}$ and π= 3.142

$$\text{Frequency of occurrence of species, } i = \frac{\text{Number of individuals of species } i}{\text{Total number of individuals of all species}}$$

$$\text{Relative frequency (Rf)} = \frac{\text{Frequency of species } i}{\sum \text{frequency of all species}} X\ 100$$

$$\text{Relative density (Rd)} = \frac{\text{Density of species } i}{\sum \text{density of all species}} \text{ X } 100$$

$$\text{Relative dominance (RD)} = \frac{\text{BA of species } i}{\sum \text{BA of all species}} \text{ X } 100$$

The IV of a species which is a relative measure of the ecological contribution of a species was obtained by adding the values of relative frequency, relative density, and relative dominance according to Cintron and Schaeffer-Novelli (1984):

Importance Values (IV) = Relative frequency + Relative density + Relative dominance

Figure 4: Mangrove covers at Etse Lagoon showing part of Site 1.

Determination of Land use in the Catchment of Etse Lagoon

The current boundary (2012) of Etse Lagoon and land use data were processed and compared with boundary data extracted from a 1973 topographic map (made from 2012 Google Earth Imagery and 1972 Topographic sheet) of the area to provide an indication of the extent of change in the surface area of the lagoon and also in the land use within the immediate surroundings of the water body. Based on the national land use classification adopted from Coastal Resource Center-Ghana/Friends of the Nation (2010), the current land use within the natural boundary of the water body was placed into four categories namely: (i) built up area (ii) sandy beach (ii) vacant/unused and (iv) vegetation and their percentage coverage were determined.

CHAPTER FOUR

RESULTS

Fluctuations in environmental parameters

Air temperature

The air temperature around the Etse Lagoon declined continuously from 28 ^{0}C in April, 2014 to 24.9 ^{0}C in August, 2014. Thereafter, it increased progressively. Highest air temperature was recorded in February, 2015 and March, 2015 whilst lowest air temperature was recorded in August, 2014. The air temperature range was 24.9 ^{0}C–28.3 ^{0}C. Figure 5 shows the monthly mean air temperature in the vicinity of the lagoon during the study period.

Water temperature

Water temperature fluctuations in the lagoon slightly mimicked that of the surrounding air temperature in. The water temperature decreased from a mean value of 31.98 ^{0}C in April, 2014 to 27.32 ^{0}C in May, 2014. Water temperature remained fairly stable through June, 2014 to 27.25 ^{0}C in July, 2014. Thereafter it increased to 32.37 ^{0}C in September, 2014 but decreased gradually to the lowest value of 25.76 ^{0}C in January, 2015 and then increased through February to 31.51 ^{0}C in March, 2015 as shown in Figure 6. The monthly mean water temperature ranged between 25.8 ^{0}C and 32.4 ^{0}C and the mean water temperature for the entire study was 29.52 ± 0.11.

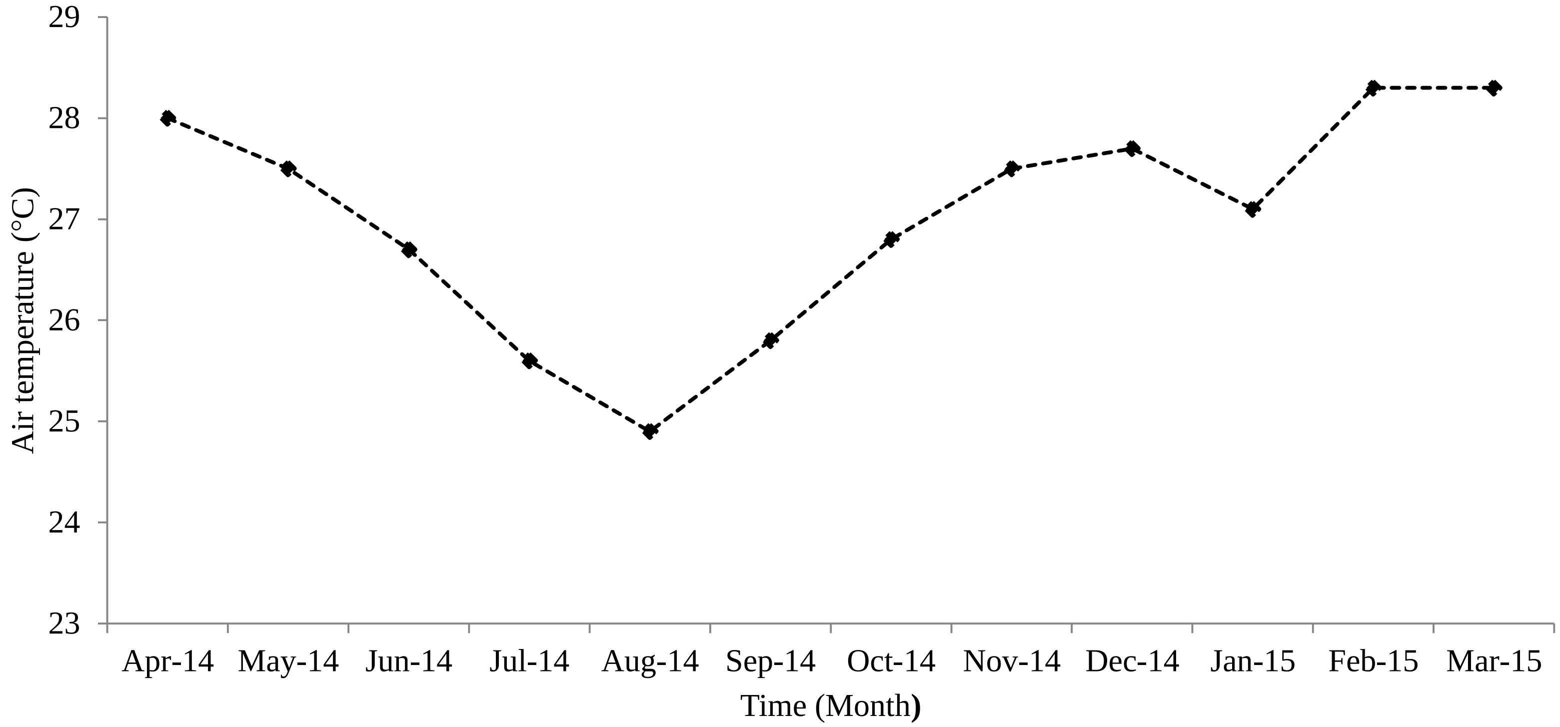

Figure 5: Monthly mean air temperature in the vicinity of Etse Lagoon from April 2014 to March 2015

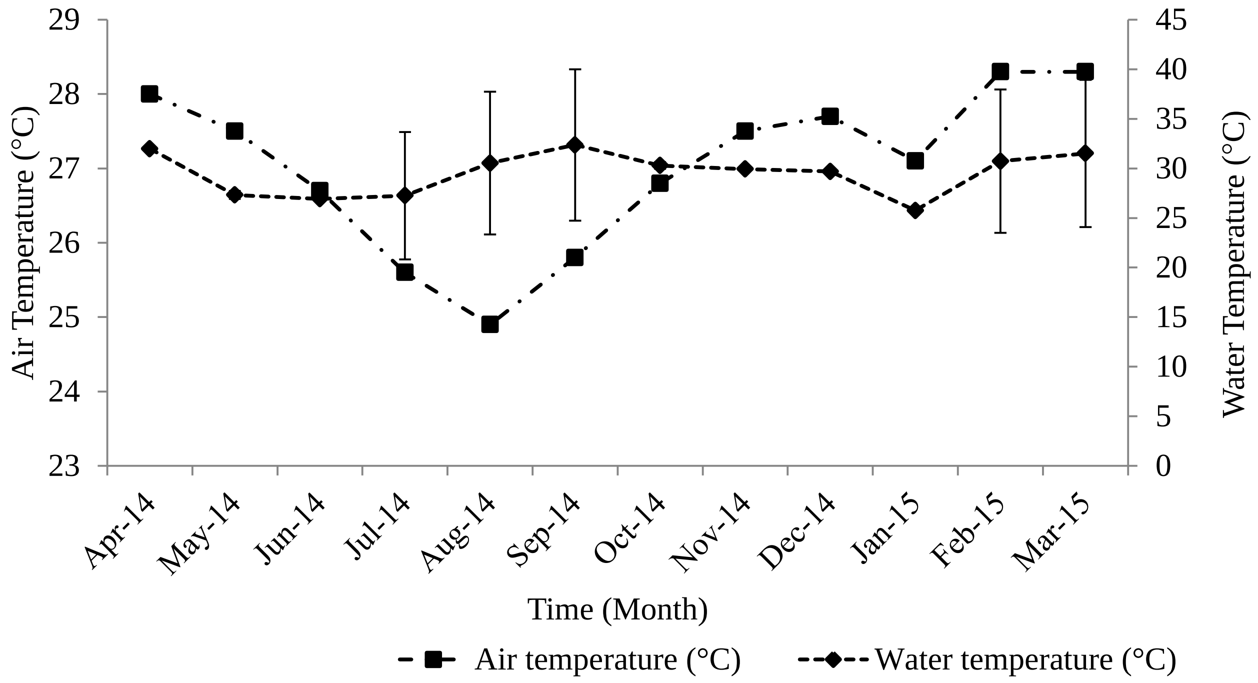

Figure 6: Seasonal variations of water temperature with air temperature, Etse Lagoon from April, 2014 to March, 2015.

The water temperature recorded at the three stations in the Etse Lagoon ranged between 24.0 °C and 36.6 °C. The minimum value of 24.0 °C was recorded at the riverine end (Station A) in the month of May, 2014 at the surface water. The highest temperature of 36.6 °C was recorded at the seaward end (Station C) in the month of February, 2015 in the subsurface water. One-way analysis of variance of spatial water temperature showed that the means were not significantly different at $P > 0.05$. The one-way analysis of variance of temporal temperature showed that their means were significantly different at $P < 0.05$. Figure 7 illustrates the monthly changes in the water temperature at Stations A (Riverine portion), B (Middle portion) and C (Seaward portion).

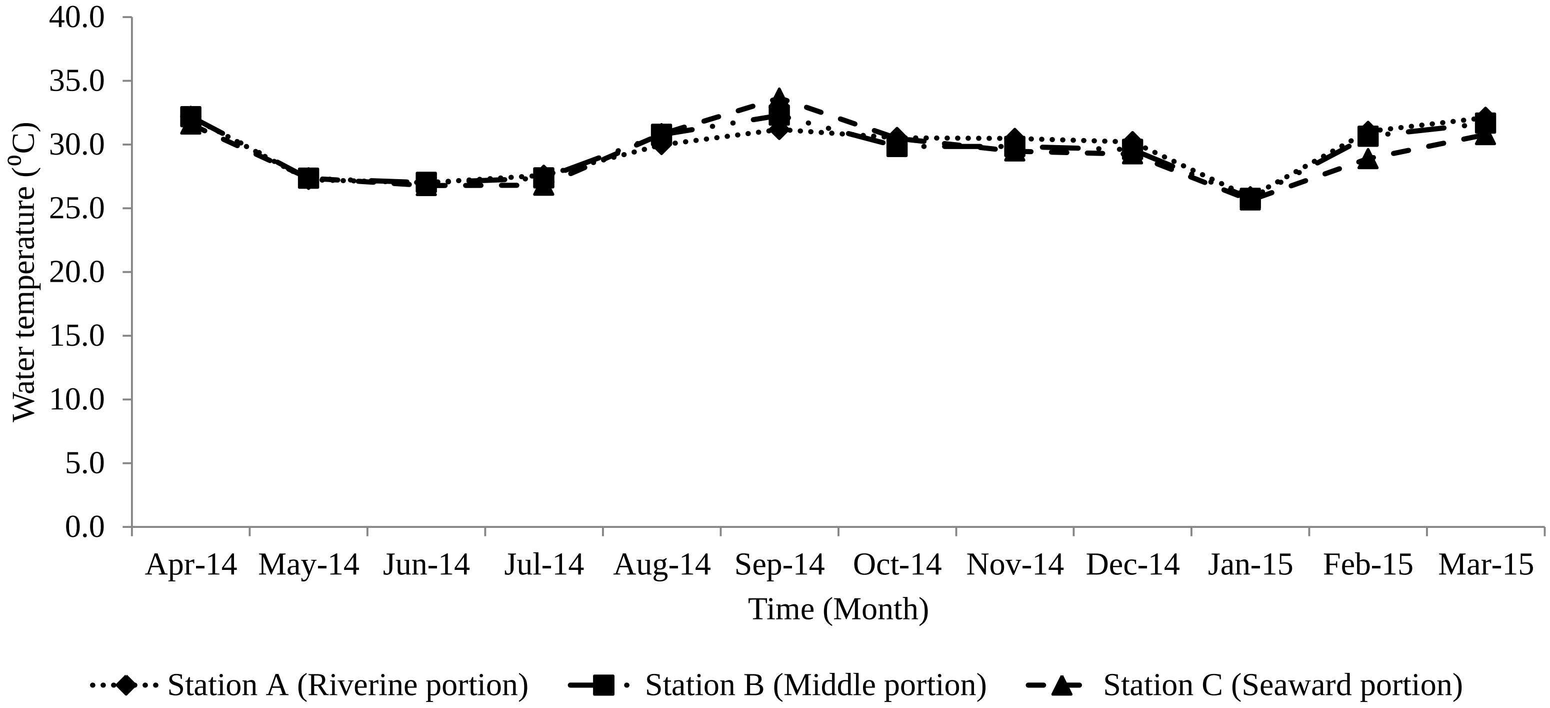

Figure 7: Seasonal variations of water temperature at Stations A (Riverine portion), B (Middle portion) and C (Seaward portion) in Etse Lagoon from April, 2014 to March, 2015.

Rainfall

The pattern of rainfall around Etse Lagoon during the study period is shown in Figure 8. The heaviest rainfall was recorded in May, 2014. This resulted in the breaching of the sand bar connecting the lagoon to the sea automatically in June, 2014. The major rains were in April, 2014 to July, 2014 with the minor rains from August, 2014 to February, 2015. March, 2015 was the onset of another major rainy season.

Salinity

Salinity recorded at the three stations in the lagoon ranged between 0.72 ‰ and 22.30 ‰ during the entire study period. The middle portion (Station B) recorded the least value of 0.72 ‰ in the month of June 2014 in the surface water. The highest value of 22.30 ‰ was recorded in the month of March, 2015 in the subsurface water at the seaward portion (Station C). A one-way analysis of variance of spatial salinity showed that the means were not significantly different ($P > 0.05$). The one-way analysis of variance of the means of temporal salinity was significantly different ($P < 0.05$). Figure 10 illustrates monthly mean salinity at Stations A (Riverine portion), B (Middle portion), and C (Seaward portion) during the study.

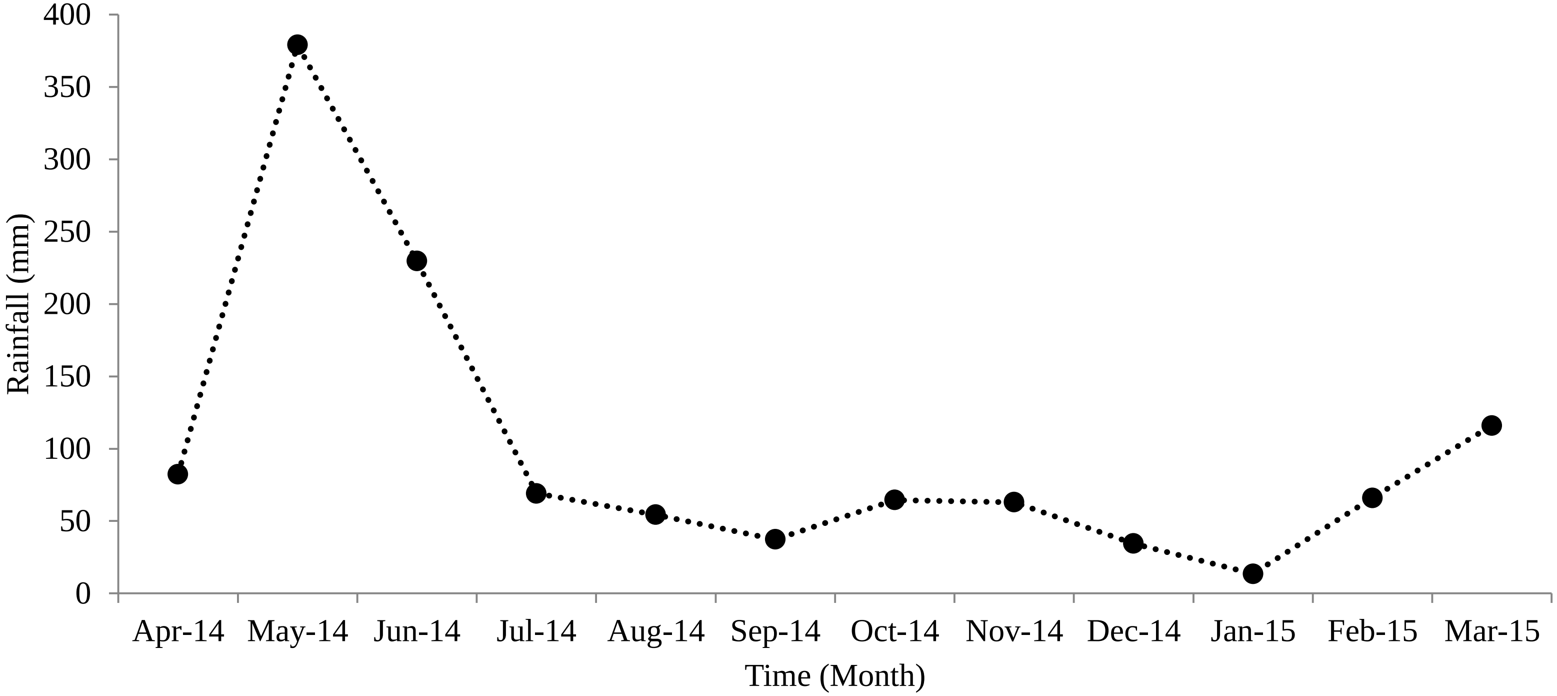

Figure 8: Rainfall pattern around Etse Lagoon from April, 2014 to March, 2015

(Source: Ghana Meteorological Service, 2014 to 2015).

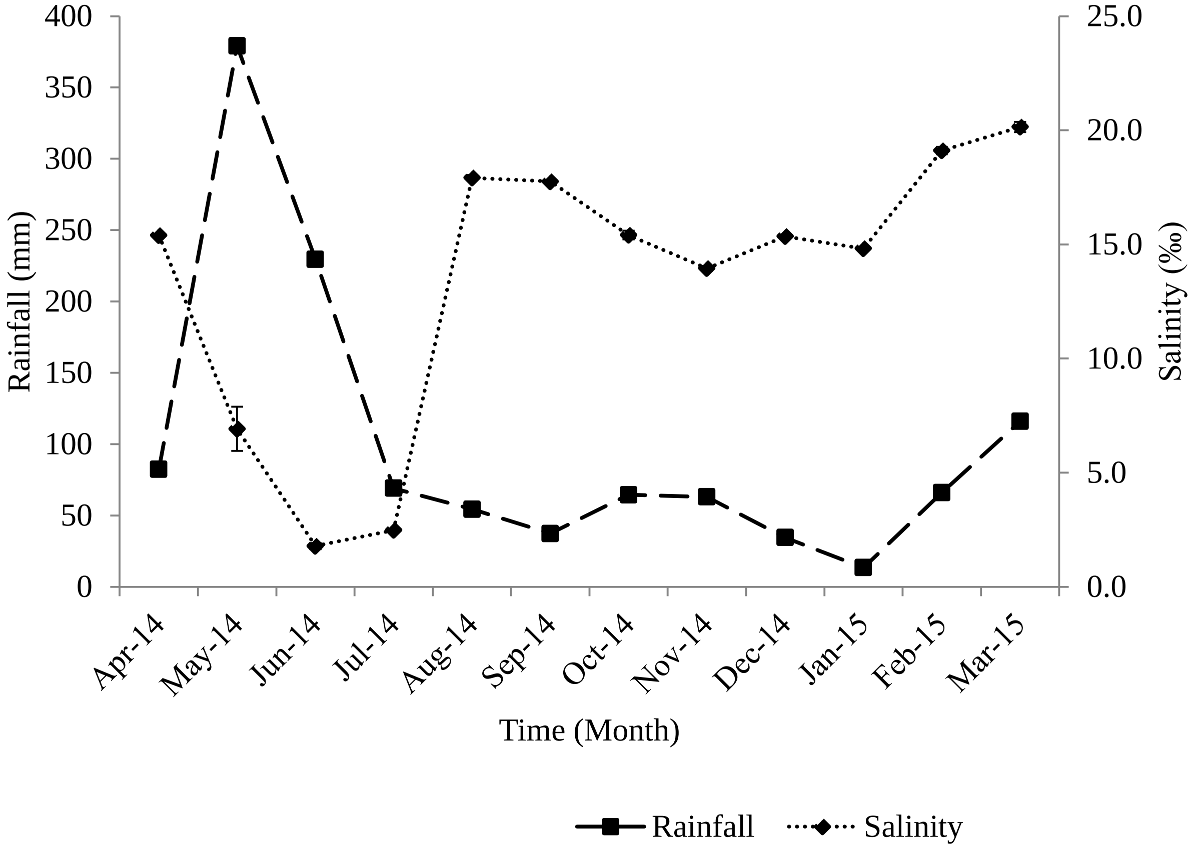

Figure 9: Seasonal variations of salinity with rainfall, Etse Lagoon from April, 2014 to March, 2015.

