UNIVERSITY OF GHANA

THE POPULATION PARAMETERS, FOOD HABITS AND PHYSICOCHEMICAL ENVIRONMENT OF THREE CICHLID SPECIES IN THE SOUTHWESTERN SECTOR OF THE KETA LAGOON

A THESIS

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BY

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DECLARATION

This thesis is the result of research work undertaken by me in the Department of Oceanography and Fisheries, University of Ghana, under the supervision of Professor C. J. Vanderpuye and Mr. A. K. Armah.

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DEDICATION

This work is dedicated to my mother, Angele R. Ababio and my father, Obed K. Ababio for educating me to this level, and to Yayra, my fiancée, for giving me a new focus in life.

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ABSTRACT

The study was carried out in the southwestern sector of the Keta lagoon, a closed coastal lagoon located in the southeastern part of Ghana. The study was aimed at studying the population parameters and the feeding habits of the major fish species (in terms of catch) in the lagoon in relation to the prevailing physicochemical parameters and the benthic macrofauna of the area.

The water physicochemical parameters studied included the electrochemical and the optical properties of the water as well as the nutrients available for production. Macrobenthic fauna studies were also carried out, in relation to sediment grain size distribution and organic matter content, as an index of the ecological state of the area. The findings from the study indicate that the seasonal precipitation pattern of the area was mainly responsible for fluctuations in the lagoon water physicochemical regime during the period of the study. The benthic fauna diversity did not indicate any effect of any external perturbation on the lagoonal environment, except salinity changes.

The study on the fishery resource of the lagoon indicated that even though the resource is highly exploited, it is able to maintain itself by rapid reproduction at an early age. However, if exploitation is maintained at or above the current rate, its effect, coupled with that of the stressful environment could result in diminishing catches, with catches comprising mainly of small-bodied fishes.

CHAPTER ONE

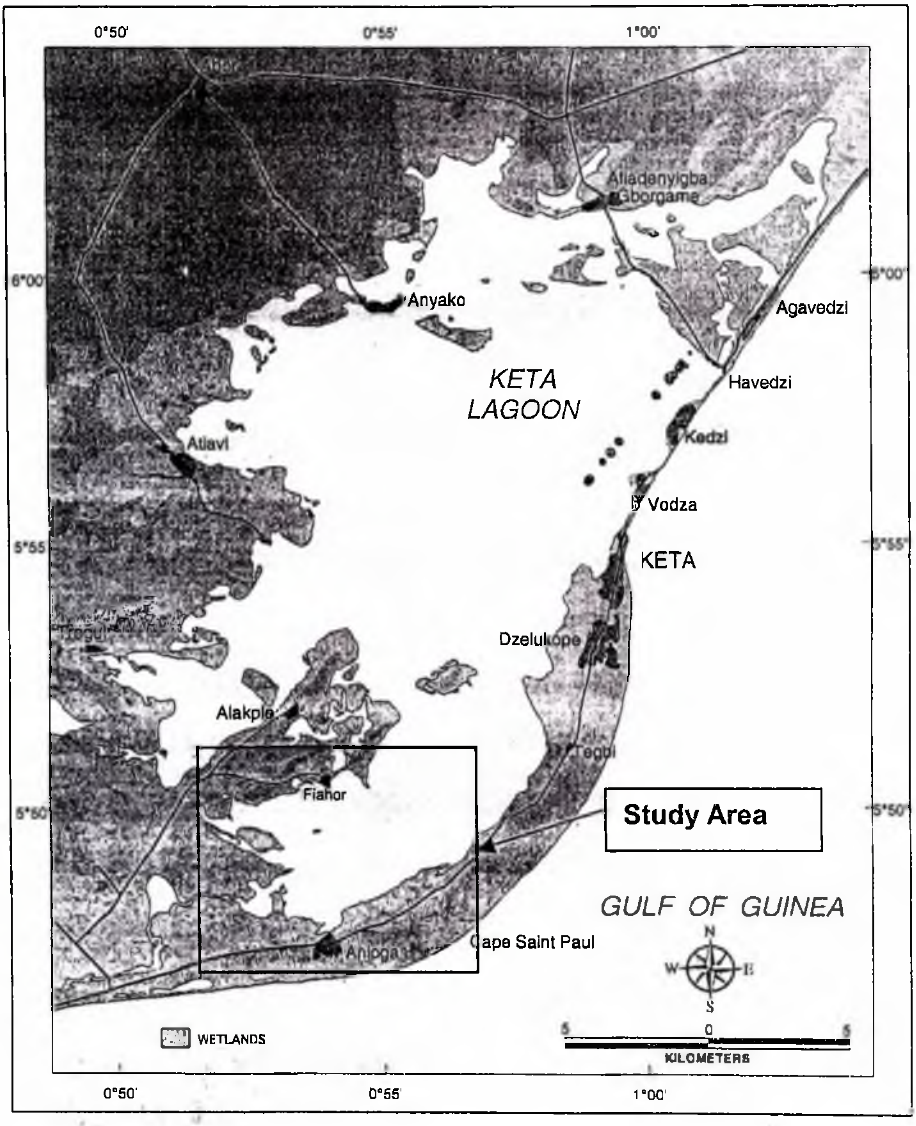
INTRODUCTION

The Keta lagoon is a closed lagoon located in the southeastern corner of the Republic of Ghana (Figure 1.0). It stretches for about 40 km along the coastline, and covers an approximate area of 350 km^2. The lagoon serves as a major source of finfish and other fishery products (e.g. shrimps, crabs) to its fringing communities, among which are Anloga, Woe, Keta , Kedzi, Anyako, Alakple, Atiavi and Fiahor.

The fishery of the Keta lagoon covers diverse groups of organisms including several finfish species, gastropods and crustaceans. However, the dominant species caught belong to the Family Cichlidae. These include *Sarotherodon melanotheron melanotheron, Tilapia guineensis,* and *Hemichromis fasciatus* (Addo, 2000; Ofori-Danson *et al.*, 1999; Shenker *et al.,* 1998; Armah *et al.,* 1997). This cichlid fishery is of cardinal importance to the fringing communities since it serves as a major source of dietary protein, employment and revenue generation; the fishes caught from the lagoon are either used for food domestically or are processed and sold.

Access to the lagoonal fishery is not restricted though certain riparian communities, such as Atiavi, have imposed taboo days when fishing is prohibited. Such prohibitions, however, are of local effect and do not prevent fishing in the lagoon as a whole. Consequently, the fishery is exploited continually throughout the year.

Figure 1.0: Map of the Keta lagoon showing the Study Area



The other uses of the lagoon include salt mining during the dry seasons and water transport. Some of the aquatic plants are harvested for mat making (*Cyperus articulatus*) and for fish processing (*Sesuvium* sp., *Phylloxerus* sp.). Shallots (*Allium ascalonicum*) and other short duration annuals such as maize, pepper and cassava are extensively cultivated on the sandbar separating the lagoon from the sea (Armah *et al*, 1997). The Keta lagoon is also important as an avifauna site and a Ramsar site. It is home to over 46 species of waterfowls comprising terns, herons, egrets and waders with peak counts in excess of 40,000 birds (Piersma and Ntiamoa-Baidu, 1995).

Tropical coastal lagoons generally experience widely fluctuating salinity regimes and water levels that induce an immense stress on the lagoonal ecosystem (Barnes, 1980). The synergistic effect of this stress, coupled with a high and unsustainable fishing pressure puts a severe stress on the lagoonal fishery, resulting in stunted fish populations (Blay and Asabere-Ameyaw, 1993) and a potential for a collapsed fishery (Pauly *et al,* 1989). However, due to the unavailability of historic data for most tropical coastal lagoons, it is difficult determining the effects stresses of this nature may have on the fishery. As a result, devising management strategies and plans for the sustainable utilization of the lagoonal fisheries resource is not easily achievable.

Historical work done on the fishery of the Keta lagoon is rather limited, principal among which are those of Shenker *et al.* (1998), Ofori-Danson *et al.* (1999) and Addo (2000). The work done by Shenker *et al.* (1998) and Ofori-

Danson *et al.* (1999) formed part of the environmental baseline studies for the Ghana Coastal Wetlands Management Project and covered relatively short durations; their focus was on a narrow range of physicochemical parameters. The various authors recommended an extensive study/monitoring of the fishery over a long-term period, especially in relation to population parameters of the fishery. Work done by Addo (2000) focused primarily on the Acadja fishery of the Keta lagoon and determined some population parameters and fecundity indices of the major cichlids in the lagoon.

The current study was carried out in the southwestern sector or the Anloga end of the lagoon. This area is heterogeneous and consists of identifiable habitats such as vegetated areas, open waters, muddy and sandy bottoms reminiscent of the entire lagoon. It is also reported by the local fishers to be the most productive part of the lagoon in terms of fish catch.

The research was aimed at studying the population parameters and the feeding habits of the major fish species of the lagoon in relation to the prevailing physicochemical parameters and the benthic macrofauna of the area. The specific objectives of the study were to:

- Determine the von Bertalanffy growth and mortality parameters of the major cichlid species from length-frequency data, as an index of the ecological state of the fishery.
- Determine the recruitment pattern and the level of exploitation of the fishery from length-frequency data and the population parameters.

- Study the benthic macrofauna as an index of the ecological state (health) of the area, and its role in the fishery of the lagoon.
- Study the physicochemical parameters of the water and sediment in the study area and determine how they impact on the benthic fauna and fishery.

The rest of the thesis is organized into five chapters. Chapter two is a review of current and relevant literature on the study, including literature on the methodologies adopted during research and data analyses. Chapter three discusses the methods employed in sampling design, sample collection and analyses both in the field and in the laboratory. Chapter four is the results obtained from the study. Chapter five discusses the finding of the study in relation to the set objectives and other published findings of similar subject. Chapter six contains the conclusions from the study and relevant recommendations for management considerations.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Keta Lagoon

The lagoon is located within the coordinates of longitudes 0°48'E and 1°01'E, and latitudes 5°48'N and 6°03'N. The climate of the region is tropical with two rainy seasons, a major season and a minor season, separated by a relatively short dry period occurring between late July and September. The major season occurs from March/April to July while the minor season is from September to November. This is followed by a second and longer dry period lasting until February. The average rainfall of the region is about 700 mm *per annum*. The mean ambient temperature is 27.5°C, the average relative humidity above 80% with a 15% seasonal variation. The mean hours of insolation is 6.9 hours, ranging from a low of 4.8 hours in June to a high of 8.4 hours in November (Finlayson *et al.*, 2000).

Geological evidence (Akpati, 1978) shows that the lagoon was formed in the Keta basin, a coastal geological subsidence which occurred in the late Precambriam era, during the separation of South America from Africa. The basal landform is mainly made up of gravel, sand, siltstone, shale and clay with layers of fossiliferous limestone (Armah *et al.*, 1997; Akpati, 1978).

The lagoon stretches for about 40 km along the coastline (Piersma and Ntiamoa-Baidu, 1995) and, with its associated wetlands, covers an area of about 702 km^2 (Armah *et al.*, 1997). The open water of the lagoon, however, covers an approximate area of 300 km^2 with the surface area varying with the seasons and water levels (Piersma and Ntiamoa-Baidu, 1995). The mean water depth is about 0.8 m (0.6 m – 1.0 m; Biney, 1984) with a maximum depth of about 3 m. Bathymetrically, the lagoon floor is plate-like with a gentle landward slope (Finlayson *et al.,* 2000).

The salinity regimes prevailing in the lagoon vary considerably with location (within the lagoon) and period of year. Piersma and Ntiamoa-Baidu (1995) estimated the salinity of the lagoon in a study conducted in late October 1994 as ranging from less than 40‰ (near Woe and Anloga) to greater than 60‰ (Fiahor). Biney (1984) reported the following physicochemical values for the lagoon: water temperature: 32.3°C, pH: 8.1, dissolved oxygen: 7.22 mg/L, phosphates: 0.023 mg/L, nitrates: 0.173 mg/L. Biney (1984) summarized the lagoon water quality as 'slightly polluted or of doubtful quality', as a result of fecal and domestic waste which contaminates it at its fringes. Finlayson *et al.* (2000) reported that the physicochemical properties of the lagoonal water were within the expected range for coastal lagoons in Ghana.

Entsua-Mensah and Dankwa (1997) chronicled three sources of water inflow into the Keta lagoon though there are probably more. The following sources have been identified (Armah *et al.*, 1997; Entsua-Mensah and Dankwa, 1997; Piersma and Ntiamoa-Baidu, 1995; A. K. Armah, pers com):

i. Runoff from the Tordzie River which enters and fills the Avu lagoon during the rainy season and overflows into the Keta lagoon via the Aglor and Agbatsivi lagoons and other smaller streams.

ii. Runoff from the Aka and Belikpa streams which enter the lagoon directly from the north.

iii. Overwash from the sea across the sandbar at the Havedzi end of the lagoon during high tides.

iv. Hydrostatic induced flow of seawater through the sandbar separating the lagoon from the sea.

v. Direct precipitation from the atmosphere into the lagoon.

vi. Interflow between the lagoon and the Volta estuary through the Anyanui creek.

The sixth source, which was very important prior to the construction of the Akosombo and Kpong dams, is currently not very significant as a source of inflow to the lagoon (Piersma and Ntiamoa-Baidu, 1995). This phenomenon was also observed during a recent study (in which the author participated and which is yet to be published) which showed that the tidal force experienced in the Volta estuary was not strong enough to move fresh water through the Anyanui creek into the lagoon. This has resulted in increased deposition and siltation along the canal, further decreasing in the flow rate through the creek. The net result is an oscillation of the same parcel of water in the creek between tidal minima and maxima.

The only identifiable source of water loss from the lagoon is by evaporation (Piersma and Ntiamoa-Baidu, 1995). The freshwater inflow to the lagoon is greatly reduced during the dry season resulting in a drastically increased salinity in the lagoon during such periods (Piersma and Ntiamoa-Baidu, 1995).

2.2 The Lagoonal Fishery

The Keta lagoon supports a large fishery with the cichlid *Sarotherodon melanotheron melanotheron* dominating the catch (Addo, 2000; Armah *et al.,* 1997). The other major fishes caught in the lagoon include *Tilapia guineensis* and *Hemichromis fasciatus* (Addo, 2000; Ofori-Danson *et al.,* 1999). Ofori-Danson *et al.* (1999) have also identified 15 finfish species in addition to two crustacean species (*Callinectes aminocola* and *Penaeus* sp.) and some molluscan species as the fishery resource of the lagoon.

Generally, the fishery resource of the lagoon may be considered in three groups consisting of different species (A. K. Armah, pers com). These are:

i. Freshwater species that swim into the lagoon via the streams discharging water into the lagoon.
ii. Juvenile forms of marine fishes washed over the sandbar into the lagoon from the sea.
iii. Permanent residents, which are indigenous to the lagoon.

The Keta lagoon is fished extensively for its shellfish and finfish resources. Crafts used for fishing in the lagoon are mainly canoes made of wooden planks (Dankwa and Entsua-Mensah, 1995), though most fishers wade in the lagoon for their fishing activities. Fishing methods and gears used in the lagoon are reported in Dankwa and Entsua-Mensah (1995); the major ones were castnets, gillnets, drag/seine nets, fish weirs, acadja and the tekali systems of fishing. Dankwa and Entsua-Mensah (1995) also report that most of the gears/methods employed were not sustainable and have the potential to negatively impact on the fishery and the ecosystem.

2.3 The Cichlids

The three fish species, *S. melanotheron melanotheron, T. guineensis and H. fasciatus* that form the main focus of this study belong to the fish family Cichlidae, Subfamily Pseudocrenilabrinae, Order Perciformes and Class Actinopterygii (Carroll, 1988). Cichlids are reported as the largest family of fishes while the order Perciformes is also reported as the largest fish order (Helfman *et al.,* 1997; Nelson, 1994). Perciformes occur in marine, freshwater and brackishwater environments, and are cosmopolitan in distribution (Helfman *et al.,* 1997; Nelson, 1994).

2.3.1 *Sarotherodon melanotheron melanotheron*

2.3.1.1 Geographic Distribution

Sarotherodon melanotheron melanotheron Rüppell 1852 is indigenous to West Africa from Senegal to southern Cameroon. It has, however, been introduced into several countries in Asia, Europe and the USA (Trewavas and Teugels, 1991).

2.3.1.2 Ecology

The melanic areas in the adult are usually present on the lower parts of the head (hence its common name, the blackchin tilapia), the cleithrum and on the apices of the caudal and soft dorsal fins. Occasional irregular and asymmetrical spots may be observed on the flanks in the form of bands. The fish aggregates in schools and is mainly nocturnal with intermittent daytime feeding; its food consists of aufwuchs and detritus (Trewavas, 1983) as well as bivalves and zooplankton (Diouf, 1996). It is demersal and occurs in lagoons and lower reaches of streams (Page and Burr, 1991; Trewavas and Teugels, 1991). It is found in freshwater and brackishwater and can tolerate wide salinity ranges (Page and Burr, 1991; Trewavas and Teugels, 1991). Its optimal pH range is between 7.0 and 8.0 while its depth range is up to 3 m (Trewavas and Teugels, 1991).

2.3.2 *Tilapia guineensis*

2.3.2.1 Geographic Distribution

Tilapia guineensis (Günther, 1862) is also indigenous to West African coastal waters, from the mouth of the Senegal River to the mouth of the Cuanza River in Angola (Teugels and Thys van den Audenaerde, 1991).

2.3.2.2 Ecology

It is benthopelagic and feeds on shrimps, bivalves, plankton and detritus (Diouf, 1996). It is commonly found in fresh or brackish water but it also tolerates high salinities (Teugels and Thys van den Audenaerde, 1991).

2.3.3 *Hemichromis fasciatus*

2.3.3.1 Geographic Distribution

Hemichromis fasciatus Peters, 1858, also known as the banded jewelfish, is found throughout Africa. Its distribution is reported from Senegal to the Nile basin, from Lake Chad to the Congo basin and Upper Zambezi and from Côte d'Ivoire and Ghana (Teugels *et al.*, 1988). It is however believed to be widely distributed in West Africa (Teugels, 1992). The species occurs in both forest and savannah biotopes (Daget and Teugels, 1991) in littoral riverine habitats and permanent floodplain lagoons with clear water (Teugels, 1992).

2.3.3.2 Ecology

It is demersal and feeds on shrimps, insects and small fish (Teugels, 1992). It is a nesting substrate spawner; the parents guard the nest and larvae (Regan, 1912).

These three species are indigenous to the Keta lagoon where they are harvested in appreciable quantities (Addo, 2000; Ofori-Danson *et al.*, 1999; Shenker *et al.*, 1998).

2.4 Growth Model and Parameters

Though several growth models are in existence for the description of fish growth (Beverton and Holt, 1957; Gulland, 1983; Pauly, 1984; Pauly and Morgan, 1987), the von Bertalanffy growth model is preferred for this study, the main reasons being its wide acceptability and use in several complex models describing fish population dynamics. The von Bertalanffy model describes the body length of fish as a function of time by the equation

$$L_t = L \quad (1\text{-}e^{-K(t-to)})$$

where L_t is the length of a fish at time (age) **t**, usually measured in years,

L is the asymptotic length of the fish, usually measured as total length in centimeters

K is the growth constant of the fish

t_o is the theoretical age when the fish has zero length and

e is the natural log base.

Other parameters that describe various properties of a fish population are estimated from these basic parameters. The growth parameters differ from species to species and also among stocks of the same species (FAO,1989). Table 2.0 shows some von Bertalanffy population parameters for the three species from Fishbase (Froese and Pauly, 2001), a web-based electronic library on the fishes of the world.

Table 2.0: Population parameters for *S. melanotheron melanotheron, T. guineensis* and *H. fasciatus* (Froese and Pauly, 2001).

	L (cm)	**K (yr^{-1})**	**Φ'**	**M (yr^{-1})**	**t_o (yr)**	**t_{max} (yr)**
S. melanotheron	26.1	1.25	2.93	2.17	-0.1	2.3
T. guineensis	20.7	0.85	2.56	1.72	-0.2	3.3
H. fasciatus	21.4	1.20	2.74	2.21	-0.1	2.4

where **Φ'** (phi prime) is the growth performance index

M is the natural mortality coefficient estimate

t_{max} is the lifespan or longevity of the fish (Alagaraja, 1984).

The growth performance index **Φ'** (Pauly and Munroe, 1984; Munroe and Pauly, 1983) is a test of the resilience of the growth model (hence parameters) estimated for a fish stock. It is calculated from the equation

$$\Phi' = \ln K + 2(\ln L\ )$$

Unlike the other growth parameters, it is fairly constant with little variability for a fish species, irrespective of where it is obtained (FAO, 1989).

The study by Ofori-Danson *et al.* (1999) on the fishery of the Keta lagoon was focused on *S. melanotheron melanotheron*. Table 2.1 presents some of the parameters they estimated.

Table 2.1: Population parameters for *S. melanotheron melanotheron* from the Keta lagoon (Ofori-Danson *et al.*, 1999).

	L (cm)	**K (yr-1)**	**Φ'**	**Z (yr-1)**	**M (yr-1)**	**F (yr-1)**	**E**
S. melanotheron	17.5	1.1	2.53	5.02	2.21	2.81	0.56

where **Z** is the total instantaineous mortality

F is the fishing mortality ,

E is the level of exploitation and

all other parameter retain their previous definitions.

