PRELIMINARY STUDIES ON IMPACTS OF OCEAN ACIDIFICATION ON DIVERSITY OF FISH SPECIES LANDED BY ARTISANAL AND SEMI-INDUSTRIAL FISHERIES AND COASTAL COMMUNITY LIVELIHOODS IN GHANA

A Thesis submitted to the Department of Marine and Fisheries Sciences of the University of Ghana

By

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DECLARATION

This is to certify that this thesis is the result of research undertaken by Edna Ekua Kwansima Quansah towards the award of the Master of Philosophy in Fisheries Science in the Department of Marine and Fisheries Sciences, University of Ghana, under the supervision of Prof. F.K.E. Nunoo, Prof. P.K Ofori-Danson and Dr. E.E. Onumah. I hereby declare that except for references to work of other scholars that have been duly cited, this thesis is entirely my original research which has neither been presented in whole nor in part to any other university for the award of a degree.

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DEDICATION

This work is dedicated to God Almighty, my parents, Mr. and Mrs. Quansah, and siblings. God bless you for your love and support throughout my educational life.

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I wish to express my heartfelt appreciation to God Almighty, who has been my pillar of strength throughout my educational life.

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ABSTRACT

Increased absorbance of carbon dioxide from the atmosphere has led to the changing of the chemistry of the oceans. In addition to already existing stressors, the resultant ocean acidification poses multiple threats to marine species biodiversity and goods and services and livelihoods that depend on them. The study set out to determine possible impacts of this phenomenon on the abundance and diversity of fin and shellfish species and ichthyoplankton in the artisanal and semi-industrial fisheries of Ghana, and the degree of reliance of the local fisher folks on these two fisheries. Physico-chemical parameters in the sites where fishing by artisanal and semi-industrial vessels were carried out were collected in the lean and peak seasons. Fish samples were collected, species identified, counted and diversity indices calculated for each fishery and season. A Canonical Correspondence Analysis (CCA) was used to identify which of the principal factors influenced the fish species. Fisher folks were randomly interviewed using structured interview guides on their reliance on the fishery and analysed using the Tobit Regression Model (TRM). Four ocean acidification parameters (pH, carbonate ion concentration, total alkalinity, Revelle factor) out of six principal components were identified to contribute significantly (RELATE, $r = 0.955$, $P < 0.05$) to biological variations observed in the two fisheries. A decreasing trend in ocean acidification indicators was observed for both fisheries and variations observed in species abundance between seasons and fisheries, which indicate the possible occurrence of ocean acidification in Ghanaian waters and likelihood of impacts on fish diversity. The Tobit model revealed a significant reliance ($P < 0.01$) of fisher folks on the two fisheries and implies that livelihoods would be impacted with occurring ocean acidification. Education and provision of alternative livelihoods for fisher folks is thus necessary in ensuring upkeep of livelihoods in the face of ongoing ocean acidification of Ghanaian coastal waters.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The oceans cover over two thirds of the earth's surface and plays a very important role in global biogeochemical cycles, contribute immensely to the biodiversity of the planet and the provision of a livelihood for millions of people. They also serve as natural reservoirs to absorb carbon dioxide from the atmosphere and thus help reduce the concentrations of carbon dioxide in the atmosphere to some extent (Turley and Gattuso, 2012). In response to recent global increase in carbon dioxide emissions primarily from anthropogenic causes (IPCC, 2001), the oceans are absorbing large amounts of carbon dioxide (CO_2) from the atmosphere. According to Fabry *et al.* (2008), the oceans have absorbed about 30% of carbon dioxide emitted into the atmosphere as a result of anthropogenic activities such as land use change, fossil fuel burning and cement production.

As much as this function of the world's oceans help curb the rate of global warming in the atmosphere, it also comes at a cost to the oceans (Barnard and Grekin, 2010) The increased absorbance of carbon dioxide from the atmosphere has led to the changing of the chemistry of the oceans (Fabry *et al.*, 2008; Cooley and Doney, 2009; Kroeker *et al.*, 2010; Armstrong *et al.*, 2012, Turley and Gattuso, 2012), resulting in a parallel increase of hydrogen ion concentration and a consequent increase in acidity (Armstrong *et al.*, 2012). This phenomenon is known as ocean acidification, also known as the other carbon problem (Armstrong *et al.*, 2012). Bates *et al.* (2012) describe this phenomenon as the oceanic uptake of anthropogenic carbon dioxide and resulting seawater chemistry changes such as reduction in seawater pH and saturation states for calcium carbonate minerals such as aragonite and calcite.

Ocean acidification is generally considered one of the multiple stressors affecting the oceans ecosystems (IPCC, 2011). In addition to already existing stressors of the oceans such as over fishing and pollution, ocean acidification would pose multiple threats to marine species, biodiversity and the goods and services the oceans provide (IPCC, 2011; Rogers and Laffoley, 2011). Several authors such as Fabry *et al*. (2008); Sumaila *et al*. (2011) and Mohammed and Uraguchi (2013) have projected ocean acidification to have varying consequences and impacts on the marine ecosystem at large and fisheries in particular. Perry (2010) anticipates that developing countries, tropical nations and the poor would be at the worst receiving end of these varying impacts.

The impacts of ocean acidification range from affecting the physiology of fish species (Dupont and Portner, 2013; Portner *et. al*., 2004; Fabry *et. al.*, 2008) to reduction of calcification rates in calcifying organisms such as crustaceans and molluscs (Vezina and Hoegh-Guldberg, 2008; Barnard and Grekin, 2010), ripple effects in the ecosystem (Hall-Spencer *et al*., 2008), food chains and webs (Turley and Gattuso, 2012), to socioeconomic impacts on the livelihoods that depend on these fisheries (Hilmi *et al.*, 2012).

Ghana has a vibrant fisheries industry which is likely to be impacted by global climate change and ocean acidification. The Ghanaian fisheries sector plays an important role in national socioeconomic development objectives relating to food security, employment, Gross Domestic Product (GDP) and foreign exchange earnings. With a marine coastline of 550 kilometres (Tamakloe 2009), the fishing industry plays a major role in sustainable livelihoods and poverty reduction in several households and communities. The sector accounts for an estimated 4.2 percent of the nation's GDP and 21.2 percent of the Agriculture GDP (Asiedu and Nunoo, 2013).

Fish is relatively a cheaper source of protein for a greater portion of Ghanaian consumers, a preferred choice due to its health benefits over other sources of protein and provides about 60 per cent of animal protein requirements. The average per capita fish consumption in Ghana is between 20 and 25 kg which is higher than the world average of 18.6 kg (FAO, 2012). Over 2 million people are supported by this sector directly and indirectly throughout the country in varied occupations such as fishermen, fishmongers, boat builders, fish carriers and dischargers, among others. It is anticipated that about ten percent of the population depend on coastal fisheries for their livelihoods (Kraan, 2009). In the light of these enormous benefits of the Ghanaian fisheries industry, impacts of ocean acidification cannot be downplayed.

The International Atomic Energy Agency and the Centre Scientifique De Monaco, in a bid to scientifically and socioeconomically quantify the various impacts of this looming challenge has engaged scientists on each continent to identify impacts of ocean acidification in a four-year co-ordinated research project (CRP), with each of the scientists having a specialised area of interest (MEEG, 2012). Results from the varied projects from all continents after the four year period would be harmonised to produce a biophysical and socioeconomic model on ocean acidification and climate change. This project forms a sub-section of the West African aspect of the bigger CRP.

1.2 Objectives

General objective

The primary objective of this study was to determine possible impacts of ocean acidification on the abundance and diversity of fin and shellfish species in coastal waters of Ghana, and possible impacts on livelihoods of local fisher folks.

Specific objectives

Specific objectives were to:

i. determine the extent and magnitude of impacts of ocean acidification on abundance and diversity of fish stocks through monitoring of physico-chemical parameters of the ocean.
ii. determine the abundance and species composition of landings of semi-industrial (trawlers) and artisanal (beach seine) fisheries and key species susceptible to ocean acidification.
iii. determine species biomass and composition of ichthyoplankton in coastal waters susceptible to ocean acidification.
iv. survey coastal communities to determine degree of human reliance on key species and on the fishery as sources of their livelihoods.

1.3 Justification

The build-up of carbon dioxide and other greenhouse gases in our atmosphere is changing several of the features of the earth's climate, oceans, coasts and freshwater ecosystems that affect fisheries and aquaculture, and this change is happening at a speed not experienced by planet earth for approximately 60 years (Turley and Gattusso, 2012). The ocean acidification phenomenon and its impacts is thus a currently growing research concern, as a result of these increased carbon dioxide and other greenhouses gases emission. Studies are however patchy globally and concentrated in a few well-studied regions, and research is therefore necessary especially in vulnerable countries.