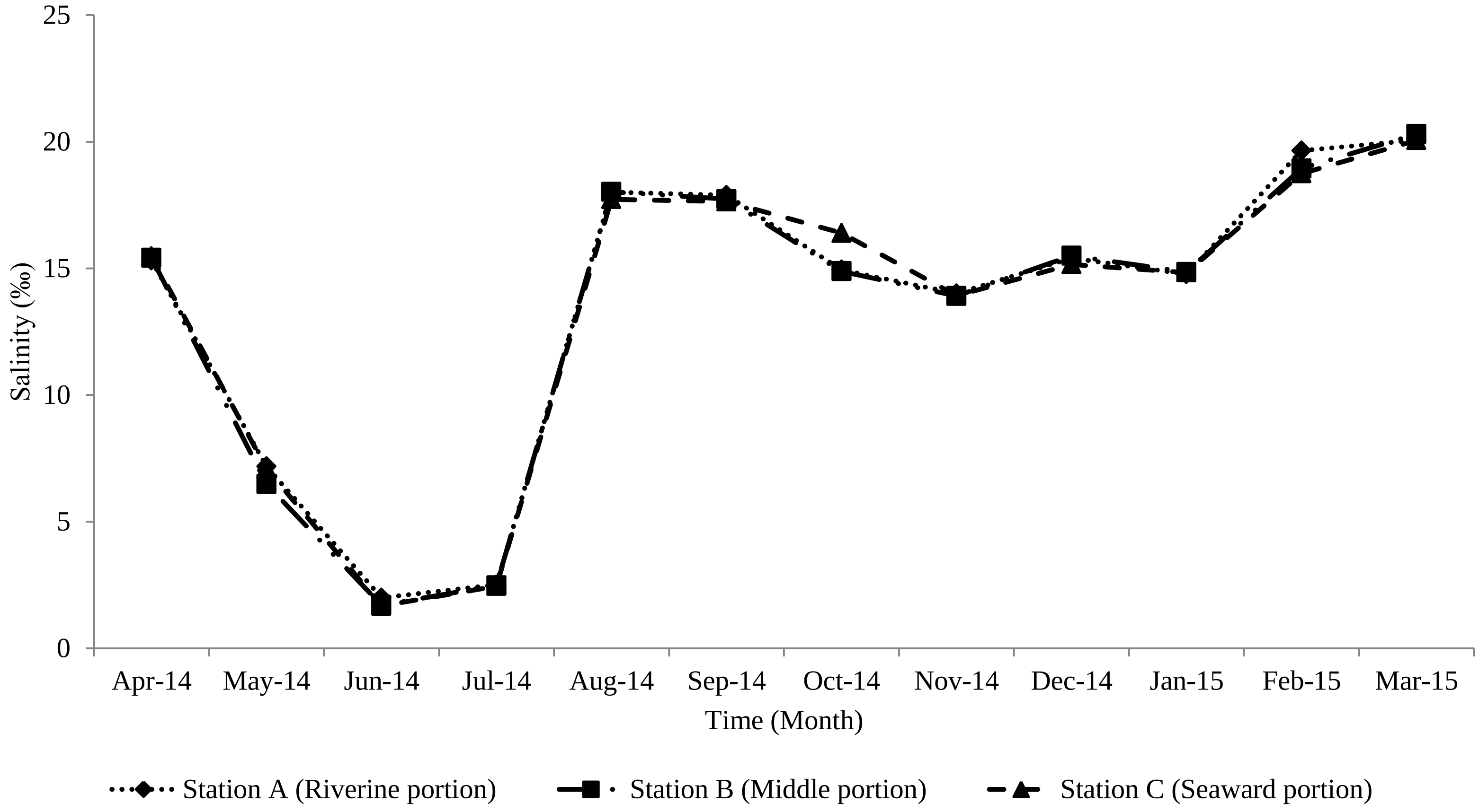

Figure 10: Monthly mean salinity at Stations A (Riverine portion), B (Middle portion), and C (Seaward portion), Etse Lagoon from April, 2014 to March, 2015.

Hydrogen ion concentration (pH)

The pH was fairly constant in the first three months but increased to a mean maximum value of 8.46 in July, 2014. Thereafter it declined to the lowest value of 6.47 in September, 2014 but increased steadily to 7.80 in March, 2015 (Figure 11). The monthly mean pH ranged between 6.47 and 8.46 with an average of 7.6 ± 0.03.

The pH recorded at the three stations during the entire study ranged between 4.6 and 8.9. The highest pH value recorded was 8.9 in the month of April, 2014 in the middle and seaward portions at the surface water. The least value of 4.6 was recorded at the riverine end (Station A) in September, 2014 at the surface water. One-way analysis of variance of means of spatial pH was significantly different ($P < 0.05$). The one-way analysis of variance of means of temporal pH was also significantly different ($P < 0.05$). Figure 12 is an illustration of monthly average pH, in Etse Lagoon during the entire study.

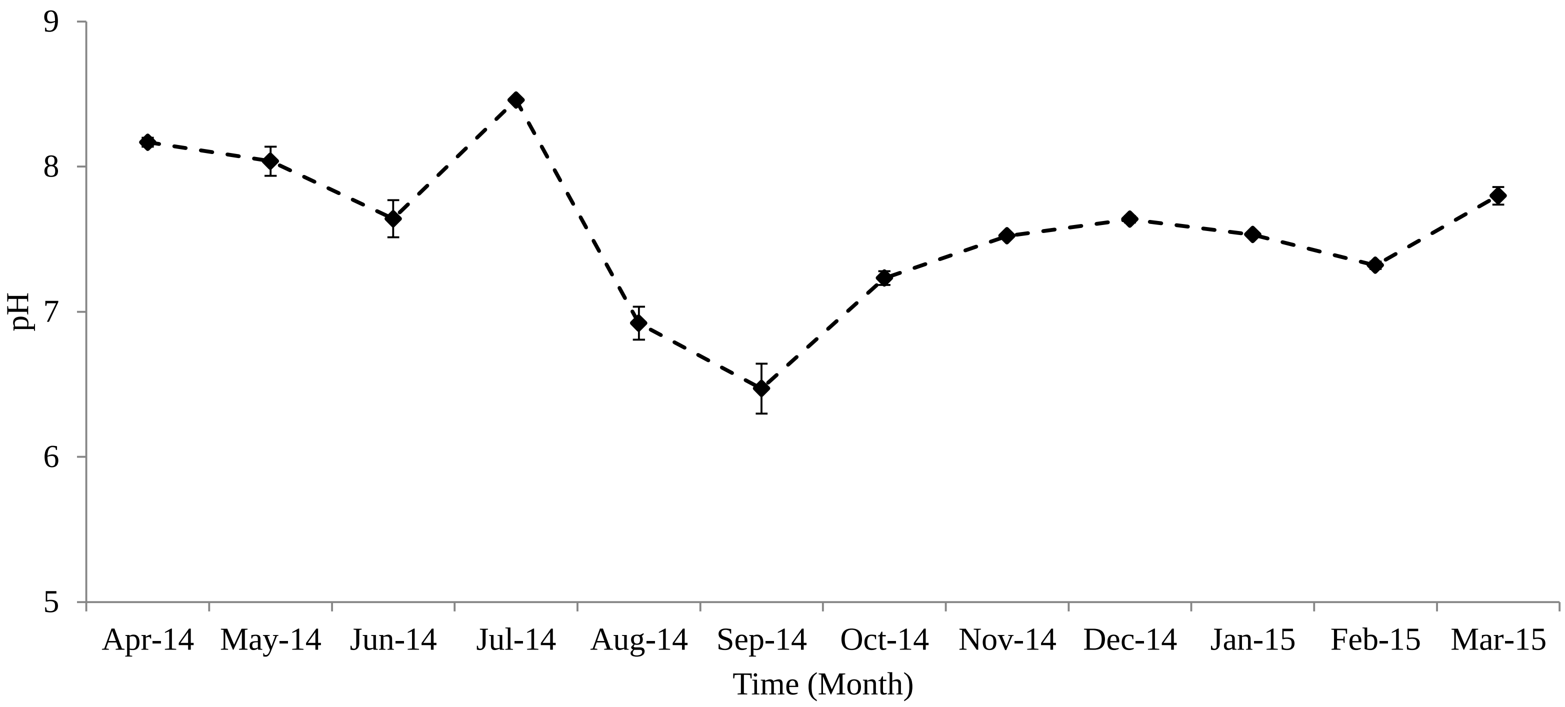

Figure 11: Monthly mean pH for the Etse Lagoon from April, 2014 to March, 2015

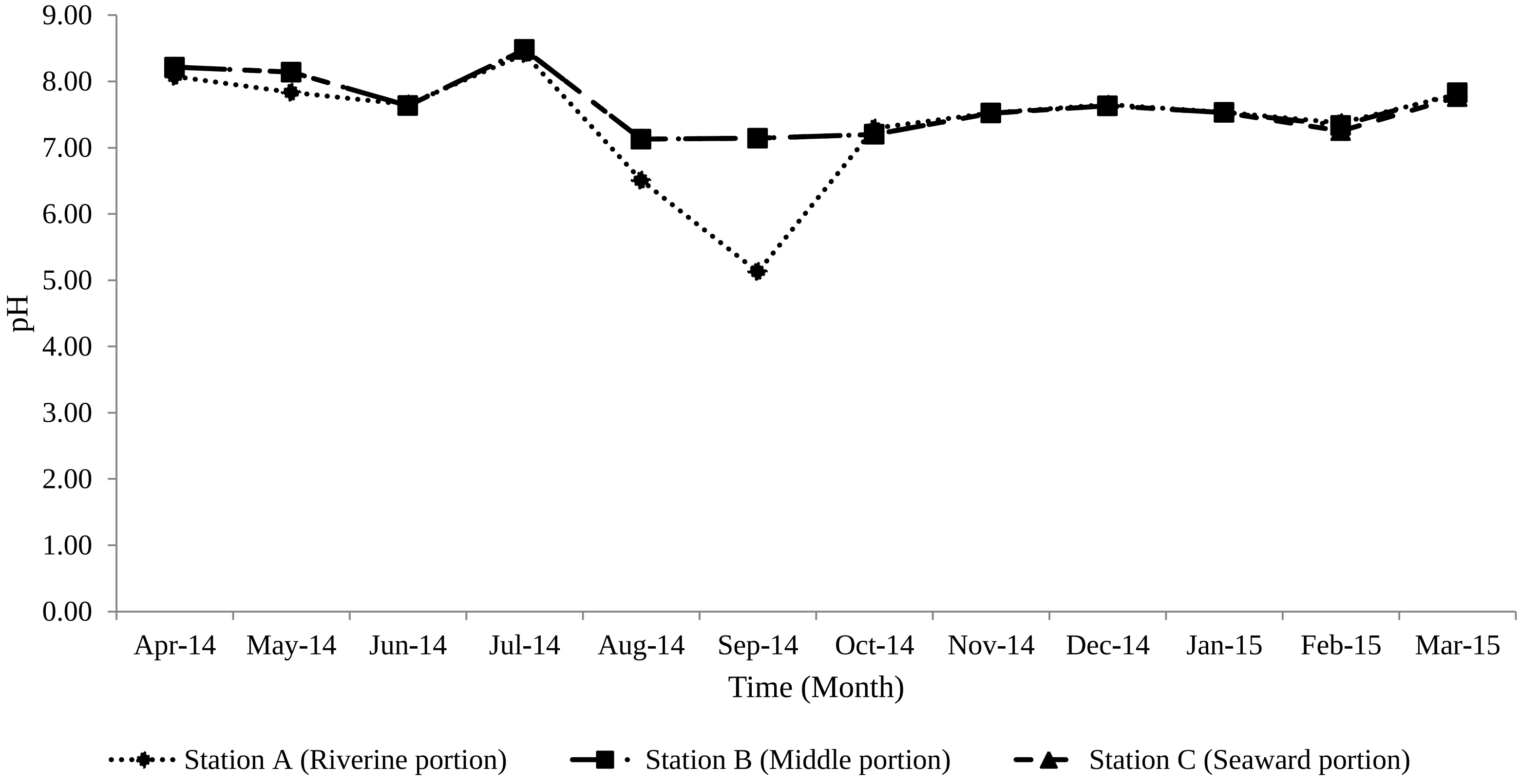

Figure 12: Monthly mean pH in Etse Lagoon at stations A (Riverine portion), B (Middle portion) and C (Seaward portion) from April, 2014 to March, 2015.

Dissolved oxygen

Dissolved oxygen varied from 3.18 mg/l to 6.81 mg/l with the mean of 5.08 ± 0.08 during the study period. It was high (> 5 mg/l) in April 2014, August 2014, September 2014, October 2014, February 2015 and March 2015. However, it was low (< 5 mg/l) in May 2014, November 2014 and December 2014. Figure 13 illustrates monthly mean DO for the Etse Lagoon from April, 2014 to March, 2015.

The DO recorded at the three stations varied from 1.65 mg/l to 11.15 mg/l. The highest DO value recorded was 11.15 mg/l in February 2015 at the riverine portion (Station A). The least value of 1.65 mg/l was recorded in June 2014 at the middle portion (Station B). A one-way analysis of variance the means of spatial dissolved oxygen were not significantly different ($P > 0.05$). The one-way analysis of variance of the means of temporal dissolved oxygen was not significantly different ($P > 0.05$). Figure 14 is an illustration of monthly mean dissolved oxygen, in Etse Lagoon during the entire study.

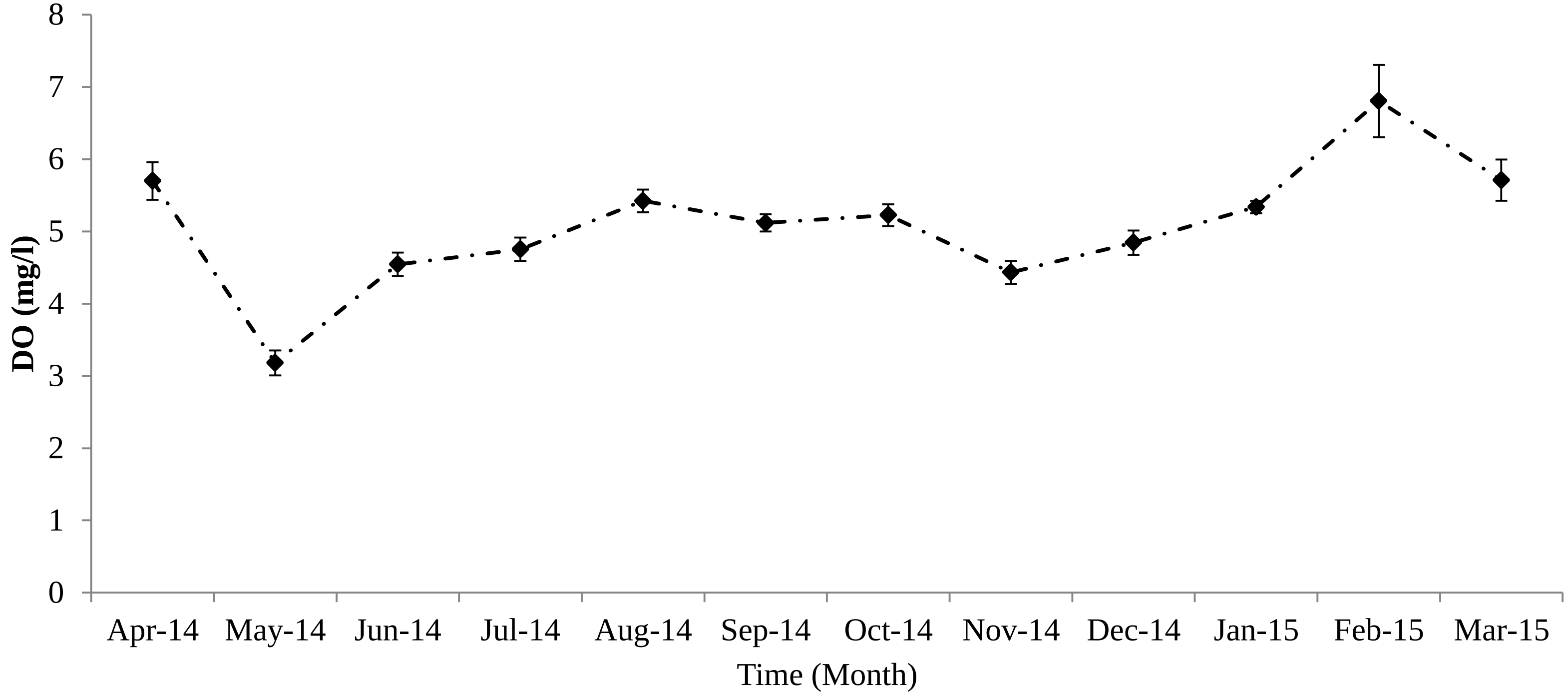

Figure 13: Monthly mean DO for the Etse Lagoon from April, 2014 to March, 2015.

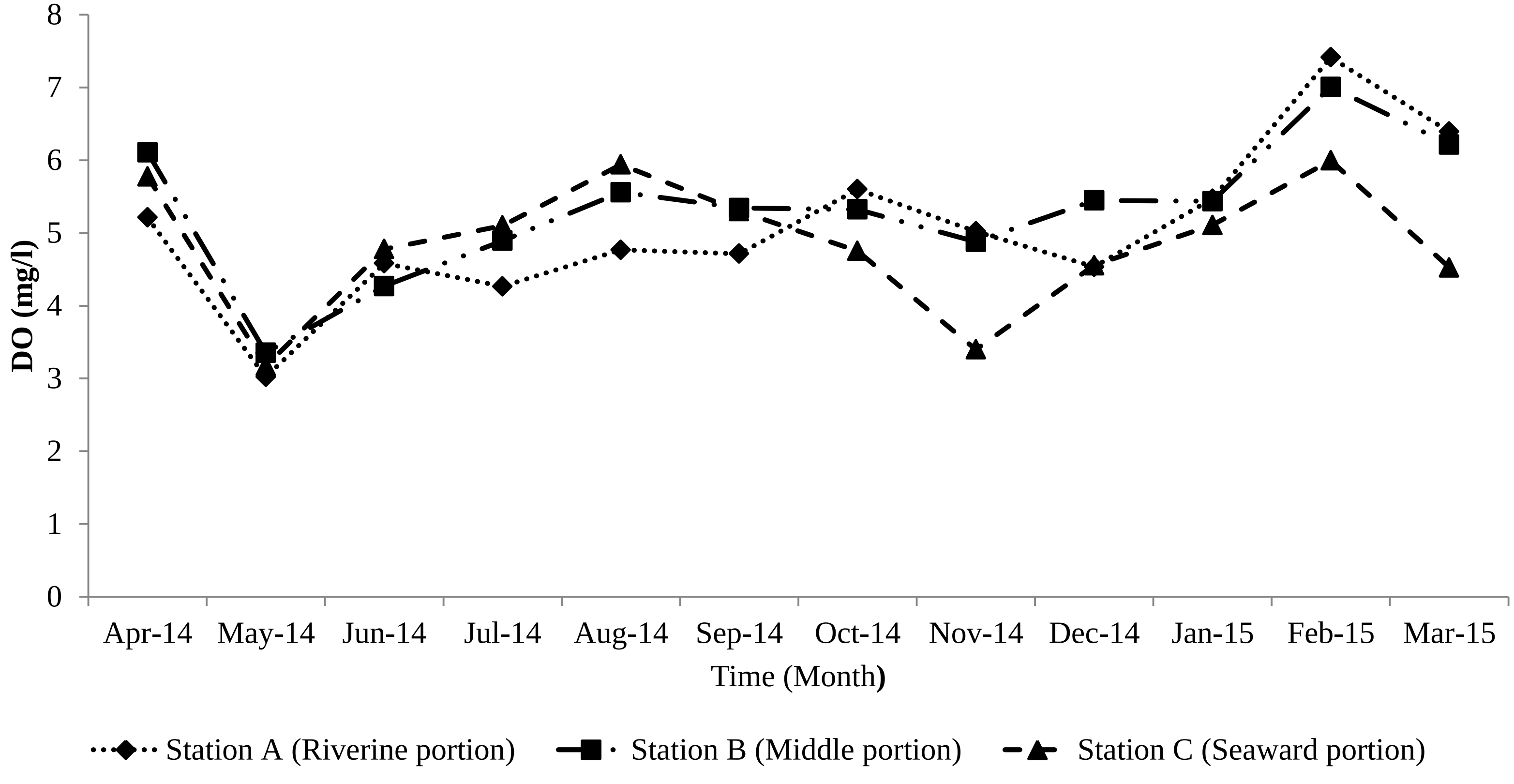

Figure 14: Monthly mean dissolved oxygen (DO) at station A (Riverine portion), B (Middle portion) and C (Seaward portion) in Etse Lagoon from April, 2014 to March, 2015.

