UNIVERSITY OF CAPE COAST

ASSESSMENT OF AQUATIC ECOSYSTEMS, THE FISHERY AND SOCIO-ECONOMICS OF A COASTAL AREA IN THE SHAMA DISTRICT, GHANA

BY

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THESIS SUBMITTED TO THE DEPARTMENT OF FISHERIES AND AQUATIC SCIENCES, SCHOOL OF BIOLOGICAL SCIENCES, UNIVERSITY OF CAPE COAST IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN FISHERIES AND AQUATIC SCIENCES

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DECLARATION

Candidate's Declaration

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

Candidate's Signature..................................... Date.....................................

Name: Isaac Okyere

Supervisors' declaration

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

Principal Supervisor's Name: Prof. John Blay

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Signature...................................... Date...............................

ABSTRACT

The study provides requisite scientific and socio-economic data for sustainable management of the fishery and aquatic ecosystems at Anlo Beach in the Shama District, Ghana. Physico-chemical conditions, macrozoobenthic fauna, and the fish and fishery characteristics of River Pra Estuary, the associated wetlands and marine waters were studied from February 2012 to December 2013. Economics of the fishery, governance and other livelihood activities were also investigated. Data were partly analyzed with quantitative (FiSAT and Ecopath with Ecosim) and qualitative (loop analysis) fishery modeling tools. High turbidities (> 500 ppm), low dissolved oxygen (< 5 mg/l) and high nitrate and phosphate concentrations were recorded in the estuary especially in 2012 possibly emanating from illegal mining activities upstream. Densities of pollution indicator animals, such as *Nereis*, *Capitella* spp. (Polychaeta), and *Tubifex* spp. (Oligochaeta) were below 1000 individuals/m^2 suggesting the ecosystems had low organic pollution. A total of 65 fish species from 38 families were found, with the highest diversity (H'= 3.42) occurring in the sea, followed by the estuary (H'= 2.63), and wetland (H'= 1.75). Results indicate the fishery may have exceeded the maximum sustainable yield, with over-exploitation (E > 0.05) of barracudas and small pelagic fishes. About 70% of the fishermen were classified as poor, earning below Ghana's 2013 minimum wage of GH¢ 5.24 (≈US$ 1.87) per day. Model predictions showed that fish stocks could be revamped by eliminating undersized mesh nets and introducing pots to exploit shrimps. Recommendations to improve water quality, fisheries management and diversified livelihood are provided.

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DEDICATION

This work is wholly dedicated to my father Mr. Samuel Asiedu

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CHAPTER ONE

INTRODUCTION

Background

Literature on interrelationship between population, environment and development offer mixed theoretical views, some of which are contradictory (Marquette, 1997; Demont, Jouve, Stessens & Tollens, 2007). For example, the Malthusian theory (Malthus, 1798; cited in Marquette, 1997) suggests that the size and growth of human population depends on food supply and ecosystem resource exploitation methods while Boserup's theory proposes that resource exploitation methods depend on the size of the population, and that in times of pressure, food production is increased by increasing workforce, machinery and other innovations (Boserup, 1965). However, in the view of Lee (1986) and Demont *et al.* (2007) both Boserupian and Malthusian processes are complementary rather than contrasting each other. In spite of the mixed views, these theories point to the fact that human existence depends on the capacity of various ecosystems to continue to provide the goods and services. Therefore, changes in availability of these ecosystem benefits could impact on the socio-economic development of societies and countries.

Ecosystem resources such as forestry, water and fisheries have long not been considered as common-pool resources (Ostrom, Gardner & Walker, 1994). In other words, the exploitation of these resources did not take into account the fact that they were systems that generated finite quantities of resource units, and one person's use subtracts from the quantity of resource units available to others. According to Hardin (1968), the "tragedy of the commons" or a system collapse will occur in such highly valued, open-access commons if those involved or external authorities do not establish an effective resource governance regime. The governance regimes are required to regulate authorization, timing, quantity, location, technology, maintenance, monitoring, enforcement, conflicts resolution, and change of rules over time with changes in the resource performance and the strategies of participants (Ostrom, 2002).

The increasing exploitation of resources has resulted in the alteration of the capacity of ecosystems to continue providing many of these services. Consequently, ensuring the viability of the world's ecosystems has become an issue of serious international concern, with the main focus being the promotion of integrated management of ecosystems which ensures conservation and sustainable use of their resources (CBD, 1992; WRI, UNDP, UNEP & World Bank, 2000; MA, 2001; World Bank, 2005; UNEP, 2009). In this regard, different frameworks have been proposed and used in the analysis of issues for strategic interventions in ecosystems and natural resource management. The environmentalist-based approaches such as the Millennium Ecosystem Assessment (MA, 2001) and the Convention on Biological Diversity (CBD, 1992) focus on the concept of 'ecosystems sustainability and human well-being' while the populist approaches focus on the concept of 'sustainable livelihoods' as central to the debate about development, natural resource management and poverty reduction (Scoones, 1998; Knutsson, 2006). In any case, the increasing rate of natural resource degradation (WRI *et al*., 2000) and the consequent serious threat posed to livelihood security (Knutsson, 2006) calls for crucial strategic management interventions in the local context within the frameworks of both environmentalist and populist approaches.

In tropical small-scale fisheries, poverty, high population growth and the lack of alternative livelihoods have been identified as the main factors driving the overexploitation of fisheries resources (Pauly & Chua, 1988; Pauly, Silvestre & Smith, 1989). In recent times, the phenomenon of Malthusian overfishing described as a situation where there is fisheries overexploitation by poor fishers in an effort to maintain their incomes and source of animal protein, has been reportedly prevalent in many artisanal fisheries of developing countries in tropical areas (Pauly, 1997; McManus, 1997). As indicated by Pauly (1997), the consequence of this overfishing on the fishers and the environment is further exacerbated by habitat degradation, pollution, damaging fishing practices and ineffective management, if any. If not effectively managed, the fish stocks and other resources could become depleted (Roughgarden & Smith, 1996) thereby depriving the dependent communities of their livelihoods and income, and further deepening poverty. It therefore presents a wake-up call for comprehensive assessment of small-scale fisheries and the environmental and socio-economic settings in which they operate in order to institute practical management interventions for their sustainability.

It is in this regard that Anlo Beach, located in the Shama District of the Western Region of Ghana with a vibrant small-scale fishery was identified for detailed study to assess fishery production levels in relation to fishing practices, environmental conditions of the aquatic ecosystems, and socio-economics of the community. Results of the study would ultimately determine the need for utilization of appropriate fisheries and ecosystem management interventions to ensure a sustainable fishery production.

The research was largely based on the sustainable livelihoods frameworks (Scoones, 1998; Knutsson, 2006; UNEP, 2009) and the Millenium Ecosystem Assessment (MA, 2001) concept which aims at establishing a scientific basis for actions required to enhance the contribution of ecosystems to human well-being, and identifying the types of responses that can be adapted from local to global scales. The MA places human well-being as the central focus for assessment, while recognizing that biodiversity and ecosystems also have intrinsic value. Therefore the MA conceptual framework assumes that a dynamic interaction exists between humans and ecosystems, with the changing human condition serving to both directly and indirectly drive change in ecosystems and with changes in ecosystems causing changes in human wellbeing. In addition, many other factors independent of the environment change the human condition, and many natural forces influence ecosystems. Particularly, the MA focuses attention on the linkages between ecosystem services and human well-being. A full assessment of the interactions between humans and ecosystems requires a multidisciplinary and multiscale approach due to the complexity and varied scales of the interrelationships. This reflects in the multiscale nature of decision-making, allowing the full examination of the endogenous and exogenous driving forces and providing a means of examining the differential impact of ecosystem changes and policy responses. Within the MA context, this study identified key variables central to the assessment to facilitate the identificaion of areas that need strategic intervention. Among the key variables considered were water quality, fisheries biodiversity and exploitation, livelihood assets, demography, cultural settings and institutional structures which are prerequisites for identification and planning of sustainable livelihood interventions. This integrated approach was meant to fill knowledge gaps that could also inform management policies under similar conditions elsewhere. It was also meant to provide a basis for empirical examination of resource management theories based on population-environment-development nexus within a developing country context.

Establishing the basis for management of the ecosystems and the fishery

As pointed earlier, the primary objective of the study was to provide both scientific and socio-economic data needed as a basis for instituting informed management actions covering the ecosystems, fishery and other livelihoods for sustainable outcomes. According to FAO (2002), such a fisheries management goal requires the collection of comprehensive data on the aquatic environment, the fish and the fishers that form an essential component of the fishery. Therefore, the study at Anlo Beach focused on assessing (a) the health of the aquatic ecosystems (b) fishery biodiversity and biology of principal species (c) characteristics of the fishery and (d) socio-economics of the area.

Aquatic ecosystem health indicators

Several authors present convergent views on the parameters that define "ecosystem health". According to Costanza (1992), an ecological system is healthy and free from 'distress syndrome' if it is stable and sustainable – that is, if it is active and maintains its organization and autonomy over time and is resilient to stress. Similarly in the view of Costanza and Mageau (1999) a healthy ecosystem has the ability to maintain its structure (organization) and function (vigor) over time in the face of external stress (resilience). Boesch and Paul (2001) also defined a healthy ecosystem as one that actively produces and maintains its biological organization over time, and is resilient to stress. In a further extension, Rapport *et al*. (2001) incorporated ecosystem ecology (i.e. organization, function and resilience), human health (the risk posed to humans from exposure to pathogens or toxicants in the aquatic environment or in seafood), socio-economic activities and livelihoods as part of the determinants of ecosystem health as they are all linked to the goods and services provided by ecosystems. From these definitions it is clear that ecosystem structure, function and resilience are the key determinants of ecosystem health. Reports (Boesch & Paul, 2001; Gaydos *et al.*, 2008) show that coastal ecosystem health largely relates to their ability to provide clean waters, assure a diverse biota and support fisheries production.

An "indicator" of ecosystem health is a parameter or value that reflects the condition of an environmental (or organismal health) component of the ecosystem, usually with a significance that extends beyond the measurement or value itself (Canada and the United States, 1999). Boesch and Paul (2001) explained that there are no commonly accepted parameters or benchmarks for assessing the health of all ecosystems. In other words, the same change in an ecosystem can be good for some, and bad for others. For this reason, this review will focus on coastal ecosystems as it pertains to this study.

In coastal ecosystems, the commonest way to monitor the ecosystem's health is to measure selected indicators in defined areas of the ecosystem to represent the whole (USEPA, 1998). Although measurement of processes or rate of activities, e.g. primary production, flux of nutrients, or yield as reflected by harvests are occasionally used as ecosystem health indicators, the most widely and commonly used indicators are broadly grouped into two categories: (i) assessment of biological structure (e.g. biomass, community composition and diversity, incidence of diseases) and (ii) measurement of physical and chemical states (e.g. temperature, transparency, turbidity, salinity, concentrations of nutrients, dissolved oxygen, pH, chlorophyll, heavy metals).

In assessing biological structures, phytoplankton community composition has proven very useful for evaluating conditions of coastal ecosystems because they are the major primary producers, have fast growth rates, and are sensitive to environmental disturbances (USEPA, 2005). However, benthic macroinvertebrates are preferred because apart from serving as reliable indicators of pollution, hydrologic stress and ecological health in general (Nazarova, Semenov, Sabirov, Efimov, & Yu, 2004), they are also inexpensive to sample and easy to identify with already established diversity and monitoring indices. Since different species of macroinvertebrates react differently to environmental stressors like pollution, sediment loading and habitat changes, quantifying the diversity and density of different benthic macrofauna at a given area can provide evidence of prevailing environmental conditions (Acharyya & Mitsch, 2001; Arslan *et al.*, 2007). In addition, the sedentary nature of macrozoobenthos, together with their ubiquitous distribution and life cycles of measurable duration allow for both long- and short-term analyses (Rosenberg & Resh, 1993).

While biological characterisations of ecosystem health are extremely important in part, they are most useful when combined with physical and chemical habitat assessments. This is because the composition and diversity of biological communities, biological productivity and other related biological interactions in ecosystems are largely dictated by the prevailing chemical and physical conditions of the habitats (Craft, 2000). For example, most aquatic organisms survive between pH range of 5 and 9, and with the exception of some bacteria and microbes, higher or lower pH than this range could lead to high mortality of aquatic organisms. Low pH increases the solubility of nutrients like phosphates and nitrates making them more readily available to aquatic plants and algae, and promoting eutrophication and algal blooms. As these blooms die, bacteria numbers increase in response to the greater food supply. They, in turn, consume more dissolved oxygen from the water, often stressing or killing fish and aquatic macroinvertebrates.

Also, Bilotta and Brazier (2008) discussed how aquatic organisms are particularly susceptible to the effects of increased sediments and turbidity. Many fish need clear water to see their prey. Macroinvertebrates, fish eggs, and larvae require oxygen-rich water circulating through clean gravel beds to survive. Sediments can smother fish eggs and aquatic insects on the bottom and can even clog the gills of clams and oysters as they filter water for food. Sediment and other dissolved substances also decrease light penetration, which inhibits aquatic plant photosynthesis. Because turbid water absorbs more of the sun's energy than clear water, high turbidity leads to higher water temperatures which can severely affect many aquatic organisms that have adapted to survive within narrow temperature ranges.

In this study, the benthic macrofauna community was surveyed as the biological component of the indicators while water temperature, turbidity, salinity, dissolved oxygen, pH, nitrates and phosphates were monitored as physico-chemical indicators of the health of the ecosystems. The state of these indicators can provide benchmarks for comparison with other waters and can also be used to define rehabilitation goals and monitor trends.

Fishery biodiversity, characteristics and exploitation

Fisheries biodiversity information is important in identifying the structure, functional role and state of ecosystems and fish communities (Scherer-Lorenzen, 2005), and is thus a useful tool in designing ecosystem management and conservation strategies (Humbert & Dorigo, 2005). Knowledge of the diversity of species exploited in the fishery (i.e. whether single species or multi-species fishery), species richness, abundance and size composition are all very relevant in defining management goals (King, 2007), as they in part contribute to addressing the issues of gear design, mesh size, allowable catch, etc. (FAO/MRC, 2003). Other population dynamics information including reproduction, recruitment and growth largely complements fisheries biodiversity data for a more efficient management planning (King, 2007).

Perhaps, the most important requirement of fisheries management is the assessment of the size and state of the stocks exploited by fishers (Hilborn & Walters, 1992). The basic concern of stock assessment, according to Hilborn and Walters (1992), is to go beyond the obvious qualitative predictions and make use of various statistical and mathematical calculations to make quantitative predictions about the reactions of fish populations or community to alternative management choices. FAO (2006) points out that the most useful data for such quantitative stock assessment purposes are biomass, stock abundance, age distribution, catch, mortality, exploitation patterns, effort, length frequencies and other important biological indices. These data are largely acquired through landing survey, laboratory studies and the use of some theoretical or synthetic indices, models, etc., which are examined to address specific management objectives.

For development of full management plans however, the FAO code of conduct advises the inclusion of other relevant ecological threats posed to the fishery as well as economic and social factors driving the exploitation of the fish stock (Cochrane, 2002). The ecological data primarily deals with the impact of fishing gears and activities on the physical habitat while the economic data include average income, costs and profitability. The social component includes the demography of fishers, role of gender in direct and indirect fishing activities and disaggregation of the various fishing activities by different age groups.

In addition to the aforementioned areas of information need, FAO (2003), Bianchi (2008), O'Boyle, Sinclair and Worcester (2008), Fletcher, Shaw, Metcalf, and Gaughan (2010) and several other workers have discussed a broader scope of data requirement in modern ecosystem based fisheries management approaches. These cut across water quality, critical habitats, climatic impacts, diversity and trophic relations including other interactions between target and associated species in a multispecies fishery, fishing effort, gear selectivity, catch and by-catch, governance structures for managing the fishery and related activities among others. Analysis of this vast array of data from various perspectives provides a more comprehensive understanding of relevant issues and enables formulation of effective management policies.

Since the present work is situated within the context of the ecosystem-based approach, the study explored the fisheries biodiversity, maturity sizes of populations, trophic relations, fishing efforts, mesh sizes, catches and catch composition. Also investigated were incomes and profitability of the fishing business from the perspective of fishermen and fishing net owners and other livelihood activities that are directly or indirectly dependent on the fishery. The broad nature of the study allowed for comprehensive identification of specific management needs for the Anlo Beach fishery. The use of ecosystem models to identify management indicators in the fishery and determine the likely impacts of alternative management options through model predictions would therefore help ascertain the appropriate "points of entry" for intervention strategies. To the best of the author's knowledge, this is the first study to comprehensively assess the fishery and socio-economics of a beach seine community in Ghana. The only known previous work focused on assessing the occurrence of macro-algal by-catch in the beach seine fisheries at Sakumono in Ghana (Nunoo & Ameka, 2005).

Employing qualitative and quantitative ecosystem models in the study

It has been discussed by Dambacher, Gaughan, Rochet, Rossignol and Trenkel (2009) that implementation of ecosystem-based fisheries management requires indicators and models that address the impacts of fishing on ecological communities. Ecological or ecosystem models (both quantitative and qualitative) have been widely used in studies that address aquatic ecosystems and related fisheries resource utilization (Stone, 1990; ICLARM, 1993; Mendoza, 1993; Pauly, Sambilay, & Optiz, 1993; Bax, 1998; Bakun & Weeks, 2006; Lozano-Montes, Loneragan, Babcock, & Jackson, 2011).

Although quantitative and qualitative models are very useful tools in ecosystem management research, each has its own limitations. According to Justus (2006) qualitative models lack precision, but Ramsey and Veltman (2005) hold the view that precise estimates of magnitude are not always necessary for management, but rather general relationships and trends. Similarly, quantitative models have been criticized to be more reliable for single species analyses than multi-species analyses because estimates of species interaction strengths are in practice less available as the degree of parameterization required increases

(Dambacher *et al*. 2009). The two are therefore sometimes employed in a single study to complement each other thereby minimizing uncertainties in model predictions (see Metcalf, 2010; Lassalle *et al.*, 2013). Qualitative loop analysis or sign digraph modelling (Puccia and Levins, 1985) and quantitative Ecopath with Ecosim (EwE) modelling (Christensen, Walters & Pauly, 2005) were independently used in this study to examine management objectives from different scenarios.

Sign digraph uses signs to show the extent of interactions between species or variables, with values of +1, −1 and 0 representing enhancing, inhibiting and null effect respectively between interactions. A detailed description of basic qualitative modelling methods including community matrices and the use of negative adjoint matrix are presented by Puccia and Levins (1985) and Dambacher, Li and Rossignol (2002). Ecopath with Ecosim is a trophic model tool that analyses organic matter and energy flows within a steady-state or static (Ecopath) and dynamic (Ecosim) mass-balance system as shown by Christensen and Walters (2004) and Christensen et al. (2005). This has been extensively used in the analysis of trophic states, fisheries utilization and policy directions many coastal-marine ecosystems (Polovina, 1984; Pranovi et al., 2003; Fetahi, 2005; Coll, Bundy & Shannon, 2008; Christensen et al., 2014).

Research objectives

The primary objective of the study was to provide both scientific and socio-economic data needed for the sustainable management of the ecosystems and fishery of the Anlo Beach area.

The specific study objectives were to:

i. monitor the seasonal changes in water temperature, salinity, turbidity, dissolved oxygen, nitrates, phosphates and pH of the River Pra estuary and adjoining marshes, and also investigate the diversity of benthic macroinvertebrate fauna as indicators of water quality and ecosystem health

ii. study the fish diversity, food habits of the species and aspects of the population dynamics of the blackchinned tilapia in the estuary

iii. assess characteristics of the fishery based on fishing effort, fishing methods, gear selectivity, fish catch and catch composition and fisheries economics

iv. examine the linkages between livelihood assets, livelihood activities and ecosystems using ecological models to identify opportunities for strategic interventions

CHAPTER TWO

MATERIALS AND METHODS

Description of study area

Anlo Beach is a small artisanal fishing community in the Shama District of the Western Region of Ghana (5° 01' 06" N, 5° 02' 14" N and 1° 35' 56"W, 1°37' 33" W) (Figure 1). It is entirely made up of migrants from the Volta Region of Ghana, settled on a strip of land between the River Pra Estuary and its associated mangrove swamp and the sea. The River Pra Estuary is the second largest estuary in Ghana after the Volta Estuary, with about 1,000 ha of adjoining marshlands and floodplains which serve as important fishery resources for Anlo Beach and nearby communities such as Shama Apo, Bosomdo and Krobo located along the banks of the estuary. At Anlo Beach, construction of artisanal fishing settlements within the vicinity of fast eroding shorelines and river banks is causing shoreline retreat, crowding of living space and increasing the risk of the settlements and infrastructure to erosion and flooding.

Data from the 2010 national census obtained from the Statistical Survey Department, Western Region, indicated a population of 3,376 in Anlo Beach comprising 1,494 males and 1,882 females living in 790 households in 785 houses. However, statistics from a census undertaken by the community elders prior to their connection to the national electricity grid indicated a population of about 5000 living in 684 houses as of 2012. According to CRC/FoN (2010), the

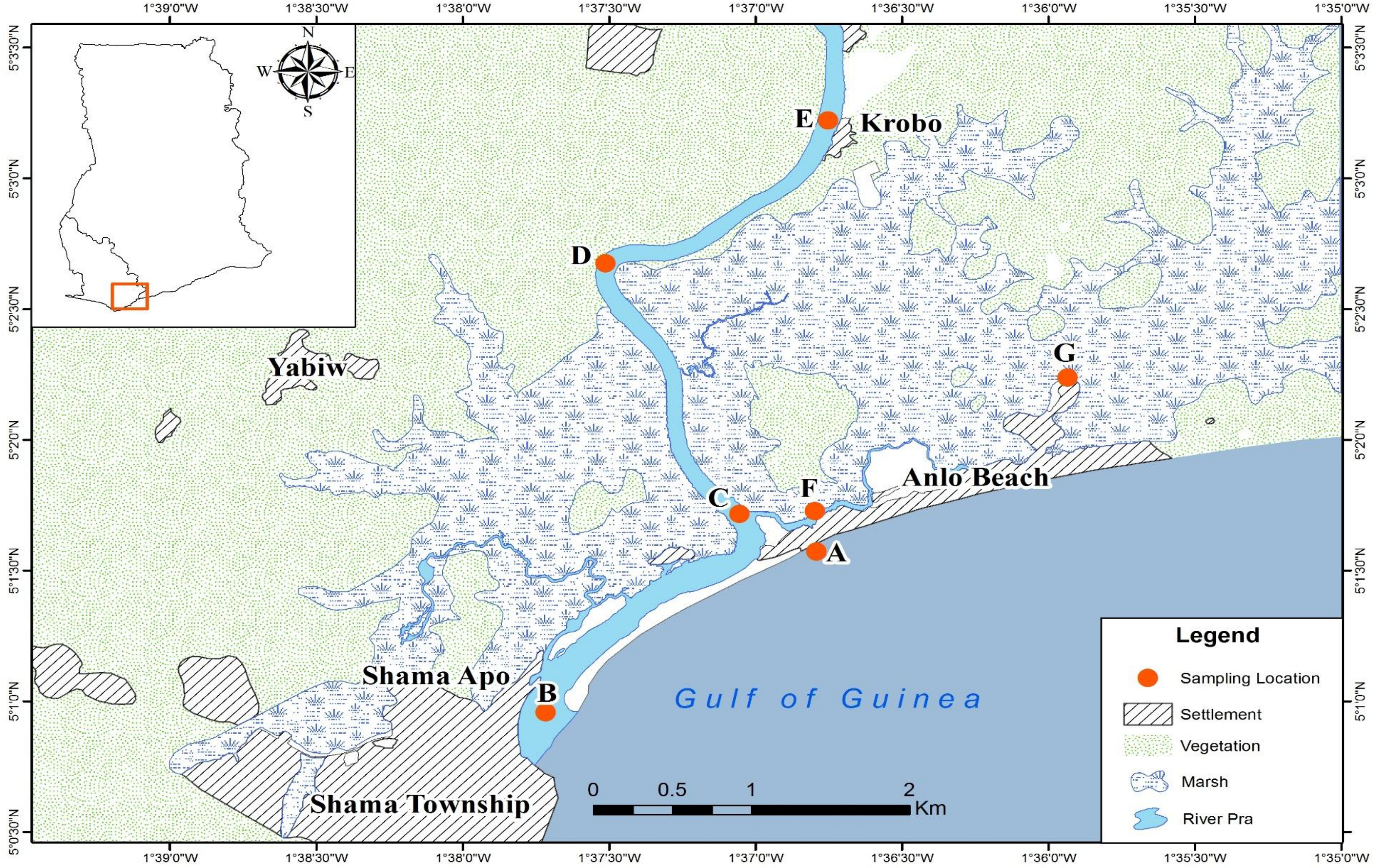


Figure 1: Map showing the Anlo Beach area and the sampling stations

settlement pattern of the community can be classified as clustered with an average cluster of three houses fenced with raffia palm fronds or bamboo. Most of the houses are built from clay bricks with thatched roof; there are few cement block houses with asbestos roofing. Coconut trees fringe the stretch of sandy beach, fronting the settlements from the Atlantic Ocean. Mangroves of the genera *Avicennia*, *Rhizophora* and *Laguncularia* fringe the banks of the estuary and extend over three kilometers on both sides of the estuary. The trees are highly exploited as the main source of firewood for cooking and smoking fish in the community thereby resulting in degradation of the mangrove forest. The adjoining marshland has the saltwater grass *Paspalum vaginatum* (Poaceae) as the main vegetation.

Fishing (beach seining) and fish monging are the major livelihood activities running from mid-July to late April. Subsistence farming becomes the predominant occupation after April, lasting for about three months in the off-fishing season after which the community switches back to fishing in mid-July or early August for the main fishing season. Menial retail activities including small scale shops and gari processing are however prevalent throughout the year, mainly operating from houses. Not all fishermen practise farming during the off-fishing months, and very few members of the community are entirely small scale farmers who only fish for subsistence. Cassava and maize are the major crops produced although a few farmers cultivate cash crops such as oil palm and coconut. Historically, coconut farming was a major livelihood of the people until the 1990s when the Cape St. Paul Wilt disease gravely destroyed their farms, causing some families whose livelihoods were dependent on the farming to migrate out of the community for greener pastures elsewhere while others engaged in fishing.

Anlo Beach has a vast array of livelihood assets and potentials, and a few services. Natural capital include the sea and fisheries resources, beach, sand, River Pra Estuary, wetlands including swamps and saltmarshes, mangrove swamp, mangrove forests, dry land and farm lands. There are no banks and savings and loans companies at Anlo Beach. There are however individual money lenders mostly fish mongers and net owners who give loans for occupational and personal activities. The Shama Credit Union and a "Susu" collection outfit are operating micro-finance institutions in the community and give loans to the contributors. The net owners and other individuals who save at the Lower Pra Rural Bank at Shama are able to secure loans from the bank. There are three basic schools in the village with about 60% of the people being literates who can read and write to a considerable extent but have had no formal training on their fishing and farming occupations. Some fishermen have apprenticeship training in other vocational skills such as carpentry, masonry, tailoring, etc. There is one community-based health planning services (CHPS) compound which serves as the only health care center in the community.

Some Non-Governmental Organizations (NGOs) currently operate in Anlo Beach on a number of issues ranging from livelihoods and microfinance to environment and sanitation. The Christian Rural Aid Network (CRAN) was instrumental in assisting the community to have a basic school, and currently provides credit to support the activities of fishermen, fishmongers and other businesses. The Institute of Environment and Sanitation Studies (University of Ghana) together with the Hans Seidel Foundation periodically engages the pupils between age 11 and 16 in issues related to appropriate sanitation practices, coastal degradation and ecosystem conservation, in the form of talks and drama. The Friends of the Nation (FoN) in collaboration with the Coastal Resources Centre of the University of Rhode Island (USA) undertook the Intergrated Coastal and Fisheries Governance (locally known as *Hen Mpoano*) project which addressed issues of sustainable fisheries management and coastal ecosystem conservation for improvement of livelihoods and reduction of poverty in the community, of which this study constituted an important component.

Three smaller communities are located along the banks of the Pra estuary; Krobo and Bosomdo about 3 km north of Anlo Beach, and Shama Apo near the Shama township occurs about 1 km west of Anlo Beach.

Sampling Stations

Seven stations were selected for the sampling for physico-chemical parameters and benthic macroinvertebrates (Figure 1). The basis for selection of the stations was to ensure that each location represents the characteristics of the ecosystem in which it is found. Station A was located in the marine environment, Stations B, C, D and E about 1 km apart in the estuarine system and Stations F and G the wetland (mangrove and marsh swamps respectively) (See detailed GPS coordinates of the stations in Appendix A). Fish sampling was however random in the three ecosystems.

Measurement of Environmental parameters

Temperature, salinity, conductivity, turbidity, dissolved oxygen and pH were measured with a portable hand-held water quality checker (Horiba, model U-10). Sampling was undertaken monthly from February 2012 to December 2013 (five days in each month at low and high tides, between 6 hrs GMT and 18 hrs GMT depending on time of occurrence of the tides), to ascertain water physico-chemical and fisheries biodiversity relative to tidal variations.

Nitrate and phosphate concentrations were assessed from December to February (dry season) and June to August (wet season). Nitrate concentration was determined using the U.V. spectrophotometric screening method following procedures in American Public Health Organization (1992) and Vogel and Mendham (2000).

Water samples for determination of total phosphates were frozen in ice. Phosphate concentration was determined using the ascorbic acid spectrophotometric method (See Vogel & Mendham, 2000).

Determination of Upwelling Index (UI)

Monthly variation of the intensity of upwelling in the coastal waters of Ghana was determined by subtracting the sea surface temperature (SST) from 25°C, the threshold set for upwelling in the Gulf of Guinea (Bakun, 1978). The higher the index the better the upwelling.

Sampling of benthic macroinvertebrates

An Ekman grab (15 cm × 15 cm) was used to sample sediments in the estuary and marshlands for the study of the species richness, composition and diversity of the macroinvertebrate community except Station A. Three replicate sediment samples were collected monthly from each station. The samples were sieved in the field using a set of sieves of mesh sizes 4000 μm, 2000 μm and 500 μm, and the animals retained in the sieves were preserved in 10% formalin for detailed examination in the laboratory. Prior to sorting, a pinch of Bengal rose dye was added to the samples to enhance visibility of the organisms. The macrofauna were examined under a dissecting microscope and identified with the aid of laboratory manuals (Day, 1967; Brinkhurst, 1971; Yankson & Kendall, 2001; Hauer & Lamberti, 2006). Counts of the different taxonomic groups in the samples were recorded for further analysis.

Fish Sampling and Data Collection

Fish were caught from the estuary at high and low tides and the wetland using a 20 mm stretched mesh cast net to determine fish community composition, richness and diversity as well as size distribution of the populations. Marine fish samples were obtained from landing in the local fishing. Samples were preserved in 10% formalin soon after capture to arrest post mortem digestion of stomach contents and transported to the laboratory for further examination. The fish were sorted and identified to their families and species using manuals and keys on finfishes and shellfishes for Ghana and West Africa (Rutherford, 1971; Schneider, 1990; Dankwa, Abban & Teugels, 1999; Paugy, Lévêque & Teugels, 2003), and the number of individuals belonging to each species was recorded.

The total length (TL) and standard length (SL) of finfish, carapace width (CW) of crabs and body length (BL) of shrimps were measured to the nearest 0.1

cm. The body weight (BW) of the finfish and shellfish (shrimps and crabs) was determined to the nearest 0.01 g. Stomachs of fish of commercial value were dissected and the content examined using a dissecting microscope where necessary.

Black-chinned tilapia (*Sarotherodon melanotheron*) specimens were sexed and the gonad weighed to the nearest 0.01 g. Gonads were classified into two stages of development; i.e. ripe or developing, following the descriptions by King (2007).

Ripe ovaries were preserved in 10% formalin for fecundity studies by the whole count method (Bagenal & Braum, 1978). Eggs were teased from the ovarian tissue in a petri dish and the immature ova were separated from mature ones prior to counting the latter.

Assessment of the fishery

Observation on the fishery in the study area was made from August 2012 to December 2013. The methods of fishing and fishing gears used were recorded. The lengths and stretched mesh sizes of fishing nets were measured using a measuring tape and a rule respectively. The number of fishing nets, the number of fishermen operating a net, the number of net hauls per group per day, and the time (h) spent per fishing operation were recorded. The time spent per fishing operation was estimated from the time the fishermen began casting the net to the time the catch from the haul was completely sorted and sold.

The catch from each haul was weighed to the nearest 0.05 kg and the daily total catch for each fishing group was determined by summing up the catches from the number of hauls per day. Where possible, catches were also sorted by species and weighed. Daily catches from 11 fishing groups were totaled on a monthly basis, and the average monthly catch per group estimated. Catch (kg) per unit effort (CPUE) was computed as (a) catch per haul per day and the mean for the month computed for 11 fishing groups, and (b) catch per hour per day based on 50 to 120 casts of the nets per month.

The income from fishing operations was determined as the market price of the fish at the time of landing, described by Hanemann (1991) as the direct pricing method. The price of fish from each haul was recorded and the daily income of each group was calculated as the sum of the income from all hauls in the day. Operational cost was estimated from the cost of casting and hauling, mainly allowances for the casting crew and those who protect the nets from being destroyed during hauling, and cost of canoe, net, and net maintenance after a fishing operation or fishing season. For costs that are not incurred on daily basis, the amount was divided by the number of fishing days in the fishing season to obtain the cost per day. Daily profit for each group was calculated as the difference between daily operational cost and daily income, half of which goes to the net owner, and the remaining half shared among the fishermen in the group. The average monthly income for each of net owner and fisherman was estimated based on the daily income.

Fish and benthic macroinvertebrate data analysis

The benthos and fish communities were analyzed for species composition, species richness and diversity. Richness and diversity were ascertained using Margalef's index and the Shannon-Wiener index (Krebs, 1999) respectively.

Margalef index (d) is given as $\frac{(s-1)}{\text{In } N}$ where s is number of species in the community, and N is the number of individuals in the community. The Shannon-Wiener index (H') is given as H' = -$\sum_{i=1}^{s} P_i(lnP_i)$, where s is the number of species in the community and P_i is the proportion of individuals belonging to species i in the community. The evenness or equitability component of diversity was calculated from Pielou's index (Pielou, 1966) given as $J' = H'/H_{max}$ where H_{max}= ln$s$.

The percentage numerical composition of the different families of macrobenthic animals in the community was calculated. The mean density of each of the families (arithmetic mean) was first calculated as the number of individuals of each family per dredge area (225 cm^2 = 0.0225 m^2), and the resultant value converted to mean number of individuals per 1 m^2 by multiplying this number by a factor of 44.4 (See Elliott, 1977).

To compute the 95% confidence limits, the variance of transformed counts was first calculated as $\frac{\sum(\log_{10} x-\bar{y})^2}{n-1}$ where $\bar{y}$ is the arithmetic mean of transformed counts and n is the sample size. The 95% confidence limits were computed as the antilog of $\bar{y} \pm t \sqrt{\frac{variance\ of\ transformed\ counts}{n}}$ where t is a tabular statistical value at the 5 % level of probability.

Stomach contents of fish were analysed using the numerical, gravimetric, "points" and the frequency of occurrence methods (Hyslop, 1980; Lima-Junior and Goitein, 2001) where applicable. The numerical, gravimetric and "points" methods give the bulk contribution of each food item to the total food consumed while frequency of occurrence expresses the number of stomachs in which each food item occurs as a percentage of all stomachs containing food. Result from each of the methods was expressed as a percentage. Using the percentage frequency of occurrence (% F), numerical percentage composition (C_n) and the gravimetric percentage composition (C_w) of the different food items, the index of relative importance (IRI) of each food item was calculated as IRI = $(C_n + C_w)$ %F (Pinkas *et al.*, 1971; cited in Blay, Awittor & Agbeko, 2006).

The extent of overlap of the diet of some commonly exploited fishes was determined by using Schroener's niche overlap index ($\propto$) expressed as $\propto = 1 - 0.5\ (\Sigma|p_{xi} - p_{yi}|)$ (Schroener, 1970), where p_{xi} = proportion of prey item *i* in the diet of species *x* and p_{yi} = proportion of prey item *i* in the diet of species *y*. The index ranges from 0 (no overlap) to 1.0 (complete overlap) and values greater than 0.6 are considered as biologically significant.

Determination of growth and mortality parameters of the blackchinned tilapia (*Sarotherodon melanotheron*) population

A regression analysis was used to establish the relationship between total length and body weight of the fish. The significance of the deviation of regression coefficient b from 3.0 was determined using the equation: $t_s = (b-3)/S_b$, where S_b is the standard error of b (Morey *et al.*, 2003).

Monthly length-frequency distribution was analyzed at 1 cm class intervals. The ELEFAN programme (Gayanilo, Sparre & Pauly 2005) in the FiSAT II software was used to estimate the von Bertalanffy growth parameters, K (growth coefficient) and L_∞ (asymptotic length). The growth performance index (ϕ') described in Moreau, Bambino and Pauly (1986) was calculated using the relationship $\phi' = \log_{10} K + 2 \log_{10} L_\infty$.

Total mortality (Z) of the population was obtained from the catch curve generated from the FiSAT programme which is a plot of the natural logarithm of the proportion of the number of fish caught in the different ages by the fishing gear against their corresponding relative ages. Natural mortality (M) was estimated from Pauly's empirical equation (Pauly, 1980a), given as $\log_{10}M = -0.0066 - 0.279 \log_{10}L_\infty + 0.6543 \log_{10}K + 0.4634 \log_{10}T$, where T is the mean annual water temperature of the habitat under study. The fishing mortality coefficient (F) was derived from the equation, Z = F + M (Ricker, 1975), and exploitation ratio (E) was obtained as E=F/Z.

Analysis of reproductive biology of the blackchinned tilapia (*Sarotherodon melanotheron*) population

Gonado-somatic index of male and female fish was used to ascertain the breeding periods of the population. This was determined from the equation $GSI = \frac{GW}{BW} \times 100$, where GW is gonad weight, and BW is body weight. The sex ratio of the population was calculated as the ratio of the number of males to females, and a Chi-squared test (Zar, 1999) was used to test the deviation of the ratio from one to one. Fecundity was determined by the whole count method and a regression analysis was used to establish the relationship between fecundity and body weight, as well as fecundity and body length.

Quantitative modelling of the trophic relations

Trophic relations in the aquatic ecosystems as well as the impact of the fishing activities on the fish stock were established using the ECOPATH with ECOSIM software. Twenty-five groups were identified based on their functional status in the ecosystems, or their commercial, social and ecological importance. The groups comprised reptiles, birds, pelagic and demersal fish and shellfish, worms, small crustaceans, plankton, macro-algae, decomposing matter and organic detritus (See Appendix H for list of functional groups and rationale for inclusion).

According to Christensen and Walters (2004), ECOPATH uses a series of simultaneous linear equations, one for each functional group to quantify the energetic flows among trophic groups according to the law of conservation of mass or energy. The model assumes that the net production of a functional group is equal to the total mass removed by its predators and the fishery plus its net migration and energy or mass that flows to detritus. This can be expressed as:

Production = mortality (Fishing + Predation + Other) + Biomass accumulation + Net Migration.

This is represented by the equation:

$$B_i \cdot (P/B)_i = Y_i + \sum_{j=1}^{n} B_j \cdot (Q/B)_j \cdot DC_{ji} + E_i + BA_i + B_i (P/B)_i \cdot (1 - EE_i)$$ (Walters, 2004), where, B_i and B_j are biomasses of prey (*i*) and predator (*j*), respectively;

P/B_i is the production to biomass ratio;

Y_i is the total fishery catch rate of group (*i*);

Q/B_j is the consumption to biomass ratio;

DC_{ij} is the fraction of prey (*i*) in the average diet of predator (*j*);

E_i is the net migration rate (emigration – immigration); and

BA_i is the biomass accumulation rate for group (*i*).

EE_i is the ecotrophic efficiency; the fraction of group mortality explained in the model.

A second assumption is that consumption within a group equals the sum of production, respiration and unassimilated food, which is expressed as:

Consumption = production + respiration + unassimilated food. A detailed expression is:

$$B \cdot (Q/B) = B \cdot (P/B) + (1 - GS) \cdot Q - (1 - TM) \cdot P + B \cdot (Q/B) \cdot GS$$ (Walters, 2004)

where GS is the proportion of unassimilated food; and TM is the trophic mode expressing the degree of heterotrophy; TM values of 0 and 1 represent autotrophs and heterotrophs respectively, while intermediate values represent facultative consumers.

The basic input data required for any particular functional group are: biomass (B; $t \cdot km^{-2}$), the ratio of production to biomass (P/B; yr^{-1}), the ratio of consumption to biomass (Q/B; yr^{-1}) and ecotrophic efficiency (EE) which has no unit. However, ECOPATH can estimate a missing parameter by the mass balance equation once three of the four parameters are known. Therefore, B, P/B and Q/B were the input data estimated in this study. In addition, the diet composition (DC) of most the functional groups and the total fishery catch rate (Y) were determined from the study.

Biomass estimates

The model covered a wider area from the catchment of the estuary up to the 60 meter depth contour of the marine habitat (Figure 2), with an estimated total area of 125.3 km^2. Biomass of marine reptiles was estimated using the average number of hatchlings and average weight reported by Nature Conservation Research Centre, Ghana (unpublished data) for sea turtles in the west coast of Ghana. The number of hatchlings was divided by the sampled area for density which was then multiplied by the average weight of individuals to obtain the biomass. Biomass of wetland reptiles in coastal Ghana was also estimated using data from the website of Mampam Conservation (http://www.mampam.com/) where the average density was multiplied by the average individual weight to obtain biomass.

The biomasses for marine finfish and shellfish were estimated from beach seine landings using the swept area method adopted from King (2007). The swept area was calculated by multiplying the length of the beach seine net (i.e. averagely 400 m = 0.4 km) by the length of the towing line (about 900 m = 0.9 km). The weight of each group in a haul was divided by the swept area to determine the biomass. This was done for 12 hauls and the average computed. A similar method was used to estimate the biomasses of the functional groups in the estuary, wetland and River Pra using a cast net which covered an area of 12 m^2 when cast.

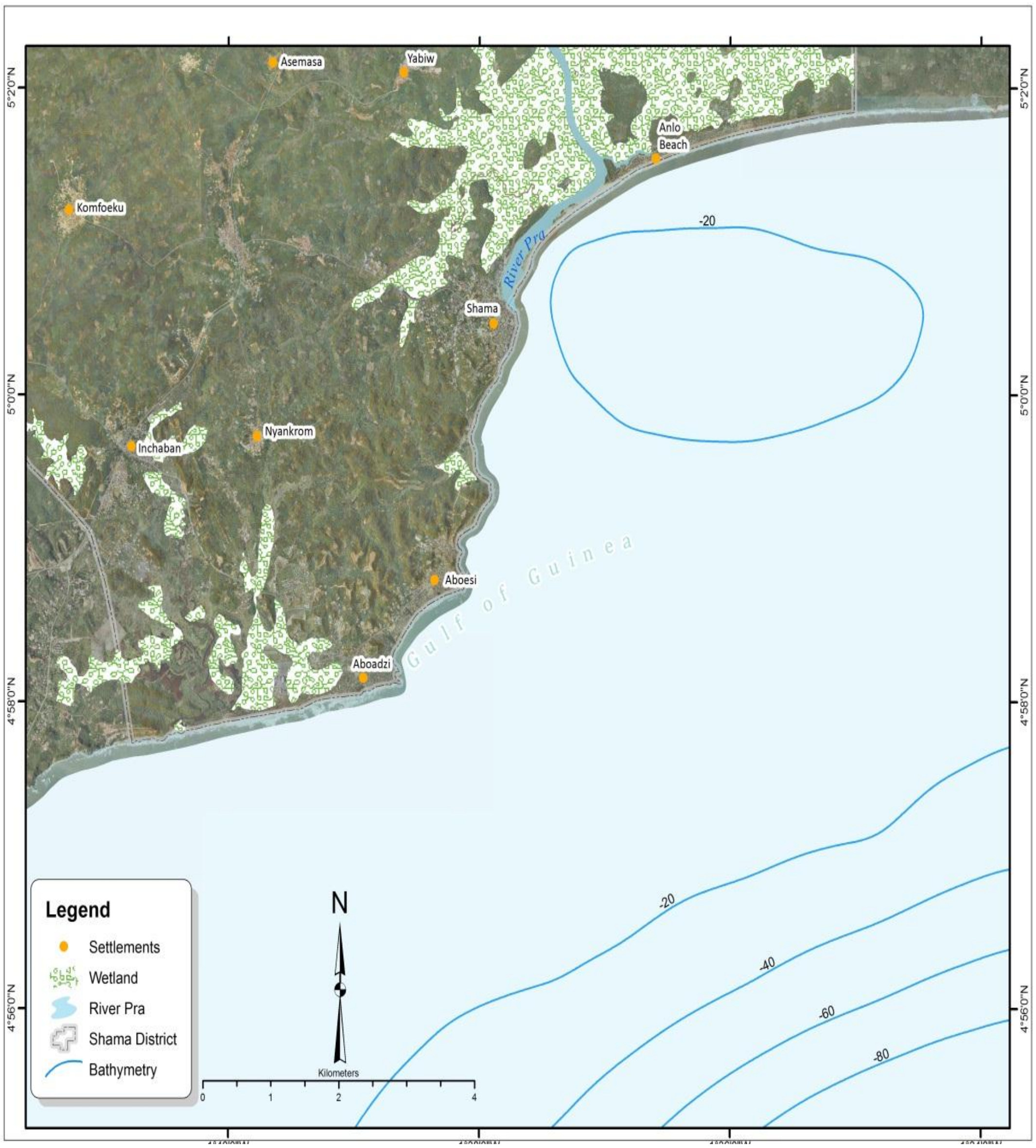


Figure 2: Map showing the area covered by the Ecopath model

For aquatic worms and crustaceans, the biomass was calculated as the product of the average weight of an individual and the mean density (number of individuals/m^2) computed from the density estimates. Since individuals were too small to weigh, the total weight of a number of specimens was determined and the average calculated to obtain the weight per individual. Data for the other functional groups were obtained from literature, e.g. the biomass for the birds was taken from Crawford (1999).

The phytoplankton biomass data on the Gulf of Guinea were obtained from Djagoua *et al.* (2011) while zooplankton data for the same area were taken from Wiafe, Yaqub, Mensah, and Frid (2008). Biomass of detritus was obtained from estimates from the Kakum River Estuary in the Central Region of Ghana (Debrah, 2013). All biomasses were expressed in tons per kilometer squared (t/km^2).

P/B and Q/B estimates

The P/B and Q/B in the current study were estimated based on reported values of B and the corresponding P/B and Q/B in literature on Ghanaian (Blay, unpublished data) and other tropical coastal waters. P/B of a functional group was calculated as $\frac{B \times P/B_1}{B_1}$, and Q/B as $\frac{B \times Q/B_1}{B_1}$, where B is the biomass in the current study, B_1 is the biomass in literature, and P/B_1 and Q/B_1 are corresponding P/B and Q/B of B_1 in literature.The B_1, P/B_1 and Q/B_1 values for the marine functional groups including finfish groups, shellfishes, phytoplankton, zooplankton and benthic worms were taken from Blay (unpublished data) and Arreguín-Sánchez, Valero-Pacheco and Chávez (1993), while that for the brackishwater and freshwater groups, and birds were obtained from De La Cruz-Aguero (1993), Aravindan (1993) and Fulton and Smith (2002) respectively.

Qualitative modelling of the fishery and related activities

Four qualitative models were developed using sign digraphs (Puccia & Levins, 1985; Dambacher *et al*., 2009; Metcalf, Gaughan & Shaw, 2009) to examine possible results of alternative management reforms. The relationships between the model variables were established in the Powerplay software [found at http://www.esapubs.org/archive/] and then converted to community matrices which were subjected to loop analysis for qualitative stability analysis (Dambacher, Luh, Li & Rossignol, 2003a) and predictions (Puccia & Levins, 1991; Dambacher, Li & Rossignol, 2003b; http://www.ent.orst.edu/loop/default/). The first model examines the interplay between the fishing nets, predatory and prey fishes including juveniles. The second and third models are alternatives to the first, and examine the possible opportunities for eliminating undersized mesh in the nets, and introducing shrimp traps (pots) into the fishery. The fourth and fifth incorporates the interrelation between all livelihood activities in the Anlo Beach Community and examines the effects of fisheries management on the other livelihood and economic activities, as well as the potential reverse effect of the other livelihood activities on the fishery.

Socio-economic studies

A Rapid Resource Appraisal (RRA) and Participatory Rural Appraisal (PRA) was undertaken through questionnaire survey and Focus Group Discussions (FGDs) on historic evolution of socio-cultural settings and livelihoods, livelihood assets including natural, social, economic and human capital, institutions, drivers of change in ecosystems and livelihood strategies (see sample questions in Appendices M and N). Community opinion leaders and fisherfolk comprising 14 men and 11 women were the respondents. Secondary data on demography was obtained from the Planning Unit of the Shama District Assembly.

Poverty and wealth ranking was assessed by compiling a list of all households in the community and documenting the sex of the head of household. A household was defined as a group of people who lived in the same house and ate from the same pot. Several households in the same compound but eating from different pots were treated as separate households. A discussion with a group of key informants on the criteria used to describe wealth was held and they classified each of the households as poor, middle class or rich, and the frequency of the different classes was calculated. Poor households were said to be those with difficulty in affording a single meal for a day, difficulty to send all their children to school, cannot afford to visit the hospital when sick, depend on other people for clothing, always working for others in farms, as fishing crew, or helping fishmongers to smoke their fish. They also worked as head porters who carried fish and farm produce for others.

CHAPTER THREE

RESULTS

Physico-Chemical conditions of the aquatic ecosystems

Water Temperature

The monthly variations in the water temperature of the three ecosystems and the annual mean temperature at the sampling stations are shown in Figure 3a and 3b respectively. Water temperature ranged from 21.8±1.3 ^{o}C to 29.7 ± 0.4 ^{o}C in the marine environment, with the highest recorded in dry season in March, 2012 and the lowest in the wet season in July, 2013 where it dropped below the 25 ^{o}C isotherm. Significantly lower mean surface temperatures occurred in the sea in 2013 than 2012, but temperature did not vary with tide. The estuary had water temperature within a range of 24.3±0.8 ^{o}C to 31.5±0.3 ^{o}C, recorded during the 2013 wet season and dry season respectively. The annual mean temperature in 2012 was not significantly different from that of 2013 at all the sampling stations in the estuary. In the wetland, the lowest water temperature of 25.3±0.9 ^{o}C was also recorded during the peak of the wet season (July 2013) and the highest of 31.7±0.7 ^{o}C in the dry season (March 2013). There was no significant difference between the wetland water temperature in 2012 and 2013 although Station G appeared warmer at low tide in 2012. In general, temperature variations followed similar trend in the three ecosystems, with relatively low temperatures during the wet season and higher temperatures during the dry season.