In Africa, few studies have been conducted pertaining to ocean acidification on our coasts, despite their biological and socioeconomical vulnerability to future global changes ((Lam *et al*., 2012; Dupont and Portner, 2013). An improved understanding of how the biophysical impacts of ocean acidification would influence catches and fish protein supply and other economic activities generated by the world's fisheries is therefore needed, especially in Ghana, where over 2 million people rely on the fisheries sector in various ways. Assessments of ocean acidification impacts are also important for predicting future climate change and marine ecosystem responses (Bates *et al.*, 2012).

Moreover, it is anticipated that ocean acidification will have significant effects on coastal ocean productivity as well as ecosystem function in the future; however, socioeconomic analyses of anticipated regional and local impacts to fishery-dependent countries such as Ghana have not yet been performed. Endeavouring to bridge knowledge gaps with regards to both biological and socioeconomic impacts of ocean acidification is important in order to supply more information about the consequences of fossil fuelled lifestyles and their resulting increase of carbon dioxide in the atmosphere. Identification of the costs and perhaps even benefits of ocean acidification are also very vital in order to give some underlying input into political agendas and choices for managing carbon emissions in the country. Knowledge gleaned from this work can guide human societal adaptive behaviour in the face of environmental change and a high CO_2 emitting world. This case study thus seeks to relate the happenings of ocean acidification and its impacts to what pertains in the coastal waters of Ghana.

In order to understand further future ocean acidification impacts on the human society, the European Science Foundation (ESF, 2009) in a science policy briefing encourages that social science in general and economic research in particular become an integral part of ocean acidification research. This is quite missing in earlier studies into the impacts of ocean acidification, as most researchers dwell on the biological, biophysical and biogeochemical impacts. The present study however incorporates a socioeconomic aspect which highlights the level of dependency of livelihoods on the affected fish stocks and the further impacts to their livelihoods.

It is worthwhile to also mention that the current understanding of the responses of marine organisms to ocean acidification has been largely based on in-vitro, short-term, tank and mesocosm experiments. These leave large knowledge gaps of the physiological and ecological impacts and broader implications for ocean ecosystems. It is also unknown if the observed responses of single-species in such mesocosm experiments can be extrapolated to the genetically diverse populations that exist in natural systems. There is therefore the need for open field researches, which is the design of this study. Furthermore, early researches have not included key variables such as nutrients which are known to affect calcification rates and their general contribution to ocean acidification impacts. This study takes note of the contribution of nutrients.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Global Increase in Carbon Dioxide Emissions and Climate Change

Change is an integral feature of the world we live in, effected either by natural means or anthropogenic-driven. This change can be said of the earth's climate, which has seen varied changes from pre-industrial times until now, and still continues to change, more rapidly now as a result of increased carbon dioxide emissions stemming from anthropogenic driven activities (IPCC, 2012; UNFCCC, 2011). This change come with it several ramifications such as sea level rise, change in weather patterns and ocean acidification. The technical summary report of the working group I of the Intergovernmental Panel on Climate change concludes unequivocally that the earth's climate is changing, and provides a suite of observations to support this fact. These include direct measurements of several climate variables such as widespread direct measurements of surface temperature since middle of the 19th century, sea level measurements for over a 100 years and long records of surface oceanic observations, (IPCC, 2001).

The last millennium has also seen considerable variations in temperature, humidity, wind, precipitation and other climatic conditions (Quante, 2010). A review of temperature changes of the Northern Hemisphere (Watkinson *et al.*, 2004) show rapid warming with mean temperatures increasing by 0.15^{o}C over the latter part of the 20th century. This has not been the case of just the Northern hemisphere, but globally, as depicted by documentations by the Intergovernmental Panel on Climate Change (IPCC, 2001). A similar review by Zunya *et al.*, (2004) of the climate in China reveal a general increase in average temperature, a decreased trend of total amount of rainfall but significant increase in precipitation during the summer, as well as increase in sea level pressure. De Wit and Stankiewicz (2006) predict that as a result of increase in global temperatures and general climate change, rainfall patterns in sub-Saharan Africa is changing and levels could drop by 10%, leading to major water shortages by the year 2050.

The Intergovernmental Panel on Climate Change defines climate change as “a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer” (IPCC, 2012). The United Nations Framework Convention on Climate Change (UNFCCC, 2011) however defines it as “a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods” (UNFCC, 2011). Thus, aside the natural internal processes or external forcings which could cause climate change over time, persistent anthropogenic changes in the composition of the atmosphere or in land use could also contribute to climate change (UNFCC, 2011). Recent model simulations have shown that natural causes of climate change alone cannot explain observed sea surface warming and changes, and attribute it to human activities which include particularly the emission of carbon dioxide and other greenhouse gases of fossil origin (IPCC, 2012).

Carbon dioxide emissions and their concentrations in the atmosphere and consequent concentrations in the oceans have been evidenced to be on the increase in recent times. The current emissions of carbon dioxide into the atmosphere as according to Bijma *et al.* (2013) are about 30 gigatonnes of carbon dioxide per year. Fabry *et al.* (2008) estimates that due to human activities such as increase in fossil fuel burn, land use change and deforestation, current atmospheric carbon dioxide is 380 ppm and rising at approximately 0.5% per year, and is estimated to be almost a 100 times faster than any change during the past 650,000 years.

Doney *et al.* (2009) observed that carbon dioxide levels in the atmosphere over the last 250 years had increased by almost 40% - an increase from approximately 280 ppm in preindustrial times to nearly 384 ppm in the year 2007. They add that this rate of increase is almost an order of magnitude faster than has occurred in more than a million years, and that the current concentration being experienced is higher than any ever experienced on earth in the past 800,000 years. They cite the same increase in human fossil fuel combustion, land use changes and deforestation as the driving forces behind this rate of increase, in concurrence with Fabry *et al.* (2008). According to Gattuso and Hansson (2011), the rate of carbon dioxide increase, which was about 1.0% per year in the 1990s, reached 3.4% per year between 2000 and 2008. Three years down the line, carbon dioxide concentration in the atmosphere in 2012 had risen to 392.52 ppm (Le Quere, 2013). Gattuso and Hanson (2011) anticipate that future levels may reach 1,071 ppm by year 2100.

The South Pole observatory and the Mauna Loa Observatory in Hawaii provide the two longest running historical records of direct measurements of atmospheric carbon dioxide concentration (Volk, 2008). Although the two sites are far apart from each other and far away from the hives of industry, the rise in carbon dioxide has been significantly the same. With a 22% increase in Mauna Loa and 21% increase in the South Pole over concentrations of 315 ppm and 382 ppm respectively from the late 1950s till the early

2000s, Volk (2008) intimates that the main conclusion is not the difference in rates of growth over a half-century for the two sites, but rather generalising from these two sites, the rise in carbon dioxide truly appears to be global. Furthermore, daily averages of carbon dioxide concentration in the Mauna Loa Observatory shot above 400 ppm for the first time in May 2013 (Le Quere *et al.*, 2013), an indicator of the ever-increasing concentrations of carbon dioxide in the atmosphere.

The oceans have absorbed their fair share of these concentrations in the atmosphere, and thus the increased emissions do not only contribute to global warming and climate change, but to another consequence in the oceans – ocean acidification. This phenomenon involves the alteration of the chemistry of seawater as a result of increased absorption of anthropogenic carbon dioxide from the atmosphere**.**

2.2 Ocean Acidification

Increased carbon dioxide is changing the chemistry of the earth's oceans, with a resultant threat to marine life. Since the beginning of the industrial revolution, the release of carbon dioxide (CO_2) from humankind's industrial and agricultural activities has increased the amount of CO_2 in the atmosphere (Doney *et al.*, 2009). According to Hilmi *et al*. (2012), over the past 200 years, atmospheric CO_2 has increased from 280 ppm to a global average of nearly 390 ppm as a result of these agricultural and industrial activities. The ocean absorbs about a quarter of this CO_2 every year (Gattuso and Hansson, 2011). Thus, as atmospheric CO_2 levels increase, so do the levels in the ocean. The cumulative total global ocean uptake of anthropogenic CO_2 since pre-industrial times is estimated at approximately 120 - 140 PgC (Bates *et al.*, 2012).

Carbon uptake by the ocean however has slowed the atmospheric increase and its associated consequences for the Earth's climate: without such uptake, it is estimated that atmospheric CO_2 would now be around 450 ppm (Hilmi *et al.*, 2012). On-going research in this field has predicted varying consequences on various levels of the marine ecosystem, including distorting food chains and webs, affecting the physiology and general fitness of fish species, as well as reducing the carbonate functioning of shelled organisms. These effects ripple down to the individuals who depend on them as sources of livelihoods and could cause a general loss of livelihoods.