Conductivity

The conductivity was high in April 2014, May 2014, June 2014 and July 2014. However, it was low from August 2014 to March 2015 (Figure 15). The monthly mean range was 11 mS/cm to 38.37 mS/cm with the mean of 18.58 ± 0.44.

The conductivity values recorded at the three stations for the entire study varied between 7.35 mS/cm and 43.3 mS/cm. The highest conductivity value recorded was 43.3 mS/cm in June 2014 and July, 2014 at the seaward portion (Station C). The minimum value of 7.35 mS/cm was recorded in April 2014 at the riverine end (Station A). A one-way analysis of variance of the means of spatial conductivity was not significantly different ($P > 0.05$). The one-way analysis of variance of the means of temporal conductivity was significantly different ($P < 0.05$). Figure 16 is an illustration of monthly average conductivity in Etse Lagoon during the entire study.

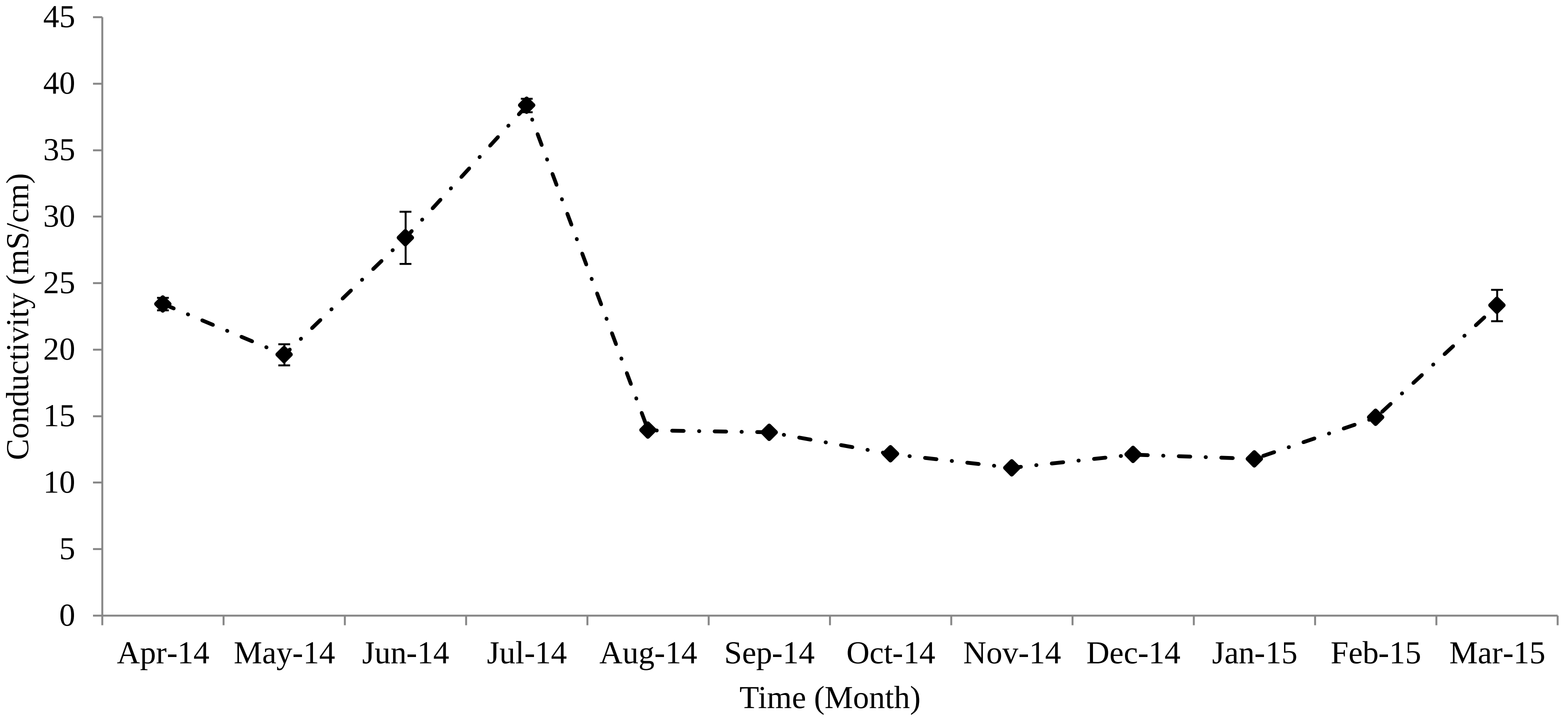

Figure 15: Monthly mean water conductivity of the entire Etse Lagoon from April, 2014 to March, 2015.

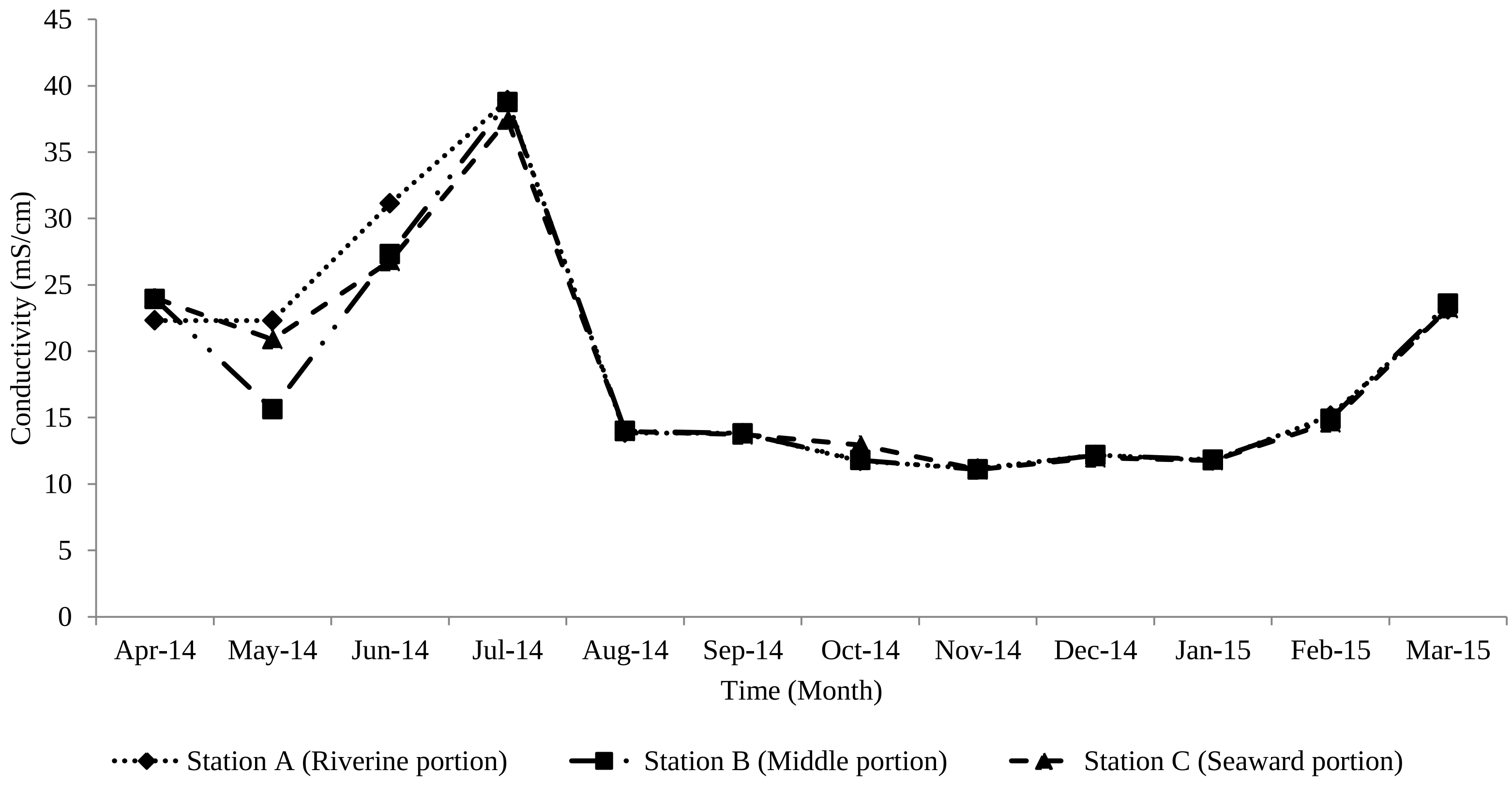

Figure 16: Monthly mean conductivity in the entire Etse Lagoon at stations A (Riverine portion), B (Middle portion) and C (Seaward portion) from April, 2014 to March, 2015.

Fish community structure

Relative abundance of fish species (Species composition)

Eighteen species were identified consisting of 15 fin fishes and 3 shellfishes and their numerical representations are shown in Figure 14. The fin fishes belonged to 9 families and 14 genera and the shellfish, 2 families and 2 genera (Table 1). *Sarotherodon melanotheron* was the dominant species with percentage proportion of 74%. *Callinectes amnicola* 7%, *Tilapia guineensis* with 4%, *Pomadasys incisus* with 4%, *Mugil curema* formed 2% and *Liza falcipinnis* with 3%. Each of the remaining species had compositions of ≤ 1 % (Table 1).

Three categories of species were sampled in Etse Lagoon. They are brackish water, freshwater and marine species. Marine species were represented most compared to the brackish and freshwater species (Table 1).

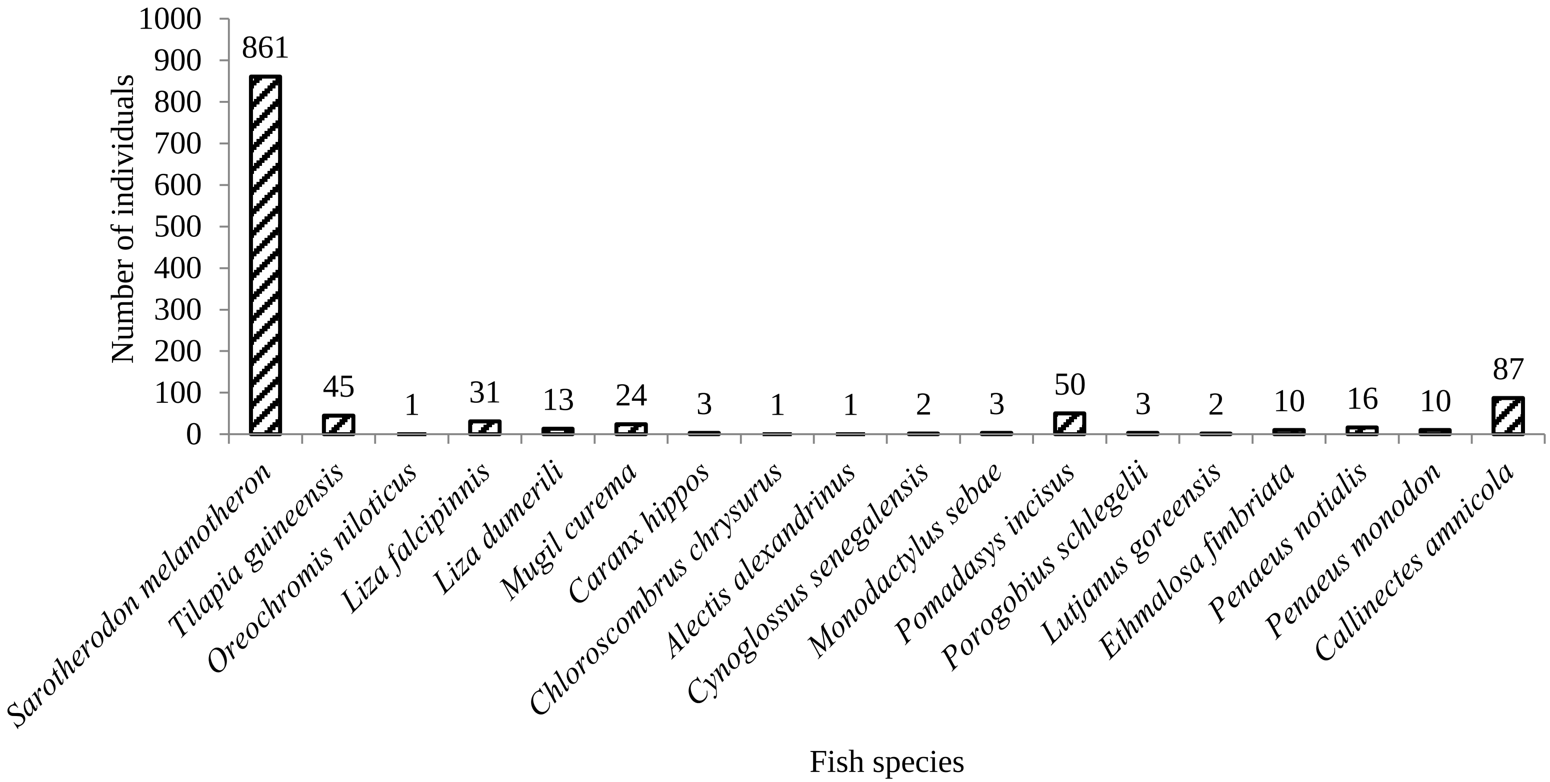

Figure 17: Numerical abundance of fish species caught from April, 2014 to March, 2015.

Table 1: *Categories and Numerical Proportion of Fish Species Encountered in Etse Lagoon*

Family	Genus	Species	Common English Name	Category	% Composition
Cichlidae	Sarotherodon	*Sarotherodon melanotheron*	Black-chinned tilapia	BW	74.0
	Tilapia	*Tilapia guineensis*	Guinean tilapia	FW	3.9
	Oreochromis	*Oreochromis niloticus*	Nile tilapia	FW	0.1
Carangidae	Caranx	*Caranx hippos*	Horse mackerel	M	0.3
	Chloroscombrus	*Chloroscombrus chrysyrus*	Atlantic bumper	M	0.1
	Alectis	*Alectis alexandrinus*	Threadfin horse mackerel	M	0.1
Clupeidae	Ethmalosa	*Ethmalosa fimbriata*	Bonga shad	M	0.9
Lutjanidae	Lutjanus	*Lutjanus goreensis*	Gorean lagoon snapper	M	0.2
Gobidae	Porogobius	*Porogobius schlegelii*	Schlegel's goby	BW	0.3
Monodactylidae	Monodactylus	*Monodactylus sebae*	African moony	BW	0.3
Mugilidae	Mugil	*Mugil curema*	White mullet	M	2.1
	Liza	*Liza falcipinnis*	Sickle fin mullet	M	2.7
	Liza	*Liza dumerili*	Mullet	M	1.1
Cynoglossidae	Cynoglossus	*Cynoglossus senegalensis*	Senegal left-eyed tongue-sole	M	0.2
Haemulidae	Pomadasys	*Pomadasys incisus*	Bastard grunt	M	4.3
Portunidae	Callinectes	*Callinectes amnicola*	Blue-legged swimming crab	M	7.5
Penaeidae	Penaeus	*Penaeus monodon*	Tiger prawn	M	0.9
	Penaeus	*Penaeus notialis*	Pink shrimp	M	1.4

The following represent the categories of fish species M = marine; BW = brackish water; FW= fresh water.

Apart from Cichlidae, Carangidae and Mugilidae families that were represented by three species each, all other fin fish families were represented by one species each. The shell fish family Penaeidae was represented by two species (*Penaeus monodon* and *P. notialis*) and the family Portunidae by one species, *Callinectes amnicola*.

In terms of composition by family, Cichlidae formed 78.4%, Mugilidae formed 5.83%, Haemulidae formed 4.29%, Carangidae formed 0.42% and the other families (Clupeidae, Gobidae, Lutjanidae, Monodactylidae, Cynoglossidae, Penaeidae and Portunidae) formed 11.06% (Figure 18).

The highest number of species was sampled in November 2014 whiles the least was sampled in April 2014 (Figure 19).

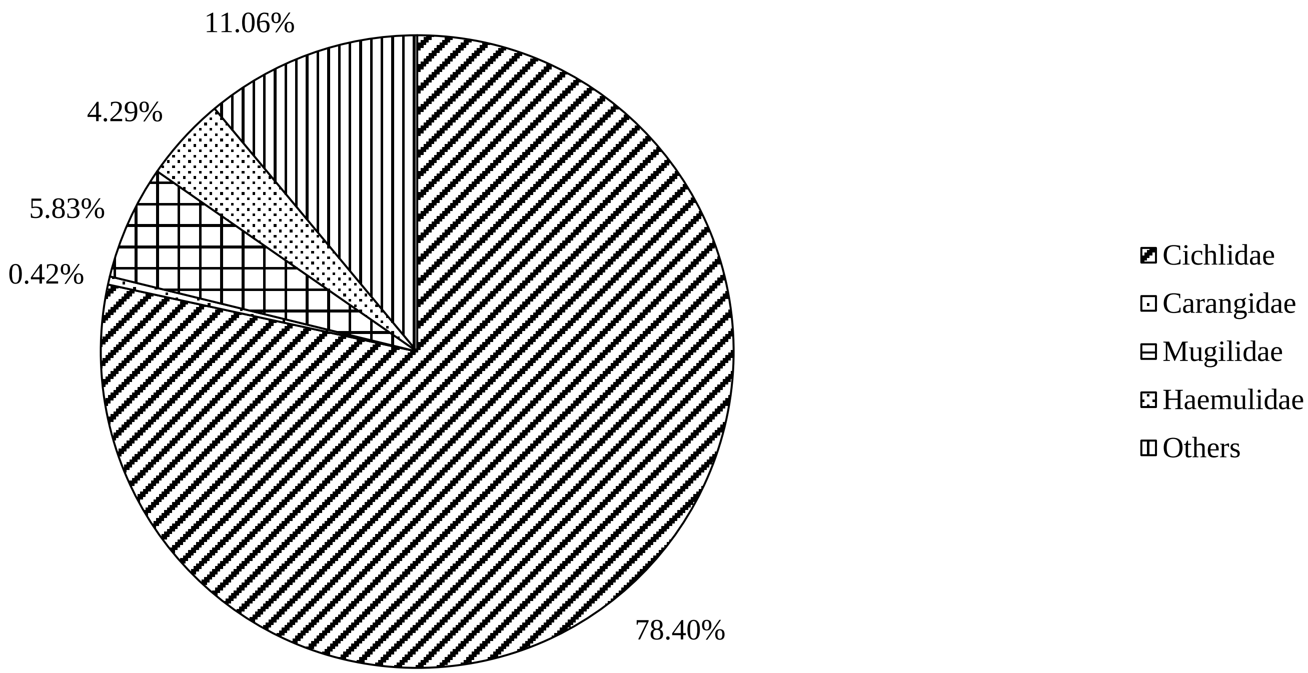

Figure 18: Relative abundance of fish families encountered in Etse Lagoon from April, 2014 to March, 2015.

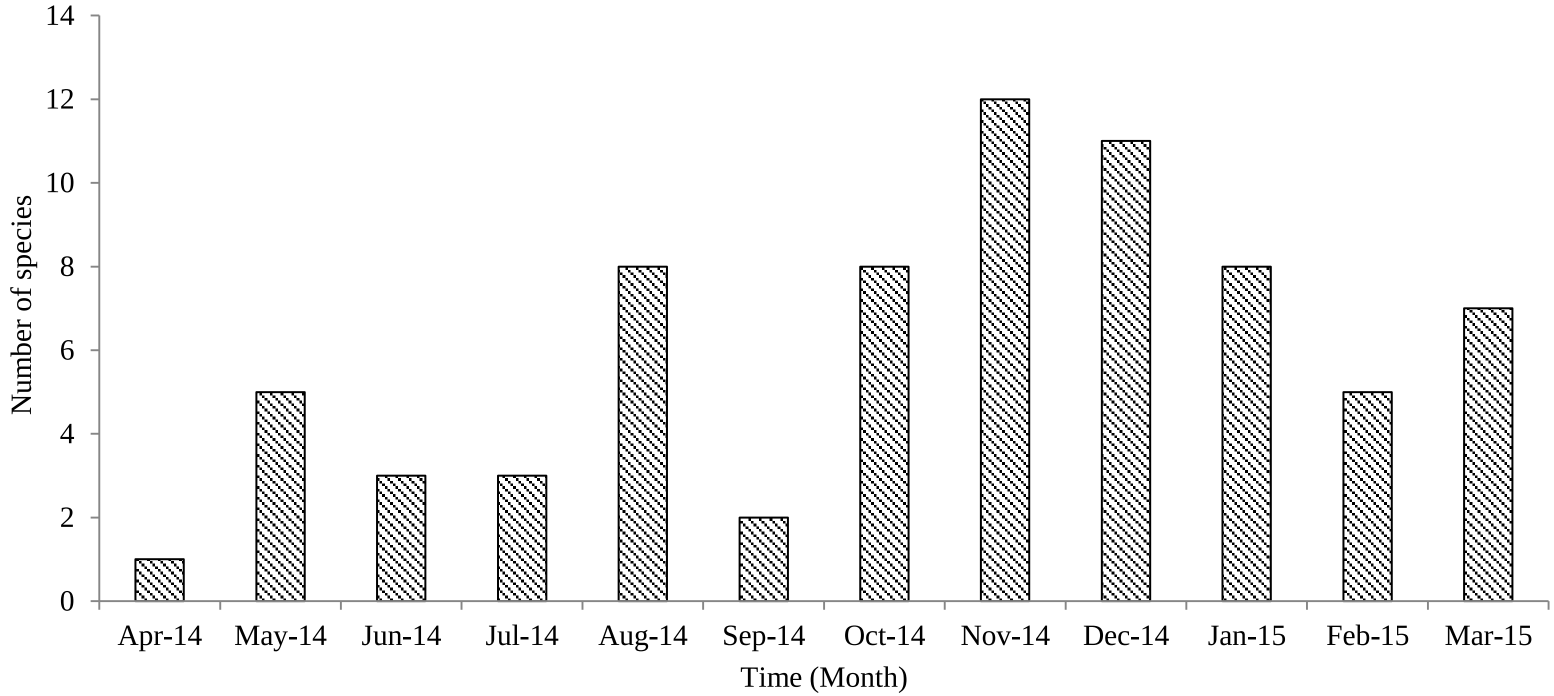

Figure 19: Monthly number of fish species sampled in Etse Lagoon from April, 2014 to March, 2015.