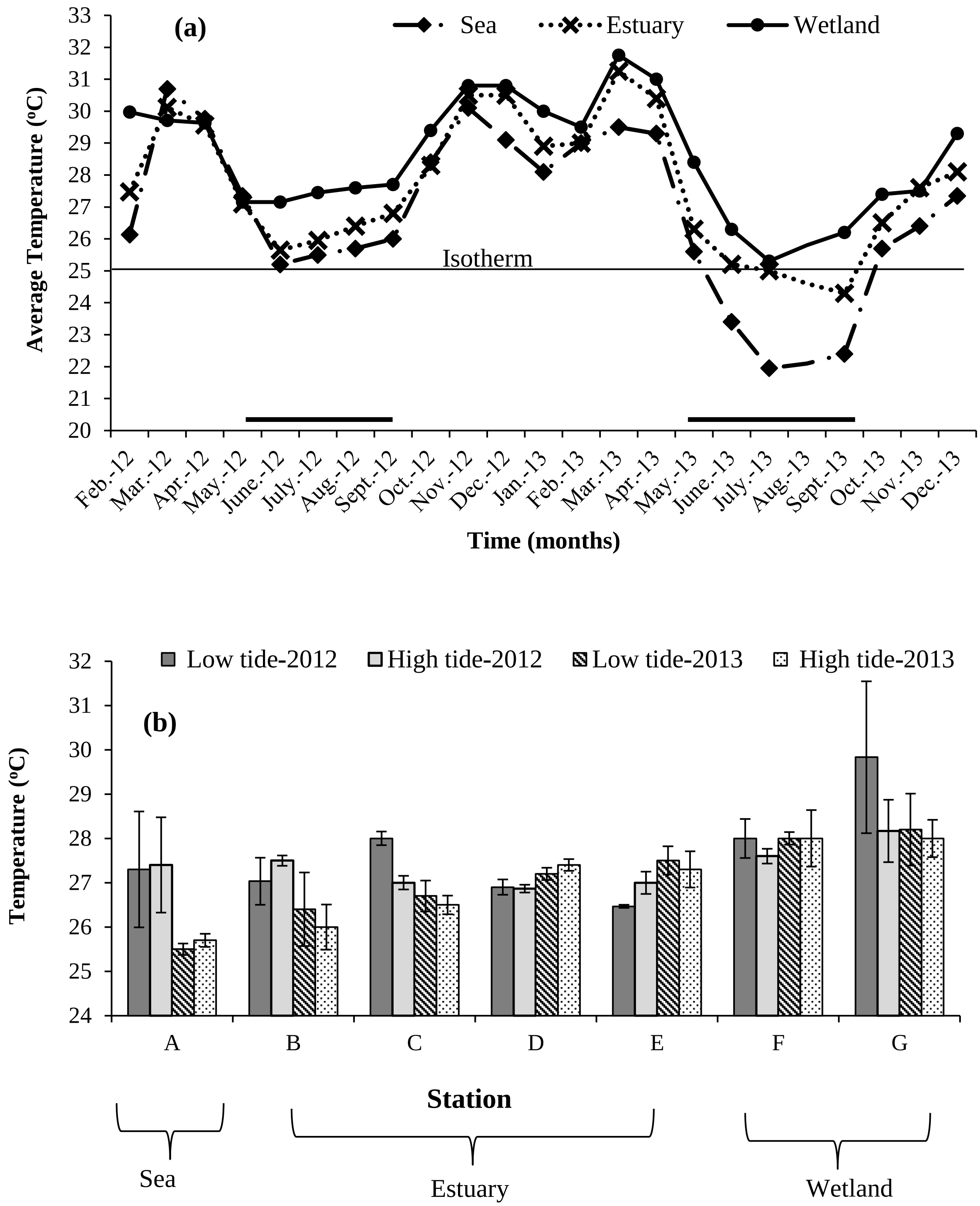


Figure 3: Variations in (a) monthly temperature during the study period and (b) mean temperature at the stations in the three ecosystems (vertical bars represent standard errors; —— wet season)

Turbidity

Figure 4 illustrates the monthly changes in turbidity of the three habitats, and the mean turbidity at the sampling locations. On average, the lowest turbidity recorded in the marine ecosystem was 55±2 ppm while the highest was 542±20 ppm. In the estuary, turbidity ranged from 60±3 to 1000±0 while a range of 55±3 to 785±21 was measured in the wetland (Figure 4a). The estuary was the most turbid habitat throughout the study period, although all the ecosystems had increased turbidities (> 400 ppm) from June –August 2012 during the rains). In February 2013, the three ecosystems were clean, (< 60 ppm) after which the sea remained persistently clean while the other habitats became turbid in the subsequent months especially during the wet season. Overall, the estuary was two to five times turbid than the marine and wetland waters, with the most turbid condition at the upper reaches of the estuary (Station E, Krobo) where mean turbidities around 1000 ppm in 2012, and 500 ppm in 2013 was recorded at both high and low tides (Figure 4b). High tide turbidities were not significantly lower than low tide turbidities in all three systems. In 2013, turbidity declined remarkably in the estuary and the sea to levels far below that of the previous year.

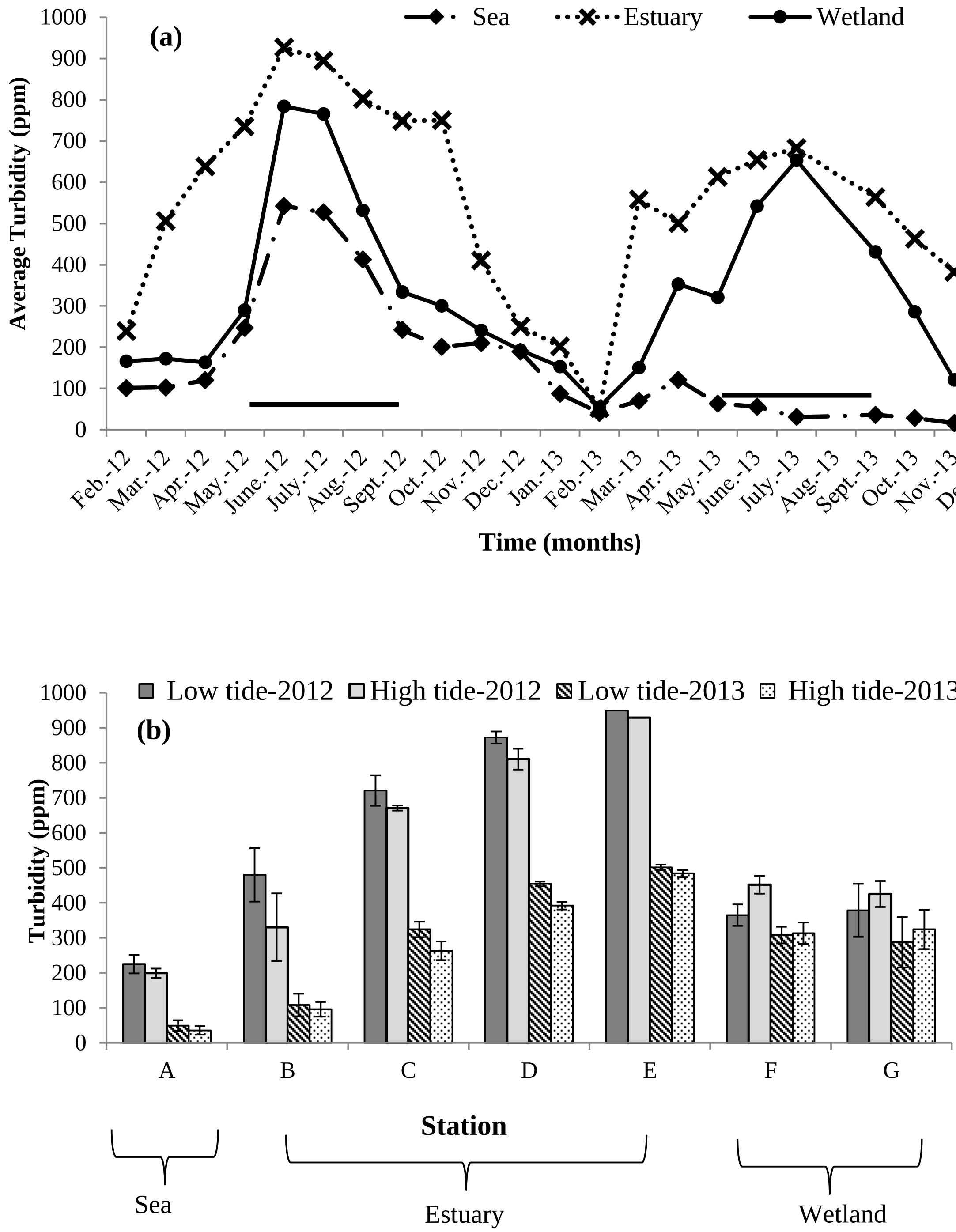


Figure 4: Variations in (a) monthly turbidity during the study period and (b) mean turbidity at the stations in the three ecosystems (vertical bars represent standard errors; ——— wet season)

Salinity

As shown in Figure 5a, salinity of the sea water remained between 30 ‰ and 35 ‰ during the study period, except in the wet season in June 2012 where it decreased to the lowest of 13.5 ± 1.3 ‰. On the average, salinity was fairly constant (mean ≈ 30.0 ‰) in the marine system (Station A) at low and high tides in 2012 and 2013 (Figure 5b).

The estuary water salinity varied between 1.5±0.4 ‰ and 21 ± 1.8 ‰ in the wet and dry seasons, and 1.1±0.2 ‰ and 29 ± 2.4 ‰ from the riverine reaches (Station E) to the mouth (Station B). High tide salinities were significantly higher than low tide, but no significant variation was observed between salinities measured in 2012 and 2013.

Salinity in the wetland ranged from 0.5±0.0 ‰ in the wet season to 30.0± 0.7 ‰ in the dry season, with high tide salinities being up to thrice that of low tide. The monthly fluctuation pattern in salinity was similar for all the ecosystems. Salinity of the sea was persistently higher than the estuary and the wetland.

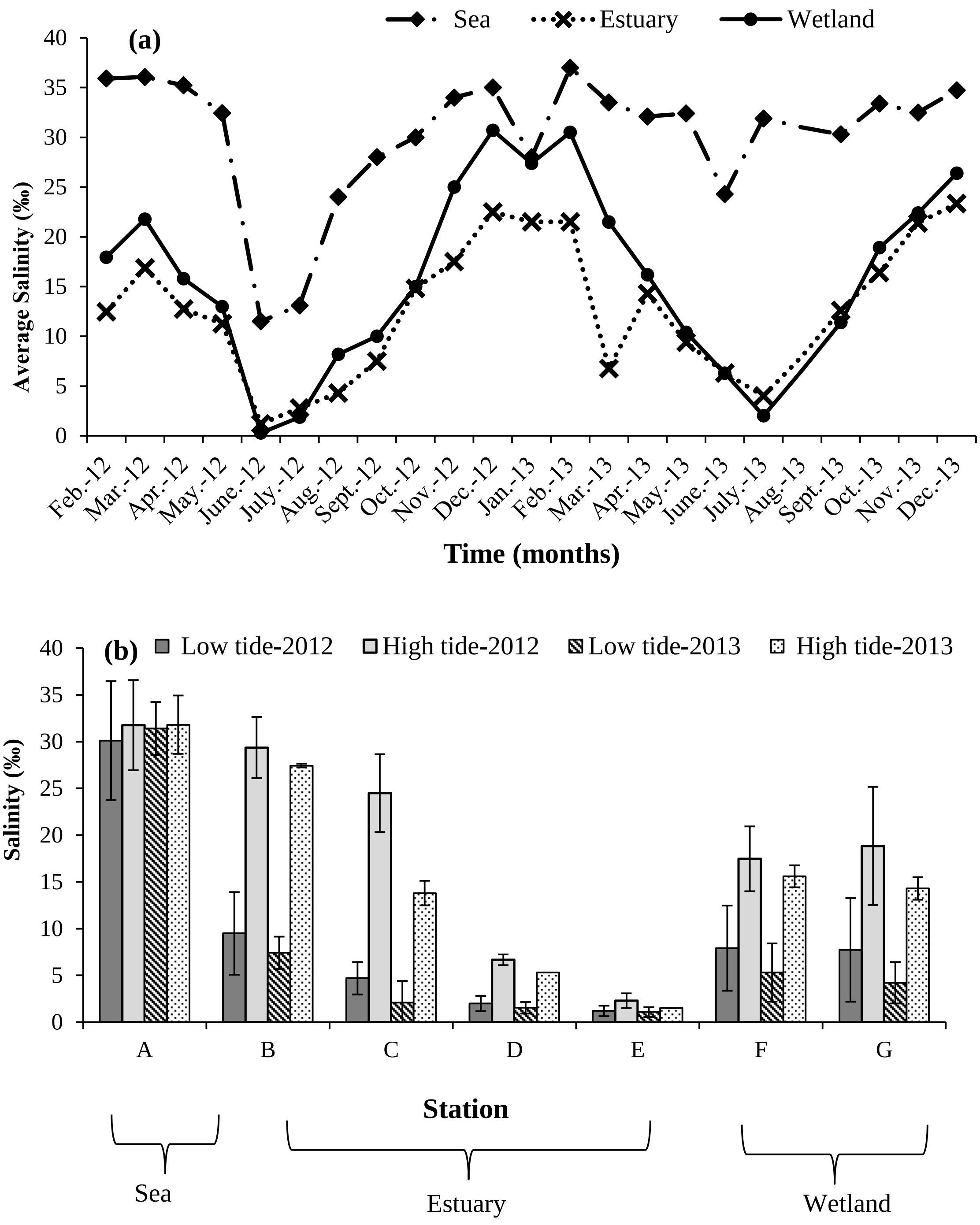


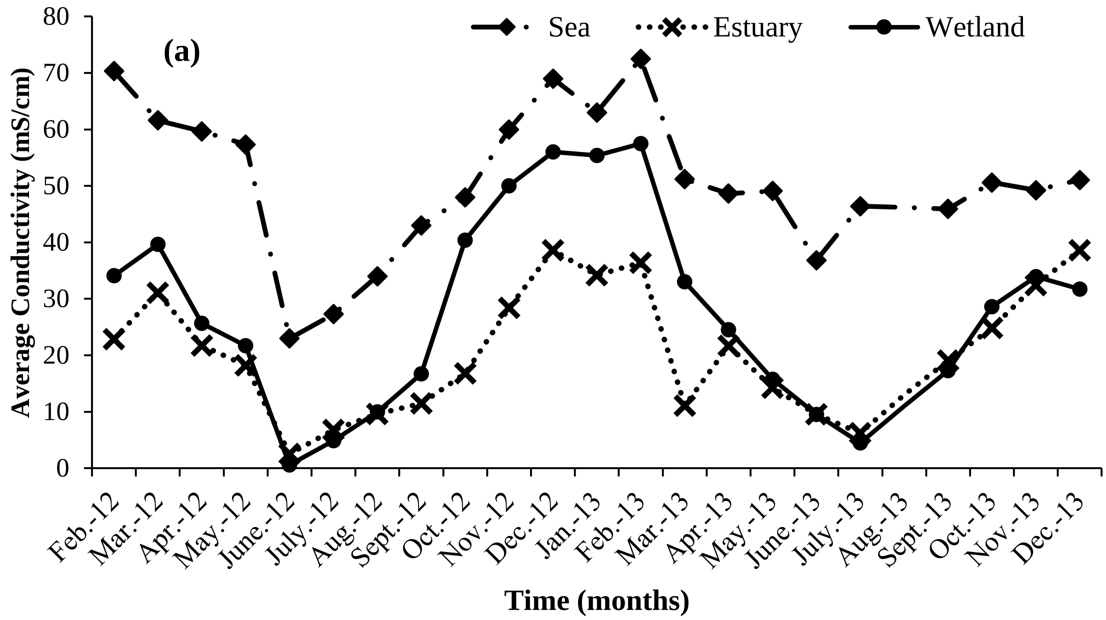
Figure 5: Variations in (a) monthly salinity during the study period and (b) mean salinity at the stations in the three ecosystems (vertical bars represent standard errors)

Conductivity

The monthly variations in the conductivity of the three ecosystems and the annual mean conductivity at the sampling stations are shown in Figure 6.

The average monthly conductivity recorded for the sea was in a range of 23±1.3 mS/cm to 72±1.7 mS/cm in the wet and dry seasons respectively, while a range of 2.3±0.9 mS/cm to 38.6±1.1 mS/cm was recorded for the estuary, and 0.5±0.0 mS/cm to 57.5±1.2 mS/cm for the wetland during the same period (Figure 6a). There was progressive decline in conductivity from the sea (Station A) to the estuary, where Krobo (Station E) had the lowest annual mean conductivity of 2.0±0.3 mS/cm at both high and low tides (Figure 6b) High tide conductivities were significantly higher than low tide values at most stations in the estuary and the wetland.

Monthly changes in conductivity followed a similar trend in all the three habitats with conductivity of the ocean remaining about two to three times that of the estuary and wetland in 2012, and even much higher in the wet season of 2013. The lowest conductivities in the three habitats were recorded during the wet seasons.



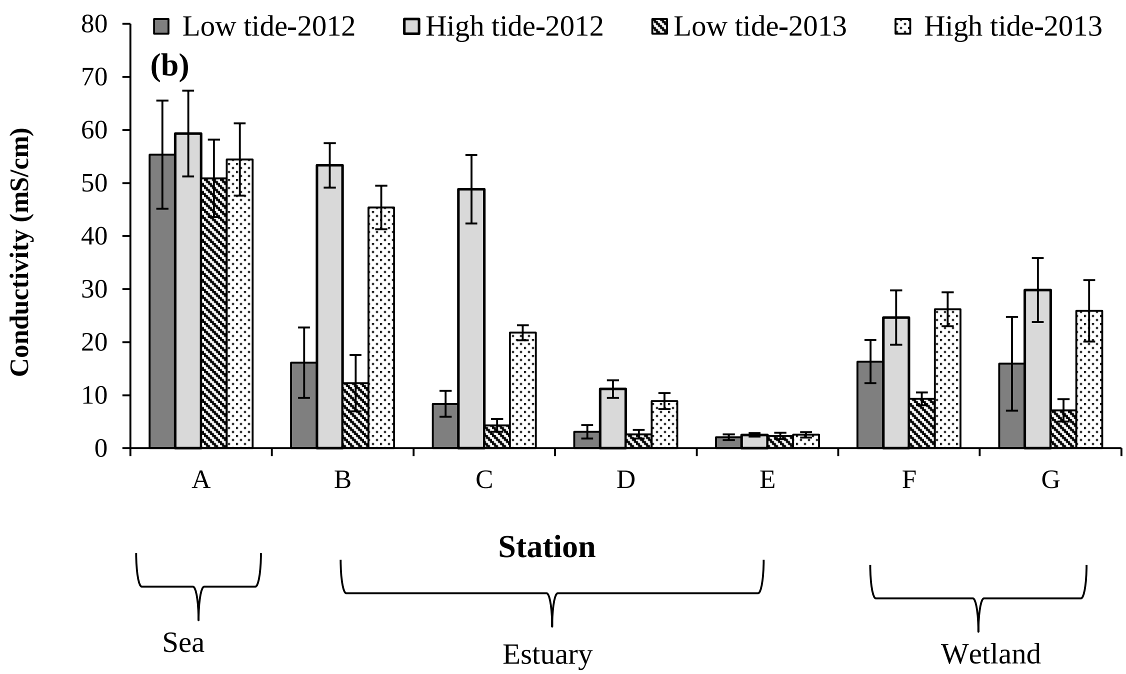


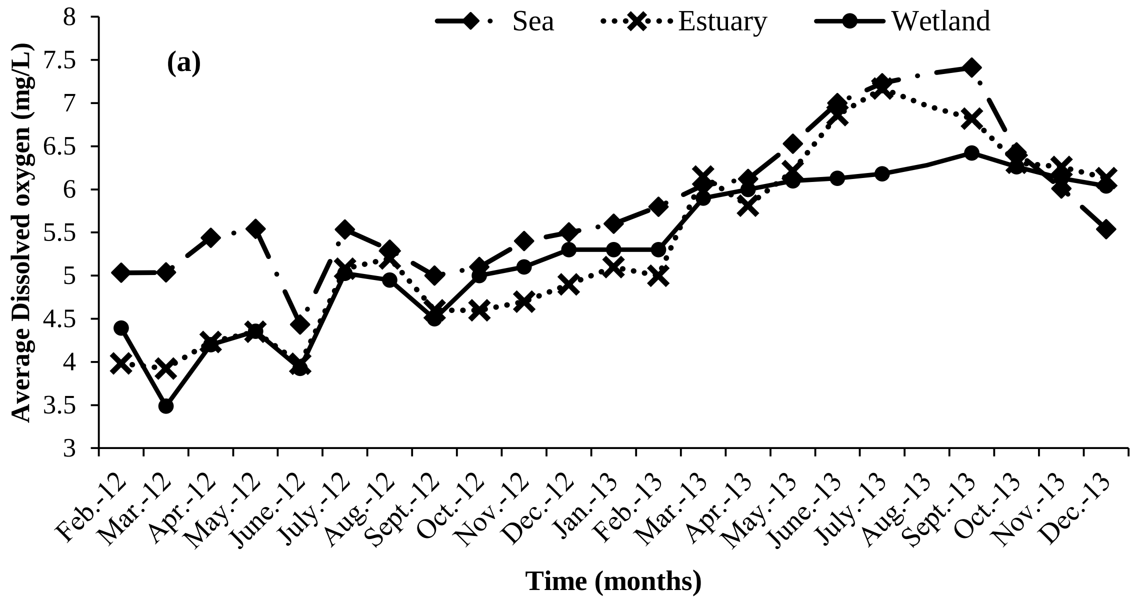
Figure 6: Variations in (a) monthly conductivity during the study period and (b) mean conductivity at the stations in the three ecosystems (vertical bars represent standard errors)

Dissolved oxygen

Figure 7 shows the monthly fluctuations in dissolved oxygen concentration in the three systems, and the mean DO at the sampling stations. Dissolved oxygen ranged from 4.4±0.2 mg/L to 7.4±0.1 mg/L in the marine environment, 4.0±0.3 mg/L to 7.1±0.2 mg/L in the estuary and 3.4 mg/L±0.1 to 6.4±0.2 mg/L in the wetland (Figure 7a). While DO was persistently greater than 5 mg/L in the sea, (except June, 2012), concentrations in the estuary and the wetland were below 4.5 mg/L in 2012 but increased progressively beyond 6.0 mg/L in 2013. This was reflected in the annual mean DO (Figure 7b) where only the marine waters (Station A) and the mouth of the estuary (Station B) had mean DO above 5 mg/L in 2012, but all the other stations had increased DO (mean > 5 mg/L) in 2013. At most of the stations in the estuary and the wetland, DO levels at high tide were significantly higher than low tide.

pH

The pH of the sea water was within a range of 6.4 to 8.9, the estuary had 6.9 to 8.0 while 6.4 to 8.6 was recorded in the wetland (Figure 8a). In general, the ecosystems were alkaline during the study period, except between August and October 2012 when the pH reduced to levels between neutral (7.0) and slightly acidic (6.5). Analysis of the annual means (Figure 8b) showed that the marine water (Station A) was alkaline while the estuary and wetland were near neutral to slightly acidic at low tide but slightly alkaline at high tide. In the estuary, the mean high tide pH was significantly higher than the mean low tide pH in 2012, but tidal pH did not differ significantly in 2013 at all the stations sampled.



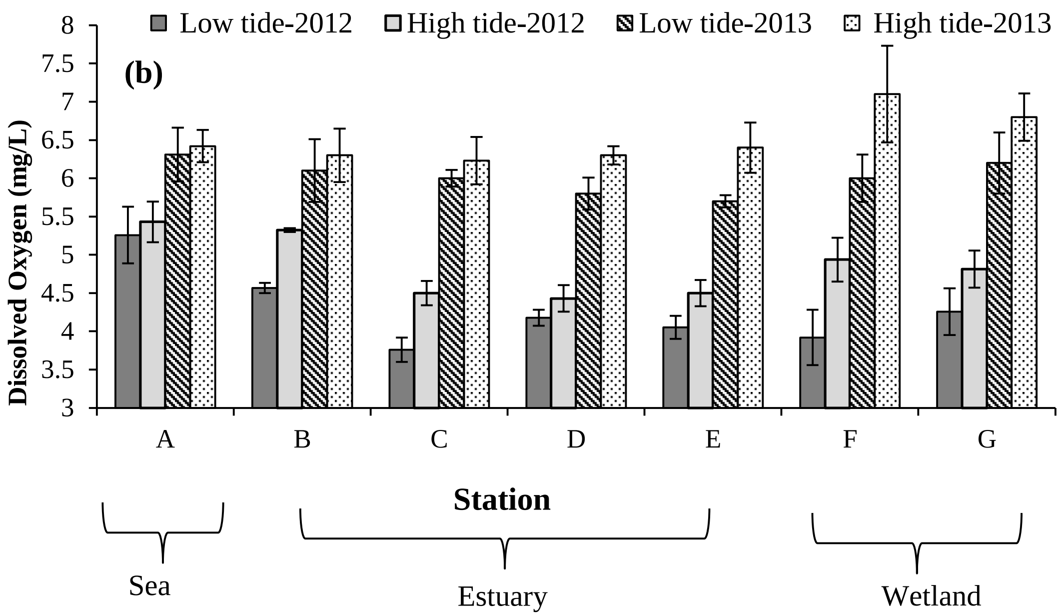


Figure 7: Variations in (a) monthly dissolved oxygen during the study period and (b) mean dissolved oxygen at the stations in the three ecosystems (vertical bars represent standard errors)

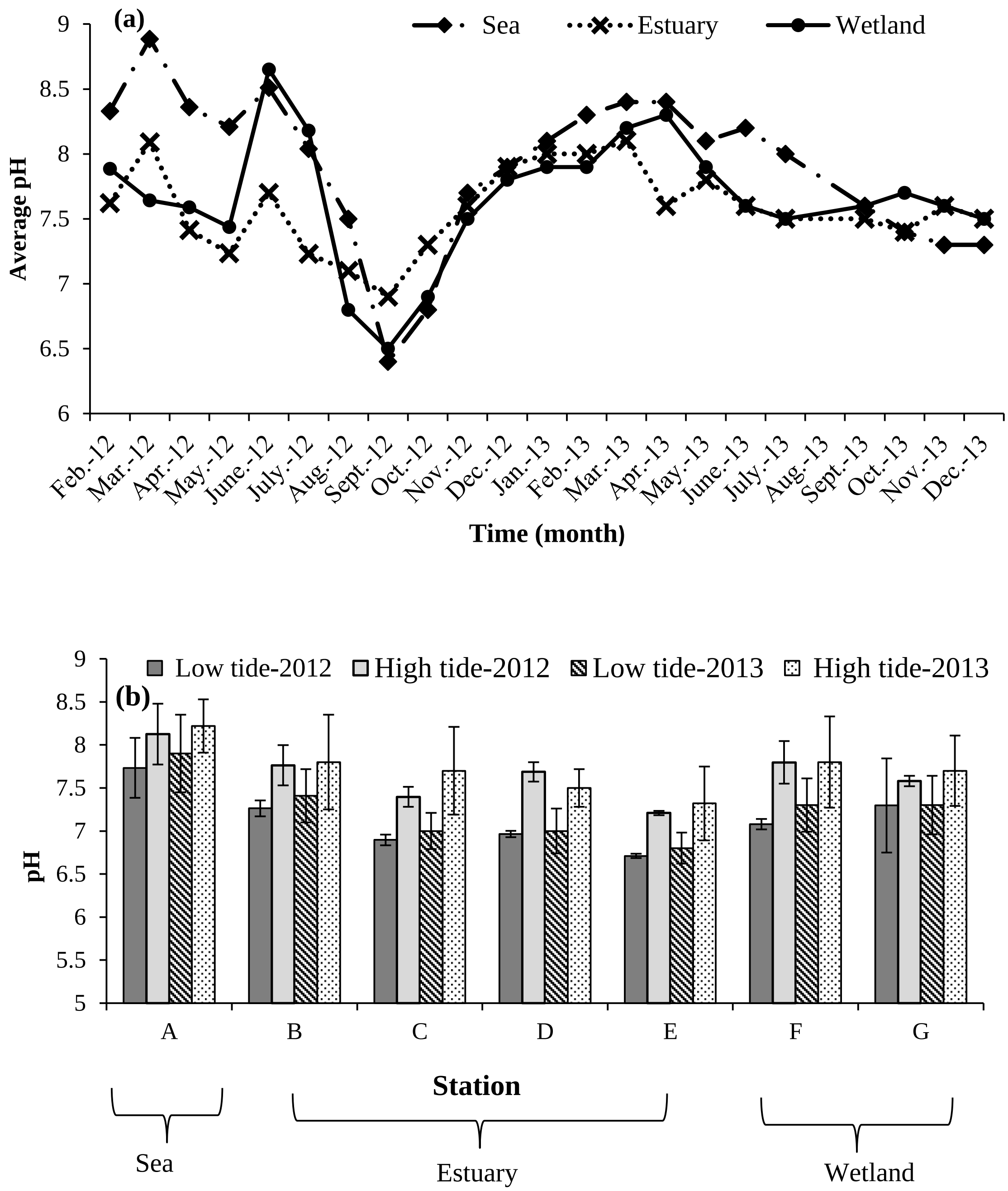


Figure 8: Variations in (a) monthly pH during the study period and (b) mean pH at the stations in the three ecosystems (vertical bars represent standard errors)

Nitrates and Phosphates

As presented in Figure 9a, nitrate values in the sea ranged from a mean of 1.8±0.5 mg/L in the wet season to 4.3±0.6 mg/L in the dry season, values in the estuary ranged from 0.8±0.0 mg/L in the wet season to 78.2 ±2.3 mg/L in the dry season while the concentration in the wetland ranged from 1.3±0.5 mg/L in the wet season to 14.6±1.7 mg/L in the dry season. Almost all the stations sampled had higher mean concentrations of nitrate in the dry season than in the wet season in 2012, but the seasonal differences were not significant in 2013 at most Stations. The highest nitrate levels in both dry (78.2 mg/L) and wet (24.4 mg/L) seasons were recorded at Krobo (E) in 2012., In 2013, nitrate levels generally reduced to about half that of 2012 in the ecosystems.

Phosphate concentration ranged from 0.06±0.01 mg/L in the wet season to 0.01±0.00 mg/L in the dry season in the marine habitat, 0.41±0.04 mg/L in the wet season to 0.01 ±0.00 mg/L in the dry season in the estuary, and 0.36±0.07 mg/L in the wet season to 0.01±0.00 mg/L in the dry season in the wetland (Figure 9b). The mean phosphate concentration was higher in the wet season than in the dry season at all stations, and Station E (Krobo) had the highest of 0.36 mg/L in the dry season and 0.41 mg/L in the wet season. Phosphate in the wet season was significantly lower in 2013 than 2012.

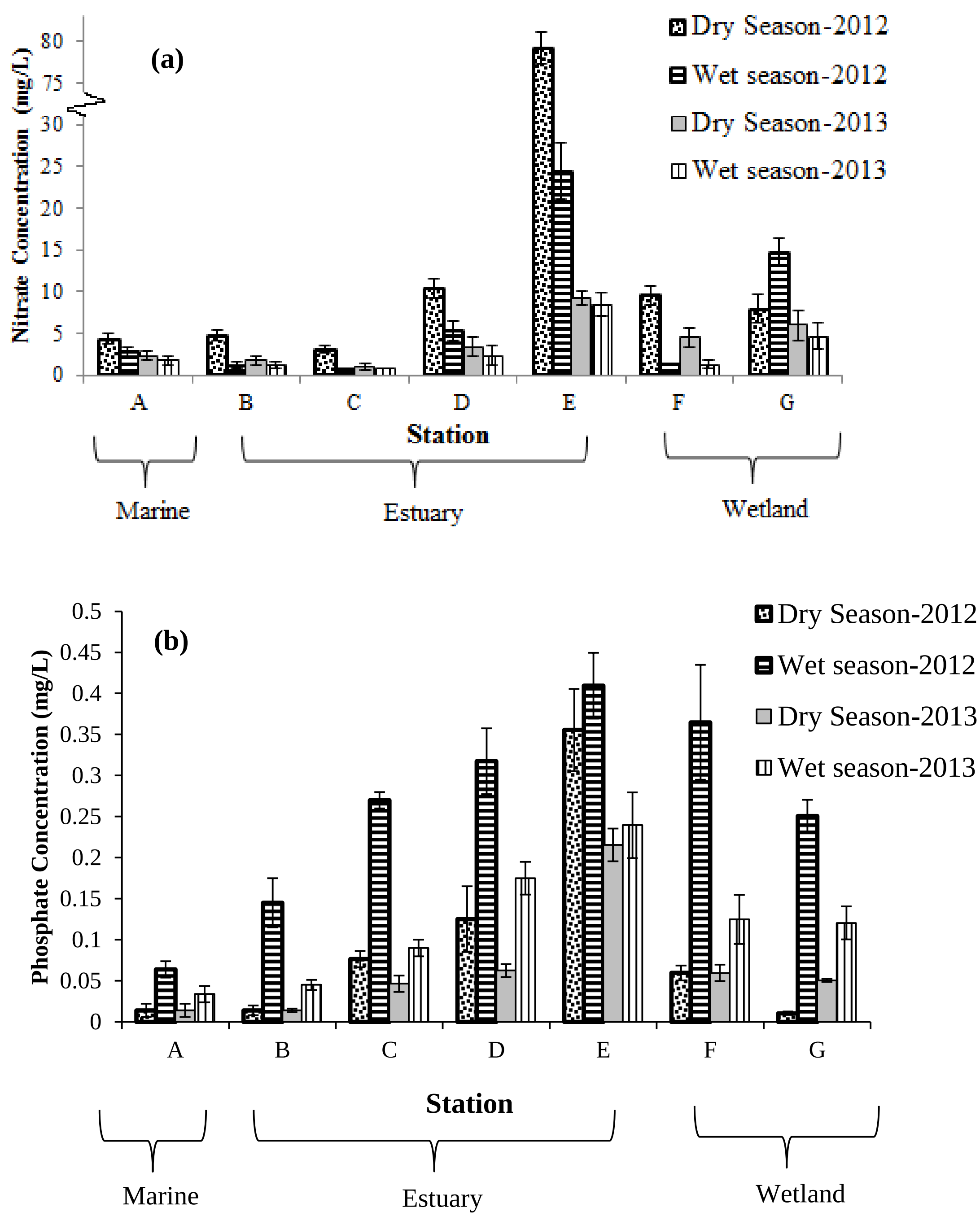


Figure 9: Mean concentration of (a) nitrates and (b) phosphates at the stations in the three ecosystems in the wet and dry seasons (vertical bars represent standard errors)

Macrozoobenthic invertebrates in the estuary and wetland

Occurrence at the different stations

A total of 1174 benthic animals belonging to 49 species were sampled. These comprised 36 species of polychaetes, 4 species of oligochaetes, 7 species of crustaceans and 2 species of insects (Table 1). The polychaetes belonged to fourteen families with Nereidae (rag worms) represented by 11 species, Capitellidae by 6 species and each of the remaining twelve families by one or 3 species. Oligochaetes were represented by only two families of which the Tubificidae had 3 species and Naidadae had one species. Amphipods of the families Corophidae, Haustoridae, Gammaridae and the isopod family Cirolanidae were the commonest crustaceans. The insects were entirely chironomid larvae from the Family Chironomidae.

Unlike polychaetes and oligochaetes which were found at virtually all stations in both habitats, crustaceans were limited to the wetland at Stations F and G only while chironomid larvae occurred considerably in the wetland, but sparingly in the estuary. Overall, 9 species were sampled from Station B, 21 from Station C, 6 from Station D and 4 from Station E in the estuary while 17 species were sampled from Station F and 21 from Station G in the wetland.

Table 1: Occurrence of benthic macroinvertebrate fauna at the six stations in the Estuary and the Wetland (+ indicates present, - indicates absent)

					Estuary				Wetland	
Phylum	**Class**	**Order**	**Family**	**Species**	**B**	**C**	**D**	**E**	**F**	**G**
Annelida	Polychaeta		Scalibregmidae	*Hyboscolex longiseta*	+	+	-	-	+	-
				Polyphysia crassa	-	+	-	-	-	-
				Asclerocheilus capensis	-	-	-	-	+	-
			Capitellidae	*Pulliella armata*	+	+	+	-	-	-
				Capitella capitata	-	+	-	+	-	+
				Notomastus aberans	-	-	-	-	+	-
				Paraheteromastus tenuis	-	-	-	-	-	+
				Heteromastus filiformis	-	+	-	-	-	-
				Dasybranchus bipartitus	-	+	-	-	-	-
			Maldanidae	*Maldanella capensis*	+	-	-	-	-	-

Table 1 continued

Phylum	Class	Order	Family	Species	Estuary B	C	D	E	Wetland F	G
				Maldane sarsi	-	+	-	-	+	+
				Euclymene quadrilobata	-	-	-	-	-	+
			Pisionidae	*Pisione africana*	+	-	-	-	-	-
			Amphimonidae	*Euphrosine capensis*	+	-	-	-	-	-
			Arenicolidae	*Branchiomaldane vincenti*	-	+	-	-	-	-
				Arenicola loveni	-	+	-	-	-	-
			Chaetopteridae	*Phyllochaetopterus herdmani*	-	+	-	-	-	+
			Nereidae	*Nemanereis quadraticeps*	-	+	-	-	-	-
				Namalycastis indica	-	-	-	-	+	-
				Dendronereides zulilandica	-	-	-	-	-	+
				Nereis granulata	-	-	+	-	-	-
				Neonereis ankyloseta	-	-	-	-	-	+

Table 1 continued

					Estuary				Wetland	
Phylum	**Class**	**Order**	**Family**	**Species**	**B**	**C**	**D**	**E**	**F**	**G**
				Nereis caudata	-	-	-	-	-	+
				Nereis operta	-	-	-	-	-	+
				Ceratonereis pachychaeta	-	+	-	-	-	+
				Micronereides capensis	-	+	-	-	-	-
				Perinereis falsovariegata	-	+	-	-	-	-
				Leonnates perisca	+	-	-	-	-	-
			Eunicidae	*Eunice siciliensis*	-	+	-	-	-	-
			Alicopidae	*Krohnia lepidota*	-	+	-	-	-	-
				Naiades centrainii	-	-	+	-	-	+
			Nephtyidae	*Nephtys debranchis*	-	-	+	+	-	-
			Sepionidae	*Prionospio cirrifera*	-	-	-	-	+	-
			Orbiniidae	*Scoloplos armiger*	-	+	-	-	-	-

Table 1 continued

Phylum	Class	Order	Family	Species	Estuary				Wetland	
					B	C	D	E	F	G
			Phyllodocidae	*Eulalia viridis*	-	-	-	-	-	+
				Eulalia microcerus	-	-	-	-	-	+
	Oligochaeta		Tubificidae	*Limnodrilus hoffmeisteri*	-	+	+	+	+	+
				Tubifex tubifex	+	+	+	-	+	+
				Limnodrilus angustepenis	-	+	-	-	+	+
			Naididae	*Pristina* sp.	+	+	-	-	+	+
Arthropoda	Insecta	Diptera	Chironomidae	*Chironomus* sp.	+	-	-	-	+	
				Tanytarsus sp.	-	-	-	+	-	+
	Crustacea	Cumacea	Ceratocumatidae	Unidentified species	-	-	-	-	+	+
		Amphipoda	Corophidae	*Corophium sp.*	-	-	-	-	+	-
			Haustoridae	Unidentified species	-	-	-	-	+	-
			Gammaridae	*Gammarus locusta*	-	-	-	-	+	+

Table 1 continued

					Estuary				Wetland	
Phylum	**Class**	**Order**	**Family**	**Species**	**B**	**C**	**D**	**E**	**F**	**G**
		Tanaidacea	Tanaidae	Unidentified species	-	-	-	-	+	-
		Isopoda	Cirolanidae	Unidentified species	-	-	-	-	+	-
		Mysidacea	Mysidae	*Mysis relicta*	-	-	-	-	-	+
Number of Families					9	11	5	4	14	12
Number of Species					9	21	6	4	17	21

Diversity and composition of macrozoobenthic communities

Table 2, shows the species richness, species diversity and evenness of the macrozoobenthic community of the different stations in the estuary and wetland. Relatively low species richness and diversity of organisms in the estuary occurred at the riverine reaches (Station E; d= 0.52, H'= 1.0) and about 1 km south of the riverine reaches (Station D; d= 0.8, H'= 1.4), while the most diverse community was found at Anlo Beach, about 1km north of the mouth of the estuary (Station C; d= 2.3, H'= 2.3). Of the six stations, Stations F and G located in the wetland had the richest benthic fauna (d = 2.6) and individuals belonging to the different species were evenly distributed among the communities ($J' > 0.6$) at most stations.

Table 2: Diversity of benthic macroinvertebrates at the stations in the estuary and the wetland

	Estuary				**Wetland**	
Station	B	C	D	E	F	G
Richness (d)	1.2	2.3	0.8	0.5	2.7	2.4
Diversity (H')	1.6	2.3	1.4	1.0	2.1	1.4
Eveness (J')	0.9	0.9	1.0	0.9	0.9	0.6

Annelids dominated the benthic community in the estuary (Figure 10), with Polychaeta constituting 87.5 %, Oligochaeta 11.2 %, and Insecta making up only 1.3 %. The community in the wetland was similarly dominated by polychaetes (51.3%) and oligochaetes (38.6 %) while crustaceans were fairly represented (7.8 %) and insect larvae were very few (2.4 %). The composition by major groups at the different stations is shown in Figure 11 and the composition by Family at the stations is presented in Figure 12. The composition by species is also presented in Appendices B to G.

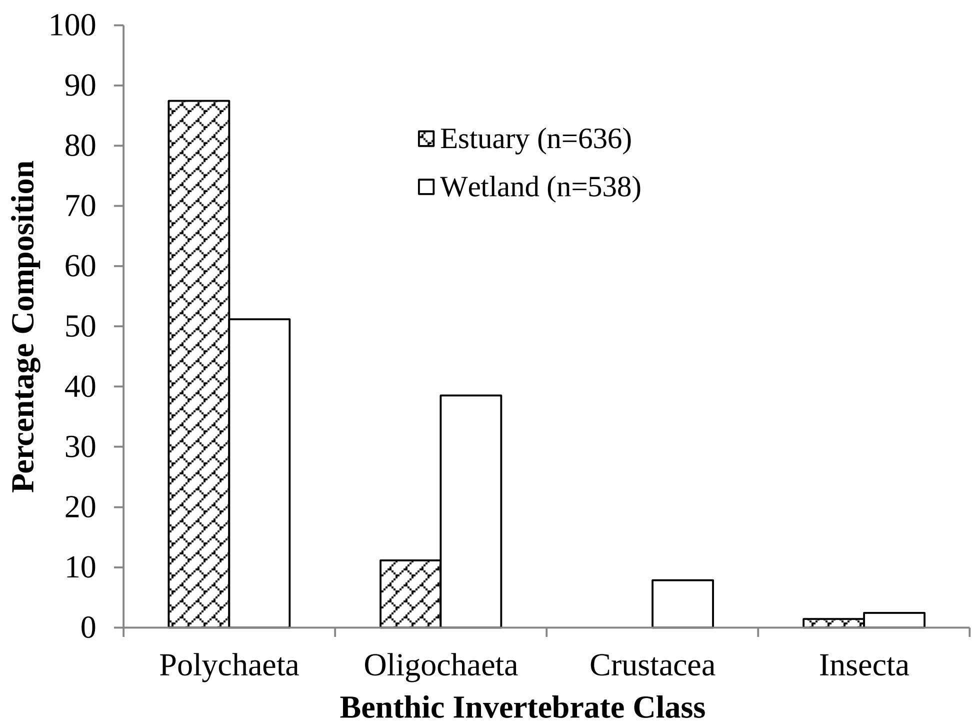


Figure 10: Composition of benthic macrofauna groups in the River Pra Estuary and adjoining wetland ecosystems

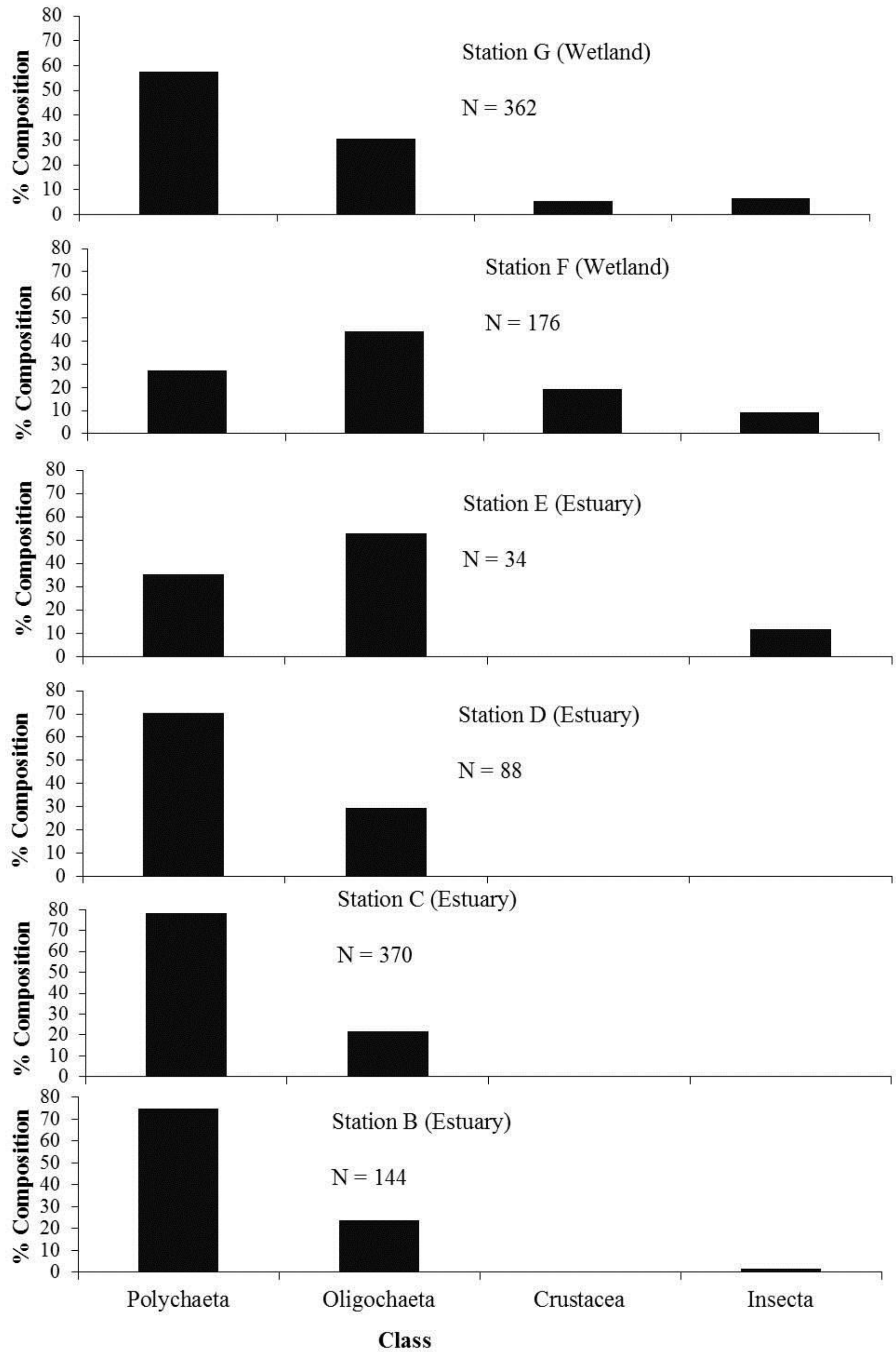


Figure 11: Composition of benthic macrofauna groups at the six stations in the two ecosystems

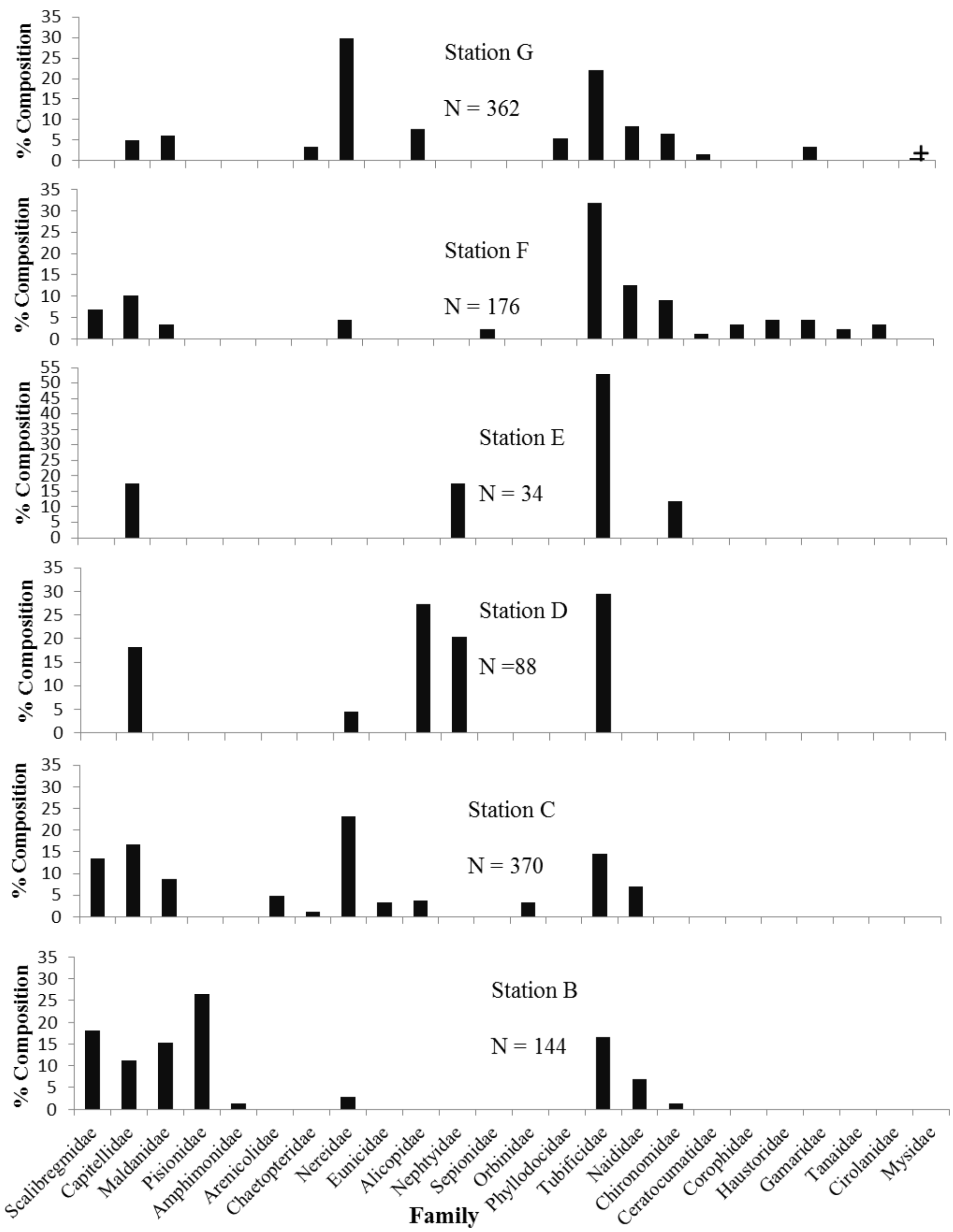


Figure 12: Composition of benthic macrofauna families at the six stations in the Estuary and the Wetland by families (+ indicates > 1%)

Density of macrozoobenthic organisms

Polychaeta were the dominant fauna in the estuary (291 individuals/m^2), followed by Oligochaeta (98 individuals/m^2) while Insecta were few (4 individuals/m^2) (Figure 13). Similarly, the wetland benthic fauna was dominated by Polychaeta (315 individuals/m^2) and Oligochaeta (231 individuals/m^2) with a considerable representation of Insecta (59 individuals/m^2) and Crustacea (60 individuals/m^2).