2.2.1 The chemistry behind Ocean acidification

Ocean acidification does not refer to an instant change of the oceans to acid, but a process of moving towards the acid end of the pH scale (Hardt and Safina, 2008). Barnard and Grekin (2010) define this term as a "progressive slide by the oceans down the pH scale, away from alkalinity and toward acidity". The increase in the rate of addition of CO_2 to seawater due to increasing anthropogenic CO_2 in the atmosphere leads to an increase in hydrogen ion (H^+) concentrations, and hence a fall in pH. Carbon dioxide mixed with seawater has the effect of reducing the availability of carbonate ions. Once dissolved, carbon dioxide reacts with water to form carbonic acid, represented by the equation;

$$\underset{\text{(Water)}}{H_2O} + \underset{\text{(Carbon dioxide)}}{CO_2} \rightleftharpoons \underset{\text{(Carbonic acid)}}{H_2CO_3}$$

This reaction is reversible, as indicted by the two-way arrow. Hence the carbonic acid breaks up to regenerate water and carbon dioxide in the reverse reaction. However, the equilibrium lies to the left, such that much more carbon dioxide is dissolved in water, generating more carbonic acid. Carbonic acid also dissolves to form the H^+ ions (an acid) and bicarbonate, HCO^{3-}(a base), represented by the equation;

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

(Carbonic acid) (Bicarbonate) (Hydrogen ion)

The bicarbonate ion also dissociates its hydrogen atom to give a proton and the carbonate ion (CO_3^{2-}), and according to Hilmi *et al.*, (2012), seawater is naturally saturated with this carbonate ion which acts like an antacid to neutralize H^+ to form more bicarbonate. Honisch *et al.* (2012) intimate that not only does the increased anthropogenic CO_2 emissions result in elevated dissolved CO_2 and decreased pH, but also a critically decreased saturation with respect to calcium carbonate ($CaCO_3$), the compound widely used by marine organisms for building of their shells and skeletons. According to Barnard and Grekin (2010), carbonate ions are currently less abundant than they had been at any other time in the last 800,000 years. Calcium carbonate dissolves in water to produce calcium ions and carbonate ions in the equilibrium shown below;

$$CaCO_{3\ (solid)} \rightleftharpoons Ca^{2+} + CO_3^{2-}$$

(Calcium carbonate) (Calcium) (Carbonate)

Any addition of acid, that is a release of hydrogen protons, to water that is already in contact with calcium carbonate will lead to the production of carbon dioxide by the reaction shown below;

$$CO_3^{2-} + 2H^+ \rightarrow H_2CO_3 \rightarrow CO_2\uparrow + H_2O$$

(Carbonate) (Hydrogen ion) (Carbonic acid) (Carbon dioxide) (Water)

This reaction leads to the destruction of calcium carbonate, rendering it critical for the survival of marine organisms which utilise calcium carbonate in building of their shells and skeletons.

Bicarbonate (HCO_3^-) tends to be the dominant carbonate species in today's seawater with surface water pH of about 8.1 (Barker and Ridgwell, 2012). Carbonate (CO_3^{2-}) is the next abundant specie and followed by $CO_{2(aq)}$ representing less than 1% of dissolved inorganic carbon (DIC). The sum of these three species makes up the total DIC in seawater. Concentrations of $CO_{2(aq)}$ and H_2CO_3 (carbonic acid), are usually combined as [$CO_{2(aq)}$] due to the very little availability of carbon in the form of carbonic acid at any moment in time in seawater. It is anticipated that all else being equal, as more CO_2 is added to seawater, the pH would slowly decrease and the balance between these three carbonate species would change, with [$CO_{2(aq)}$] and [HCO_3^-] increasing and [CO_3^{2-}] decreasing. Barker and Ridgwell (2012) conclude that this is a fingerprint of anthropogenic ocean acidification.

Over the last 250 years, oceans have absorbed about 530 billion tons of CO_2, triggering a 30 percent increase in ocean acidity (Natural Resources Defense Council – NRDC, 2009). The pH of surface seawater has fallen from 8.2 to 8.1, in a few hundred years, after remaining constant for millions of years. According to the NRDC (2009), ocean pH had been relatively stable for the previous 20 million years, before people started burning coal and oil. On the logarithmic scale, a decline of 0.1 pH units translates to a 30 percent rise in acidity (Hardt and Safina, 2012).

Researchers predict that if carbon emissions continue at their current rate, ocean acidity would more than double by 2100 (NRDC, 2009). Munday *et al.* (2009) asserts to this fact, indicating that owing to the existing and future emissions of CO_2, ocean pH is projected to drop another 0.3 to 0.4 units by 2100. Vezina and Hoegh-Guldberg (2008) add to this assertion with the general acceptance that average global ocean pH has already fallen by 0.1 units and is likely to fall a further 0.3 units by 2050 and 0.5 units by 2100.

In a recent study, Dupont and Portner (2013) attribute the 30 percent increase in the acidity of the surface ocean and a possible double or triple of this figure further by 2100 to the growing human population which leads to higher CO_2 emissions. According to Portner (2008), the present increase in CO_2 levels in the atmosphere is approximately a 100-fold faster than at the end of the last ice ages when CO_2 levels rose by about 80 ppm over 6000 years. Now exceeding 380 ppm, the present CO_2 content is the highest in the atmosphere for the last 420,000 years and possibly more than 10 million years.

2.2.2 Indicators of Ocean acidification

Since acidity is commonly measured using the pH scale, the greatest indicator of ocean acidity is pH (Bates *et al.*, 2012). A pH of about 7 is considered neutral, below 7 is considered acidic whereas above 7 is basic or alkaline. Thus as the pH of a substance decreases, the more acidic the substance becomes. Because the pH scale is based on a logarithmic scale or on powers of 10, a pH decrease of one unit is equivalent to 10 units. Thus, a substance of pH 3 is 10 times more acidic than a substance with pH of 4.

Two other indicators for ocean acidification are the saturation states of calcite (Ωc) and aragonite (Ωa) (Barker and Ridgwell, 2012; Bates *et al.*, 2012). The availability of carbonate ions is crucial for marine calcifying organisms for formation of the skeletons and shells that are made of different crystalline forms such as calcite and aragonite. Aragonite is however more soluble than calcite. Reduced saturation levels of the aragonite indicate increased acidity. Similarly, reduced saturation state of calcite relates to increased acidity.

The carbonate concentration of seawater is also used as an indicator of ocean acidification (Bates *et al.*, 2012). Moreover, since ocean acidification involves the alteration of the chemistry of the ocean, other seawater carbonate chemistry parameters such as dissolved inorganic carbon, partial pressure of carbon dioxide, total alkalinity and the Revelle factor have been used by several authors such as (Beaufort *et al.*, 2011; Bates *et al.*, 2012) as indicators among several physico-chemical parameters in determining the impacts of ocean acidification.

2.2.3 Evidence of ocean acidification occurrence

Ocean acidification is already occurring and affecting marine ecosystems and their services to humankind (Dupont and Portner, 2013). This is evidenced by many laboratory mesocosm experiments and some few field studies. The CO_2 budget of the ocean comprises about 1 percent physically dissolved CO_2, including H_2CO_3, as well as about 91 percent bicarbonate (HCO_3^-) and 8 percent carbonate (CO_3^{2-}). Model calculations revealed that in comparison with pre-industrial times, the accumulation of CO_2 in 1996 had already caused a pH decrease beyond 0.1 units equivalent to an increase of H^+ ion activity by 30% in the surface ocean (Haugan and Drange, 1996). With the continued use of fossil fuels, atmospheric CO_2 concentrations are expected to rise from current 380 ppm to more than 750 ppm (IPCC, 2001) or even more than 1000 ppm (Royal Society, 2005) in 2100, and will climb to more than 1500 ppm between 2100 and 2200 (Portner, 2008).