Fish species diversity, richness, dominance and evenness

The Shannon-Wiener Index (H') calculated for the fish community of Etse Lagoon ranged from 0 to 2.15. The highest value of 2.15 and a least value of 0 recorded were in the months of April 2014 and November 2014 respectively. The average value recorded during the entire study period was 0.76 ± 0.17.

Margalef's species richness index (d) calculated for the fish community had the highest value of 2.28 in the month of November 2014 and the least value of 0 in the month of April 2014. The average value recorded during the study was 1.07 ± 0.21.

Simpson's dominance index recorded for the fish community had the highest value of 1.80 in the month of September 2014 and the least value of 0 in the month of April 2014. The mean value recorded during the study was 0.64 ± 0.13.

Pielou's evenness index recorded for the fish community of Etse Lagoon had the highest value of 0.87 in November 2014 and the least value of 0 in April 2014. The mean value was 0.41 ± 0.07. The species diversity, dominance, richness and evenness indices for the entire study are represented in Figure 20.

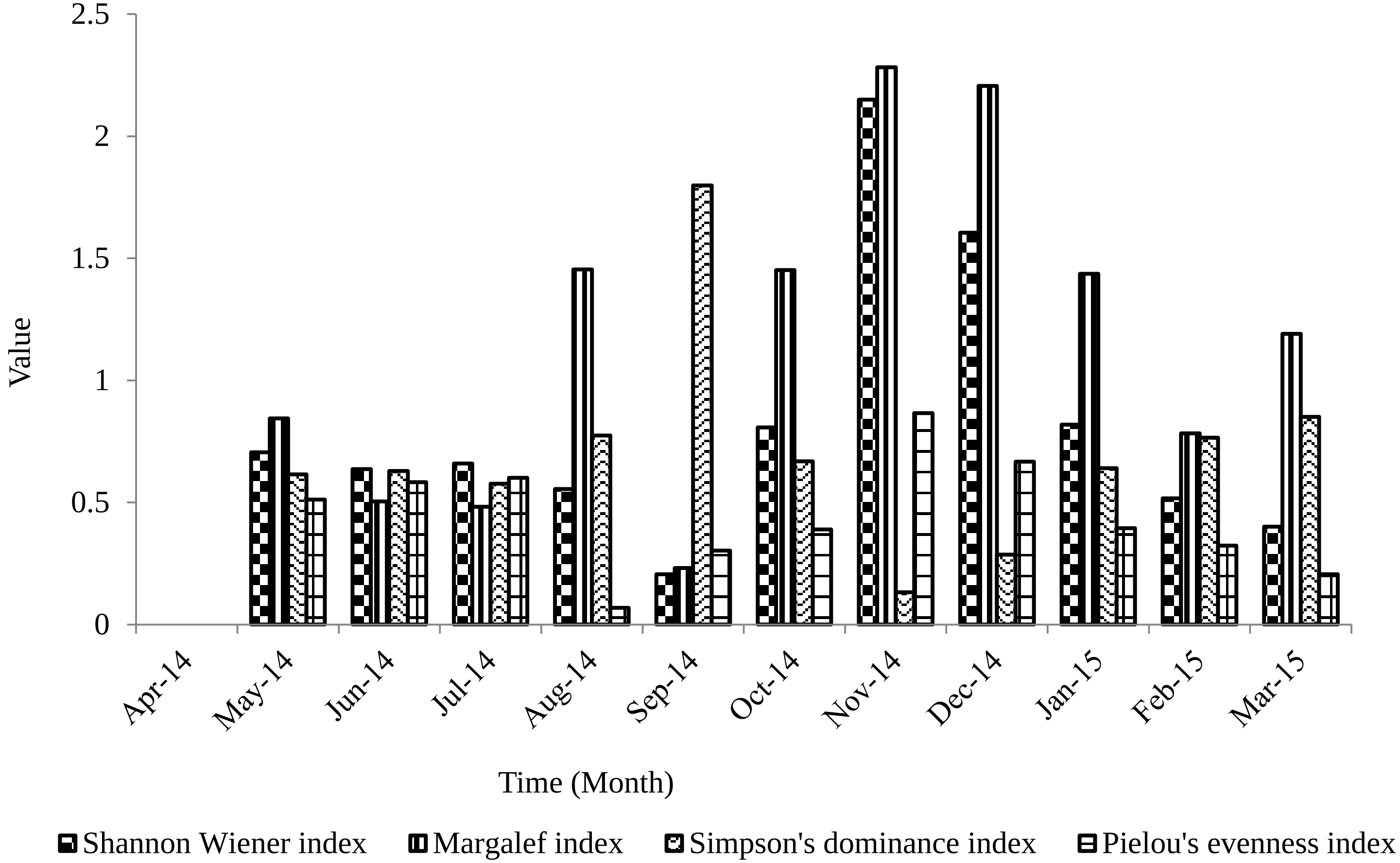

Figure 20: Monthly diversity, richness, dominance and evenness indices of fish for Etse Lagoon from April, 2014 to March, 2015.

Relationship between environmental parameters and biological data

Tables 2 to 7 show the correlation between environmental parameters and biological data of the Etse Lagoon over the study period. Over the study period, it was observed that there was a strong positive correlation between temperature and salinity, and dissolved oxygen but there was a weak negative correlation between temperature and conductivity. There was a weak negative correlation between salinity and pH, but a strong negative correlation between salinity and conductivity in the lagoon (Table 2).

There was a weak positive correlation between monthly fish abundance and temperature but a strong positive correlation between fish abundance and salinity, and DO. A weak negative correlation between monthly fish abundance and pH and conductivity was observed whilst a strong negative correlation was observed between monthly fish abundance and conductivity during the study as shown in Table 3.

Table 2: *Pearson's Correlation Analysis of Water Quality Parameters of the Etse Lagoon from April, 2014 to March, 2015*

Parameter	Temperature (°C)	Salinity(‰)	pH	DO (mg/l)	Conductivity (mS/cm)
Temperature (°C)	1				
Salinity (‰)	0.72	1			
pH	0.41	0.55			
DO (mg/l)	-0.42	-0.55	-0.27		
Conductivity (mS/cm)	-0.29	-0.69	-0.15	0.68	1

Table 3 *Pearson's Correlation Analysis of Water Quality and Monthly Fish Abundance from April, 2014 to March, 2015*

Parameter	Temperature (°C)	Salinity (‰)	DO (mg/l)	pH	Conductivity (mS/cm)	Monthly Fish Abundance
Temperature (°C)	1					
Salinity (‰)	0.72	1				
DO (mg/l)	0.41	0.55	1			
pH	-0.42	-0.55	-0.27	1		
Conductivity (mS/cm)	-0.29	-0.69	-0.15	0.68	1	
Monthly Fish Abundance	0.18	0.62	0.54	-0.42	-0.47	1

There was a weak negative correlation between mean monthly fish diversity, water temperature, dissolved oxygen and conductivity but the correlation between monthly fish diversity, salinity and pH were insignificant (Table 4).

Mean monthly species richness estimate was correlated with several environmental factors (Table 5). Mean monthly species richness estimate was positively correlated with salinity. In contrast, mean monthly species richness estimate was negatively correlated with water temperature, dissolved oxygen, pH and conductivity.

Table 4 : *Pearson's Correlation Analysis of Water Quality and Monthly Fish Species Diversity from April, 2014 to March, 2015*

	Temperature (^{0}C)	Salinity (‰)	DO (mg/l)	pH	Conductivity (mS/cm)	Monthly Fish Species Diversity
Temperature (^{0}C)	1					
Salinity (‰)	0.72	1				
DO (mg/l)	0.41	0.55	1			
pH	-0.42	-0.55	-0.27	1		
Conductivity (mS/cm)	-0.29	-0.69	-0.15	0.68	1	
Monthly Fish Species Diversity	-0.25	-0.08	-0.33	0.03	-0.38	1

Table 5: *Pearson's Correlation Analysis of Water Quality and Monthly Fish Species Richness from April, 2014 to March, 2015*

Parameter	Temperature (^{0}C)	Salinity (‰)	DO (mg/l)	pH	Conductivity (mS/cm)	Monthly Fish Species Richness
Temperature (^{0}C)	1					
Salinity (‰)	0.72	1				
DO (mg/l)	0.41	0.55	1			
pH	-0.42	-0.55	-0.27	1		
Conductivity (mS/cm)	-0.29	-0.69	-0.15	0.68	1	
Monthly Fish Species Richness	-0.11	0.27	-0.16	-0.15	-0.59	1

There was a weak positive correlation between monthly fish species evenness and pH but a strong negative correlation between monthly fish species evenness and temperature, salinity and dissolved oxygen (Table 6).

Monthly fish species dominance correlated negatively with pH and conductivity whilst a weak positive correlation was between monthly fish species dominance and temperature and salinity. The correlation between dissolved oxygen and monthly fish dominance was insignificant (Table 7).

Table 6 **:** *Pearson's Correlation Analysis of Water Quality and Monthly Fish Species Evenness from April, 2014 to March, 2015*

	Temperature (^{0}C)	Salinity (‰)	DO (mg/l)	pH	Conductivity (mS/cm)	Monthly Fish Species Evenness
Temperature (^{0}C)	1					
Salinity (‰)	0.72	1				
DO (mg/l)	0.41	0.55	1			
pH	-0.42	-0.55	-0.27	1		
Conductivity (mS/cm)	-0.29	-0.69	-0.15	0.68	1	
Monthly Fish Species Evenness	-0.50	-0.51	-0.48	0.20	0.01	1

Table 7: *Pearson's Correlation Analysis of Water Quality and Monthly Fish Species Dominance, April, 2014 to March 2015*

	Temperature (^{0}C)	Salinity (‰)	DO (mg/l)	pH	Conductivity (mS/cm)	Monthly Fish Species Dominanc e
Temperature (^{0}C)	1					
Salinity (‰)	0.72	1				
DO (mg/l)	0.41	0.55	1			
pH	-0.42	-0.55	-0.27	1		
Conductivity (mS/cm)	-0.29	-0.69	-0.15	0.68	1	
Monthly Fish Species Dominance	0.22	0.21	0.08	-0.67	-0.10	1

Length-frequency distribution

Length-frequency distribution of Sarotherodon melanotheron

Standard length of the 861 specimens of *Sarotherodon melanotheron* caught by the fishermen ranged from 3.9 to 13.8 cm. Using 1.0 cm class intervals, the length-frequency distribution was unimodal with the mode at 7.0 to 7.9 (Figure 21).

Length-frequency distribution of Callinectes amnicola

Carapace length of the 87 specimens of *Callinectes amnicola* caught by the fishermen ranged from 3.5 to 13.0 cm. Using 1.0 cm class intervals, the length-frequency distribution was unimodal with the mode at 8.0 to 8.9 (Figure 22).

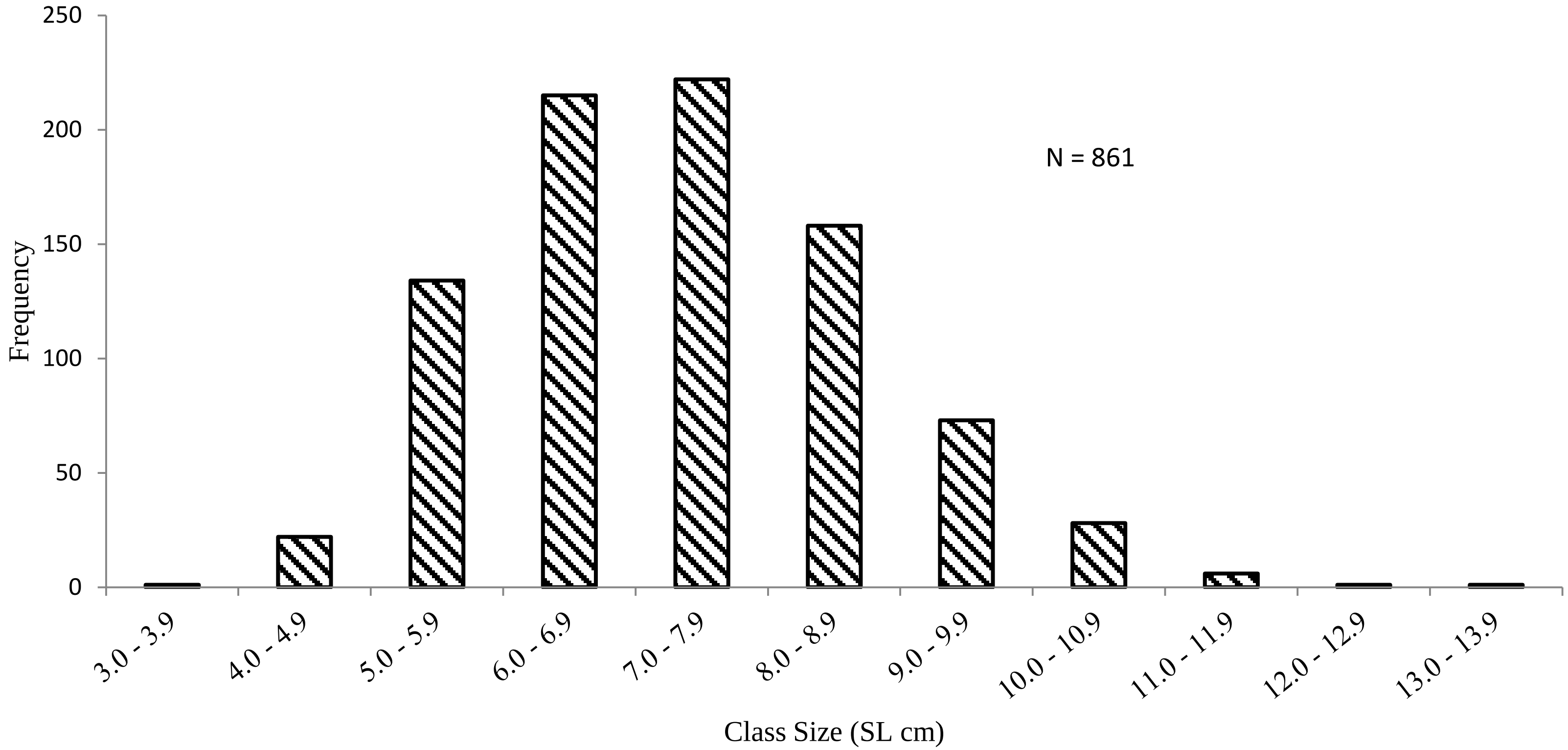

Figure 21: Length-frequency distribution of *Sarotherodon melanotheron* from Etse Lagoon.

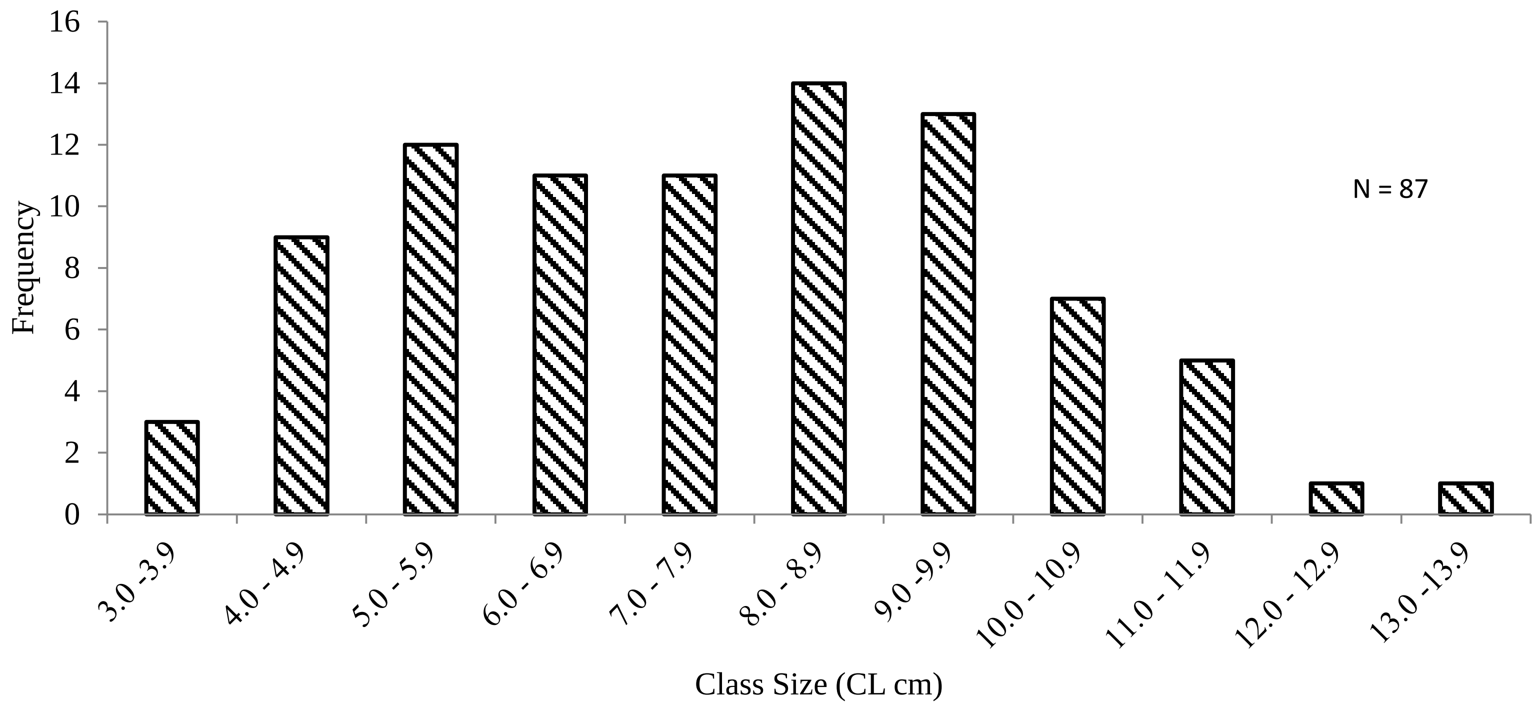

Figure 22: Length-frequency distribution of *Callinectes amnicola* from Etse Lagoon**.**

Length-weight relationship

The relationship between body weight and standard length (but carapace length of *Callinectes amnicola*) of each of the most encountered fin fish and shell fish species was established with the use of scatter plots.

Length-weight relationship of Sarotherodon melanotheron

The length-weight relationship of *Sarotherodon melanotheron* population was described by the equation:

Log BW = 2.8724SL – 1.3378

where BW = body weight (g) and SL = standard length (cm) (Figure 23). The power of the equation ($b = 2.87$) which was not significantly different ($P \geq 0.05$, $t = 4.5$) from the hypothetical value (3) indicated that the growth of *Sarotherodon melanotheron* in the Etse Lagoon was isometric. The regression coefficient (r) of the equation (0.96) indicated that there was a strong positive correlation between weight and length of *Sarotherodon melanotheron* population ($P \leq 0.05$) in the lagoon.