Though no yield data was available for the lagoon, Ofori-Danson *et al.* (1999) reported that experimental fishing yielded 791.3g and 332.0g of *S. melanotheron melanotheron* and *T. guineensis per* man-hour respectively

Ofori-Danson *et al.* (1999) however did not estimate the population parameters of the other major fishes they identified in the Keta lagoon. Their study also did not include the food and feeding habits of the fishes or the environmental integrity of the lagoon.

S. melanotheron melanotheron is reported as the dominant fish in catches in studies on other coastal lagoons in Ghana (Koranteng *et al.*, 2000; Koranteng *et al.*, 1998; Blay and Asabere-Ameyaw, 1993; Pauly, 1976). Studies on the Muni lagoon, Densu-Delta and Sakumo II lagoon (Koranteng, *et al.*, 2000; Koranteng *et al.*, 1998) all indicate *S. melanotheron melanotheron* as dominating the catch, accounting for 99.9% (by weight) of catch in the Muni lagoon, 96.4% in the Sakumo II lagoon and 85.6% in the Densu-delta. Some population parameters estimated for *S. melanotheron melanotheron* from the Muni lagoon (Koranteng *et al.*, 2000) are:

L = 12.5 cm (SL),

$K = 0.71\ yr^{-1}$,

$t_o = -0.01$ yr and

$t_{max} = 4.2$ yr

Pauly (1976) reported that the Sakumo I lagoon yielded 50 kg of fish per day while Blay and Asabere-Ameyaw (1993) reported annual yields of between 452 – 664 kg/ha of fish for the Fosu lagoon.

The study by Shenker *et al.* (1998) focused mainly on the gonado-somatic index and length-weight relationship as well as size/sex relationship and mean abundance of species in the Keta lagoon. They however did not estimate population parameters of the fishes they studied. Addo (2000) whose main focus was on the Acadja fishery of the Keta lagoon determined the gonado-somatic index and the feeding habits of the major cichlids in the Keta lagoon.

2.5 Sediment and Benthic Fauna

Though Armah et al. (1997) reported on the sediment of the Keta lagoon, the only comprehensive study so far to have been carried out on the lagoonal sediment was by Finlayson et al. (2000), who studied the spatial distribution of the sediment grain size and the benthic macrofauna of the lagoon. Their findings indicate that the lagoonal sediment is basically clayey, but contains a large proportion of fine sand and silt elements. The larger particles were usually shell fragments or shell relics (Finlayson *et al.,* 2000). They however did not comment on the temporal dynamics of the sediment distribution.

The benthic fauna of the lagoon, as reported by Finlayson *et al.* (2000), was made up of 10 species of annelids, 13 species of molluscs and 9 species of crustaceans. According to the authors, the most encountered species was the bivalve *Tivela tripla* followed by the gastropod *Tympanotonus fuscata.* They however did not relate sediment properties with benthic faunal distribution.

The relation between sediment properties and the distribution of infaunal invertebrates has been a subject of numerous studies (Snelgrove and Butman, 1994). This has however not produced a universally accepted 'animal-sediment' model (Seiderer and Newell, 1999; Snelgrove and Butman, 1994). The current school of thought is that 'animal-sediment' relations may be influenced by other factors such as bottom boundary-layer flow (Miller and Sternberg, 1988; Butman, 1987; Nowell and Jumars, 1984; Palmer, 1983), hydrodynamics and sediment transport processes (Cacchione and Drake, 1990; Butman, 1987; Grant and Madsen, 1986; Nowell, 1983). However some evidence exists in support of sediment grain size distribution as being a factor in infauna distribution (Palacin *et al.,* 1991; Ishikawa, 1989; Nichols, 1970; Cassie and Michael, 1968; Sanders, 1958; Thorson, 1957).

The organic content of benthic sediment is considered by some authors (Gray *et al.,* 1990; Pearson and Rosenberg, 1978) as a more likely factor in determining infauna distributions. This is because organic matter in sediment is a major source of food supply for deposit feeders (Snelgrove and Butman, 1994).

The current study was focused on the Anloga end of the lagoon. This area was selected since, according to the local fisherfolk, it is the most productive part of the lagoon. In terms of biotopes also, the area is more or less a microcosm of the entire lagoon.

Sampling covered a period of nine months enabling the effects of seasons on the environment and the fishery to be determined. Environmental parameters and benthic faunal surveys were carried out in addition to the fishery studies in order to determine the effects of the environment on the fishery.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The study site is the southwestern corner or the Anloga end of the lagoon (Figure 1.0). It is located within the coordinates of latitude 05°52'N and 05°42'N and longitude 00°52'E and 00°56'E, covering an approximate area of 35 km^2. The principal factors taken into consideration in the location of sampling stations was salinity, vegetation cover, water depth and sediment structure.

A preliminary survey was carried out in the first week of January 2000 in the study area to design a sampling strategy that will address the objectives of the study and to locate sampling stations, taking into account the identifiable biotopes in the area. It was realized that the salinity values in the study area increased northwards (towards Fiahor) away from the sea. Preliminary analysis also indicated that the sediment, while being muddy generally, had more sand content at the northward (Fiahor) end of the study area than at the seaward end. No clear pattern was observed in the depth of the water column in the study area, the water depth being shallow. Vegetation however was more concentrated close to Anloga with open water near Fiahor.

Based on these considerations, the sampling stations were located along a belt transect in identifiable habitats from Anioga to Fiahor (Figure 3.0). The study area is approximately 35 km^2. Seven sampling stations were located in all, at about a kilometer apart (Table 3.0).

Table 3.0: Coordinates of Sampling Stations in the study area.

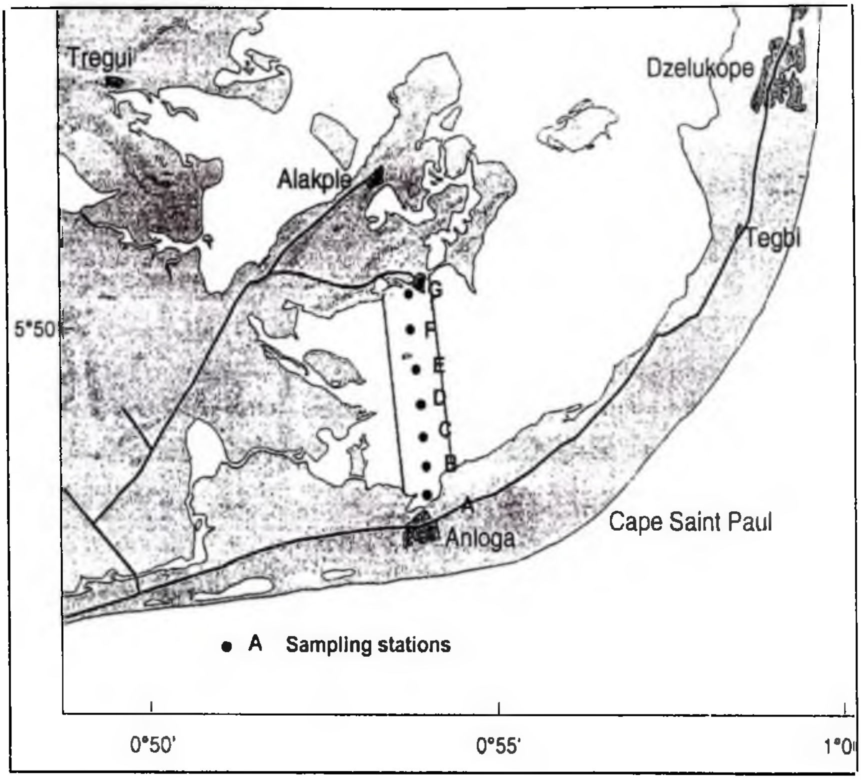
Station	Latitude	Longitude
A	05°47'58"	00°54'16"
B	05°48'27"	00°54'15"
C	05°48'57"	00°54'25"
D	05°49'27"	00°54'12"
E	05°49'57"	00°54'05"
F	05°50'22"	00°54'07"
G	05°50'48"	00°53'55"

The sampling stations were located with a handheld Magellan 4000X Geosatelite Positioning System (GPS) receiver.

3.2 Description of Sampling Stations

The sampling stations were lettered A to G. Stations A, B and C were located close to Anloga, and were mainly in vegetated areas. Stations A and B were located in densely vegetated areas while station C was in a relatively sparsely vegetated area. Station D was located at the edge of the vegetated area while Stations E and F were located in open water devoid of any vegetation. Station G was located close to Fiahor, also without vegetation.

Figure 3.0: Map of the Study area showing sampling stations along belt transect



3.3 Sampling

Sampling was carried out from January to September 2000, a period of nine months. This period was chosen because it was possible to observe the effect of season on the lagoon.

Sampling was carried out for the following:

- Water physicochemical parameters
- Sediment grain size distribution and total organic (detrital) content

- Macrobenthic fauna
- Fish

Samples for the water physicochemical parameters and fish studies were taken at monthly intervals while bi-monthly samples were taken for the sediment grain size analysis, organic content and benthic fauna. Sample collection usually took place during the last week of a month. The samples were collected between 6:00 hours and 11:00 hours. The same sequence of sample collection was adopted so that samples were collected at approximately the same time each month.

3.3.1 Water Physicochemical Parameters

The physicochemical parameters of the water which were measured were salinity, conductivity, total dissolved solids, pH, dissolved oxygen, nitrates, phosphates, sulphates, silicates, water temperature, total suspended solids and turbidity. The lagoon water was sampled employing a tight closing 250 ml plastic bottle. The bottles were washed and rinsed with deionised water in the laboratory to remove any contaminant. Just before samples were taken, a small amount of the water at the station was used in rinsing the sample bottle in order to get rid of any other contamination that may have occurred during transportation or handling. The sample bottle was then dipped below the water surface to about 0.5 m to collect subsurface water sample. The sample bottle was tightly closed while still below the surface of the water; a precaution taken to ensure that no air bubble entered or was trapped in the bottle. The occlusion of air from the bottle was done to reduce to a minimum any biochemical activity occurring in the bottle. This was further ensured by placing the water sample in a thermos chest containing ice cubes.

The dissolved oxygen content of the water and water temperature were, however, measured *in situ* employing a hand held YSI 55 dissolved oxygen meter with a built-in thermometer. The other parameters were determined in the laboratory soon on arrival from the field.

3.3.2 Sediment and Macrobenthic Fauna

The sediment was sampled employing a 3-inch diameter PVC pipe corer with a fitted plunger. During sampling six inches of the corer was pushed into the sediment and the trapped sediment taken. The plunger was used in pushing out the trapped sediment. Four replicate samples were taken *per* station for the benthic fauna study. Each sample was washed in a box sieve of 0.5 mm mesh size in order to get rid of excess silt and clay components in the sample while retaining the benthic macrofauna. The residual sample was then placed in a tight-closing plastic container and preserved with 10% buffered formaldehyde solution. A few drops of Rose Bengal stain was added to each sample container to make the identification of living tissue easier.

One additional sediment sample *per* station was taken for sediment grain size and total organic content analysis. The sample was taken in the same way as that for the benthic fauna, except that after coring, the sample was not sieved but was rather placed whole in a container. No preservative or stain was added to it.

3.3.3 Fish

The fish samples were obtained from the fishermen fishing in the study area. Care was taken that the fish so obtained was:

- caught in the study area and
- not sorted into samples of different sizes, as usually occured before they were sold on the market.

In order to meet the above requirements, the fish samples were bought from the fishermen while they were still at work on the lagoon.

The gut contents of the fish samples were then fixed *in situ* by injecting a 4% buffered formaldehyde solution into the gut. They were then placed in a thermos chest containing ice to aid in their preservation. On arrival in the laboratory, the fish samples were transferred to a deep freezer and kept there till they were analyzed.

3.4 Laboratory Analyses

3.4.1 Water Physicochemical Parameters

The nutrients (i.e. nitrates, phosphates, sulphates and silicates) were analyzed using a Hach DR2010 direct-reading spectrophotometer and Hach prepackaged reagents. The protocols followed was as outlined in the Hach DR2010 user manual (Hach, 2000a) and the Hach water quality analysis handbook (Hach, 2000b), supplied with the spectrophotometer. These involved the addition of the prepackaged specific reagents to an aliquot of the water to be analyzed. This produces compounds of varying color or turbidity, which is then measured with the spectrophotometer. The optical properties of the water (i.e. turbidity and total suspended solids) were also analyzed using the Hach DR2010 spectrophotometer, following protocols outlined in the user manual and handbooks (Hach, 2000a, Hach, 2000b).

The electro-chemical properties of the water (i.e. salinity, conductivity and total dissolved solids) were measured using a Hach portable salinity, conductivity and total dissolved solids meter with a built-in automatic temperature compensation facility. The pH was measured using a Hach pH meter with a built-in automatic temperature compensation facility. The protocols followed, as before, were those outlined in the Hach user manual and methods books (Hach, 2000a, Hach 2000b).

3.4.2 Sediment

In the laboratory, the sediment samples for the benthic fauna analysis were washed with tap water in a stainless steel 500 pm mesh-size precision sieve to get rid of the fixative. It was then spread on an examination tray in which grids had been drawn to facilitate examination. The sample was then examined carefully and organisms present were picked out and placed in a 70% alcohol-glycerol preservative. Identification and counting were done under a dissecting microscope with samples identified to the species level.

Sediment grain-size distribution was determined by taking 130 g of the core sample and washing it in a 63 µm mesh-size precision sieve to remove the silt and clay component. The residual was heated in an oven at 60°C for 6 hours, and reweighed to obtain the mass of the silt and clay fraction. It was then treated with 1% sodium hydroxide solution to destroy any organic component and to prevent clumping. The sodium hydroxide solution was washed out of the sediment and the sediment was reheated at 60°C for 6 hours to obtain a constant weight. 100 g of this treated sediment was then placed on the uppermost sieve of a nest of 7 sieves of mesh sizes 2 mm 1 mm 0.75 mm, 0.5 mm 0.355 mm, 0.25 mm and 0.063 mm. The nest of sieves was agitated using an Endecot sieve shaker at an amplitude of 7 mm for 10 minutes. This resulted in the separation of the sediment components into various grain-size classes in the sieves. Each component so trapped was weighed to determine the weight contribution of that class of grain size to the sediment in whole.

The total organic (detrital) content of the sediment was also determined. During this analysis, 30 g of the sediment was treated in a beaker with 10% hydrochloric acid solution to remove excess carbonates due to shells. The residual was heated at 60°C to a constant weight. Approximately 20 grams of this was then placed in a muffle furnace and heated at 600°C for 6 hours for the organic content to burn. After ashing, the residual was then weighed again, the difference being the organic (detrital) content of the sediment.

3.4.3 Fish

The fish samples were identified to species level and analyzed for length-weight data and gut content. The total length was measured to the nearest 0.1 cm employing a fish measuring board. The weight was measured on a Mettler

Toledo balance to the nearest 0.01g. The gut content was then removed and preserved in a 70% alcohol-glycerol solution till it was analyzed.

For the gut content analysis, the preserved gut was cut open and the content washed out into a petri dish. The food items in the gut were identified and analyzed as percentage composition by weight and occurrence. A Costello analysis (Costello, 1990) was carried out on this data to determine the feeding strategy of each species and the importance of each food item to a species. This involved plotting the percent weight of food found in the gut of the fish against its percent occurrence.

Multivariate analyses on the water physicochemical parameters, sediment data and benthic macrofauna diversity index were carried out employing the PRIMER (Plymouth Routines in Multivariate Ecological Research) software package developed at the Plymouth Marine Laboratory, United Kingdom (Carr, 1996). The fish population parameter estimation was done employing the FiSAT (Fish Stock Assessment Tools) software package developed jointly by ICLARM (International Center for Living Aquatic Resource Management) and FAO (Gayanilo *et al.*, 1995). All other data analysis and graphing was performed using Microsoft Excel Spreadsheet software developed by Microsoft Corporation.

CHAPTER FOUR

RESULTS

4.1 Water Physical and Chemical Parameters

4.1.1 Salinity, Conductivity and Total Dissolved Solids (TDS)

The mean monthly salinity, conductivity and total dissolved solids (TDS) values for the study area are presented in Figures 4.0 and 4.1. Salinity, conductivity (Figure 4.0) and total dissolved solids (Figure 4.1) values generally increased from January to September with a slight depression observed in April and May. There was more variation between values towards the end of the year with September values showing more deviation than January values.

Figure 4.0: Mean monthly salinity and conductivity distribution with standard deviation bars for the study area

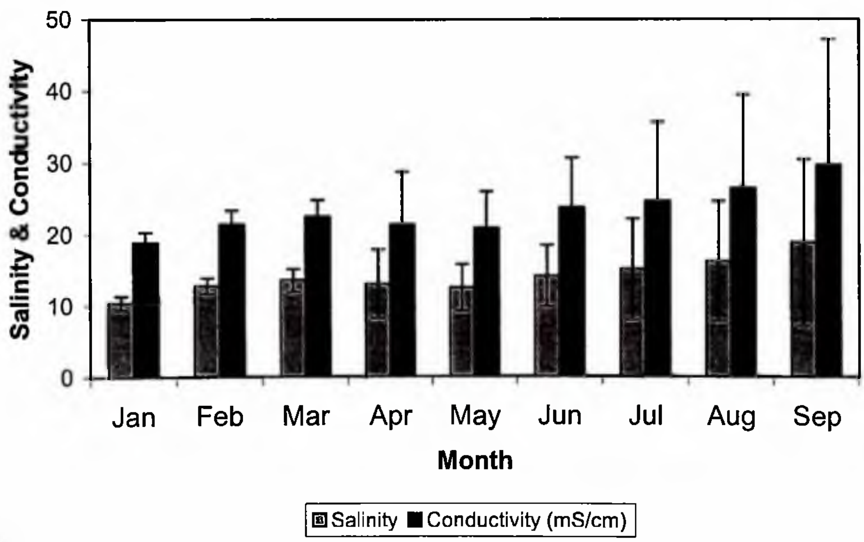
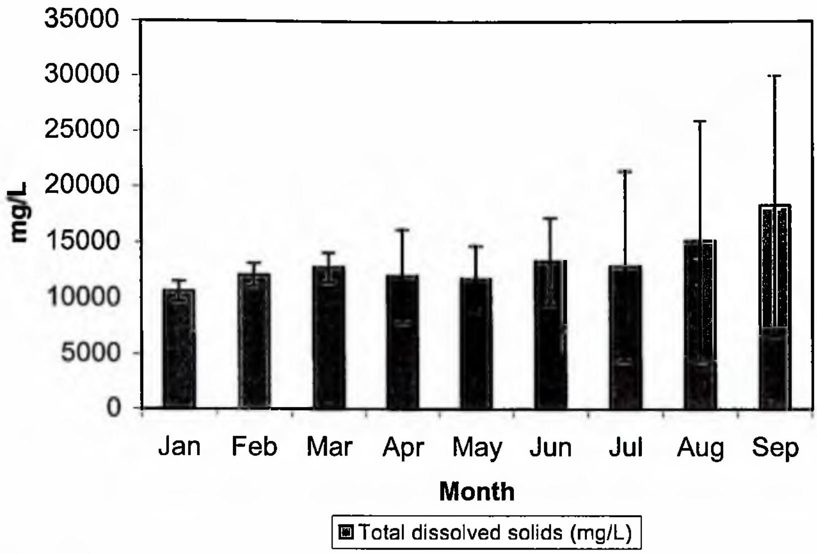


Figure 4.1: Mean monthly total dissolved solids (TDS) distribution with standard deviation bars for the study area



Figures 4.2 and 4.3 show the mean salinity, conductivity and total dissolved solids values for the stations sampled. There was a general increase in the values from Station A to Station G, i.e. an increase in the values northwards, away from the sea. Stations F and G recorded the highest values for the three parameters on the average. There was more variation in the values for Stations E, F and G than the other stations, as seen in their standard deviation bars.