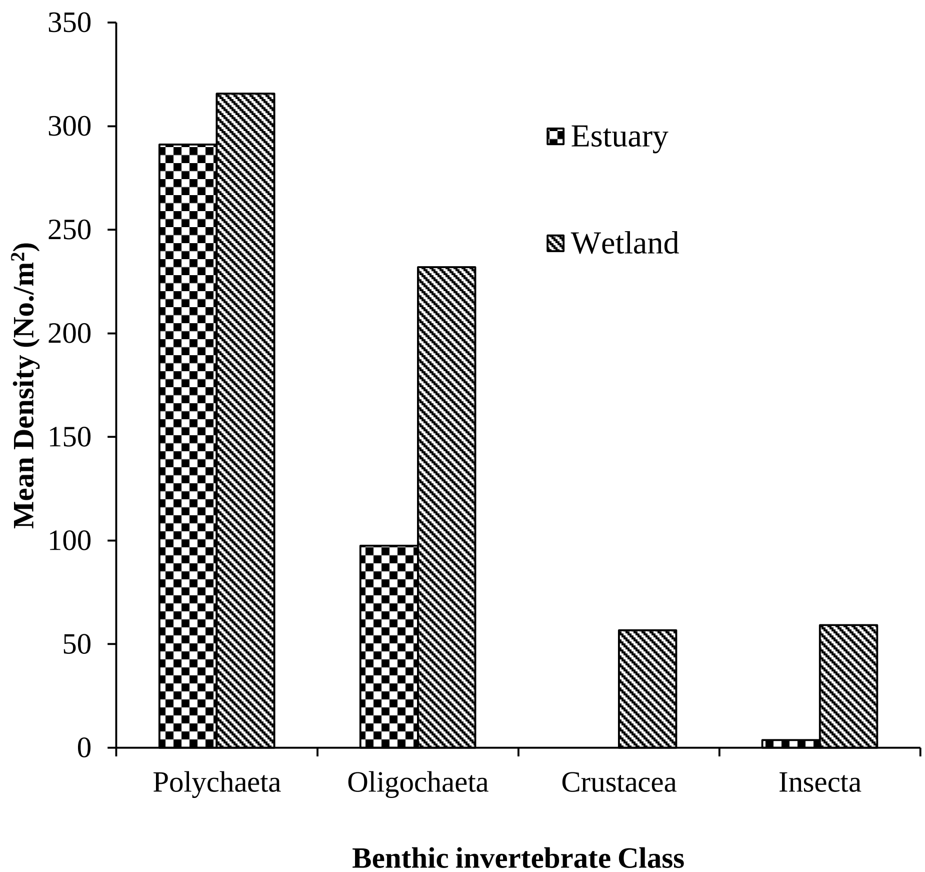


Figure 13: Mean density of benthic macrofauna groups in the estuary and the wetland ecosystems

The density by major groups at the different stations is shown in Figure 14 while the composition by Family at the stations is presented in Figure 15. The polychaetes *Pisione africana* (Pisionidae) and *Hyboscolex longiseta* (Scalibregmidae) dominated the benthos at the mouth of the Pra Estuary (Station B) with densities of 94 individuals/m^2 and 63 individuals/m^2 respectively, followed by the oligochaetes *Tubifex tubifex* (Tubificidae) with 59 individuals/m^2. At Station C which is approximately 1 km away from the mouth, the most densely populated organisms were the polychaetes *Nemanereis quadraticeps* (94 individuals/m^2), *Pulliella armata* (79 individuals/m^2), *Maldane sarsi* (79 individuals/m^2), *Polyphysia crassa* (69 individuals/m^2) and the oligochaetes *Pristina* sp. (64 individuals/m^2). Station D was dominated by the polychaetes *Naiades centrainii* (Alicopidae) with a density of 59 individuals/m^2 while the riverine reaches of the estuary (Station E) was inhabited by only four species of benthic fauna of which the oligochaete *Limnodrilus hoffmeisteri* was dominant (44 individuals/m^2).

In the wetland, Oligochaeta was the most densely populated fauna at Station F where *Tubifex tubifex* had the highest density of 79 individuals/m^2 followed by *Pristina* sp. with 54 individuals/m^2. At Station G, the polychaetes *Maldane sarsi*, *Nereis caudata*, *Nereis operta* and *Naiades centrainii*, the oligochaetes *Tubifex tubifex* and *Pristina* sp., and the chironomid larve *Tanytarsus* sp. were the most abundant macrozoobenthic animals with densities varied between 54 and 94 individuals/m^2. Appendices B to G shows the detailed composition and mean density of zoobenthic species at each of the six stations.

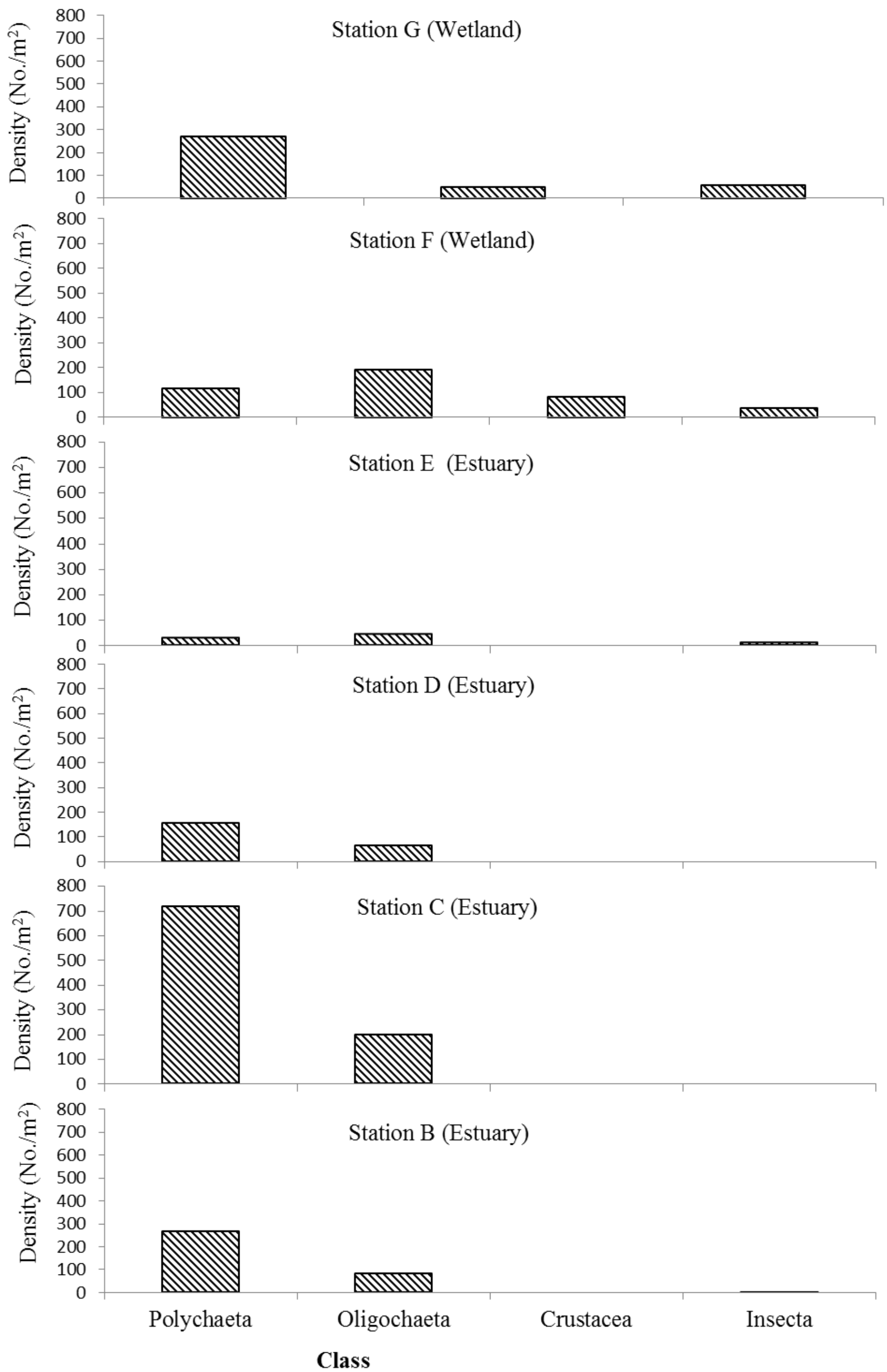


Figure 14: Mean density of benthic macrofauna groups at the six stations in the Estuary and the Wetland

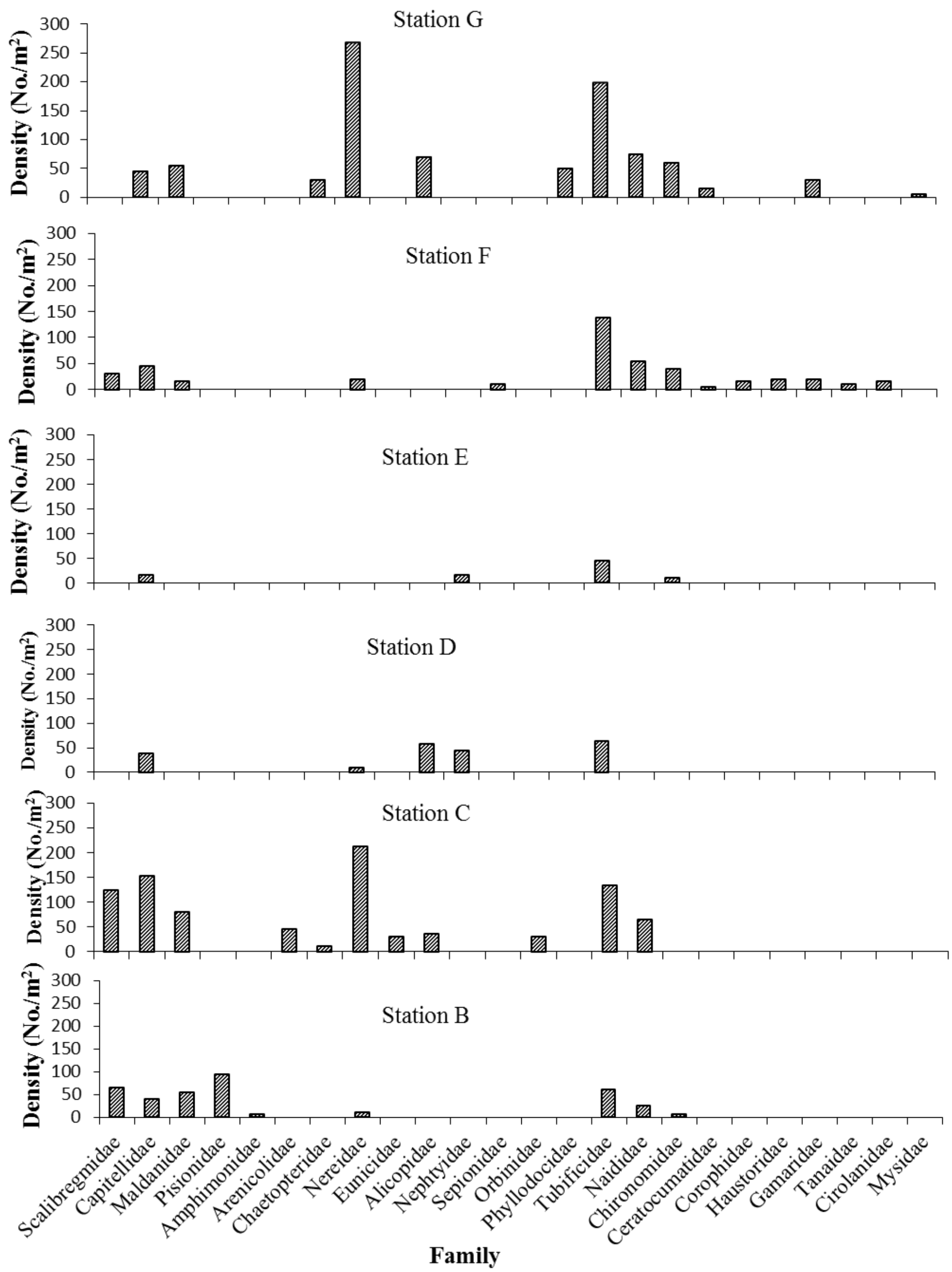


Figure 15: Mean density of benthic macrofauna families at the six stations in the Estuary and the Wetland ecosystems

The Fish Communities

Occurrence of fish species in the ecosystems

The occurrence of fish species in the three ecosystems is presented in Table 3. A total of 47 species belonging to 32 families were collected from the marine ecosystem, 32 species from 19 families from the estuary, and 20 species belonging to 11 families from the wetland.

The most commonly occurring marine fishes were the cutlass fish *Trichiurus lepturus* (Trichiuridae), the barracuda *Sphyraena sphyraena* (Sphyraenidae), the Bonga shad *Ethmalosa fimbriata* (Clupeidae), the cassava fishes *Pseudotholithus senegalensis*, *P. typus* and *P. elongatus* (Sciaenidae), and the marine catfish *Arius latiscutatus* (Ariidae). Others were the moonfish *Selene dorsalis* and Atlantic bumper *Chloroscombrus chrysurus* (Carangidae), the bigeye grunt *Brachydeuterus auritus* (Haemulidae), anchovies *Engraulis encrasicolus* (Engraulidae) and shellfishes mainly the white shrimps *Exhippolysmata hastatoides* (Hippolytidae) and *Nematopalaemon hastatus* (Palaemonidae).

Thirty-two species were sampled from the estuary of which 24 were marine, the commonest being grey mullets *Liza falcipinnis*, *Liza dumerilii, Mugil bananensis* and *Mugil curema* (Mugilidae), the marine catfish *Arius latiscutatus* (Ariidaea), *Ethmalosa fimbriata*, the threadfin *Galeoides decadactylus* (Polynemidae), the snapper *Pomadasys peroteti* (Haemulidae), and the pink shrimp *Penaeus notialis*. The brackish water fishes found were the black-chinned tilapia *Sarotherodon melanotheron* (Cichlidae), the mudskipper *Periophthalmus barbarus* (Gobiidae), and the crab *Goniopsis pelii* (Grapsidae).

Table 3: Occurrence of fish species in the three ecosystems (+, occurred; - , absent; M, Marine species; F, Freshwater species; BW, Brackishwater species)

FAMILY	SPECIES	ECOSYSTEM		
		Marine	Estuary	Wetland
Finfish				
Ariidae	*Arius latiscutatus* (M)	+	+	-
Batrachoididae	*Holobatrachus didactylus* (M)	+	-	-
Bothidae	*Citharichthys stampflii* (M)	+	+	-
	Scyacium micrurum (M)	+	+	-
Carangidae	*Caranx hippos* (M)	+	+	+
	Caranx latus (M)	+	+	-
	Selene dorsalis (M)	+	-	-
	Chloroscombrus chrysurus (M)	+	-	-
Cichlidae	*Sarotherodon melanotheron* (BW)	-	+	+

Table 3 continued

		ECOSYSTEM		
FAMILY	SPECIES	Marine	Estuary	Wetland
	Tilapia zillii (F)	-	+	+
	Hemichromis fasciatus (F)	-	+	+
Clariidae	*Clarias gariepinus* (F)	-	-	+
Clupeidae	*Ethmalosa fimbriata* (M)	+	+	-
	Sardinella aurita (M)	+	+	-
	Sardinella maderensis (M)	+	-	-
	Ilisha africana (M)	+	-	-
Engraulidae	*Engraulis encrasicolus*(M)	+	-	-
Cynoglossidae	*Cynoglossus senegalensis* (M)	+	+	-
Dactylopteridae	*Dactylopterus volitans* (M)	+	-	-
Dasyatidae	*Dasyatis margarita* (M)	+	-	-
Drepanidae	*Drepane africana* (M)	+	-	-

Table 3 continued

		ECOSYSTEM		
FAMILY	SPECIES	Marine	Estuary	Wetland
Eleotridae	*Eleotris senegalensis* (F)	-	+	+
	Kribia kribensis (F)	-	-	+
Elopidae	*Elops lacerta* (M)	+	+	+
Gerreidae	*Eucinostomus melanopterus* (M)	+	+	-
Gobiidae	*Porogobius schlegelii* (F)	-	-	+
	Periophthalmus barbarous (BW)	-	+	+
	Gobionellus occidentalis (F)	-	-	+
	Bathygobius soporator (F)	-	+	+
	Gobioides africanus (F)	-	+	+
Haemulidae	*Pomadasys peroteti* (M)	+	+	-
	Plectolynchus macrolepsis (M)	+	+	-
	Brachydeuterus auritus (M)	+	-	-

Table 3 continued

		ECOSYSTEM		
FAMILY	SPECIES	Marine	Estuary	Wetland
Hemirmphidae	*Hemiramphus brasiliensis* (M)	+	-	-
Lobotidae	*Lobotes surinamensis* (M)	+	+	-
Mugilidae	*Liza falcipinnis* (M)	+	+	+
	Mugil bananensis (M)	-	+	+
	Mugil curema (M)	-	+	-
	Liza dumerillii (M)	-	+	+
	Mugil cephalus (M)	-	+	-
	Liza graudisquamis (M)	-	+	-
Muraenidae	*Channomuraena vittata* (M)	+	-	-
Platyrhinidae	*Zanobatus schoenleinii* (M)	+	-	-
Poecilidae	*Aplocheithys spilauchen* (F)	-	-	+
Polynemidae	*Galeoides decadactylus* (M)	+	+	-

Table 3 continued

FAMILY	SPECIES	ECOSYSTEM		
		Marine	Estuary	Wetland
Sciaenidae	*Pseudotholithus elongatus* (M)	+	+	-
	Pseudotholithus typus (M)	+	-	-
	Pseudotholithus senegalensis (M)	+	-	-
	Argyrosomus holosepidotus (M)	+	-	-
Scombridae	*Scomba japonicas* (M)	+	-	-
Serranidae	*Epinephelus aeneus* (M)	+	+	-
	Polyprion americanus (M)	+	-	-
Soleidae	*Synaptura lusitanica* (M)	+	-	-
Sphyrraenidae	*Sphyraena sphyraena* (M)	+	-	-
Tetradontidae	*Lagocephalus laevigatus* (M)	+	-	-
	Ephippion guttiffer (M)	+	-	-
Trichiuridae	*Trichiurus lepturus* (M)	+	-	-

Table 3 continued

		ECOSYSTEM		
FAMILY	SPECIES	Marine	Estuary	Wetland
Shellfish				
Shrimps				
Palaemonidae	*Macrobrachium microbrachion* (F)	-	+	+
	Nematopalaemon hastatus (M)	+	-	-
Penaeidae	*Penaeus notialis* (M)	+	+	-
	Penaeus kerathurus (M)	+	-	-
Hippolytidae	*Exhippolysmata hastatoides* (M)	+	-	-
Lobster				
Palinuridae	*Panulirus regius* (M)	+	-	-
Crabs				
Portunidae	*Callinectes amnicola* (M)	+	+	+
Grapsidae	*Goniopsis pelii* (BW)	-	-	+
Cephalopod				
Sepiidae	*Sepia officinalis* (M)	+	-	-
Number of Species		**47**	**32**	**20**
Number of Families		**32**	**19**	**11**

The fish species sampled from the wetland inluded *Liza falcipinnis, Mugil bananensis, Caranx hippos* (Carrangidae), *Elops lacerta* (Elopidae) and *Callinectes amnicola* (Portunidae). Others were *Sarotherodon melanotheron, Tilapia zillii* and *Hemichromis fasciatus* (Cichlidae), *Gobioides africanus* and *Gobionellus occidentalis* (Gobiidae), *Eleotris senegalensis* (Eleotridae), the lampeye *Aplocheilichthys spilauchen* (Poecilidae), the catfish *Clarias gariepinus* (Clariidae) and the freshwater shrimp *Macrobrachium microbrachion*.

Species found in all three ecosystems were the West African ladyfish *Elops lacerta* (Elopidae), *Caranx hippos* (Carangidae), the sickle fin mullet *Liza falcipinnis* and the swimming crab *Callinectes amnicola* (Portunidae). Most of the freshwater fishes were collected from the wetland, although the cichlids *T. zillii* and *H. faciatus,* the eleotrid *E. senegalensis* and the gobies *G. africanus* and *Bathygobius soporator* were also found in the estuary.

Fish numerical composition

The numerical composition of the fish communities is presented in Figure 16. The marine fish community was predominantly cutlass fish *T. lepturus* (12.3 %), the anchovy *E. encrasicolus* (10.8 %), the barracuda *S. sphyraena* (10.6 %), the bonga shad *E. fimbriata* (9.1 %) and two white shrimps *E. hastatoides* (7.8 %) and *N. hastatus* (6.3 %). The round sardine *Sardinella aurita*, some fishes of the family Carangidae, the cassava croaker *P. senegalensis* and the bigeye grunt *Brachydeuterus auritus* composed less 5 % each of the community. Thirty four other species altogether made up 14.1 % of the community.

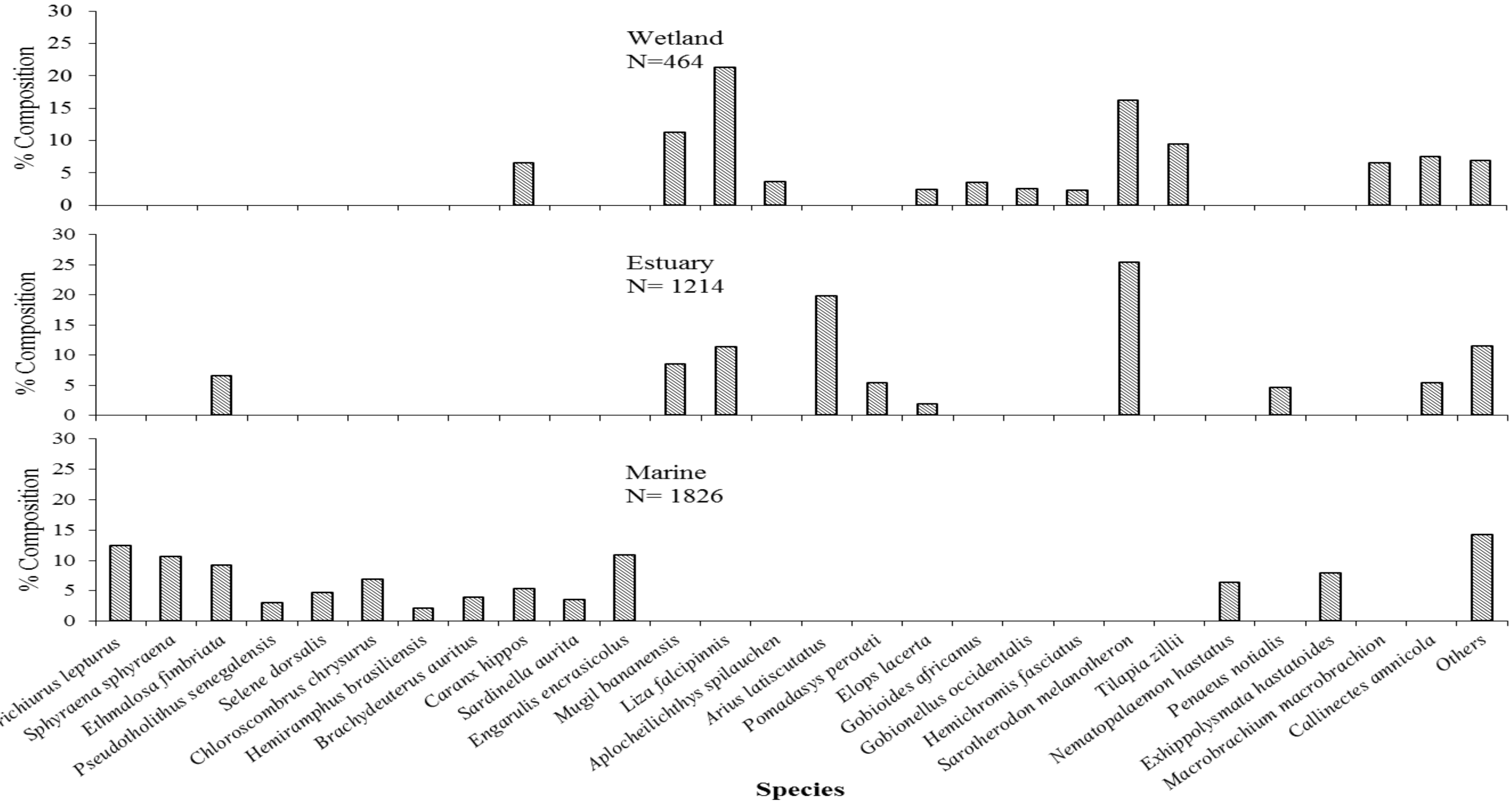


Figure 16: Species composition of the fish communities in the three ecosystems at Anlo Beach

The estuarine community comprised mainly the black-chinned tilapia *S. melanotheron* (25.3 %), the marine catfish *A. latiscutatus* (19.7 %), the sickle fin mullet *L. falcipinnis* (11.3%) and banana mullet *M. bananensis* (8.5 %). Shrimps (*Penaeus notialis),* crabs (*C. amnicola*), the shad (*E. fimbriata*) and the snaper (*Pomadasys peroteti*) comprised 4 % to 7 % respectively of the community. *Elops lacerta* had a composition of 1.9 % and twenty-three other species were each less than 1% of the community.

The wetland was dominated by *L. falcipinnis* (21.3 %), *S. melanotheron* (16.2 %) and *M. bananensis* (11.3 %). *T. zilli, Caranx hippos, C. amnicola* and *M. microbrachion* were also considerably present in the community (6.5 to 9.5 % each) while *Aplocheilichthys spilauchen*, *Elops lacerta*, the gobies *G. africanus* and *G. occidentalis* as well as the cichlid *H. fasciatus* constituted less than 4% each. Eight other species together made up 11.3% of the community.

Diversity of fish in the ecosystems

The richness and diversity index values for the fish communities are presented in Table 4. The marine ecosystem had the richest and most diverse community with 47 species from 32 families (d = 3.61, H'= 3.42), followed by the estuary with 32 species from 19 families (d = 2.57, H'= 2.63). The wetland had the least diverse fish community represented by 20 species from 11 families.

Table 4: Richness and diversity of fish species in the three ecosystems

Ecosystem	Number		Richness (*d*)	Diversity (*H'*)	Evenness (*J'*)
	Families	Species			
Wetland	11	20	1.25	1.75	0.53
Estuary	19	32	2.57	2.63	0.81
Marine	32	47	3.61	3.42	0.64

The fish community in the estuary was richer and more diverse at high tide than low tide (Figure 17) in most of the study months, except in February-July 2013 when diversity at low tide equaled or slightly exceeded that at high tide. Fish diversity declined steadily from February 2012 to June 2012 at high and low tides, remaining fairly constant between August 2012 and July 2013 especially at high tide. However, the diversity at both tides showed a generally remarkable increase during the latter period of the study.

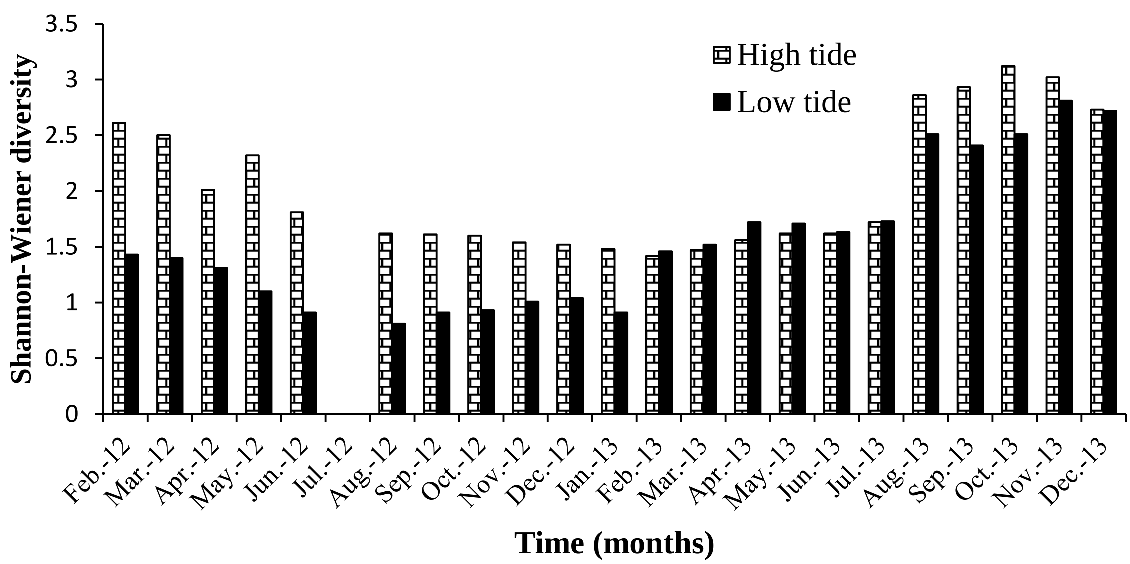


Figure 17: Monthly changes in the Shannon-Wiener diversity values of the fish community at high and low tides (Feb. 2012 to Dece. 2013)

Size distribution of the common species in the ecosystems

Table 5 shows the size range and modal size of common fishes sampled from the three ecosystems and their maturity sizes as reported in literature or determined in the present study. A few species e.g. black chinned tilapia *Sarotherodon melanotheron*, cassava croaker *Pseudotholithus senegalensis*, swimming crab *Callinectes amnicola* and the shrimps *Exhippolysmata hastatoides* and *Nematopalaemon hastatus* were caught with individuals at advanced stages of maturity. Majority of the marine fishes e.g. *Sphyraena sphyraena* (modal length range = 25.0-25.9 cm TL), *Ethmalosa fimbriata* (modal length range = 9.0-9.9 cm TL) and *Trichiurus lepturus* (modal length range = 60.0-69.0 cm TL), as well as the catfish *Arius latiscutatus* (modal length range = 9.0-9.9 cm) and other species caught from the estuary had modal sizes smaller than their respective maturity sizes (See Table 5).

Table 5: Length range of fish species sampled from the three ecosystems (percentage composition in parenthesis)

	Marine			Estuary			Wetland			Maturity
		Size-TL (cm)			Size-TL (cm)			Size-TL (cm)		Size
Species	N	Range	Mode	N	Range	Mode	N	Range	Mode	**(TL cm)**
Arius latiscutatus (M)	1	65.3	-	239	5.3-16.5	9.0-9.9(78.4)	-	-	-	-
Citharichthys stampflii (M)	12	13.3-14.8	14.0-14.9(53.4)	24	7.1-10.0	7.0-7.9(84.6)	-	-	-	-
Scyacium micrurum (M)	23	25.3-32.3	26.0-26.9(64.6)	4	6.5-8.0	-	-	-	-	-
Caranx hippos (M)	87	6.3-14.6	7.0-7.9(75.3)	12	4.8-9.0	6.0-6.9(77.9)	30	4.2-7.3	6.0-6.9(65.2)	55-65[c]
Chloroscombrus chrysurus (M)	124	7.8-17.6	9.0-9.9(72.3)	-	-	-	-	-	-	-
Sarotherodon melanotheron(BW)	-	-	-	956	3.4-15.3	10.0-10.9(46.7)	75	3.5-10.1	7.0-7.9(41.3)	10.0[a]
Tilapia zillii (F)	-	-	-	32	5.8-16.4	7.0-7.9(63.4)	43	3.8-6.2	5.0-5.9(36.0)	-
Hemichromis fasciatus (F)	-	-	-	5	7.7-11.1	-	11	11-13.3	11-11.9(26)	-
Ethmalosa fimbriata (M)	202	6.5-23.4	9.0-9.9(78.6)	36	6.4-12.1	8.0-8.9(86.6)	-	-	-	22.0[j]
Sardinella aurita (M)	35	-	8.0-8.9(84.7)	4	5.3-7.1	-	-	-	-	17.5-21.5[d]
Sardinella maderensis (M)	21	8.4-26.5	9.0-9.9(79.4)	-	-	-	-	-	-	-

Table 5 continued

Species	Marine			Estuary			Wetland			Maturity Size
		Size-TL (cm)			Size-TL (cm)			Size-TL (cm)		
	N	Range	Mode	N	Range	Mode	N	Range	Mode	(TL cm)
Ilisha africana (M)	16	6.3-19.4	8.0-8.9(65.3)	-	-	-	-	-	-	-
Cynoglossus senegalensis (M)	4	28.4-36.8	-	5	14.1-29.0	-	-	-	-	-
Eleotris senegalensis (F)	-	-	-	1	23.2	-	2	9.4	-	-
Elops lacerta (M)	3	46.4-52.1	-	5	10.5-21.2	-	11	5.8-19.5	-	-
Porogobius schlegelii (F)	-	-	-	-	-	-	10	4.9-6.7	5.0-5.9(24.3)	4.9[a]
Gobionellus occidentalis (F)	-	-	-	-	-	-	12	7.4-11.2	8.0-8.9(31.0)	-
Gobioides africanus (F)	-	-	-	11	7.7-10.0	9.0-9.9	16	8.3-10.5	9.0-9.9(21.9)	-
Pomadasys peroteti (M)	23	12.2-23.4	14.0-14.9(65.3)	64	4.3-14.3	9.0-9.9(78.8)	-	-	-	-
Plectorhynchus macrolepsis (M)	15	14.2-21.4	14.0-14.9(64.2)	14	4.6-10.2	7.0-7.9(75.1)	-	-	-	-
Brachydeuterus auritus (M)	69	6.4-17.3	10.0-11.0(65.0)	-	-	-	-	-	-	14.4[b]
Hemiramphus brasiliensis (M)	38	10.2-16.5	13.0-13.9(90.1)	-	-	-	-	-	-	16.0[g]
Lobotes surinamensis (M)	4	6.3-28.0	-	6	5.9-11.8	-	-	-	-	-

Table 5 continued

	Marine			Estuary			Wetland			Maturity Size
	Size-TL (cm)			Size-TL (cm)			Size-TL (cm)			
Species	N	Range	Mode	N	Range	Mode	N	Range	Mode	**(TL cm)**
Liza falcipinnis (M)	1	16.3	-	137	5.1-23.2	9.0-9.9(63.0)	98	4.1-9.7	5.0-5.9(48.3)	11.6-12.1[i]
Mugil bananensis (M)	-	-	-	103	5.0-22.6	6.0-6.9(56.9)	52	5.2-7.0	6.0-6.9(36.1)	19.2[a]
Mugil curema (M)	-	-	-	12	11.3-22.6	-	-	-	-	16.0[a]
Liza dumerillii (M)	-	-	-	21	4.2-11.1	7.0-7.9(67.6)	5	11.4-12.1	-	-
Galeoides decadactylus (M)	46	12.1-21.2	19.0-19.9(73.9)	6	10.7-11.4	-	-	-	-	-
Pseudotholithus typus (M)	34	26.4-60.9	40.0-49.9(55.4)	-	-	-	-	-	-	21.3[a]
Pseudotholithus senegalensis(M)	54	23.7-68.3	40.0-49.0(64.1)	13	11.1-17.3	-	-	-	-	24.2[a]
Epinephelus aeneus (M)	6	21.3-28.4	-	12	7.9-9.4	-	-	-	-	-
Sphyraena sphyraena (M)	96	23.5-34.6	25.0-25.9(98.4)	-	-	-	-	-	-	26.7-27.6[e]
Trichiurus lepturus (M)	126	24.5-78.3	60.0-69.0(63.2)	-	-	-	-	-	-	79.0[f]
Nematopalaemon hastatus (M)**	166	1.6-5.8	3.0-3.9(85.5)	-	-	-	-	-	-	3.2[a]

Table 5 continued	Marine			Estuary			Wetland			Maturity
	Size-TL (cm)			Size-TL (cm)			Size-TL (cm)			Size
Species	N	Range	Mode	N	Range	Mode	N	Range	Mode	**(TL cm)**
Penaeus notialis (M)**	54	2.5-18.4	10.0-10.9(65.3)	11	5.7-20.6	-	-	-	-	-
Exhippolysmata hastatoides (M)**	197	1.5-6.0	3.0-3.9(87.6)	-	-	-	-	-	-	3.5[a]
Callinectes amnicola (M)*	24	5.5-16.3	9.0-9.9(65.7)	65	3.0-10.1	5.0-5.9(59.0)	34	2.6-8.4	4.0-4.9(48.1)	5.3-6.2[h]

*denotes carapace width; ** denotes body length;

a = smallest mature specimen observed in the samples; b= Samb (2003); c = Ospina-Arango, Pardo-Rodríguez & Álvarez-León (2008), Panfili, Thior, Ecoutin, Ndiaye & Albaret (2006); d= Mensah (1975); e = Allam, Faltas & Ragheb (2004); f = Al-Nahdi, Al-Marzouqi, Al-Rasadi & Groeneveld (2009); g = McBride & Thurman (2003); h = Impraim (2009); i= Lawson, Akintola & Olatunde (2010); j: Blay & Eyeson (1982)

Food habits of economically important species

Examination of the stomach content of six commercially important species in the Anlo Beach marine landings showed that shrimps were the most consumed prey items by the bigeye grunt *Brachydeuterus auritus*, the threadfin *Galeoides decadactylus* and the cassava croakers *Pseudotholithus senegalensis* and *Pseudotholithus typus* (Figure 18). Shrimps occurred in 80% to 100% of the stomach while the numerical and gravimetric composition varied between 45% and 80% in their diet. Unidentified juvenile fishes were also highly consumed, with occurrence frequency from 20% to 80% and constituting 14% to 25% numerically and 10% to 50% by weight. On the other hand, the other two most important species, *Trichiurus lepturus* and *Sphyraena sphyraena* consumed more of unidentified juvenile fish (100% occurrence, > 40 % numerical composition and > 30 % gravimetric composition), and juveniles of the clupeids (*Ilisha africana* and *Ethmalosa fimbriata*), and grunts mainly *Brachydeuterus auritus*. Shrimps were seldom consumed.

Figure 19 illustrates the Index of Relative Importance (IRI) for the different food items. This further shows that shrimps were the most important prey for *B. auritus*, *G. decadactylus*, *P. senegalensis* and *P. typus*, with the index ranging from 185,750 to 599,508, while fish was the most important food for *T. lepturus* and *S. sphyraena* with IRI values of 136,080 for the former and 323,744 for the latter.

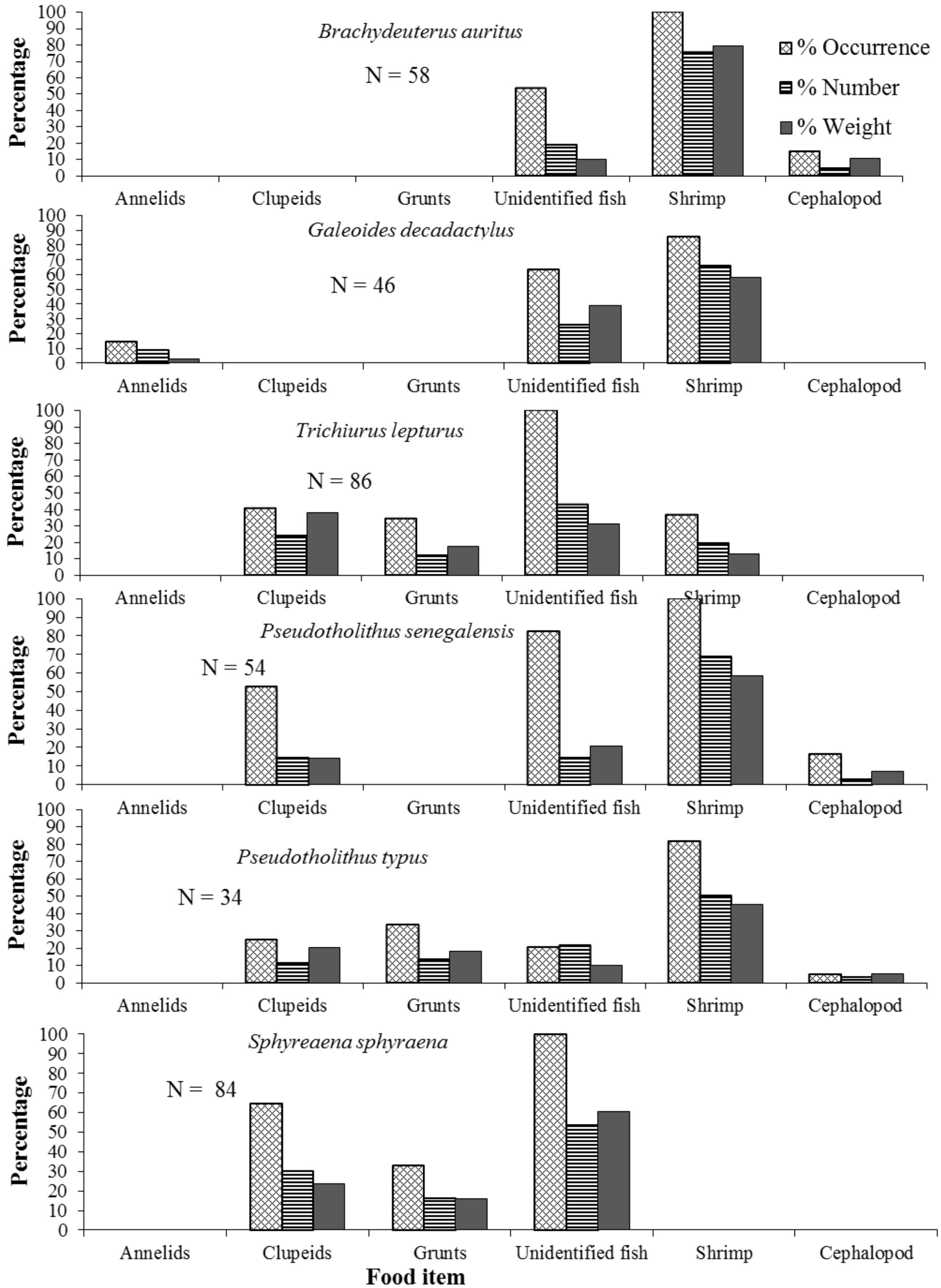


Figure 18: Percentage occurrence, numerical and gravimetric composition of the prey of six commercially important species in the marine fishery

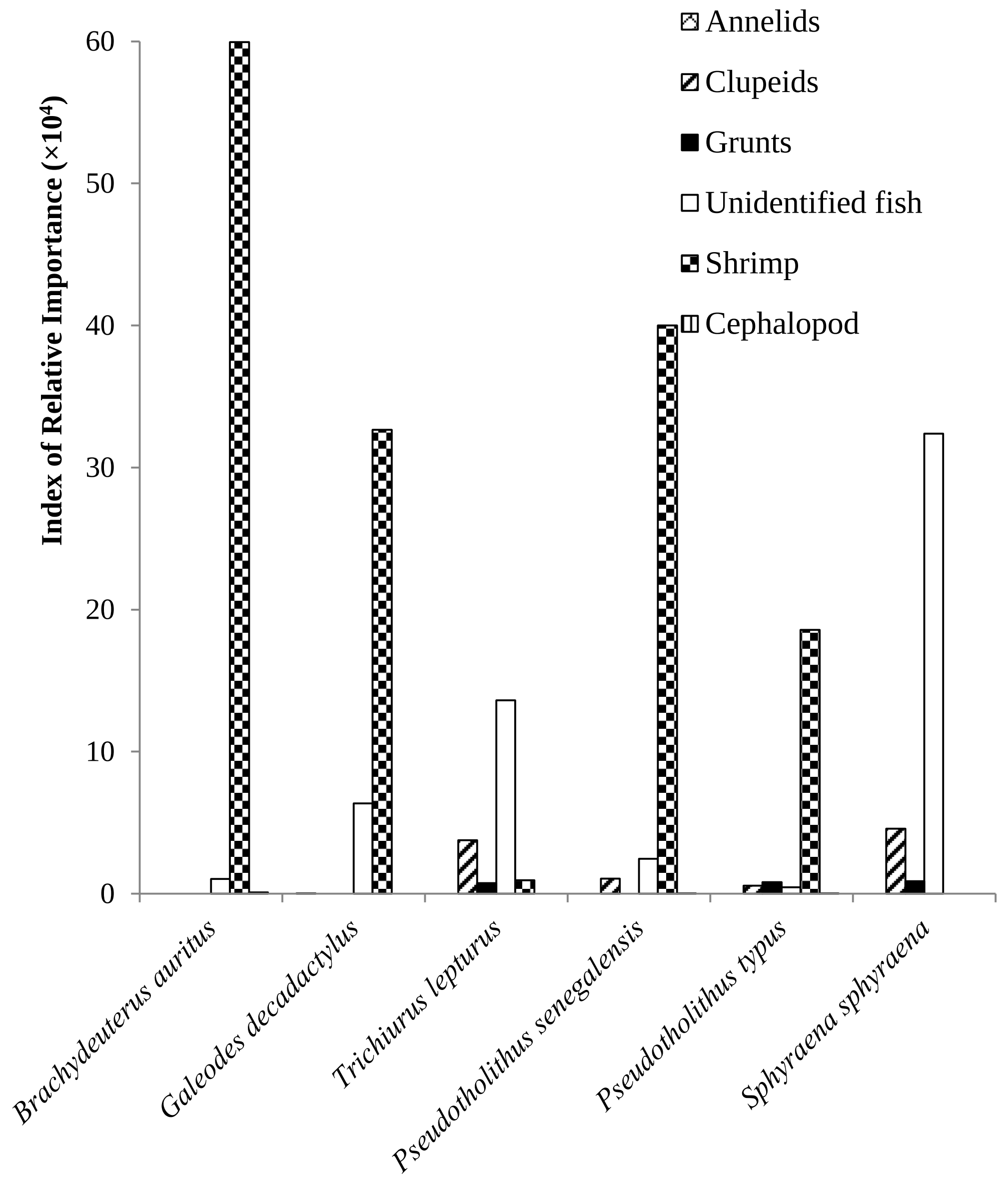


Figure 19: Relative importance of the prey of six commercially valuable fishes

The extent of overlaps of the trophic niches of the species are shown in Table 6. There was a significant overlap in the food items eaten by *B. auritus*, *G. decadactylus*, *P. senegalensis* and *P. typus* indicated a significant overlap of their diets (Schroener's niche overlap index, $\propto > 6.0$). The food niche of the ribbon fish *T. lepturus* overlapped significantly with that of *S. sphyraena* ($\propto = 0.71$) and *P. typus* ($\propto = 0.61$).

Table 6: Overlap of the diet of six commercially valuable fishes

	Schroener's niche overlap index (∝)				
Species	*B. auritus*	*G. decadactylus*	*T. lepturus*	*P. senegalensis*	*P. typus*
G. decadactylus	0.68				
T. lepturus	0.23	0.46			
P. senegalensis	0.75	0.79	0.48		
P. typus	0.61	0.56	0.61	0.75	
S. sphyraena	0.10	0.40	0.71	0.35	0.47

Trophic interactions and the fishery

Twenty five groups were identified and used in constructing the Ecopath model, the inputs and outputs of which are presented in Table 7 (Table 8 presents the diet matrix of the groups). Generally, detrital materials and algae (i.e. primary producers) were at the lowest trophic levels with trophic level (TRL) of 1.0. The primary consumers occupied TRL between 2.0 and 2.5 and these included zooplankton, worms (polychaetes and oligochaetes), small crustaceans (isopods, amphipods, tanaids, etc.) and crustacean shellfish (shrimps, crabs and lobsters). Others were planktivorous fish (grey mullets and tilapias), gobbies and related fishes (gobbies, eleotrids, cyprinodontiform fishes, etc.). The primary consumers had higher total mortality (higher P/B and Q/B ratios) in the trophic system. The secondary consumers occurring at TRL 2.5 - 2.9 were the small pelagics (sardines, shads, carangids, etc.), the marine catfish (*Arius* sp.) and the freshwater catfish (*Clarias* sp.). The remaining groups in the ecosystem were tertiary consumers (TL > 3.0) with lower P/B and Q/B ratios, with the top predators being the barracudas (*Sphyraena* spp., *Trichiurus* sp., *Elops* sp., etc.) with TRL of 3.83.