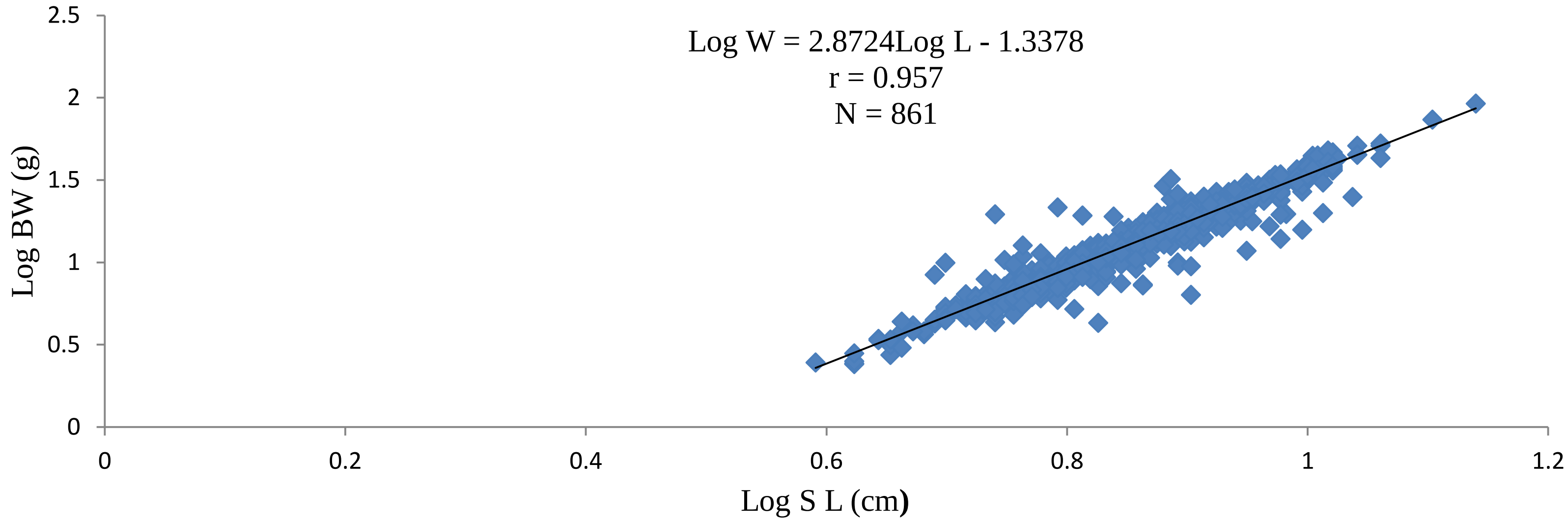

Figure 23: Length-weight relationship of *Sarotherodon melanotheron* in Etse Lagoon from April, 2014 to March, 2015.

Length-weight relationship of Callinectes amnicola

The length-weight relationship of *Callinectes amnicola* was described by the equation:

Log BW = 2.2183 CL – 0.6582

where BW = body weight (g) and CL = carapace length (cm) as shown in Figure 35. The power of the equation (b = 2.22) which was significantly different ($P \leq 0.05$, t = 3.8) from the hypothetical value (3) indicated that the growth of *Callinectes amnicola* in the Etse Lagoon was allometric. The regression coefficient (r) of the equation (0.76) indicated that there was a strong positive correlation between weight and length of *Callinectes amnicola* population ($P \leq 0.05$) in the lagoon as shown in Figure 24.

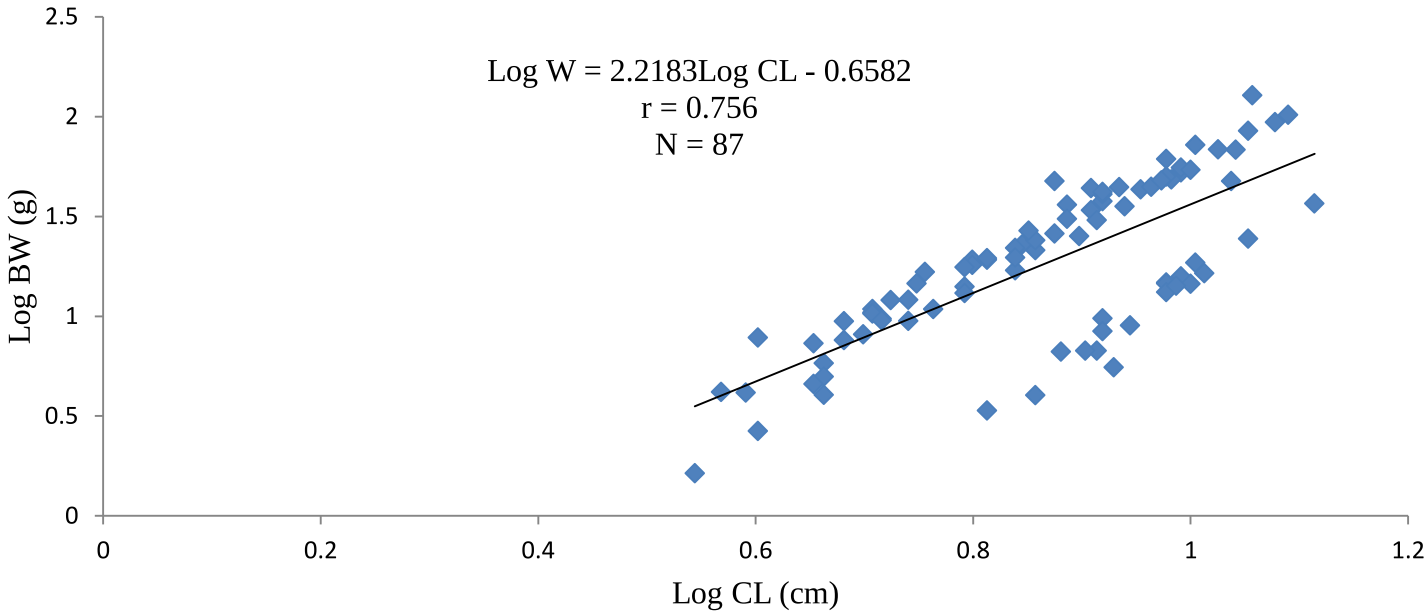

Figure 24: Length-weight relationship of *Callinectes amnicola* in Etse Lagoon from April, 2014 to March, 2015.

Growth and mortality parameters estimates

Growth parameters

The estimates of the growth parameters from the length-frequency data obtained by the ELEFAN I programme gave an asymptotic length ($L\infty$) of 14.25 cm SL and growth constant (K) of $0.93yr^{-1}$. Figure 25 illustrates the growth curve fitted to the monthly length-frequency distribution of the *S. melanotheron* population. Through substitution of the estimated values of $L\infty$ and *K* into Pauly's (1983a) empirical equation, $\log_{10} t_0 = -0.3922 - 0.2752 \log_{10} L\infty - 1.038 \log_{10} K$ the growth parameter t_0, which refers to the age at which the length of the fish is zero (Gulland, 1983) was calculated as -2.231yr. On a yearly basis, therefore the growth of the tilapia population in Etse Lagoon could be described by the von Bertalanffy equation:

$L_t = 14.25\ [1^{-e-0.90(t\ +\ 2.231)}]$ cm SL for Etse Lagoon. Where L_t is the length of fish at age t.

Figure 25 shows the growth curve of the *Sarotherodon melanotheron* population superimposed on the monthly length frequency histograms.

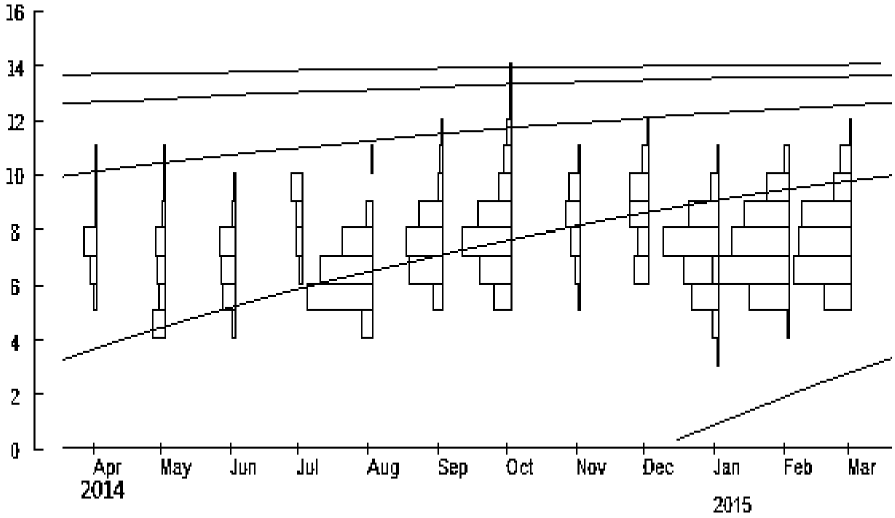

Figure 25: Growth curve of *S. melanotheron* population superimposed on the monthly length-frequency histograms.

Longevity

The longevity (t_{max}) of the *S. melanotheron* population computed from the equation $t_{max} = 3/K$ (Pauly, 1983a), was about 3.2 years.

Growth performance

The growth performance of the population was assessed using Moreau *et al*. (1986) index (Φ′) defined as

$\Phi' = \log_{10} K + 2 \log_{10} L\infty$

where *K* is the growth constant (yr^{-1}) and L∞ is the asymptotic length (SL in cm).The growth performance index was calculated as 2.28. Figure 26 illustrates the estimation of L∞ and Z/K using the modified Powell-Wetherall method, based on length-frequency data of *Sarotherodon melanotheron* from Etse Lagoon.

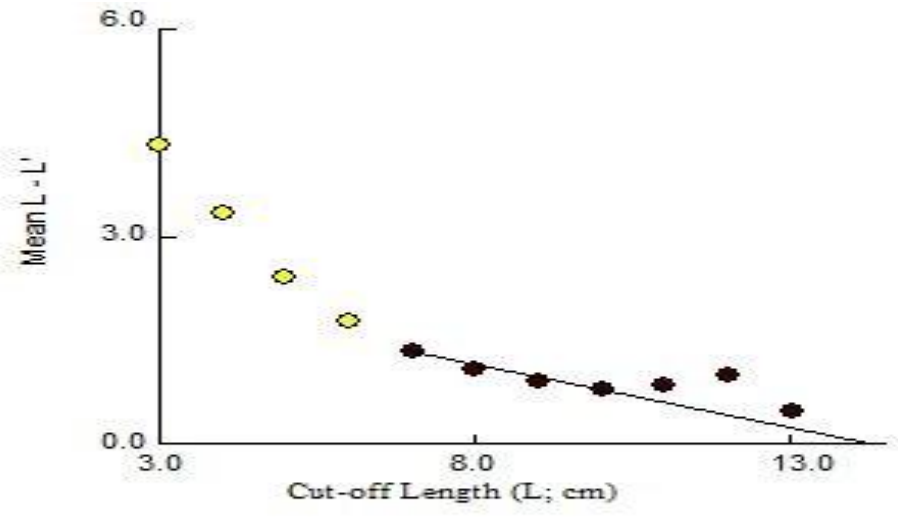

Figure 27: Estimation of L∞ and Z/K using the modified Powell-Wetherall method, based on length-frequency data of *Sarotherodon melanotheron* from Etse Lagoon.

Mortality parameters

Figure 27 shows the length-converted catch curve for the *S. melanotheron* population generated by the ELEFAN I programme. The total mortality rate (Z) was determined only for fish that were fully recruited to the catch samples. Looking at Figure 21, fish are fully recruited at 7-7.9 cm. The regression analysis on the descending part of the curve, therefore, excluded the backward projected points referring to fish not fully recruited to the catches and the points representing older fish with lengths near the asymptote (Pauly, 1983b). According to the slope of the regressions, the total mortality rate was 5.09 yr^{-1}.

The natural mortality coefficient (M) was determined as 2.15 yr^{-1}, by substituting the annual mean water temperature of 29.4 $^{\circ}C$ and growth parameters for the *S. melanotheron* population in the empirical equation of

Pauly (1980). Hence the fishing mortality coefficient (F) of *S. melanotheron* population was 2.95 yr^{-1}. The age at which the length of the fish is zero ($-t_0$) as estimated from Pauly (1979) was -2.23. Figure 27 is the length-converted catch curve for *Sarotherodon melanotheron*.

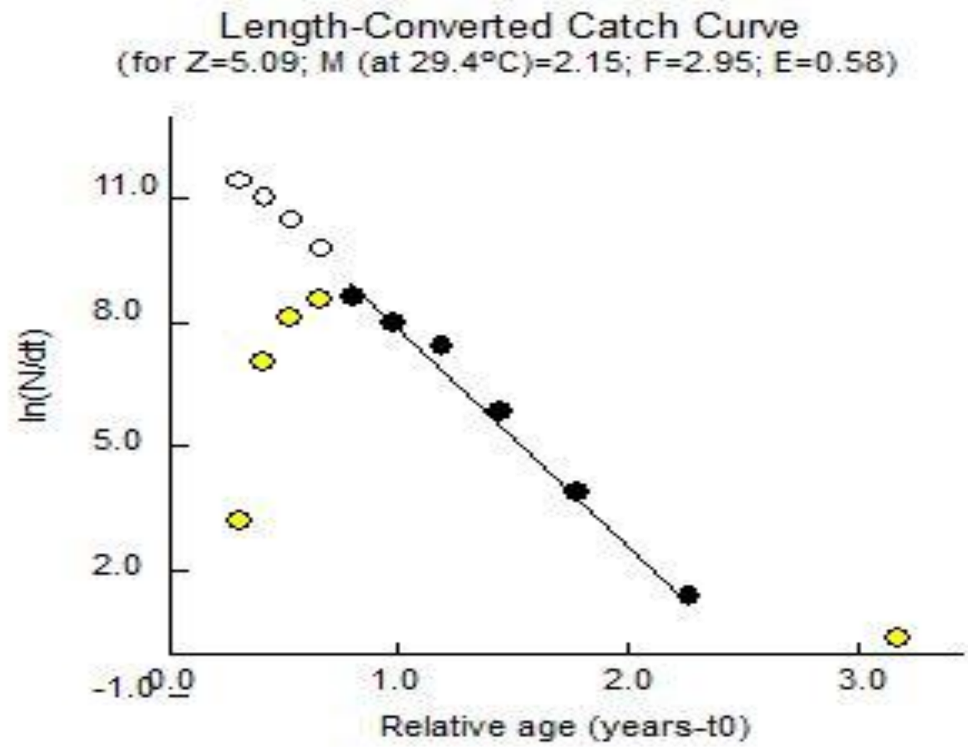

Figure 28: Length-converted catch curve for *Sarotherodon melanotheron* from Etse Lagoon from April, 2014 to March, 2015.

Recruitment pattern of Sarotherodon melanotheron

The recruitment pattern of *S. melanotheron* in the Etse Lagoon occurred throughout the year with two peaks, the major and minor ones coinciding with the rainy season and dry season respectively. The highest recruitment occurred in April, and the lowest occurred in September as illustrated in Figure 28.

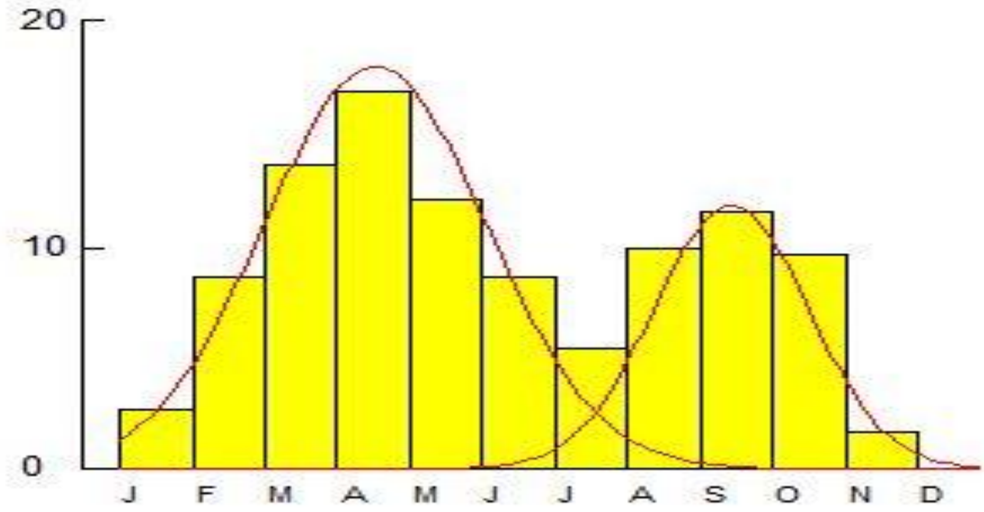

Figure 29: Recruitment pattern of *Sarotherodon melanotheron* from

Etse Lagoon.

Exploitation rate

The exploitation rate (E) of *Sarotherodon melanotheron* was estimated at 0.58.

Population and structural parameters of mangrove species

Two species of mangroves were found at the two sites and their characteristics are presented in Tables 8-12.

At Site 1, the number of mangrove trees found in Plot I, II, III and IV ranged from 4 to 6. No mangrove tree was found in Plot V. The mean tree height ranged from 4.7 m to 5.9 m, the mean DBH ranged from 10.38 cm to 11.73 cm and the mean basal area ranged from 4.32 m^2/hectare to 6.4 m^2/hectare as shown in Table 10.

Table 8**:** *Summary of Mangrove Characteristics for Site 1 at Etse Lagoon*

Plot No.	No. of Trees	Mean Height (m)	Mean DBH (cm)	Total Basal Area (m^2/hectare)
I	4	5.6	11.73	4.32
II	6	5.9	11.12	6.4
III	6	4.7	10.38	5.45
IV	5	5.6	11.34	5.26
V	–	–	–	–

At Site 1, *Rhizophora mangle* was the most important species in Plots I, II and IV while *Avicennia germinans* was the most important species in Plot III as shown in Table 11. *Rhizophora mangle* had the highest relative density in Plots I and IV and had the highest relative dominance in Plots I, II and IV. *Avicennia germinans* had the highest relative dominance of 60.70 in Plot III while *Rhizophora mangle* had 39.30 in Plot III as shown in Table 9.

Table 9**:** *A Summary of Mangrove Parameters for Site 1 at Etse Lagoon (R = Rhizophora mangle, A = Avicennia germinans)*

Plot No.	Relative Density (%)		Relative Dominance (%)		Relative Frequency (%)		Importance Value		Importance Rank	
	R	A	R	A	R	A	R	A	R	A
I	75	25	72.52	27.48	75	25	222.52	77.48	1	2
II	50	50	53.79	46.21	50	50	153.79	146.21	1	2
III	50	50	39.30	60.70	50	50	139.3	160.7	2	1
IV	100	0	100	0	100	0	300	0	1	2
V	–	–	–	–	–	–	–	–	–	–

At Site 2, the number of mangrove trees found in Plot I, II, III, IV and V ranged from 5 to 14. The mean tree height ranged from 5 m to 6.4 m, the mean DBH ranged from 9.6 cm to 13.5 cm and the mean basal area ranged from 9.46 m^2/hectare to 11.3 m^2/hectare as shown in Table 10.

Table 10: *Summary of Mangrove Characteristics for Site 2 at Etse Lagoon*

Plot No.	No. of Trees	Mean Height (m)	Mean DBH (cm)	Total Basal Area (m^2/hectare)
I	14	6.1	9.6	10.77
II	7	6.4	13.5	10.55
III	8	6	12.1	9.46
IV	9	5	11.3	11.3
V	5	5.7	10.9	10.9

Rhizophora mangle was found to be the most important mangrove species at Site 2 as shown in Table 11. The highest relative frequency, density and dominance encountered in all the five plots were for *Rhizophora mangle*. *Avicennia germinans* recorded the least relative values in all the five plots. No *Avicennia germinans* was encountered in Plot V as shown in Tables 9 and 11. However, a sapling of *Laguncularia racemosa* was encountered at Site 2 Plot I. Unfortunately it was washed away when the sand bar got breached on June 4, 2014.

Table 11**:** *A Summary of Mangrove Parameters for Site 2 at Etse Lagoon (R = Rhizophora mangle*, A = *Avicennia germinans*)

Plot No.	Relative Density		Relative Dominance		Relative Frequency		Importance Value		Importance Rank	
	R	A	R	A	R	A	R	A	R	A
I	71.43	28.57	84.78	15.22	71.43	28.57	227.61	72.39	1	2
II	57.14	42.86	59.63	40.37	57.14	42.86	173.91	126.09	1	2
III	62.5	37.5	71.09	28.91	62.50	37.50	196.09	103.91	1	2
IV	77.78	22.22	72.72	27.28	77.78	22.22	228.28	71.72	1	2
V	100	-	100	-	100	-	300	-	1	2

The data show that the forest structure was dominated by *Rhizophora mangle* as shown by the relative frequency values, density and dominance (Table 12). The data confirmed that the principal species *Rhizophora mangle* is significantly larger in terms of diameter at breast height of 11.36 cm, basal area of 106.01m^2 /hectare and density of 1.8 m^{-2}. However, it has mean height of 5.7 m. This was followed by *Avicennia germinans* with mean height of 5.9 m, diameter at breast height of 10.71 cm, basal area of 98.03 m^2 /hectare and density of 0.8 m^{-2} (Table 12).

The regression analysis for *Avicennia germinans* gave the coefficient of determination (R^2) of 0.4032 (Figure 29) while *Rhizophora mangle* had 0.2848 (Figure 30).