Figure 4.2: Mean station values of salinity and conductivity with standard deviation bars for the study area

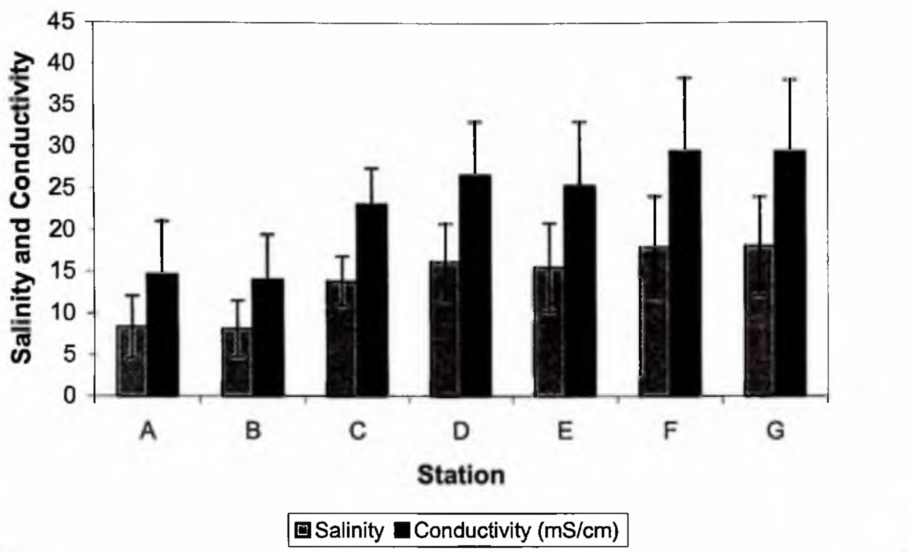
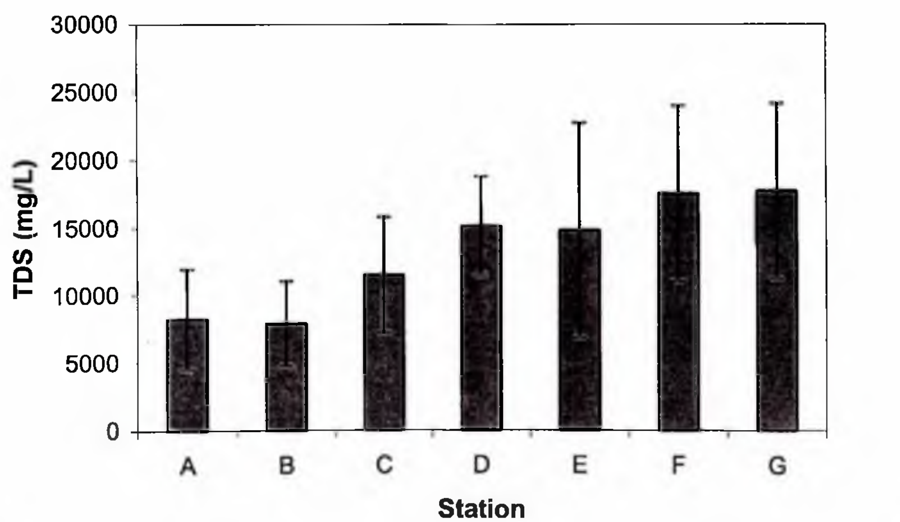


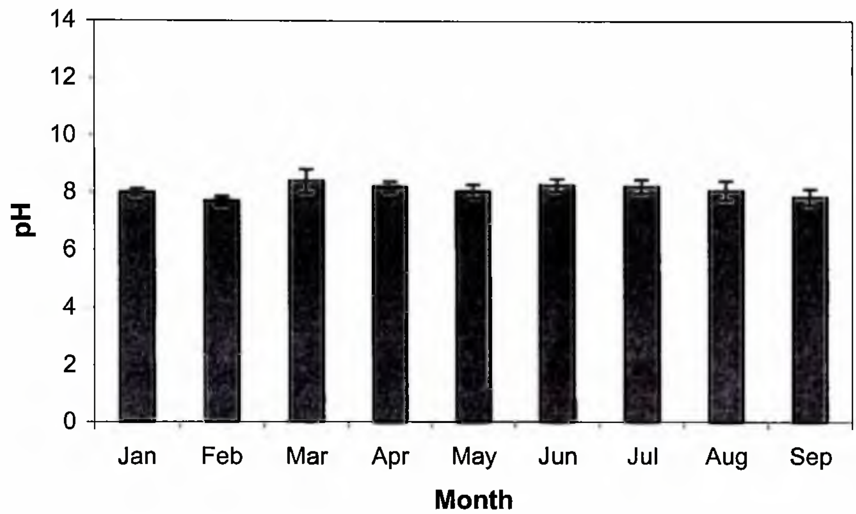
Figure 4.3: Mean station values of total dissolved solids (TDS) with standard deviation bars for the study area



4.1.2 pH

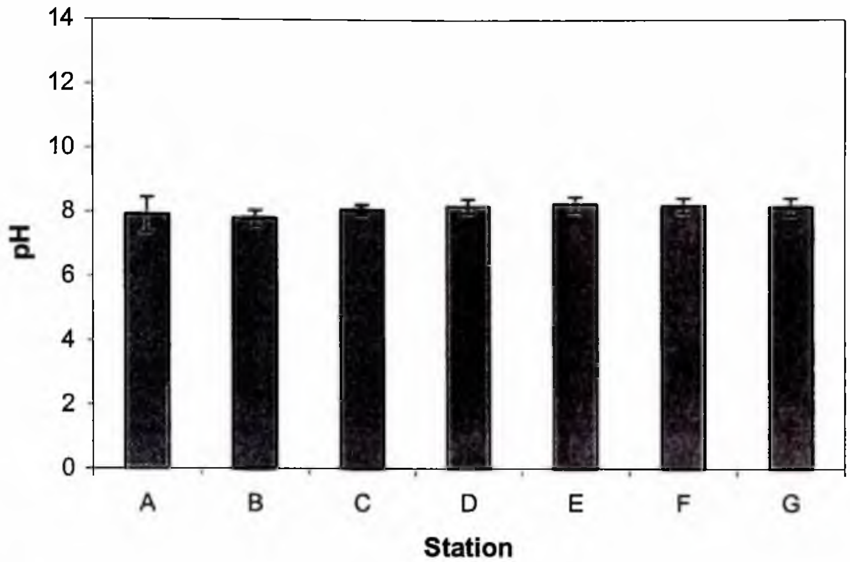
The mean pH values with their deviations for each month and for each station are presented in Figures 4.4 and 4.5. The mean values were quite constant across the months (Figure 4.4) and showed little variation within each month, as seen in the very short standard deviation bars.

Figure 4.4: Mean monthly pH distribution with standard deviation bars for the study area



The mean pH values *per* station were also constant and showed little variation within each station.

Figure 4.5: Mean station values of pH with standard deviation bars for study area



4.1.3 Dissolved Oxygen (DO) and Water Temperature

Figures 4.6 and 4.7 show the dissolved oxygen (DO) and water temperature distribution for the study area during the period of study. The DO values were similar for the stations sampled (Figure 4.6) and for the months sampled (Figure 4.7). The values also showed little variation within station and month, as evidenced by the short deviation bars.

The mean water temperature dipped slightly between May and August (Figure 4.6) but was generally constant between stations (Figure 4.7). Little variation was also observed within month and station values.

Figure 4.6: Mean monthly dissolved oxygen (DO) and water temperature distribution with standard deviation bars for the study area

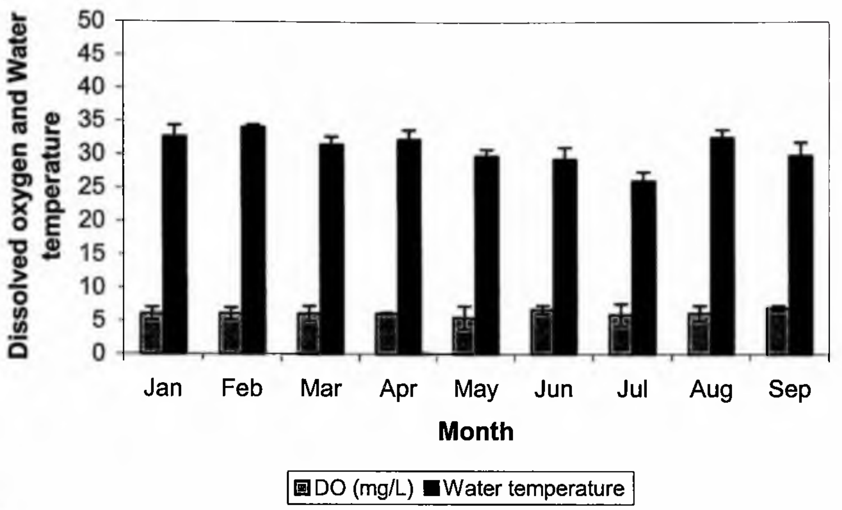
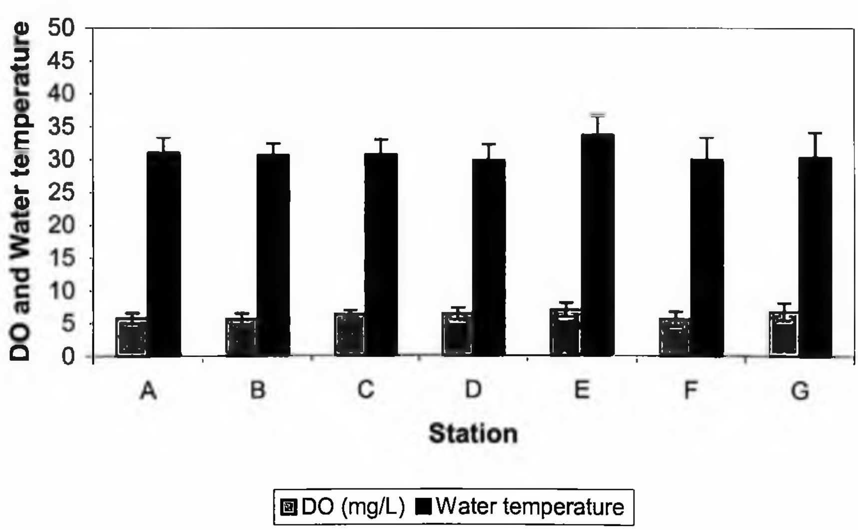


Figure 4.7: Mean station values of dissolved oxygen (DO) and water temperature with standard deviation bars for the study area



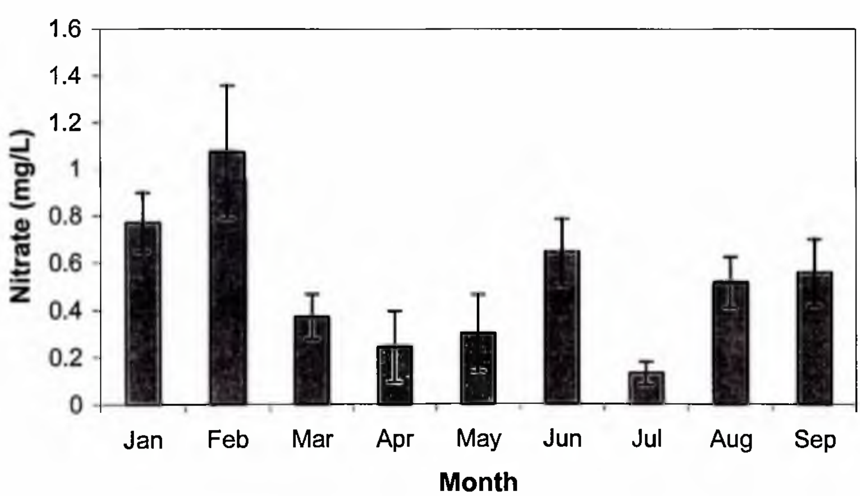
4.1.4 Inorganic Nutrients

The nutrients measured during the study were nitrates (NO_3^{2-}), phosphates (PO_4^{3-}), sulphates (SO_2^{3-}) and silicates (SiO_2^{-}).

4.1.4.1 Nitrates (NO_3^{2-})

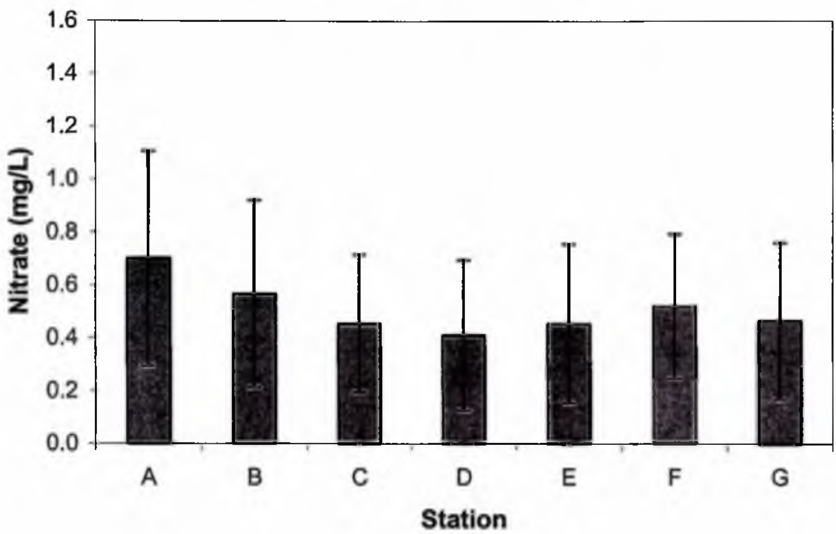
The mean monthly nitrate distribution for the study area is shown in Figures 4.8 and 4.9. The mean monthly values were higher for January and February than the other months (Figure 4.8). Low values were recorded in March, April, May and July. The variations in monthly samples were highest in February but were generally lower than variations in station samples.

Figure 4.8: Mean monthly nitrate distribution with standard deviation bars for the study area



The mean spatial distribution generally decreased from Station A to Station G, though a slight increase was observed at Station F (Figure 4.9). The standard deviation within the station values were, however, appreciably higher than the monthly averages.

Figure 4.9: Mean station values of nitrate with standard deviation bars for the study area



4.1.4.2 Phosphates (PO_4^{3-})

Figures 4.10 and 4.11 shows the mean phosphate distributions for the study area. The mean monthly distribution (Figure 4.10) shows a bi-modal pattern of distribution with first and second peaks obtained in February and July. Low values were recorded in May and June. The standard deviation values were also very large, indicating high variation in values of samples within each month.

Figure 4.10: Mean monthly phosphate distribution with standard deviation bars for study area

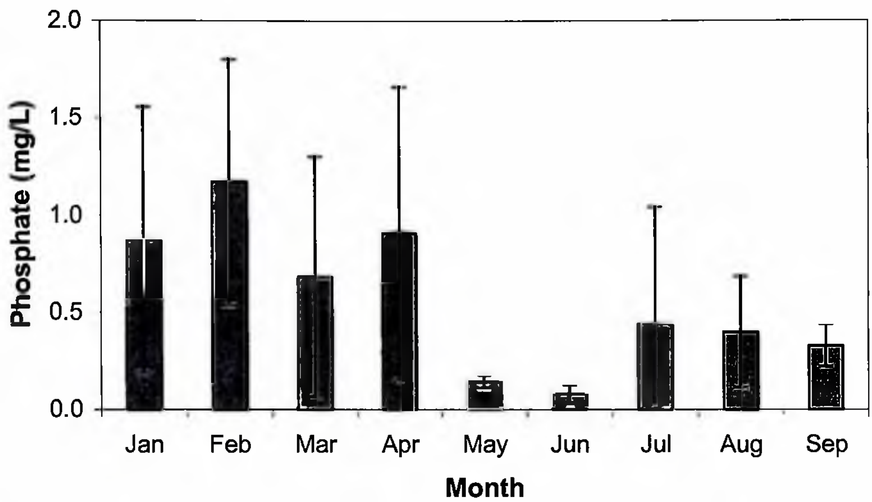
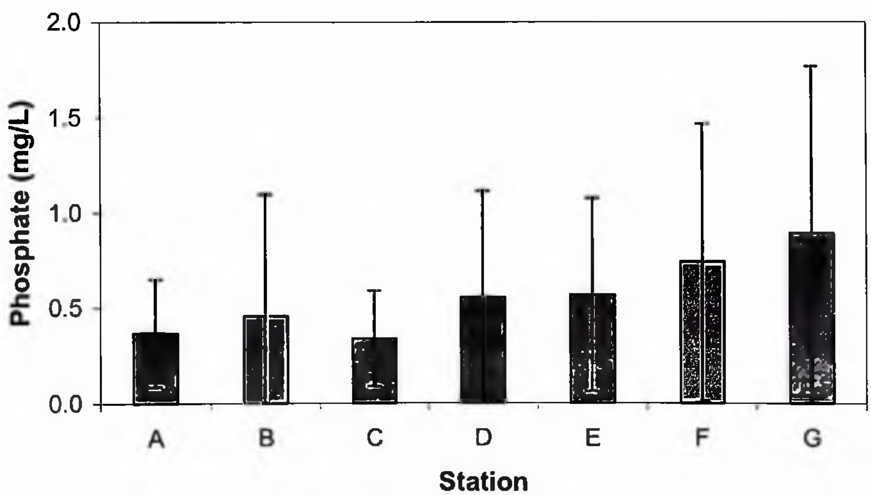


Figure 4.11: Mean station values of phosphate with standard deviation bars for the study area

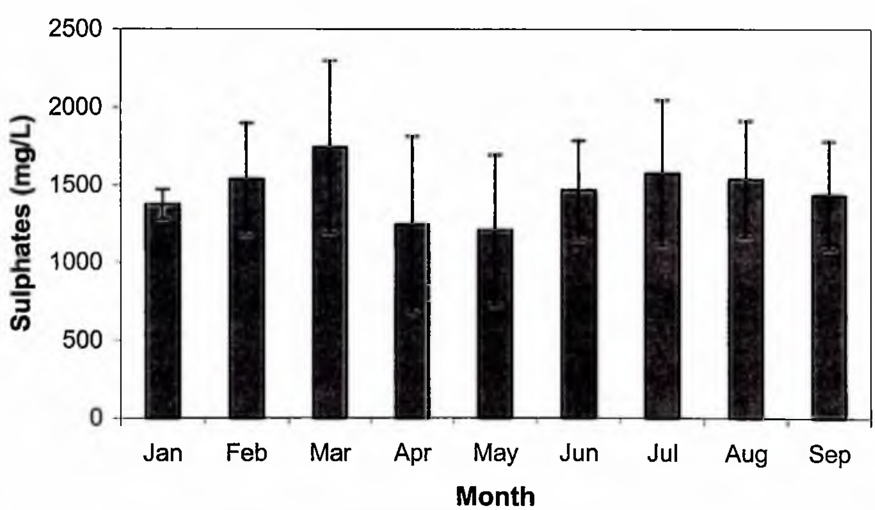


Spatially, there was a gradual increase in phosphate levels from Station A to Station G (Figure 4.11). The standard deviations were also large indicating, in this case also, large variations in phosphate values within stations.

4.1.4.3 Sulphates (SO_2^{3-})

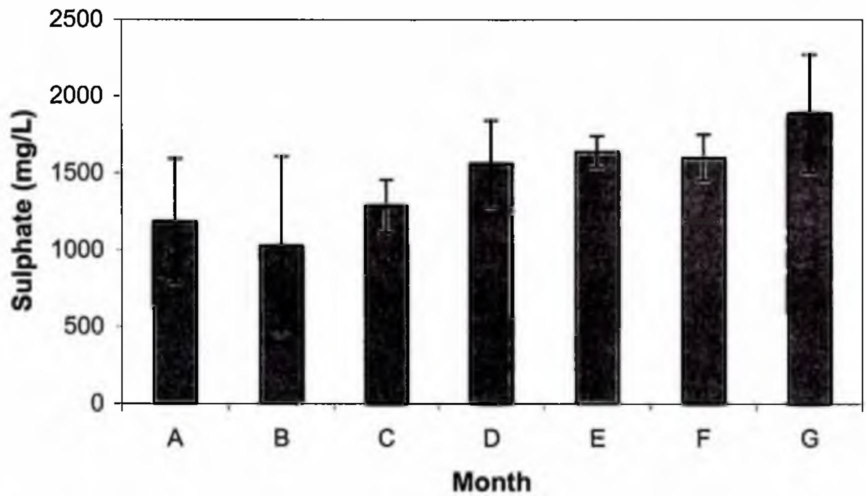
Figures 4.12 and 4.13 shows the sulphate values recorded for the study. The mean monthly values (Figure 4.12) were bi-modal with peaks in March and July and low values occurring in April and May. The value for January showed the least variation with the shortest standard deviation bar, with the values in March and April showing the most variation.

Figure 4.12: Mean monthly sulphate distribution with standard deviation bars for the study area



The spatial values showed an increase from Station A to Station G, though Station B had the least value (Figure 4.13). There was more variation in the values for Station B with Station E having the least variation.

Figure 4.13: Mean station values of sulphate with standard deviation bars for the study area



4.1.4.4 Silicates (SiO_2^{-})

Figures 4.14 and 4.15 shows the silicate distribution for the study. The mean temporal distribution (Figure 4.14) shows two peaks occurring in February and September, with a low value occurring in July. The deviations in the monthly values were small in February and May with the largest calculated value being for April. The mean spatial distribution was similar between the stations though it decreased slightly from Station A to Station G (Figure 4.15). The deviation in the station values were also similar but were higher for Station D.