Table 7: Biomass and trophic data of the functional groups used in constructing the Ecopath VI model of the Anlo Beach ecosystems (outputs or derived estimates from Ecopath in brackets)

	Group name	Trophic level (TRL)	Biomass in habitat area (t/km²)	Biomass (t/km²)	P / B (/year)	Q / B (/year)	EE	P / Q
1	Marine reptiles	(3.51)	0.48[a]	(0.43)	0.31[a]	(65.45)	0.95	(0.00)
2	Wetland reptiles	(2.82)	0.09[b]	(0.01)	0.09[b]	8.24	(0.17)	(0.01)
3	Large coastal demersals	(3.66)	11.91	(10.48)	5.60[c]	15.98[c]	(0.83)	(0.35)
4	Flatfish or flounders	(3.38)	5.80	(5.19)	5.20[c]	12.63[c]	(0.70)	(0.41)
5	Threadfins	(3.59)	3.20	(2.86)	2.23	5.78	(0.71)	(0.39)
6	Barracudas	(3.83)	14.85	(13.06)	4.80	8.43	(0.87)	(0.57)
7	African pike	(3.52)	0.40	(0.01)	2.70[j]	7.21[j]	(0.06)	(0.37)
8	Mangrove birds	(3.18)	0.02[d]	(0.01)	0.11[k]	0.41[k]	0.95	(0.26)
9	Sea birds	(3.70)	0.04[d]	(0.04)	0.21[k]	5.32[k]	0.95	(0.04)
10	Small pelagics	(2.76)	26.06	(23.31)	14.65[c]	28.72[c]	(0.91)	(0.51)

Table 7 continued

	Group name	Trophic level (TRL)	Biomass in habitat area (t/km²)	Biomass (t/km²)	P / B (/year)	Q / B (/year)	EE	P / Q
11	Cephalopods	(3.40)	8.20	(7.25)	11.40 [c]	23.20 [c]	(0.73)	(0.49)
12	Crustacean shellfish	(2.34)	14.88	(13.31)	25.30 [c]	64.20 [c]	(0.88)	(0.39)
13	Catfish	(2.95)	4.20	(3.76)	6.20[j]	20.25[j]	(0.64)	(0.31)
14	Gobbies & related fishes	(2.05)	7.10	(6.35)	5.40[j]	8.77[j]	(0.74)	(0.62)
15	Herbivorous fish	(2.00)	4.21	(3.92)	6.80[j]	16.40[j]	(0.83)	(0.41)
16	Planktivorous fish	(2.00)	13.40	(11.98)	34.80[i]	102.80[i]	(0.86)	(0.34)
17	Worms	(2.00)	1.36	(1.22)	29.40 [c]	72.60 [c]	(0.32)	(0.40)
18	Small crustaceans	(2.00)	1.56	(1.40)	64.43 [c]	163.83 [c]	(0.57)	(0.39)
19	Zooplankton	(2.00)	5.21[f]	(4.66)	138.40 [c]	355.30 [c]	(0.74)	(0.39)
20	Macrophytes	(1.00)	6.00[h]	(0.69)	128.98[h]	0.00	(0.36)	
21	Macro-algae	(1.00)	0.34[h]	(0.31)	138.40[h]	0.00	(0.64)	
22	Phytoplankton	(1.00)	2.66[e]	(2.38)	248.10 [c]	0.00	(0.24)	

Table 7 continued

	Group name	Trophic level (TRL)	Biomass in habitat area (t/km²)	Biomass (t/km²)	P / B (/year)	Q / B (/year)	EE	P / Q
23	Carcasses	(1.00)	0.01	(0.00)				
24	Detritus from run-off	(1.00)	0.02	(0.00)				
25	Detritus from riparian flora	(1.00)	0.60[g]	(0.07)			(0.93)	

a = Nature Conservation Research Centre (unpublished data)

b = Mampam Conservation (http://www.mampam.com/)

c = Blay (unpublished data)

d = Crawford (1999)

e = Djagoua *et al.* (2011)

f = Wiafe, Yaqub, Mensah, and Frid (2008)

g = Debrah (2013)

h = Arreguín-Sánchez, Valero-Pacheco and Chávez (1993)

i = De La Cruz-Aguero (1993)

j = Aravindan (1993); k = Fulton and Smith (2002)

Table 8: Diet compositions of the functional groups in the Anlo Beach ecosystems' Ecopath VI model (1-19 represent the first 19 functional groups where 1 = Marine reptiles and 19 = Zooplankton)

		Predator																		
	Prey	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1	Marine reptiles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Wetland Reptiles	-	-	-	-	-	-	-	0.17	-	-	-	-	-	-	-	-	-	-	-
3	Large coastal demersals	-	-	-	-	-	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-
4	Flatfish or Flounders	-	-	0.02	-	-	0.10	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Threadfins	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	Barracudas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	African pike	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Mangrove birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Sea Birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Small pelagics	-	0.05	0.10	0.10	0.33	0.30	0.10	0.26	0.24	-	0.25	-	-	-	-	-	-	-	-

	Prey	Predator																		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
11	Cephalopods	0.19	0.10	0.28	0.07	0.11	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-
12	Crustacean Shellfish	0.77	-	0.50	0.60	0.55	0.10	0.10	-	0.32	-	0.61	-	0.18	-	-	-	-	-	-
13	Catfish	-	-	-	-	-	0.10	0.43	-	-	-	-	-	-	-	-	-	-	-	-
14	Gobbies & related fishes	-	0.14	-	-	-	0.05	0.08	0.17	-	-	-	-	0.26	-	-	-	-	-	-
15	Herbivorous fish	-	0.15	-	-	-	0.05	0.07	-	-	-	-	-	0.20	-	-	-	-	-	-
16	Planktivorous fish	-	0.10	0.10	-	-	0.10	0.23	0.13	0.13	-	0.14	0.33	0.20	-	-	-	-	-	-
17	Worms	0.02	0.09	-	0.10	0.01	-	-	0.06	0.05	-	-	-	0.03	0.04	-	-	-	-	-
18	Small Crustaceans	-	-	-	0.13	-	-	-	0.05	-	0.05	-	0.01	0.01	0.01	-	-	-	-	-
19	Zooplankton	-	-	-	-	-	-	-	-	-	0.71	-	-	-	-	-	-	-	-	-
20	Macrophytes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.50	-	-	-	-
21	Algae	0.02	-	-	-	-	-	-	-	-	0.03	-	-	-	-	-	-	0.03	0.20	0.1
22	Phytoplankton	-	-	-	-	-	-	-	-	-	0.21	-	-	-	-	-	-	-	0.40	0.8

Table 8 continued

		Predator																		
	Prey	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
23	Carcasses	-	0.36	-	-	-	-	-	0.17	-	-	-	0.33	0.04	0.19	-	-	0.08	-	-
24	Detritus from run-off	-	-	-	-	-	-	-	-	-	-	-	0.17	-	0.38	-	0.50	0.08	0.17	-
25	Riparian detritus flora	-	-	-	-	-	-	-	-	-	-	-	0.17	0.08	0.38	0.50	0.50	0.81	0.23	0.10
	Import	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	(1 - Sum)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Evaluating the model's performance

In order to check the model's thermodynamic consistency, some of its output routines were used to evaluate its performance. The first indicator was the ratio of respiration to assimilation (R/A). In Ecopath, respiration (expressed in t/km^2/year) is used only to balance the flows, it is impossible to enter respiration data. The ratio cannot exceed 1.0 since respiration cannot exceed assimilation. In general, R/A is expected to be close to 1.0 for top predators, while it will tend to be lower (but positive) for organisms at lower trophic levels (see Loneragan, Babcock, Lozano-Montes & Dambacher, 2010). Figure 20 shows the relationship between R/A and the trophic levels predicted by the model. The positive slope indicates that the model is thermodynamically consistent.

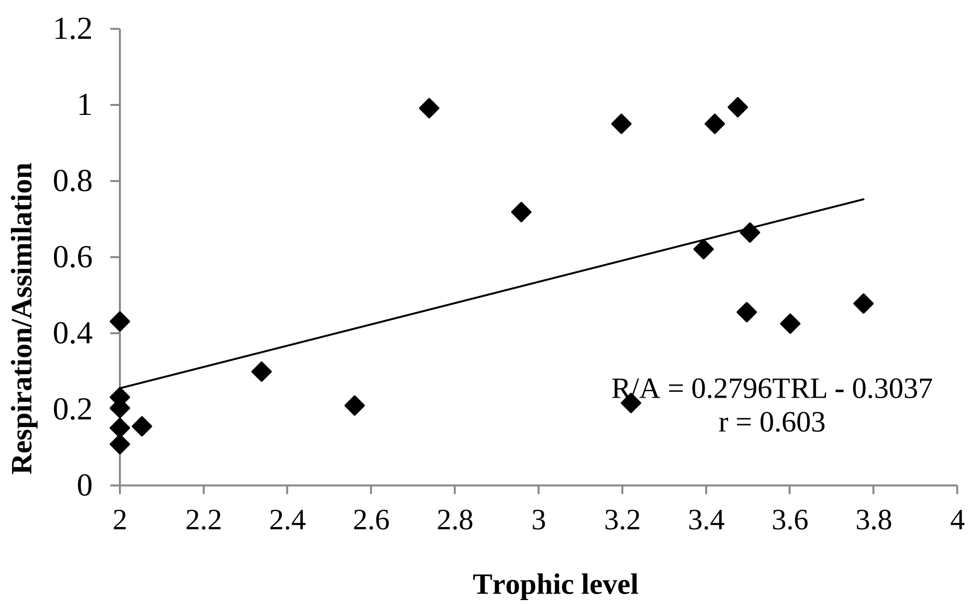


Figure 20: Relationship between the respiration to assimilation ratio and the predicted trophic levels (TRL) in the Anlo Beach model.

Another indicator was the gross food conversion efficiency (GE) which represents the ratio between production and consumption (P/Q). Consumption is expected to range from three to ten times greater than production. In most cases therefore, P/Q ratios should range from 0.1 to 0.3 (Loneragan et al. 2010). The P/Q values of the living groups (Table 7) were within the range of 0.0 to 0.45 indicating that the model is largely consistent with the expected range of 0.1-0.3.

The third indicator was the percentage transfer efficiency between trophic levels. Generally, about 15 % transfers are expected between trophic levels. In the Anlo Beach model, the transfer was found to range between 20 % and 30 % indicating that the transfers were not much higher from the expected 15 % between the trophic levels.

Trophic relations and trophic impacts

From the flow diagram (Figure 21), Phytoplankton was the largest functional group (in terms of biomass) at the base of the food web in the ecosystems. Among the secondary consumers, the small pelagic fishes and crustacean shellfishes including shrimps and crabs were the largest groups, followed by the planktivorous tilapias and mullets. The largest tertiary consumers in the food web were the large coastal demersal fishes such as the cassava croakers (*Pseudotholithus* spp.) and the bigeye grunt (*Brachydeuterus auritus*.), and the barracudas.

Figure 22 illustrates the relative impacts of the predatory fishes on the prey in the food web as well as the impacts of the fishing gears on the trophic chain. Mangrove birds had relatively high negative impacts on the mangrove

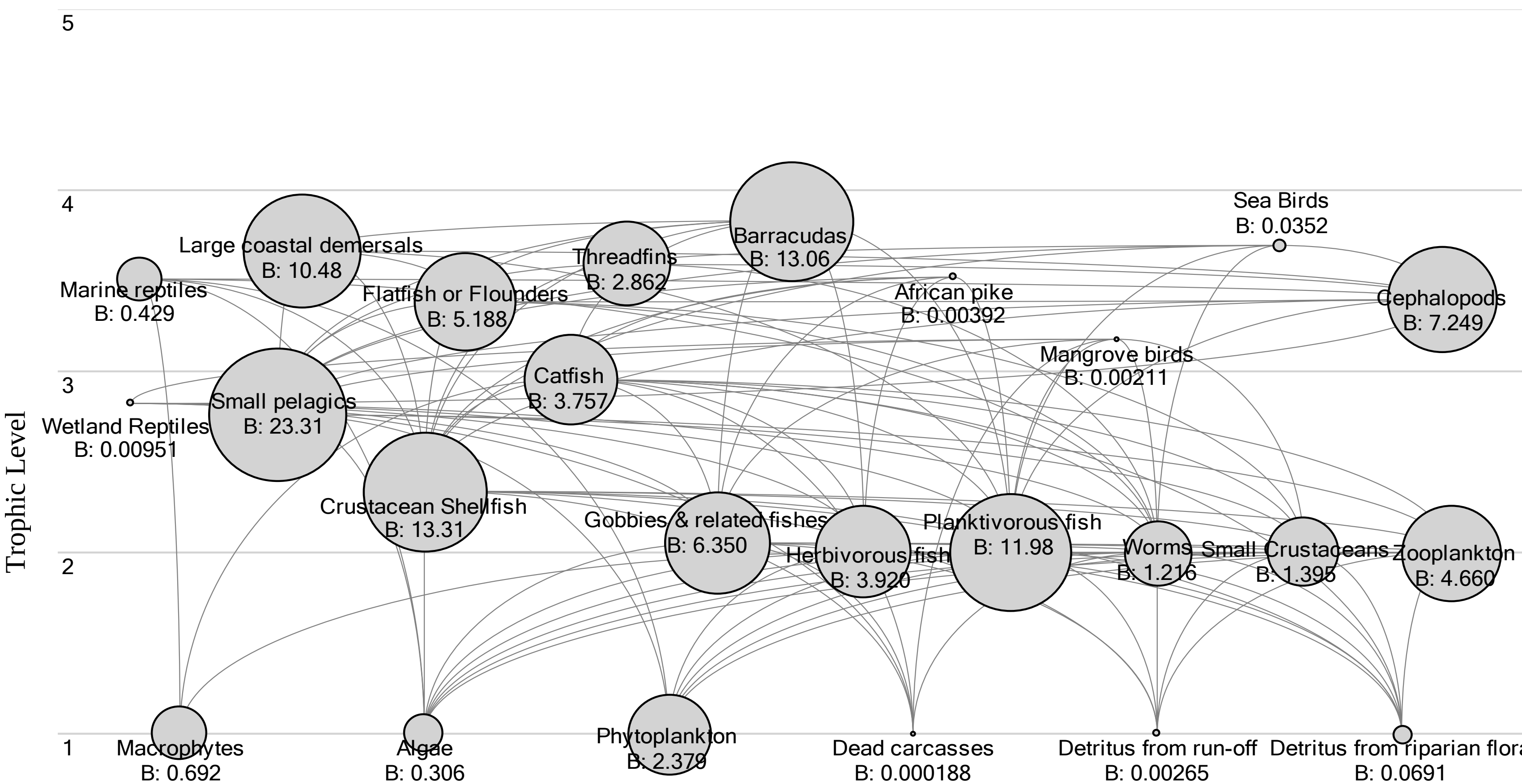


Figure 21: Flow diagram of trophic relations and food web in the Anlo Beach Ecopath VI model (circles represent relative biomass; B= actual biomass of organisms)

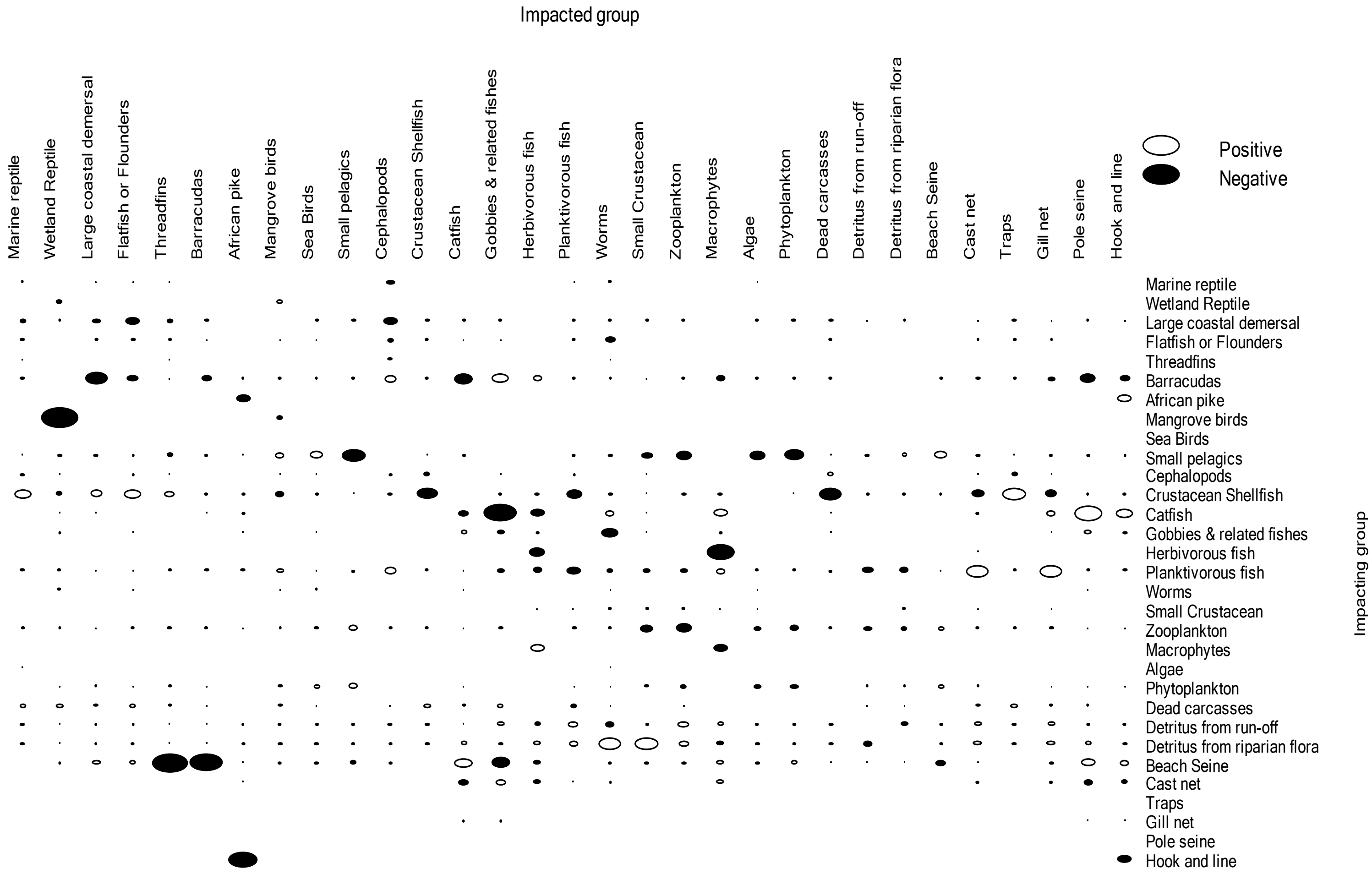


Figure 22: Mixed trophic impacts in the Anlo Beach Ecopath VI model (circles represent relative impact)

reptiles. The catfish negatively impacted the gobbies, eleotrids, etc., which also negatively impacted the worms. The most negatively impacted group by beach seine activities were the top predators especially the threadfins and the barracudas. The marine catfish benefited from the removal of their predators and were therefore positively enhanced by the fishing activity. Hook and line also negatively impacted the African pike through removal of their prey from the system.

Mortalities

The Ecopath analysis (Table 9) shows that fishing mortality (F) contributed more to the total mortality (Z) of threadfins, barracudas and small pelagics. These groups therefore had exploitation ratio (E), calculated as E =F/Z, to be greater than 0.5 suggesting that they were possibly overexploited.

Table 9: Mortality rates of finfish and shellfish groups in the Anlo Beach ecosystems Ecopath model (overexploited groups in bold)

Group name	Fishing mortality (F/year)	Predation mort. rate (/year)	Other mort. rate (/year)	Total Mortality (Z/year)	F/Z
Large coastal demersals	2.38	2.10	0.93	5.60	0.42
Flatfish or Flounders	0.87	2.77	1.56	5.20	0.17
Threadfins	1.57	0.01	0.65	2.23	**0.70**
Barracudas	4.18	0.00	0.62	4.80	**0.87**
African pike	0.15	0.00	2.55	2.70	0.06
Small pelagics	8.91	4.46	1.29	14.65	**0.61**
Cephalopods	0.19	8.14	3.06	11.40	0.02
Crustacean Shellfish	1.20	21.12	2.98	25.30	0.05
Catfish	1.06	2.94	2.21	6.20	0.17
Gobbies & related fishes	0.01	3.99	1.40	5.40	0.00
Herbivorous fish	0.36	5.30	1.14	6.80	0.05
Planktivorous fish	0.92	29.13	4.75	34.80	0.03

Predicting time dynamics and other impacts of the fishery

The model was calibrated to run time dynamic scenarios with the Ecosim software through fitting of time series data on biomass, CPUE and fishing mortality of barracudas, small pelagics and large coastal demersals from 1980 to 2013 (Appendix I). The data for the 1980's and 1990's were obtained from focus group discussions and records from fisher groups, and averages were estimated for years where data were not available.

The fishing mortality at maximum sustainable yield (F_{MSY}) for each of the groups was estimated using the equilibrium routine in Ecosim. The results (Figure 23) show that at the maximum sustainable yield, the fishing mortality (F_{MSY}) of the barracudas was 3.13 yr^{-1} compared to the current fishing mortality of 4.18 yr^{-1} for the group (Table 9) indicating that the barracuda stocks have been overexploited. Similarly, small pelagics have also been overexploited (F_{MSY} = 8.01 yr^{-1}; current F = 8.91 yr^{-1}). However, the large coastal demersal stocks have not been overexploited (F_{MSY} = 2.46 yr^{-1}; current F = 2.38 yr^{-1}).

Using Ecosim simulations, a 50 % reduction in fishing effort resulted in an increase in the biomass of barracudas from the current 13.06 t km^{-2} to 23.23 t km^{-2} a 77.8 % increase over a decade, and further to 34.63 t km^{-2} or 165.2% increase in two decades (Table 10). During the 20 year period, catches for the group would be expected to increase by 96.8 % while fishing mortality decreases from 4.18 yr^{-1} to 3.10 yr^{-1}, about the same as the F_{MSY} of 3.13 yr^{-1} estimated for the group with Ecopath. Similarly, small pelagic fish biomass would increase by 241 % from 23.06 t km^{-2} to 78.63 t km^{-2} in 20 years when fishing effort is halved (Table 11).

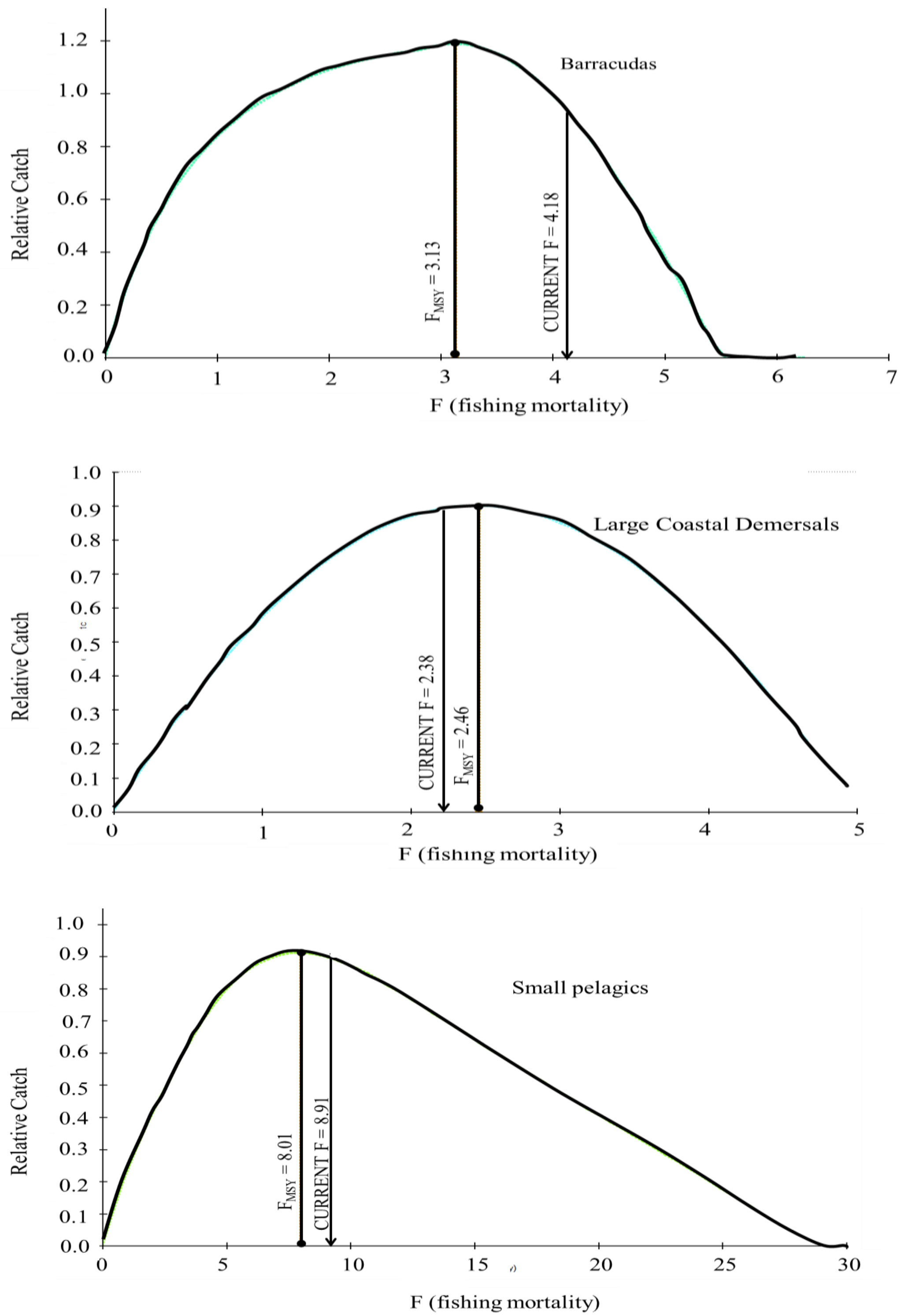


Figure 23: Comparison of estimated fishing mortality rate at MSY and the current fishing mortality of the major exploited groups in the Anlo Beach fishery

This will increase catches by 205 % and reduce fishing mortality rate by 10.2 % from the current 8.9 yr^{-1} to 7.99 yr^{-1}, hence, below the F_{MSY} of 8.01 yr^{-1}.

Table 10: Predicted results of reduction in fishing effort on the stock of the barracudas [% change in parenthesis; bold indicates lower fishing mortality (F) than F_{MSY}]

	Current (2013)	**50 % effort reduction**	
		Predicted change in 10 years (2023)	Predicted change in 20 years (2033)
Catches (t km^{-2} yr^{-1})	54.55	86.65 (58.8 %)	107.35 (96.8 %)
Biomass (t km^{-2})	13.06	23.23 (77.8 %)	34.63 (165.2%)
Fishing mort. (yr^{-1})	4.18	3.73 (-10.7 %)	**3.10** (-25.8%)

Table 11: Predicted results of reduction in fishing effort on the stock of the small pelagics [% change in parenthesis; bold indicates lower fishing mortality (F) than F_{MSY}]

		50 % effort reduction	
	Current (2013)	Predicted change in 10 years (2023)	Predicted change in 20 years (2033)
Catches (t km^{-2} yr^{-1})	205.5	340.30 (65.6 %)	628.2 (205.7 %)
Biomass (t km^{-2})	23.06	40.32 (74.8 %)	78.63 (241.0 %)
Fishing mort. (yr^{-1})	8.9	8.44 (-5.16 %)	**7.99** (-10.2 %)

Biology of the black-chinned tilapia (*Sarotherodon melanotheron*) population

Overall Length-frequency distribution

The length-frequency distribution of black-chinned tilapia population in River Pra Estuary is shown in Figure 24. Specimens measured 3.4 cm to 15.8 cm TL. The population was normally distributed with the 10.0-10.9 cm class constituting the mode of 17.4 %.

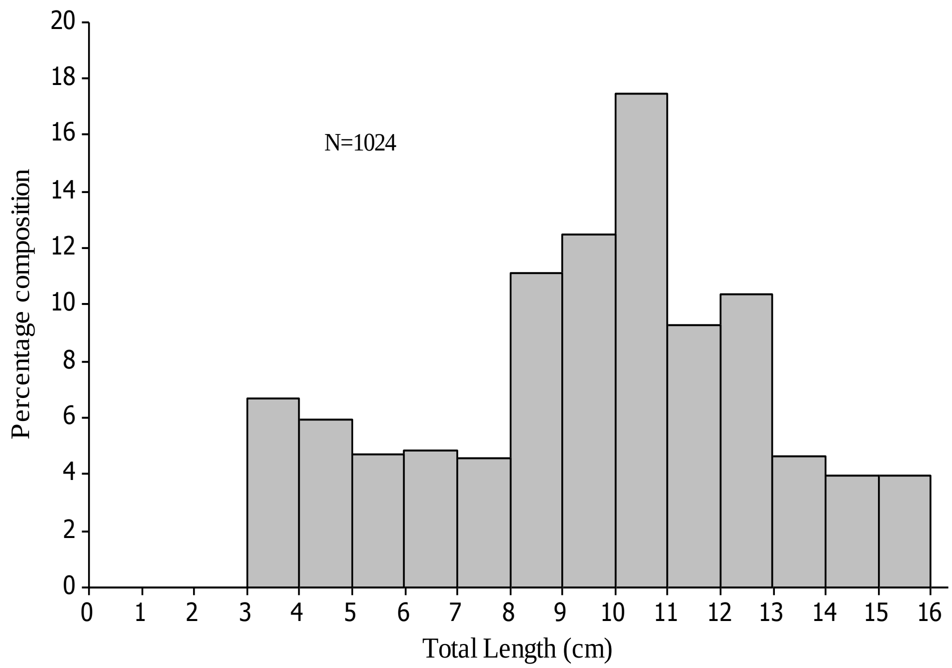


Figure 24: Monthly length-frequency distribution of the *S. melanotheron* samples collected from the Pra Estuary from 2012 to 2013

Length-weight relationship

The length-weight relationship of *S. melanotheron* in the River Pra Estuary (Figure 25) is described by the equation BW = $0.0166TL^{2.94}$ (r = 0.96), where BW is the body weight in grams and TL is the total length in centimeters.

The growth coefficient (b= 2.94) was not significantly different from the theoretical value of 3.0 for isometric growth (t = 1.92, $P > 0.05$).

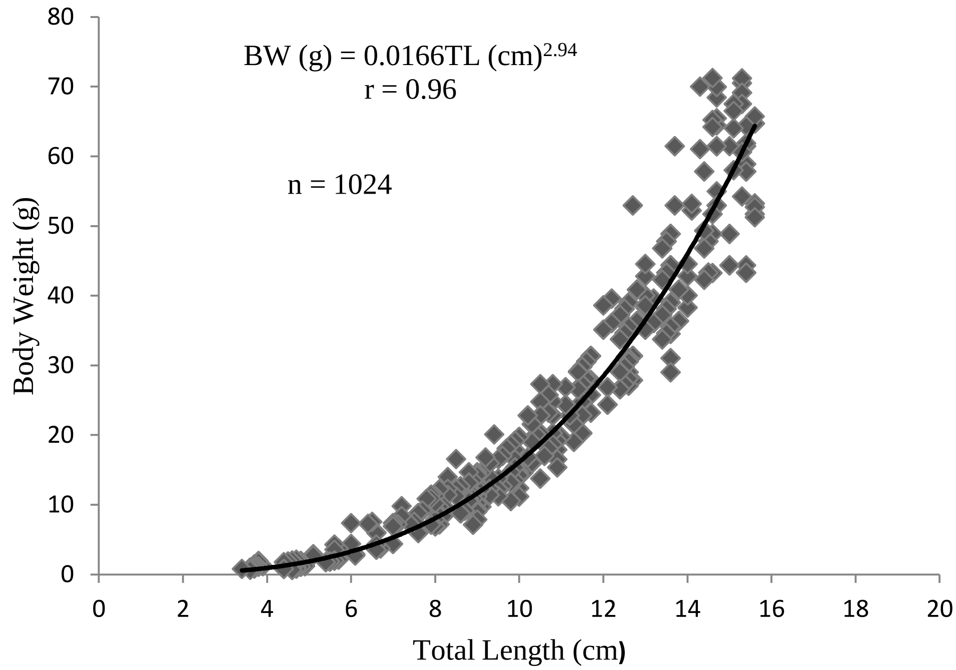


Figure 25: Regression plot of total length-body weight relationship of the *S. melanotheron* sample from the Pra Estuary

Monthly Length-frequency distribution

Figure 26 illustrates the monthly length-frequency distribution of the black-chinned tilapia during the twenty-three month study period. The catches from August to November were dominated by smaller fish in the 3.0-3.9 and 4.0 -4.9 cm classes. Modal length fluctuated between the 8.0-8.9 cm and 10.0-10.9 cm classes with shifts to the 3.0-3.9 cm and 4.0-4.9 cm classes particulary between August and October each year.

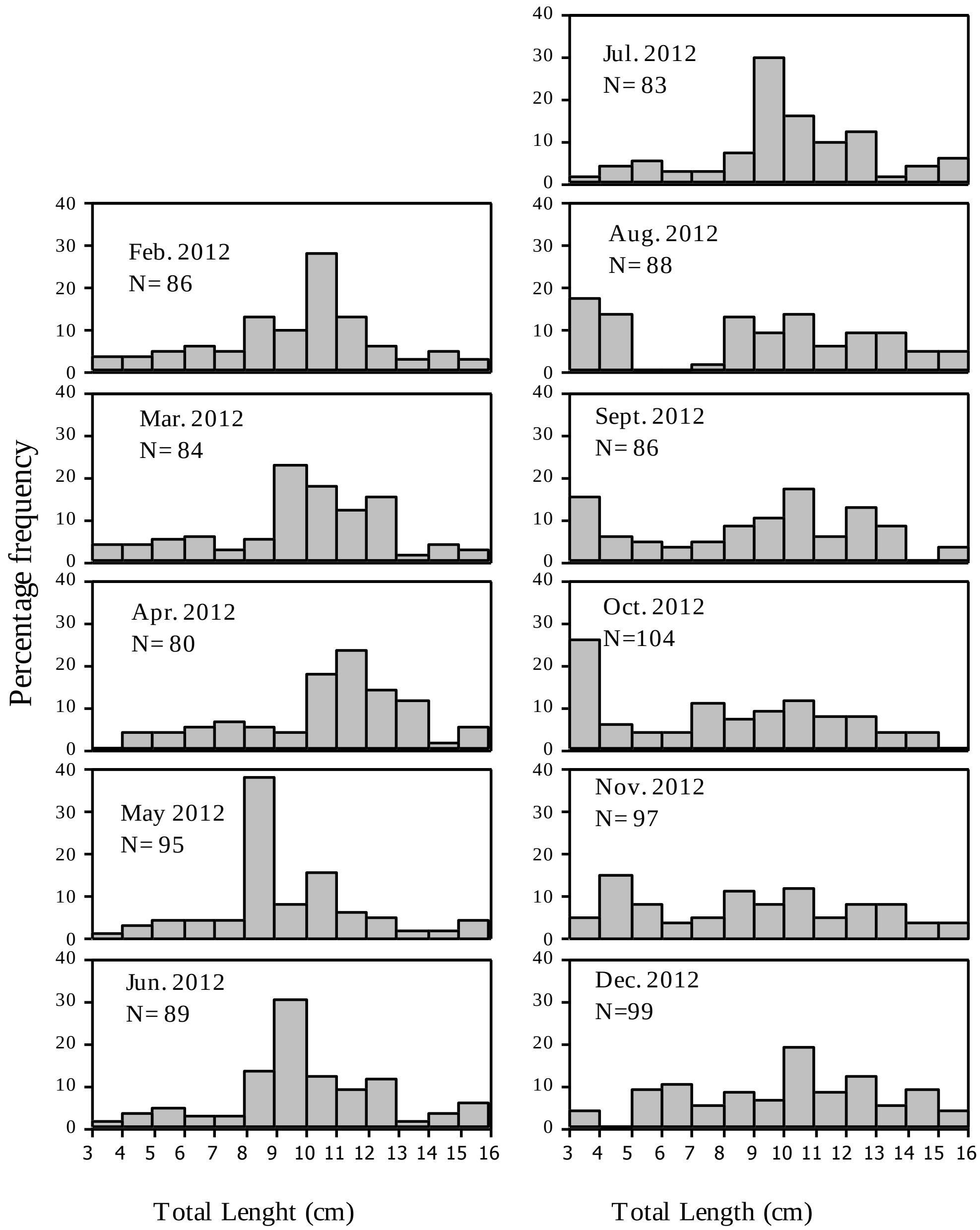


Figure 26: Monthly length-frequency distribution of the *Sarotherodon melanotheron* samples from the Pra Estuary from February 2012 to December 2013

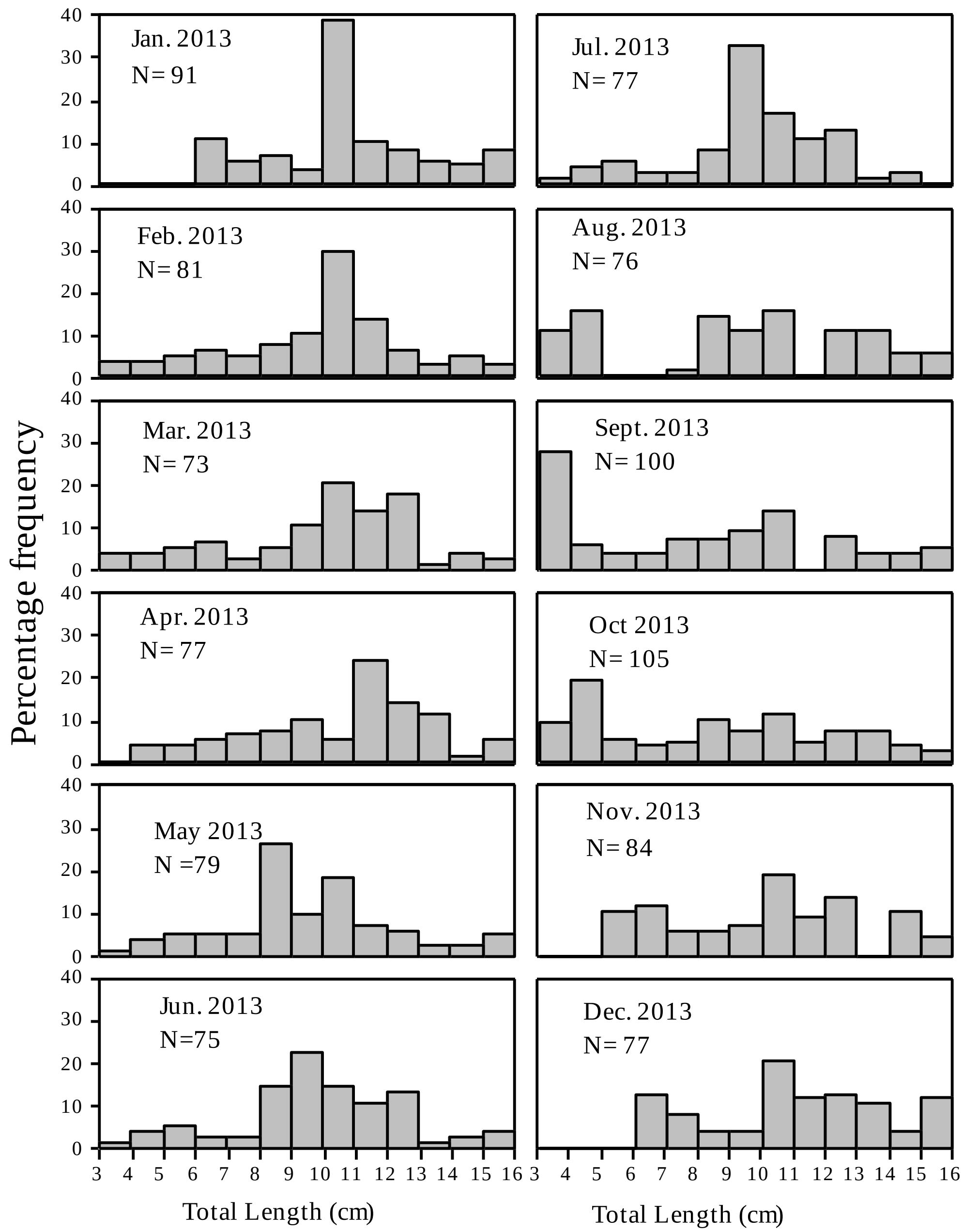


Figure 26 continued: Monthly length-frequency distribution of the Sarotherodon melanotheron samples from the Pra Estuary from February 2012 to December 2013

Growth and mortality parameters

Figure 27 presents the monthly length-frequency data of the tilapia population fitted with the von Bertalanffy growth curve using the ELEFAN programme of FiSAT II software. The asymptotic length (L_∞) was estimated as 16.84 cm TL while the growth constant (K) was 0.65/year. Substituting the values of L_∞ and K into the growth performance index equation resulted in a (ϕ') value of 2.26. Also, substituting the estimated values of L and K into Pauly's (1983) empirical equation, $\log_{10}t_0 = -0.3922 - 0.2752\log_{10}L_\infty - 1.038 \log_{10}K$, the parameter t_0 which refers to the age at which the length of the fish is zero (Gulland, 1983) was estimated as -0.29 year. The longevity (t_{max}) of the population, determined from the formula $t_{max} = 3/K$ (Pauly, 1983) was 4.6 years.

Using the estimated growth parameters, the growth of the population on a yearly basis, could be described by the von Bertalanffy equation $L_t = 16.84[1 - e^{-0.65(t+0.29)}]$, where L_t is the length of fish at age t. Figure 28 shows the von Bertalanffy curve derived for the population. It could be deduced from the figure that the tilapia attains their L_∞ between ages 9 and 10.

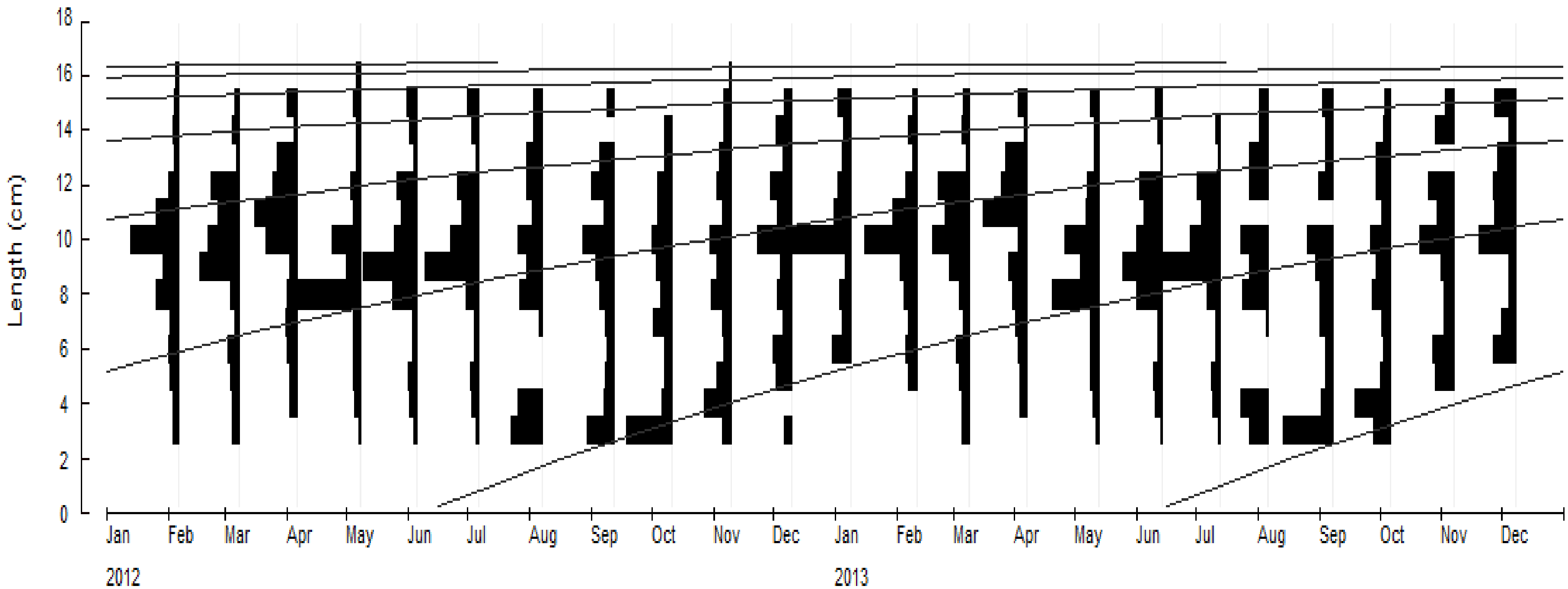


Figure 27: Monthly length-frequency distribution of the *S. melanotheron* from Pra Estuary fitted with growth curve from ELEFAN suite of FiSAT II Routine

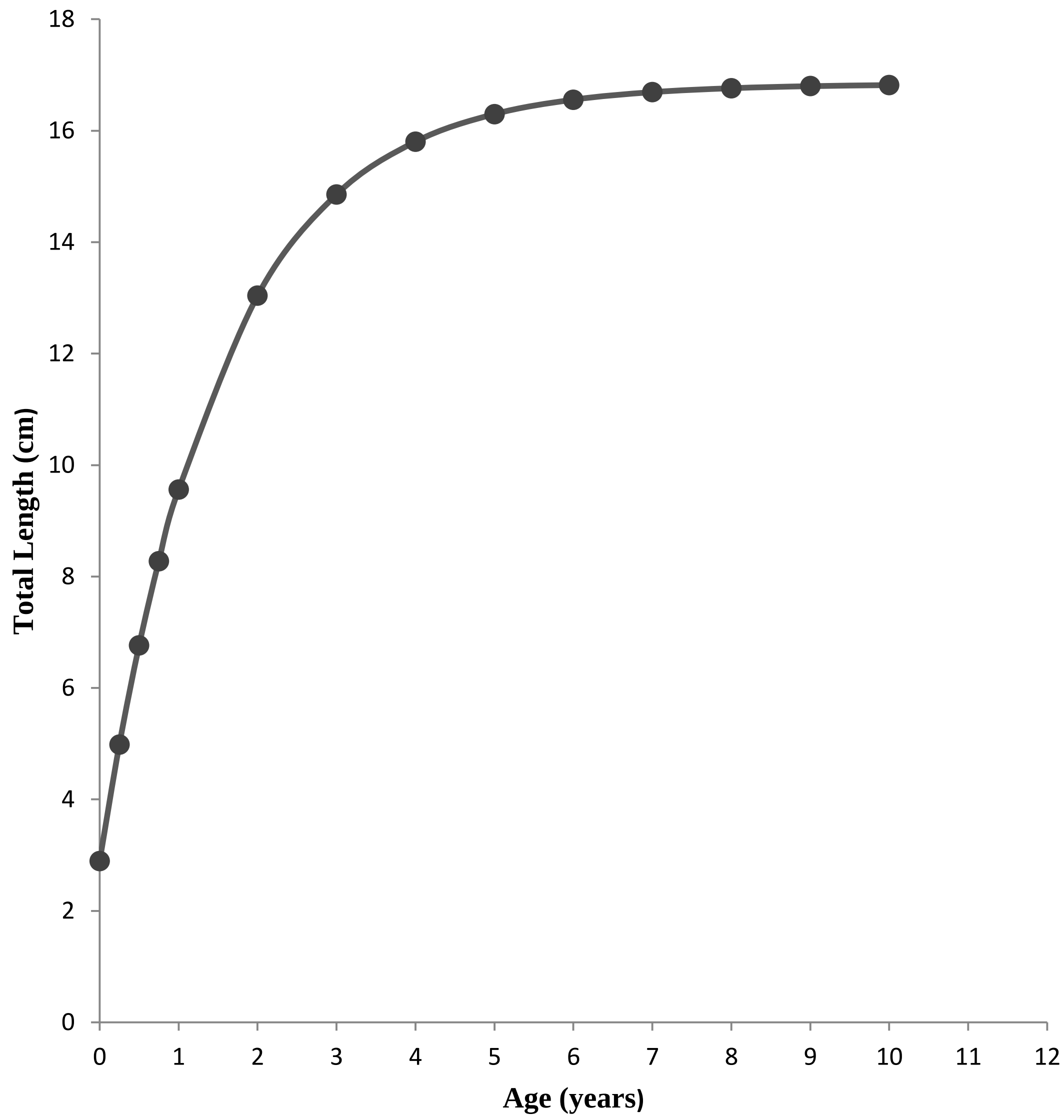


Figure 28: von Bertalanffy curve of the *Sarotherodon melanotheron* population in the Pra Estuary

The total mortality coefficient (Z) determined from the length-converted catch curve (Figure 29) was 1.69 per year while the the natural mortality coeficient (M) calculated from the Pauly's empirical equation was estimated as 1.57 per year. The fishing mortality coeficient (F) for the population was therefore 0.12 per year. The exploitation ratio (E= F/Z) was 0.07 indicating that the fish are underexploited.