Dore *et al*. (2009) reported results of nearly 20 years of time series measurements of Seawater pH and associated parameters at station ALOHA in the central North Pacific Ocean near Hawaii. They found a significant long-term decreasing trend of -0.0019 ± 0.0002 per year in surface pH which was indistinguishable from the rate of acidification expected from equilibration with the atmosphere. Furthermore these findings were similar to those observed by Bates (2007) and Santana-Casiano *et al.* (2007) at the Bermuda Atlantic Time series Study (BATS) station located near the Northwest Atlantic Ocean and the European Station for Time series in the Ocean Canary Islands (ESTOC), located near Gran Canaria in the Northeast Atlantic Ocean. The study done by Bates (2007) revealed that surface seawater dissolved inorganic carbon (DIC) and partial pressure of carbon dioxide (pCO2) had increased annually at rates similar to those expected from oceanic equilibration with increasing CO_2 in the atmosphere. Seawater pH, $CaCO_3$ saturation states and carbonate ion concentrations, all three being indicators of ocean acidification, had also decreased over time. The series of experimental pH data observed by Santana-Casiano *et al*. (2007) also confirmed the acidification of surface waters in the east Atlantic Ocean, with an inter-annual decrease of 0.0017 ± 0.0004 pH units per year.

Bates *et al.* (2012) further examined direct observations of the seawater carbonate system changes resulting from ocean uptake of CO_2 over 30 years in the subtropical gyre of the North Atlantic Ocean near Bermuda. The total alkalinity (TA) and dissolved inorganic carbon (DIC) were calculated for water samples taken from two sites 50 km apart and the CO2calc software designed by Robbins *et al.* (2010) used to compute the other components of the seawater carbonate system. The data gathered allowed for direct detection of signals of ocean acidification in surface waters of the North Atlantic. Results for this study showed that the buffer capacity of the subtropical gyres to absorb carbon dioxide had reduced over time. Trend analysis of the data also showed that the primary indicator of ocean acidification, seawater pH, as well as the three other indicators (Carbonate, saturation states of calcite and aragonite) had reduced over time. It is worth mentioning that this study was done over an extended period of time (30 years).

2.3 Impacts of Ocean Acidification

The on-going change in seawater chemistry is anticipated to have numerous and varying effects on marine systems with very little doubts (Fabry *et al*., 2008; Cooley and Doney, 2009; Dupont and Portner, 2013). Many studies have made attempts to various degrees of certainties to quantify some of the impacts this on-going global phenomenon will have on the oceans. A general conclusion from many studies indicates that marine ecosystems would be impacted. The type of impacts, however, will either be positive, negative or neutral. The impacts generally affect all spheres of the marine system, basically the biogeochemical cycles. Socioeconomic impacts are also not left out, as the various impacts reverberate on the society as well as the livelihoods that depend on the marine resource.

2.3.1 Biological and ecosystem impacts of ocean acidification

The way and manner biological organisms would react or respond to ocean acidification would vary, due to opposing sensitivities (Cooley and Doney, 2009). The NRDC (2009) however expects the new chemical composition of the oceans as a result of on-going ocean acidification to harm a wide range of ocean life, particularly creatures with shells. It stresses that the various changes of the oceans associated with ocean acidification such as the lowering of pH level is enough to threaten the very survival of many marine organisms such as finfish, shell fish and corals. Together with other environmental stressors like overfishing and pollution, ocean acidification could impact massively on the marine food chain. The resulting disruption to the ocean ecosystem could have a widespread ripple effect and could collapse many marine ecosystems as well as further deplete already struggling fisheries worldwide. The various paths of biological impacts to varying marine organisms are as follows:

Calcifying organisms

According to Munday *et al.* (2009), reduced carbonate ion saturation states that is associated or accompanies ocean acidification could have significant impacts for many calcifying organisms, especially corals and other invertebrates that build shells and skeletons. Barnard and Grekin (2010) indicate that when seawater is under-saturated with minerals such as calcite and aragonite as a result of ocean acidification, the seawater becomes corrosive. This makes it harder and more energy costly for marine organisms to form their shells and skeletons. As a result, ocean acidification would affect the development and survival as well as the physiology of such organisms. Organisms which use carbonate minerals to form skeletons and shells include crustose coralline algae, some phytoplankton, warm and cold-water corals (Barnard and Grekin, 2010), a wide range of invertebrates from small snails to lobsters. These organisms do not exist in isolation but however represent important components of the marine food chain in almost all ecosystems and thus whatever affects them, or their loss to ocean acidification, could alter predator-prey relationships (Dixson *et al.*, 2010) and could have ripple effects on the entire marine ecosystem.

In building their shells and skeletons, some organisms directly deposit calcium carbonate along their inner shell walls, and thus depend on a sufficient ambient carbonate concentration to accumulate their shells successfully. Such organisms exert low biological control over calcification and include molluscs, some gastropods and corals. Other organisms such as the sea urchins and most crustaceans exert high biological control over calcification, and these build their shells by accumulating intracellular stocks of carbonate ions gradually and harden their chitin and protein exoskeletons by depositing calcium carbonate from within (Cooley and Doney, 2009). In either way the organism is formed, calcium carbonate appears to be very important and such organisms are at risks from ocean acidification, as earlier reiterated. Beaufort *et al.* (2011) used physicochemical parameters to determine cocolitholith mass in response to ocean acidification. His work revealed that differential calcified species and morphotypes were distributed in the ocean according to carbonate chemistry and that this poses a substantial impact on the marine carbon cycle upon extrapolation of such a correlation to predicted ocean acidification in the future.

Coral reefs, which are also calcifying organisms, are typically biodiversity hotspots and serve as important refuges, feeding grounds and nurseries for deep sea organisms, including some commercial fish. Their disappearance would be akin to rainforests being wiped out worldwide. Such losses would reverberate throughout the marine environment and have profound social impacts as well, especially on the fishing and tourism industries (NRDC, 2009). Ocean acidification is expected to have particularly negative effects on the calcification rates of both cold and warm-water reef building stony corals, according to Barnard and Grekin (2010).

Non-calcifying organisms

Many ascertain that the ocean acidification problem would be more implicate to calcifying organisms, as Vezina and Hoegh-Guldberg (2008) put it, “the rise of CO_2 in ocean waters leads to more corrosive conditions for calcifying organisms, making it more difficult for them to build and maintain their carbonate skeletons”. However, Munday *et al.* (2009) expresses that over the next century, ocean acidification could have significant impacts on a wide range of marine species, not just those with calcified skeletons. Dupont and Portner (2013) also indicate the clarity of the fact that ocean acidification would not only affect calcifying organisms, but a whole range of biological processes. The increased levels of dissolved CO_2 do not only acidify the ocean, but they also act to decrease the pH of animal tissue.

When exposed to high levels of CO_2 and low pH, many organisms can regulate their acid–base balance by intra- and extracellular bicarbonate buffering and active ion transport. Fishes in general appear to be relatively tolerant to mild increases in CO_2 and decreases in pH because they are able to control their tissue pH by bicarbonate buffering and the exchange of ions, mostly across the gills (Fabry *et al.*, 2008). Small changes in internal or external pH can thus readily be compensated. Although these compensatory mechanisms are not detrimental in the short term, ultimately they may have long term consequences for individual performance due to their energetic cost, or because they affect the function of other physiological processes, especially for species or life stages with high metabolic demands (Vezina and Hoegh-Guldberg, 2008; Munday *et al.*, 2009). Alternatively, incomplete regulation of acid–base balance can directly affect the efficiency of cellular activities, with potential long-term effects for growth and reproduction (Portner *et al.*, 2004).

Ocean acidification has also been generally discovered to impact on several aspects of the fishes' biological system and community – on physiology (Fabry *et al.,* 2008), fish eyesight (Chung *et al.,* 2014), olfactory behaviour (Munday *et al.,* 2008; Dixson *et al.,* 2010), auditory behaviour (Simpson *et al.*, 2011) and community structure (Aschan *et al.*, 2013). None of these and other studies however have ascertained the impacts of ocean acidification on fish diversity.

The ability to detect and avoid predators is one important mechanism to ensure survival, especially at the juvenile stage when most fishes are highly vulnerable. When marine organisms are under high predation risk, innate predator recognition is very important, and as Dixson *et al.* (2010) states "if an individual fails to detect a predator when first encountered, it may not get a second chance". Detecting predators is thus very critical to marine life, especially fish. Fishes employ a range of mechanisms to detect predators, such as vision, auditory response and olfaction. Research however indicates that elevated levels of carbon dioxide in seawater impairs or impacts the sensory responses of these predator detection mechanisms. The study by Dixson *et al.* (2010) to investigate the innate ability of the orange clownfish (*Amphiprion percula*) to detect predators revealed that newly hatched larvae of this fish innately detect predators using olfactory cues and this ability is retained through to settlement. This was confirmed when aquarium-reared larvae, not previously exposed to predators, were able to distinguish between olfactory cues of predatory and non-predatory species. However, under ocean acidification scenarios, that is, when the eggs and larvae of the orange clownfish were exposed to seawater simulating ocean acidification, the ability to discriminate between predators and non-predators were lost. Such losses, when translated to high mortality rates could have dire consequences for stock replenishment and decreased abundance, as well as a loss of diversity.