Figure 4.14: Mean monthly silicate distribution with standard deviation bars for the study area

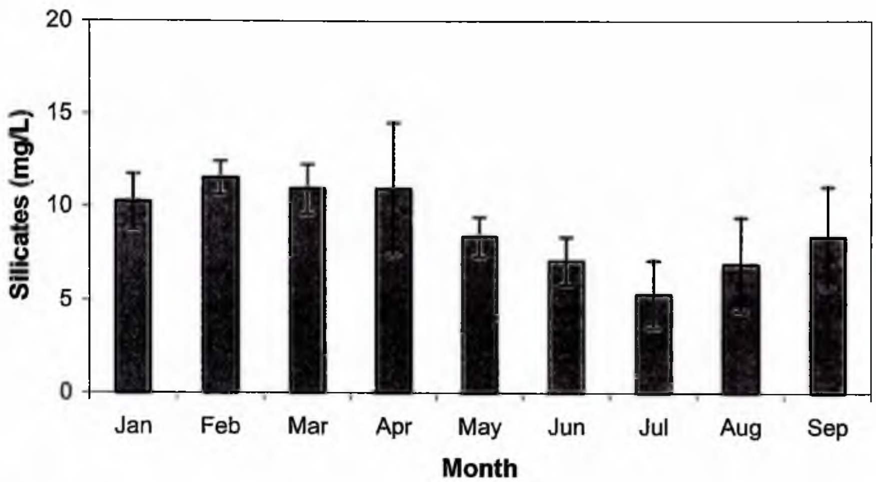
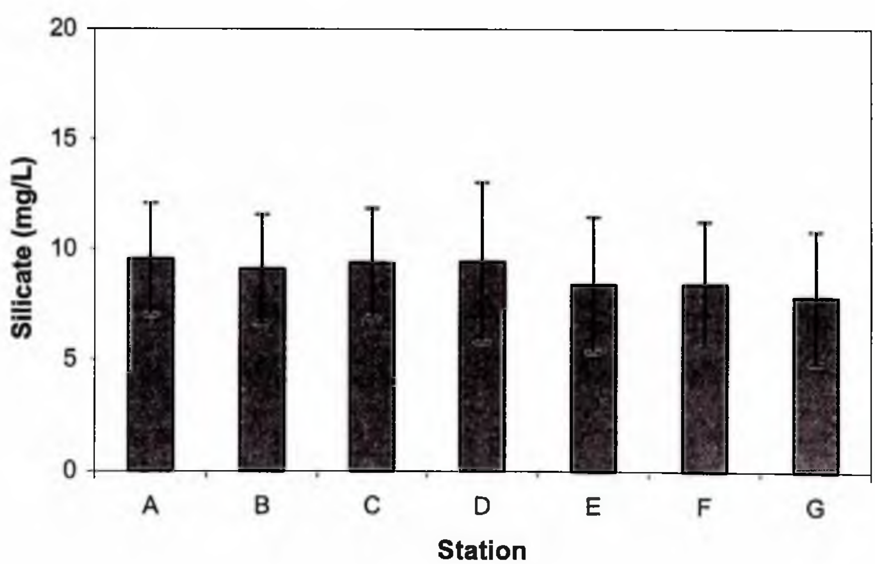


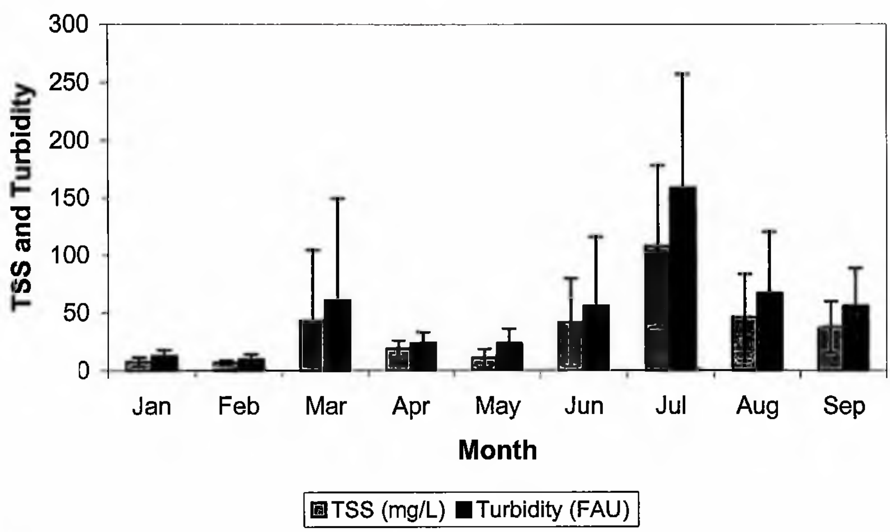
Figure 4.15: Mean station values of silicate with standard deviation bars for the study area



4.1.5 Total Suspended Solids (TSS) and Turbidity

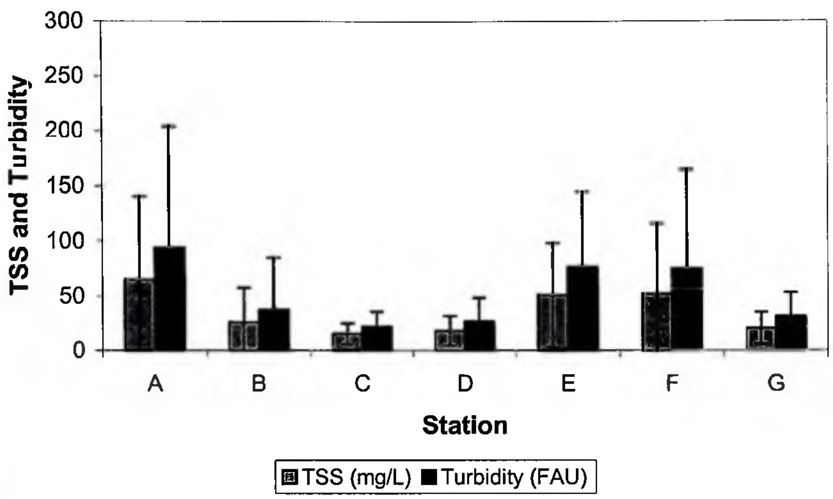
Figures 4.16 and 4.17 shows the TSS and turbidity values for the study. The temporal distribution values (Figure 4.16) show two peaks, one occurring in March and the second in July for both TSS and turbidity. Low values were recorded in January, February, April and May. The values also showed relative large deviations for each month sampled.

Figure 4.16: Mean monthly total suspended solids (TSS) and turbidity distribution with standard deviation bars for the study area



The mean values for the stations were lower for Stations B, C, D and G (Figure 4.17) and highest for Station A. The deviations *per* station in this were large instance also.

Figure 4.17: Mean station values of total suspended solids (TSS) and turbidity with standard deviation bars for the study area



4.1.6 Similarity analysis

A similarity analysis was conducted to test for significant spatial and temporal differences in the water physicochemical parameters. The methods adopted were those of Bray and Curtis (Everitt, 1980; Cormack, 1971; Bray and Curtis, 1957) and Kruskal and Wish (1978). In the methods, a similarity matrix was generated on the physicochemical data set after standardization. A cluster analysis (Everitt, 1980; Cormack, 1971; Bray and Curtis, 1957) and a multi-dimensional scaling (MDS) (Kruskal and Wish, 1978) are performed on the similarity matrix. The output was a dendrogram (for the cluster analysis) and an MDS plot (for the MDS analysis) showing data sets of similar nature clustering together from dissimilar ones. These were then used as an index of the degree of similarity in the data sets. The PRIMER software, which includes these methods, was used for the analysis.

Figure 4.18 shows the dendrogram of the Bray-Curtis similarity analysis of the physicochemical parameters. This shows all the samples clustering together above 80% similarity and 93.7% of the samples clustering above 90% similarity.

The MDS plot (Figure 4.19) of the similarity matrix shows a major aggregation of the samples into three groups (unbroken ellipse), which coincides with 94% similarity and a sub-aggregation into four groups (broken ellipse) coinciding with 95% similarity on the dendrogram.

Figure 4.18: Cluster analysis (Bray-Curtis) of the water physicochemical parameters

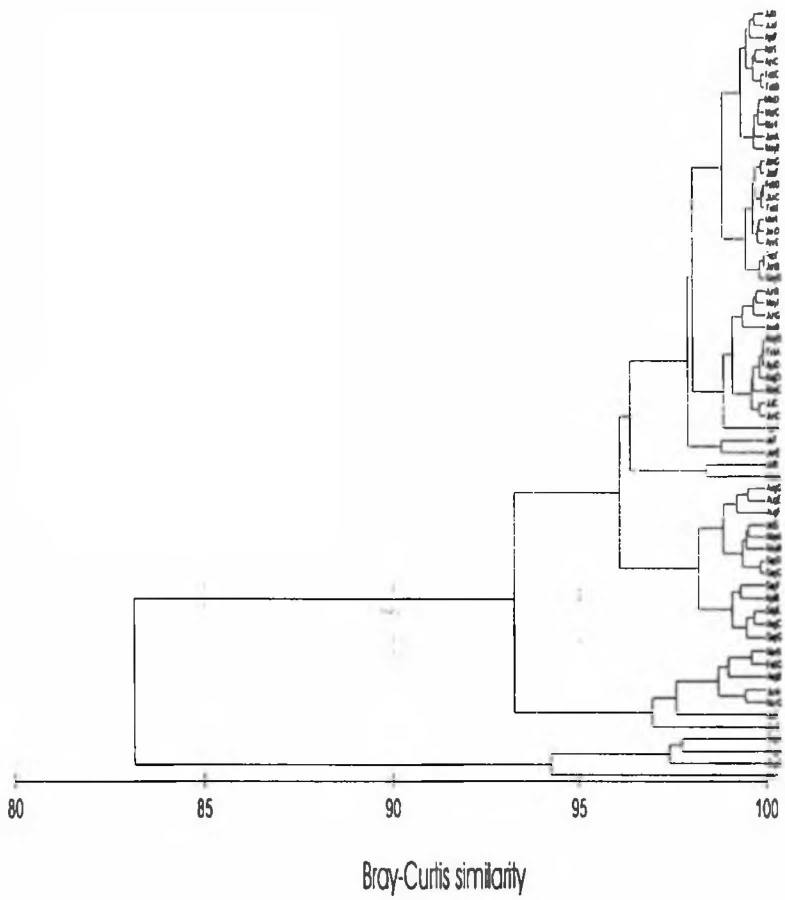
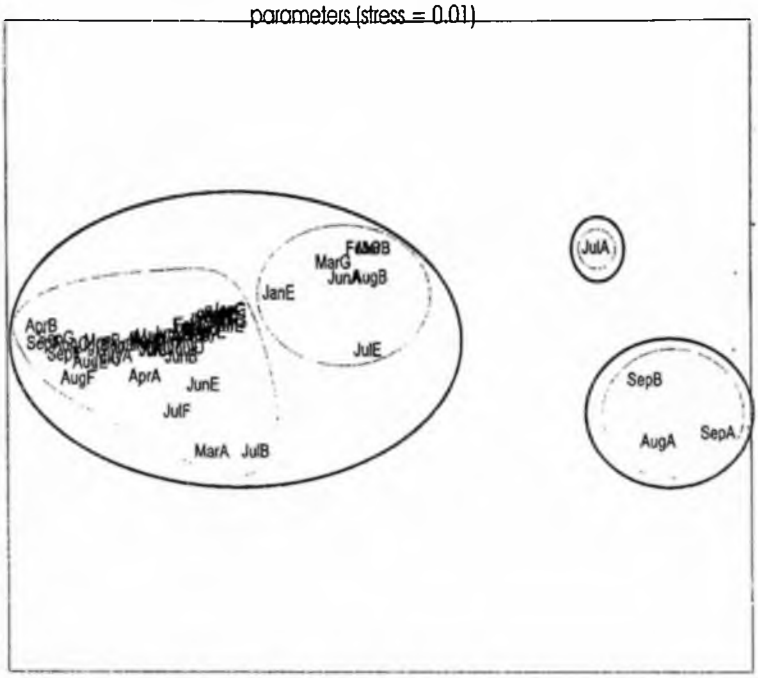


Figure4.19: MDS plot of water physicochemical parameters (stress = 0.01)



4.2 Sediment Grain Size Distribution

The phi (Φ) scale (Barnes, 1980) is computed for the sediment grain size using the relationship:

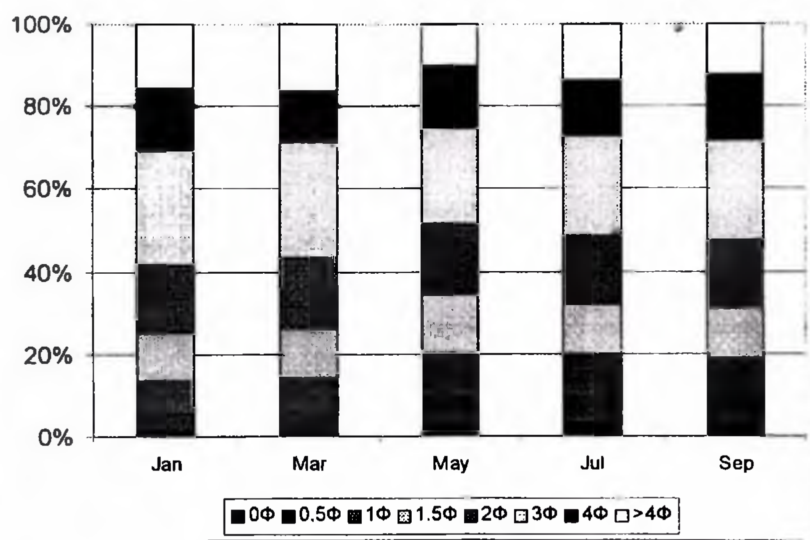
$$\Phi = -\log_2 d$$

Where **d** (in millimeters) is the diameter of a sediment grain particle.

4.2.1 Spatial distribution

Figure 4.20 is a percentage stacked column graph comparing the average percentage each grain size category contributed to the Station average.

Figure 4.20: Spatial distribution of sediment in study area

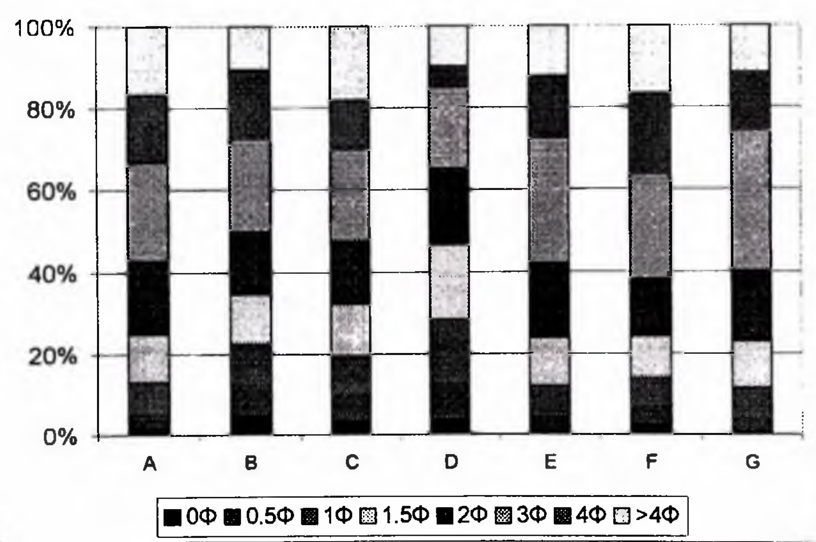


No distinct spatial distribution pattern was observed between the stations during the study period. From the graph (Figure 4.20), Station D and F had the least and largest percentage respectively of very fine (≥4Φ) grain size components. Station D however had the highest amount of coarse (≤1Φ) grains. The mean grain size ranged from 1.76Φ (Station D) to 2.51Φ (Station F), indicating that fine sand predominates in the study area.

4.2.2 Temporal Distribution

The percentage stacked column graph comparing the average percentage each grain size category contributes to the monthly average is presented in Figure 4.21. Generally the grain size distribution remained fairly constant during the study period, indicating little sediment movement. The mean coarse sand percentage however increased slightly towards September. This is probably due to a reduction in the percent of fine sediments transported to the study area.

Figure 4.21 Temporal distribution of sediment in study area



The dendrogram (Figure 4.22) and the MDS plot (Kruskal and Wish, 1978) constructed from a cluster analysis of a Bray-Curtis similarity matrix (Everitt, 1980; Cormack, 1971; Bray and Curtis, 1957) of the grain size distribution of the area shows a major aggregation of the samples into six groups (unbroken ellipse), coinciding with 85% similarity on the dendrogram and a sub aggregation into eleven groups (broken ellipse) coinciding with 90% similarity (Figure 4.23).

Figure 4.22: Cluster analysis (Bray-Curtis) dendogram for grain size in study area

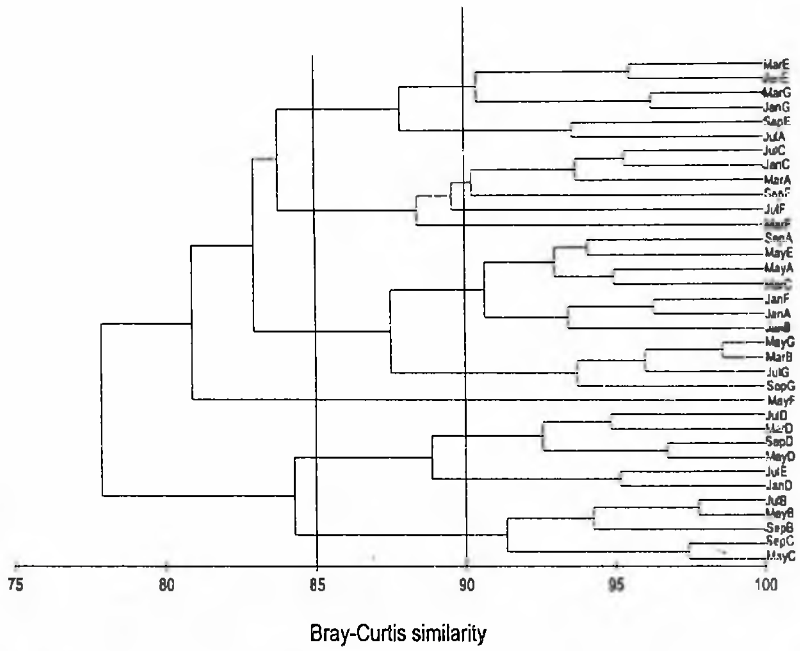
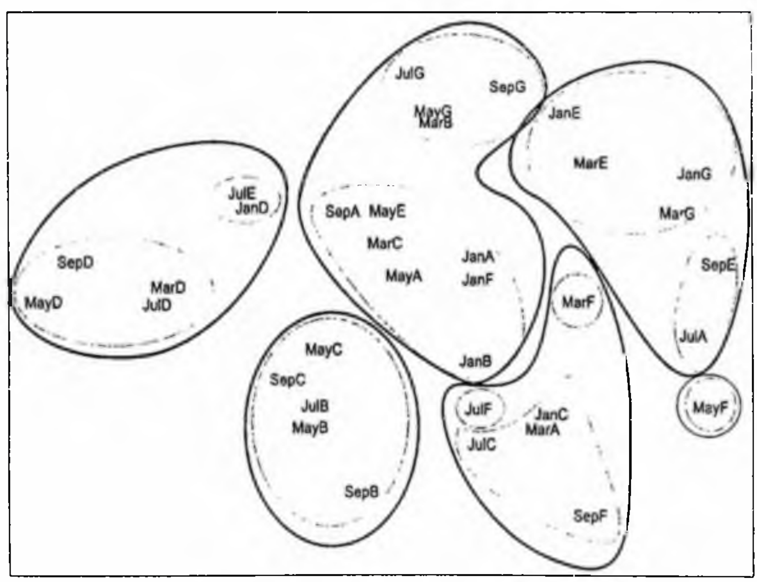


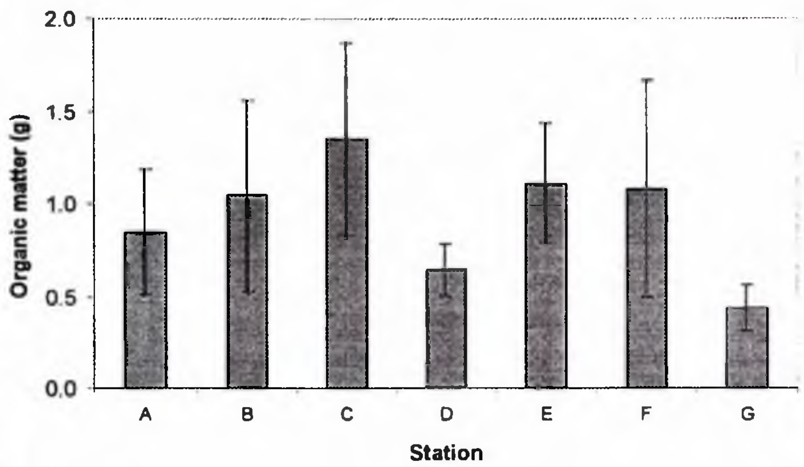
Figure 4.23: MDS plot of grain size in study area (stress = 0.11)



4.3 Sediment Organic (Detrital) Matter Content

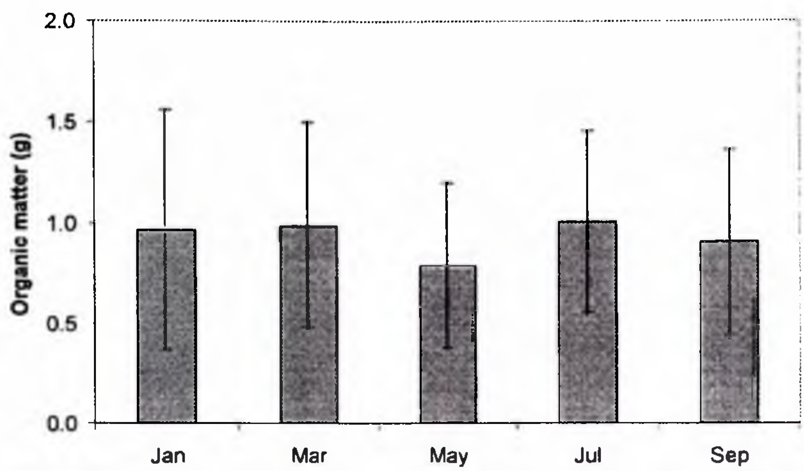
Figure 4.24 and 4.25 show the spatial and temporal distribution (with error bars) of the organic content over the study period. No clear distribution pattern was observed in the sediment organic matter content during the study period.