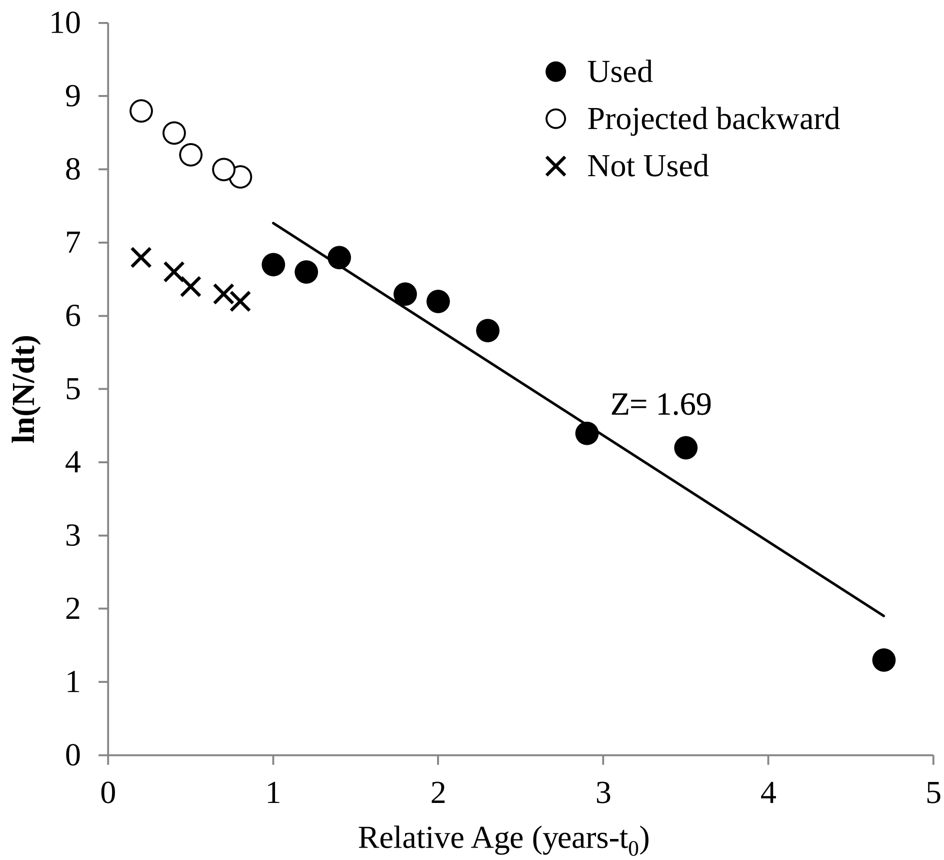


Figure 29: Length-converted catch curve for *Sarotherodon melanotheron* from Pra Estuary based on the length-frequency data from February 2012 to December 2013 in Figure 39

Maturity

The minimum length at maturity (Lm) was found to be 9.2 cm TL and the length at which 50 % of the population matured (Lm_{50}) was estimated as10.7 cm TL for females and 11.4 cm for males as indicated in Figure 30. The maturity-length ratio (Lm_{50}/L_{∞}) was calculated to be 0.68.

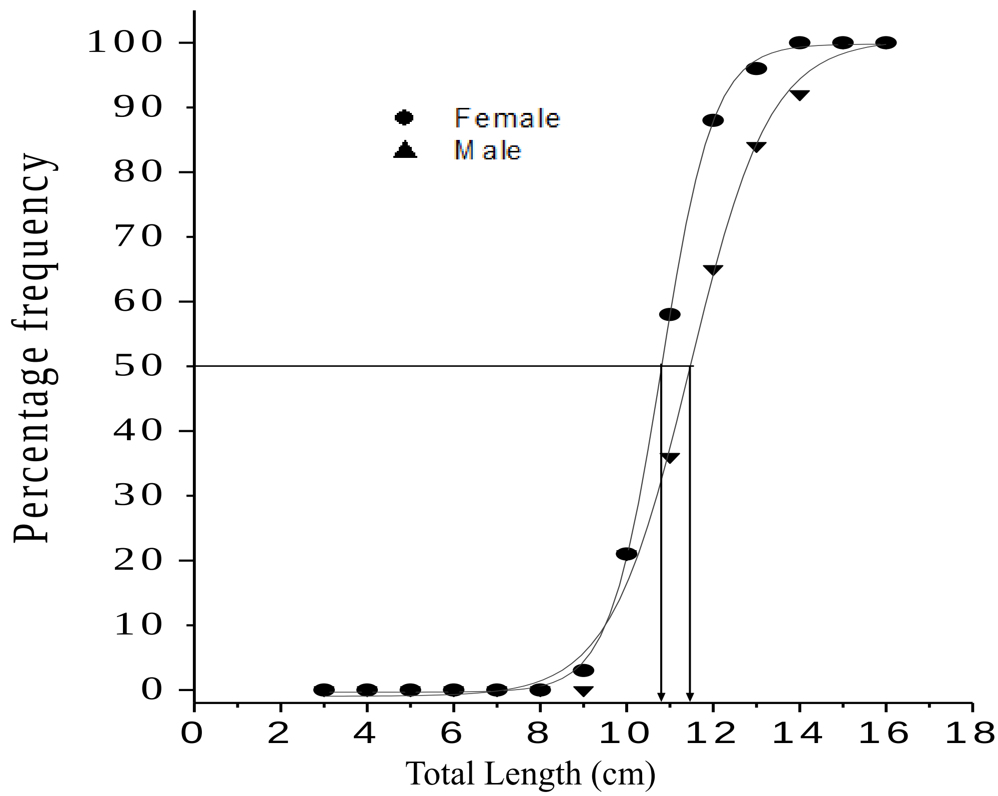


Figure 30: Length at maturity (Lm_{50}) of the *Sarotherodon melanotheron* population from Pra Estuary

Sex ratio

The monthly sex ratio of the *S. melanotheron* population is presented in Table 12. Results indicated that the sex ratio did not differ significantly from 1:1.

Table 12: Monthly sex ratio of *Sarotherodon melanotheron* from the River Pra Estuary

Month	N	Male	Female	M:F	χ^2	$P_{(0.05)}$
Feb.-12	65	27	38	1: 1.4	1.86	NS
Mar.-12	66	31	35	1:1.1	0.24	NS
Apr.-12	61	26	35	1:1.3	1.33	NS
May.-12	71	32	39	1:1.2	0.69	NS
Jun.-12	69	32	37	1:1.2	0.36	NS
Jul.-12	62	32	30	1:0.9	0.06	NS
Aug.-12	65	35	30	1:0.9	0.38	NS
Sep.-12	55	24	31	1:1.3	0.89	NS
Oct.-12	78	43	35	1:0.8	0.82	NS
Nov.-12	68	32	36	1:1.1	0.24	NS
Dec.-12	70	33	37	1:1.1	0.23	NS
Jan.-13	57	28	29	1:1.0	0.02	NS
Feb.-13	68	30	38	1:1.3	0.94	NS
Mar.-13	59	26	33	1:1.3	0.83	NS
Apr.-13	60	32	28	1:0.9	0.27	NS
May.-13	69	40	29	1:0.7	1.75	NS
Jun.-13	60	28	32	1:1.1	0.27	NS
Jul.-13	60	29	31	1:1.1	0.07	NS
Aug.-13	54	26	28	1:1.1	0.07	NS
Sep.-13	56	27	29	1:1.1	0.07	NS
Oct.-13	92	40	52	1:1.3	1.57	NS
Nov.-13	67	34	33	1:1.0	0.01	NS
Dec.-13	50	24	26	1:1.1	0.08	NS

NS : Not Significant

Monthly fluctuation in gonado-somatic index

Figure 31 indicates that the mean monthly gonado-somatic indices of males and females followed similar trend, with major peaks occurring between March and May, and troughs between June and August. The female GSI for example had a peak of 2.64 in March 2012, declining significantly to the lowest of 0.27 in July 2012 while the male peak of 0.18 in April 2012 also declined to the lowest of 0.03 in August 2012. Both increased progressively to a minor peak in December 2012 (male = 0.197, female = 1.96), declining slightly in January-February and peaking again between March and May 2013. Both dropped sharply in June – July where 0.04 and 0.23 were recorded for males and females respectively.

Monthly changes in the proportion of ripe fish

Figure 32 presents the variations in monthly percentage of males and females with gonads at the developing and ripe stages. Like the GSI, the trend of monthly changes in the gonadal stages was also similar for both sexes, with between 50 % and 90 % of the population having ripe gonads (Stage III) between March and May, and the number declining below 15 % between June and August. Individuals with developing gonads (Stage II) dominate the population (60% - 80%) during June and August.

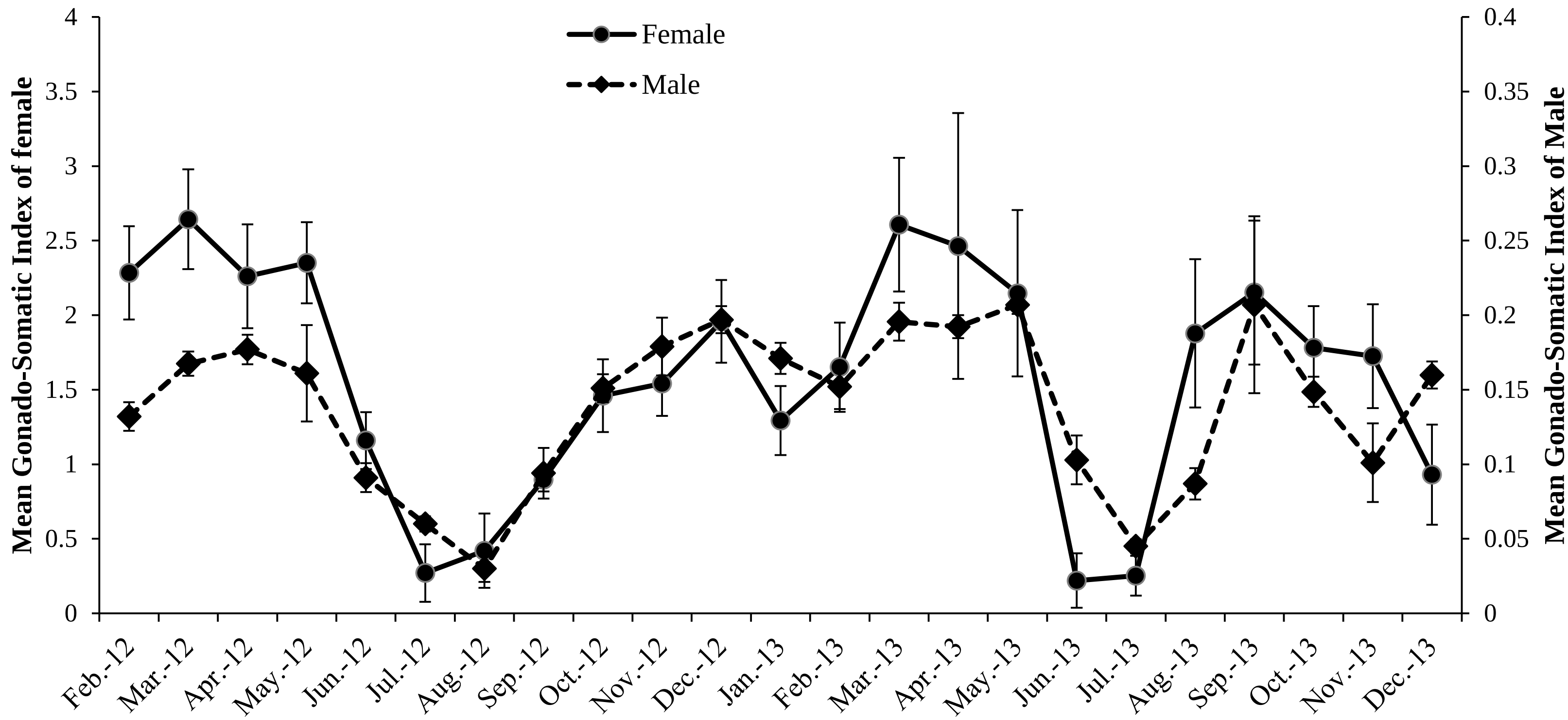


Figure 31: Monthly fluctuation of gonado-somatic index (mean±standard error) of *Sarotherodon melanotheron* in the Pra Estuary from 2012-2013

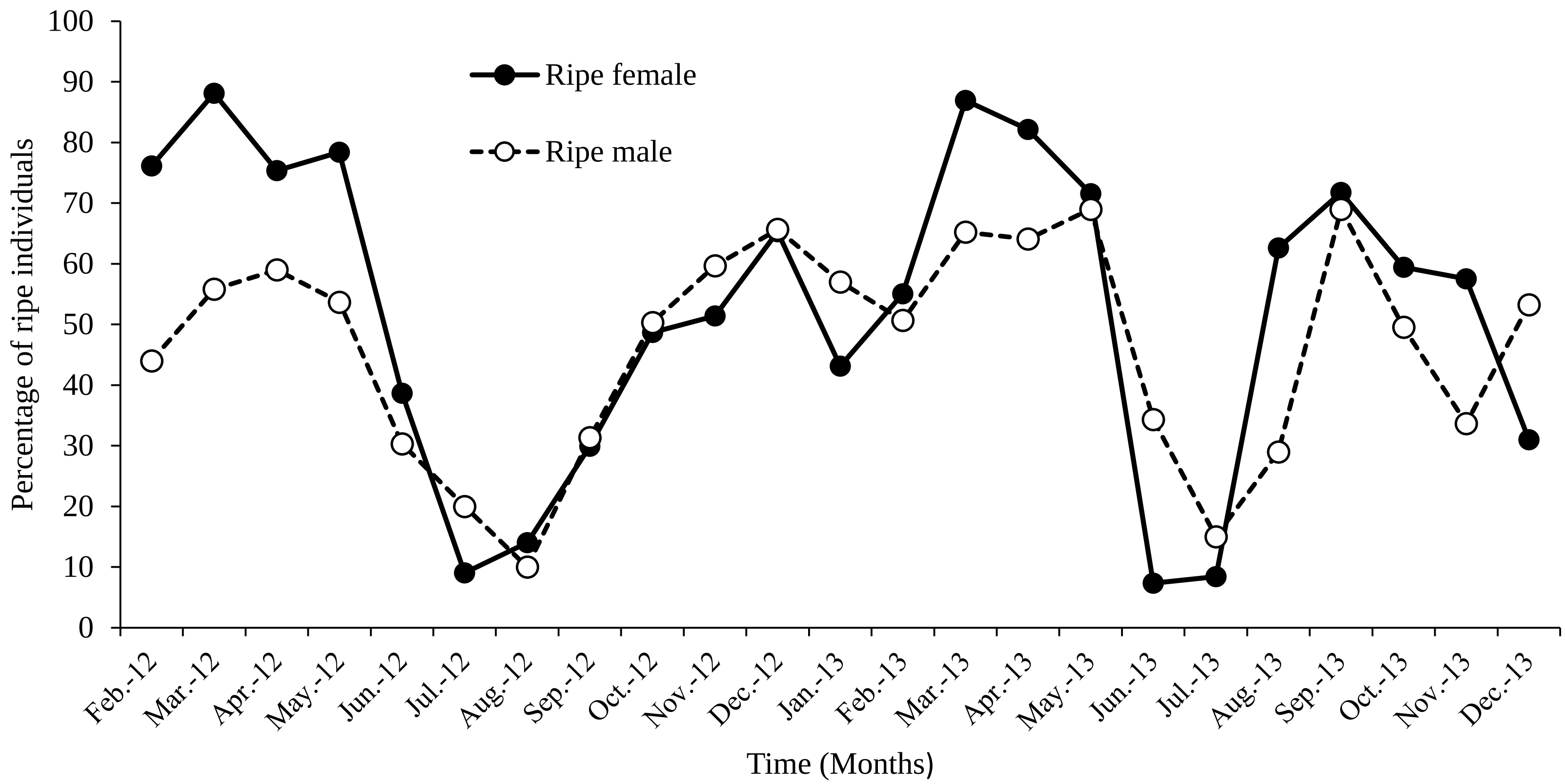


Figure 32: Variations in monthly percentage of ripe males and females of *Sarotherodon melanotheron* in the River pra Estuary from 2012 to 2013

Fecundity

A total of 302 ripe females measuring 10.5 cm to 15.6 cm TL with body weight ranging from 13.8 g to 70.0 g were examined for fecundity. Absolute fecundity ranged from 74 to 263 eggs per female, with a mean of 152 ±73. Fecundity correlated positively with total length (Figure 33) and body weight (Figure 34) in linear relationships described by the equations Fec = 32.1TL-242 and Fec = 3.16BW +49.4. The correlation coefficient was slightly stronger for body weight (r = 0.70) than total length (r = 0.65).

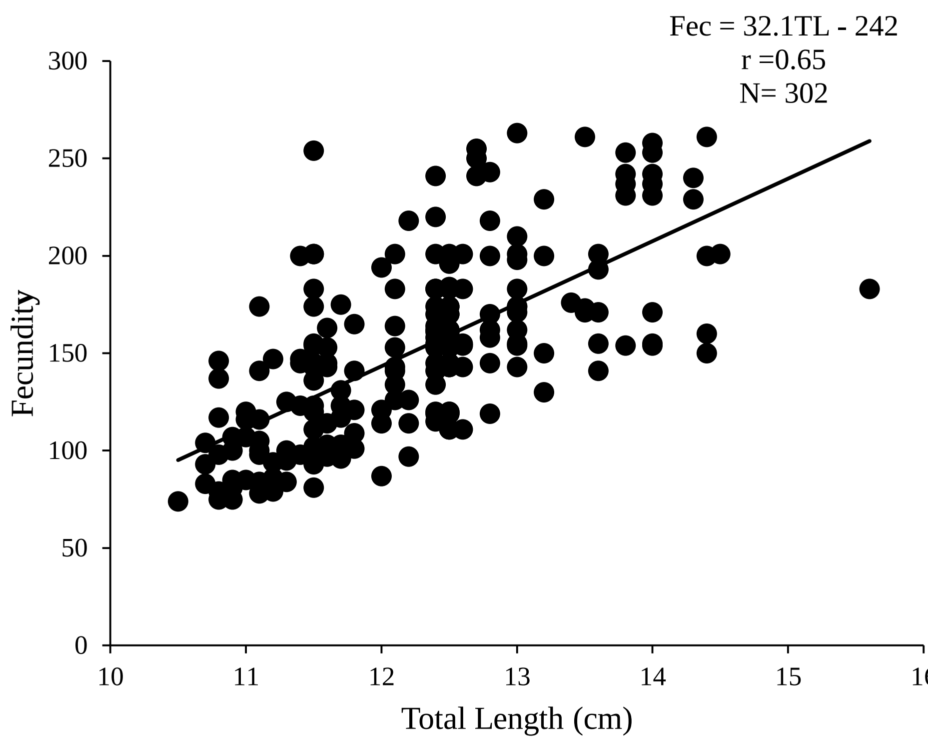


Figure 33: Fecundity-total length relationship of *Sarotherodon melanotheron* in the River pra Estuary

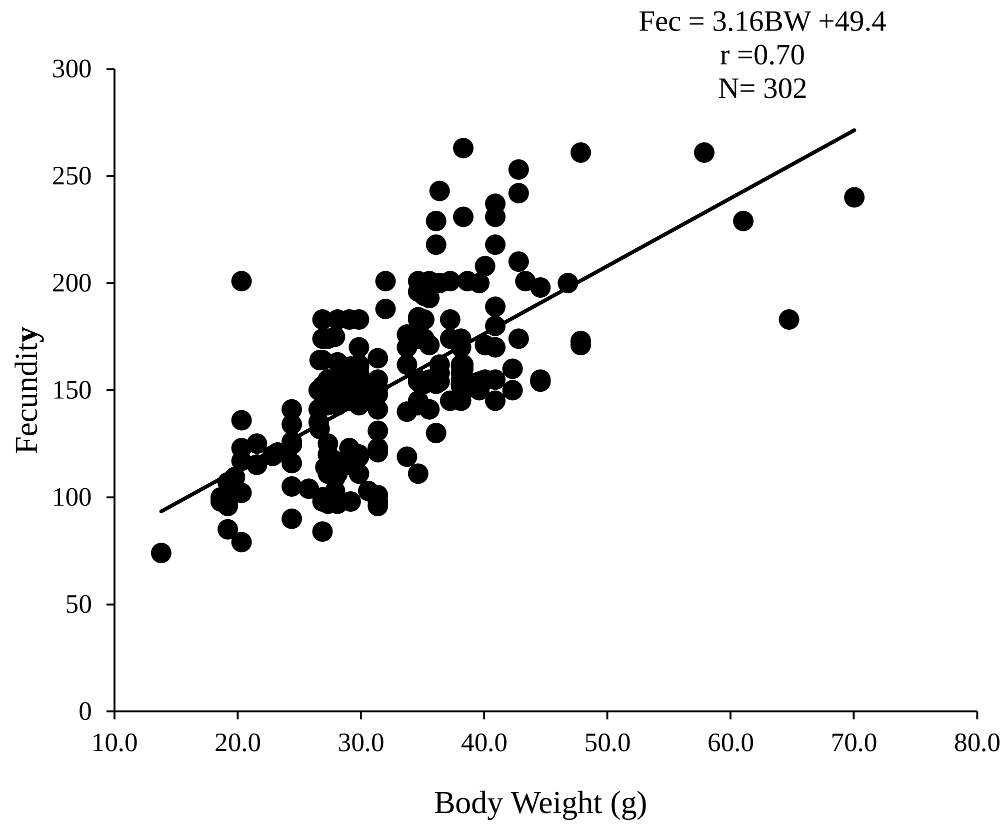


Figure 34: Fecundity-body weight relation of *Sarotherodon melanotheron* in the River pra Estuary

Upwelling Index in Anlo Beach waters

The monthly variability of the upwelling index (UI) in the marine ecosystem is presented in Figure 35. Negative values suggest weak or poor upwelling intensity while positive values suggest strong intensity (Djagoua *et al.*, 2011). While upwelling was weak between June and August 2012 (UI = -0.2 to -0.7), the intensity was strong (UI = 1.6 to 2.6) during the same period in 2013 with a peak of 3.02 was recorded in July 2013.

Observations on the Fishery

The wetland fishery

Fishing activities in the wetland was observed mostly during the wet season when floodwaters inundated the wetland. Averagely 15 fishermen per day were counted fishing with cast nets and pole seine nets during this period. Children were also occasionally sighted using pole seine nets and hook and line during high tides in the dry season when tidal waters flow into the wetland.

The fishes caught during the wet season are mostly freshwater catfishes, freshwater cichlids, gobbies and eleotrids while the blackchinned tilapia and juveniles of marine fishes including grey mullets are the main fish caught during the dry season.

The estuary fishery

Fishing occurs in the estuary throughout the year. The number of fishers per day varied between 20 and 40, with the highest number of fishermen recorded on Tuesdays when marine fishing is prohibited. Cast nets, gill nets, pole seine nets

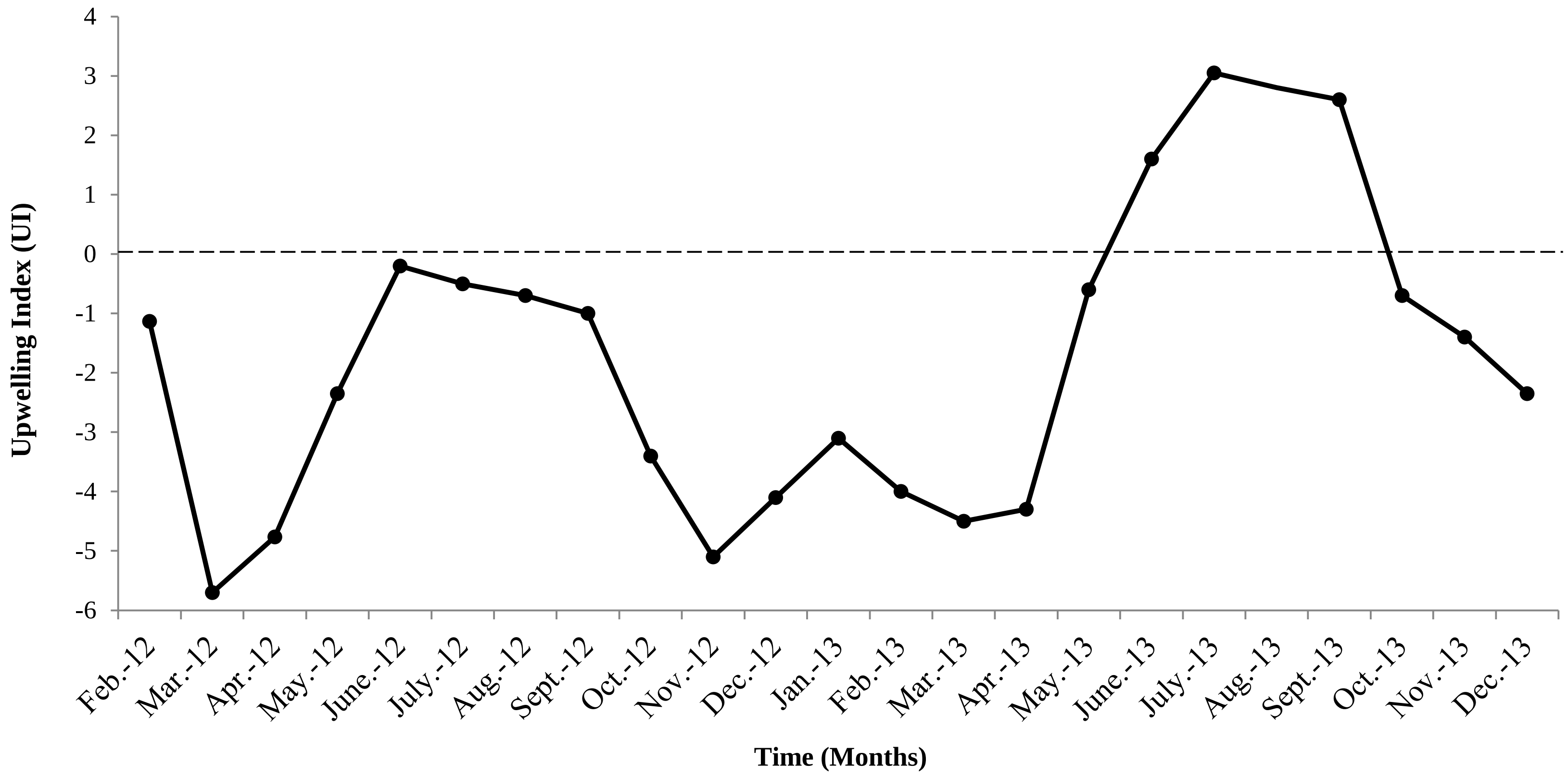


Figure 35: Variations of monthly upwelling intensity in marine waters at Anlo Beach from 2012 to 2013

and crustacean pots were deployed in the estuary. Details of the fishing gears deployed in the estuary and their sizes are shown in Table 13.

The common fishes caught include the blackchinned tilapia, grey mullets, the marine catfish and the swimming crab. The estuary fishery is largely on subsistence basis with very little commercial interest during the off-fishing season in the marine fishery.

The marine fishery

The marine fishery is the mainstay for the people of Anlo Beach with very high commercial interest. Beach seine nets are the only gear used in the marine fishery at Anlo Beach and are operated by “companies”. Thirty-one of such groups were observed each of which consisted of 25 to 55 people depending on the size of their net. The nets ranged from 100 m to 800 m in length, with 3 to 5 different meshes (50 mm stretched mesh from the head rope to 20 mm stretched mesh at the cod end) (Table 13).

Table 13: Fishing gears deployed in the three ecosystems

Gear	**Total No.**	**Ecosystem**	**Range of sizes (m)**	**No. of meshes**	**Range of stretched mesh sizes (mm)**
Beach seine	31	Marine	100 - 800	3-5	20 - 50
Cast net	50-60	Estuary/Wetland	4 - 7	1-2	20 - 32
Gill net	15-20	Estuary	30 - 50	1-2	25 - 30
Pole Seine nets	8	Estuary/Wetland	10 -15	1	25 - 30
Traps	>100	Estuary	-	1	32
Hook and line	< 20	Wetland	-	-	-

Marine fish catch statistics

Figure 36 shows fish percentage composition by weight of species in the marine fish catches at Anlo Beach. Anchovies *Engraulis encrasicolus* was the most common species constituting 19.8 % of the total catch by weight. This was followed by the large hair-tail cutlass fish *Trichiurus lepturus* with a composition of 16.5 % while the cassava croakers *Pseudotholithus* spp. and the barracuda *Sphyraena sphyraena* made up 8.8 % and 6.1 % respectively, of the catch. The weights of *Ethmalosa fimbrita*, *Chloroscombrus chrysurus* and shrimps were between 1 % and 4 % of the overall catch. A mixture of small fishes largely juveniles of clupeids, grunts, carangids and many other less important species (categorized as "others") constituted over 42.1 % of the total catch.

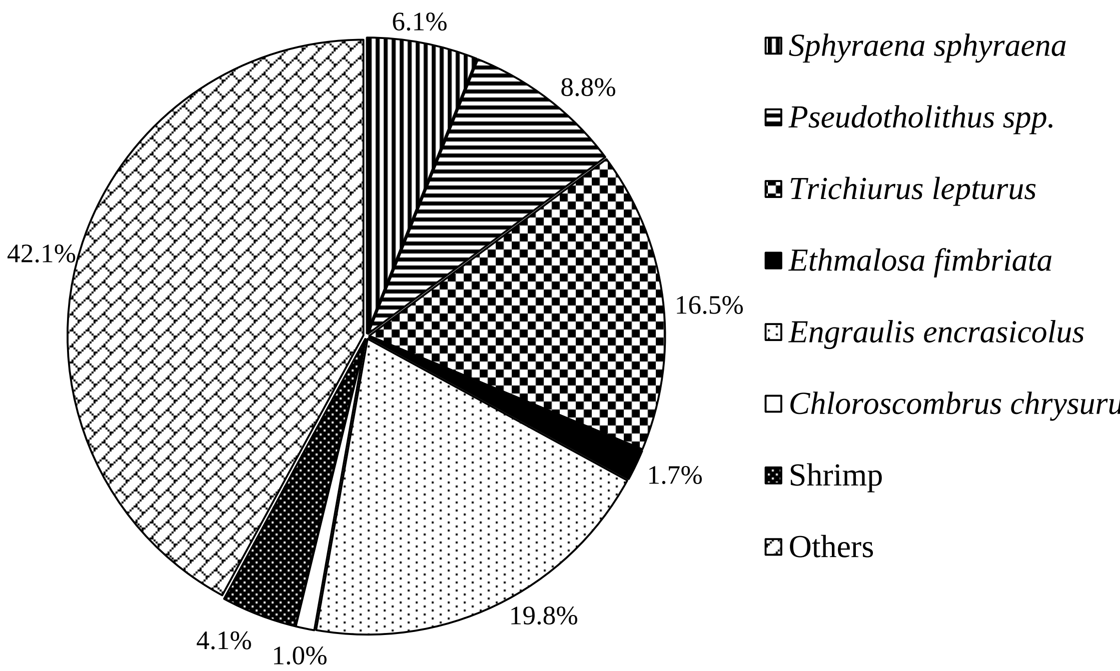


Figure 36: Percentage composition by weight of species in marine fish catches at Anlo Beach.

The monthly fish catches by species in the Anlo Beach fishery is shown in Figure 37. During the study, marine fish catches determined as the monthly total catch of the fishermen increased from 103,678 kg in August 2012 to a peak of 171,190 kg in November, declining steadily until March-May 2013 (3,000 kg - 5,000 kg). Shrimps were the main species caught during June and July. The 2013 fish landings were about double that of 2012. Catches progressed from 201678 kg in August, peaking at 393469 kg in November, and declining to 239826 kg in December, where the anchovy *Engraulis encrasicolus* comprised over 50 % of the landings in October and November and 25 % in December 2013. Of the fishes caught (see Plate 1), a mixture of small fishes largely juveniles of clupeids, grunts, carangids and many other species categorized as "others" constituted between 30 and50 % of the catches in a number the months while bigger fish, e.g. *Pseudotholithus* species, *T. lepturus, S. sphyraena* and a few others constituted less than 50 % of the monthly catches.

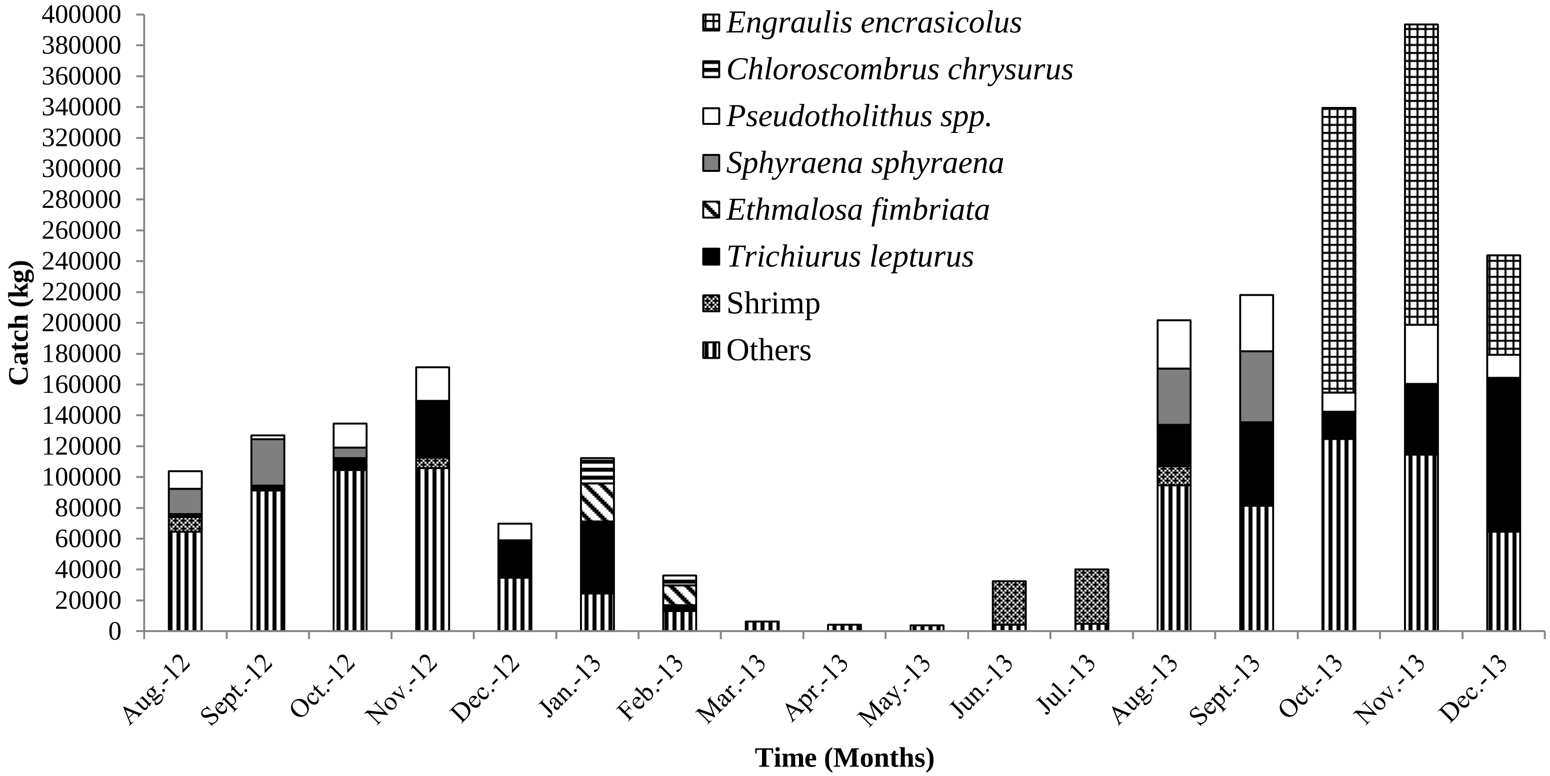


Figure 37: Monthly marine fish catches by species from August 2012 to December 2013

Plate 1: Common fishes landed in the Anlo Beach marine fishery

TRICHIURIDAE

Trichiurus lepturus (Large hair-tail cutlass fish)

Large proportions of juveniles of *Sardinella, Ilisha, Ethmalosa, Caranx, Selene, Chloroscombrus, Brachydeuterus,* etc.

Plate 1 continued: Common fishes landed in the Anlo Beach marine fishery

CICHLIDAE

Sarotherodon melanotheron (Black-chin tilapia

MUGILIDAE

Liza falcipinnis (Sickle-fin mullet)

Plate 2: Some fishes landed in the Anlo Beach (Pra) estuarine fishery

Catch Per Unit Effort

Catch per unit effort (CPUE) was assessed as (a) catch per group (company), (b) catch per haul per day and (c) catch per hour per day (Figure 38). Catch per group (Figure 38a) ranged from 8640.24 (± 997.56) kg to 14266.32 (± 3926.70) kg in August - November 2012, decreasing to the lowest in March-May 2013 (< 500 kg). There were marginal increases in the CPUE in June (2701.41± 55.31 kg) and July (3336.63±675.21 kg) 2013 followed by a significant increase in August (16807.55±1212.11 kg) which continued to a peak in November (32789.76±4356.43 kg), and then dropped in December 2013 (19986.91±241.33 kg).

Figure 38b shows fluctuations in catch per haul per day, and catch per hour per day. The former ranges from 11.9±0.0 to 1514.4±198.0 and the latter from 1.7±0.0 to 302.9±74.3. Both followed a similar trend, increasing from August to a peak in October-November 2012. A significant decrease occurred in December 2012 which continued to the lowest in April- May, 2013. In July, both indices started rising, reaching a peak in October-November 2013, after which they declined in December 2013. It can be seen that the mean catch per haul per day was about 5 to 8 times higher than the mean catch per hour per day (except in the off-fishing months), indicating an average of 5 to 8 hours per fishing operation.

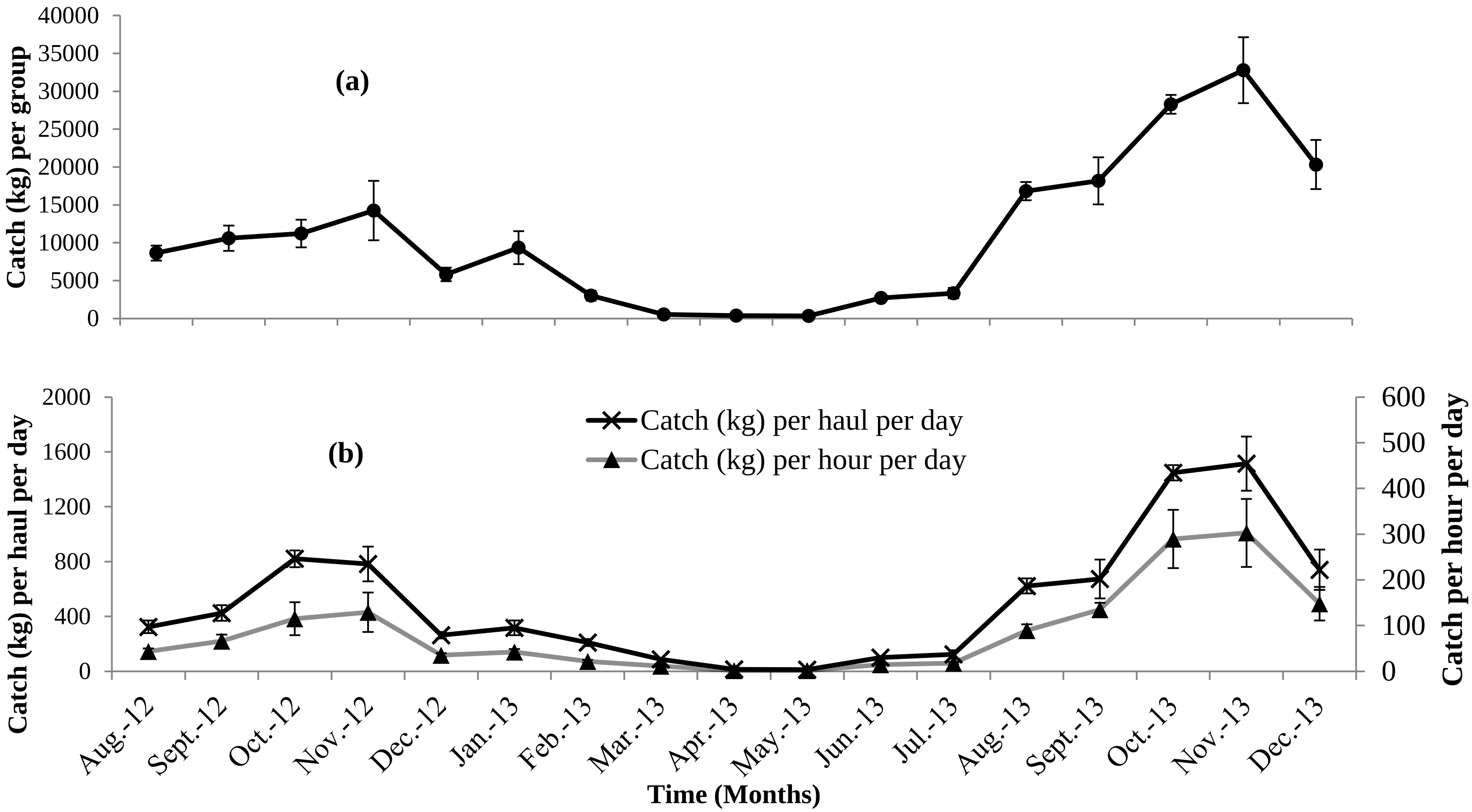


Figure 38: Mean monthly ctach per unit effort by (a) catch per group and (b) catch per haul per day and catch per hour per day from the Anlo Beach fishery (vertical bars represent standard errors)

Economics of the fishery

Table 14 shows the average price per kg of the major fish species in the main and lean fishing seasons. The most expensive fishes in the fishery were the cassava fishes *Pseudotholithus* spp., followed by the cutlass fish *Trichiurus lepturus*, shrimps and the barracuda *Sphyraena sphyraena*. Other species such as *Chloroscombrus chrysurus* and *Ethmalosa fimbriata* fetched lower prices. In general, fish prices were were higher in the lean fishing season with price difference of about 17 – 114 % for the different species.

Gross monthly income from the catches in the 2012 main fishing season (Figure 39) was between GH¢ 107,267 (US$ 59,592) and GH¢ 238,079 (US$ 132,266) with the peak in November 2012 while that for the main season in 2013 varied between GH¢ 254,728 (US$ 141,515) and GH¢ 438,844 (US$ 243,802) with the peak in November 2013. The gross incomes for the 2013 main season was about double that of 2012. Lean season (Dec. – Feb.) incomes were between GH¢ 43,559 (US$ 24,199) and GH¢ 159,974 (US$ 88,874) while off-season (Mar. – Jul.) income was below GH¢ 50,000 per month.

Of the fishes landed, *Pseudotholithus* spp. contributed more than 50 % of the monthly gross income, followed by *Trichiurus lepturus* and other species. Anchovies also made a substantial contribution to the incomes in October-December 2013.

Table 14: Comparison of average price per kg of the major fish species in the main and lean seasons

Type of fish	Average price per kg				% Change
	Main season (Aug-Nov.)		Lean season (Dec.-Feb.)		
	GH¢	US$	GH¢	US$	
Pseudotholithus spp.	5.45	2.60	7.27	3.46	33.39
Trichiurus lepturus	1.53	0.73	1.79	0.85	16.99
Sphyraena sphyraena	1.43	0.68	-	-	-
Chloroscombrus chrysurus	-	-	1.48	0.71	-
Ethmalosa fimbriata	-	-	1.21	0.58	-
Engraulis encrasicolus	0.53	0.25	-	-	-
Shrimp	1.50	0.71	2.40	1.14	60.00
Others (Mixture of various)	0.50	0.24	1.07	0.51	114.00

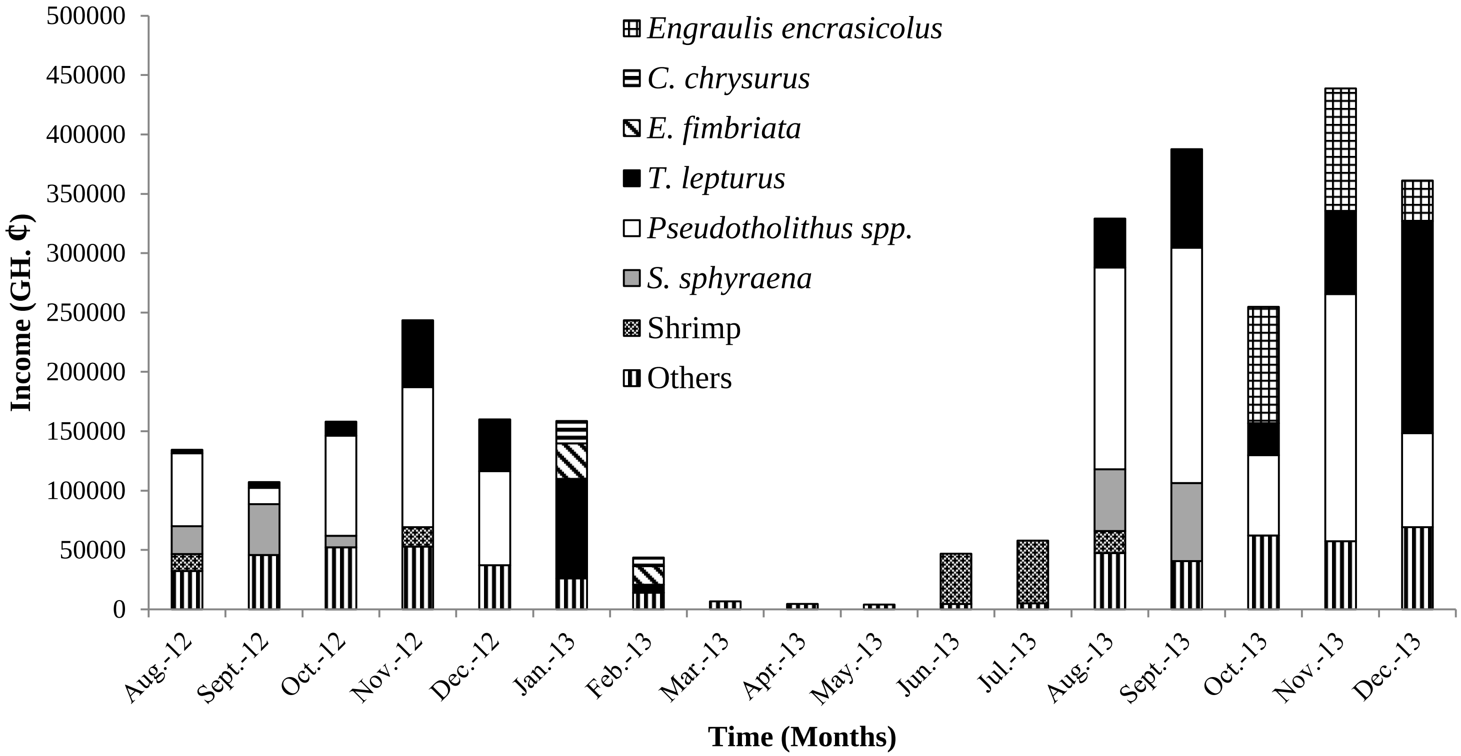


Figure 39: Gross income per species in the fishery (August 2012 to December 2013)

The data in Table 15 show that the highest income of each fisherman averaged GH¢ 343 per month during the 2013 main fishing season while the lowest was GH¢ 20 during the lean season. A net owner earned on average GH¢ 10,243 and GH¢ 609 per month in the main and lean seasons, respectively. Earnings were as low as GH¢ 3 - GH¢ 5 per fisherman during some off-season months.

Table 15: Monthly net income per net owner and per fisherman from August 2012 to December 2013

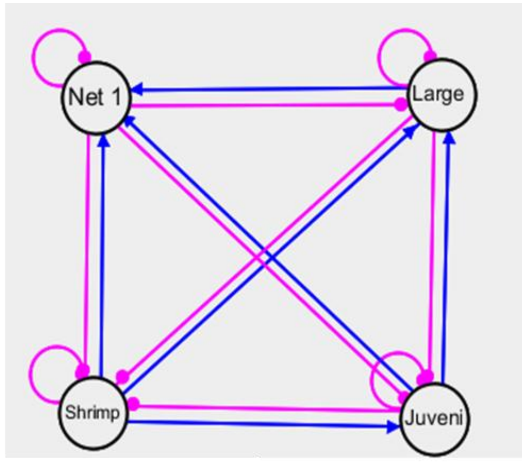
		Mean Income (GH¢) (± Standard deviation)	
Season	**Month**	Net owner	Fisherman
Main season	Aug.-12	2,807.62 (±500.13)	94.29 (±16.10)
	Sept.-12	2,013.33 (±621.22)	67.81 (±24.48)
	Oct.-12	2,339.75 (±481.52)	78.90 (±32.64)
	Nov.-12	5,243.21 (±942.54)	175.76 (±48.50)
Lean Season	Dec.-12	3,002.43 (±421.91)	100.51 (±11.71)
	Jan.-13	3,455.91 (±804.73)	115.70 (±23.68)
	Feb.-13	609.34 (±153.42)	20.26 (±10.54)
Off-fishing season	Mar.-13	153.90 (±24.22)	5.16 (±0.42)
	Apr.-13	114.50 (±21.21)	3.86 (±0.26)
	May.-13	103.30 (±24.32)	3.49 (±0.41)
	Jun.-13	1,170.02 (±121.20)	39.05 (±4.59)
	Jul.-13	1,449.34 (±130.87)	48.38 (±4.71)
Main season	Aug.-13	7,401.81 (±432.11)	246.73 (±19.31)
	Sept.-13	9,019.56 (±623.21)	300.77 (±28.96)
	Oct.-13	5,756.28 (±525.21)	191.90 (±22.41)
	Nov.-13	10,300.12 (±843.24)	343.34 (±30.21)
	Dec.-13	8,216.08 (±624.21)	273.91 (±31.25)

Modeling the relationship between fishing nets and fish catches

In qualitative modelling, the main parameters analyzed are system stability, prediction of response to perturbations, and the probability that the predictions are reliable. For class I models such as those examined in this study (see Dambacher *et al.*, 2003a), the stability is judged by the weighted feedback metric ${}_wF_n$. Values of ${}_wF_n$ range between –1 and +1, where –1 indicates a very stable system, +1 indicates an unstable system and 0 indicates that system stability is ambiguous. A model with ${}_wF_n < –0.5$ has a relatively high potential for stability. Perturbation is a change (i.e. an increase or a decrease) in the quantity or intensity of a variable, and response is the consequent change(s) in other variable(s) in the model.

Model I, (Figure 40) represents the current situation in the Anlo Beach marine fishery based on trophic ecology and catch data. "Net 1" represents the beach seine nets currently in use with < 25mm stretched mesh while "Large fish" comprise predatory species mainly *Pseudotholithus* spp., *Trichiurus lepturus* and *Sphyraena sphyraena*, and other predatory species such as *Galeoides decadactylus* and *Brachydeuterus auritus*. According to the sign digraph in Model I, large and juvenile fishes prey on shrimps while large fishes additionally prey on juvenile fishes. The current beach seine nets (Net 1) are unselective capturing mature and juvenile fishes, as well as shrimps which constitute a major food source for the fishes. A qualitative stability analysis of the community matrix of from Model I using the Maple Software Suite indicated that the system is a moderately stable Class I model (wF_n = -0.33).