In the impairment of vision, Chung *et al.* (2014) observed that the critical flicker fusion (CFF) of the spiny damselfish (*Acanthochromis polyacanthus*), a reef fish highly abundant on the Great Barrier Reef and able to use their eyes to detect rapid eye flickers, at present day carbon dioxide levels was around 90 Hz, but had fallen to about 78 Hz in those that had 6 days exposure to carbon dioxide levels predicted at the turn of the next century. They also observed that high carbon dioxide levels disrupt one of the brain's key neurotransmitters – Gamma-amino butyric acid (GABA), which are involved in vision and behaviour, and could possibly make a predator appear attractive to a prey. These led the team to conclude that increasing levels of carbon dioxide concentration would impact the vision of fish. According to the team, because having a good temporal resolution is very critical in the detection of fast-moving objects, it is likely that the reduction of vision would translate into a reduced ability to react to fast events probably by 10 – 15%. This reduction could have negative consequences for prey fish in the visual detection of their predators, making them more liable to predation.

Simpson *et al.* (2011) provide the first evidence that ocean acidification affects auditory response of fishes with potentially detrimental impacts on early survival in a study which used an auditory choice chamber to study the influence of carbon dioxide enriched conditions on directional responses of the juvenile orange clownfish (*Amphiprion percula*) to daytime reef noise. They observed that daytime reef noise was avoided by free-swimming larvae of the clownfish reared in ambient carbon dioxide conditions but this response was absent in larvae reared at higher carbon dioxide levels. Thus, the team concluded that ocean acidification could compromise auditory behaviours which are crucial for fish survival.

Significant effects of ocean acidification are most likely to be detected in the early life stages of fish such as in the embryos and larvae. These embryos and larvae are particularly sensitive to pH changes, in part because they form their internal skeletons out of amorphous calcite which is more soluble than other forms of carbonate (Vezina and Hoegh-Guldberg, 2008; Munday *et al.*, 2009). Portner (2008) adds that tolerances to climate-related factors might be very different between larvae and adult organisms, and also between species.

Ocean acidification will cause marine ecosystems to undergo major changes that scientists are only beginning to understand. Previous studies have tended to focus on the immediate responses of single marine species to acidification, but researchers now know that some species are more resilient to rising acidity than others. The challenge is to understand how whole ecosystems react to a range of climate-related stressors, including temperature (Dupont and Portner, 2013). Other organisms can be both vulnerable and resilient at different times in their life cycles, such as some phytoplankton, fish and sea urchins. Initially, female green sea urchins (*Strongylocentrotus droebachiensis*) that are exposed to acidification produce around one-fifth the numbers of eggs produced by urchins in current ocean pH conditions. But after 16 months, adults acclimatize and reproduce as normal. Juvenile urchins, however, remain sensitive to acidification and show up to a nine-fold increase in mortality (Dupont and Portner, 2013).

Increasing atmospheric CO_2 will also cause average global temperatures to rise. Temperature is a key driver for biological change. Organisms specialize within certain temperature ranges and are sensitive to extremes. Ocean acidification modulates responses to temperature, and vice versa. The combined effects of local variability in acidity, temperature and human-made eutrophication or pollution may be more detrimental than for each factor alone (Dupont and Portner, 2013).

2.3.2 Impacts of ocean acidification on fish diversity

Ocean acidification is also widely expected to affect biodiversity through its various channels of impacts - from calcifying organisms through to the entire ecosystem. Calcifying organisms play a crucial role in marine food chains and food webs, and any effects to them would translate to changes in biodiversity. These effects are seen through loss of certain fish species in some fishing areas and the rise of new species in other areas. Simulation models employed by Sumaila *et al.* (2011) to project future fish production under two IPCC emission scenarios predict an increase of production in the Artic and sub-Artic regions and a decreased catch potential in the tropics, with a general increase in the relative abundance of warm-water species in most communities. Since fishes are mostly noted to be common ocean prey and thus are at or with the top of the marine food chain, disruptions in the food chain tend to affect more of their diversity. Based on a recent study by Munday *et al*. (2014) which studied the behaviour of common reef fish in response to predation in naturally occurring carbon dioxide vents in Mine Bay in eastern Papua Guinea, it was concluded that escalating carbon dioxide emissions, which relates to ocean acidification, would cause fish to lose their fear of predators, potentially damaging the entire marine food chain.

2.3.3 Socioeconomic impacts of Ocean acidification

Ocean acidification is expected to have socioeconomic impacts, which will partly depend on the combined adaptations of marine ecosystems and human resource management, and also expected to largely affect relatively poor and under-resourced people, such as those of developing countries (Kite-Powell, 2009). With experimental results clearly demonstrating that the rate of calcification in marine calcifiers is directly related to the seawater carbonate saturation state (Beaufort *et al.*, 2011), it can be predicted that goods and services provided by the ocean upon which human populations are dependent, will be different under future acidified oceans as increasing partial pressure of carbon dioxide influences the physiology, survival and development of marine organisms.

Some few studies have estimated generally the socioeconomic impacts associated with ocean acidification on various marine resources (Wootton *et al.*, 2008; Brander *et al.*, 2009; Cooley and Doney, 2009; Sumaila *et al.*, 2011). Almost all of these studies identified a sort of general decline in harvests and thus a reduction in economic rents, sales as well as profits/income. These negative effects transform to the livelihoods of those depending on the resources. It is also worthwhile to note that most of these few studies which address the economic aspect of ocean acidification are most of the time partial analyses and include large uncertainties, as documented by Armstrong *et al.*, (2012). Using the United States commercial fishery revenues as a case study, Cooley and Doney (2009) predicts that there would be the occurrence of substantial revenue declines, job losses, and other indirect economic costs as ocean acidification continually broadly damages marine habitats, alters marine resource availability, and disrupts other ecosystem services.

Socioeconomic impacts on fisheries in developing countries

Fish provides about 20% of average per capita animal protein intake for more than 3.0 billion people worldwide. For developing countries such as Bangladesh, Gambia and Ghana, fish accounts for about 16.6% of the global population's intake of animal protein and 6.5 percent of all protein consumed (FAO, 2012). It is anticipated that the true significance of seafood especially fish to human wellbeing may even be higher than these figures, as most of the subsistence fisheries data are usually not captured (Kite-Powell, 2009). All in all, it shows the importance of fish to many livelihoods. About 54.8 million people and livelihoods are supported by fisheries sectors worldwide, with Africa being the second largest employer of fisher folks after Asia (FAO, 2012).

In Ghana, about 2 million people are employed directly and indirectly by the fisheries sector. Vulnerability studies to climate change and its consequences conducted by Allison *et al.* (2009) however placed Ghana as the 25th most vulnerable country out of a total of 132 countries analysed. The vulnerability was due to combined effects of predicted warming, relative importance of fisheries to national economies and diets and limited societal capacity to adapt to potential impacts and opportunities.

The acidity of the oceans is one important parameter that influences fish production among others and according to Kite-Powell (2009), the direct impacts associated with ocean acidification may impose costs on the order of 10% of marine fishing production, perhaps in the order of $10 billion per year. While it is possible to assert that the global economic value of fisheries production is potentially at risk from ocean acidification, few studies available indicate that it is difficult to anticipate with confidence how the value generated by fishery production will change due to lower ocean pH without making extensive assumptions.

Most of the socioeconomic impacts of ocean acidification to fisheries are resultant from the effects/impacts of ocean acidification on fish stocks. Naturally as ocean acidification retrogresses the growth and survival of fish, the level of harvest reduces. As harvest reduces, price of fish begins to increase and fishers tend to put in more effort for lesser and lesser gains. The shifts associated with ocean acidification also imply that some regions would benefit whereas others loose. For the regions which loose out, fish shifts in distribution would mean employing greater effort to get to the new areas where a good catch is assured. This mostly involves moving into deeper waters. This comes at a more increased cost for fishers and is translated into fish price. Most of the fishers that cannot put up with the new fishing costs more or less drop out of business, with its attendant loss of livelihoods.

2.4 The Fisheries Sector and Fish Diversity in Ghana

The Ghanaian fisheries industry consists of the capture fisheries and the culture fisheries, commonly referred to as aquaculture. However, aquaculture is limited to fish farming in Ghana. Under capture fisheries, there are two main divisions – coastal fisheries and inland fisheries. Accounting for about 80% of total fish production, the coastal fisheries further consists of three divisions; the artisanal fisheries, also known as the small scale fisheries, the semi-industrial fishery, also known as the inshore fishery and the industrial fishery also known as the distant water fleet. Two of these fisheries – the artisanal and the semi-industrial, are the focus of this study because of the certainty of fishing in Ghanaian coastal waters.