Figure 4.24: Spatial distribution of sediment organic matter in study area



Spatially, Stations A and G (Figure 4.24) had the lowest organic matter levels while Station C had the highest. The mean temporal values were fairly consistent over the study period (Figure 4.25). the mean values however have large deviations suggesting wide variability in values obtained *per* month.

Figure 4.25: Temporal distribution of sediment organic matter in study area



4.4 Benthic Fauna Diversity

Sixteen benthic faunal species were encountered during the study. They were made up of 8 annelids, 4 molluscs and 4 crustaceans. Tables 4.0 and 4.1 show their distributions (presence/absence) temporally and spatially. The dominant species in almost all the stations (counts *per* species) was *Nereis* sp.

Table 4.0. Benthic macrofauna presence/absence data for stations sampled

Species	A	B	C	D	E	F	G
Nerieis sp.	■	■	■	■	■	■	■
Notomastus sp.	■	■	■	■	■	■	■
Capittelid	■	■	■	■	■	■	■
Eunicid			■		■		
Corbula trigona	■		■	■	■	■	■
Pena sp.				■			
Ischyrocerus sp.	■	■	■	■	■	■	■
Polychaete indet A	■	■		■			■
Orbinid sp.							
Nermetine						■	■
Spionid		■			■		■
Polychaete indet B			■	■	■	■	■
Neanthes sp.			■	■			■
Tellina nymphalis				■	■	■	■
Tympanotonus sp.							■
Amphipod				■			■

Key: Presence ■ Absence □

Table 4.1. Benthic macrofauna presence/absence data for months sampled

Species	January	March	May	July	September
Nerieis sp.	■	■	■	■	■
Notomastus sp.	■	■	■	■	■
Capittelid	■	■	■	■	■
Eunicid		■		■	
Corbula trigona		■	■	■	■
Pena sp.		■			■
Ischyrocerus sp.	■	■	■	■	■
Polychaete indet A	■	■	■	■	
Orbinid sp.	■				
Nermetine	■				
Spionid	■	■	■	■	■
Polychaete indet B		■	■	■	■
Neanthes sp.		■	■	■	■
Tellina nymphalis		■	■	■	■
Tympanotonus sp.		■	■		
Amphipod					■

Key: Presence ■ Absence □

Four diversity indices were estimated for the benthic fauna from the study area (Magurran, 1991; Heip *et al*, 1988; Pielou, 1975). These are:

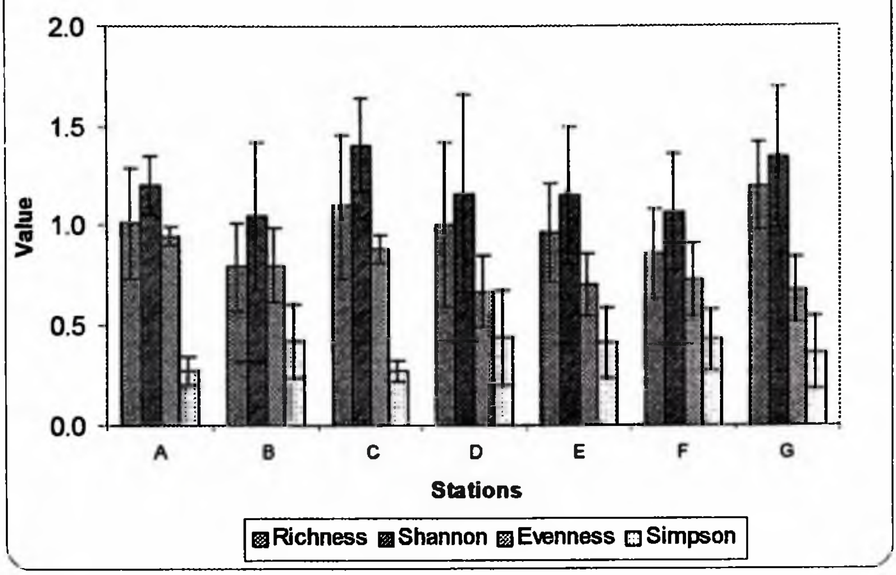
1. Margalef's index of species richness
2. Shannon-Wiener diversity index
3. Pielou's evenness index, and
4. Simpson's dominance index

The diversity indices were calculated from the species abundance (counts *per* species) data (Appendix E) employing the PRIMER software. A fourth-root transformation was carried out on the data to weigh the contribution of common and rate species in the data.

4.4.1 Spatial Distribution

Figure 4.26 shows the spatial distribution of the diversity indices for the study area. Station C on the average had the highest diversity index (Shannon-Wiener) while Station B had the lowest, though the species richness (Margalef) was highest for Station G and lowest for Station B. Station A had the highest species evenness (Pielou) index while Station D had the lowest. Station A on the other hand had the lowest species dominance indices (Simpson) while Station D had he highest.

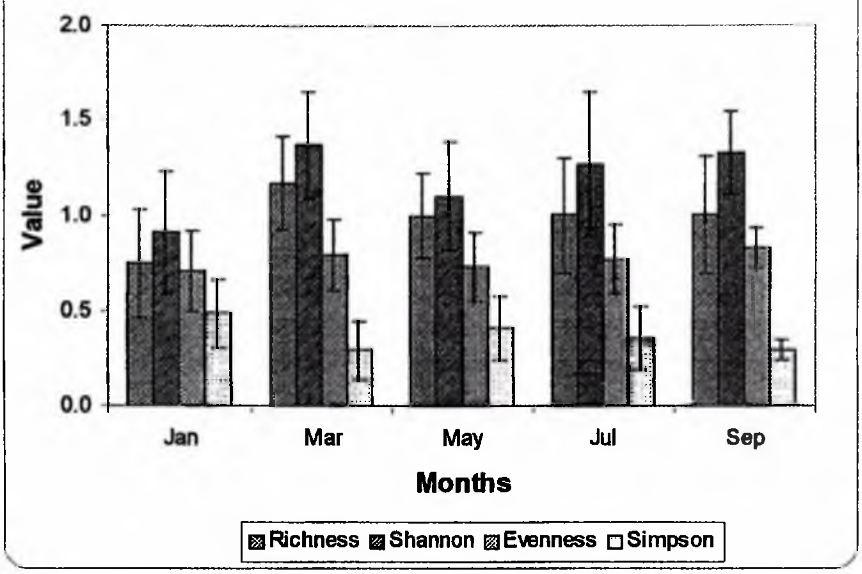
Figure 4.26: Spatial distribution of diversity indices for study area



4.4.2 Temporal Distribution

The temporal distribution graph is presented in Figure 4.27. The month of March, on the average, recorded the highest values for species richness and evenness and the lowest value for dominance. Species diversity and richness were also low for the month of January, and this was correlated with a high dominance index. This suggests that a few species which were able to withstand the stressful conditions encountered during January became dominant in the environment. Dominance was lowest in September with a correspondingly high evenness, suggesting an equitable distribution of species in the study area during that month.

Figure 4.27: Temporal distribution of diversity indices for study area



4.5 Population Parameter of Major Fishery

The population parameter estimated were growth, mortality and recruitment from length-frequency and weight-frequency data. A von Bertallanfy growth pattern was assumed for the species.

4.5.1 Growth Parameters

The fish samples obtained measured between 4.4 cm and 18.2 cm with a median class of 8.0 cm for *S. melanotheron melanotheron*, 4.3 cm and 15.2 cm with a median class of 9.5 cm for *T. guineensis* and 4.7 cm and 20.6 cm with a median class of 12.5 cm for *H. fasciatus* (Figures 4.28, 4.29 and 2.30).

Figure 4.28: Length-frequency distribution of *S. melanotheron* from Study Area

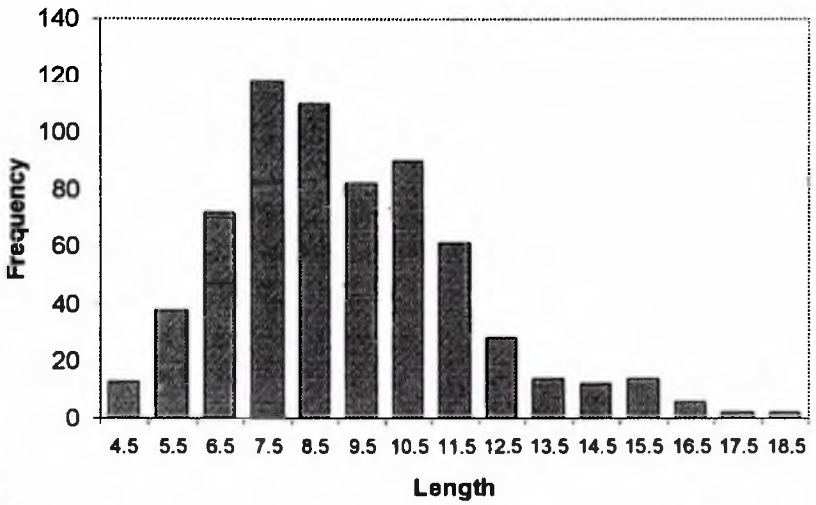


Figure 4.29: Length-frequency distribution of *T. guineenis* from the Study Area

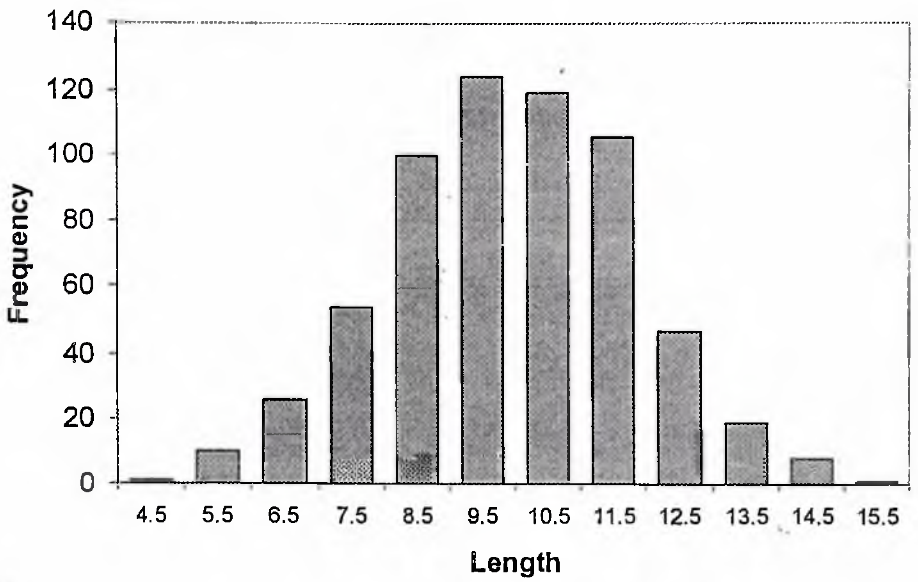
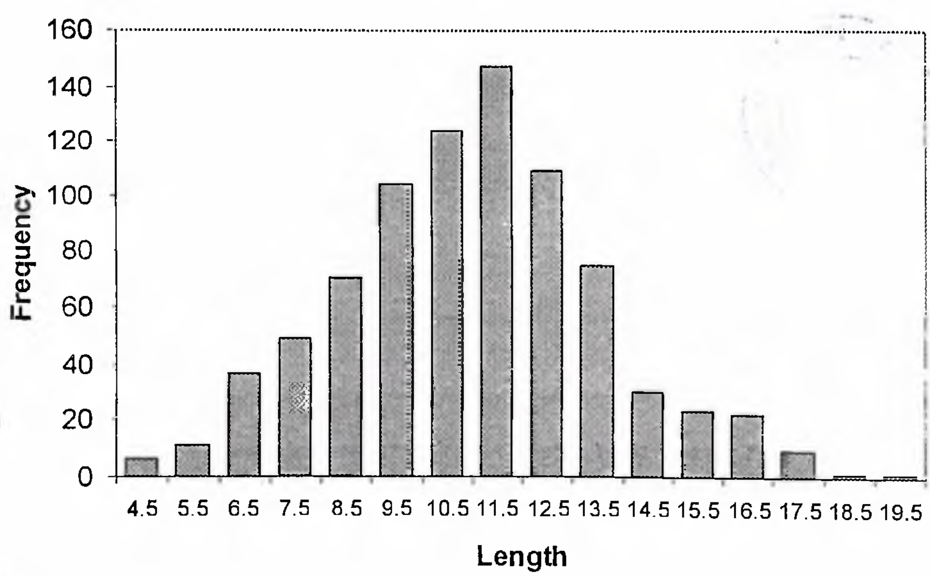


Figure 4.30: Length-frequency distribution of *H. fasciatus* from the Study Area



Figures 4.31, 4.32 and 4.33 show the power regression function relating fish length and weight for each species.

Figure 4.31: Length-weight relationship of *Sarotherodon melanotheron melanotheron* from the Study Area

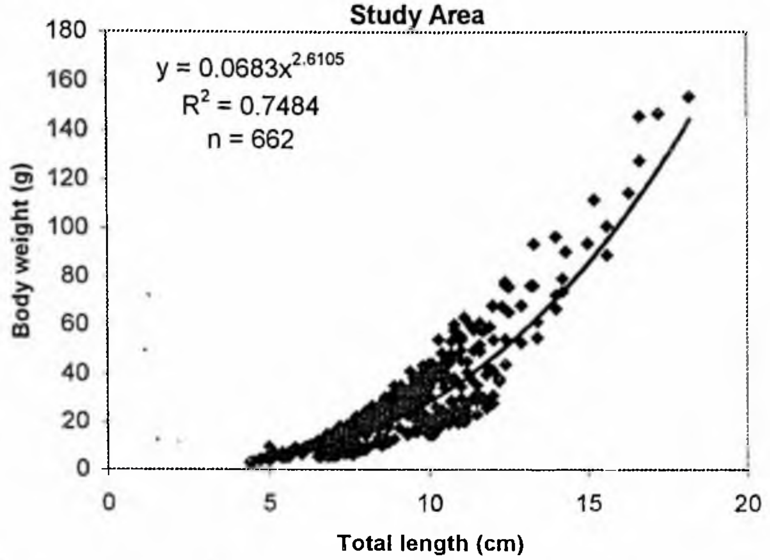


Figure 4.32: Length-weight relationship for *Tilapia guineensis* from the Study Area

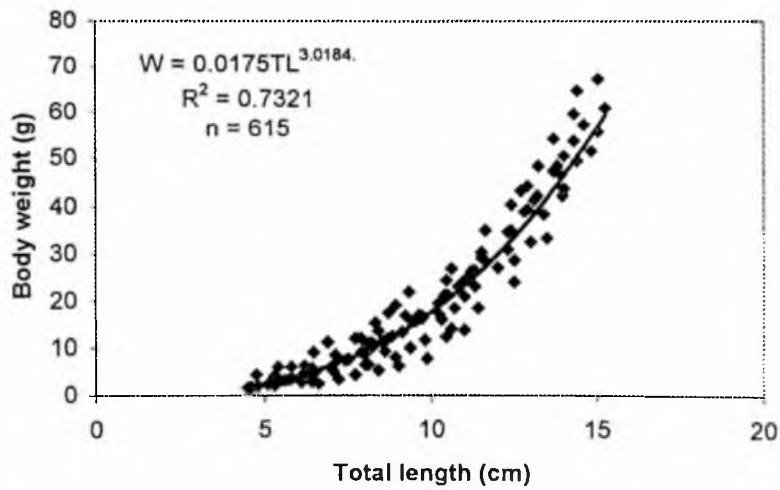
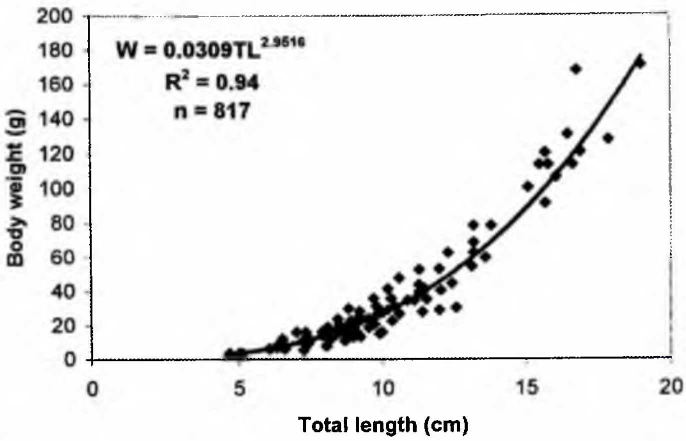


Figure 4.33: Length-weight relationship for *Hemichromis fasciatus* from the Study Area



A length progression analysis was generated with the FiSAT software, using monthly length frequency data, from which was obtained estimates of the asymptotic length (**L∞**) and the growth constant (**K**) for each species. From these parameters, the theoretical length (**t_0**) when the fish is zero years old is estimated from Pauly's equation

$$\mathbf{Log_{10}(-t_0) = -0.3922 - 0.2752 Log_{10} L\infty - 1.038 Log_{10} K}$$

The result for each species is presented in table 4.2 below.

Table 4.2: Population parameters estimated for the fish species

Fish species	**L∞**	**K**	**t_0**
S. melanotheron	21.40	0.78	-0.225
T. guineensis	19.10	0.85	-0.213
H. fasciatus	19.29	1.50	-0.369

Substituting the parameters into the von Berttalanfy growth function for fish

$$L_t = L\infty(1 - e^{-K(t-to)})$$

Where L_t is the length of a fish at age **t** years, we obtain the derived growth function for each fish species (Figures 4.37, 4.38 and 4.39).

Figure 4.37: Derived growth curve of *Sarotherodon melanotheron melanotheron* from the Study area

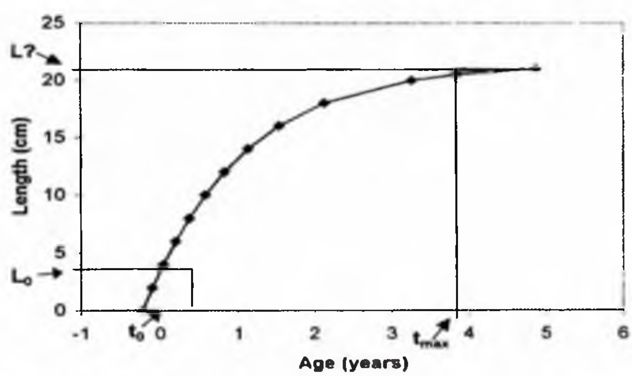


Figure 4.38: Derived growth curve for *Tilapia guineensis* from the Study area

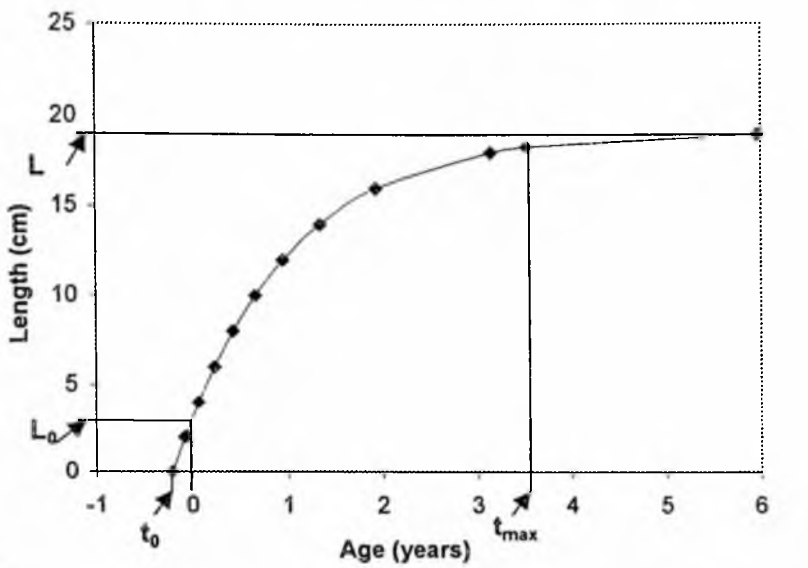
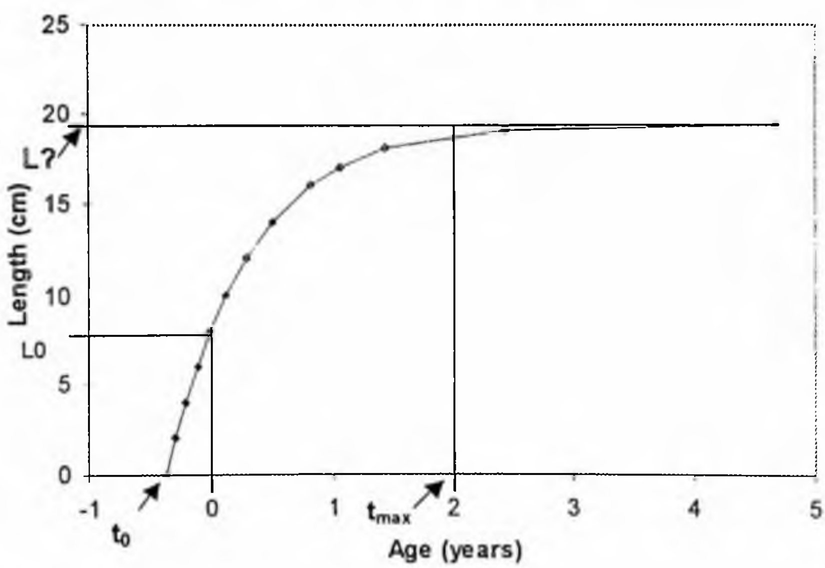


Figure 4.39: Derived growth curve for Hemichromis fasciatus from the Study Area



The maximum attainable age (longevity) of each species, t_{max}, is computed from the relationship

$$t_{max}=3/K$$

The growth performance index, Φ' (phi prime), (Pauly and Munroe, 1984; Munroe and Pauly, 1983) is given by the relationship

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

The growth performance index, unlike the other population parameters is species specific and is to a very small extent influenced by the environment. Hence it serves as a test of the robustness of the other parameter estimated.