Model I



Community Matrix:

	Net 1	Large fish	Juvenile fish	Shrimp
Net 1	-1	1	1	1
Large fish	-1	-1	1	1
Juvenile fish	-1	-1	-1	1
Shrimp	-1	-1	-1	-1

Adjoint Matrix:

	Net 1	Large fish	Juvenile fish	Shrimp
Net 1	4	0	0	4
Large fish	-4	4	0	0
Juvenile fish	0	-4	4	0
Shrimp	0	0	-4	4

Absolute Feedback:

	Net 1	Large fish	Juvenile fish	Shrimp
Net 1	6	6	6	6
Large fish	6	6	6	6
Juvenile fish	6	6	6	6
Shrimp	6	6	6	6

Weighted Predictions:

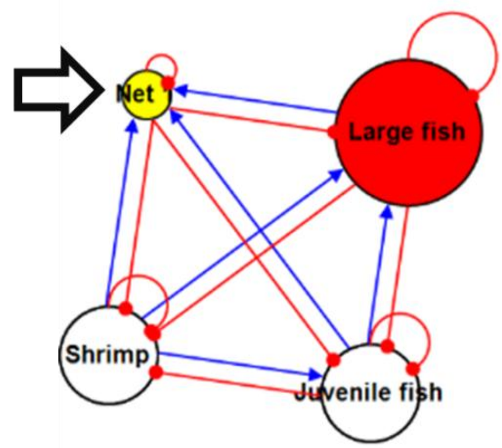
	Net 1	Large fish	Juvenile fish	Shrimp
Net 1	0.67	0	0	0.67
Large fish	0.67	0.67	0	0
Juvenile fish	0	0.67	0.67	0
Shrimp	0	0	0.67	0.67

Figure 40: Model I and the resultant community matrix, adjoint matrix, absolute feedback and weighted predictions

In examining the response to perturbations in Model I, decreasing the fishing effort by reducing the number or sizes of nets resulted in an increase in large fish stock in the inshore waters (Figure 41a), while increasing the number or sizes of the beach seine nets drastically reduced the large fish stock (Figure 41b) over a long term (probability of prediction being reliable = 0.92). The effect on shrimps and juvenile fishes in either case was uncertain in the prediction model.

Click the column header as a negative impac

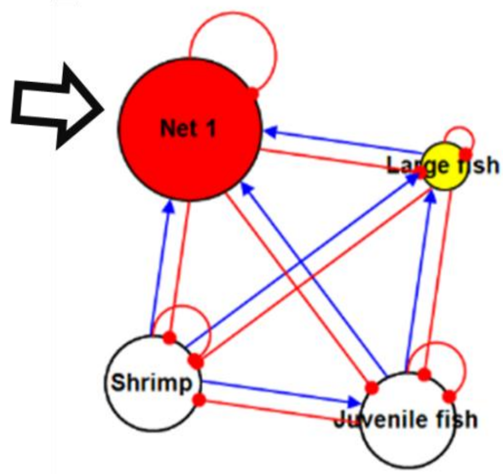
Net 1	Large fish	Juvenile fish	Shrimp
-4	0	0	-4
4	-4	0	0
0	4	-4	0
0	0	4	-4



a.

Click the column header as a positive impact

Net 1	Large fish	Juvenile fish	Shrimp
4	0	0	4
-4	4	0	0
0	-4	4	0
0	0	-4	4

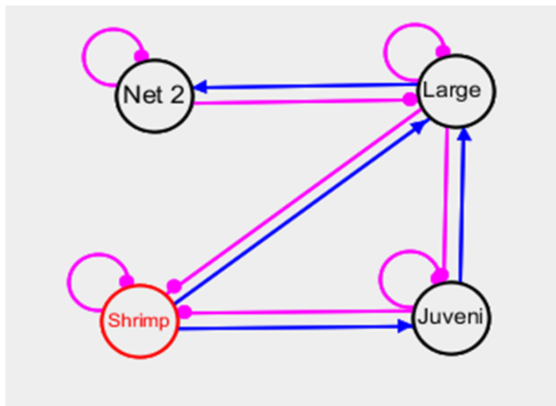


b.

Figure 41: Response to perturbations in the fishery due to (a) decreasing and (b) increasing fishing effort with undersize meshes in Model I (Arrow points to perturbed variable, large red = increase, small yellow = decrease, transparent = ambiguous)

Model II (Figure 42) is an alternative to Model I which depicts the possible conditions of the fishery if undersize meshes were eliminated and nets of the prescribed meshes were used. Thus “Net 2” in this model represents selective beach seines excluding those with stretched mesh less than 25 mm. This model assumes that “Net 2” is selective and captures only large and presumably mature

Model II



Community Matrix:

	Net 2	Shrimp	Juvenile fish	Large fish
Net 2	-1	0	0	1
Shrimp	0	-1	-1	-1
Juvenile fish	0	1	-1	-1
Large fish	-1	1	1	-1

Adjoint Matrix:

	Net 2	Shrimp	Juvenile fish	Large fish
Net 2	4	2	0	2
Shrimp	0	3	-3	0
Juvenile fish	2	1	3	-2
Large fish	-2	2	0	2

Absolute Feedback:

	Net 2	Shrimp	Juvenile fish	Large fish
Net 2	6	2	2	2
Shrimp	2	3	3	2
Juvenile fish	2	3	3	2
Large fish	2	2	2	2

Weighted Predictions:

	Net 2	Shrimp	Juvenile fish	Large fish
Net 2	0.67	1	0	1
Shrimp	0	1	1	0
Juvenile fish	1	0.33	1	1
Large fish	1	1	0	1

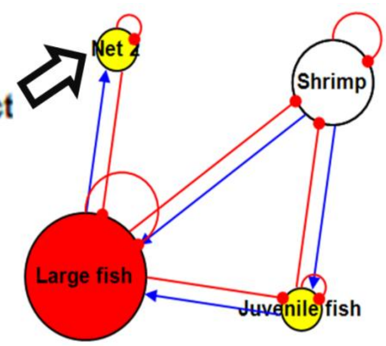
Figure 42: Model II and its resulting community matrix, adjoint matrix, absolute feedback and weighted predictions

fishes while shrimps and juvenile fishes escape capture to grow to large sizes before capture. The model was found to be a Class I model with a very stable system (${}_{w}F_{n}$ = -0.75) following a qualitative stability analysis.

Predictions from Model II indicated that regulating fishing effort by decreasing the number or size of Net 2 led to an increase in the large fish stock (Probability = 1.0) which would in turn increase predation on the juveniles and decrease the juvenile stock size significantly (Figure 43a). On the other hand, uncontrolled increase in the number or size of Net 2 decreased the mature fish stock, leaving a large juvenile population (Figure 43b).

Click the column header as a negative impact

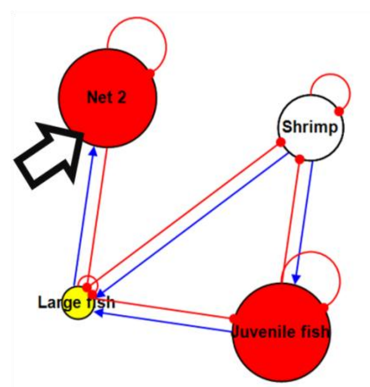
Net 2	Shrimp	Juvenile fish	Large fish
-4	-2	0	-2
0	-3	3	0
-2	-1	-3	2
2	-2	0	-2



a.

Click the column header as a positive impact

Net 2	Shrimp	Juvenile fish	Large fish
4	2	0	2
0	3	-3	0
2	1	3	-2
-2	2	0	2



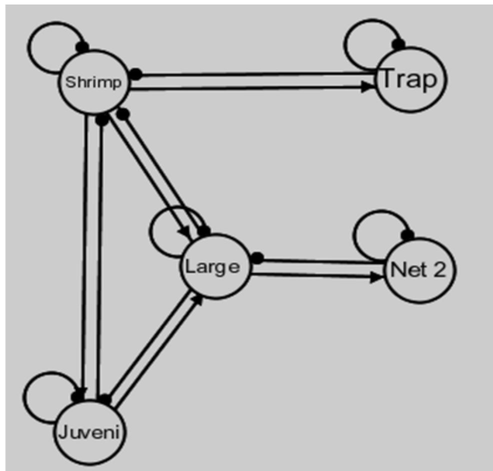
b.

Figure 43: Response to the use of larger mesh sizes in the fishery. (Arrow points to perturbed variable, large red = increase, small yellow = decrease, transparent = uncertain)

Model III (Figure 44) assesses the potential of introducing shrimp traps or pots to complement Net 2 after eliminating Net 1 which captures both fish and shrimp. From the model, the shrimp trap captures only shrimps while Net 2 captures only mature or “Large” fish. The concept examines the possibility of maintaining both finfish and shrimp fisheries and thus sustaining the livelihood of the fishers without harming the juvenile fish stock. The qualitative stability analysis indicated a Class I model with a very stable system (wF_n = -0.82).

Analysis of perturbations in Model III showed that increasing the number or size of Net 2 while maintaining the same shrimp traps number, on average, led to a significant decrease in the mature fish stock but increased the juvenile stocks (Figure 45a). However, a decrease in the number or size of Net 2 led to an increase in the mature fish stock which increased predation on the juveniles and subsequently reduced the juvenile stock (Figure 45b). This prediction was reliable with a 100% probability.

Model III



Community Matrix:

	Shrimp	Large fish	Juvenile fish	Net 2	Trap
Shrimp	-1	-1	-1	0	-1
Large fish	1	-1	1	-1	0
Juvenile fish	1	-1	-1	0	0
Net 2	0	1	0	-1	0
Trap	1	0	0	0	-1

Adjoint Matrix:

	Shrimp	Large fish	Juvenile fish	Net 2	Trap
Shrimp	3	0	-3	0	-3
Large fish	2	3	1	-3	-2
Juvenile fish	1	-3	5	3	-1
Net 2	2	3	1	6	-2
Trap	3	0	-3	0	6

Weighted Predictions:

	Shrimp	Large fish	Juvenile fish	Net 2	Trap
Shrimp	1	0	1	0	1
Large fish	1	1	0.33	1	1
Juvenile fish	0.33	1	1	1	0.33
Net 2	1	1	0.33	0.75	1
Trap	1	0	1	0	0.75

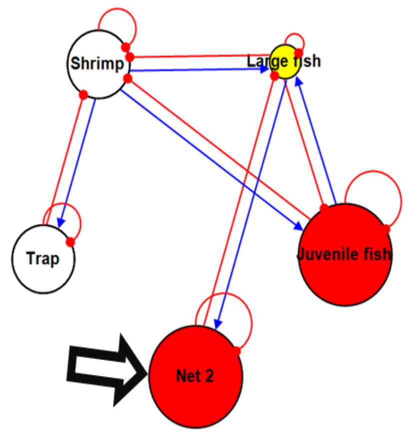
Absolute Feedback:

	Shrimp	Large fish	Juvenile fish	Net 2	Trap
Shrimp	3	2	3	2	3
Large fish	2	3	3	3	2
Juvenile fish	3	3	5	3	3
Net 2	2	3	3	8	2
Trap	3	2	3	2	8

Figure 44: Model III and its resulting community matrix, adjoint matrix, absolute feedback and weighted predictions (generated from loop analysis http://www.ent.orst.edu/loop/default.aspx).

Click the column header as a positive impact

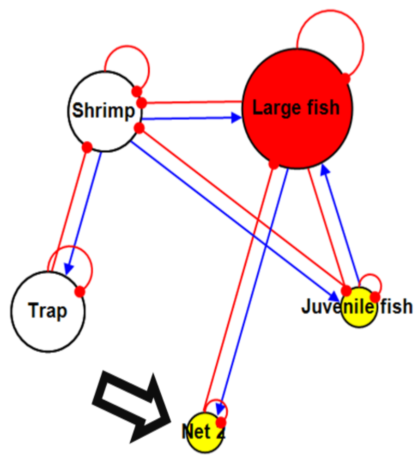
Shrimp	Large fish	Juvenile fish	Net 2	Trap
3	0	-3	0	-3
2	3	1	-3	-2
1	-3	5	3	-1
2	3	1	6	-2
3	0	-3	0	6



a.

Click the column header as a negative impact

Shrimp	Large fish	Juvenile fish	Net 2	Trap
-3	0	3	0	3
-2	-3	-1	3	2
-1	3	-5	-3	1
-2	-3	-1	-6	2
-3	0	3	0	-6



b.

Figure 45: Response to perturbations in the fishery through (a) increasing fishing and (b) decreasing fishing effort in Model III (Arrow points to perturbed variable, large red = increase, small yellow = decrease, transparent = uncertain)

Further analyses of response to perturbations in Model III through varying the number of shrimp traps (Figure 46) indicated that an increase in shrimping activities depleted the shrimp stock and deprived large and juvenile fish stocks of their prey. This resulted in a significant decline in the population of large and juvenile fish (Figure 46a), and a subsequent decrease in fishing effort. On the contrary, keeping a few or reduced number of shrimp traps (Figure 46b) triggered a positive effect by enhancing the growth of the shrimp stock to provide more food for both juvenile and adult fish stocks causing the stocks to boom (in a positive feedback cycle), and attracting increased investment in fishing effort (net 2) as catches rose. This prediction has a 100% chance of being reliable.

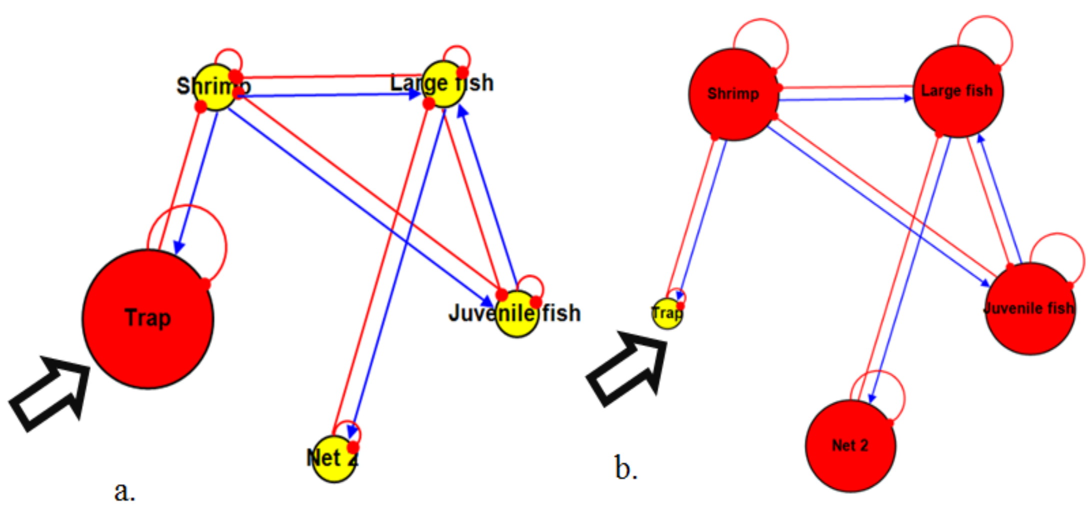


Figure 46: Response to (a) increasing and (b) decreasing shrimp traps in the fishery (Arrow points to perturbed variable, large red = increase, small yellow = decrease)

Population growth and fisheries exploitation

Figure 47 illustrates a historical timeline of population growth and fisheries exploitation at Anlo Beach over the last forty years solicited through Focus Group Discussion. In the 1970s when the population of the community was a little over 1000, many people were engaged in coconut farming while the others were fishermen operating with about 10 beach seine nets. The nets were on average 200 m long and the average catch per haul was 1,700 kg. About 500 m towing lines were used in deploying and hauling the nets, with a fishing operation lasting for about 4 hours.

Although the population grew progressively through the 1980s, there was no corresponding increase in investment in the fishery until the 1990s when the Cape St. Paul Wilt disease destroyed coconut farms, causing some families whose livelihoods were dependent on these farms to migrate elsewhere which led to a decline in the community's population. During the same period, some of the farmers who lost their coconut plantations invested in the fishery, leading to a significant increase in the number of fishing "companies" from 10 to about 20 nets in the 2000s. Catch per haul dwindled to about 1000 kg from 1500 kg. As the population increased in the 2000s, more nets were introduced into the fishery while catches continued declining. In a bid to increase catches, the fishermen kept increasing the sizes of fishing nets as well as the lengths of towing lines to more than double those used in the 1970s and 1980s thereby doubling the time spent in a fishing operation. Today, the population is over 5000 and the number of beach seines has increased to 31, some of which measure about 800 m in length. The nets are being hauled with up to 2 km towing lines, with some fishing operations lasting up to 10 hours, but catches have declined significantly to an average of 500 kg per haul.

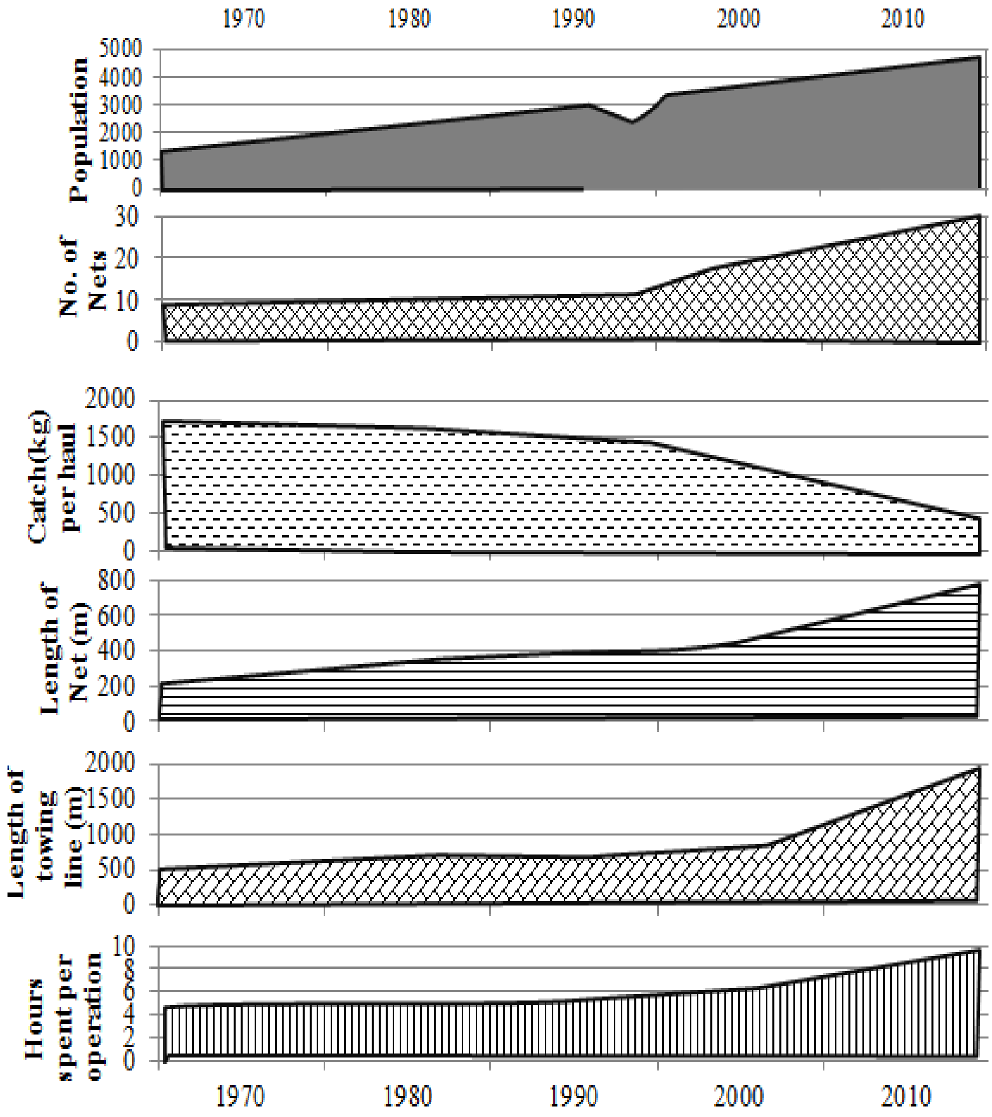


Figure 47: Population growth and fisheries exploitation indices from 1970 to 2010 (sketch not to scale)

Interrelation between the fishery and other livelihood activities

Models were developed to examine the interrelation between fishing, fish monging, farming and retail activities at Anlo Beach. Model IV (Figure 48) integrates assumptions from Model III where shrimping with pots was separated from fishing with beach seines (Net 2). It also assumes that catches depended on effort (i.e. number of nets or traps) and stock quantity, hence the positive links from the fishing gears and stock to catch. Part of the profit made from catches and fish monging were invested in farming and retail business, while part supported daily living expenses. Gains from retail and farming (both fiscal and farm produce) also partly support living and re-investment in fishing gears. Subjection of the the model to qualitative stability analysis showed it as an unstable Class I model (*w*F*n*= 0.15).

Since the Model IV presents and unstable scenario, Model V in Figure 49 was developed as an alternative where certain assumptions were modified. Catch was made to be solely dependent on stock, with an assumption that the fishery that has exceeded its maximum sustainable yield. This alteration resulted in a moderately stable Class I model (*w*F*n* = -0.42) primarily confirming that the Anlo Beach fishery has exceeded its MSY from qualitative perspective.

The corresponding community matrix and probabilities at which predictions are reliable are presented in Tables 16 and 17 while the adjoint matrix, weighted predictions, absolute feedback are presented in Appendices J, K and L.

Model IV

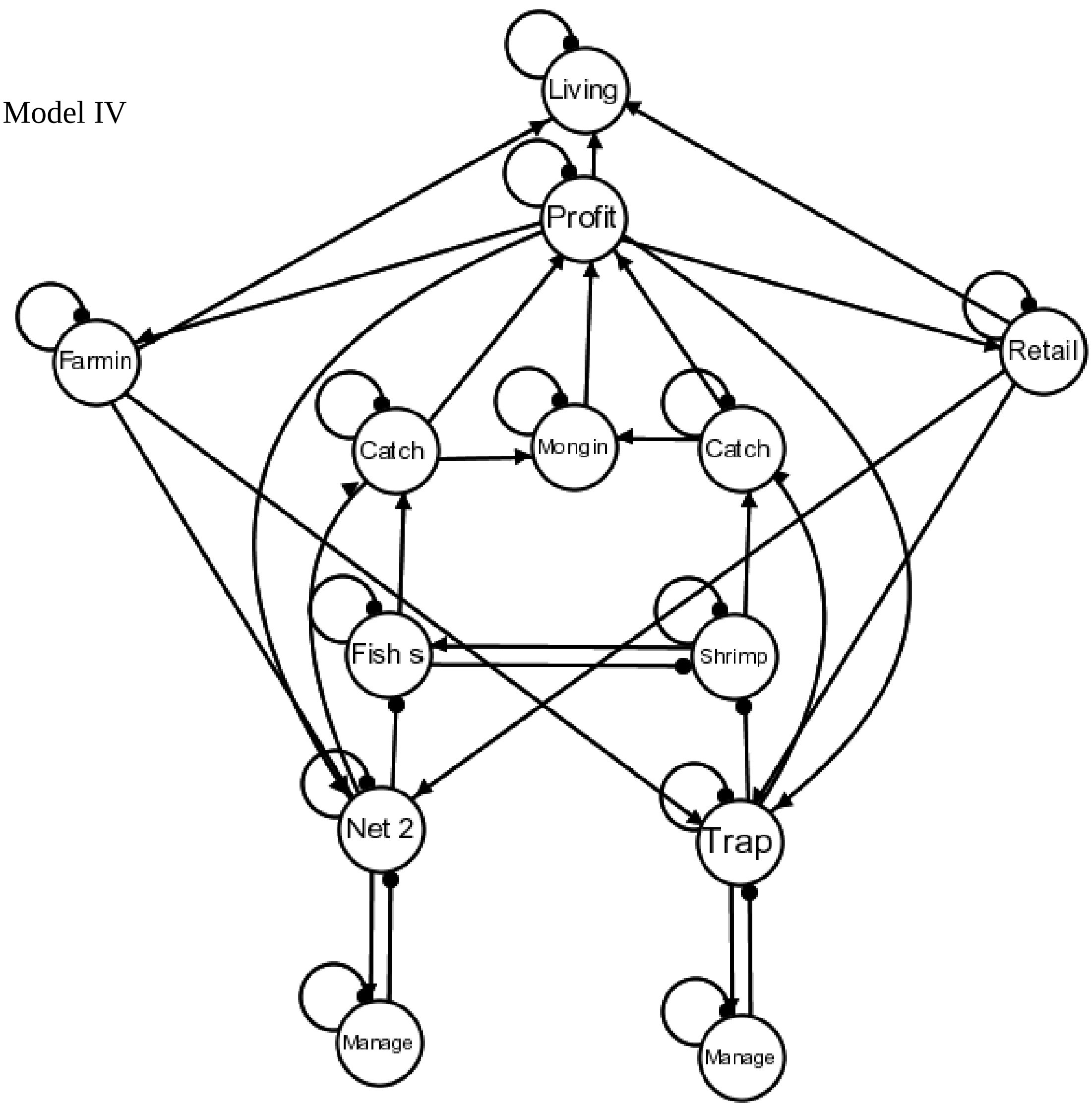


Figure 48: Model IV showing the interrelation between the different livelihood activities at Anlo Beach

Model V

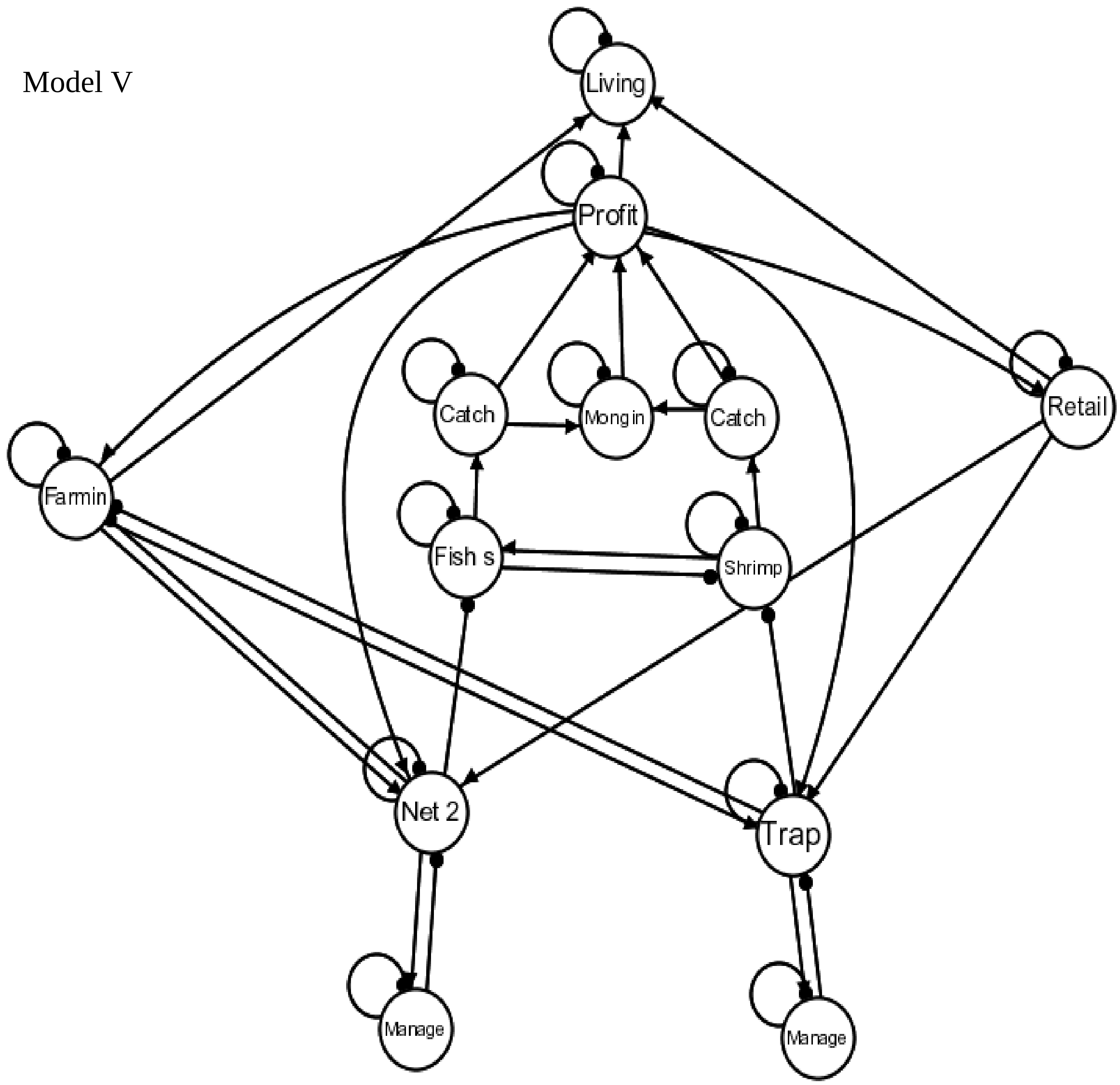


Figure 49: Model V, showing the interrelation between the different livelihood activities at Anlo Beach as an alternative to Model IV

Table 16: The adjoint matrix for Model V

	Profit	Catch (fish)	Catch (shrimp)	Trap	Monging	Shrimp Stock	Net 2	Fish Stock	Management (Shrimp)	Management (Fish)	Retail	Farming	Living
Profit	16	32	32	-12	16	32	4	0	12	-4	-8	-8	0
Catch(fish)	-12	16	-24	4	-12	-4	-8	20	-4	8	-4	-4	0
Catch(shrimp)	0	0	40	-10	0	20	10	-20	10	-10	0	0	0
Trap	12	24	24	6	12	24	-2	0	-6	2	4	4	0
Monging	-12	16	16	-6	28	16	2	0	6	-2	-4	-4	0
Shrimp Stock	0	0	0	-10	0	20	10	-20	10	-10	0	0	0
Net 2	12	24	24	-14	12	24	18	0	14	-18	4	4	0
Fish Stock	-12	-24	-24	4	-12	-4	-8	20	-4	8	-4	-4	0
Management (Shrimp)	12	24	24	6	12	24	-2	0	34	2	4	4	0
Management (Fish)	12	24	24	-14	12	24	18	0	14	22	4	4	0
Retail	16	32	32	-12	16	32	4	0	12	-4	32	-8	0
Farming	-8	-16	-16	-4	-8	-16	-12	0	4	12	-16	24	0
Living	24	48	48	-28	24	48	-4	0	28	4	8	8	40

Table 17: The probabilities for predictions to perturbations in Model V

Probabilities	Profit	Catch (fish)	Catch (shrimp)	Trap	Monging	Shrimp Stock	Net 2	Fish Stock	Management (Shrimp)	Management (Fish)	Retail	Farming	Living
Profit	1	1	1	0.95	1	1	0.73	0.50	0.95	0.73	0.77	0.89	1
Catch(fish)	0.92	0.83	0.95	0.82	0.92	0.66	0.96	0.96	0.82	0.96	0.73	0.79	1
Catch(shrimp)	0.50	0.50	0.98	1	0.50	0.96	1	0.96	1	1	0.50	0.50	1
Trap	0.92	0.95	0.95	0.80	0.92	0.95	0.64	0.50	0.80	0.64	0.68	0.70	1
Monging	0.80	0.83	0.83	0.85	0.94	0.88	0.64	0.50	0.85	0.64	0.68	0.73	1
Shrimp Stock	0.50	0.50	0.50	1	0.50	0.88	1	0.96	1	1	0.50	0.50	1
Net 2	0.92	0.95	0.95	1	0.92	0.96	1	0.50	1	1	0.68	0.70	1
Fish Stock	0.92	0.95	0.95	0.82	0.92	0.95	0.96	0.96	0.82	0.96	0.73	0.79	1
Management (Shrimp)	0.92	0.95	0.95	0.80	0.92	0.66	0.64	0.50	0.94	0.64	0.68	0.70	1
Management (Fish)	0.92	0.95	0.95	1	0.92	0.95	1	0.50	1	0.85	0.68	0.70	1
Retail	1	1	1	0.95	1	1	0.73	0.50	0.95	0.73	0.95	0.89	1
Farming	0.82	0.85	0.85	0.66	0.82	0.85	0.87	0.50	0.66	0.87	0.88	0.95	1
Living	0.91	0.96	0.96	0.93	0.91	0.96	0.58	0.50	0.93	0.58	0.62	0.66	0.94

From the adjoint matrix in Table 16 which also reflects in the prediction digraph in Figure 50, increase in fishing activity (or fishing effort) as a result of high investment in beach seine nets, or prolonged fishing period, resulted in increased fish monging business and high overall profit from the fishery in the short term which also enhanced retail business in the community. The booming fishing business diminished the people's interest in shrimping and farming,

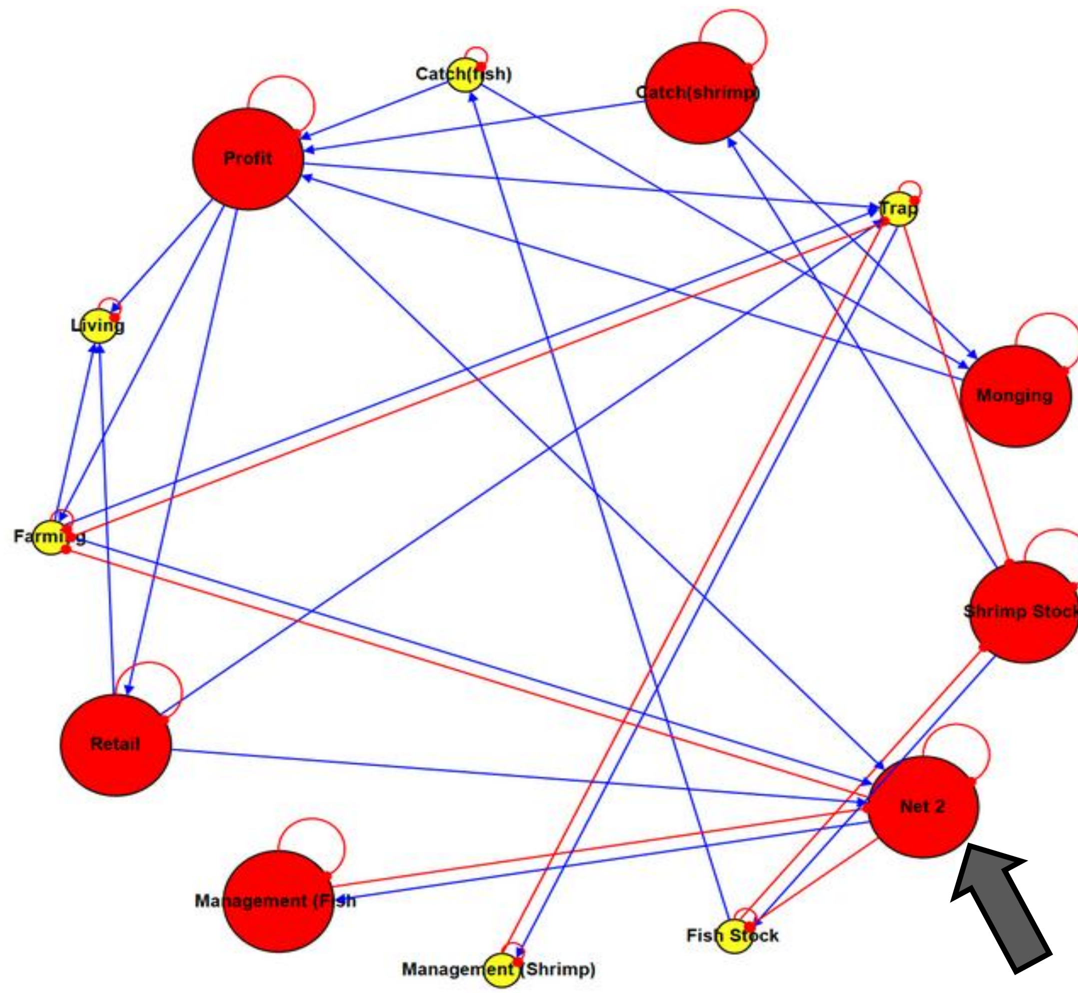


Figure 50: Analysis of response of other livelihood activities to increasing fishing pressure in Model V (Arrow points to perturbed variable, large red = increase, small yellow = decrease)

causing farming activities and shrimping to decline. In the long term, fish catches will decline as a result of depleted fish stocks while the shrimp stock would increase due to the reduced predation and trapping. Living would become difficult owing to the reduced subsistence farming and dwindled fish stock. These predictions have a 0.6 to 1.0 probability (i.e. 60 % – 100 % chance) of being reliable (See probabilities under “Net 2” column in Table 17).

In another scenario, should farming activities decline (e.g. due to prolonged drought), the fishery (both fishing and shrimping) will suffer significantly due to the diminished flow of income from farm produce to support investment in fishing gears (Figure 51). While the consequence of reduced fishing pressure on the shrimp fishery was ambiguous and therefore could not be predicted in this model, fish stocks were predicted to increase in a long term. Fisheries management activities would possibly be minimal during this period as investment in fishing effort would be greatly reduced. Low farming activity in the model also had serious negative impacts on the daily living standard of the people as whole since farm produce for daily subsistence would dwindle. Many farmers would likely shift to retail business in order to increase their incomes and profits. There is a 50% to 100% chance that these predictions are accurate (see Table 17 for probabilities).

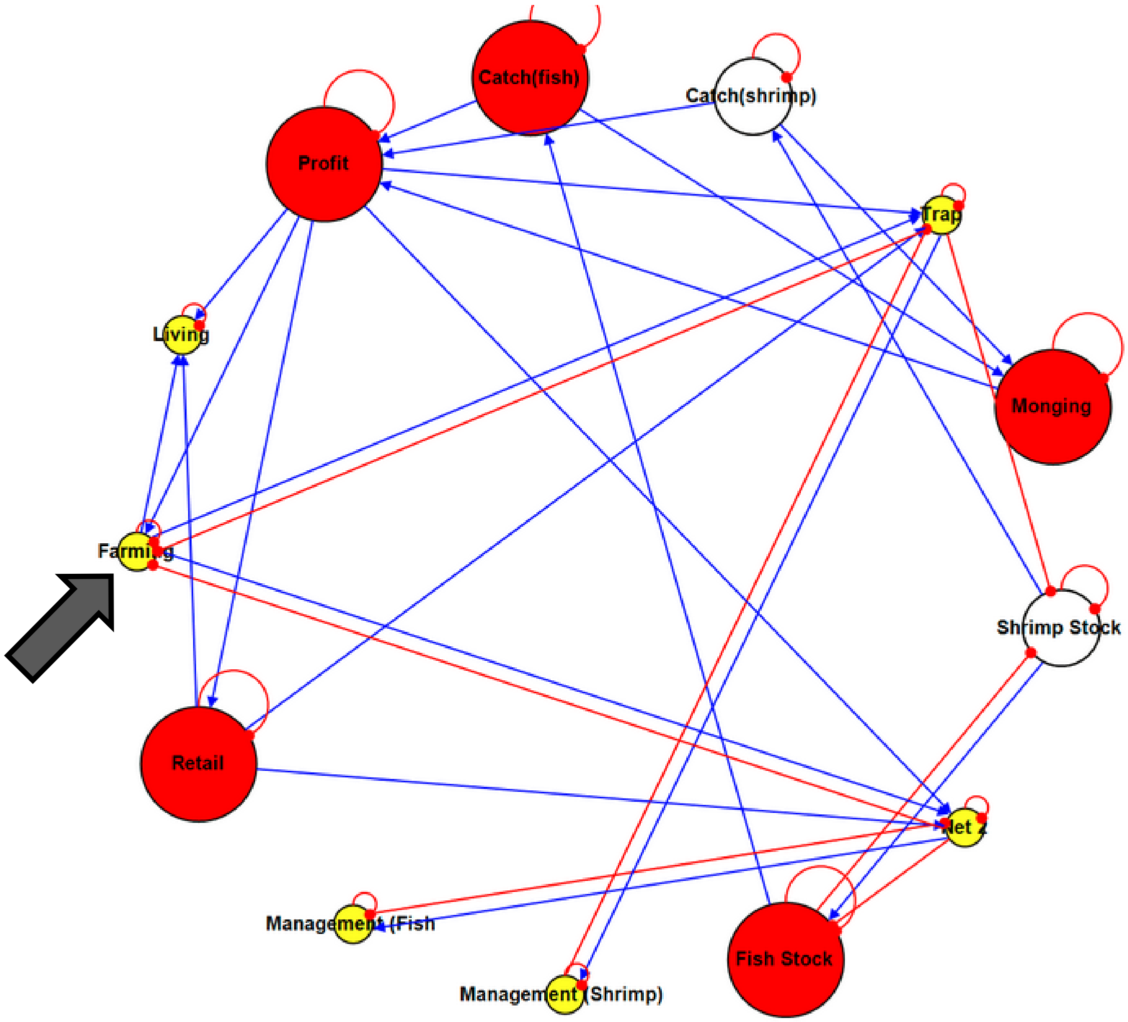


Figure 51: Analysis of response of other livelihood activities to decreased farming activities in Model V (Arrow points to perturbed variable, large red = increase, small yellow = decrease, transparent = ambiguous)

As shown in Figure 52, in the event that the retail business collapses in Anlo Beach probably through currency depreciation or other economic crisis, there is 0.5 to 0.95 probability that the fishery would once again be the most affected as the profits from the retail that supported fishing activities (investment in gears and other efforts) will be cut off. Fish stocks would increase in the face of the declining numbers of fishing nets and traps, but the effects on shrimps stock was ambiguous in the model as there could be high predation on the shrimps. People would shifted to farming to maintain their incomes, hence, the increased farming and profit in the model.

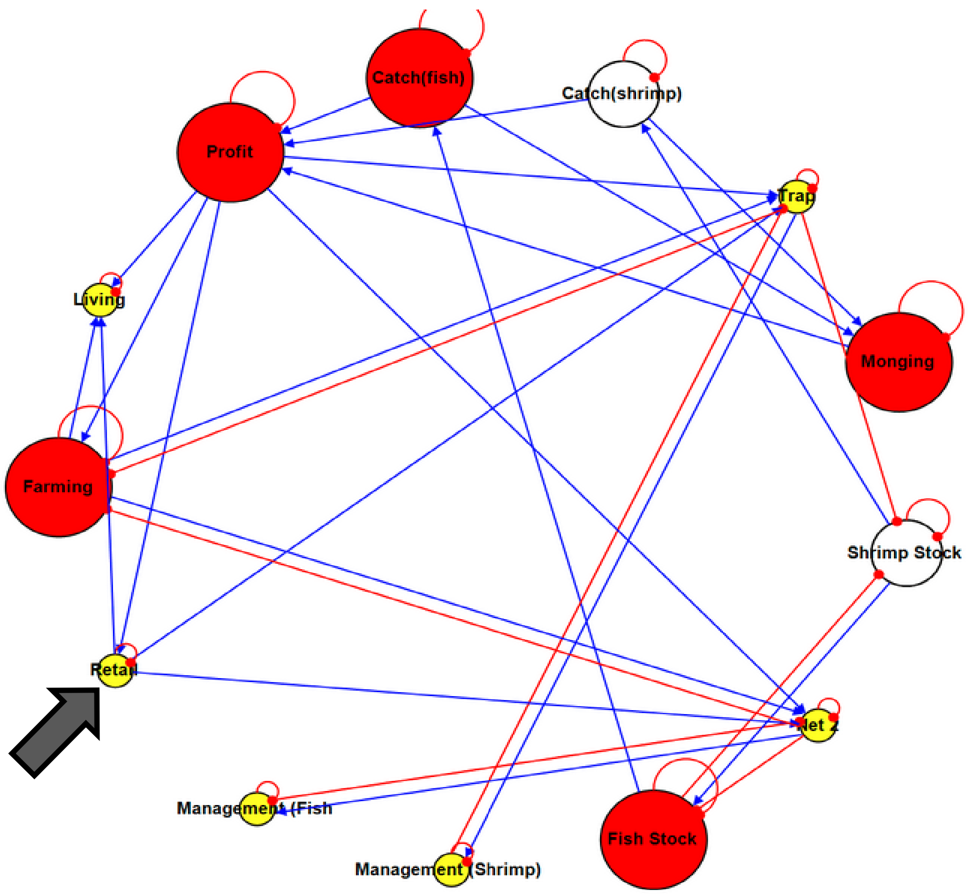


Figure 52: Response of other livelihood activities to decreased retail activities in Model V (Arrow points to perturbed variable, large red = increase, small yellow = decrease, transparent = ambiguous)

On the other hand, should retail business become highly attractive, there would be increased investment in fishing effort with funding from the retail business which would increase the pressure on fish stocks, decline fish catches and lessen fish monging business in the long term (Figure 53). Increased investment in the fishery would also cause farming and agricultural production to decline. The combined effect of the depleted fish stocks, reduced catches, low fish monging activities and diminished agricultural production would significantly reduce overall incomes and profits in the community.

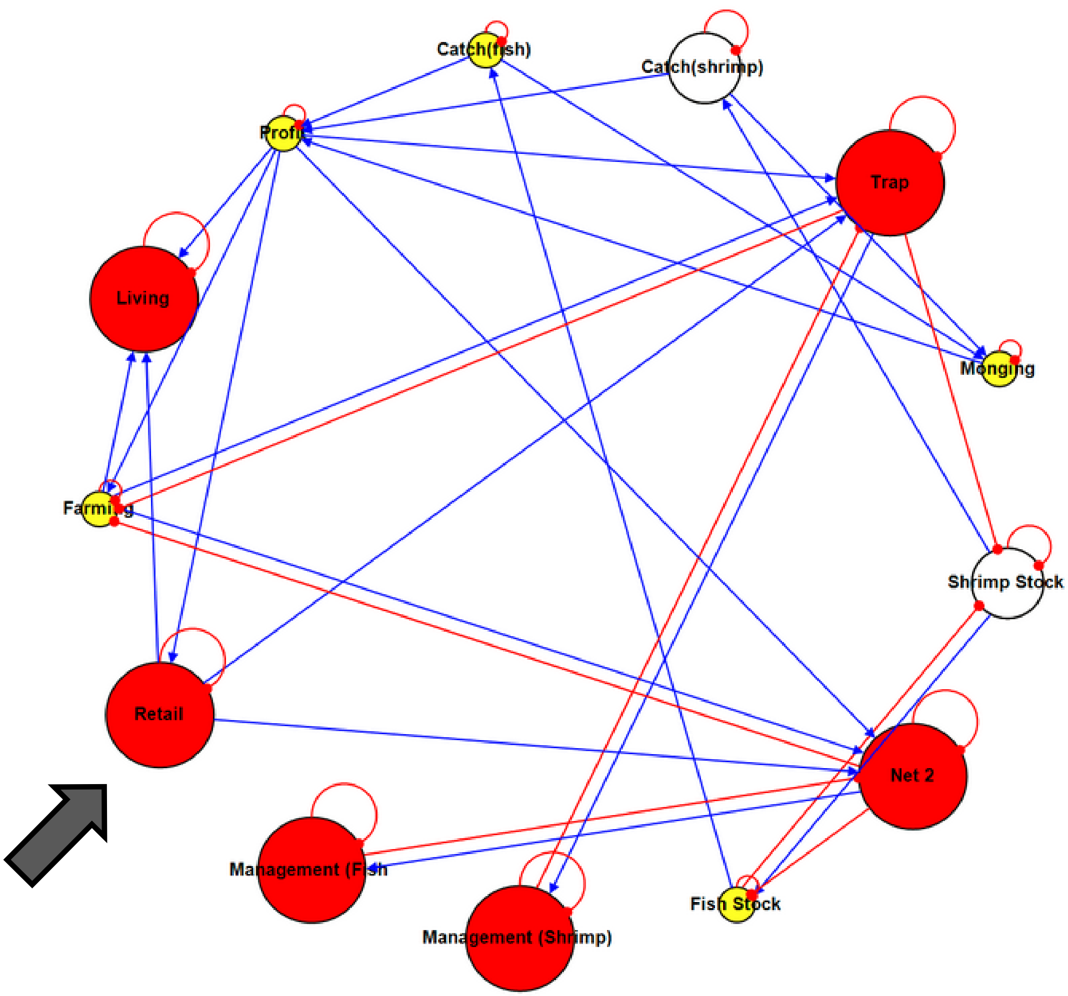


Figure 53: Response of other livelihood activities to decreased retail activities in Model V (Arrow points to perturbed variable, large red = increase, small yellow = decrease, transparent = ambiguous)

CHAPTER FOUR

DISCUSSION

Health of the aquatic ecosystems

The physico-chemical factors surveyed in this work were used as the environmental indicators of the ecological health of Lower Pra coastal ecosystems while the benthic macrofauna communities were used as biological indicators. Of the environmental parameters studied, turbidity, dissolved oxygen, nitrate and phosphate concentrations showed critical levels across the ecosystems.

Turbidities caused by suspended silt are threats to many coastal environments around the world (Gordon & Baretta, 1982; Airoldi, 2003). High turbidities were persistently recorded in the estuary where the most turbid condition occurred at the upper reaches at Krobo (Station E) reaching 1000 ppm at both high and low tides. The murky coloration of the Pra Estuary throughout the year could be attributed to high silt loading possibly from illegal mining activities upriver. Such silt related turbidities are reportedly influencial on other physicho-chemical factors in aquatic ecosystems (Ishaq & Khan, 2013). In 2012, the estuarine and wetland waters at Anlo Beach generally had dissolved oxygen concentrations below 5 mg/l, the threshold for survival of aquatic life in running waters (Hynes, 1970; Palanna, 2009). As explained by LaSalle (1990), the suspended particles absorb heat from sunlight, making turbid waters warmer and reducing the concentration of oxygen in the water. Costa *et al.* (2013) also indicated that the suspended particles scatter light thereby decreasing the photosynthetic activity of plants and algae which contributes to lowering of the oxygen concentration even more. It is therefore possible that the low DO recorded during the period was further exacerbated by the poor photosynthetic activity resulting from the limited light penetration. Presumably, the improvement of water turbidity in 2013 enhanced the rise in DO levels in the waters.

Turbidity also possibly influenced the high levels of phosphates and nitrates in the habitats. The highest nitrate concentration of 78.2 mg/L and the highest phosphate contentration of 0.41 mg/L were recoreded at Krobo (Station E) where the highest turbidity occurred. It has been reported by Nordlie and Kelso (1975) that there is greater input of aIlochthonous materials into tropical estuaries by river flow during the rains, and this increases the turbidities of estuaries during the rainy season (Costa, Pereira, Costa, Monteiro & Flores-Montes, 2013). According to the National Research Council (2000) and Iida and Shock (2007), a significant release of nitrates and phospates accumulated in the soils from industrial and agricultural activities upstream occur through multiple run-offs thereby increasing the concentrations in estuaries during the rains when turbidity is high. Tufuor *et al.* (2007) previously observed the high levels of nitrates (33.8±0.5 mg/l) and phosphates (3.9±0.1 mg/l) in the Pra Estuary and cautioned the potential of nutrient pollution due to high levels of these compounds resulting from the mining and other industrial activities upstream as well as fertilizers used in farming along the banks of the Pra River. Similarly, the concentrations recorded at most stations in the ecosystems were far beyond the upper limits of

0.1 mg/l phosphate and 1.0 mg/l nitrate recommended as the suitable range in estuaries and coastal ecosystems for avoidance of algal blooms (NOAA/EPA, 1988). The results indicate excessive presence of nutrients in the ecosystems suggesting capacity for high primary productivity which is probably hampered by limited light penetration due to extreme turbid conditions.