The artisanal fishery mainly uses dug-out canoes, both motorised and un-motorised, and a wide range of fishing gears to exploit fish in coastal waters. Some of these gears or fishing methods include the beach seine, which is widely practised on the sandy beaches of Ghana (Nunoo *et al.*, 2006). Fish species exploited by the artisanal fishery are mainly small pelagics.

The beach seine fishery is of paramount socioeconomic importance to a vast number of coastal communities in the country and contributes 12% to the total artisanal fisheries production (Nunoo, 2007). The small-scale fishery as a whole plays a very significant role in food production, employment and the creation of wealth in rural areas. An additional significant aspect of the small-scale fisheries is a thriving post-harvest sector which involves mainly women fish processors, wholesalers and retailers (MOFI, 2008).

The semi-industrial fishery consists of a fleet of 230 locally constructed vessels (MOFI, 2008), operating from eight landing sites throughout the country, including the Tema inshore landing site. According to MOFI (2008), the semi-industrial fleet lands about 2% of total marine fish production. The semi-industrial fishery exploits both pelagic and demersal species such as scombrids, sciaenids, sea breams, snappers and cuttlefish.

Ghanaian fisheries are typically of a multi-species diverse assemblage. A total of 347 marine fish species belonging to 82 taxonomic families have been recorded by the Ministry of Environment and Science (MES, 2002). A documentation of the fishes in the coastal waters of Ghana by Kwei and Ofori-Adu (2005) also revealed 127 species from 53 taxonomic families. Nunoo (2003) recorded a total of 75 fish species belonging to 35 taxonomically different families in nearshore marine environments in Sakumono, Accra, while Aggrey-Fynn and Sackey-Mensah (2012) recorded 56 species from 30 taxonomic families in the central coastal waters of Ghana. Some taxonomic families include Carangidae, Clupeidae, Polynemidae, Pomadasydae, Scianidae and Scombridae. Species such as *Sardinella* sp., anchovies and mackerels are usually associated with the upwelling seasons when they are harvested in large quantities.

According to Koranteng (2001), studies of fish communities have shown that natural and anthropogenic factors could induce changes in the structure of assemblages and diversity of species, and could consequently affect the general well-being of fishery resources. He further intimated that the occurrence of significant changes in the biological and physical components of the Gulf of Guinea marine ecosystem over the last three decades could have an effect on species aggregations in the sub-region. Notable recorded changes include the decline and subsequent recovery of the round sardinella (*Sardinella aurita*), proliferation and subsequent decline of the grey triggerfish (*Balistes capriscus*) and increase in abundance of cuttlefish (*Sepia officinalis*) and globefish (*Lagocephalus laevigatus*).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Sampling Strategy

The study was carried out in two parts – the first was data collection on biological and physico-chemical parameters and the second was data collection on socioeconomic parameters. A two-level sampling strategy was adopted for both data collections of this study. The first was a geographical stratification, which thus selected two geographical sites. The first site was the Teshie Sangonaa fish landing beach, located in Teshie, to represent the artisanal fishery, while the second site was the Tema Inshore fish landing beach in Tema, to represent the semi-industrial fishery. The second level of stratification was on seasonal basis, where data was collected in the lean and peak seasons. The lean fishing season usually runs from December/January to February/March while the peak fishing season usually runs from June/July to September/November (MOFI, 2008). However, in recent years, there have been seasonal shifts generally in the fishing industry as well as seasonal shifts of the onset of harvest of specific species, which is attributed to climate change (Dulvy *et al.*, 2010). An example is a bumper harvest of Sardines (Family Clupeidae) in Elmina in October 2010 as against the usually anticipated catch in July and August (Paintsil, 2010). What pertained on the field prior to sampling and during sampling was no different, and as such, the lean season for this study was defined as months from January to May, and the peak season defined as months from June to December.

3.2 Description of Study Area

3.2.1 Teshie Sangonaa Fish Landing beach

The Teshie Sangonaa landing beach is located within the Teshie Township, a suburb in the Greater-Accra Region of Ghana (Figure 1). The beach is located between GPS coordinates Latitude 05^{o} 35.004"N, Longitude 000^{o} 05.362"W and Latitude 05^{o} 34.533"N, Longitude 000^{o} 05.460"W. The beach serves the artisanal fishers within the Teshie community for landing of their catch and the fishmongers who come there purposely to buy catch from the fishers. Fishing crafts present on the beach are dugout canoes, with a majority of them being motorised and a few small sized semi-industrial trawlers. There are about an average of sixty-seven (67) of these canoes on the beach. The fishing gears employed by the fishers utilising these canoes include the cast net, gill net and seine net (both beach seine and purseine).

There is a small lagoon present at the site which enters into the sea. The point where the lagoon enters the sea is usually filled with plastics and fish waste and most of the fishmongers often sit to de-gut and de-scale their fish in this area. However, at high tides, the area is submerged by sea water.

3.2.2 Tema Inshore Fishing Harbour

The Tema Inshore fishing harbour is located within the Tema Inner fishing harbour, which provides a holding facility for semi-industrial and industrial fishing vessels (Figure 1). It is located between GPS coordinates; Latitude 05^{o}38.264"N, Longitude 000^{o}00.595"E and Latitude 05^{o}38.233"N, Longitude 000^{o}00.530"E.

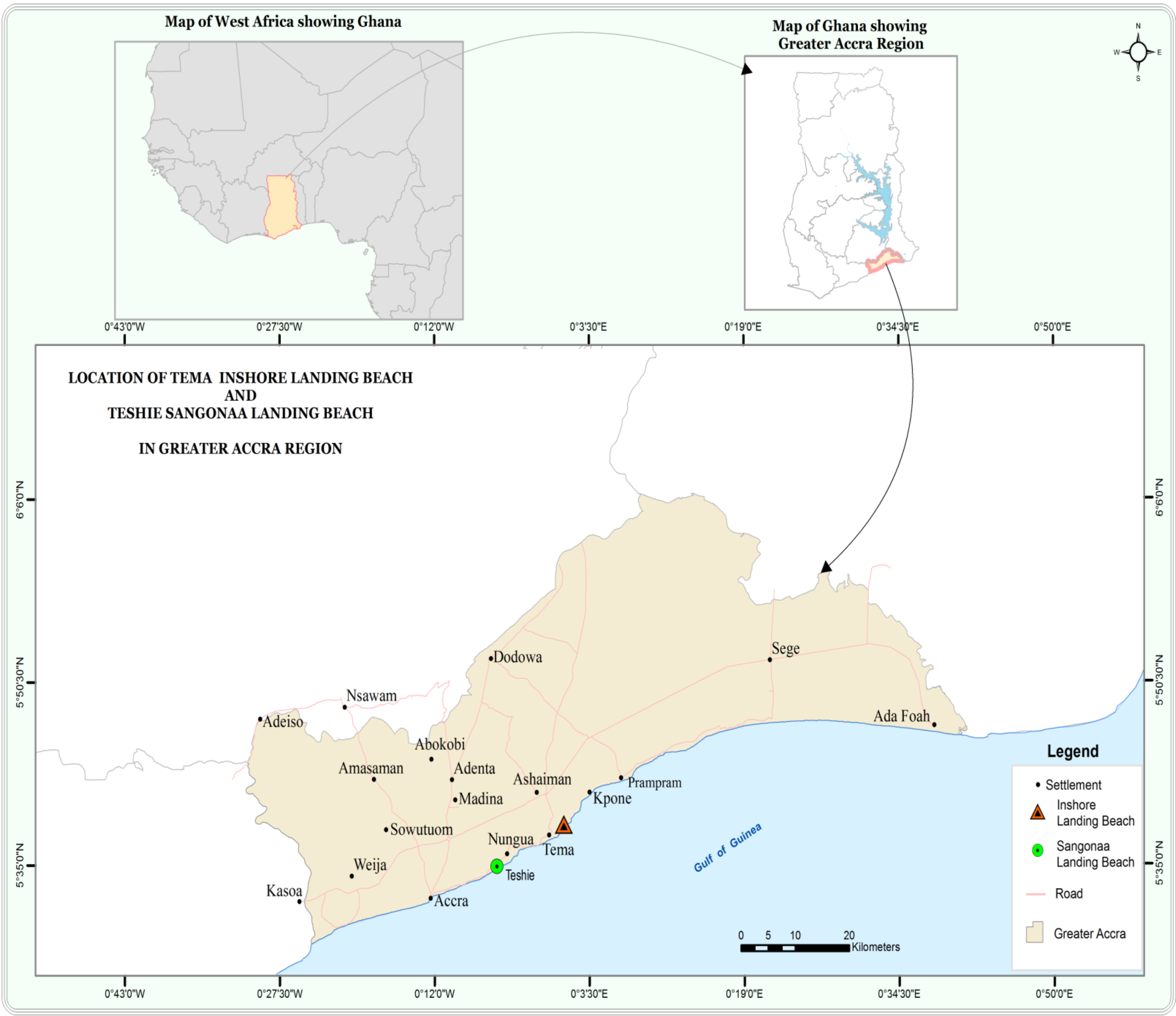

Figure 1: Map showing the selected study sites

The Tema Inshore fishing harbour is home to about an average of a hundred and twenty (120) vessels. Most of these vessels have their origin from either one of the semi-industrial landing beaches in Elmina, Mumford and Takoradi (Secretary, Ghana Inshore Fisheries Association, pers. comm.). The vessels are mainly trawlers of small to medium sizes ranging from eight (8) to thirty-seven (37) m long with motorised engines of horsepower ranging from twenty-five (25) to ninety-eight (98) and beyond, depending on the allowable capacity of the vessel engine.