Table 4.3 shows the longevity (tmax) and growth performance index (Φ') computed for each species.

Table 4.3: Longevity and growth performance index estimated for the fishes

Fish species	t_{max}	Φ'
S. melanotheron	3.85	2.55
T. guineensis	3.53	2.49
H. fasciatus	2.00	2.74

4.5.2 Mortality Parameters

The length-converted catch curve (Figures 4.40, 4.41 and 4.42) is used in computing the total mortality coefficient Z for each species.

Figure 4.40: Length-converted catch curve for *S. melanotheron melanotheron* from the Keta lagoon

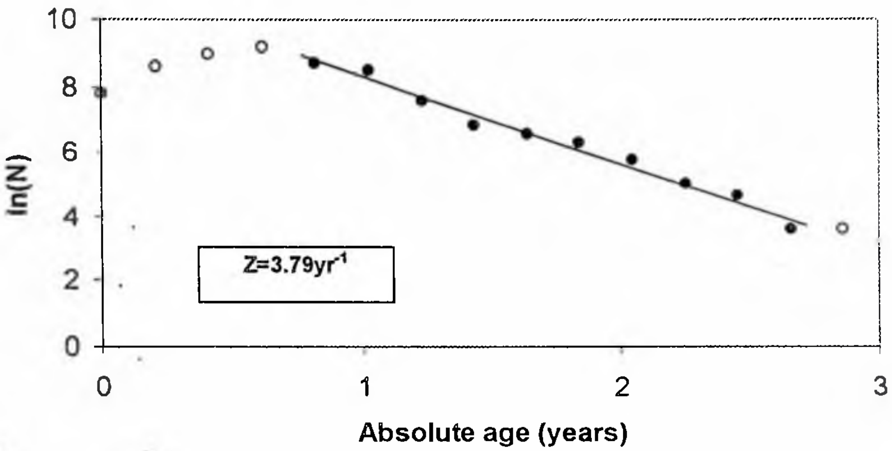


Figure 4.41: Length-converted catch curve for *Tilapia guineensis* from the Keta lagoon

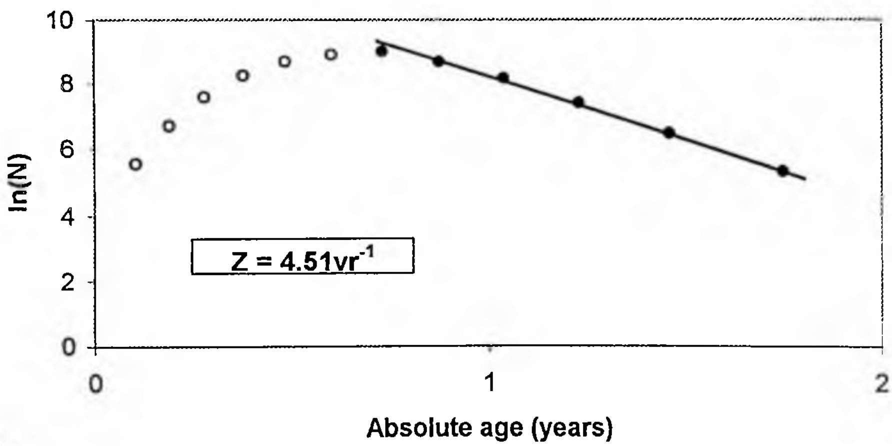
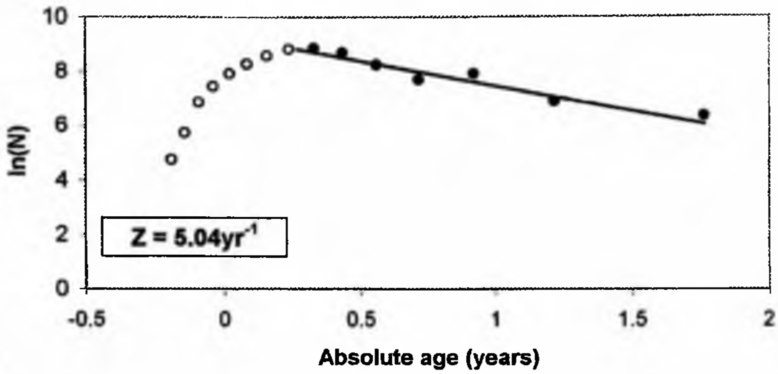


Figure 4.42: Length-converted catch curve for *Hemichromis fasciatus* from the Keta lagoon



The natural mortality coefficient M is calculated from Pauly's M-equation as

$$\ln M = -0.0152 - 0.279 \ln L_\infty + 0.6543 \ln K + 0.463 \ln T$$

where T is the average water temperature in degrees Celsius (°C).

From the relationship **Z=F+M**, we obtain the fishing mortality for each species as the difference between the total mortality **Z** and the natural mortality **M**. The level of exploitation of the fishery, or the exploitation ratio, **E**, is computed as **E=F/Z**. Table 4.4 shows the morality parameters and the exploitation ratio computed for the species.

Table 4.4: Mortality parameters and exploitation ratio estimated for the fishes

Fish species	Z	M	F	E
S. melanotheron	3.79	1.74	2.05	0.54
T. guineensis	4.51	1.90	2.61	0.58
H. fasciatus	5.04	2.75	2.29	0.45

4.5.3 Recruitment Pattern

Figures 4.43, 4.44 and 4.45 show the recruitment patterns for *S. melanotheron*, *T. guineensis* and *H. fasciatus* respectively.

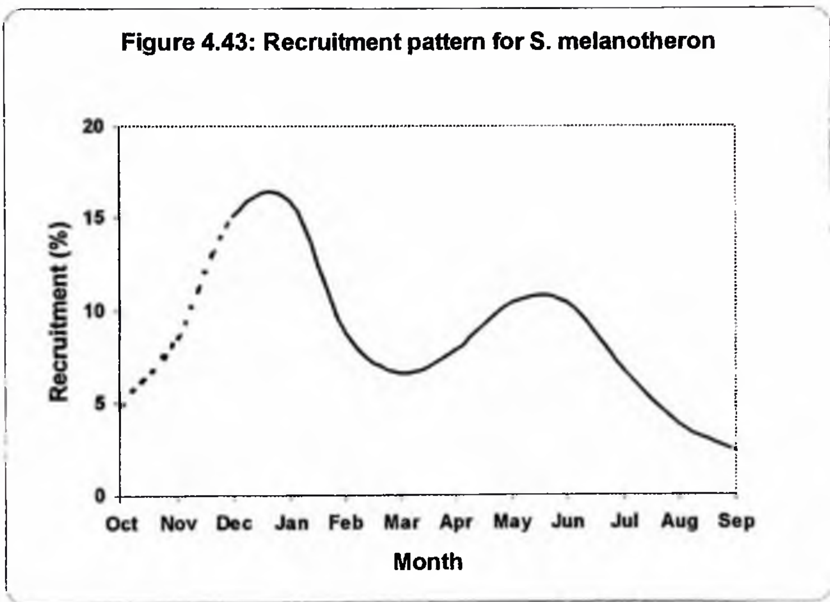


Figure 4.44: Recruitment pattern for *Tilapia guineensis* from the Study Area

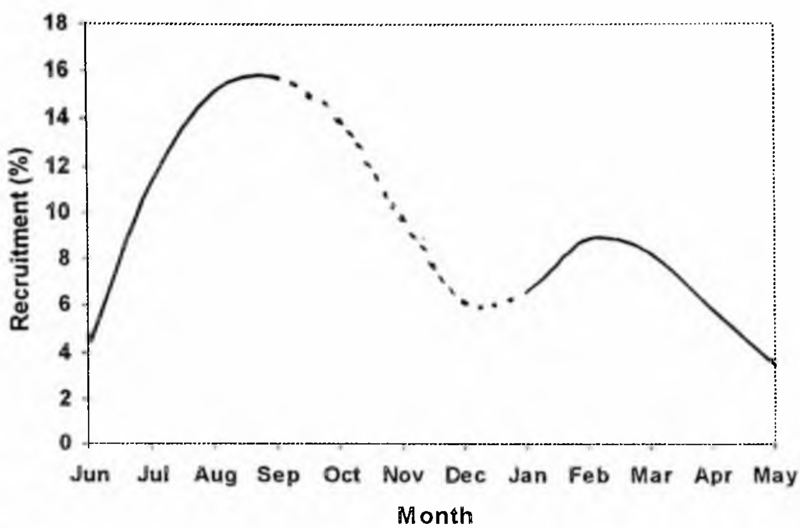
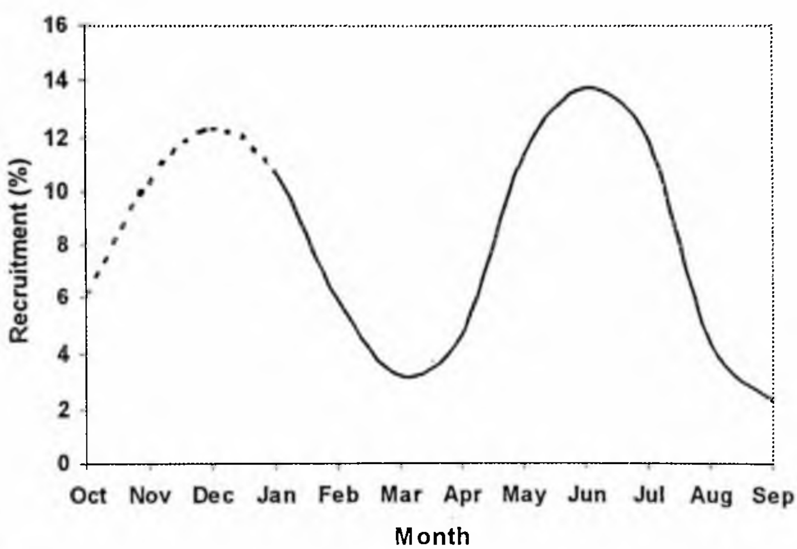


Figure 4.45: Recruitment pattern for *Hemichromis fasciatus* from the Study Area



The broken portion of the curves indicates periods for which data was estimated. A bimodal recruitment pattern was observed for all the three species, one during the dry season and a second during the wet season. However, it was obvious that recruitment generally continued throughout the year for the species. *S. melanotheron melanotheron* had its maximum recruitment peak between December and January and a minor peak between May and June. The recruitment pattern for *T. guineensis* peaked in September with a second smaller peak in February. For *H. fasciatus*, the recruitment peaks were more clearly defined, and generally very similar in value. The peaks occurred first in December, then in June.

4.6 Food Habit Studies

The food items found in the gut of the fish species studies were plant materials, mud/debris, benthos, gastropods, aufwuchs/diatoms and juvenile forms of fishes. The benthos refers to benthic organisms with the exception of gastropods found in the guts. The fishes found in the guts were mainly juvenile forms of either cichlids or gobies, which could not be clearly identified due to their advanced stated of decomposition. The table below (Table 4.5) shows the presence (shaded portions) of each of the aforementioned food items in the gut of the different species.

Table 4.5: Food items in gut of fishes studied

Fish species	Mud/ debris	Plant material	Benthos	Gastropods	Aufwuchs /diatoms	Juvenile fishes
S. melanotheron						
T. guineensis						
H. fasciatus						

Generally, plant materials dominated the food in the gut of *S. melanotheron* and *T. guineensis* while fish was only present in the gut of *H. fasciatus*. A Costello graphical analysis (Marshall and Elliott, 1997,Costello, 1990) performed to investigate the feeding strategies and the importance of each food item to the fish species is presented in Figures 4.46, 4.47 and 4.48.

Figure 4.46: Feeding strategy and prey importance for *S. melanotheron* in the study area

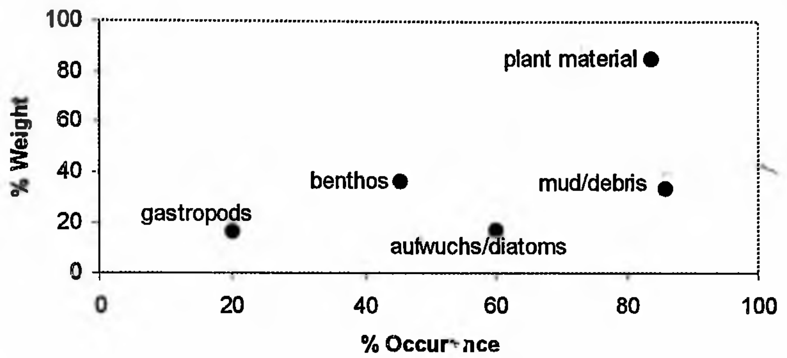


Figure 4.47: Feeding strategy and prey importance for *T. guineensis* in the study area

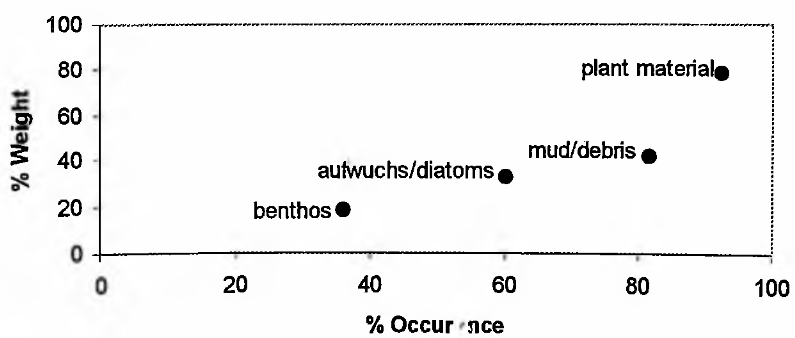
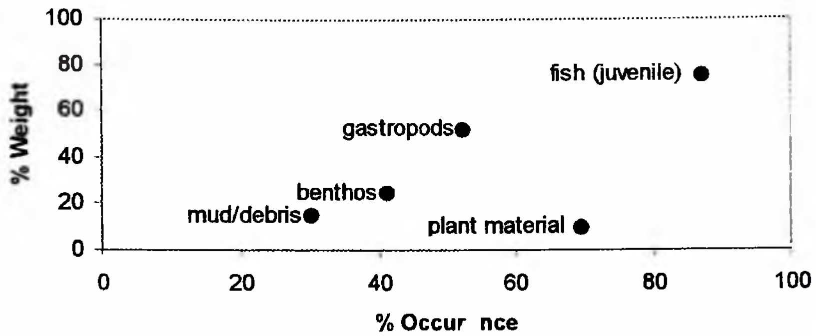


Figure 4.48: Feeding strategy and prey importance for *H. fasciatus* in study area



From the analysis, each species does not show any specialization for a particular food type, the dominant food for both *S. melanotheron melanotheron* and *T. guineensis* was plant material indicating that they probably grazed on plant for food. However, with mud and debris occurring as a generalized food type, it may be concluded that they also feed on benthic organisms, probably sifting through the mud/detritus in search of food. This is evident in the presence of some benthic organisms such as gastropods and polychaetes in their guts. The analysis also shows the benthos as being infrequent in their diet. Inference to this, however, must be drawn with caution taking cognizance of the fact that most benthic organisms, being soft bodied tend to digest rather readily in the gut of fish.

Hemichromis fasciatus, on the other hand, had fish dominating its diet with plant material occurring generally. Benthos and mud/debris was rare in the diet while gastropods occurred midway between the four feeding strategies.

The inference here is that *H. fasciatus*, though carnivorous also feeds on benthic organisms. The plant materials present in its gut may be mainly as a result of the fishes browsing on aquatic plants for food.

5.1.2 Spatial distribution

The spatial distribution describes the mean values obtained per station and gives an insight into the variations obtained at each sampling station over the sampling period. Salinity, conductivity and TDS values were increasingly higher in a northwards direction along the transect as one moves between stations A and G. This can be attributed to the fact that inflowing fresh water to the lagoon mixes with and dilutes lagoonal water close to station A than close to station G. The spatial distribution of dissolved oxygen, water temperature and pH values were fairly constant for the stations sampled during the sampling period, implying that they were not affected by inflowing fresh water or rainfall into the lagoon. No definite pattern was observed in the spatial distribution of nutrients in the study area.

Turbidity and TSS distribution was higher at stations A, B, E and F than at the other stations. The values at stations A and B are thought to be influenced by inflowing water into the lagoon while those at station E and F were as a result of re-suspension of sediments under the influence of strong winds and the activities of fishers.

5.1.3 Similarity analysis

The similarity analysis conducted on the water physicochemical parameters showed that the various stations located in the lagoon were generally homogenous in terms of water quality, and are clustered close together. This is seen in the dendrogram where 82.5% of all the samples were clustered above the 95% similarity (Bray-Curtis) index. From the MDS plot, the samples can be clustered into three main groups coinciding with about 94% similarity (on the dendrogram), and further clustered into four subgroups, greater than 95% similarity. Comparing the results of the similarity analysis with the sample graphs, the major factors responsible for the sample aggregations were salinity and turbidity. This is evidenced by the fact that the four stations clustered separately (July A, August A, September A and September B) had the lowest salinity and highest turbidity values.

5.2 Benthic Studies

5.2.1 Sediment analysis

The sediment grain size analysis showed that the lagoon sediment in the study area over the period studied was basically clayey, with about 50% sediment composition being clay or very fine sand. The other half was mainly made up of fine sand, some coarse sand and shells/shell fragments.

5.2.1.1 Temporal distribution

A slight increase in the percentage composition of coarse sand was observed in May and July, with a concurrent decrease in very fine sand composition. No clear reason could be assigned for this, however it is possible that this percentage shift was as a result of re-suspension of fine sediment during these periods.

The sediment organic matter content was fairly constant over the period studied with slight depressions observed in May and in September. It is inferred that the organic matter content is mainly generated internally in the lagoon, and is influenced to a very small extent by external factors. The standard deviation bars however suggest that there is much variation observed for the samples taken each month.

5.2.1.2 Spatial distribution

Stations B, C and D had the highest percentage of coarse sediment in the study area while Station D had the lowest very fine sand composition. No clear spatial pattern was observed in the sediment grain size distribution. Stations A, B and C, which were vegetated had high clay/very fine sand components. This could be attributed to the vegetation entrapping fine suspended sediment matter in solution, causing them to settle. However, Stations E and G, which were not vegetated, also had a high clay/very fine sand component. It is thought that the clay/very fine sediment at these stations may have originated from surface runoff from land.

The high sediment organic matter content observed at Station A, B and C was thought to be influenced by decaying matter from dead vegetation in those area, which could increase the sediment organic matter content. Stations D and G, which are devoid of vegetation, showed low organic matter content. Stations E and F on the other hand, though devoid of vegetation exhibited high organic matter content. It is thought that the increased sediment organic matter observed could have been derived from other areas of the lagoon, or from land-based sources.

5.2.1.3 Cluster analysis

Results from the cluster analysis showed a high similarity between the samples. Six main groupings were observed above the 85% similarity (Bray-Curtis) index while eleven sub-groups were observed above 90% similarity. Some aggregation of samples based on their location in the lagoon was observed form the cluster analysis. This clustering is however not considered significant enough as to warrant an inference of some strong heterogeneity between the stations sampled, based on grain size distribution. It is rather inferred from the analysis that very little sediment movement occurred in the study area during the study period, accounting for some form of higher aggregation of samples from the same stations. Comparing the cluster analysis to the sediment graphs, it is deduced that the main factor controlling the spatio-temporal distribution of sediment in the study area was the presence of clay/very fine sediment.

5.2.2 Benthic fauna analysis

The benthic fauna diversity for the study area was low, compared with studies by Finlayson et al. (2000) which recorded higher number of species for the entire lagoon. It is however surmised that since Finlayson *et al.* (2000) worked in the entire lagoon, they may have encountered species at other locations in the lagoon which were localized to those area and hence were not encountered in this study.

5.2.2.1 Temporal distribution

The temporal distribution of the benthic faunal diversity, with the exception of the dominance index, showed a pattern reminiscent of the salinity distribution. The Shannon-Wienner index, which incorporates the other diversity indices was lowest in January and highest in March and September. This pattern is similar to the salinity, TDS and conductivity distribution for the area. The species dominance index was the inverse of the evenness index distribution.

5.2.2.2 Spatial distribution

The benthic faunal diversity was highest for Stations C, G and A in decreasing order of magnitude. No clear reason could be adduced for this spatial distribution since the pattern compares weakly with the water physicochemical and sediment property distributions. The distribution pattern can however be compared to the sediment organic matter contend distribution, though the similarity is rather weak.

5.3 Fishery Studies

5.3.1 Growth, mortality and recruitment

The study on the fish populations indicates that fish catches responded to the physicochemical regimes prevailing in the lagoon with periods of high salinity recording lower catches. This was inferred from communications with the fishers on the lagoon who indicated that they tend to obtain low catches at periods coinciding with high salinity. It was hence concluded that salinity influenced catches in the lagoon.