The least richness and diversity of the benthic macroinvertebrate community in the ecosystems were observed at the most turbid sampling location, Krobo (Station E), where only four species of zoobenthic organisms were found with low densities (less than 45 individuals/m^2). In addition to decreasing primary production, large amounts of suspended matter cause clogging and irritation of gills of fish (Simenstad, 1990) and filter-feeding invertebrates (Kyte & Chew, 1975; Barnes, Chytalo, & Henrickson, 1991). According to Schubel (1977), acute effects of turbidities on estuarine organisms occur at levels beyond 500 ppm, a concentration far below the values aound 1000 mg/l recorded at Krobo. The extremely high turbidity at the upper reaches of the estuary could therefore account for the correspondingly poor macrozoobenthic community. This is similar to the observations of Ishaq and Khan (2013) in the Yamuna river in India where the average macrozoobenthic density showed an inverse relationship with turbidity but was positively correlated with transparency. Presumably, the gradual disappearance of the mangrove oyster (*Crassostrea tulipa*) from the estuarine environment as reported by the community members (Pers. comm.) may be consequences of the intolerable turbidities.

Annelids dominated the benthic community in the Pra estuary with Polychaeta constituting 87.5 %, Oligochaeta 11.2 %. Insecta made up only 1.3 % of the community. The taxa of macrozoobenthic organisms inhabiting the estuary were fewer than the communities in the Nyan and Kakum estuaries in Ghana where Dzapkasu (2012) found Annelida, Phoronida, Nemertea, Crustacea, Insecta and Mulluca. Polychaetes constituted about 60 % of the benthic macrofauna in the Nyan estuary while crustaceans made up about 65 % of the community in the Kakum Estuary. It is possible that the two estuaries had more macrozoobenthic taxa due to their low turbidities; the highest turbidity of 120 NTU (≈ 150 ppm) was recorded for Nyan and 60 NTU (≈ 90 ppm) for Kakum (Dzapkasu, 2012). This could explain why Pra was dominated by polychaetes of the Families Capitellidae and Nereidae which are known to be typical inhabitants of muddy waters (Yankson & Kendall, 2001), while Nyan was dominated by Orbiniidae (*Scoloplos* sp.) which are reported to prefer clean coarse and fine sands (Fish & Fish, 1996). The occurrence of *Tanytarsus* sp. (Chironimidae) at only Station E in the estuary confirms the reports of Cuomo and Zinn (1997) that freshwater macroinvertebrates such as chironomid larvae usually inhabit the more riverine areas of estuaries.

The benthic community in the wetland comprised a fair representation of oligochaetes, polychaetes, crustaceans and insects (mainly chironomid larvae). This was richer and diverse compared to the Kakum estuary wetland where Okyere, Blay and Aggrey-Fynn (2011) reported of only chironomid larvae and oligochaetes being the benthos inhabiting the habitat. The difference could be attributed to the persistence of the pools inhabited by the benthic organisms in the Pra saltmarsh due to continuous tidal inflows as opposed to the ephemeral nature of the pools in the Kakum marsh that form during the rains and dries up during the dry season. Another reason may be the relatively higher dissolved oxygen range in the current wetland (3.5 – 6.5 mg/l) which probably favoured more fauna than the Kakum estuary wetland (2.5 to 4.5 mg/l) which had only organisms that tolerate low DO.

Estuarine macrozoobenthic communities are well known to be dominated by polychaetes and some species of oligochaetes due to their euryhaline capacities (Cuomo & Zinn, 1997; Chainho *et al*., 2006). The high abundance of polychaetes and oligochaetes in the Pra Estuary and connecting wetland was therefore expected. However, the polychaete Families Capitellidae and Nereidae, and the oligochaete Family Tubificidae that dominated the benthos of the habitats are known to be tolerant of low oxygen tensions and organic pollution (Yankson & Kendall, 2001). Kenney, Sutton-Grier, Smith and Gresens (2009) have reported the importance of benthic macroinvertebrates as indicators of water quality. Among the benthic macroinvertebrate species occurring in the estuary and wetland studied, *Capitella* spp., *Nereis* spp., *Tubifex* spp. and *Chironomus* spp. have been used as indicators of organic pollution (Rae, 1989; Dean, 2008; Martins, Stephan & Alves, 2008). In organically polluted systems, density of *Tubifex* exceeds 5000 individuals/m^2 (Martins *et al.*, 2008) while density of the polychaetes could reach 10,000 individuals/m^2 (Giangrande, Liccian & Musco, 2005). However, none of the benthic animals encountered in this study exhibited such densities, the highest density being 991 individuals/m^2 for *Tubifex tubifex* in the wetland. This might suggest low organic pollution in the Pra River Estuary and its connecting wetlands.

Apart from the parameters discussed, the others were within the accepted range for estuaries and other aquatic ecosystems. Taking pH for example, Wood (1967) puts the range between 6.5 and 9.4 for estuaries. Alabaster and Lloyd (1980) also gave the limits of 5.0-9.0, below and above which is potentially lethal especially to freshwater fish. Clearly, the pH recorded from the three ecosystems throughout the study (6.5 - 9.0) was within the required range for coastal ecosystem processes and aquatic life.

The fish communities

Forty-seven species belonging to thirty-two families were sampled from the marine ecosystem, thirty-two species from nineteen families from the estuary, and twenty species belonging to eleven families from the wetland. Analysis of the index of diversity indicated that the marine ecosystem had the highest diversity, followed by the estuary, and the adjoining wetland having the least diversity. Similarly, Blay (1997) found 28 species of fish in the Kakum estuary in Ghana compared to the 18 species found in the adjoining wetland (Okyere *et al*., 2012). This trend has also been observed on the southeast coast of India (Murugan *et al.*, 2014) where the number of species and diversity decreased from the marine environment towards freshwater zone. As explained by Okyere *et al*. (2012), this is attributable to the permanent connection of the estuary to the sea which enables more species to enter the estuary than the adjacent wetland where entry is regulated by tidal variations and seasonal floods. In comparison, a more diverse fish community inhabits the Pra Estuary and adjoining wetland than the Kakum Estuary and its adjacent marshland. However, the present 32 fish species from 19 families recorded in the estuary is similar to the 32 species from 21 families reported in the Volta estuary in Ghana (Segbefia, Nunoo & Dankwa (2013) but far less than the 70 species from 32 families in the Gambia estuary (Albaret *et al*., 2004). The difference in number of species observed could be attributed to the geographical differences and other variabilities in environmental conditions.

The commonest fish caught from the estuary was the black-chinned tilapia *Sarotherodon melanotheron* which constituted 25.3 % of the community. Others were the marine catfish *Arius latiscutatus* (19.7 %), the sickle fin mullet *Liza falcipinnis* (11.3%) and the banana mullet *Mugil bananensis* (8.5 %). This composition was similar to the Whin estuary icthyofauna where *S. melanotheron* (26.5%) was dominant (Okyere *et al.*, 2011), but different from other estuaries in Ghana such as the Kakum estuary where grey mullets dominated the fish fauna by 63 % (Blay, 1997), and the Volta River Esturay community which was predominantly *Caranx hippos* (38%), *Ethmalosa fimbriata* (15%) and *Mugil Cephalus* (17%) (Segbefia *et al.*, 2013).

Twenty-four of the thirty-two species sampled from the estuary and six of the twenty species collected from the wetland were marine species, most being juveniles except the black-chinned tilapia *Sarotherodon melanotheron* and the swimming crab *Callinectes amnicola* that were caught as adults. Freshwater fishes such as *Tilapia zillii, Hemichromis faciatus, Eleotris senegalensis*, *Gobiodes africanus* and *Bathygobious soporator* which were collected from the wetland also occurred in the estuary. These observations enforce the fact that the Pra Estuary and its connecting wetlands are important breeding, nursery and feeding grounds for juvenile freshwater and marine fishes as also reported for the Kakum (Blay, 1997; Okyere, Blay, Aggrey-Fynn & Aheto, 2012) and Whin (Okyere, Aheto & Aggrey-Fynn, 2011) estuaries in Ghana.

Different authors have attributed the occurrence and diversity of fish species in estuarine ecosystems to different environmental factors on temporal and spatial scales. Albaret *et al.* (2004) tried establishing the relationship between environmental factors and fish assemblages in the Gambia Estuary but could not clearly point out which factors influenced fish occurrence and diversity in the estuary. However, the study by Segbefia *et al*. (2013) revealed temperature and salinity as primary driving forces amongst a host of other interacting factors influencing fish abundance in the Volta estuary in Ghana. Hossain, Das, Sarker and Rahaman (2012) also reported temperature and rainfall as the main factors influencing fish abundance and distribution in the Meghna river estuary in Bangladesh. Chowdhury, Hossain, Das, and Barua (2010) found salinity and turbidity as the main parameters controlling the occurrence and distribution fish in the Naaf River Estuary (Bangladesh). Nitrate concentration, depth, dissolved oxygen and temperature were found to be the most important predictors of fish diversity in the Tagus estuary, Portugal (Gutie´rrez-Estrada, Vasconcelos & Costa, 2008).

In the Pra Estuary, fish diversity seemed to be largely regulated by diurnal tidal variations, as the fish community was more diverse at high tide than low tide during most of the study months. It therefore appears that salinity was the principal physico-chemical factor that dictated the daily variations in the fish community of the brackishwater environment. Furthermore, many of the fishes encountered in the estuary at high tide were of marine origin, the commonest being juveniles of the marine catfish *Arius* spp., grey mullets *Liza* spp. and *Mugil* spp., bonga shad *Ethmalosa fimbriata*, parrot grunt *Pomadasys peroteti*, West African ladyfish *Elops lacerta*, the sole *Cynoglossus senegalensis*, peneid shrimp *Penaeus notialis*, swimming crab *Callinectes amnicola*, among others. The low tide samples generally comprised brackishwater fish such as the tilapias *Sarotherodon melanotheron* and freshwater species such as *Hemichromis fasciatus*, the lampeye *Aplocheilichthys spilauchen*, the gobbies *Gobioides africanus* and *Gobionellus occidentalis*, and the eleotrid *Eleotris senegalensis*.

It could be noticed from the first year of the study that species diversity generally declined (especially at high tide) till February 2013 after which it started rising, with a remarkably high increase after July 2013. In general, a high biodiversity is desirable and provides indications of relatively good health status of the ecosystem (Okyere *et al*., 2011). A multiplicity of factors could account for the fluctuating species diversity in the estuary. A decline in diversity may indicate deteriorating water quality resulting from the high turbidity at the time, as many fish need clear water to spot their prey (Bilotta & Brazier, 2008), and the silt could also cause fish gill clogging and irritation (Simenstad, 1990). Secondly, the dissolved oxygen concentration which remained below 5 mg/l throughout 2012 could be a factor because low DO is stressful to most aquatic organisms as it could cause suffocation (Gupta, 2011). The increased fish species richness and diversity occurred when turbidity and DO improved in 2013. The sharp rise in fish diversity after July 2013 coincided with the peak upwelling event in the inshore waters suggesting a possible abundance of food in the estuary. This may have encouraged the entry of many species that use this habitat as feeding grounds.

The brackishwater fishery

The estuarine fishery at Anlo Beach is active but largely on subsistence basis with 20 − 40 fishermen fishing per day. Fishermen exploit the fishes briefly in a day, and spend majority of the time working in the beach seine fishery since they derive their incomes mainly from the marine landings. Most of the fishermen engage in the brackishwater fishery as a secondary source of fish for subsistence in the absence of marine fish especially during the off-fishing season. Therefore, unlike the fisheries of some brackishwater systems in Ghana such as the Fosu and Muni lagoons in which there are intense fishing pressures on the fish stocks, (Blay & Asabere-Ameyaw, 1993; Koranteng, Ofori-Danson & Entsua-Mensah, 2000), fishing pressure is low in the Pra estuary. Cast net was the most deployed gear in the estuary followed by gill nets, pole seine nets and crustacean pots. The predominant fish caught was the black-chinned tilapia *S. melanotheron* which constituted 25−30 % of the catches while the marine catfish *Arius* sp. (15-20 %)

and grey mullets *Liza* spp. and *Mugil* spp. (15-20 %) were also appreciably caught.

Biology of the black-chinned tilapia population

The *S. melanotheron* specimens ranged from 3.4 cm to 15.8 cm TL with the 10.0-10.9 cm class constituting the mode. The maximum length of 15.8 cm TL (=12.6 cm SL) observed in the Pra estuary *S. melanotheron* is similar to the 15.9 cm TL specimen reported in the Fosu Lagoon (Blay & Asabere-Ameyaw, 1993) and less than the 15.0 cm SL (=19.0 cm TL) fish caught in the Benya Lagoon (Blay, 1998). It is however slightly bigger than that of the species in other coastal systems in Ghana such as the Butuah Lagoon (10.5 cm TL; Okyere *et al.*, 2011), Muni Lagoon (12 cm SL; Koranteng *et al.*, 2000), Kakum Estuary (12.l cm TL; Blay, 1998), and Whin Estuary (15.5 cm TL; Okyere *et al.*, 2011).

Growth rate of the Pra Estuary fish (K= 0.65 yr^{-1}) was slower than populations in the Fosu Lagoon (0·82 yr^{-1}; Blay & Asabere-Ameyaw, 1993), Kakum Estuary (1.25 yr^{-1}; Blay, 1998) and Muni Lagoon (0.7 yr^{-1}; Koranteng *et al.*, 2000), but slightly faster than the Benya Lagoon population (K=0.61 yr^{-1}; Blay, 1998). The slower growth rate in the Pra estuary population reflected in its longer asymptotic length (L_∞= 16.84 cm TL; = 13. 5 cm SL) compared to the other Ghanaian populations. According to Iles (1970; quoted in Blay, 1998), a low maturity-length ratio (L_m/ L_∞= 0.50 and below) is associated with stunted populations while a maturity-length ratio of 0.70 and above is characteristic of normal growing tilapias. Compared to the stunted Kakum, Benya and Fosu populations which mature at 3-5 months and have a low maturity-length ratio (L_m/

$L_\infty < 0.50$), the relatively high maturity-length ratio of the Pra population (0.68) suggests that the tilapias are not stunted.

Fishing mortality (F) of the tilapia stock was estimated as 0.12 per year while natural mortality (M) and total mortality (Z) were calculated to be 1.57 and 1.69 per year, respectively. These mortalities are far lower than the rates reported for other Ghanaian coastal populations such as the stocks in Fosu lagoon ($F = 3{\cdot}05\ yr^{-1}$, $M = 1{\cdot}90\ yr^{-1}$, $Z = 4{\cdot}95\ yr^{-1}$; Blay & Asabere-Ameyaw, 1993), Benya lagoon ($F = 1.98\ yr^{-1}$, $M = 1.51\ yr^{-1}$, $Z = 3.49\ yr^{-1}$; Blay, 1998) and Kakum estuary ($F = 2.83\ yr^{-1}$, $M = 2.83\ yr^{-1}$, $Z = 5.17\ yr^{-1}$; Blay, 1998) as well as the Densu delta, Muni, Sakumo, Songhor and Keta lagoons ($F = 1.75 - 3.50\ yr^{-1}$, $M = 1.55 - 2.21\ yr^{-1}$, $Z = 2.96 - 5.43\ yr^{-1}$; Entsua-Mensah, Ofori-Danson & Koranteng, 2000). Therefore unlike these populations which face the problem of overfishing ($E > 0.5$), the Pra stock is under-exploited ($E = 0.07$). This was again confirmed in the ECOPATH mortality estimates where the functional group to which *S. melanotheron* belonged, i.e. “Planktivorous fish”, had an exploitation ratio of 0.03. The low fishing pressure in the estuary could likely account for the low fishing mortality of the tilapia stock and therefore the very low exploitation ratio.

Reports indicate that *S. melanotheron* populations have protracted breeding activities occurring throughout the year, with the major spawning season occurring between April and July which coincides with the major rainy season (Blay, 1998; Faunce, 2000; Koranteng, *et al.*, 2000; Guèye, Kantoussan & Tine, 2013). The monthly changes in the gonado-somatic index and occurrence of ripe gonads demonstrated that the population in the Pra estuary also spawns mainly between May and July, with minor spawning between September and February. The dominance of smaller individuals (< 4 cm) from August to November in the samples suggests an earlier recruitment of juveniles. Although the major breeding of the fish has always been associated with rainfall, a detailed study by Guèye *et al*. (2013) on populations in brackishwater and freshwater habitats in Senegal revealed that higher reproductive activity in the species is enhanced by the combined effect of prolonged photoperiodicity and low salinities both of which occur during the rainy season. Photoperiodicity was not studied in the current research, but salinity levels in the estuary were lowest (< 5 ‰) in June and July which coincided with the major breeding period.

Fecundity of the tilapia ranged from 74 to 263 eggs per female, with a mean of 152 ±73 ova. This compares favourably with the absolute fecundity range of 111 – 226 eggs observed for the Kakum estuary wetland population (Okyere, 2010), 55−351 eggs for the species in Fosu lagoon (Apenuvor, 2014) and 97 to 379 eggs with a mean of 206 reported for the fish in Dominli lagoon (Arizi, 2014) in Ghana. In fish species, egg production has been found to relate to the degree of parental care and survival rates. Fecundity is low in species that provide a moderate or high degree of care for their eggs and larvae, while those that provide little or no parental care often have high fecundity (Fuiman, 2002). The low fecundity of *S. melanotheron* is attributable to its paternal oral brooding habit (Trewavas, 1983) which ensures a high degree of survival of their brood.

The positive linear relationships between fecundity − total length and fecundity − body weight for the population studied have also been reported by

Apenuvor (2014) and Arizi (2014) for Fosu and Dominli populations, respectively. Unlike the Dominli population in which fecundity correlated poorly with fish size (r= 0.13 for length and 0.19 for weight), fecundity had strong correlation with length (r =0.65) and weight (0.70) for the Pra fish as similarly described for the species in Fosu (r =0.52 for length and 0.61 for weight).

The marine fishery

Upwelling intensity in the Anlo Beach inshore waters was stronger in 2013 (UI = 1.6 to 2.6) than 2012 (UI = -0.2 to -0.7). Upwelling is a major process that drives productivity in Ghanaian and Ivorian marine waters (Djagoua *et al.*, 2011). Water temperature is the principal factor that triggers upwelling although other oceanographic processes including local winds, currents and salinity are also reportedly instrumental in driving this process (Houghton, 1973; Roy, 1995). Bakun (1978) found sea surface temperature of 25°C as the maximum threshold for upwelling in the Gulf of Guinea. Furthermore, temperatures between 22°C and 19°C in Ghanaian waters reportedly coincided with very high upwelling intensity (Houghton, 1973). Conceivably, the warmer condition in the Anlo Beach marine waters in 2012 may have caused a weak upwelling. The colder conditions in 2013 probably enhanced the upwelling process during the main season, as temperatures dropped below 22ºC in July with a stronger upwelling intensity.

Pertinently, the 2013 fish landings from the marine fishery were about double that of 2012. It has been indicated by Demarcq and Aman (2002) that Ghana experiences seasonal upwelling, a major event occurring from July to November with the highest intensity in August and a minor upwelling from

January to April with weaker intensity in April. According to Koranteng (1997), the small pelagic fishes (sardines, anchovies, etc.) are the main stocks that form the backbone of Ghana's inshore artisanal fishery, and their abundance strongly depend on the intensity of the upwelling season. It is therefore possible that the weak upwelling in 2012 contributed to the lower fish catches during the main fishing season that year while the stronger upwelling in 2013 enhanced the higher fish catches in the main fishing season and the sudden abundance of anchovies in October 2013 which had never occurred in 2012 and early 2013.

The dearth of information on beach seine fisheries largely constrains the effectictive comparison of the present work with other studies in Ghana and elsewhere. Nevertheless, the present research could serve as a reference point for future workers on similar artisanal fishery systems. The beach seine fishery at Anlo Beach employs over 70% of the people. It is governed by traditional rules that are enforced by the Anlo Beach fisher folk together with the traditional authorities which directly or indirectly promote the management of the fishery. Fishing is prohibited on Tuesdays, during funerals, and until the body of a drowned member of the community is found should such accident occur. These rules are effectively enforced with hefty fines to offenders. Other local regulations include a ban on the use of drag nets in the Pra River Estuary and restriction of the Anlo people from harvesting the mangroves, but these are not strictly enforced by the Shama traditional authorities.

A common problem is the utilization of undersized meshes (< 25 mm stretched mesh) in fishing, which the fishermen acknowledge as improper knowing that such small meshes are banned (Ghana Fisheries Act 2003). The destructive effect of using small nets was evident in the landing of large quantities of small fishes mainly juveniles of clupeids, grunts, carangids and many other species which together constituted over 50 % of the monthly catches, but generated less than 30 % of the monthly income.

The Ecopath model showed that the fishery currently exploits some primary consumers and lower secondary consumers at trophic level (TRL) 2.0 − 2.5 (e.g. shrimps, crabs and lobsters), the higher secondary consumers at TRL 2.5 − 2.9 (i.e. small pelagics), the tertiary consumers at TRL 3.0 − 3.5 (e.g. *Pseudotholithus* spp.) and the top tertiary predators at TRL > 3.5 (i.e. *Sphyraena* spp., *Trichirus lepturus*, *Elops lacerta*, etc.). Analysis of the trophic interactions and fishing impacts in the fish community showed that two groups of top predators, the threadfins (*Galeodes*) and the barracudas, were the most impacted fish groups by the beach seine fishery as their favourite prey, the small pelagics, were highly exploited. In highlighting the detrimental effects of these beach seine nets to coastal fisheries, Blay *et al.* (2006) pointed out that not only do they capture fingerlings but also affect the flow of trophic energy in the ecosystem through disruption of the food chain. Likewise, the present work points out the need to curb the use of illegal meshes in beach seine nets to ensure sustainable explotation of fish stocks in artisanal coastal fisheries in Ghana.

Under optimum exploitation conditions for a fishery (Gulland, 1977; Pauly, 1980b), the fishing mortality (F) is expected to constitute between one-third and half of the total mortality (Z). The sustainable exploitation ratio (E =

F/Z) range for exploited fish species is therefore 0.3 – 0.5. Values beyond 0.5 indicate that the stock is overexploited. The Ecopath mortality analysis showed that the barracudas and small pelagics were overexploited. This was further confirmed by the MSY estimates from Ecosim where the stocks of barracudas and small pelagics exceeded their maximum production levels. Overexploitation of the fish stocks in artisanal fisheries of tropical areas occur as a result of a number of factors ranging from social to economic as discussed by Pauly *et al.* (1989). In examining the socio-economic environment in which tropical small-scale fisheries occur, Pauly *et al*. (1989) cited poverty, population growth and the lack of alternative livelihoods as the main factors driving the overexploitation of fisheries resources. Malthusian overfishing (described by Pauly as the situation where poor fishers overexploit fisheries resources in an effort to maintain their incomes and food) is overriding artisanal fisheries of developing countries in tropical areas, and the consequent increased poverty levels are further exacerbated by the impacts of habitat degradation through pollution and damaging fishing practices coupled with ineffective management (Pauly, 1997; McManus, 1997).

Analysis of incomes from the Anlo Beach fishery revealed that a fisherman earned far below the Ghana's 2013 minimum wage of GH¢ 5.24 (≈US$ 1.87) in the lean season months, and a little above the minimum wage in the main season. In a wealth ranking exercise undertaken during the study, 70 % of the households in the community were ranked as poor with difficulties in affording a single meal a day, sending all their children to school, visiting the hospital when sick, and were dependent on other people for clothing, always working for others in farms, as fishing crew, or helping fishmongers to smoke their fish.

Given the poverty level in the community and the declining fish catches in the face of increasing population, increasing number of fishing nets, expanded net sizes and lengths of towing lines, and increased fishing periodicity especially over the last two decades, the community and its fishery seem to have almost been caught in Malthusian overfishing. Pertinently, the use of undersized mesh nets and larger net sizes may be contributing significantly to the declining catches through growth overfishing, with majority of the juveniles being fished before they reach maturity to spawn (King, 2007). This reinforces the advocacy of Aheto *et al*. (2012) that the “open access” nature of Ghana’s artisanal fishery is not sustainable and management reforms are long overdue. It also confirms the need to regulate the use of resources with population growth as discussed by Hardin (1968) in the “Tragedy of the Commons” where he indicated that “the commons, if justifiable at all, is justifiable only under low human population density and should be abandoned with the growth of population”.

Qualitative models showed that the fishery could be revived by eliminating undersize meshes and introducing shrimp pots. Presently, fishers use banned nets because of their ability to retain the shrimp species mainly *Exhippolysmata hastatoides* and *Nematopalaemon hastatus* which though small in size form substantial part of catches and fetch considerable income. While a kilogram of shrimp cost more than a kilogram of some fishes, the former in general did not constitute significant proportions by weight of the monthly landings. Since small shrimps make the most important contribution to income of fishermen in July and August, the use of the small meshed-nets throughout the year cannot be justified as in other reasons only juvenile fishes are captured by such nets.

In an effort to reduce by-catch in the fishery of the Canary Islands in North-West Africa, Arrasate-López *et al*. (2012) investigated the possibility of deploying shrimp pots as selective gears to complement fishing nets and found them to be very effective. Similarly, the present study showed in Model III that introducing a few shrimp pots and eliminating undersize mesh in the nets would yield a positive response where shrimp, juvenile and mature fish stocks would be increased. It is further predicted from the Ecosim that reducing the number of beach seine nets from the current 30 to about 15 would lead to quadrupling the biomass of the stocks (i.e. the small pelagics and the barracudas) within two decades and thus restore the fishery to the maximum sustainable yield.

Ambiguities observed in the qualitative models could be resolved through detailed field study. In Model I for example, the effect of increasing or reducing the number of fishing nets on shrimps and juvenile fishes was uncertain in the prediction model, as it would depend on the strength of the interaction between the net, shrimps and juvenile fish, as well as between the large fish, shrimps and juvenile fish. From field observations however, shrimp and juvenile populations could also possibly increase following a reduction in the number or sizes of the current nets, and decrease following an increase in the number or sizes of nets since more shrimps and juveniles are lost through fishing than predation as a result of the undersize mesh. Similarly in Models II and III, the consequence of varying fishing effort on the shrimp stock was ambiguous and could be resolved through a detailed study on the variation in the diet composition of the fishes at different life stages. If large fish consume more shrimps than juvenile fish do, then shrimp stock will decline with an increase in large fish stock (despite a reduction in the juvenile stock), and increase with a reduction in large fish stock. On the other hand, if juvenile fish prey more on shrimps than large fish do, then shrimps will increase while the juvenile stock decreases (despite an increase in the large fish stock), and reduce when the juvenile stock increases.

Relationship between the fishery and other livelihoods

Predictions from different scenarios of the qualitative Model V revealed that overinvestment in the fishery in terms of increased number of nets will result in a temporary increase in returns while the fish stocks will be depleted in a long term. The former will boost the retail business and and possibly reduce people's interest in farming while the latter scenario would lead to decline in living standards.

In another instance, should retail business become highly attractive, there would be increased investment in fishing with funding from the retail business which would increase pressure on the fish stocks. Increased investment in the fishery would also cause agricultural production to decline. The combined effect of the depleted fish stocks, reduced catches and diminished agricultural production will highly reduce overall incomes. Conversely, should retail business collapse, the fishery would once again be the most affected livelihood as the profits from the retail business to support fishing activities will be cut off.

In the event of farming declining such as during prolonged drought or attack by crop disease, produce from subsistence farming would be affected and the fishery would also suffer significantly as many farmers would likely shift to fishing in order to increase their incomes provided they have the means. This scenario is what possibly happened during the 1990s when the Cape Saint Paul Wilt disease destroyed the vibrant coconut plantations of the farmers in the community thereby leading to the current high fishing effort and declined catches.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The research has shown that turbidity, dissolved oxygen, nitrates and phosphates were the main physico-chemical parameters threatening the quality of the waters of the Pra Estuary and its connecting wetlands. Turbidity ranged from 55±2 ppm to 542±20 ppm in the marine ecosystem, 60±3 to 1000±0 in the estuary and 55±3 to 785±21 in the wetland. The estuary was the most turbid habitat throughout the study period. Turbidities around 1000 ppm known to have detrimental effects on estuarine organisms were persistently recorded at the riverine reaches at Krobo (Station E). In 2012, the dissolved oxygen concentrations in the estuary and the wetland were below 5 mg/l, the threshold for survival of aquatic life in running waters. DO however increased progressively beyond 6.0 mg/L in 2013. Concentrations of nitrates and phosphates in the ecosystems were far beyond the optimum levels of 0.1 mg/l phosphate and 1.0 mg/l nitrate required in estuaries and coastal ecosystems for avoidance of algal blooms.

Annelids dominated the benthic community in the Pra estuary and the adjoining wetland, with Polychaeta constituting between 51.3% and 87.5 %, and Oligochaeta making up 11.2 % to 38.6 % of the communities. Insecta (mainly chironomid larvae) constituted only 1.3 % of the community in the estuary and

2.4 % of the wetland benthos while Crustacea were present only in the wetland where they had a composition of 7.8 %. The lowest richness and diversity of benthic macrofauna (only 4 species) was observed at the most turbid sampling location (Station E). Although the macrozoobenthic communities were dominated by polychaete genera *Capitella* and *Nereis*, and the oligochaete genus *Tubifex* which are used as bio-indicators of organic pollution, their densities were far below reported benchmarks for polluted systems, suggesting low organic pollution in the Pra estuary and its connecting wetlands.

A total of 47 fish species were sampled from the marine ecosystem, 32 from the estuary and 20 from the wetland. *Trichiurus lepturus*, *Engraulis encrasicolus*, *Sphyraena sphyraena* and *Ethmalosa fimbriata* were the dominant fish in the marine catches while *Sarotherodon melanotheron*, *Arius latiscutatus*, *Liza falcipinnis*, *Mugil bananensis*, *Caranx hippos* and *Callinectes amnicola* were the commonest fish caught from the estuary and the wetland. It was found that 24 of the 32 species from the estuary and 6 of the 20 species from the wetland were marine species, most of which were juveniles. This suggests that the Pra Estuary and its connecting wetlands are nursery and feeding grounds for juveniles of commercially valuable marine species, and reinforces the need to protect the waters of these habitats from ascending levels of siltation.

The black-chin tilapia *S. melanotheron* was the most common fish caught in the estuarine fishery mainly with cast net. Analysis of the growth parameters for the fish showed a slower growth rate ($K= 0.65\ yr^{-1}$) which reflected in its longer asymptotic length ($L_{\infty}= 16.84$ cm TL) compared to some other populations in Ghana. The population had maturity-length ratio (L_m / L_∞) of 0.68 indicating that the tilapias are not stunted. Their fishing mortality rate of 0.12 yr^{-1}, natural mortality of 1.57 yr^{-1} per year and total mortality of 1.69 yr^{-1} were lower than many other local populations, and the resultant low exploitation ratio ($E = 0.07$) presumes the Pra estuary stock is under-exploited possibly due to the low fishing pressure in the estuary.

There were 31 beach seine nets in Anlo Beach marine fishery operating as companies each of which consisted of 25 to 55 people depending on the size of their net. A common problem in the marine fishery is the utilization of undersized meshes (< 25 mm stretched mesh) in the beach seine nets, which resulted in the landing of large quantities of small fishes mainly juveniles of clupeids, grunts, carangids and many other species which together constituted over 50 % of the monthly catches, but generated less than 30 % of the monthly income.

Mortality estimates from the Ecopath model showed that barracudas and small pelagic stocks were overexploited in the fishery ($E > 0.5$), and further analysis from Ecosim indicated their stocks have been exploited beyond the maximum sustainable yield. To avert this situation, predictions from the qualitative models revealed that the fish stocks could be increased by eliminating undersized meshes in the beach seine nets and introducing shrimp pots. A 50 % reduction in fishing effort over two decades is predicted to quadruple the biomass of the overexploited stocks and restore them to their maximum production levels.

Recommendations

Recommendations for improving the water quality in the ecosystems

The high siltation of the Pra River should be controlled by combined effort of the Water Resources Commission, Minerals Commission, Ministry of Environment, Science and Technology and the Security Services which are the main institutions with the mandate of curbing illegal mining activities in and around waterbodies in Ghana. These institutions should clamp down illegal mining known as "galampsey" within the catchment areas of the Offin River in the Ashanti Region and the Birim River in the Eastern Region both of which flow into the Pra River, and within the catchment of the Pra in the Central and Western regions. With Friends of the Nation (FoN) and *Hen Mpoano* being the ecosystem oriented NGOs in the Western Region, it is suggested that they remain a strong mouthpiece, bringing together all relevant agencies, interested partners, local and traditional stakeholders, etc. in the districts in this region where "galampsey" activities directly or indirectly impact the Pra River, to dialogue on the possible ways of combating this menace within their capacities. At the community level, the local authorities in Anlo Beach should institute anti-galamapsey measures such as confiscation of the mining facilities and handing over to the police.

The Agricultural Extension Officers of the Ministry of Food and Agriculture in Takoradi who visit farmers in the Anlo Beach area should educate them on good agrochemical practices near the Pra River to avoid polluting the river with excessive nitrate, phosphate and other chemical compounds from fertilzers, pesticides, herbicides, etc.

Shama, Anlo Beach, Krobo and other communities living near or having access to the mangroves should be educated on the importance of these plants in water purification. They should be guided by FoN, Hen Mpoano and the Takoradi regional Agricultural Extension Officers working in these communities to undertake sustainable exploitation practices particularly cultivation of mangroves and other wood lots as firewood for household cooking and fish smoking as practised in Anyayui along the banks of the Volta River Estuary in Ghana.

Recommendations for managing the fishery

Given the absence of an effective institution for governing the fishery at Anlo Beach, the fisheries co-management committee system proposed by *Hen Mpoano* should be established in the community and the membership should have a fair representation of fishing net owners as they are influential "employers" in the village. They should be deeply involved in decision making, as well as implementation and enforcement of fisheries laws and local by- laws because they may pose serious challenges to the implementation and enforcement processes if not directly involved.

With FoN, *Hen Mpoano*, the Fisheries Commission (Takoradi) and the appropriate authorities from the Shama District Assembly as facilitators, a sensitization platform should be organised to educate the fishermen on good fishing practices, national fisheries laws and district and local by-laws including punishments for non-compliance.

The committee should ensure that the fishing net owners remove undersize meshes from their nets. They shoud also ensure that fishing effort is gradually reduced either through allowing about half of the 30 fishing “companies” to operate in a day, or by each company reducing the size of their beach seine net until a 50 % reduction in fishing effort is achieved. Shrimp pots could be introduced to complement the reduced fishing effort.

Recommendations for improving the economic security of the fishermen

Given the high poverty levels among the fisherfolk in the community, the “Susu” collection companies, Shama Credit Union, Christian Rural Aid Network, Lower Pra Rural Bank and other micro-financial institutions that support business of the fisherfolk could be brought under one umbrella to identify the feasibility of mobilizing some contributions from the fishermen and investing for their “old age security”.

Although it may be difficult, the local traditional authorities and the fisheries management committee may together dialogue with the net owners to reconsider the current tenancy agreement with their crew for an option that will enhance the incomes of fishermen as this may feed into their contributions for the suggested “old age security”.

Recommendations for further studies into potential alternative livelihoods

Hen Mpoano could collaborate with the Marine Fisheries Research Division (Tema) and Department of Fisheries and Aquatic Sciences (UCC) to design shrimp pots that take into account the maturity sizes of the different species of shrimps, test the efficiency of bottom and semi-floating traps in commercial shrimping and give interested shrimpers the necessary orientation of the shrimping business.

These institutions could also run tilapia and catfish aquaculture trials on best stocking densities, feeding rates and table sizes to inform interested culturists on culture practices upon improvement of water turbidity.

Oyster culture could also be experimented using local collectors to determine spat availability, effects of physicho-chemical factors and mortalities, biofouling levels and harvestable sizes, and also identify possible marketing channels. This would also be possible upon improvement in water turbidity.

Recommendations for other studies

Future post graduate studies could focus on socio-economic settings of women in Anlo Beach with special attention to the fish mongers, their incomes and opportunities for diversified livelihood within the community.

An ecological assessment of the mangrove forest structure, functional state, support to the fishery and degradation rates is also very important.

Finally, there is the need for a comprehensive evaluation of the threat of climate change to households, livelihoods and food security in the community.

REFERENCES

Acharyya, S. & Mitsch, W. J. (2001). Macroinvertebrate diversity and its ecological implications in two created wetland ecosystems. In W. J. Mitsch & L. Zhang (Eds.), *The Olentangy River Wetland Research Park at The Ohio State University Annual Report* 2000 (pp. 65-76). The Ohio State University, Columbus, USA.

Aheto, D. W., Asare, N. K., Quinoo, B., Tenkorang, E. Y., Asare, C. & Okyere, I. (2012). Economic Value Assessment of Small-Scale Fisheries in Elmina, Ghana. *Sustainability, 4*, 2785-2794.

Airoldi, L. (2003). The effects of sedimentation on rocky coast assemblages. *Oceanography and Marine Biology: An Annual Review, 41*,161-236.

Alabaster, J. S. & Lloyd, R. (1980). *Water quality criteria for freshwater fish.* European Inland Fisheries Advisory Commission Report (FAO). Buttersworth, London-Boston. 297 pp.

Albaret, J-J., Simier, M., Darboe, F. S., Ecoutin, J-M., Raffray, J. & Morais, L. T. (2004). Fish diversity and distribution in the Gambia Estuary, West Africa, in relation to environmental variables. *Aquatic Living Resources*, *17*, 35–46.

Allam, S. O., Faltas, S. N. & Ragheb, E. (2004). Reproductive Biology of *Sphyraena* species in the Egyptian Mediterranean off Alexandria. *Egyptian Journal of Aquatic Research*, *30* (B), 255 – 270.

Al-Nahdi, A., Al-Marzouqi, A., Al-Rasadi E.& Groeneveld, J. C. (2009). The size composition, reproductive biology, age and growth of Largehead Cutlassfish *Trichiurus lepturus* (Linnaeus) from the Arabian Sea Coast of Oman. *Indian Journal of Fisheries*, *56* (2), 73-79.

American Public Health Organization (1992). *Standard methods for the examination of water and wastewater* (19th Ed.), pp. 4 – 91.

Apenuvor, T. (2014). *Crossing, sex reversal and reproductive capacity of some populations of Sarotherodon melanotheron (Cichlidae) from the Central Region of Ghana*. M. Phil. Thesis, University of Cape Coast, Ghana. 128pp.

Aravindan, C. M. (1993). Preliminary trophic model of Veli Lake, South India. In V. Christensen & D. Pauly (Eds.), *Trophic models of aquatic ecosystems* (pp. 87-89). ICLARM, Philippines.

Arizi, E. K. (2014). *Aspects of the biology and ecology of Sarotherodon melanotheron with notes on other cichlids in the Dominli Lagoon, Western Region, Ghana*. M. Phil. Thesis, University of Cape Coast, Ghana. 128pp.

Arrasate-López, M., Tuset , V. M., Santana, J. I., García-Mederos, A., Ayza, O. & González, J. A. (2012). Fishing methods for sustainable shrimp fisheries in the Canary Islands (North-West Africa). *African Journal of Marine Science*, *34*(3), 331–339.

Arreguín-Sánchez, F., Valero-Pacheco, E. & Chávez, E. A. (1993). A trophic box model of the coastal fish communities of the Southwestern Gulf of Mexico. In V. Christensen & D. Pauly (Eds.), *Trophic models of aquatic ecosystems* (pp. 197-199). ICLARM, Philippines.

Arslan, N., Ilhan, S., Şahin, Y., Filik, C., Yilmaz, V. & Öntürk, T. (2007). Diversity of Invertebrate Fauna in Littoral of Shallow Musaözü Dam Lake in Comparison with Environmental Parameters. *Journal of Applied Biological Sciences*, *1*(3), 67-75.

Bagenal, T. B. & Braum, E. (1978). Eggs and Early life history. In T. Bagenal (Ed.), *Methods of assessment of fish production in freshwaters* (pp. 165-201). Oxford, IBP Handbook No. 3, Blackwell Scientific Publications

Bakun, A. & Weeks, S. J. (2006). Adverse feedback sequences in exploited marine systems: are deliberate interruptive actions warranted? *Fish and Fisheries 7*, 316–333.

Bakun, A. (1978). Guinea Current Upwelling. *Nature*, *271*, 147-150.

Barnes, D. K., Chytalo, K. & Henrickson, S. (1991). *Final policy and generic environmental impact statement in management of shellfish in uncertified areas program.* New York Department of Environmental Conservation, Division of Fish, Wildlife and Marine Resources, East Setauket, New York.

Bax, N.J. (1998) The significance and prediction of predation in marine fisheries. *ICES Journal of Marine Science*, *55*, 997–1030.

Bianchi, G. (2008). The Concept of the Ecosystem Approach to Fisheries in FAO. In G. Bianchi & H. R. Skjoldal (Eds.), *The ecosystem approach to fisheries* (pp. 20-37). CABI. 196pp. doi: 10.1079/9781845934149.0309.

Bilotta, G. S & Brazier, R. E. (2008). Understanding the influence of suspended solids on water quality and aquatic biota. *Water Research*, *42* (12), 2849-2861.

Blay, J. & Asabere-Ameyaw, A. (1993). Assessment of the fishery of a stunted population of the cichlid, *Sarotherodon melanotheron* (Rüppel), in a "closed" lagoon in Ghana. *Journal of Applied Ichthyology, 9*(1), 1 – 11.

Blay, J. Jr & Eyeson, K. N. (1982). Observations on the reproductive biology of the shad, *Ethmalosa fimbriata* (Bowdich), in the coastal waters of Cape Coast, Ghana. *Journal of Fish Biology, 21*(5), 485–496.

Blay, J. Jr., (1997). Occurrence and diversity of juvenile marine fishes in two brackishwater systems in Ghana. In: D. S. Amlalo, L. D. Atsiatorme & C. Fiati (Eds.), *Biodiversity Conservation: Traditional Knowledge and Modern Concepts* (pp. 113-119). UNESCO-BRAAF Proceedings, Cape Coast.

Blay, J. Jr. (1998). Growth and mortality parameters of *Sarotherodon melanotheron melanotheron* (Teleostei: Cichlidae) in two brackish water systems in Ghana. *Ghana Journal of Science, 38*, 47 – 55.

Blay, J. Jr., Awittor, W. K. & Agbeko, D. (2006). Seasonal Variation in Food Preference and Feeding Ecology of Two Juvenile Marine Fishes, *Pseudotolithus senegalensis* (Sciaenidae) and *Brachydeuterus auritus* (Haemulidae) off Cape Coast, Ghana. *West African Journal of Appied Ecology*, *9*, 149-155.

Boesch, D. F. & Paul, J. F. (2001). An Overview of Coastal Environmental Health Indicators. *Human and Ecological Risk Assessment*, ***7***(5), 1409-1417.

Boserup, E. (1965). *The Conditions of Agricultural Growth*. George Allen and Urwin, London.

Brinkhurst R. O. (1971). *A Guide for the Identification of British Aquatic Oligochaeta*. (2nd Ed.), Freshwater Biological Association, Scientific Publication No. 22, 55pp.

Canada and the United States (1999). *State of the Great Lakes 1999*. Toronto and Chicago. 89pp.

CBD (1992). *The Convention on Biological Diversity*. United Nations. 28 pp.

Chainho, P., Costa, J. L., Chaves, M. L., Lane, M. F., Dauer, D. M. & Costa, M. J. (2006). Seasonal and Spatial Patterns of Distribution of Subtidal

Benthic Invertebrate Communities in the Mondego River, Portugal–A Poikilohaline Estuary. *Hydrobiologia, 555*(1), 59-74.

Chowdhury, M. S. N., Hossain, M. S., Das, N. G. & Barua, P. (2010). Environmental variables and fisheries diversity of the Naaf River Estuary, Bangladesh. *Journal of Coastal Conservation*, *15* (1), 163-180.

Christensen, V., and Walters, C. J. (2004). Ecopath with Ecosim: methods, capabilities and limitations. *Ecological modelling*, *172*, 109-139.

Christensen, V., Coll, M., Piroddi, C., Steenbeek, J., Buszowski, J. & Pauly, D. (2014). A century of fish biomass decline in the ocean. *Marine Ecology Progress Series*, *512*, 155–166.

Christensen, V., Walters, C. J. & Pauly, D. (2005). *Ecopath with Ecosim: A user's guide*. Fisheries Centre, University of British Columbia, Vancouver, Canada. 154 pp.

Cochrane, K. L. (2002). The use of scientific information in the design of management strategies. In: Cochrane, K.L. (Ed.), *A fishery manager's guidebook: Management measures and their application* (pp. 95-130). Rome: FAO Fisheries Technical Paper. No. 424.

Coll, M., Bundy, A. & Shannon, L. J. (2008). Ecosystem modelling using the Ecopath with Ecosim approach. In B. Megrey & E. Moksness (Eds.), *Computers in fisheries research* (2nd Edition) (p 225–91). New York: Springer.

Costa, A. K. R., Pereira, L. C. C., Costa, R. M., Monteiro, M. C. & Flores-Montes, M., (2013). Oceanographic processes in an Amazon estuary during a typical rainy season. In D. C. Conley, G. Masselink, P. E. Russell, & T. J. O'Hare (Eds.), *Proceedings 12th International Coastal Symposium* (Plymouth, England), *Journal of Coastal Research*, *65*, 1104-1109.

Costanza, R. (1992). Toward an operational definition of health. In R. Costanza, B. Norton & B. Haskell, (Eds.), *Ecosystem Health: New Goals for Environmental Management* (pp. 239–256). Island Press, Washington DC.

Costanza, R. & Mageau, M. (1999). What is a Healthy Ecosystem? *Aquatic Ecology*, *33*, 105–115.

Craft, C. (2000). Co-development of wetland soils and benthic invertebrate communities following salt marsh creation. *Wetlands Ecology and Management*, *8*, 197-207.

Crawford, R. J. M. (1999). Seabird responses to long-term changes of prey resources off southern Africa. In N. J. Adams & R. H. Slotow (Eds.), *Procedings of the 22nd International Ornithological Congress, Durban* (pp. 688-705). Johannesburg: BirdLife South Africa.

CRC/FoN (Coastal Resources Center / Friends of the Nation) (2010). Report on Characterization of Coastal Communities and Shoreline Environments in the Western Region of Ghana. Integrated Coastal and Fisheries Governance Initiative for the Western Region of Ghana. Coastal Resources Center, University of Rhode Island, 425pp.

Cuomo, C. & Zinn, G. A. (1997). Benthic invertebrates of the Lower West River. In D. G. Casagrande (Ed.), *Restoration of an Urban Salt Marsh: An Interdisciplinary Approach* (pp. 152–161). Bulletin Number 100, Yale School of Forestry and Environmental Studies, Yale University, New Haven, CT.

Dambacher, J. M., Gaughan, D. J., Rochet, M.-J., Rossignol, P. A. & Trenkel, V. M. (2009). Qualitative modelling and indicators of exploited ecosystems. *Fish and Fisheries*, *10*, 305–322.

Dambacher, J. M., Li, H. W. & Rossignol, P. A. (2003b). Qualitative predictions in model ecosystems. *Ecological Modelling*, *161*,79 – 93.

Dambacher, J. M., Li, H. W. and Rossignol, P. A. (2002). Relevance of community structure in assessing indeterminacy of ecological predictions. *Ecology*, *83*, 1372–1385.

Dambacher, J. M., Luh, H.-K., Li, H. W. & Rossignol, P. A. (2003). Qualitative Stability and Ambiguity in Model Ecosystems. *The American Naturalist*, *161* (6), 876-888.

Dambacher, J. M., Luh, H-K, Li, H. W. & Rossignol, P. A. (2003a). Qualitative Stability and Ambiguity in Model Ecosystems. *The American Naturalist*, *161* (6), 876 – 888.

Dankwa, H. R., Abban, E. K. & Teugels, G. G. (1999). *Freshwater Fishes of Ghana*. Annales Sciences Zoologiques. 53pp.

Day, J. H. (1967). *A Monogragh on the Polychaeta of Southern Africa* (Parts I&II). London: British Museum (Natural History), 878 pp.

De La Cruz-Aguero, G. (1993). A preliminary model of Mandinga Lagoon, Veracruz, Mexico. In V. Christensen & D. Pauly (Eds.), *Trophic models of aquatic ecosystems* (pp. 193-196). ICLARM, Philippines.

Dean, H. K. (2008). The use of polychaetes (Annelida) as indicator species of marine pollution: a review. *Revista de Biologia Tropical*, *56* (Suppl. 4), 11-38.

Debrah, E. A. (2013). *Assessment of leaf litter productivity of the Kakum River Estuary mangrove ecosystem*. BSc. Dissertation, University of Cape Coast. 32pp.

Demarcq, H. & Aman, A. (2002). A multi-data approach for assessing the spatio-temporal variability of the Ivorian-Ghanaian coastal upwelling: Understanding pelagic fish stock dynamics. In J. M. McGlade, P. Cury, K. A. Koranteng & N. J. Hardman-Mountford (Eds.), *The Gulf of Guinea Large Marine Ecosystem: Environmental Forcing and Sustainable Development of Marine Resources* (pp. 83-92). Elsevier B.V.

Demont, M., Jouve, P., Stessens, J. & Tollens, E. (2007). Boserup versus Malthus revisited: Evolution of farming systems in northern Côte d'Ivoire. *Agricultural Systems*, *93*, 215-228.

Djagoua, É. V., Kassi, J. B., Mobio, B., Kouadio, J. M., Dro, C., Affian, K. & Saley, B. (2011). Ivorian and Ghanaian upwelling comparison: intensity and impact on phytoplankton biomass. *American Journal of Scientific and Industrial Research*, *2(*5), 740-747.