Table 12: Structural Parameters of *Avicennia germinans* and *Rhizophora mangle* identified at Etse Lagoon

Species	No. of trees (n_i)	Mean diameter at breast height (DBH ± SD; cm)	Mean height (H ± SD; m)	Basal area (BA; m^2 /hectare)	Density (D; m^3)	Relative Values (%)			Importance Value (IV)
						Frequency	Density	Dominance	
A.germinans	19	10.7 ±3.27	5.9 ±0.86	98.03 ±54.61	0.8	29.69	29.69	28.08	87.45
R.mangle	45	11.4 ±2.45	5.7 ±1.05	106.01 ±48.39	1.8	70.31	70.31	71.92	212.55
TOTAL						100.00	100.00	100.00	300.00

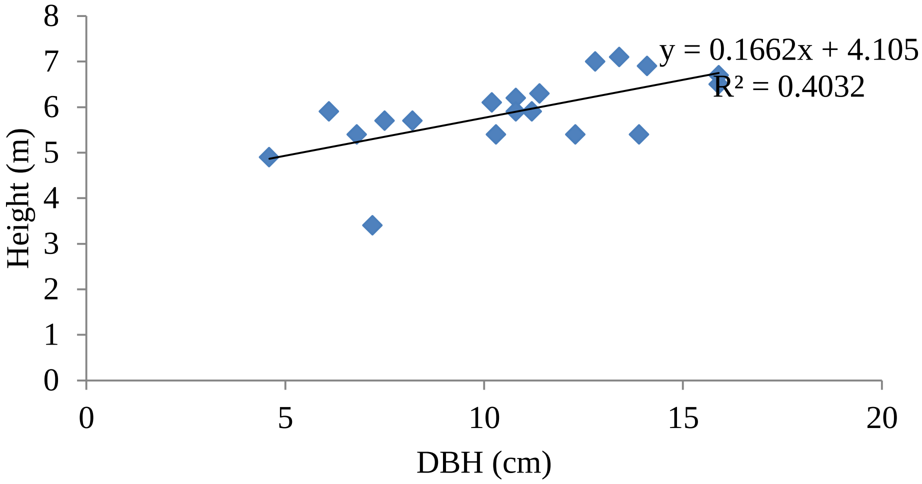

Figure 30: Height – DBH distribution of *Avicennia germinans* at Etse Lagoon.

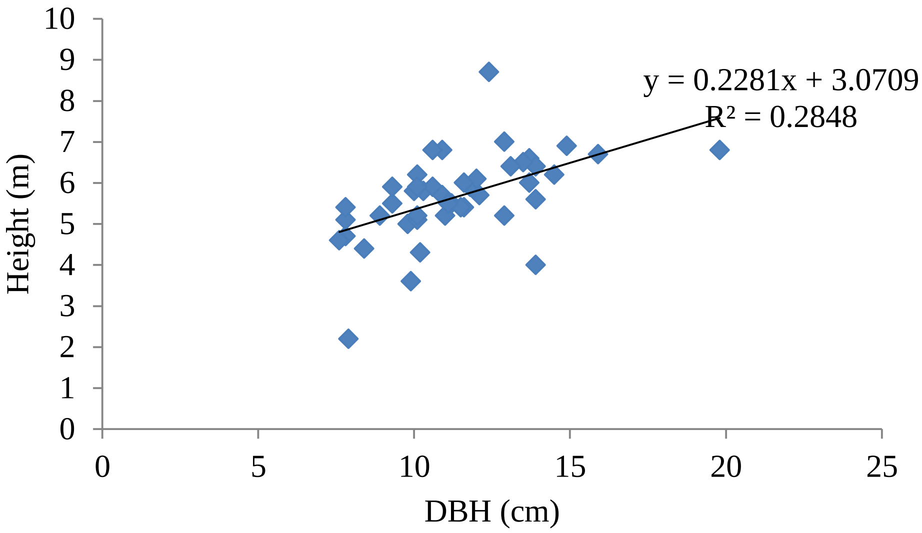

Figure 31: Height – DBH distribution of *Rhizophora mangle* at Etse Lagoon.

Land use in the catchment of Etse Lagoon

Spatial information on Etse Lagoon

The spatial structure of the Etse Lagoon showing change in area of water body between 1973 and 2012 and land use around Etse Lagoon as at 2012 is illustrated in Figure 31. The aerial coverage of the lagoon in 1973 was 2.79 hectares while it was 2.71 hectares in 2012 (Table 15).

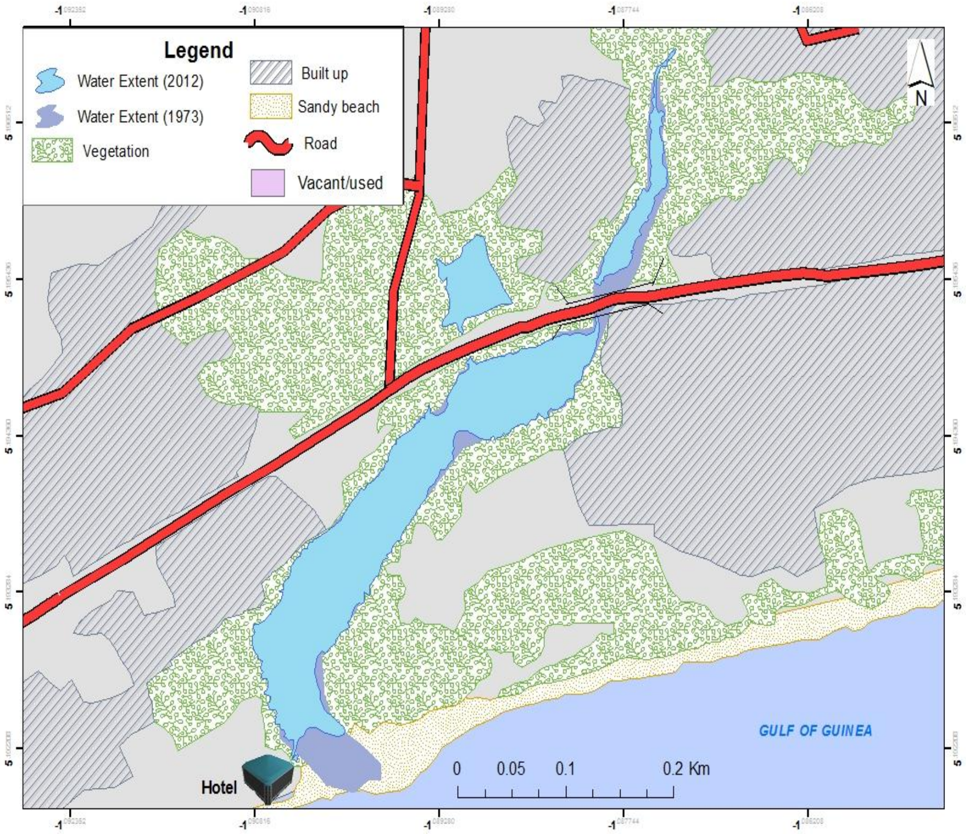

Figure 32: Spatial structure of the Etse Lagoon showing change in area of water body between 1973 and 2012, and land use around the lagoon as at 2012 (Source: Geography Department, U.C.C.)

The change in the extent of the surface area of the lagoon from 1973 to 2012 is shown in Table 13. The lagoon had decreased in water surface area by 2.86 % over the last 39 years.

Table 13 : *Extent of the Surface Area of the Lagoon in 1973 and 2012 (Obtained from 1972 Topographic sheet and 2012 Google Earth Imagery)*

Date	Surface Area (hectare)
1973	2.79
2012	2.71
Change	- 0.08

Table 14**:** *Categories of Land use within the Catchment of Etse Lagoon*

Land use Category	Area	
	Extent (hectare)	Percentage Covered (%)
Built up	75.6	74.4
Vegetation	18.8	18.5
Sandy beach	3.1	3.1
Vacant or unused area	4.0	4.0

No comparisons could be made on the change in land use scenario due to lack of previous data. However, the current land use around the lagoon showed that built up area was 74.4 %, vegetation was 18.5 %, vacant or unused area was 4.0 % and beach sand was 3.1 %.

CHAPTER FIVE

DISCUSSION

Lagoons have a great influence on the socio-economic well-being and health of the communities that live close to them and those beyond them in Ghana (Entsua-Mensah, 1998). They vary greatly in size, depth and salinity and thus it is difficult to generalize on their ecology as each has its special characteristics (Colombo, 1977). Lagoons are simple systems that are easily disturbed both by natural processes and by an array of physical, chemical and biological factors. Due to their generally shallow nature and small size, environmental factors have a marked bearing on the flora and fauna inhabiting lagoons (Colombo, 1977). The environmental factors studied were water temperature, salinity, DO, pH and conductivity. Fish fauna, mangroves and the current boundary and land use around the lagoon were also studied.

Environmental parameters

Water quality is a critical factor in the life of aquatic organisms because it significantly affects their health and productivity and consequently the livelihoods of dependent human populations. Optimal water quality tolerance levels vary by species and must be monitored to identify their impacts on the type, abundance, growth and survival of organisms inhabiting aquatic ecosystems. Ofonmbuk et al. (2014) emphasized that water quality plays a vital role in the distribution, abundance and diversity of aquatic organisms. More so, salinity (Martino & Able, 2003; Sosa-Lopez et al., 2007; Castro et al., 2009; Maci & Basset, 2009), water temperature, DO and pH often regulate community structure in coastal lagoons (Fortes et al., 2014).

Therefore, it is important to study the correlations of these environmental variables as structuring components of the fish community.

Changes in air temperature strongly influence the water temperature of slow-moving, shallow water bodies such as coastal lagoons (Turner, 2003). Because air temperatures increase more quickly over land than over oceans, coastal water temperatures are also likely to increase more rapidly (Harley et al., 2006). Also, the shallow nature and low flushing rates of coastal lagoons indicate that water temperatures in lagoons will increase even more rapidly than water temperatures in open estuaries (Anthony et al., 2009).

In the present study, monthly mean water temperature ranged from 25.8 °C to 32.4 °C with the average of 29.52 °C ± 0.11. Even though the water temperature range was wide, the average value was within the acceptable levels for survival, metabolism and physiology of aquatic organisms; most especially fish.

Water temperature has some positive and negative effects on aquatic plant and fish growth. According to Lawson (2011) the most suitable water temperature for plant growth is 20 °C–35 °C. Water temperature over 30 °C can cause regression in growth and decay in plants (Kara et al., 2004). Badu-Borteley (2014) stated that diatoms grow well at temperatures of 15 °C–25 °C, green algae at 25 °C–35 °C, and blue-green algae at 30 °C-40 °C. However, tropical fishes survive best in a range of 21 °C-32 °C but may not survive in a temperature below 15 °C. *Sarotherodon melanotheron* is the dominant fish species in the Etse Lagoon, as in other lagoons in Ghana due to their ability to withstand wide variations in the environmental conditions.

The monthly mean salinity range of 1.79 ‰ to 20.14 ‰ with the average of 13.42 ‰ ± 0.30 observed in this study was brackish and fell within the range reported by Biney (1990) for lagoons in Ghana. The three stations were chosen to reflect the salinity gradient from the confluence of the Woraba stream and the Etse Lagoon to the seaward side i.e. north to south. The middle portion of the lagoon (Station B) recorded the least value of 0.72 ‰ in June, 2014 at the surface water. This was due to the high amounts of rainfall recorded in May, 2014 and June, 2014 (379.2 mm and 229.6 mm respectively), and Station B was closest to the outlet of the channel that empties run-offs from the Abandze community into the lagoon and the riverine portion (Station A). This increased the dilution of water in that part of the lagoon and since freshwater is less dense than saline water the freshwater remained on the surface hence the less salinity recorded on the water surface. Entsua-Mensah (1998) reiterated that rainfall has both a diluting and enriching effect due to the restoration of flow in rivers and streams which are dry in the dry season.

Generally, low salinity levels were recorded in all stations in the rainy season; the influence of the Woraba stream and rainwater was great. The highest salinity value of 22.30 ‰ was recorded in March, 2015 in the water column at the seaward end of the lagoon due to little rains in the preceding months (July, 2014 to February, 2015) and also the close proximity of Station C to the sea, which enhances interstitial seepage of water across the sand bar. This confirms the assertion of Chagas and Suzuki (2005) that variations in salinity could be due to the shallowness, macroclimatic conditions and inputs of sea and freshwater.

Generally, higher salinities were recorded across the stations during the dry months than the wetter months. This may be due to the reduced freshwater inputs resulting in reduced dilution and also increased rate of evaporation in the dry months. In the wet months there was increased freshwater inputs resulting in increased dilution of the water, hence the lower salinity values. This was further emphasised by Koffi et al., (2014) that coastal lagoons depend on freshwater supply: lagoon salinity is relatively lower when freshwater inputs are higher and vice versa or during sea water intrusions. This was in agreement with reports of Lapido et al. (2011) of the Lagos Lagoon and Lawson (2011) on water from mangrove swamps of Lagos lagoon.

The salinity preference and tolerance can influence the occurrence and abundance of fish species in aquatic ecosystems. Yanez-Arancibia (1978) recorded major decline in fish species diversity, densities and biomass when salinities rose above 34‰ or declined below 15‰ in Mexican estuarine lagoons. Also, Thiel et al., (1995) observed that as salinity decreased upstream, species diversity decreased. The salinity range recorded during the study was favourable to a lot of fish species hence the high number of different fish species encountered. The strong positive correlation between salinity and monthly fish abundance implies that salinity has an impact on the fish abundance in the lagoon.

Dissolved oxygen values ranged between 1.65 mg/l and 11.15 mg/l with an average of 5.09 ± 0.08. The least value was recorded at the middle portion (Station B) in June, 2014. According to EPA (2000), instances of low DO readings during the wet season could be indicative of heavy algal concentrations or decomposition of plants that was exacerbated by heavy point source freshwater inflows carrying excess nutrients into this system. Also, the solubility of oxygen in water is influenced by salinity. Increasing salinity results in decreasing solubility of oxygen in water. In addition, relatively high air temperatures typical to the locality could also increase water temperatures resulting in the reduction of DO. According to Green (1968), temperature is a more potent factor than salinity over the normal brackish range in determining the solubility of oxygen. Apart from the effect in lowering the solubility of oxygen, there will also be an increase in the metabolic rate of organisms when the temperature is raised, thus making greater demands on the available oxygen.

Dissolved oxygen levels were generally high but variable between different locations of the lagoon. The Etse Lagoon is a closed lagoon and its stagnant nature for the greater part of the year probably encourages the growth of both micro- and macrophytes which oxygenate the waters by their photosynthetic activities as observed also in Abrubi Lagoon by Entsua-Mensah (1998). Additionally, since the lagoon is shallow, DO levels may have been high due to wind-assisted surface mixing and also the generation of oxygen by photosynthesising algae (Chagas & Suzuki, 2005; Lapido et al., 2011). Therefore, the monthly mean dissolved oxygen values which varied from 3.18 mg/l to 6.81 mg/l in many of the locations indicated a good aeration or quick re-aeration of water as a result of strong winds (Chagas & Suzuki, 2005). More so, Connell and Miller (1984) reiterated that DO consumption and production are influenced by plant and algal biomass, light intensity and water temperature which are subject to diurnal and seasonal variations. The DO values obtained in this study fell within the 0.0 mg/l to 8.0 mg/l range reported by Biney (1986) for lagoons in Ghana. Various studies suggested that maintaining minimum daily dissolved oxygen concentrations above 3 mg/l in channel catfish and penaeid shrimp ponds assured better feed consumption and growth than it was possible in ponds with lower concentrations (Boyd, 2010). Low DO concentrations can have negative impact on aquatic life. For aquatic animals, extended periods of DO below 5 mg/l can cause adverse effects to larval life-stages (EPA, 2002). In addition, chronic hypoxia leads to changes in benthic community structure characterised by a persistent shift in species composition to more hypoxia-tolerant species and an overall decrease in species diversity (Conley et al., 2007; Anthony et al., 2009). Diaz and Rosenberg (1995) observed that should DO concentrations become slightly lower, catastrophic events may overcome the systems and alter the productivity base of economically important fisheries. More so, aquatic biota exposed to low DO concentrations may be more susceptible to adverse effects of other stressors such as disease, toxic chemicals, and habitat modification (Holland et al., 1977). The sensitivity of fish to low concentrations of DO differs between species, between different life processes, swimming ability and specialised behaviour (Alabaster & Lloyd, 1982) and most species living in tropical lagoons and estuaries are able to tolerate levels of DO lower than 5 mg/l (Entsua-Mensah, 1998). In this study the average DO level recorded was within tolerable limits for fish.

The measurement of pH is done on a pH scale of 0 to 14. A value of pH 7 at 25 °C indicates a neutral condition, 6.9 to 0 indicate increasing acidity and 7.5 to 14 indicates decreasing acidity and increasing alkalinity.

The monthly mean pH range of 6.47 to 8.46 with the mean of 7.5 ± 0.03 recorded in the Etse Lagoon depicted slightly alkaline condition and this is typical of coastal waters. Also, the range falls within the minimum range of 6 to 9 which is the narrow range suitable for the existence of most biological life that was reported by Metcalf and Eddy (2003). The general alkaline state may be partly due to the influence of seawater, which has pH range of 7.5 to 8.4.

The monthly mean conductivity recorded in Etse Lagoon ranged between 11.11 mS/cm and 38.37 mS/cm with the average of 18.57 ± 0.43. According to Coastal Resource Center-Ghana/Friends of the Nation (2010) high conductance readings could come from industrial pollution or urban runoff-water running off of streets, buildings, parking lots or garages. This could account for the highest conductivity value of 43.3 mS/cm recorded in June, 2014 and July, 2014 when rainfall was at its peak and more turbid water was washed into the lagoon since the lagoon also served as a receptacle for run offs.

Highest conductivity values were recorded at the seaward portion (Station C) in June, 2014 and July, 2014 when the narrow sandbar got breached, allowing the influx of seawater into the lagoon. This tidal mixing caused fine sediment to re-suspend thus increasing the particle load of the water hence the high conductivity values recorded. This can have negative impacts on the aquatic organisms. Brando et al., (2012) observed that tidal mixing lowers the residence time of algae in the photic zone and also causes fine sediment to re-suspend reducing the amount of light available for photosynthesis. Since photosynthetic organisms are part of the food chain, reduction in photosynthesis can reduce their abundance leading to a reduction in the number of species and biomass of fish. The suspended particles can also clog the gills of fish and result in their death. The minimum value of 7.35 mS/cm was recorded in April, 2014 when there was little or no rainfall and salinity was highest. This was not in agreement with the fact that the more salts are dissolved in the water; the higher is the value of conductivity (Lawson, 2011).

Fish community structure

Fish abundance and species composition

It is well known that lagoons and estuaries are important breeding, nursery and feeding areas for fish (Maci & Basset 2009; Vasconcelos et al., 2010; Pe′rez-Castan˜eda *et al*., 2010; Monteiro-Neto et al., 2003; Fortes et al., 2014).

The present study provides the baseline information on fin and shell fish abundance and diversity in the Etse Lagoon system. The family cichlidae represented by the tilapias were the most abundant fish biota (total number 861) in the lagoon relative to the other families because they show a great tolerance to low oxygen concentration (Philippart & Ruwet, 1982) and are able to use the upper water layer with higher oxygen concentration (Dussart, 1963). They can resist very high CO_2 concentrations, high turbidities and organic or inorganic pollution (Magid & Babiker, 1975). They are euryhaline (Albaret, 1994) and eurythermal (Welcomme, 1972). These physiological qualities of tilapias can also help to explain the resilience of these species in the face of a changing environment (Lae, 1997). According to Lae (1997), tilapias are considered as the world's most productive fish and are able to feed as detritivores and herbivores at the base of the aquatic food chain. Also, tilapias reproduce continuously. The continuous reproduction of tilapias is an important factor in enabling these species to remain resilient, whilst all other species become less abundant when subjected to intensive fishing pressure and fluctuating environmental parameters.

The genus *Sarotherodon* has a worldwide distribution and is found in Africa, Central, and South America, West Indies, Madagascar, Syria and Coastal India. *Sarotherodon melanotheron* occurs in both fresh and brackish water from Senegal to Zaire, and is abundant in the mangrove zone (Trewavas, 1983). It serves as an important source of protein in a number of coastal West African countries and its fishery is a good source of employment and income (Entsua-Mensah, 1998). In Ghana, *Sarotherodon melanotheron* constitutes a very important part of lagoon fisheries (Eyeson, 1983; Blay & Asabere-Ameyaw, 1993; Koranteng, 1995) and make up about 80 %-90 % of all fishes caught in lagoons (Pauly, 1975, 1976; Denyoh, 1982; Ntiamoa-Baidu, 1991) and also constitutes above 59 % of the biomass in Ghanaian coastal waters (Blay, 1998). This is probably due to the fact that the tilapia, *Sarotherodon melanotheron*, a male mouth brooder, which enables it to protect its eggs from predators, also has special ability to withstand wide variations in physicochemical parameters, and also feed on the fine fraction of the sediment. This has enabled it to dominate completely the fauna of small closed lagoons along the West African coast (Pauly, 1976 and Lae, 1997).