Fish growth can be described by the exponential function of the form relating length **(y)** to weight **(x)** as follows:

$$y = ax^b$$

The fish growth is said to be isometric if the exponent b ≅ 3 (King, 1995). From the length-weight relationships estimated, the following exponents (b) was obtained for the cichlids studied:

- *S. melanotheron melanotheron* = 2.6105
- *T. guineensis* = 3.0184
- *H. fasciatus* = 2.9516

This leads to the conclusion of isometric growth for the cichlids studied. The growth constant K for the fishes studied, which is an index of the rate of growth, were found to compare with values from Fishbase (Froese and Pauly, 2001) and with previous results obtained in the same lagoon (Ofori-Danson *et al.*, 1999). The asymptotic lengths of the cichlids studied were however found to be lower than those from Fishbase (Froese and Pauly, 2001) though that for *S. melanotheron melanotheron* was found to be higher than that estimated by Ofori-Danson *et al.* (1999) in the same lagoon. The longevity or lifespan of the cichlids, compared to those from Fishbase (Froese and Pauly, 2001), was shorter for *H. fasciatus* but longer for *S. melanotheron melanotheron* and *T. guineensis.*

The estimated ages of the largest fishes captured were 3 years, 2 years and 2.5 years for *S. melanotheron melanotheron, T. guineensis* and *H. fasciatus* respectively. The lengths and age of these fishes indicate that they were closer to the asymptotic length and their maximum lifespan in the lagoon.

However, the median length of the fishes caught were 8.0 cm, 9.5 cm and 125 cm for *S. melanotheron melanotheron, T. guineensis* and *H. fasciatus* respectively, indicating that they were caught within their first year in the lagoon. The inference is that more juvenile fishes are being caught in the lagoon, which could result in a high rate of growth overfishing (Pauly *et al*, 1989; Beverton and Holt, 1957) occurring in the lagoon. Growth overfishing generally results in stunted populations of fish since the exploitation pressure would result in premature reproduction by the fishes to regain a balance in their populations.

The mortality parameters estimated for the species show that *H. fasciatus* is currestly expoited at optimal levels while *S. melanotheron melanotheron* and *T. guineensis* are being exploited above the optimal level. The fishery is, hence, currently able to maintain itself due to the high recruitment of juveniles into the fishery as a result of their high growth rates despite the growth overfishing being experienced. This recruitment is evident in a continuous recruitment pattern throughout the year with peaks occurring both in the dry and wet seasons for the species. Generally, the species studied exhibited a bimodal recruitment pattern during a year with *H. fasciatus* having the most distinct modes. The import of this is that there will be several juveniles to repopulate the system during the raining season when conditions are less stressful.

5.3.2 Food habits

The result from the food studies indicates that plant material and detritus play important roles in the diet of *S. melanotheron melanotheron* and *T. guineensis,* whereas *H. fasciatus* is basically a piscivorous predator. The fishes did not exhibit any form of specialized feeding during the study period. Benthos was rare in the diet of *H. fasciatus* and not very abundant in the diet of the other species. However, this is seen in the light of the fact that benthic organisms, being soft-bodied, may be digested faster in the gut of the fishes, hence their under-representation in the diet. Hence benthic fauna may well be more important, especially in the diets of *S. melanotheron melanotheron* and *T. guineensis* than was shown in the analysis. This is seen also in the presence of large amounts of mud/detritus in the gut of these fishes. It is inferred that the fishes sift through the mud for benthic fauna, hence the presence of mud in their gut.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The study sought to find out the water physicochemical regime, the sediment grain size distribution and organic matter content, the benthic macrofauna diversity and some population parameters of the major cichlid fishery in the study area. The findings indicate that the seasonal precipitation pattern of the area was mainly responsible for changes in the lagoon water physicochemical regime during the period of the study. The effect is most observed in the salinity, conductivity and total dissolved solids (TDS) values, and to some extent in the turbidity, total suspended solids (TDS) and nutrient values. The suspended matter responsible for turbidity changes are thought to be mainly from an external source; carried into the lagoon by the inflowing waters that feed the lagoon. The dissolved oxygen (DO) content of the water, the water pH and temperature, however, were fairly stable during the period studied. However periodic fluctuations observed could cause severe stresses for the lagoon biota. The similarity analysis, however, indicate that the samples were largely similar between and within stations for the period studied, with minor fluctuations under the influence of the seasons. These leads to the conclusion that the lagoon water is of a good-enough quality in terms of supporting aquatic life.

Several studies (Seiderer and Newell, 1999; Snelgrove and Butman, 1994; Palacin *et al.*, 1991; Cacchione and Drake, 1990; Gray *et al.*, 1990; Ishikawa, 1989; Miller and Sternberg, 1988; Butman, 1987; Grant and Madsen, 1986; Nowell and Jumars, 1984; Nowell, 1983; Palmer, 1983; Pearson and Rosenberg, 1978; Nichols, 1970; Cassie and Michael, 1968; Sanders, 1958; Thorson, 1957) correlating benthic faunal diversity with sediment grain size distribution have been carried out with varying results. It is now generally accepted that other interactions, in addition to grain size distribution, may be responsible for benthic faunal distribution. This study also does not show a clear spatio-temporal effect of sediment distribution on benthic faunal diversity. However salinity and sediment organic matter content rather showed some level of correlation with benthic faunal diversity distribution in the study area.

Generally, no major spatio-temporal dynamics could be shown for the sediment grain size distribution in the study area. Further, no clear-cut dissimilarity could also be proved for the grain size distribution among the stations sampled. Hence it is possible that the effect of these factors on the benthic sediment diversity could be masked in the study area by other factors such as the hydrodynamics of the sediment-water interface and bottom boundary-layer flow effects.

The benthic fauna diversity did not indicate any effect of any external perturbation on the benthic environment, except salinity changes. Hence it is expected that periods of increased salinity could result in a lowered benthic fauna diversity. Indeed increased salinity would select for species which are able to tolerate such stress, leading to increases in the species dominance index and a reduction in diversity. Since the fishes studied rely to some extent on benthic organisms for food, such a stress could affect their nutrition and, consequently, their production in the lagoon.

The study on the major fishery resource of the lagoon indicated that even though the resource is highly exploited, it is able to maintain itself by rapid reproduction at an early age. The reproduction also occurs throughout the year. However, if exploitation is maintained at or above the current rate, its effect, coupled with that of the stressful environment could result in diminishing catches, with catches comprising mainly of small-bodied fishes. In the absence of any restriction on fishing or fishing gear, there is a high potential for 'Malthusian' overfishing (Pauly *et al.*, 1989) resulting in the eventual collapse of the fishery and the degradation of the environment itself.

6.2 Recommendations

The following recommendations are made for management considerations and for a more full understanding of the dynamics of the lagoon towards a sustainable exploitation and utilization of the lagoon.

- Existing rules and legislation governing the exploitation of the lagoonal resource should be strengthened and enforced. This is particularly essential with regards to mesh-size restrictions and destructive fishing methods so that the fishery does not suffer unduly from the use of illegal and unapproved gears and methods. The harmonization and strengthening of traditional regulations such as the imposition of no-fishing days would also help to reduce the stress on the fishery.
- A frame survey should be conducted to estimate the current fishing effort in the lagoon, and hence to determine the yield of the lagoon. This survey should include a socio-economic component to identify the potential effects rules and regulations enforcement would have on the riparian communities which depend on the lagoonal resource for their sustenance.
- A time-series data should be collected on the lagoonal physicochemical state as well as fishery and other resource through regular monitoring of the lagoon. This should be done, at least, on quarterly basis. The data so obtained should be modeled such that it would serve as an early warning system indicative of any major stress which could cause damage to the lagoon ecology.
- Alternate sources of livelihood should be made available to the riparian communities to reduce the current pressure on the lagoonal fishery

resource. This could include the encouragement of eco-tourism in the lagoon, and the redirection of income generating activities to fishing in the adjacent sea and farming on the sandbar through the provision of necessary logistics.

REFERENCES

Addo, S. (2000). *The Acadja fishery of the Keta lagoon.* M.Phil Thesis. University of Ghana, Legon.

Akpati, B.N. (1978). Geological structure and evolution of the Keta basin, Ghana, West Africa. *Geol. Soc. of Amer. Bull.* 89:124-132.

Armah, A.K. and Amlalo, D.S. (1998). *Coastal zone profile of Ghana.* Gulf of Guinea Large Marine Ecosystem Project. Ministry of Environment, Science and Technology, Accra, Ghana. vii + 111 pp.

Armah, A.K., Awumbila, M., Clark, S., Dzietror, A., Foster-Smith, R., Porter, R. and Young, E.M. (1997). Coping responses and strategies in the coastal zone of south-eastern Ghana: a case study in the Anloga area. In: S.M. Evans, C.J Vanderpuye and A.K. Armah (eds.). *The Coastal Zone of West Africa: Problems and management.* Proceedings of an International Seminar on ICZM in Accra, Ghana, 25-29 March, 1996. Penshaw Press, UK.

Beverton, R.J.H. and Holt, S.J. (1957). On the dynamics of exploited fish populations. Fish. *Invest Minist. Agric. Fish Food.* GB. (2 Sea Fish.) 19:533p.

Biney, C.A. (1990). A review of some characteristics of freshwater and coastal ecosystems in Ghana. *Hydrobiologia.* 208:45-53.

Blay, J. and Asabere-Ameyaw, A. (1993). Assessment of the fishery of a stunted population of the cichlid *Sarotherodon melanotheron* (Ruppel), in a 'closed' lagoon in Ghana. *Ichthyology.* 9:1-11.

Bray, J.R. and Curtis, J.T. (1957). An ordination of the upland forest communities of Southern Wisconsin. *Ecol. Monogr.* 27:325-349.

Butman, C.A. (1987). Larval settlement of soft-sediment invertebrates: the spatial scales of patterns explained by active habitat selection and the emerging role of hydrodynamic processes. *Oceanography and Marine Biology: An annual Review.* 25:113-165

Cacchione, D.A. and Drake, D.E. (1990). Shelf sediment transport: an overview with applications to the northern California continental shelf. In: *Sea volume Nine: Ocean Engineering Science.* Two Volume Set. Chichester, England. John Wiley. Pp729-773

Carr, M.R. (1996). *PRIMER user manual.* Plymouth Marine Laboratory, Plymouth, U.K

Carrol, R. (1988). *Vertebrate paleontology and evolution.* W. H. Freeman, New York. 698p.

Cassie, R.M. and Michael, A.D. (1968). Fauna and sediments of an intertidal mudflat: a multivariate analysis. *Journal of Experimental Marine Biology and Ecology.* 2:1-23

Cormack, R.M. (1971). A review of classifications. *J. R. Statist. Sec. Ser. Am.* 134:321-367.

Costello, M.J., (1990). Predator feeding strategy and prey importance: a new graphical analysis. *J. Fish Biol.* 36:261-263.

Daget, J. and Teugels, G.G. (1991). Hemichromis, p 187-194. J. Daget, J.-P. Gosse, G.G. Teugels and D.F.E. Thys van den Audenaerde (eds.) *Checklist of the freshwater fishes of Africa,* (CLOFFA). ISNB, Brussels; MRAC, Tervuren; and ORSTOM, Paris. Vol. 4.

Dankwa, H.R. and Entsua-Mensah, M. (1996). Fishing gears and methods used in lagoons and estuaries in Ghana. *IAB Tech. Rep. 155.*

Diouf, P.S. (1996). *Les peuplement de poisons des milieux estuarine de l'Afrique de* l'Ouest: *L'exemple de lestuaire hyperhilin du Sine-Saloum.* These presentée a L'Universite de Montpellier II pour l'obtention du Diplome de Doctorat. Theses et Documents Microfiches. No. 156. ORSTOM, Paris. (abs).

Entsua-Mensah, M. and Dankwa, H.R. (1997). Traditional knowledge and management of lagoon fisheries in Ghana. *WRI Tech. Rep. 160.*

Everitt, B. (1980). Cluster analysis, 2nd Ed. Heinemann, London

FAO (1989). Introduction to tropical fish stock assessment. Part 1, Manual. *FAO Fish. Tech. Pap.* (306):1 337p.

Finlayson, C.M., Gordon, C., Ntiamoa-Baidu, Y., Tumbulto, J. and Storrs, M. (2000). *The hydro biology of Keta and Songor lagoons: Implications for coastal wetland management in Ghana.* Supervising Scientist Report 152, Supervising Scientist, Darwin.

Froese, R. and Pauiy, D. (eds.) (2001) *Fishbase.* World Wide Web electronic publication. www.fishbase.orq.

Gayanilo, F.C. Jr., Soriano, M. and Pauly, D. (1988). *A draft guide to the CQMPLEAT ELEFAN.* ICLARM Software Project 2. 65p.

Grant, W.D. and Madsen O.S. (1986). The continental-shelf bottom boundary layer. *Annual review of Fluid Mechanics.* 18:265-305

Gray, J.S., Clarke, K.R., Warrwick, R.M. and Hobbs, G. (1990). Detection of initial effect of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. *Marine Ecology Progress Series.* 66:285-299

Gulland, J.A. (1983). *Fish stock assessment: a manual of basic methods.* Chichester, U.K., Wiley Interscience, FAO/Wiley series on food and agriculture, 1:233p.

Hach. (2000a). *Water analysis handbook* Hach Company, USA. ix + 831 p.

Hach. (2000b). *Laboratory analysis manual.* Hach Company, USA.

Heip, C., Herman, P.M.J. and Soetaert, K. (1988) Data processing, evaluation and analysis, p 197-231. In: R.P Higgins and H. Thiel (eds.). *Introduction to the study of meiofauna.* Smithsonian Institution, Washington DC.

Helfman, G., Collette, B. and Facey, D. (1997). *The diversity of fishes.* Blackwell Science, Maiden, M. A. 528p.

Ishikawa, K. (1989). Relationship between bottom characteristics and benthic organisms in the shallow water of Oppa Bay, Miyagi. *Marine Biology.* 102:265-273

Koranteng, K.A., Entsua-Mensah, M and Ofori-Danson, P.K. (1997). The current status of the fishery of a small West African lagoon. *Ghana J. of Sc.* Vol. 37.

Koranteng, K.A., Ofori-Danson, P.K. and Entsua-Mensah, M. (1998). Comparative study of the fish and fisheries of three coastal lagoons in West Africa.

International J. of Ecology and Env. Sc. 24:371-382. Int. Sc. Pub., New Delhi, India.

Koranteng, K.A., Ofori-Danson, P.K. and Entsua-Mensah, M. (2000). Fish and fisheries of the Muni lagoon in Ghana, West Africa. *Biodiversity and Conservation.* 9:487-499. Kluwer Academic Publishers, Netherlands.

Kruskal, J.B. and Wish, M. (1978). *Multidimensional scaling.* Sage Publications, Beverley Hills, California.

Lewis, L.J., Davenport, J. and Kelly, T.C. (2002). A study of the impact of a pipeline construction on estuarine benthic invertebrate communities. *Estuarine, Coastal and Shelf Science* 55: 213-221

Magurran, A.E. (1991). *Ecological diversity and its measurement* Chapman and Hall, London.

Marshall, S. and Elliott, M. (1997). A comparison of univariate and multivariate numerical and graphical techniques for determining inter- and intraspecific feeding relationships in estuarine fish. *J. of Fish Biology* 51:526-545.

Miller, D.C. and Sternberg, R. W. (1988). Field measurement of the fluid and sediment-dynamic environment of a benthic deposit feeder. *Journal of Marine Research.* 46:771-796

Munroe, J.L. and Pauly, D. (1983). A simple method for comparing growth of fishes and invertebrates. *ICLARM Fishbyte,* 1(1):5-6.

Nelson, J.S. (1994). *Fishes of the world.* 3rd Ed. John Wiley and Sons, Inc. New York. 600p.

Nichols, F.H. (1970). Benthic polychaete assemblages and their relationship to the sediment in Port Madison, Washington. *Marine Biology.* 6:48-57

Nowell, A.R.M. (1983). The benthic boundary layer and sediment transport. *Reviews of Geophysics and Space Physics.* 21:1181-1192

Nowell, A.R.M. and Jumars, P.A. (1984). Flow environment of aquatic benthos. *Animal Review of Ecology an Systematics.* 15:303-328

Ofori-Danson, P.K., Entsua-Mensah, M. and Biney, CA. (1999). *Monitoring of fisheries in five lagoon Ramsar sites in Ghana.* A report Submitted to the Department of Game and Wildlife under the GCWMP. 1 16p.

Page, L.M. and Burr, B.M. (1991). *A field guide to freshwater fishes of North America north of Mexico.* Houghton Muffin Company, Boston. 432p.

Palacin, C. Martin, D. and Gili, J.M. (1991). Features of spatial distribution of benthic infauna in a Mediterranean shallow-water bay. *Marine Biology.* 110:315-321

Palmer, M.A. (1988). Dispersal of marine meiofauna: a review and conceptual model of explaining passive transport and active emergence with implications for recruitment. *Marine Ecology Progress Series.* 48:81-91

Pauly, D. (1976) The biology, fishery and potential for aquaculture of Tilapia melanotheron in a small West Africa Lagoon. *Aquaculture.* 7:33-49.

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *.J. Cons. Int. Explor. Mer.* 39:175-192.

Pauly, D. (1983a). Some simple methods for the assessment of tropical fish stocks. *FAQ Fish. Tech. Pap.* 234, 52pp.

Pauly, D. (1983b). Length-converted catch curves: a powerful tool for fisheries research in the tropics (Part I). *Fishbyte.* 1(2):9-13.

Pauly, D. and Morgan, G.R. (eds.) (1987). Length-based methods in fisheries research. *ICLARM Conf Proc.,* 13:468p.

Pauly, D. and Munroe J.L. (1984) Once more on the comparison of growth in fish and invertebrates. *ICLARM Fishbyte,* 2(1):21

Pauly, D., Silvestre, C. and Smith, I.A. (1989). On development, fisheries and dynamite: A brief review of tropical fisheries management. *Natural Resource Modeling.* 3(3)307-329.

Person, T.H. and Rosenberg, R. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: an Annual Review.* 16:229-311

Pielou, E.G. (1975). Ecological diversity. Wiley, New York.

Pielou, E.G. (1984). *The interpretation of ecological data. A primer on classification and ordination.* Wiley, New York.

Piersma, T. and Ntiamoa-Baidu, Y. (1995). *Waterbird ecology and the management of coastal wetlands in Ghana.* NIOZ report 6, Texel, the Netherlands.

Regan, C.T. (1912). The classification of the blennioid fishes. *Ann. Mag. Nat Hist* 10:265-280

Sanders, H.L. (1958). Benthic studies in Buzzards Bay. 1. Animal-sediment relationships. *Limnology and Oceanography.* 3:245-258

Seiderer, L.J. and Newell, R.C. (1999). Analysis of the relationship between sediment composition and benthic community structure in coastal deposits:

implications for marine aggregate dredging. ICES *Journal of Marine Science.* 56:757-765

Shenker, .LM., Dankwa, H., Lin, J., Ofori-Danson, P.K. and Ntiamoa-Baidu, Y. (1998). *Fisheries of Keta and .Songhor lagoons.* Final Report. Ghana Coastal Wetlands Management Project. Env. Baseline Studies. 82p.

Snelgrove, P.V.R. and Butman, C.A. (1994). Animal-sediment relationships revisited: Cause versus effect. *Oceanography and marine biology: An annual review.* 32:111-177

Teugels, G.G. (1992). Cichlidae, p 714-779. in C. Lévêque, 0. Paugy, and G.G. Teugels(eds.) *Faune des poisons déaux douces et Saumâtres dAfrique de l'Ouest* Tome 2. Coll. Faune tropicale no 28. Musée Royal de l'Afrique Central, Tervuren, Belgique and ORSTOM, Paris, 9O2p.

Teugels, G.G. and Thys van den Audenaerde D.F.E. (1991). Tilapia, p482-508. In: J. Daget, J-P. Gosse, G.G. Teugels and D.F.E. Thys van den Audenaerde (eds.) *Checklist of the freshwater fishes of Africa.* (CLOFFA). ISNB, Brussels; MRAC, Tervuren; and ORSTOM, Paris. Vol. 4.

Teugels, G.G., Lévêque, C., Paugy, D. and Traore, K. (1988). Annotated check-list of the freshwater fishes of the coastal basins of Ivory Coast and Western Ghana. *Rev. Hydrobiol.* Trop. 21(3):221-237.

Thorson, G. (1957). Bottom communities (sublittoral or shallow shelf). *Geological Society of America Memoir*. 67:461-534

Trewavas, E. (1983). *Tllapiine fishes of the genera Sarotherodon, Oreochromis and Daniakilia.* British Museum of Natural History, London, U.K.583p.

Trewavas, E. and Teugels, G.G. (1991) Sarotherodon, p 425-437. In: J. Daget, J.-P. Gosse, G.G. Teugels and D.F.E. Thys van den Audenaerde (eds.) *Checklist of the freshwater fishes of Africa*. (CLOFFA). ISNB, Brussels; MRAC, Tervuren; and ORSTOM, Paris. Vol. 4.