Dzapkasu, M. F. A. (2012). *Comparative ecological study of the Nyan and Kakum estuaries, Ghana*. M. Phil. Thesis, University of Cape Coast, Ghana. 168pp.

Elliott, J. M. (1977). *Some Methods for the Statistical Analysis of Samples of Benthic Invertebrates*. Freshwater Biological Association, Scientific Publication No. 25, 160 pp.

Entsua-Mensah, M., Ofori-Danson P. K. & Koranteng, K. A. (2000). Management issues for the sustainable use of lagoon fish resources. In E. K. Abban, C. M. V. Casal, T. M. Falk & R. S. V. Pullin (Eds.), *Biodiversity and sustainable use of fish in the coastal zone*. (p. 24-27). ICLARM Conf. Proc. 63, 71 p.

FAO (2006). *Stock Assessment for Fishery Management: A framework guide to the stock assessment tools of the Fishery References*. FAO. 67pp.

FAO. (2002). *A fishery manager's guidebook: Management measures and their application.* K. L. Cochrane (Ed.), Rome: FAO Fisheries Technical Paper. No. 424., 231pp.

FAO. (2003). *The ecosystem approach to fisheries*. FAO Technical Guidelines for Responsible Fisheries. No. 4, Suppl. 2. FAO, Rome, Italy, 112 pp.

FAO/MRC. (2003). *New Approaches for the improvement of inland capture fishery statistics in the Mekong Basin*. Ad-hoc expert consultation, Udon Thani, Thailand, RAP Publication 2003/01. 145pp.

Faunce, C. H. (2000). Reproduction of Blackchin Tilapia, *Sarotherodon melanotheron*, Within an Impounded Mangrove Ecosystem in East-central Florida. *Environmental Biology of Fishes,* 57(4), 353-361.

Fetahi, T. (2005). *Trophic analysis of Lake Awassa using mass-balance Ecopath model.* MSc. Thesis, Addis Ababa University, Ethiopia. 99 pp.

Fish, J. D. & Fish, S. (1996). *A student's guide to the seashore. Second edition.* Cambridge: Cambridge University Press.

Fletcher, W. J., Shaw, J., Metcalf, S. J. & Gaughan, D. J. (2010). An Ecosystem Based Fisheries Management framework: the efficient, regional-level planning tool for management agencies. *Marine Policy 34*(6), 1226–1238.

Fuiman, L. A. (2002). Special Consideration of Fish Eggs and Larvae. In L. A. Fuiman & R. G. Werner, (Eds.), *Fishery Science: The unique contributions of early life stages* (pp 1 – 32). UK: Blackwell Publishing Co. Ltd.

Fulton, E. A. and Smith, T. (2002). *Ecosim case study: Port Phillip Bay, Australia.* Fisheries Centre Research Report, 10 (pp 83–93). Fisheries Centre, University of British Columbia, Vancouver.

Gayanilo, F. C. Jr., Sparre, P. & Pauly, D. (2005). FAO-ICLARM Stock Assessment Tools II (FiSAT II). User's guide. *FAO Computerized Information Series (Fisheries)*. No. 8, Revised version. Rome, FAO.168 pp.

Gaydos, J. K., Dierauf, L., Kirby, G., Brosnan, D., Gilardi, K. & Davis, E. G. (2008). Top 10 Principles for Designing Healthy Coastal Ecosystems like the Salish Sea. *EcoHealth*, *5*, 460–471.

Giangrande, A., Licciano, M. & Musco, L. (2005). Polychaetes as environmental indicators revisited *Marine Pollution Bulletin*, *50*, 1153–1162.

Glazier, E. (2011). *Ecosystem Based Fisheries Management in the Western Pacific*. Wiley-Blackwell, 312 pp.

Gordon, D. C. Jr. & Baretta. J. W. (1982). A preliminary comparison of two turbid coastal ecosystems: The Dollard (Netherlands-FRG) and the Cumberland Basin (Canada). *Hydrobiological Bulletin*, *16* (2-3), 255-267.

Guèye, M., Kantoussan, J. & Tine, M. (2013). The impact of environmental degradation on reproduction of the black-chinned tilapia *Sarotherodon melanotheron* from various coastal marine, estuarine and freshwater habitats. *Comptes Rendus Biologies*, *336*, 342–353.

Gulland, J. A. (1977). Fish Population Dynamics (2nd ed). John Wiley & Sons, London. 372 pp.

Gulland, J. A. (1983). *A Fish Stock Assessment: a manual of basic methods*. Chichester, U.K., Wiley Interscience, FAO/Wiley series on food and agriculture, Vol. I, 223 pp.

Gupta, S. K. (2011). *Modern Hydrology and Sustainable Water Development*. Wiley-Blackwell. 464 pp.

Gutie´rrez-Estrada, J. C., Vasconcelos, R. & Costa M. J. (2008). Estimating fish community diversity from environmental features in the Tagus estuary (Portugal): Multiple Linear Regression and Artificial Neural Network approaches. *Journal of Applied Ichthyology*, *24*,150–162.

Hanemann, W. M., (1991). Willingness to pay and willingness to accept: How much can they differ? *American Economic Review*, *81*(3), 635–647.

Hardin, G. (1968). The Tragedy of the Commons. *Science*, *162*, 1243-1248.

Hauer, F. R. & Lamberti, G. A. (2006). *Methods in Stream Ecology*. (2nd Ed.), U.S.A.: Burlington, Elsevier Inc., 877 pp.

Hilborn, R. & Walters, C. J. (1992). *Quantitative fisheries stock assessment*: *choice, dynamics and uncertainty*. New York: Chapman and Hall. 570pp.

Hossain, M. S., Das, N. G., Sarker, S. & Rahaman, M. Z. (2012). Fish diversity and habitat relationship with environmental variables at Meghna river estuary, Bangladesh. *Egyptian Journal of Aquatic Research*, *38*, 213–226.

Houghton, R. W. (1973). Evaporation during upwelling in Ghanaian coastal waters. *Journal of Physical Oceanography, 3*, 487–489.

Humbert, J.-F. & Dorigo, U. (2005). Biodiversity and aquatic ecosystem functioning: A mini-review. *Aquatic Ecosystem Health and Management*, *8*, 367–374

Hynes, H. B. N. (1970). *The ecology of running waters*. Liverpool: Liverpool University Press. 555 pp.

Hyslop, E. J. (1980). Stomach contents analysis-a review of methods and their application. *Journal of Fish Biology*, *17*, 411-429.

ICLARM (1993). *Trophic models of Aquatic Ecosystems*. V. Christensen & D. Pauly (Eds.), ICLARM. Manila, Philippines. 389 pp.

Iida, C. L. & Shock, C. C. (2007). The Phosphorus Dilemma. *Sustainable Agricultural Techniques*. Oregon State University Extension Service, Corvallis. EM 8939-E. 4pp.

Impraim, L. (2009*). Aspects of Growth and Reproductive Biology of Callinectes amnicola (De Rocheburne, 1883) in two Lagoons in Ghana*. M. Phil Thesis, University of Cape Coast, Ghana. 157 pp.

Ishaq F. & Khan A. (2013). Seasonal limnological variation and macro benthic diversity of river Yamuna at Kalsi Dehradun of Uttarakhand. *Asian Journal of Plant Science and Research, 3*(2), 133-144.

Justus, J. (2006). Loop analysis and qualitative modeling: limitations and merits. *Biol Philos 21*, 647–666. DOI 10.1007/s10539-006-9050-x

Kenney, M. A., Sutton-Grier, A. E., Smith R. F. & Gresens, S. E. (2009). Benthic macroinvertebrates as indicators of water quality: The intersection of science and policy. *Terrestrial Arthropod Reviews*, *2*, 99–128.

King, M. (2007). *Fisheries Biology, Assessment and Management*. Blackwell Publishing Company. 382 pp.

Knutsson, P. (2006). The Sustainable Livelihoods Approach: A Framework for Knowledge Integration Assessment. *Human Ecology Review, 13* (1), 90 – 99.

Koranteng K. A. (1997). Marine Fishery Resources of Ghana's Coastal Zone. In S. M. Evans, C. J. Vanderpuye & A. K. Armah (Eds.), *The Coastal Zone of West Africa: Problems and Management*. Proceedings of an international Seminar 23-28 March, 1996, Accra, Ghana.

Koranteng, K. A., Ofori-Danson, P. K. & Entsua-Mensah, M. (2000). Fish and fisheries of the Muni lagoon in Ghana, West Africa. *Biodiversity and Conservation*, *9* (4), 487-499.

Krebs, C. J. (1999). *Ecological Methodology*. Canada, Addison-Welsey Educational Publishers Inc., 620 pp.

Kyte, M. A. & Chew, K. K. (1975). *A review of the hydraulic escalator shellfish harvester and its known effects in relation to the soft shell clam*, *Mya arenaria*. Washington Sea Grant Publication WSG 75-2, (pp. 1-32). Washington Sea Grant Program, University of Washington, Seattle, WA.

LaSalle, M. A. (1990). Physical and chemical alterations associated with dredging. In C. A. Simenstad (Ed.), *Effects of dredging on anadromous Pacific coast fishes*: Workshop proceedings. University of Washington and Washington Sea Grant Program, Seattle, Washington.

Lassalle, G., Nelva Pasqual, J-S., Boët, P., Rochet, M-J., Trenkel, V. M. & Niquil, N. (2013). Combining quantitative and qualitative models to identify functional groups for monitoring changes in the Bay of Biscay continental shelf exploited food web. *ICES Journal of Marine Science*, doi:10.1093/icesjms/fst107.

Lawson, E. O., Akintola, S. O. & Olatunde, O. A. (2010). Aspects of the Biology of Sickle fin mullet, *Liza falcipinnis* (Valenciennes, 1836) from Badagry creek, Lagos, Nigeria. *Nature and Science*, *8* (11), 168-182.

Lee, R. (1986). Malthus and Boserup: A Dynamic Synthesis. In D. Colman & R. Schofield (Eds.), *The State of Population Theory* (pp.96-130). London: Basil Blackwell.

Lima-Junior, S. E. & Goitein, R. (2001). A new method for the analysis of fish stomach contents. *Maringá*, *23* (2), 421-424.

Loneragan, N. R., Babcock, R. C., Lozano-Montes, H. & Dambacher, J. M. (2010). *Evaluating how food webs and the fisheries they support are affected by fishing closures in Jurien Bay, temperate Western Australia*. FRDC Project No. 2006/038. 172pp.

Lozano-Montes H. M., Loneragan N. R., Babcock, R. C. & Jackson, K. (2011). Using trophic flows and ecosystem structure to model the effects of fishing in the Jurien Bay Marine Park, temperate Western Australia. *Marine and Freshwater Research, 62*, 421–431.

MA (Millennium Ecosystem Assessment) (2001). *Ecosystems and Human Well-being*- Washington, DC: Island Press, 216 pp.

Marquette, C. (1997). *Turning but not Toppling Malthus: Boserupian Theory on Population and the Environment Relationships*. Working Paper, Chr. Michelsen Institute, Development Studies and Human Rights, Bergen, Norway. 16 pp.

Martins, R. T., Stephan, N. N. C. & Alves, R. G. (2008). Tubificidae (Annelida: Oligochaeta) as an indicator of water quality in an urban stream in southeast Brazil. *Acta Limnologica Brasiliensia*, *20* (3), 221-226.

McBride, R. S. & Thurman, P. E. (2003). Reproductive Biology of *Hemiramphus brasiliensis* And *H. balao* (Hemiramphidae): Maturation, Spawning Frequency, and Fecundity. *The Biological bulletin, 204* (1), 57-67.

McManus, J. W. (1997). Tropical marine fisheries and the future of coral reefs: a brief review with emphasis on Southeast Asia. *Coral Reefs*, *16*, Suppl: S121-S127.

Mendoza, J. J. (1993). A preliminary biomass budget for the north-eastern Venezuela shelf ecosystem. In V. Christensen & D. Pauly (Eds.), *Trophic models of aquatic ecosystems* (pp. 285-297). ICLARM, Philippines.

Mensah, M. A. (1975). *Report for the biennium, 1973 – 1974 on the Fisheries Unit*, Tema, Ghana.

Metcalf, S. J. (2010). Qualitative Models to Complement Quantitative Ecosystem Models for the Analysis of Data-Limited Marine Ecosystems and Fisheries. *Reviews in Fisheries Science*, *18* (3), 248-265.

Metcalf, S. J., Gaughan, D. J. & Shaw, J. (2009). *Conceptual models for Ecosystem Based Fisheries Management (EBFM) in Western Australia*. Fisheries Research Report No. 194. Department of Fisheries, Western Australia. 42pp.

Moreau, J., Bambino, C. & Pauly, D. (1986). Indices of overall growth performance of 100 tilapia (Cichlidae) populations. In J. N. Maclean, L. B. Dizon & L. V. Hesillas, *The First Asian Fisheries Forum* (pp. 201-206). Manila, Philippines: Asian Fisheries Society.

Morey, G., Moranta, J., Massuti, E., Grau, A., Linde, M., Riera, F. & Morales-Nin, B. (2003). Weight-length relationships of littoral to lower slope fishes from the Western Mediterranean. *Fisheries Research*, *62*, 89-96.

Murugan, S., Khan, S. A, Lyla, P. S., Manokaran, S., Raja1 S. & John, B. A. (2014). Spatial and Temporal Variability in Fish Diversity of Vellar Estuary (South East Coast of India). *Annual Research & Review in Biology*, *4*(13), 2147-2162.

National Research Council (2000). *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*. Washington, DC: The National Academies Press.

Nazarova, L., Semenov, B., Sabirov, V. F., Efimov, R. M., & Yu, I. (2004). The state of benthic communities and water quality evaluation in the Cheboksary Reservoir. *Water Resources*, *31*(3), 316–322.

NOAA/EPA (1988). *Northeast Case Study: Susceptibility and concentration status of Northeast estuaries to nutrient discharges*, Part 3. Strategic Assessment of near Coastal Waters. United States. National Oceanic and Atmospheric Administration, United States. Environmental Protection Agency. 50 pp.

Nordlie, F. G. & Kelso, D. P. (1975). Trophic relationships in a tropical estuary. *Revista de Biología Tropical*, *23*(1), 77-99.

Nunoo, F. K. E. & Ameka, G. K. (2005). Occurrence of macro-algae in the by-catch of beach seine fisheries at Sakumono, Ghana. *West African Journal of Applied Ecology, 8 (1)* doi: http://dx.doi.org/10.4314/wajae.v8i1.45787.

O'Boyle, R., Sinclair, M. & Worcester, T. (2008). Research Requirements of an Ecosystem Approach to Fisheries. In G. Bianchi & H. R. Skjoldal (Eds.), *The ecosystem approach to fisheries* (pp 95-112). CABI. 196pp.doi: 10.1079/9781845934149.0309.

Okyere, I. (2010). *Observations on the benthic macroinvertebrate and fish communities of the kakum estuary wetland in Ghana*. M. Phil. Thesis, University of Cape Coast, Ghana. 130pp.

Okyere, I., Aheto, D. W. & Aggrey-Fynn, J. (2011). Comparative ecological assessment of biodiversity of fish communities in three coastal wetland systems in Ghana. *European Journal of Experimental Biology*, *1* (2), 178-188.

Okyere, I., Blay, J. & Aggrey-Fynn, J. (2011). Hydrographic conditions and the macrozoobenthos of a coastal wetland in Ghana. *International Journal of Ecology and Environmental Sciences*, *37* (1), 15 – 22.

Okyere, I., Blay, J., Aggrey-Fynn, J. & Aheto, D. W. (2012). Composition, diversity and food habits of the fish community of a coastal wetland in Ghana. *Journal of Environment and Ecology*, *3* (1), 1-17.

Ospina-Arango, J. F., Pardo-Rodríguez, F. I. & Álvarez-León, R. (2008). Gonadal maturity of the fish in the Cartagena Bay, Colombian Caribbean. *Boletin Cientifico Museo de Historia Natural Universidad de Caldas*, *12*(9), 117–140.

Ostrom, E. (2002). Common-pool resources and institutions: Toward a revised theory. In L. G. Bruce & G. C. Rausser (Eds.), *Handbook of agricultural economics* (pp.1315-1339). Elsevier.

Ostrom, E., Gardner, R. & Walker, J. M. (1994). *Rules, games and common-pool resources*. University of Michigan Press, Ann Arbor, Michigan, 369 pp.

Palanna O. G. (2009). *Engineering Chemistry*. Tata McGraw-Hill Education Pvt. Ltd. 629 pp.

Panfili, J., Thior. D., Ecoutin. J.-M., Ndiaye P. & Albaret J.-J. (2006). Influence of Salinity on the Size at Maturity for Fish Species Reproducing in Contrasting West African Estuaries. *Journal of Fish Biology, 69* (1), 95-113

Paugy, D., Lévêque, C. & Teugels, G. G. (2003). *The Fresh and Brackish Water Fishes of West Africa.* Vol. II. IRD Editions, Publications Scientifiques du Muséum, MRAC, 815 pp.

Pauly, D. (1980a). On the relationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *Journal du Conseil international d'Exploration de la Mer*, *39*(3),175-192.

Pauly, D. (1980b). A selection of simple methods for the assessment of tropical fish stock. FAO Fisheries Circular 729, 1–54.

Pauly, D. (1983). *Some simple methods for assessment of tropical fish stocks*. FAO Fisheries Technical Paper 234, 52 pp.

Pauly, D. (1997). Small-scale fisheries in the tropics: marginality, marginalization, and some implications for fisheries management. In E. K. Pikitch, D. D. Huppert & M. P. Sissenwine (Eds.), *Global Trends: Fisheries Management* (pp. 40-49). American Fisheries Society Symposium 20, Bethesda, Maryland: American Fisheries Society.

Pauly, D. & Chua T. E. (1988). The overfishing of marine resources: Socioeconomic background in Southeast Asia. *Ambio, 17* (3), 200–206.

Pauly, D., Sambilay, V. Jr. & Optiz, S. (1993). Estimates of relative food consumption by marine mammals, fish and invertebrates populations, required for modelling the Boliao reef ecosystem, Philippines. In V. Christensen & D. Pauly (Eds.), *Trophic models of aquatic ecosystems* (pp. 236-251) ICLARM, Philippines.

Pauly, D., Silvestre, G. & Smith, I. R. (1989). On development, fisheries and dynamite: A brief review of tropical fisheries management. *Natural Resource Modelling, 33,* 307-329.

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology, 13***,** 131-144.

Polovina, J. J. (1984). Model of a coral reef ecosystem: the ECOPATH model and its application to French Frigate Shoals. *Coral Reefs*, *3(1)*, 1–11.

Pranovi, F., Libralato, S., Raicevich, S., Granzotto, A., Pastres, R. & Giovanardi, O. (2003). Mechanical clam dredging in Venice lagoon: ecosystem effects evaluated with trophic mass-balance model. *Marine Biology*, *143*, 393–403.

Puccia, C. J. & Levins, R. (1985). *Qualitative modelling of complex systems*. Cambridge, Massachusetts: Harvard University Press. 259 pp.

Puccia, C. J. & Levins, R. (1991). Qualitative Modeling in Ecology: Loop Analysis, Signed Digraphs, and Time Averaging Qualitative Simulation Modeling and Analysis. *Advances in Simulation*, *5*, 119-143.

Rae, J. G. (1989). Chironomid Midges as Indicators of Organic Pollution in the Scioto River Basin, Ohio. *Ohio Journal of Science*, *89* (1), 5-9.

Ramsey, D. & Veltman, C. (2005). Predicting the effects of perturbations on ecological communities: What can qualitative models offer? *Journal of Animal Ecology*, *74*, 905–916.

Rapport, D. J., Fyfe, W. S., Costanza, R., Spiegel, J., Yassie, A., Bohm, G. M., Patil, G. P., Lannigan, R., Anjema, C. M., Whitford, W. G. & Horwitz, P. (2001). Ecosystem health: Definitions, Assessment and Case Studies. In M. Tolba, (Ed.), *Our Fragile World: Challenges and Opportunities for Sustainable Development* (pp. 21-42). Oxford: EOLSS.

Ricker, W. E. (1975). Computation and interpretation of statistics of fish populations. *Bull. Fish. Res. Bd. Can*. 191. 382 pp.

Rosenberg, D. M. & Resh, V. H. (1993). *Freshwater Biomonitoring and Benthic Macroinvertebrates*. New York, USA: Chapman and Hall publishers, 488pp.

Roughgarden, J. & Smith, F. (1996). Why fisheries collapse and what to do about it. *Proceedings of the National Academy of Sciences* (USA-Ecology), *93*, 5078-5083.

Roy, C. (1995). The Côte d'Ivoire and Ghana Upwellings: Dynamics and Changes. In F. X. Bard & K. A. Koranteng (Ed.), *Dynamics and Use of Sardinella Resources from Upwelling off Ghana and Ivory Coast* (pp 346 – 361). Paris: OSTROM Editions.

Rutherford, C. T. (1971). Fresh-water Shrimps in the area of Cape Coast, Ghana. *Ghana Journal of Science*, *11* (2), 87-91.

Samb, B. (2003). On the Biology of *Brachydeuterus auritus* from Sénégalese Waters. In M. L. D. Palomares, B. Samb, T. Diouf, J. M. Vakily & D. Pauly (Eds.), *Fish Biodiversity: Local Studies as Basis for Global Inferences* (pp. 1-13). ACP-EU Fisheries Research Report (14).

Scherer-Lorenzen, M. (2005). Biodiversity and Ecosystem Functioning: Basic Principles. In Barthlott, W., Linsenmair, K. E. and Porembski, S. (Ed.) *Biodiversity: Structure and Function*. UK, Oxford: EOLSS Publishers. http://www.eolss.net (Accessed on July 8, 2013).

Schneider, W. (1990). *FAO species identification for fishery purposes: Field guide to the commercial marine resources of the Gulf of Guinea.* FAO pbl. RAFR/F1/90/2, Rome, 268 pp.

Schroener, T. W. (1970). Non-Synchronous Spatial Overlap of Lizards in Patchy Environments. *Ecology*, *51*, 408-418.

Schubel, J. R. (1977). Sediment and the quality of the estuarine environment: Some observations. In I. H. Suffet (Ed.), *Fate of pollutants in the air and water environments* (pp. 399-424). Part 1. *Mechanism of interaction between environments and the mathematical modeling and the physical fate of pollutants*. New York: John Wiley and Sons.

Scoones, I. (1998). *Sustainable rural livelihoods: a framework for analysis*. IDS Working Paper, 72. Brighton: Institute of Development Studies 22 pp.

Segbefia J., Nunoo, F. K. E. & Dankwa H. R. (2013). Species Composition, Abundance, and Growth of Three Common Fish Species of the Volta Estuary, Ghana. *International Journal of Fisheries and Aquaculture Sciences*. *3,* (1), 79-97.

Simenstad, C. A. (1990). *Effects of dredging on anadromous Pacific coast fishes*: Workshop proceedings. University of Washington Sea Grant Program, Seattle, Washington.

Stone, L. (1990). Phytoplankton-bacteria-protozoa interactions: a qualitative model portraying indirect effects. *Marine Ecology Progress Series*, *64*, 137-145.

Trewavas, E. (1983). *Tilapiine Fishes of the genera Sarotherodon, Oreochromis and Danakilia*. British Museum (Natural History). Ithaca, New York, Cornell University Press, pp 12-22.

Tufuor, J. K., Dodoo, D.K., Armah, A. K., Darpaah, G. A. & Essumang, D. K. (2007). Some Chemical Characteristics of the River Pra Estuary in the Western Region of Ghana. *Bulletin of the Chemical Society of Ethiopia*, *21*(3), 341-348.

UNEP (2009). *Ecosystem Management Programme: A new Approach to Sustainability*. Kenya: Division of Environmental Policy Implementation, United Nations Environment Programme, 24 pp.

USEPA (U.S. Environmental Protection Agency) (1998). *Condition of the Mid-Atlantic Estuaries*. EPA/600/R-98/147. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC, USA.

USEPA (U.S. Environmental Protection Agency) (2005). *New Indicators of Coastal Ecosystem Condition.* EPA/600/S-05/004. Office of Research and Development, Washington DC, USA.

Vogel, A. I. & Mendham, J. (2000). *Vogel's textbook of quantitative chemical analysis* (6th Edition). Prentice Hall, 806 pp.

Wiafe, G., Yaqub, H. B., Mensah, M. A., & Frid, C. L. J. (2008). Impact of climate change on long-term zooplankton biomass in the upwelling region of the Gulf of Guinea. *ICES Journal of Marine Science*, *65*, 318–324.

Wood, E. J. F. (1967). Microbiology of Oceans and Estuaries. Amsterdam: Elsevier Publ. Co. 319 pp.

World Bank (2005). *Social Analysis Guidelines in Natural Resource Management: Incorporating social dimensions into Bank-Supported projects*. Social analysis sector guidance note series, Social Development Department, The World Bank, Washington, DC. 58 pp.

WRI, UNDP, UNEP & World Bank (2000). *World Resources 2000–2001- People and Ecosystems: The Fraying Web of Life*. Washington, DC: World Resources Inst., 389 pp.

Yankson, K. & Akpabey, J. F. (2001). A preliminary survey of the mcro-invertebrate fauna at Iture rocky beach, Cape Coast, Ghana. *Journal of Natural Sciences, 1*, 11-22.

Yankson, K. & Kendall, M. (2001). *A Student's Guide to the Seashore of West Africa*. Darwin Initiative Report 1, Ref. 162/7/451. 132 pp.

Zar, J. H. (1999). *Biostatistical Analysis*. 4th Edition, Upper Saddle River, New Jersey: Prentice Hall. 633 pp.

APPENDICES

Appendix A: GPS Coordinates of the sampling locations

STATION LABEL	DECIMAL DEGREES	DEGREES, MINUTES & SECONDS	
		Latitude	Longitude
A	5.0262, -1.6132	5° 01' 34" N	1° 36' 47" W
B	5.0184, -1.6261	5° 01' 06" N	1° 37' 33" W
C	5.0277, -1.6179	5° 01' 39" N	1° 37' 04" W
D	5.0446, -1.6252	5° 02' 40" N	1° 37' 30" W
E	5.0537, -1.6119	5° 03' 12" N	1° 36' 42" W
F	5.0288, -1.6133	5° 01' 43" N	1° 36' 47" W
G	5.0373, -1.5989	5° 02' 14" N	1° 35' 56" W

Appendix B: Composition and densities of the various macrozoobenthic species sampled from Station B

Family/Species	Composition (%)	Derived mean (no./225cm^2)	Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max
Scalibregmidae					
Hyboscolex longiseta	18.1	1.43	63	28	143
Capitellidae					
Pulliella armata	11.1	0.89	39	5	310
Maldanidae					
Maldanella capensis	15.3	1.22	54	11	274
Pisionidae					
Pisione africana	26.4	2.11	94	35	252
Amphimonidae					
Euphrosine capensis	1.4	0.11	5	0	210
Naididae					
Pristina sp.	6.9	0.56	25	2	339
Chironomidae					
Chironomus sp	1.4	0.11	5	1	42
Nereidae					
Leonnates perisca	2.8	0.22	10	2	46
Tubificidae					
Tubifex tubifex	16.7	1.33	59	4	920

Appendix C: Composition and densities of the various macrozoobenthic species sampled from Station C

Family/Species	Composition (%)	Derived mean (no./225cm^2)	Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max
Scalibregmidae					
Hyboscolex longiseta	5.9	1.22	54	6	535
Polyphysia crassa	7.6	1.56	69	26	186
Capitellidae					
Pulliella armata	8.6	1.78	79	19	320
Capitella capitella	3.2	0.67	30	9	93
Heteromastus filiformis	2.7	0.56	25	5	124
Dasybranchus bipartitus	2.2	0.44	20	4	110
Maldanidae					
Maldane sarsi	8.6	1.78	79	11	573
Arenicolidae					
Branchiomaldane vincenti	3.8	0.78	35	2	537
Arenicola loveni	1.1	0.22	10	1	136
Chaetopteridae					
Phyllochaetopterus herdmani	1.1	0.22	10	3	35

Family/Species	Composition (%)	Derived mean (no./225cm^2)	Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max
Nereidae					
Nemanereis quadraticeps	10.3	2.11	94	30	294
Ceratonereis pachychaeta	6.5	1.33	59	16	213
Micronereides capensis	5.4	1.11	49	28	87
Perinereis falsovariegata	1.1	0.22	10	2	40
Orbiniidae					
Scoloplos armiger	3.2	0.67	30	1	960
Eunicidae					
Eunice siciliensis	3.2	0.67	30	3	252
Alicopidae					
Krohnia lepidota	3.8	0.78	35	2	505
Tubificidae					
Limnodrilus hoffmeisteri	3.8	0.78	35	4	272
Tubifex tubifex	5.4	1.11	49	3	912
Limnodrilus angustepenis	5.4	1.11	49	16	155
Naididae					
Pristina sp.	7.0	1.44	64	14	291

Appendix D: Composition and densities of the various macrozoobenthic species sampled from Station D

Family/Species	Composition (%)	Derived mean (no./225cm^2)	Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max
Capitellidae					
Pulliella armata	18.2	0.89	39	22	70
Nereidae					
Nereis granulata	4.5	0.22	10	2	50
Alicopidae					
Naiades centrainii	27.3	1.33	59	19	186
Nephtyidae					
Nephtys debranchis	20.5	1.00	44	16	120
Tubificidae					
Limnodrilus hoffmeisteri	11.4	0.22	10	1	182
Tubifex tubifex	18.2	0.44	20	5	80

Appendix E: Composition and densities of the various macrozoobenthic species sampled from Station E

Family/Species	Composition (%)	Derived mean (no./225cm^2)	Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max
Capitellidae					
Capitella capitella	17.6	0.33	15	1	202
Nephtyidae					
Nephtys debranchis	17.6	0.33	15	2	125
Tubificidae					
Limnodrilus hoffmeisteri	52.9	1.00	44	16	120
Chironomidae					
Tanytarsus sp.	11.8	0.22	10	1	136

Appendix F: Composition and densities of the various macrozoobenthic species sampled from Station F

Family/Species	Composition (%)	Derived mean (no./225cm^2)	Mean Density (no./m^2)	Density (No./m^2) 95% CL Min	Max
Scalibregmidae					
Hyboscolex longiseta	3.4	0.33	15	1	274
Asclerocheilus capensis	3.4	0.33	15	4	60
Capitellidae					
Notomastus aberans	10.2	1.00	44	8	247
Maldanidae					
Maldane sarsi	3.4	0.33	15	4	53
Nereidae					
Namalycastis indica	4.5	0.44	20	1	477
Sepionidae					
Prionospio cirrifera	2.3	0.22	10	1	66
Tubificidae					
Limnodrilus hoffmeisteri	8.0	0.78	35	4	294
Tubifex tubifex	18.2	1.78	79	7	835
Limnodrilus angustepenis	5.7	0.56	25	5	124

Family/Species	Composition (%)	Derived mean (no./225cm^2)	Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max
Naididae					
Pristina sp.	12.5	1.22	54	6	535
Chironomidae					
Chironomus sp.	9.1	0.44	20	2	223
Corophidae					
Corophium sp.	3.4	0.33	15	5	46
Amphipoda/Haustoridae					
Unidentified species	4.5	0.44	20	2	181
Tanaidae					
Unidentified species	2.3	0.22	10	4	27
Isopoda/Cirolanidae					
Unidentified species	3.4	0.33	15	1	396
Cumacea/Ceratocumatidae					
Unidentified species	1.1	0.11	5	1	39
Amphipoda/Gamaridae					
Gammarus locusta	4.5	0.44	20	4	100

Appendix G: Composition and densities of the various macrozoobenthic species sampled from Station G

Family/Species	Composition (%)	Derived mean (no./225cm^2)	Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max
Capitellidae					
Capitella capitata	3.3	0.67	30	1	715
Paraheteromastus tenuis	1.7	0.33	15	5	46
Maldanidae					
Maldane sarsi	5.0	1.22	54	13	220
Euclymene quadrilobata	1.1	0.44	20	4	110
Chaetopteridae					
Phyllochaetopterus herdmani	3.3	0.67	30	8	106
Nereidae					
Dendronereides zulilandica	2.8	0.56	25	8	77
Neonereis ankyloseta	5.5	1.11	49	14	177
Nereis caudata	9.9	2.00	89	8	939
Nereis operta	6.6	1.33	59	7	503
Ceratonereis pachychaeta	5.0	1.00	44	6	322
Alicopidae					
Naiades centrainii	7.7	1.56	69	9	543
Phyllodocidae					

Family/Species	Composition (%)	Derived mean (no./225cm^2)	Mean Density (no./m^2)	Density (No./m^2) 95% CL	
				Min	Max
Eulalia viridis	3.3	0.67	30	2	547
Eulalia microcerus	2.2	0.44	20	6	62
Tubificidae					
Limnodrilus hoffmeisteri	6.1	1.22	54	4	746
Tubifex tubifex	10.5	2.11	94	9	991
Limnodrilus angustepenis	5.5	1.11	49	18	133
Naididae					
Pristina sp.	8.3	1.67	74	18	300
Chironomidae					
Tanytarsus sp.	6.6	1.33	59	6	626
Cumacea/Ceratocumatidae					
Unidentified species	1.7	0.33	15	5	40
Amphipoda/Gamaridae					
Gammarus locusta	3.3	0.67	30	2	407
Mysidae					
Mysis relicta	0.6	0.11	5	1	25

Appendix H: List of functional groups included in the Ecopath Model and the rationale for inclusion

Functional group		Name(s) of members/species	Rationale
1	Marine reptiles	Marine turtles	Conservation interest
2	Wetland reptiles	Nile monitor	Aggregate group
3	Large coastal demersals	Croakers, grunts	Commercial
4	Flatfish or flounders	Sole, flounder	Commercial
5	Threadfins	Threadfins	Commercial
6	Barracudas	Cutlass fish, Barracuda, Lady fish	Commercial
7	African pike	African pike	Commercial
8	Mangrove birds	Mangrove birds, wetland birds	Conservation interest
9	Sea Birds	Sea birds	Conservation interest
10	Small pelagics	Sardines, shads, some carangids, anchovies	Commercial
11	Cephalopods	Cattle fish, octopus	Commercial
12	Crustacean Shellfish	Shrimps, crabs, lobsters,	Commercial
13	Catfish	Marine and freshwater catfish	Aggregate group
14	Gobbies & related fishes	Lampeye, gobbies, eleotrids, barbs	Energy transfer
15	Herbivorous fish	Red breast tilapia	Energy transfer
16	Planktivorous fish	Black-chined tilapia, grey mullets	Commercial
17	Worms	Oligochaetes, polychaetes	Energy transfer/ pollution control

Functional group		Name(s) of members/species	Rationale
18	Small Crustaceans	Amphipods, Isopods	Energy transfer
19	Zooplankton	Copepods, rotifers, etc.	Energy transfer
20	Macrophytes	Aquatic plants	Basal group/Primary production
21	Algae	Ulva, sargassum,	Basal group/ Primary production
22	Phytoplankton	Diatoms, dinoflagellates, blue-green algae, etc.	Basal group/Primary production
23	Dead carcasses	Carcases of discarded fish, dead invertebrates, other fauna	Energy cycling
24	Detritus from run-off	Detritus from agricultural farms and other run-offs	Energy cycling
25	Riparian flora Detritus	Detritus from mangroves and grasses	Energy cycling

Appendix I: Time Series data used for calibrating the Ecosim Model [B= biomass (tkm^{-2}), F= fishing mortality rate (year^{-1}), CPUE = catch per unit effort (tkm^{-2}yr^{-1}net^{-1})]

	Large coastal demersal			Barracudas			Small pelagics		
Title	B	F	CPUE	B	F	CPUE	B	F	CPUE
Pool code	3	3	3	6	6	6	10	10	10
Type	1	4	0	1	4	0	1	4	0
1980	33.42	2.34	8.69	51.21	2.64	15.02	96.4	7.37	78.93
1981	33.42	2.34	8.43	50.52	2.65	14.89	94.18	7.46	72.71
1982	32.41	2.35	8.11	50.17	2.68	14.45	92.17	7.68	70.84
1983	31.38	2.35	7.68	49.83	2.71	14.18	89.15	7.75	67.96
1984	30.36	2.36	7.55	49.22	2.73	13.63	85.13	7.77	65.23
1985	30.35	2.36	7.23	48.52	2.75	13.28	83.11	7.81	63.37
1986	29.33	2.37	6.89	48.21	2.76	12.71	81.95	7.84	61.58
1987	29.31	2.37	6.54	47.95	2.77	12.54	80.83	7.91	60.79
1988	29.26	2.38	6.33	46.93	2.79	12.26	78.63	7.99	58.92
1989	28.24	2.38	6.18	45.85	2.8	11.97	76.52	8.11	57.09
1990	28.21	2.38	6.10	45.4	2.81	11.65	75.4	8.16	55.93
1991	27.11	2.39	5.82	43.2	2.86	11.52	71.93	8.17	53.68
1992	26.81	2.4	5.51	38.14	2.91	10.61	67.86	8.18	47.26
1993	25.62	2.41	5.34	34.66	3.01	9.84	63.47	8.23	45.43
1994	24.34	2.43	4.83	33.29	3.19	8.21	59.41	8.26	42.74
1995	23.2	2.53	4.22	32.7	3.24	7.77	57.63	8.29	38.86
1996	22.16	2.57	3.74	30.42	3.29	6.35	55.59	8.3	32.35
1997	21.84	2.59	3.22	28.53	3.34	5.66	53.14	8.31	28.83
1998	19.41	2.62	2.88	27.61	3.47	5.03	52.72	8.32	24.65
1999	18.39	2.64	2.65	26.04	3.57	4.63	50.84	8.33	22.51
2000	18.24	2.66	2.43	25.31	3.65	4.62	49.21	8.33	20.51
2001	18.01	2.61	2.00	23.32	3.74	4.33	47.2	8.36	19.21
2002	17.83	2.58	1.78	20.52	3.77	3.95	43.14	8.39	18.54
2003	17.72	2.57	1.55	19.67	3.82	3.91	40.32	8.44	17.65
2004	16.54	2.52	1.38	18.48	3.86	3.82	38.52	8.51	15.43
2005	15.31	2.51	1.23	17.97	3.89	3.75	36.61	8.53	14.97
2006	15.21	2.5	1.22	16.54	3.93	3.31	34.62	8.59	13.81
2007	14.18	2.5	1.04	15.31	3.99	3.14	30.52	8.64	12.42
2008	14.05	2.49	1.00	15.31	4.07	2.89	28.21	8.71	11.46
2009	13.93	2.45	0.97	14.36	4.09	2.69	27.95	8.76	10.37
2010	12.92	2.42	0.95	14.14	4.11	2.32	25.93	8.84	9.74
2011	11.85	2.41	0.93	13.65	4.13	2.18	24.85	8.86	8.94
2012	10.83	2.4	0.88	13.33	4.15	1.72	23.67	8.88	7.21
2013	10.41	2.38	0.83	13.06	4.18	1.82	23.31	8.9	6.92

Appendix J: The community matrix for Model V

	Profit	Catch (fish)	Catch (shrimp)	Trap	Monging	Shrimp Stock	Net 2	Fish Stock	Management (Shrimp)	Management (Fish)	Retail	Farming	Living
Profit	-1	1	1	0	1	0	0	0	0	0	0	0	0
Catch(fish)	0	-1	0	0	0	0	0	1	0	0	0	0	0
Catch(shrimp)	0	0	-1	0	0	1	0	0	0	0	0	0	0
Trap	1	0	0	-1	0	0	0	0	-1	0	1	1	0
Monging	0	1	1	0	-1	0	0	0	0	0	0	0	0
Shrimp Stock	0	0	0	-1	0	-1	0	-1	0	0	0	0	0
Net 2	1	0	0	0	0	0	-1	0	0	-1	1	1	0
Fish Stock	0	0	0	0	0	1	-1	-1	0	0	0	0	0
Management (Shrimp)	0	0	0	1	0	0	0	0	-1	0	0	0	0
Management (Fish)	0	0	0	0	0	0	1	0	0	-1	0	0	0
Retail	1	0	0	0	0	0	0	0	0	0	-1	0	0
Farming	1	0	0	-1	0	0	-1	0	0	0	0	-1	0
Living	1	0	0	0	0	0	0	0	0	0	1	1	-1

Appendix K: The absolute feedback for Model V

	Profit	Catch (fish)	Catch (shrimp)	Trap	Monging	Shrimp Stock	Net 2	Fish Stock	Management (Shrimp)	Management (Fish)	Retail	Farming	Living
Profit	16	32	32	16	16	32	16	32	16	16	32	16	0
Catch(fish)	20	56	40	10	20	28	10	28	10	10	16	12	0
Catch(shrimp)	20	40	56	10	20	28	10	28	10	10	16	12	0
Trap	20	40	40	18	20	40	14	40	18	14	24	20	0
Monging	40	56	56	14	56	36	14	36	14	14	24	16	0
Shrimp Stock	20	40	40	10	20	28	10	28	10	10	16	12	0
Net 2	20	40	40	14	20	40	18	40	14	18	24	20	0
Fish Stock	20	40	40	10	20	28	10	28	10	10	16	12	0
Management (Shrimp)	20	40	40	18	20	40	14	40	78	14	24	20	0
Management (Fish)	20	40	40	14	20	40	18	40	14	78	24	20	0
Retail	16	32	32	16	16	32	16	32	16	16	64	16	0
Farming	24	48	48	28	24	48	28	48	28	28	40	40	0
Living	56	112	112	60	56	112	60	112	60	60	136	72	96

Appendix L: The weighted predictions for Model V

	Profit	Catch (fish)	Catch (shrimp)	Trap	Monging	Shrimp Stock	Net 2	Fish Stock	Management (Shrimp)	Management (Fish)	Retail	Farming	Living
Profit	1.00	1.00	1.00	0.75	1.00	1.00	0.25	0.00	0.75	0.25	0.25	0.50	0.00
Catch(fish)	0.60	0.29	0.60	0.40	0.60	0.14	0.80	0.71	0.40	0.80	0.25	0.33	0.00
Catch(shrimp)	0.00	0.00	0.71	1.00	0.00	0.71	1.00	0.71	1.00	1.00	0.00	0.00	0.00
Trap	0.60	0.60	0.60	0.33	0.60	0.60	0.14	0.00	0.33	0.14	0.17	0.20	0.00
Monging	0.30	0.29	0.29	0.43	0.50	0.44	0.14	0.00	0.43	0.14	0.17	0.25	0.00
Shrimp Stock	0.00	0.00	0.00	1.00	0.00	0.71	1.00	0.71	1.00	1.00	0.00	0.00	0.00
Net 2	0.60	0.60	0.60	1.00	0.60	0.60	1.00	0.00	1.00	1.00	0.17	0.20	0.00
Fish Stock	0.60	0.60	0.60	0.40	0.60	0.14	0.80	0.71	0.40	0.80	0.25	0.33	0.00
Management (Shrimp)	0.60	0.60	0.60	0.33	0.60	0.60	0.14	0.00	0.44	0.14	0.17	0.20	0.00
Management (Fish)	0.60	0.60	0.60	1.00	0.60	0.60	1.00	0.00	1.00	0.28	0.17	0.20	0.00
Retail	1.00	1.00	1.00	0.75	1.00	1.00	0.25	0.00	0.75	0.25	0.50	0.50	0.00
Farming	0.33	0.33	0.33	0.14	0.33	0.33	0.43	0.00	0.14	0.43	0.40	0.60	0.00
Living	0.43	0.43	0.43	0.47	0.43	0.43	0.07	0.00	0.47	0.07	0.06	0.11	0.42

Appendix M: Sample Questions covering the range of issues for the Anlo Beach Area Focus Group Discussions

1. LIVELIHOOD ASSETS

1.1 Natural Capital

A. What kind of uses/services do you derive/benefit from the following ecosystems in and around your community?

Ecosystem	**Kind of uses/services**
Sea	
Beach	
Sand	
Estuary	
Pra River	
Wetland/Saltmarsh	
Mangrove/mangrove forest	
Other.	

B. Let us re-group the uses/services given in A above under the following categories:

Ecosystem	**Category of service**					
	Recreational	Religious/Cultural	Domestic	Ecological	Economic	Social
Sea						
Beach						
Sand						

Estuary						
Pra River						
Wetland						
Mangrove						
Other….						

1.2 Social capital

A. What associations/unions/network groups do you have in your community?

B. What is the main operational aim(s) of each of these associations/ unions/network groups?

Name of association/ union/network groups?	**operational aim(s)**

C. What other relations/networks does the community or some individuals in the community have with some other communities or external organizations?

1.3 Economic capital

A. Are there any financial institutions such as banks, savings and Loans Company, Susu collection Company or Individual money lenders in your community?

B. If there are any such institutions, what kind of services do they provide to the community?

C. If there are not, how do you achieve the following?

i. receive loans/funds for your occupational activities

ii. receive loans for your personal activities

iii. Save income from your occupational activities

D. Do you receive any support in the form of equipment for your occupational operations? If yes, what is/are the source(s) and how do you pay back?

1.4 Human capital

A. Are there some individuals or group of people in the community who have been given education/skill/training or any form of knowledge in any occupational activity in your community?

B. If yes to A above, specify who received the education/training, in what occupation, what kind of training/education and who provided the training/education.

Kind of occupation	Group/individual trained/educated	Kind of training/ education	Individual/body that provided the training/education

2. INSTITUTIONS AND STRUCTURES

2.1 Governance

A. What are the institutional structures in place for governing your community?

B. What are the institutional structures in place for governing the exploitation/utilization of ecosystems/natural resources in your community?

C. What are the institutional structures in place for governing other occupational/livelihood activities in your community?

D. What specific resources or occupational/livelihood activities do these institutional structures in B and C above govern?

Name of institutional structure	**Kind of natural resource(s) governed**

E. Which of the associations/unions/network groups mentioned in Section 1.2 A is involved in governance of natural resource utilization or occupational/livelihood activities in your community?

F. What specific role(s) does each of the institutional structures mentioned in Section 2.1 B and C above and associations/unions/network groups mentioned in Section 2.1 E above play in the governance of natural resource utilization or occupational/livelihood activities in your community?

Institutional structure/ Association	**Description of governance role played**

2.2 Local customs

A. In your local custom, how do you perceive your natural resource assets such as the sea, the estuary, the Pra River, the beach, the forest etc.

B. What customary rights are being performed in relation to your natural resource assets, why do you perform such rights and when do you perform them?

Nature of customary right	**Natural resource concerned**	**Reason for the customary right**	**Period for performance of customary right**

C. In your opinion, what is/are the effect(s)/impact(s)/influence of the customary rights on these resources or their exploitation/utilization?

2.4 Rules and regulations

A. What are the traditional norms/rules/regulations regarding the use/exploitation of the various natural resources or undertaking of livelihood activities on these resources in your community? Which institutions are involved in the enforcement and how effective are they?

Resource/livelihood activity	**Type of rule/regulation**	**Institution involved in enforcement**	**Functional state** i.e. Functional/Not functional	**Effectiveness i.e.** Not effective, Somehow effective, Effective Very effective

B. For the traditional norms/rules/regulations that are no more functional, why are they not functional anymore?

C. For the traditional norms/rules/regulations that are not effective, what contributes to the ineffectiveness?

D. Aside the traditional regulations, do you have local by-laws regulating the use/exploitation of the various natural resources or undertaking of livelihood activities on these resources in your community? If yes, let us complete the table below:

Resource/livelihood activity	Type of rule/regulation	Institution involved in enforcement	Functional state i.e. Functional/Not functional	Effectiveness i.e. Not effective, Somehow effective, Effective Very effective

E. For the local by-laws that are not functional, why are they not functioning?

F. For the local by-laws that are not effective, what contributes to the ineffectiveness?

G. Do you know of any district, regional or national laws regarding the use/exploitation of natural resources such as the Fisheries Act? If yes, what specific component(s) of the law(s)/act(s) do you know?

H. Which of the institutional structures/associations/network groups in your community is/are responsible for ensuring compliance to these district/regional/national law(s)/act(s)? And how effective is the enforcement/compliance?

I. In your opinion, how beneficial have the traditional norms/rules/regulations as well as the district/regional/national law(s)/act(s) been in sustaining or improving the various natural resources and livelihood activities in your community?

J. Is/Are there any local by-law(s) that you would wish that is introduced to regulate the use/exploitation of the various natural resources or undertaking of livelihood activities on these resources in your community? If yes, describe the by-law(s) and explain the need.

Policies

A. Do you have any local policy concerning fishing/fisher folk, farming/farmers and other livelihood activities in your community? If yes, describe the policy, the institution(s) involved in executing the policy, how effective the policy is, and how the policy has benefited the community or individuals in the community.

B. Do you know of any district, regional or national policy concerning fishing/fisher folk, farming/farmers and other livelihood activities that is operational in your community? If yes, describe the policy, the institution(s) involved in executing the policy, how effective the policy is, and how the policy has benefited the community or individuals in the community.

C. Is/Are there any policy/policies concerning fishing/fisher folk, farming/farmers and other livelihood activities that you would wish that is introduced in your community? If yes, describe the policy, the institution(s) that will be involved in executing the policy and how the policy will benefit the community, individuals in the community or livelihood activities in the community.

Organizational bodies

A. What organizational bodies such as NGO's or Agencies of Government have aided livelihood or developmental activities in your community in the past and at present? And what were/are the main focus areas of these organizations?

Organizational body		Focus area
In the past	At present	

B. How has/have the operational activity/activities of these organizational bodies improved/transformed the developmental/livelihood activities and conditions of living of people in your community?

C. Is/ are there any further areas/activities that you would wish that the present organizational body/bodies in your community add to their focus operational areas/activities? If yes, state the organizational body/bodies, describe the areas/activities and explain how the areas/activities will benefit the community, individuals in the community or livelihood activity

Appendix N: Table of the Questionnaire used in gathering the population-fishery timeline data

	1970-1980	1980-1990	1990-2000	2000-2010
Population	1000-1200	2000-2500	3000-3500	5000
Fishing Nets	10-12	10-12 (200 to 400 yards)	15-20(400-600 yards)	20-30 (400-1300 yards)
Fish catches	50-100 baskets per haul	30-50 baskets per haul	20-30 baskets per haul	3-25 baskets per haul
Adaptation	2 robes	3 robes, shorter time spent per cast, three casts daily 1 robe=200 yards		About 15 robes, longer time spent, averagely one cast daily

Remarks: Emigration in the 1990s due to Cape St. Paul Wilt disease of coconut farming, led to withdrawal from farming and relocation to Half Assini, Butre, Princess town, Akwadae, Nakwa, etc. **)**