The fish species encountered during the study were similar to those that occur in almost all coastal lagoons in Ghana as reported by Dankwa and Entsua-Mensah (1996), Koranteng et al. (1998) and Badu-Borteley (2014). The shellfish, *Callinectes amnicola, Penaeus monodon* and *Penaeus notialis* were the only shell fish encountered during the study and they formed 7.5 %, 0.9 % and 1.4 % respectively of the total catch. Abowei (2010) noted that most organisms including shrimps do not tolerate wide variations of pH over time. This could account for their low abundance and diversity since wide variation of pH was recorded during the study. Also, some studies emphasized that human activities like dredging, aquaculture, fishing and increasing urban population have major effects on lagoons and estuaries by changing habitat variability and the relative abundance of several fish species (Perez-Ruzafa *et al*., 2006; Franca et al., 2012; Verdiell-Cubedo et al., 2012). More so, Pe′rez-Ruzafa et al. (2006) indicated that lagoon size, substratum diversity, environmental heterogeneity and its degree of communication with the open sea are important factors influencing diversity. The Etse Lagoon is a relatively small lagoon and its connectivity with the adjacent sea is limited since it is a closed lagoon and is dependent upon the amount of rainfall which enables the breaching of the sand bar. This feature of the system restrains most marine stragglers and migrants from having access to this confined habitat thereby reducing the number and variety of fish species in the lagoon. Some of the fish species encountered during the study such as *Lutjanus goreensis* live on rocky bottoms whilst species such as *Pomadasys incisus* live on both rocky and sandy bottoms. This shows the diversity of the substratum of Etse Lagoon since it supports these organisms too.

Liza dumerili, *Liza falcipinnis* and *Mugil curema* show a remarkable adaptation to hyperhaline environments whilst species like *Sarotherodon melanotheron* and *Porogobius schlegelii* can tolerate wide range of salinity but freshwater species such as *Tilapia zillii* was also encountered (Paugy, Leveque & Teugels, 2003).

The monthly number of species encountered was also estimated. The highest number of species was recorded in November, 2014 and the least number was recorded in April, 2014. The difference in the species composition and abundance of the various months could be due to the variation in physicochemical parameters such as temperature, salinity, pH, DO and conductivity in the Etse Lagoon.

Etse Lagoon has a relatively high diversity of fish. This could be attributed to the riparian mangrove vegetation associated with the Etse Lagoon. Dankwa et al., (1997) observed that both closed and open lagoons with extensive mangrove cover had high species diversity. Some examples of these lagoons are Domini (24 species), Kpani (28 species), Kpeshie (15) and Brenu and Kako (12 species). This further confirmed the fact that mangroves indeed provide feeding, breeding and nursery sites for various fish species. Also, the differences between the diversity patterns among lagoons may be assigned to different sampling gear used (Monteiro-Neto & Musick, 1994; Gray et al., 2005; Monteiro-Neto & Prestrelo, 2013) or due to intrinsic differences of local environment (Fortes et al., 2014) and also the effort and the associated fishing pressure (Badu-Borteley, 2014).

Fish diversity, richness, dominance and evenness

Structural and functional attributes of fish community have been widely employed to monitor the ecological quality of estuarine or transitional water ecosystems (Deegan et al., 1997; Whitfield and Elliott, 2002; Harrison and Whitfield, 2004, 2006; Briene et al., 2007; Coates et al., 2007; Delpech et al., 2010). Most of the fish based methods employed to assess the ecological status of coastal and transitional water ecosystems relies on an array of metrics, as species richness and diversity measures, fish abundance, composition or structure of the fish assemblage in ecological or trophic guilds (Bilkovic et al., 2004; Harrison and Whitfield, 2004; Franco et al., 2008a).

Fish community diversity is a basic ecological indicator of the health or well-being of aquatic ecosystems. Therefore, the knowledge of the fish species diversity is necessary for the correct exploitation, regulation and management of fishery resources (Magurran, 1988; Koffi et al., 2014). Diversity indices summarize the numerical associations of organisms and allow populations to be compared; they are generally more reliable indicator of environmental health or stress than are individual indicator species (Cain and Dean, 1976). The community structure was analysed by means of abundance and diversity indices such as Shannon-Wiener diversity index (H'), Margalef's species richness (d) and Simpson's dominance (D). The Shannon-Wiener diversity is a combined measure of both species richness and evenness (Hamillton, 2005). The Shannon - Wiener Index (H') calculated for Etse lagoon ranged from 0 to 2.15. The highest value of 2.15 and a least value of 0 recorded were in the months of November, 2014 and April, 2014 respectively. Margalef (1972) stated that the Shannon – Wiener diversity index usually falls between 1.5 and 3.5 and rarely surpasses 4.5. Higher species diversity indicates a healthier ecosystem and vice versa. Only *Sarotherodon melanontheron* was encountered in April, 2014, hence the least value of 0 and the highest number of species was encountered in November, 2014. This confirmed the observation made by Badu-Borteley (2014) that a minimum value of 0 for this index shows a community with single species and it increases as species evenness and richness increases. The highest diversity of 2.15 recorded indicated a healthy ecosystem.

The differences in monthly species diversity can be attributed to variations in both biotic (e.g. predation, migration, fishing mortality etc.) and abiotic factors (e.g. variations in temperature, salinity, pH, DO etc.). Badu-Borteley (2014) noted that the variations in nutrient levels can also be a factor, increased salts such as nitrates and phosphates are important in supporting phytoplankton growth which is the basis for the primary food chain, and eventually enhances fish production greatly. The opening of the sand bar at the peak of the rainy season also enhanced the exchange of water between the lagoon and the sea and also the entrance of marine species into the lagoon, thereby enriching the species diversity and community structure of the lagoon.

A weak positive correlation was recorded between fish species richness and salinity. This implies that the fish species in the Etse Lagoon were distributed homogeneously along salinity gradient. This was not in agreement with the findings of Sosa-Lopez et al. (2007) who recorded negative correlation between fish species richness and salinity in the Terminos coastal lagoon located in the Southern Gulf of Mexico. Also, the correlation analyses revealed that among the environmental parameters measured in this study, conductivity showed the most significant negative correlation with fish species richness. This could probably account for the low species richness recorded when conductivity was greatest during the study.

pH was the most important environmental parameter that impacted on fish species dominance. *Sarotherodon melanotheron* was found to have dominated the fish fauna of Etse Lagoon due to its ability to tolerate wide variations in pH of the lagoon.

Significant negative correlation was recorded between fish species evenness, water temperature, and salinity and dissolved oxygen. This probably could be as a result of the inability of individuals of most fish species to tolerate variations in water temperature, salinity and dissolved oxygen over the study period.

Length-weight Relationship of *Sarotherodon melanotheron* and *Callinectes amnicola*

Arizi et al. (2015) reported a modal length of 10.0 cm SL for *Sarotherodon melanotheron* in the Dominli Lagoon whilst Blay (1998) reported a modal length of 6.0 cm for the species in Benya Lagoon. Comparatively, a modal length of 6.5 cm SL was recorded for *Sarotherodon melanotheron* in Etse Lagoon. This shows that *Sarotherodon melanotheron* in Etse Lagoon reaches a larger size than their counterparts in Benya Lagoon but smaller than their counterparts in Dominli Lagoon. Arizi et al. (2015) reported a maximum total length of 23.8 cm TL for *Sarotherodon melanotheron* in Dominli Lagoon while Blay and Asabere-Ameyaw (1993) reported a maximum total length of 15.9 cm TL in Fosu Lagoon. Also, Entsua-Mensah (1998) reported a maximum TL of 17 cm in Abrubi Lagoon. In comparison, the maximum total length of 17.7 cm observed for *Sarotherodon melanotheron* in the present work is relatively longer than those reported for the fish in the Fosu Lagoon and Abrubi Lagoon but relatively smaller than those reported for the same species in the Dominli Lagoon. The observed maximum total length for *Sarotherodon melanotheron* in the Etse Lagoon is smaller than the maximum length of 25.0–27.0 cm TL documented for certain lagoon and freshwater populations in other parts of West Africa (Daget & Iltis, 1965; Ugwumba & Adebisi, 1992).

Fish provide a better understanding of changing aquatic conditions in the absence of chemical and microbiological data and are therefore used to assess water quality since they are long term indicators of water quality (Ofonmbuk et al., 2014). According to Ecoutin et al. (2005), length and body data are of great importance in fisheries research because they are associated with provision of population parameters necessary for proper fisheries management and sustainable yield of fish stock. Pauly (1993) stated that length-weight relationship (LWR) provides pertinent information on the habitat where fish lives. The growth constant (b value) of the length-weight relationship is between 2.5 and 3.5 demonstrating normal growth dimensions or interpretation of well-being of fish population (Carlander, 1969; Bagenal, 1978; King, 1996). With reference to this range, isometric growth pattern occurs in fish species when b value is equal to 3 whereas allometric growth pattern may be positive when $b > 3$ or negative when $b < 3$.

The relationship between body weight and standard length of *Sarotherodon melanotheron* populations in the Dominli Lagoon was described by the equation:

$BW = 0.0814\ SL^{2.7}$ (Arizi et al. 2015). The power of the equation ($b = 2.7$) and correlation coefficient ($r = 0.96$) indicated negative allometric growth pattern implying that the fish grew relatively more slender as it increased in weight and a strong correlation between length and body weight respectively. Blay (1998) described the relationship between body weight and standard length of

Sarotherodon melanotheron populations in the Benya lagoon by the equation: $BW = 0.0380\ SL^{3.03}$. The power of the equation ($b = 3.03$) and correlation coefficient ($r = 0.99$) indicated isometric growth and strong correlation between length and weight respectively. The relationship between standard length and body weight of *Sarotherodon melanotheron* from the Etse Lagoon was described by the equation $BW = 0.0459\ SL^{2.87}$. The power of the equation ($b = 2.87$) which was not significantly different ($P > 0.05$, $t = 4.5$) from the hypothetical value (3) indicating that the growth of *Sarotherodon melanotheron* in the Etse Lagoon was isometric.

The length-weight relationship of *Callinectes amnicola* was described by the equation: $\text{Log } BW = 0.2197\ CL^{2.22}$. The power of the equation (2.22) which was significantly different ($P < 0.05$, $t = 3.8$) from the hypothetical value (3) indicated that the growth of *Callinectes amnicola* in the Etse Lagoon was allometric. The correlation coefficient (r) of the equation (0.76) indicated that there was a strong positive correlation between weight and length of *Callinectes amnicola* population ($P < 0.05$) in the lagoon.

Condition factor of *Sarotherodon melanotheron* and *Callinectes amnicola*

The condition factor is an estimation of the general wellbeing of fish (Oni et al., 1983). It is based on the hypothesis that heavier individual fish of a given length are in better condition than less weightier fish (Bagenal & Tesch, 1978). Condition factors have been used as an index of growth and feeding intensity. Bagenal & Tesch (1978) reported that the condition factors of different populations of the same species are indicative of food supply and timing and duration of breeding.

From the weight-length relationship, the condition factor of *Sarotherodon melanotheron* ranged from 3.03 to 3.99 with the mean of 3.61 ± 0.07. The least value was recorded in November, 2014 and the highest value was recorded in September, 2014. The value of C. F. is influenced by age of the fish, sex, stage of maturation, fullness of gut, type of food consumed, amount of fat reserve and degree of muscular development (Ogamba & Abowei, 2012). Comparisons therefore could be meaningful if these factors are roughly equivalent among the samples to be compared (Ogamba & Abowei, 2012). With females, the C. F. value will decrease rapidly when the eggs are shed.

The condition factor recorded for *Sarotherodon melanotheron* in Etse Lagoon was relatively high. The condition factor of fish can be affected by a number of factors such as stress, sex, season, availability of food, and other water quality parameters (Khallaf et al., 2003). Even though seasonal variations were observed in the condition factor of *Sarotherodon melanotheron*, the fluctuations in the environmental parameters seemed not to have much influence on the condition of *Sarotherodon melanotheron* in Etse Lagoon; the fluctuations may be due to physiological factors. However, the highest monthly mean condition factor of 3.99 was recorded in September, 2014 when the monthly mean water temperature was also highest (32.37 ^{o}C) whilst salinity was 17.75 ‰, pH was 6.47, DO was 5.12 mg/l and conductivity was 13.79 mS/cm. According to Faunce and Lorenz (2000), accumulation of sexual products which is characteristic of enhanced reproduction in cichlids, is normally accelerated at high temperatures. This period probably coincided with the period when the fish had high gonadosomatic index. This could account for the highest average condition factor recorded when average water temperature was highest.

Growth, mortality, recruitment and exploitation rate of *Sarotherodon melanotheron*

The estimated growth parameters indicate that *S. melanotheron* in Etse Lagoon grows at a faster rate (K = 0.93 yr^{-1}) but attains a relatively shorter asymptotic length ($L\infty$ = 14.25 cm SL) than the same species in the Benya Lagoon (0.61 yr^{-1} and 16.4 cm SL) as reported by Blay (1998) and Abrubi Lagoon (K = 0.79 yr^{-1} and $L\infty$ = 15 cm SL) as reported by Entsua-Mensah (1998). Arizi et al. (2014) reported that *S. melanotheron* in the Dominli Lagoon grows at a faster rate (K = 0.97 yr^{-1}) and attains a relatively longer asymptotic length ($L\infty$ = 20.48 cm SL) than their counterparts in the Etse Lagoon. Also, *Sarotherodon melanotheron* from a lagoon in Togo grows at a relatively slower rate (K = 0.44 yr^{-1}) and attains a relatively longer asymptotic length ($L\infty$ = 32.6 cm) as reported by Lae (1996).

The estimated growth performance index for *Sarotherodon melanotheron* population in Etse Lagoon was 2.28. The *Sarotherodon melanotheron* population in Etse Lagoon had a better growth performance than the same species in the Benya Lagoon (2.14) as reported by Blay (1998). Arizi et al. (2015) reported a growth performance index of 2.6 for the same species in Dominli Lagoon.

Sarotherodon melanotheron was fully recruited into the Etse Lagoon fishery at a size of 3.9 cm SL smaller than the 10.13 cm SL of the same species in Dominli Lagoon reported by Arizi et al. (2015). This implies that a large proportion of the fish sampled from the lagoon was in the small size category range of 2–12 cm of African freshwater fishes as reported by Pauly (1995).

The two overlapped waves of recruitment showing all-year-round seasonal trend of recruitment suggests that *Sarotherodon melanotheron* bred throughout the year in the Etse Lagoon. This agrees with Arizi et al. (2015), Fagade (1973) and Legendre and Ecoutin (1989). The continuous reproduction and recruitment and protection for eggs through oral brooding exhibited by *Sarotherodon melanotheron* in the Etse Lagoon might have contributed to their population and resilience as was also observed by Arizi et al. (2015) for the same species in Dominli Lagoon.

The population of *Sarotherodon melanotheron* in Etse Lagoon can be described by its longevity as short-lived fish. The short life span of 3.2 years shown by *Sarotherodon melanotheron* in the Etse Lagoon probably influences their growth in a way that makes them reach the asymptotic length at a faster rate as was also observed by Arizi et al. (2015) in Dominli Lagoon. This could compensate for the high natural and fishing mortality rates for Etse Lagoon.

The estimate of the natural mortality (2.15 yr^{-1}) for *S. melanotheron* in the Etse Lagoon could be considered as reliable in as much as M/K ratio (2.31) for the lagoon specimens is within the range of 1.12-2.50 calculated for most fish populations (Beverton & Holt, 1957). The fishing mortality (2.95 yr^{-1}) was comparatively higher than the natural mortality (2.15 yr^{-1}) for the *Sarotherodon melanotheron* in the Etse Lagoon. The natural mortality observed for *S. melanotheron* in the Etse Lagoon may be due to the presence of few piscivores and predatory birds. Etse Lagoon has a high bird population. In addition, the natural mortality of fishes also correlates directly to environmental temperature (Pauly, 1980). According to Winberg (1960), fishes occurring at higher temperatures have more chance to encounter 'hungry' predators rather than satiated ones because tropical fishes have to eat more than temperate fishes to satisfy their high metabolism needs. Entsua-Mensah (1998) suggested that the high mortality rates observed in Abrubi Lagoon could be due to multiple recruitments.

The exploitation rate assesses if a stock is over fished or not, on the assumption that optimal value E (E opt) is 0.5 (Ogamba & Abowei, 2012). The use of 0.5 as optimal value for the exploitation rate is based on the assumption that the sustainable yield is optimized when F = M (Gulland, 1971).

The optimal exploitation ratio of 0.50 (E opt = 0.50) in comparison with the current rate of exploitation (E = 0.58) of *S. melanotheron* in the Etse Lagoon gives an indication of its stock being overexploited (Pauly, 1984). This is because *Sarotherodon melanotheron* with an exploitation rate of 0.58 is above the optimal value for sustainable yield, for the exploitation of the fishery. Relatively higher fishing mortalities of *Sarotherodon melanotheron* in Etse Lagoon (2.95 yr^{-1}) might account for the overexploitation of the fish stock since fishing mortality is directly proportional to the rate of exploitation. Comparatively, higher exploitation rate (E = 0.61) was reported for Sakumo 2 lagoon by Koranteng et al. (1997), Abrubi Lagoon (E = 0.64) by Entsua-Mensah (1998) and Fosu Lagoon (E = 0.62) by Blay and Asabere-Ameyaw (1993). However, the low fishing mortality of *Sarotherodon melanotheron* that occurred in the Dominli Lagoon might have contributed to the under-exploitation status of fish stock (Arizi et al., 2014).

Structural parameters of mangrove species

Some sections of the Etse Lagoon were surrounded by mangrove trees. These plants concentrate high amounts of organic matter and detritus which serve as food for the inhabiting fauna. Their root system also serves as safe haven and nursery grounds for juvenile fish, and consequently boosting the productivity of fish. They also help in trapping sediments, thereby helping stabilize the shoreline. In view of their contributions to the health of the lagoon ecosystem the structural parameters of the various species identified were studied to ascertain their levels of development.

The diameter at breast height (DBH) and height (H) of the trees are standard measures for investigating large plants (Gehring et al., 2008). Forests of large plants can be categorized based on their level of structural development deduced from their diameter at breast height (DBH) and height (H) of the plant species. According to Pellengrini et al. (2009), a mangrove forest that has a maximum structural development has a DBH between 27.0 and 29.9 cm, 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 22.7 m, a forest that has an 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 that has low structural development has a DBH between 1.6 and 3.1cm, and mean height of the most developed trees between 2.4 and 4.7 m.

The mean DBH of *Avicennia germinans* at Etse Lagoon was 10.7 ± 3.27cm and its mean height was 5.9 ± 0.86 m. The mean DBH of *Rhizophora* *mangle* was 11.4 ± 2.45cm and had a mean height of 5.7 ± 1.05 m. Therefore, the mangrove forest at Etse Lagoon can be described as having an intermediate structural development. The coefficient of determination (R^2) of *Avicennia germinans* was 0.4032 and that of *Rhizophora mangle* was 0.2848. This showed that *Avicennia germinans* was taller than *Rhizophora mangle*.

Even though the mangroves are cut, they are not over exploited compared to the mangroves at the Kakum River estuary which has a low level of structural development; since cutting of the trees reduces the potential for height and DBH increase over time (Aheto et al. 2011).

The importance value (IV) is a relative measure of the ecological contribution of a species in terms of its relative frequency, relative density and relative dominance. The importance value (IV) estimated for *Avicennia germinans* and *Rhizophora mangle* were 87.45 and 212.55 respectively. Based on this value, the principal mangrove species at Etse Lagoon was *Rhizophora mangle* since it had the highest importance value.

Land use in the catchment of Etse Lagoon

Land use can leave a distinctive legacy in composition of terrestrial and aquatic communities, even when the vegetation appears to have recovered (Turner et al., 2003). For proper management of important ecosystems such as lagoons, it is necessary to assess the land use in its catchment and their possible impacts on the lagoon system.

Geographic information system information shows that the water surface area of Etse Lagoon has decreased by about 2.86 % between 1973 and 2012. Currently, four main categories of land use within the natural boundaries of the Etse Lagoon were identified. These are built up area, sandy beach, vacant or unused places and vegetation, representing 74.4 %, 3.1 %, 4.0 % and 18.5 % respectively.

Due to lack of previous data on land use in the catchment of Etse Lagoon, no comparisons could be made to ascertain the change in land use in the immediate catchment of the lagoon. However, built-up areas are the most prevalent land use category around the lagoon. This could be as a result of high population growth with its attendant rise in the demand for housing. This expansion of built-up areas probably has resulted in the rapid loss of substantial areas of natural vegetation and the encroachment of settlements on the banks of the lagoon. The clearances of the vegetation around the lagoon and the increase in impervious surfaces associated with urbanization could lead to an increase in the volume and rate of runoff entering the lagoon. This has resulted in increased sediment loads in the water body with the accompanying siltation and gradual reduction in the surface area of the Etse Lagoon.