APPENDIX

Appendix A
Water physicochemical parameters

January: Preliminary studies

Station	SAL	CON	TDS	PH	DO	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2^-	Temp(W)	TSS	TURBIDITY
A	10	21.50	12200	7.60	8.0			1350			3	1
B	13	18.17	10300	7.16	3.8			1250			1	2
C	10	17.31	9790	7.82	7.5			1250			4	2
D	12	17.37	9820	7.76	8.3			1500			4	5
E	13	18.13	10200	7.76	8.4			1350			12	17
F	13	18.37	10500	7.88	7.5			1350			3	3
G												

January

Station	SAL	CON	TDS	PH	DO	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2^-	Temp(W)	TSS	TURBIDITY
A	12	22.10	12600	7.74	5.7	1.0	0.25	1500	7.8	30.60	7	11
B	11	18.69	10600	8.09	4.35	0.8	0.19	1300	10.9	31.20	7	11
C	10	18.12	10300	8.05	6.65	0.8	0.83	1300	11.6	33.00	9	11
D	9	17.99	10200	8.00	6.55	0.8	0.82	1300	8.4	30.80	15	24
E	10	18.10	10300	8.12	6.6	0.6	0.48	1520	11.0	34.52	5	12
F	10	18.53	10500	7.98	5.85	0.7	1.46	1350	10.9	34.80	5	9
G	10	18.23	10400	7.99	7.25	0.7	2.08	1350	11.2	33.40	4	8

February

Station	SAL	CON	TDS	PH	DO	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2^-	Temp(W)	TSS	TURBIDITY
A	15	25.40	14300	7.54	4.6	1.6	0.92	1350	12.3	34.60	8	11
B	13	21.90	12400	7.48	5.1	1.3	2.11	1400	10.8	33.50	5	4
C	13	21.10	11900	7.91	7.0	0.8	0.51	1350	12.4	34.20	5	4
D	12	19.44	11100	7.77	6.4	0.9	1.56	1400	10.4	34.00	10	17
E	12	20.30	11500	7.84	6.6	1.1	0.60	1450	12.7	34.10	6	10
F	13	20.80	11800	7.78	6.4	0.9	0.73	1450	11.1	33.70	7	10
G	13	21.00	11900	7.58	6.6	0.9	1.76	2350	11.1	34.50	6	10

March

Station	SAL	CON	TDS	PH	DO	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2^-	Temp(W)	TSS	TURBIDITY
A	11	19.04	10800	9.27	5.4	0.5	0.1	1000	12.3	33.90	182	261
B	12	20.1	11400	7.95	5.62	0.2	0.27	2300	11.6	31.20	10	18
C	13	22.1	12500	8.26	5.92	0.3	0.32	1450	12.2	31.90	22	20
D	14	23.2	13200	8.24	5.82	0.4	1.35	1550	8.6	29.80	20	26
E	14	23.7	13400	8.33	6.12	0.4	0.46	1700	10.9	31.10	29	44
F	14	23.9	13500	8.37	5.52	0.4	1.73	1550	9.8	31.20	23	38
G	16	25.5	14600	8.4	8.52	0.4	0.59	2650	11.2	31.30	13	21

April

Station	SAL	CON	TDS	PH	DO	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2^-	Temp(W)	TSS	TURBIDITY
A	7	11.4	6320	7.9	6.0	0.5	0.50	550	10.6	31.10	28	22
B	7	12.2	6800	8.07	6.1	0.4	0.50	350	10.7	31.30	11	8
C	11	18.8	10700	8.09	6.2	0.2	0.45	1200	6.7	31.50	14	29
D	18	29.4	16400	8.18	6.1	0.2	0.24	1550	18.4	31.70	10	15
E	16	26.4	14900	8.35	6.3	0.2	0.68	1650	10.7	32.30	21	33
F	17	27.7	15700	8.35	6.2	0.1	1.80	1700	10.1	32.50	21	25
G	14	23.6	13200	8.43	6.3	0.1	2.17	1700	9.4	35.30	26	33

May

Station	SAL	CON	TDS	PH	DO	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2^-	Temp(W)	TSS	TURBIDITY
A	9	14.7	8290	7.78	5.0	0.4	0.16	650	7.5	28.40	7	31
B	8	14.2	7970	7.72	6.05	0.3	0.11	600	8.3	29.00	4	12
C	11	19.0	10800	7.98	6.09	0.3	0.13	1050	10.0	29.30	2	7
D	13	21.5	12200	8.09	5.84	0.1	0.20	1150	9.7	29.40	5	13
E	14	23.8	13500	8.26	8.44	0.2	0.13	1600	8.0	30.40	23	42
F	15	25.4	14400	8.24	3.08	0.6	0.11	1500	7.5	30.50	18	32
G	17	27.3	15400	8.27	4.17	0.2	0.16	1900	7.6	31.20	15	25

June

Station	SAL	CON	TDS	PH	DO	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2^-	Temp(W)	TSS	TURBIDITY
A	8	13.7	7710	8	6.74	0.7	0.1	1400	7.2	31.50	24	23
B	8	14.6	8220	8.01	6.41	0.7	0.16	850	6.8	31.50	24	30
C	14	23.8	13500	8.14	6.45	0.7	0.06	1300	9.0	30.20	28	32
D	16	26.2	14900	8.53	7.98	0.5	0.02	1550	8.4	27.20	11	5
E	17	28.1	15700	8.31	6.96	0.4	0.07	1650	6.9	28.50	125	186
F	17	30	16800	8.46	6.54	0.7	0.11	1800	5.8	27.90	44	64
G	18	29.7	16700	8.38	6.12	0.8	0.06	1700	5.5	28.30	34	50

July

Station	SAL	CON	TDS	PH	DO	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2^-	Temp(W)	TSS	TURBIDITY
A	6	10.8	6000	7.92	6.68	0.2	0.39	550	6.0	27.70	202	295
B	6	10.1	5570	7.87	4.49	0.2	0.13	600	4.3	27.60	99	148
C	18	28.7	16200	8.30	5.31	0.1	0.14	1550	7.0	26.90	28	48
D	21	33.7	19100	8.39	4.87	0.1	0.20	2100	7.9	25.70	51	80
E	12	19.44	1100	8.45	9.18	0.1	1.79	1100	5.0	25.10	128	187
F	20	33.4	18900	8.39	4.94	0.1	0.30	2150	2.7	24.80	196	276
G	23	35.7	23396	8.16	9.31	0.1	0.15	2400	4.2	24.50	51	79

August

Station	SAL	CON	TDS	PH	DO	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2^-	Temp(W)	TSS	TURBIDITY
A	5	9.2	5050	7.64	5.2	0.7	0.6	550	9.5	28.90	65	96
B	5	9.3	5020	7.64	5.4	0.5	0.16	950	7.6	28.90	18	26
C	17	28.0	1600	8.00	6.2	0.4	0.14	1950	5.6	28.70	19	28
D	22	34.1	19500	8.24	6.4	0.4	0.31	1850	6.9	29.60	21	31
E	15	24.2	24297	8.54	6.12	0.5	0.62	2400	4.0	30.00	59	86
F	25	40.1	26197	8.24	5.3	0.6	0.12	2700	10.5	27.80	118	169
G	24	39.6	24497	8.20	8.52	0.5	0.82	2400	4.2	28.00	21	33

September

Station	SAL	CON	TDS	PH	DO	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2^-	Temp(W)	TSS	TURBIDITY
A	3	5.6	2920	7.45	6.63	0.7	0.3	350	12.7	32.20	63	98.00
B	3	5.6	2950	7.47	6.87	0.7	0.50	400	10.8	31.40	56	81.00
C	18	28.5	16000	7.8	7.08	0.5	0.47	1850	9.7	31.20	12	18.00
D	21	34.0	19300	8.17	7.6	0.3	0.27	1600	6.0	30.70	18	30.00
E	28	44.0	28494	7.98	6.6	0.6	0.27	2900	6.3	28.00	61	87.00
F	30	45.5	29590	8	6.61	0.6	0.29	3300	7.1	27.40	35	53.00
G	28	44.0	29097	8	7.26	0.5	0.22	3200	5.9	27.80	15	22.00

Appendix B
Sediment grain size distribution

January

Station	1.000mm	0.750mm	0.500mm	0.355mm	0.250mm	0.125mm	0.063mm	>0.063mm
A	1.1916	3.4828	7.3281	12.0782	19.0508	24.5219	18.4843	13.8623
B	2.4776	4.8630	8.3581	11.1599	14.9013	22.4299	21.5597	14.2505
C	2.2312	4.3067	7.3255	9.7842	13.8139	23.0150	14.5176	24.9393
D	1.5073	5.7784	13.3559	17.2802	20.0077	23.5723	6.9671	11.5311
E	0.6164	2.3396	5.9864	10.5428	18.5677	35.9248	15.8692	10.1532
F	1.8438	4.4078	7.9684	11.5014	17.3101	25.6153	17.1232	14.2291
G	0.8746	2.0251	5.2059	8.6118	13.3507	38.1396	12.4158	19.3765

March

Station	1.000mm	0.750mm	0.500mm	0.355mm	0.250mm	0.125mm	0.063mm	>0.063mm
A	1.4862	3.5074	6.8271	10.7223	16.6332	20.5341	14.4456	25.8441
B	1.4536	5.0816	9.3348	12.6616	19.2116	31.2762	14.4242	6.5565
C	1.9952	4.8326	9.2429	13.7538	20.1970	24.8650	9.6889	15.4246
D	2.8944	7.9837	15.2125	18.5924	18.3223	18.3231	7.1908	11.4809
E	1.1591	2.6031	5.2986	9.0335	17.4892	34.8735	15.7364	13.8066
F	2.7851	4.0932	6.7176	9.9371	15.7191	29.4606	10.0911	21.1963
G	0.6098	1.8951	5.1243	8.6137	14.2290	34.8752	13.7986	20.8544

May

Station	1.000mm	0.750mm	0.500mm	0.355mm	0.250mm	0.125mm	0.063mm	>0.063mm
A	2.3347	4.9601	8.9094	13.5867	19.4662	22.4547	14.2301	14.0579
B	7.3499	9.0234	11.6870	12.6412	14.1660	19.6259	15.2361	10.2707
C	4.1774	7.9481	11.7909	14.0216	15.3629	21.6239	11.2295	13.8457
D	5.6235	11.0174	17.4325	19.1027	18.0982	16.8649	3.9199	7.9410
E	1.1390	2.9806	9.3361	15.9409	20.4102	22.5592	16.1599	11.4742
F	1.4464	3.1492	6.0709	9.5246	13.4553	27.5765	31.0754	7.7017
G	1.3402	5.3467	9.6379	12.3121	19.6175	31.7026	13.7692	6.2738

July

Station	1.000mm	0.750mm	0.500mm	0.355mm	0.250mm	0.125mm	0.063mm	>0.063mm
A	1.0595	2.3182	4.3844	7.0305	14.1765	28.1714	22.3784	20.4811
B	7.1907	8.5941	11.1737	12.7329	15.0996	19.5413	14.2031	11.4647
C	3.8073	6.0223	8.6741	9.7854	13.7298	21.7352	14.2193	22.0266
D	4.6119	8.9999	14.5176	17.0514	18.9703	20.0827	4.4077	11.3585
E	2.8823	6.8459	12.7315	15.5316	21.7700	24.2038	6.4836	9.5513
F	3.1101	5.4643	10.8984	8.5995	13.0028	23.4910	18.0852	17.3487
G	0.8001	4.2168	10.1364	14.1232	20.9407	21.5930	13.2825	4.9073

September

Station	1.000mm	0.750mm	0.500mm	0.355mm	0.250mm	0.125mm	0.063mm	>0.063mm
A	2.2977	5.1923	10.0743	14.9648	21.4278	23.3202	13.4247	9.2982
B	7.2638	8.2233	9.9895	11.1017	13.0339	19.6222	20.2696	10.4961
C	5.5105	8.4518	12.4257	13.9226	14.9510	20.3607	10.4344	13.9432
D	4.7169	10.5220	16.9065	18.7212	18.8660	19.0591	4.2262	6.9820
E	0.3933	1.3912	3.9744	7.9735	14.3251	32.5336	23.3152	16.1037
F	3.0424	4.1763	6.2325	8.7158	11.8757	20.6182	23.0215	22.3176
G	0.5738	2.7897	7.3656	12.1537	19.9725	33.4412	15.7265	6.9771

Appendix C

Sediment organic (detrital) matter content (mg/g)

Station	Jan	Mar	May	Jul	Sep
A	0.9530	0.6940	0.5840	1.3910	0.6180
B	0.9970	1.9470	0.7280	0.8260	0.7330
C	2.1290	0.8340	1.2420	1.5640	0.9800
D	0.5730	0.8590	0.7010	0.5580	0.5150
E	0.6650	1.3780	1.4510	0.9750	1.0920
F	1.1590	0.7730	0.2850	1.3530	1.8260
G	0.2710	0.4320	0.5350	0.3660	0.5740

Appendix D
Mean diversity indecies

January

Station	Richness	Shannon	Evenness	Simpson
A	1.08	1.21	0.88	0.30
B	0.48	0.56	0.81	0.57
C	0.54	1.08	0.98	0.33
D	0.42	0.53	0.48	0.74
E	1.04	1.37	0.77	0.30
F	0.68	0.89	0.64	0.50
G	1.00	0.73	0.41	0.67

March

Station	Richness	Shannon	Evenness	Simpson
A	1.44	1.39	1.00	0.14
B	1.03	1.45	0.90	0.24
C	1.03	1.43	0.89	0.25
D	1.25	1.43	0.73	0.30
E	1.28	1.59	0.89	0.23
F	0.76	0.74	0.46	0.63
G	1.42	1.54	0.70	0.27

May

Station	Richness	Shannon	Evenness	Simpson
A	0.87	1.28	0.93	0.28
B	0.87	1.22	0.88	0.30
C	1.10	1.33	0.83	0.30
D	0.88	0.72	0.52	0.64
E	0.75	0.68	0.49	0.67
F	1.14	1.15	0.83	0.34
G	1.39	1.35	0.65	0.34

July

Station	Richness	Shannon	Evenness	Simpson
A	0.69	1.06	0.97	0.32
B	0.91	0.75	0.47	0.65
C	1.52	1.74	0.89	0.19
D	0.96	1.64	0.92	0.20
E	1.06	1.08	0.61	0.47
F	0.64	1.02	0.74	0.42
G	1.22	1.58	0.81	0.25

September

Station	Richness	Shannon	Evenness	Simpson
A	0.96	1.04	0.95	0.29
B	0.65	1.25	0.90	0.32
C	1.27	1.44	0.81	0.28
D	1.51	1.48	0.67	0.30
E	0.67	1.03	0.74	0.40
F	1.04	1.51	0.94	0.22
G	0.93	1.52	0.78	0.26

Appendix E

Length-frequency distribution of fish samples (grouped data)

Sarotherodon melanotheron melanotheron

Mid class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
4.5			6		1		2	4	
5.5	2		16		4		6	10	
6.5	4		18	7	6	2	13	19	3
7.5	5	2	14	30	12	6	26	13	10
8.5	6	6	9	11	14	23	16	9	16
9.5	8	11	5	9	9	18	7	7	8
10.5	14	16	2	23	5	9	5	8	8
11.5	20	12	1	7	9	2	0	5	5
12.5	12	5	2	2	1	1	0	2	3
13.5	6	4	1		1		0	2	
14.5	4	6	1				1		
15.5	1	12	1						
16.5		6							
17.5		2							
18.5		2							
19.5									
20.5									

Tilapia guineensis

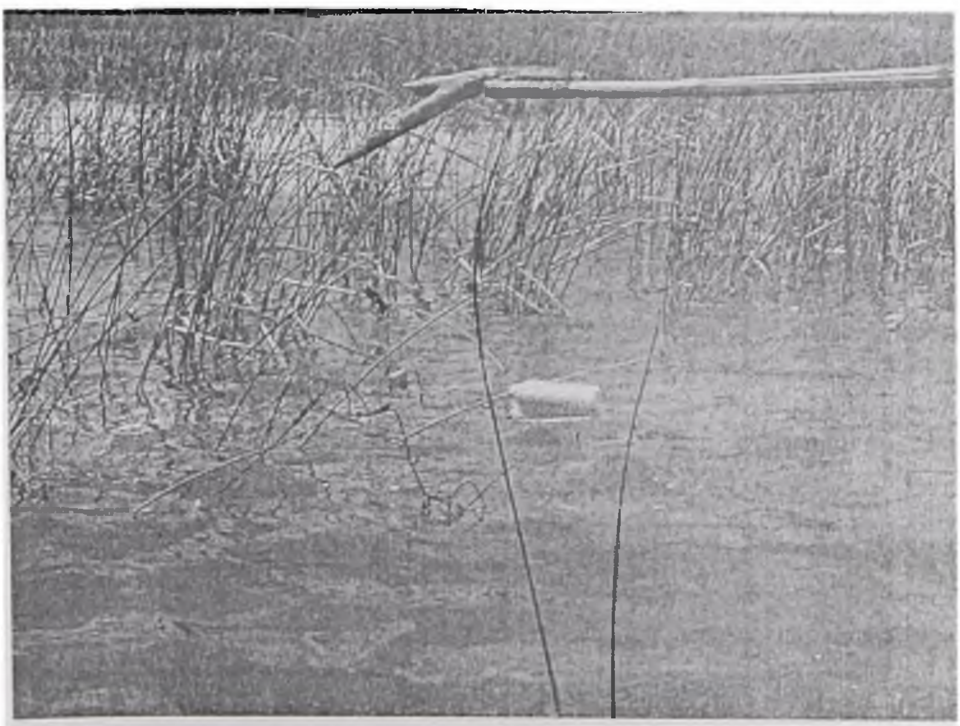
Mid class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
4.5						1			
5.5			1	3	1	3	2		
6.5	4	2	2	4	4	2	5		3
7.5	9	6	4	3	9	3	9	5	6
8.5	19	14	8	12	18	7	7	6	9
9.5	28	16	6	16	17	12	11	6	12
10.5	11	21	10	8	5	15	21	11	17
11.5	7	10	15	6	3	9	16	18	22
12.5	3	4	4	3	1	8	5	9	10
13.5		1	2	3		2		5	6
14.5			2			2		1	3
15.5								1	
16.5									
17.5									
18.5									
19.5									
20.5									

Hemichromis fasciatus

Mid class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
4.5									
5.5					5				1
6.5	2				4	3	2		0
7.5	6	3	2		4	9	8	3	2
8.5	8	2	2		7	8	14	3	5
9.5	16	4	3	4	6	10	14	8	5
10.5	18	13	4	5	10	23	11	14	6
11.5	14	12	3	11	25	14	16	16	13
12.5	9	16	12	25	16	9	24	17	19
13.5	4	8	18	15	8	9	10	16	21
14.5	3	3	10	9	3	4	8	23	11
15.5		2	4	0		2	7	12	3
16.5			4	6			3	6	4
17.5			5	6			2	6	3
18.5			3				2	4	0
19.5								1	0
20.5									1

Appendix F: Plates

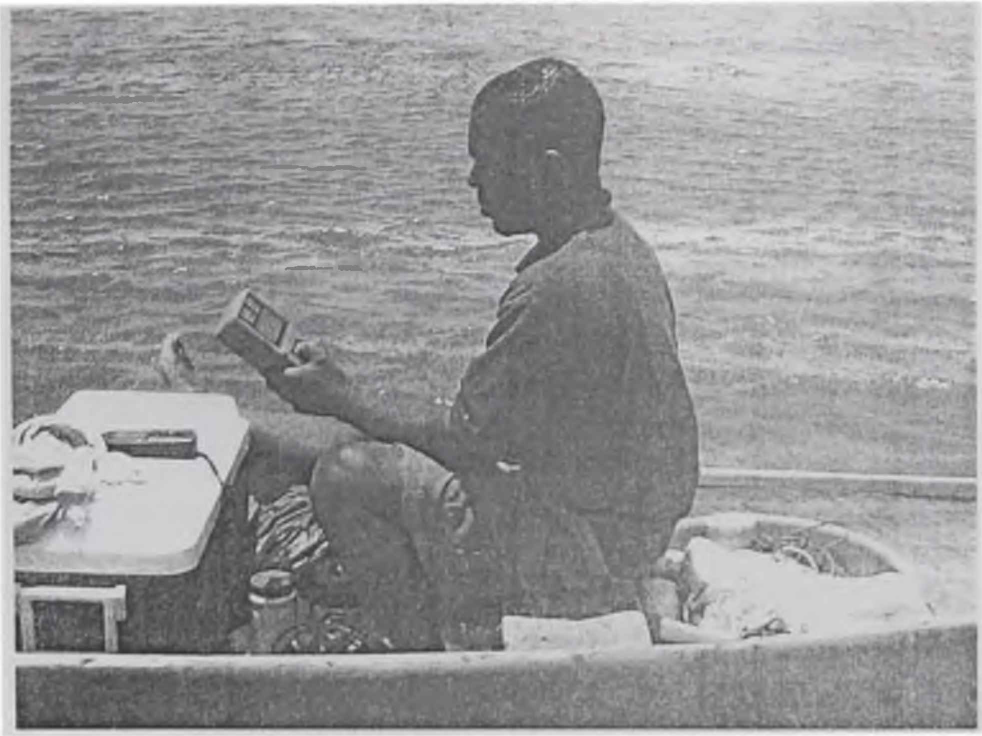
A crab trap: A fishing gear used in the Keta lagoon



A gill net: A fishing gear used in the Keta lagoon

An Atidja and a fish weir (background): Fishing methods in the lagoon

Using a GPS receiver to locate stations in the lagoon (near Fiahor)



Taking *in situ* water parameters (DO)

Taking sediment samples with a PVC corer

Sieving sediment samples for benthic macrofauna

A densely vegetated portion of the lagoon, close to Station B

A scene at the Anloga landing

Fish catches at the Anloga landing