The site is also home to over a hundred (100) push trucks, which mainly serve the purpose of discharging fish from the vessels when they land. A long shed the size of about a hundred and twenty by eight metres (120 x 8 m) provides shelter for idle fishers and dischargers during no-fishing times, and for fishmongers with their buckets awaiting catch from vessels during fishing times. Many wooden crates are also present on the docks, and these are used in the carriage of fish from the vessels. Behind the shed is a security-manned gate that leads to the Tema fish market, enabling easy access of transporting landed fish to this market.

3.3 Biological/Physico-Chemical Data Collection and Laboratory Procedures

3.3.1 Fish species composition

Monthly fish samples were collected from the artisanal fishery and semi-industrial fishery from January to December, 2013. A standard sample of one bucket, weighing an average of 8 kg when full, was taken from total fish caught in one haul by the artisanal fishery in Teshie and total fish landed by the semi-industrial fishery in Tema respectively before sorting by fishermen. The sample taken was then weighed in kilograms using a field hand scale KERN CH15K20 (Appendix D), and kept on ice for about an hour of transportation to the laboratory. Samples were immediately analysed for their morphometric measurements or otherwise kept in a deep freezer and analysed within 48 hours.

In the laboratory, fish species were sorted out in the laboratory and identification made to the lowest taxonomic level as much as possible using identification guides (Schneider, 1990; Kwei and Ofori-Adu, 2005). Morphometric measurements of standard, forked and total lengths in centimetres to two decimal places were taken on each individual fish using a standard fish measuring board.

For crustaceans, the carapace length was taken with a pair of Vernier callipers in centimetres, while length along the back from the front to the rear was measured as total body length for molluscs.

The weight of all individual fish species was taken using a PHILLIP HARRIS A20002 weighing scale in grams to two (2) decimal places. Sexes of fish were determined through manual sexing (Nielson and Johnson, 1985). Total number of individual species as well as total weight were then quantified and extrapolated to the catch using the raising factor (R), which is obtained by dividing the total catch over the sample catch.

3.3.2 Physico-chemical parameters

Seawater samples were collected within the perimeter where fishing from which fish samples were taken, was carried out, within the hours of 0700 and 0900 GMT, from a depth of between 2 and 3 centimetres beneath the water surface from both the artisanal and semi-industrial fisheries. Measurement of physical parameters such as temperature, salinity, pH and pressure were undertaken *in situ* offshore, aboard a motorised vessel with a HANNA 9828 multi-parameter probe (Appendix D). Three replicates of these readings were taken and three replicates of water samples also collected, using water sample bottles. The samples were kept on ice for transportation to the laboratory of the Marine and Fisheries Sciences Department of the University of Ghana, where they were preserved in a refrigerator at a temperature of 4^oC and analysed within 48 hours of preservation.

Analysis of physico-chemical parameters were carried out at the postgraduate laboratory of the Department of Marine and Fisheries Sciences using standard protocols according to APHA (1998). Nutrients (nitrates, phosphates, silicates and sulphates) and alkalinity analyses were carried out using Spectrophotometer DR2800 (Appendix D) and alkalinity test kit respectfully. Iron, calcium, magnesium and carbon dioxide determination analyses were done using a photometer. Seawater partial pressure of Carbon dioxide (pCO_2), Dissolved Inorganic Carbon (DIC), Carbonate ion concentration [CO_2^{3-}], mineral saturation states for calcite (Ωcalcite) and aragonite (Ωaragonite), and the Revelle factor (β) were computed from pH, Total alkalinity, temperature, salinity and pressure data using the programme CO2calc (Robbins *et al.*, 2010). Partial pressure of carbon dioxide, dissolved inorganic carbon, total alkalinity and the Revelle factor constituted seawater carbonate chemistry parameters, while pH, carbonate ion concentration, aragonite saturation state and calcite saturation state constituted ocean acidification parameters (Bates *et al.*, 2012). Samples were analysed for nutrients using the following standard protocols according to APHA (1998):

Iron (Fe)

Test tube was filled with sample to the 10 ml mark. The tablet reagent was added, crushed and mixed to dissolve. The solution was allowed to stand for one minute to allow for full colour development, after which it was transferred into a cuvette, placed in the photometer and the reading taken. The concentration was estimated as Mg/l Fe.

Calcium (Ca)

Test tube was filled with sample to the 10ml mark. The reagent, Calcicol No.1 tablet was first added crushed and mixed to dissolve. It was then followed with Calcicol No.2 tablet which was also crushed and mixed to dissolve. After two minutes of full colour development, the solution was poured into a cuvette and placed in the photometer. The concentration was estimated as Mg/l Ca.

Magnesium (Mg)

1ml of the sample was taken with a measuring syringe and transferred to the test tube and made up to the 10ml mark with deionised water. This dilution was necessary because sea water generally has a large amount of magnesium present and thus the dilution prevents an over the range reading from the photometer. The reagent, Magnecol tablet, was then added, crushed and mixed to dissolve. The solution was allowed to stand for five minutes to allow for full colour development and then transferred to the cuvette for further reading in the photometer.

Phosphate

Phosphate was determined in the water samples using the ascorbic acid method. 10ml of the sample was measured into the reaction bottle. The phosphate reagent was then added to the sample and swirled to fully dissolve. After allowing solution to stand for two minutes, it was poured into the cuvette, placed in the spectrophotometer and the reading taken at a wavelength of 880 nm.

Nitrate

The cadmium reduction method according to APHA (1998) was used to determine nitrates in the seawater samples. 10 ml of the sample was measured into the reaction bottle and the reagent (Nitriver 5) added. The mixture was shaken vigorously for a minute and allowed to stand for five minutes. It was then poured into the cuvette for reading in the spectrophotometer at a wavelength of 500 nm.

Sulphate

The SulfaVer 4 method according to APHA (1998) was used in determining sulphate in the water samples. Using a drop pipette, 0.1 ml of the sample was measured into the reagent bottle and deionised water added to make the 10 ml mark. After adding the reagent, the mixture was swirled and then allowed to stand for five minutes. Solution was transferred to the cuvette and reading taken in the spectrophotometer in mg/L SO_4^{2-} at a wavelength of 450 nm. Readings were multiplied by a dilution factor of 100.

Silicate

The silicomolybdate method according to APHA (1998) was used in determining silicate amounts in seawater samples. The first reagent, silica molybdate, was added to 10 ml of the sample in a reaction bottle. After swirling, the second reagent, acid reagent, was added and mixture allowed standing for 10 minutes. The third reagent, citric acid, was added and allowed to stand for another two minutes. The solution was then transferred to the cuvette for reading in the spectrophotometer in mg/L SiO2 at a wavelength of 452 nm.

Total Alkalinity

Total alkalinity was determined using the digital titration method according to APHA (1998). A clean delivery tube was attached to a 1.600 ± 0.008N Sulphuric acid titration cartridge and attached onto a digital titrator. The delivery knob of the titrator was turned to eject air and a few drops of the titrant. The counter was reset to zero and the tip of the tube wiped. Using a graduated cylinder, 20 ml of the sample was measured out and transferred to a clean 250-ml Erlenmeyer flask. 80 ml of deionised water was measured out and added to sample, bringing total sample volume to a 100 ml. Addition of the contents of one phenolphthalein indicator powder pillow elicited no colour change, indicating that phenolphthalein endpoint was zero. Contents of one Bromcresol methyl red indicator powder pillow was then added, swirled and titrated with 1.600 ± 0.008N Sulphuric acid while swirling the flask until contents changed from green to a light pink colour. Digits displayed on the counter are then recorded and multiplied by the dilution factor of 5. Using the multiplier provided in the protocol corresponding to the normality of the acid, the total alkalinity was calculated as follows:

$$\text{Digits x multiplier} = \text{mg/L as } CaCO_3 \text{ Total alkalinity}$$

The multiplier for the 1.600 ± 0.008N Sulphuric acid was 1.0.