Implications for small scale fisheries management

Unhealthy aquatic environment, overfishing, mangrove habitat destructions and poor land use land cover scenarios in the catchment of a coastal lagoon have the potential to undermine the sustainability of the coastal lagoon fishery and the socio-economic security of dependant human populations. The result is poverty among the coastal inhabitants and high vulnerability to natural disasters, diseases, and pollution; exacerbated by dwindling resources, loss of habitat, biodiversity, aesthetic value and fisheries productivity. These implications can reach far beyond the coastal zone.

The water quality of the Etse Lagoon is relatively good and thus it supports relatively large diversity of fish fauna. More so, it can serve as a good culture environment most especially for the most dominant fin and shell fish species namely *Sarotherodon melanotheron* and *Callinectes amnicola*, since they exhibit excellent growth.

The *Sarotherodon melanotheron* fishery in Etse Lagoon is threatened by overfishing and poverty of the fishers rather than environmental degradation. This is manifested in the high exploitation rate of *Sarotherodon melanotheron* and the relatively small sizes encountered. The exploitation level (0.58) suggests overexploitation, capitalizing upon the rather fast growth and continuous spawning habit of *Sarotherodon melanotheron* in the Etse Lagoon. Fishing in the lagoon goes on throughout the year. This helps provide fish and sustain employment of most fisher folks, most especially during the marine fishery off-season. However, overfishing in the lagoon would in the near future change the size structure of the fish and also the species composition of the catches of the fishers. In addition, overfishing threatens human well-being through declining fish food availability in the long term, since fewer fish would be available for consumption and the price of fish would increase.

The fringe mangrove forest at Etse Lagoon is a forest with intermediate structural development. This implies that the mangroves are not over exploited but the 'open access nature' of the forest and the encroachment of human settlements even on the banks of the lagoon make the fringe mangroves vulnerable to destruction. This will consequently result in loss of feeding, nursery and roosting grounds for commercially important fish species and migratory water birds and the subsequent reduction in the productivity of the lagoon.

Land use can influence water quality and biodiversity, and can alter the abundance and spatial pattern of native habitats, often resulting in habitat loss and fragmentation. Poor land use in the catchment of the Etse Lagoon can leave a distinctive legacy in composition of terrestrial and aquatic communities, even when the vegetation appears to have recovered. Even though there is no previous data on the land use in the catchment of the lagoon the current percentage coverage of built-up compared to that of natural vegetation cover is high. This implies that the rate of vegetal loss is probably higher than the nation's deforestation rate of 1.96 %. This could result in the increase in impervious surfaces, thereby increasing the rate of inflow of flood water into the lagoon, siltation of the lagoon and poor precipitation in the area and the eventual loss of the Etse Lagoon ecosystem.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Summary

Aspects of the ecology and spatial context of the Etse Lagoon were studied from April 2014 to March 2015. The environmental parameters studied were water temperature, salinity, pH, dissolved oxygen and conductivity. The values recorded were within the tolerance limits of fish. The water quality of the Etse Lagoon is relatively good and thus it supports relatively large diversity of fish fauna. More so, it can serve as a good culture environment most especially for the most dominant fin and shell fish species namely *Sarotherodon melanotheron* and *Callinectes amnicola*.

There was a strong positive correlation between monthly fish abundance and salinity. This could be as a result of the sand bar opening during the rainy season and more fish from the sea swam into the lagoon thereby increasing the number and diversity of fish fauna.

Eighteen fish species were encountered with *Sarotherodon melanotheron* as the dominant fish species by numbers. *Sarotherodon melanotheron* exhibited isometric growth while *Callinectes amnicola* (the dominant shell fish) exhibited allometric growth. *Sarotherodon melanotheron* population in the Etse Lagoon was over exploited.

Two mangrove species were identified at the Etse Lagoon. These were *Rhizophora mangle* and *Avicennia germinans*. The principal mangrove species was *Rhizophora mangle*. The mangrove forest was a forest that has an intermediate structural development. The Etse Lagoon has decreased in surface area by 2.86 % between 1973 and 2012.

Conclusion

In general, the environmental parameters of the lagoon were within the acceptable levels for the sustenance of aquatic life in coastal lagoons. Hence, Etse Lagoon could be described as ecologically healthy.

In terms of species composition, 18 species of fish comprising 15 fin fish and 3 shell fish were encountered in Etse Lagoon. Among these species *Sarotherodon melanotheron* was the most dominant fish species estimated as 74 %.

The growth of *Sarotherodon melanotheron* in the lagoon was described as isometric with strong correlation between body lengths and weights. The most dominant shell fish *Callinectes amnicola* (blue-legged swimming crab) in the lagoon was also described as allometric with strong correlation between standard lengths and body weights. Both *Sarotherodon melanotheron* and *Callinectes amnicola* were found to be in good physiological condition with average condition factor of 3.63 ± 0.03 and 5.5 ± 0.3 respectively.

The breeding activities of *Sarotherodon melanotheron* occurred throughout the year with the major breeding activity occurring in the rainy or wet season and the minor one in the dry season. Recruitment pattern of *Sarotherodon melanotheron* showed that recruitment of juveniles into *Sarotherodon melanotheron* population was all year round. *Sarotherodon melanotheron* in the lagoon had a relatively fast growth rate and therefore the asymptotic length was approached more quickly. The fishing mortality was comparatively higher than the natural mortality for the *S. melanotheron* in the lagoon. This implies that more *S. melanotheron* die as a result of fishing than by natural causes such as predation by piscivores and diseases.

The exploitation rate of *Sarotherodon melanotheron* (0.58) was above the maximum exploitation rate (0.5). The highest diversity of 2.15 recorded in the lagoon indicated a healthy ecosystem.

The Etse Lagoon had decreased in surface area about 2.86 % between 1973 and 2012. This implies a gradual decrease in the surface area of the lagoon. Currently land use within the immediate catchment of the lagoon was categorized as built up area, sandy beach, vacant or unused places and vegetation.

Recommendations

The riparian settlements of the lagoon should be sensitized to desist from channelling effluents from their homes directly into the lagoon in order to prevent the water from being subjected to pollution. It is necessary to construct appropriate drainage systems through which the wastes could be channelled into the sea since the community is close to sea.

Closed fishing seasons should be established during the year and strictly adhered to in order to regulate the fishing activities of the local fishermen in the lagoon especially during the major and minor recruitment seasons (April and September) so as to give room for recruitment to the fish stock.

The riparian communities of the lagoon should be educated on the importance of mangroves in order to prevent the mangroves from being exploited unsustainably and also to encourage them to plant more mangroves around the lagoon.

The macro benthos and bird communities and the food and feeding habits of the fin fish species of the Etse Lagoon should be studied to broaden knowledge on the biodiversity and food and feeding habits of fish species in this lagoon.

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APPENDICES

APPENDIX A

Rainfall and air temperature data for the study area (Source: Ghana Meteorological Service, 2014 to 2015)

MONTH	AVERAGE RAINFALL (mm)	AVERAGE AIR TEMPERATURE (^{0}C)
April 2014	82.3	28
May 2014	379.2	27.5
June 2014	229.6	26.7
July 2014	69.1	25.6
August 2014	54.4	24.9
September 2014	37.3	25.8
October 2014	64.5	26.8
November 2014	63	27.5
December 2014	34.5	27.7
January 2015	13.5	27.1
February 2015	66	28.3
March 2015	116	28.3

APPENDIX B

Averages of environmental parameters of the three stations at Etse Lagoon sampled from April 2014 to March 2015 (each value is an average of three measurements)

Surface water temperature

MONTH	AVERAGE SURFACE WATER TEMPERATURE (^{0}C)		
	STATION A (Riverine portion)	STATION B (Middle portion)	STATION C (Seaward portion)
April 2014	32.7	32.6	31.7
May 2014	26.8	26.9	26.9
June 2014	26.8	26.9	26.6
July 2014	27.0	26.9	26.4
August 2014	30.0	30.8	30.9
September 2014	31.7	32.8	33.6
October 2014	30.6	29.9	31.0
November 2014	30.6	29.9	29.6
December 2014	30.3	29.7	29.4
January 2015	26.0	25.8	25.7
February 2015	31.1	30.6	30.2
March 2015	32.5	31.8	30.9

APPENDIX C

Subsurface water temperature

MONTH	AVERAGE SUBSURFACE WATER TEMPERATURE (^0C)		
	STATION A (Riverine portion)	STATION B (Middle portion)	STATION C (Seaward portion)
April 2014	31.7	31.7	31.5
May 2014	27.7	27.8	27.9
June 2014	27.3	27.1	26.9
July 2014	28.1	27.8	27.2
August 2014	29.9	30.8	30.8
September 2014	31.8	31.8	33.7
October 2014	29.8	29.8	30.0
November 2014	29.8	29.8	29.4
December 2014	29.5	29.5	29.2
January 2015	25.8	25.8	25.6
February 2015	30.7	30.7	30.8
March 2015	31.6	31.6	30.6

APPENDIX D

Surface water salinity

MONTH	AVERAGE SURFACE WATER SALINITY (‰)		
	STATION A (Riverine portion)	STATION B (Middle portion)	STATION C (Seaward portion)
April 2014	15.28	15.40	15.46
May 2014	6.35	6.26	6.26
June 2014	1.98	1.61	1.61
July 2014	2.46	2.37	2.37
August 2014	18.07	18.15	18.15
September 2014	17.82	17.75	17.69
October 2014	14.98	14.91	16.74
November 2014	14.01	13.91	13.96
December 2014	15.38	15.45	15.13
January 2015	14.64	14.87	14.80
February 2015	19.75	18.60	18.70
March 2015	20.45	20.36	20.43

APPENDIX E

Subsurface water salinity

MONTH	AVERAGE SUBSURFACE WATER SALINITY (‰)		
	STATION A (Riverine portion)	STATION B (Middle portion)	STATION C (Seaward portion)
April 2014	15.33	15.43	15.50
May 2014	8.01	7.98	7.93
June 2014	2.01	1.71	1.73
July 2014	2.57	2.54	2.54
August 2014	17.96	18.04	17.31
September 2014	17.96	17.72	17.59
October 2014	14.91	15.40	16.05
November 2014	14.00	13.91	13.90
December 2014	15.42	15.55	15.19
January 2015	14.90	14.84	14.88
February 2015	19.55	19.28	18.80
March 2015	19.69	20.25	19.69

APPENDIX F

Surface water dissolved oxygen

MONTH	AVERAGE SURFACE WATER DISSOLVED OXYGEN (mg/l)		
	STATION A (Riverine portion)	STATION B (Middle portion)	STATION C (Seaward portion)
April 2014	5.53	6.33	5.87
May 2014	3.39	3.94	3.54
June 2014	4.67	4.25	4.97
July 2014	4.43	4.95	5.50
August 2014	5.22	6.47	6.25
September 2014	5.24	5.43	5.45
October 2014	5.75	5.55	4.63
November 2014	5.42	5.09	3.56
December 2014	4.52	5.85	4.92
January 2015	5.66	5.57	5.02
February 2015	7.67	7.29	6.48
March 2015	7.47	6.75	5.13

APPENDIX G

Subsurface water dissolved oxygen

MONTH	AVERAGE SUBSURFACE WATER DISSOLVED OXYGEN (mg/l)		
	STATION A (Riverine portion)	STATION B (Middle portion)	STATION C (Seaward portion)
April 2014	4.90	5.89	5.68
May 2014	2.65	2.77	2.80
June 2014	4.49	4.29	4.59
July 2014	4.10	4.84	4.70
August 2014	4.31	4.65	5.63
September 2014	4.19	5.25	5.15
October 2014	5.45	5.10	4.88
November 2014	4.62	4.67	3.24
December 2014	4.55	5.04	4.19
January 2015	5.28	5.30	5.19
February 2015	7.16	6.73	5.57
March 2015	5.31	5.68	3.93

APPENDIX H

Surface water pH

MONTH	AVERAGE SURFACE WATER pH		
	STATION A (Riverine portion)	STATION B (Middle portion)	STATION C (Seaward portion)
April 2014	8.07	8.29	8.29
May 2014	8.00	8.08	8.08
June 2014	7.71	7.64	7.64
July 2014	8.43	8.51	8.51
August 2014	6.46	7.11	7.11
September 2014	5.13	7.11	7.11
October 2014	7.29	7.22	7.22
November 2014	7.53	7.52	7.52
December 2014	7.65	7.63	7.63
January 2015	7.53	7.51	7.51
February 2015	7.36	7.34	7.30
March 2015	7.83	7.84	7.77

APPENDIX I

Subsurface water pH

MONTH	AVERAGE SUBSURFACE WATER pH		
	STATION A (Riverine portion)	STATION B (Middle portion)	STATION C (Seaward portion)
April 2014	8.08	8.14	8.14
May 2014	7.67	8.20	8.20
June 2014	7.60	7.63	7.63
July 2014	8.40	8.45	8.45
August 2014	6.55	7.14	7.14
September 2014	5.13	7.18	7.18
October 2014	7.30	7.19	7.19
November 2014	7.52	7.52	7.52
December 2014	7.65	7.64	7.64
January 2015	7.55	7.55	7.55
February 2015	7.39	7.33	7.21
March 2015	7.79	7.81	7.77

APPENDIX J

Surface water conductivity

MONTH	AVERAGE SURFACE WATER CONDUCTIVITY (mS/cm)		
	STATION A (Riverine portion)	STATION B (Middle portion)	STATION C (Seaward portion)
April 2014	20.89	23.92	24.01
May 2014	19.00	15.64	17.20
June 2014	30.88	27.10	25.87
July 2014	38.12	37.90	37.10
August 2014	13.99	13.96	14.04
September 2014	13.81	13.82	13.73
October 2014	11.76	11.82	13.24
November 2014	11.17	11.11	10.64
December 2014	12.22	12.22	11.88
January 2015	11.64	11.64	11.75
February 2015	15.20	15.20	14.57
March 2015	23.60	23.60	23.62

APPENDIX K

Subsurface water conductivity

MONTH	AVERAGE SUBSURFACE WATER CONDUCTIVITY (mS/cm)		
	STATION A (Riverine portion)	STATION B (Middle portion)	STATION C (Seaward portion)
April 2014	23.75	23.97	24.03
May 2014	25.62	15.64	24.59
June 2014	31.40	27.52	27.70
July 2014	39.68	39.63	37.77
August 2014	13.71	14.02	13.90
September 2014	13.82	13.82	13.71
October 2014	11.69	11.78	12.65
November 2014	11.14	11.10	11.52
December 2014	12.15	12.13	12.09
January 2015	11.90	11.88	11.79
February 2015	15.09	14.90	14.70
March 2015	22.70	23.48	22.85

APPENDIX L

Monthly fish species occurrence in Etse Lagoon from April 2014 to March 2015

SPECIES NAME	MONTH												
	Apr 2014	May 2014	Jun 2014	Jul 2014	Aug 2014	Sep 2014	Oct 2014	Nov 2014	Dec 2014	Jan 2015	Feb 2015	Mar 2015	TOTAL
Sarotherodon melanotheron	18	27	41	17	108	72	101	30	45	104	156	142	861
Pomadasys incisus				1	2		7	21	1	4	14	1	50
Mugil curema									14	1	5	4	24
Liza falcipinnis			2		8	4	3	14					31
Liza dumerili					1			12					13
Monodactylus sebae							3						3
Cynoglossus senegalensis								1		1			2
Tilapia guineensis								13	16	13	1	2	45
Oreochromis niloticus												1	1
Chloroscombrus chrysurus					1								1
Caranx hippos								1	2				3

Alectis alexandrinus					1								1
Porogobius schlegelii		1							1			1	3
Lutjanus goreensis					1				1				2
Ethmalosa fimbriata							1	4	1	1	3		10
Callinectes amnicola		6	10	45	1			10	7	5		1	87
Penaeus monodon		1					4	3	3				11
Penaeus notialis							2	10	2	2			16
TOTAL	18	35	53	63	123	76	121	119	93	131	179	152	1164

APPENDIX M

Size distribution of fish species from Etse Lagoon

Family/Species	Number	SL (cm)		TL (cm)		BW (g)	
		Min	Max	Min	Max	Min	Max
CICHLIDAE							
Sarotherodon melanotheron	861	3.9	13.8	5	17.7	2.41	91.74
Tilapia guineensis	45	4.7	7.8	6.2	10.3	3.61	18.67
Oreochromis niloticus	1	6.9	-	8.9	-	11.48	-
CARANGIDAE							
Caranx hippos	3	11.2	19.5	14.8	26.2	24.67	243.12
Chloroscombrus chrysurus	1	5.9		8	-	5.36	-
Alectis alexandrinus	1	8.8	-	11.7	-	13.46	-
CLUPEIDAE							
Ethmalosa fimbriata	10	5.8	10.4	7.3	13.5	2.15	23.53
LUTJANIDAE							
Lutjanus goreensis	2	6.8	7	8.7	8.8	9.44	10.35
GOBIDAE							
Porogobius schlegelii	3	5.9	9	7.7	11.2	4.37	10.65
MONODACTYLIDAE							
Monodactylus sebae	3	4.6	5.5	6.8	7.7	10.74	14.52
MUGILIDAE							
Mugil curema	24	7.8	18.5	10.4	24.5	9.99	124.45
Liza falcipinnis	31	5	14.2	6.7	18.3	2.76	67.21
Liza dumerili	13	5.5	8	7.1	10.5	2.3	9.08

CYNOGLOSSIDAE							
Cynoglossus senegalensis	2	7.2	11.5	9	13.8	4.99	28.82
HAEMULIDAE							
Pomadasys incisus	50	6	8.3	8	10.4	3.28	13.3
PORTUNIDAE							
Callinectes amnicola	87	1.8*	10*	3.5**	13**	1.63	127.59
PENAEIDAE							
Penaeus monodon	11	10.1	16	12.2	19	10.6	43.94
Penaeus notialis	16	8.4	11.5	10.2	13.5	6.26	17.28

Asterics (*) denotes carapace width and (**) denotes carapace length

APPENDIX N

Mangrove species and their structural parameters

Family/Species	Height (m)	DBH (cm)
AVICENNIACEAE	5.4	12.3
Avicennia germinans	5.7	7.5
Avicennia germinans	6.5	15.9
Avicennia germinans	5.7	8.2
Avicennia germinans	6.2	10.8
Avicennia germinans	6.7	15.9
Avicennia germinans	3.4	7.2
Avicennia germinans	6.1	10.2
Avicennia germinans	4.9	4.6
Avicennia germinans	5.4	6.8
Avicennia germinans	5.9	6.1
Avicennia germinans	6.9	14.1
Avicennia germinans	7	12.8
Avicennia germinans	7.1	13.4
Avicennia germinans	5.9	11.2
Avicennia germinans	5.9	10.8
Avicennia germinans	5.4	10.3
Avicennia germinans	6.3	11.4
Avicennia germinans	5.4	13.9

APPENDIX O

Mangrove species and their structural parameters

Family/Species	Height (m)	DBH (cm)
RHIZOPHORACEAE		
Rhizophora mangle	5.4	11.6
Rhizophora mangle	5.9	11.8
Rhizophora mangle	5.8	10.3
Rhizophora mangle	5.2	8.9
Rhizophora mangle	6.7	15.9
Rhizophora mangle	3.6	9.9
Rhizophora mangle	5.9	10.6
Rhizophora mangle	2.2	7.9
Rhizophora mangle	4.7	7.8
Rhizophora mangle	5	9.8
Rhizophora mangle	6.6	13.7
Rhizophora mangle	5.4	11.5
Rhizophora mangle	6.4	13.9
Rhizophora mangle	5.1	7.8
Rhizophora mangle	5.4	7.8
Rhizophora mangle	5.5	9.3
Rhizophora mangle	6.2	10.1
Rhizophora mangle	8.7	12.4
Rhizophora mangle	6.8	10.9
Rhizophora mangle	6.8	10.6
Rhizophora mangle	6.5	13.5

Rhizophora mangle	7	12.9
Rhizophora mangle	5.7	10.9
Rhizophora mangle	5.8	10
Rhizophora mangle	6.8	19.8
Rhizophora mangle	6	13.7
Rhizophora mangle	5.2	11
Rhizophora mangle	6.1	12
Rhizophora mangle	6.2	14.5
Rhizophora mangle	6.9	14.9
Rhizophora mangle	5.6	13.9
Rhizophora mangle	5.9	9.3
Rhizophora mangle	4	13.9
Rhizophora mangle	5.1	10.1
Rhizophora mangle	5.2	10.1
Rhizophora mangle	5.2	12.9
Rhizophora mangle	4.3	10.2
Rhizophora mangle	5.5	11.1
Rhizophora mangle	4.4	8.4
Rhizophora mangle	4.6	7.6
Rhizophora mangle	5.9	10.1
Rhizophora mangle	6.4	13.1
Rhizophora mangle	5.7	12.1
Rhizophora mangle	6	11.6
Rhizophora mangle	5.5	11.2