3.3.3 Ichthyoplankton Biomass and Composition

An ichthyoplankton net of 200 microns (Appendix D1) was towed in a step-oblique pattern within the perimeter of the beach seine haul for a standard total time of 18 minutes. This was within 10 to 50 m depth. The net was lowered vertically, towed horizontally for 3 minutes, further lowered and towed horizontally again for 3 minutes until the standard 18 minutes, at a boat speed of 3 knots. Sample collects in the sampler of the net and this was backwashed into a sample bottle and fixed with 40% formalin for preservation.

In the laboratory, formalin was drained off the sample with a sieve of 500 microns and made up to 200 ml in a round bottom flask. Using a 10 ml measuring flask, 10 ml portions of the sample were taken and smaller portions of it poured in a petri dish and viewed under the microscope with a magnification of 4x to identify fish eggs and larvae. Identification of larvae was done to the lowest taxonomic level possible using FAO species identification keys (Fischer *et al*., 1981). Calculations were then carried out to estimate the total biomass of fish eggs and larvae as follows (Perry *et al.,* 1993):

Total number of ichthyoplankton in 10ml of sample = a

Total number in 200ml (N) = (200 x a) / 10 ml (this represents the total number of larvae in volume of seawater filtered by the net).

Volume of seawater filtered by the net (V) = RF m^3

Where R = number of revolutions and F = flow meter constant given as 0.11960

Therefore the number of larvae per m^3 of seawater = V/N

3.4 Socioeconomic data collection

Residents within the environs of the two sampling sites (Teshie and Tema) were interviewed on their dependency on the respective fisheries as a source of livelilihood and fish as a source of protein. Open and closed ended questions from the interview guide (Appendix A) administered were read out and explained in a local language which was well understood to each respondent. Records were made of spoken responses, including further explanations that helped to clarify certain issues or provided additional information. A total of fifty of such interviews were randomly conducted during the lean fishing season for both the artisanal and semi-industrial fishery and another fifty conducted during the peak fishing season for the artisanal and semi-industrial fishery.

3.5 Data Analysis

3.5.1 Biological/Physico-chemical data

Statistical analyses were designed to access the effect of the environmental variables and parameters that contribute to ocean acidification on the abundance and diversity of fish species in the two fisheries, and which species were being driven by those parameters. Species composition and abundance data and physico-chemical data were captured in Microsoft excel 2010 prior to analysis. The Shapiro-wilk test (Shapiro and Wilk, 1965) was used to test for normality of data, and after data proved to be non-parametric from the test, the Kruskal-Wallis H test was used to test for significant differences in relative abundance of species between seasons and fisheries, using the XLSTAT 2012 computer software. Margalef, Pielou, Shannon-weiner and Simpson diversity indices were computed for fish data using the Diverse feature in Primer 6 software. A Principal Components Analysis (PCA) was then conducted to identify parameters with greater influence on variations in terms of abundance and diversity in the various sites using the RELATE and BVSTEP functions in Primer 6 software (Clarke and Warwick, 2001). All environmental data was log transformed and normalised (logx+1) to take care of all zeros, while fish data was square root transformed in order to weight the contribution of common and rare species in the non-parametric abundance data before analysis in the Primer 6 software. A canonical correspondence analysis (CCA) using the CANOCO 4.5 software (ter Braak, 1986) for windows was then conducted to ordinate the principal variables identified from the PCA with the identified fish species.

3.5.2 Socioeconomic data

Statistical analyses were designed to evaluate the percentage share of fish consumption demands in relation to sources of protein as a measure of estimating the reliance of livelihoods on the artisanal and semi-industrial fisheries. Descriptive statistics was used to analyse the socioeconomic characteristics of the respondents as well as their preferred fish species, using the Stata SE 13 statistical software (StataCorp, 2013). Raw data from respondents were entered and coded in Microsoft excel 2010 prior to analysing with STATA 13 software. Using the same software, the Tobit model (Tobin, 1958) was used to analyse factors affecting the dependence of respondents on the two fisheries. The Tobit model is very useful when there are zero cases in the dependent variable. Usually, cross-sectional data are complicated by the existence of zero observations in the data, implying that the relationship between the independent variables and the dependent variables may be more complex than that in conventional regression models. Unlike the Probit analysis and other multiple regression models, the Tobit model accommodates censoring in the dependent variable and is designed to overcome the bias associated with assuming a linear functional form in the presence of such censoring. The Tobit model assumes that all zeros are attributable to standard corner solutions, and the model was proposed by Tobin (1958) and specified as:

$$y_i^* = x_i\beta + \varepsilon_i$$

$$y_i = y_i^* \quad \text{if } y_i^* > 0$$

$$y_i = 0 \quad \text{if } y_i^* \leq 0$$

where y_i^* is the latent dependent variable, y_i is the observed dependent variable, $\mathbf{x}_i$ is the vector of the independent variables, β is the vector of coefficients, and the ε_i's are assumed to be independently normally distributed: $\varepsilon_i \approx N(0, \sigma)$ (and therefore $yi \approx N(\mathbf{x}i\beta, \sigma)$) (Sigelman and Zeng, 1999).

The Empirical Model

The Tobit model considered for this study is given as

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 + \varepsilon$$

Where:

Y = percentage share of fish in relation to other protein sources consumed per year.

X_1 = Household Head: the household head measured as dummy such that when the respondent is a male, it is given one and when a female, it is zero.

X_2 = Age: the age of the respondent measured in years.

X_3 = Educational level: the educational status of respondents measured in levels. When a respondent has not been to school or had any formal education = 0, from primary to junior high school (JHS) = 1, senior high school (SHS) = 2, technical training = 3 and University degree = 4.

X_4 = Major Occupation: whether fishing is the major occupation of the respondents measured as a dummy such that if fishing is the main occupation then the respondent is given one, otherwise zero.

X_5 = Revenue: the revenue made by a respondent from his/her involvement from fisheries related activities measured in Ghana cedis.

X_6 = Number of Men in Household (Men_fish): men in household involved in fisheries related activities such as fishers, boat builder and fish carrier/discharger measured in numbers.

X_7 = Number of Women in Household (Women_Fish): females in household involved with fisheries related activities such as fish mongers and fish carriers measured in numbers.

X_8 = Number of Children in Household (Children_Fish) = children in household of respondent involved in fisheries related activities such as fishers, fish mongers or fish carriers and measured in numbers.

CHAPTER FOUR

4.0 RESULTS

4.1 Physico-chemical Parameters

Table 1 shows the mean and standard deviations of physico-chemical parameters measured for both the lean and peak fishing seasons of Teshie (artisanal fishery site) and Tema (semi-industrial fishery site). Mean temperature values reduced from 28.03^{o}C in the lean season to 26.14^{o}C in the peak season. The semi-industrial fishery also experienced a decrease in mean temperature values from the lean season to the peak season. Figures 2 and 3 show a decreasing trend of the seawater carbonate chemistry parameter total alkalinity, for both the artisanal and semi-industrial fishery. Dissolved inorganic carbon and partial pressure of carbon dioxide also show an overall decreasing trend, but tends to increase during the months of the lean seasons of the two fisheries, resulting in one major peak in the artisanal fishery and two major peaks in the semi-industrial fishery. Revelle factor for both fisheries however had an increasing trend. Figures 4 and 5 also show a decreasing trend for the ocean acidification indicators (pH, aragonite saturation, calcite saturation, carbonate ion concentration) for both the artisanal and semi-industrial fisheries, with the semi-industrial fishery having two major peaks.

Table 1: Mean (± standard deviation) values of physico-chemical parameters measured in the lean and peak seasons of both fisheries in the year 2013.

Physico-chemical parameters	Sites/seasons			
	Teshie lean	Teshie peak	Tema lean	Tema peak
Salinity (ppt)	34.14±0.85	28.97±0.65	29.68±1.57	32.82±4.30
Temperature (^{o}C)	28.03±0.57	26.14±2.03	26.73±1.72	23.14±1.26
Pressure (dbars)	7.63±1.60	6.07±1.65	83.90±52.75	53.34±5.04
Total alkalinity (µmol/kg)	1423.72±600.50	1182.27±72.11	2897.39±282.59	1655.17±570.42
pH	8.30±0.21	8.33±0.19	7.63±0.65	7.29±0.16
DIC (µmol/kg)	1001.94±484.11	895.93±58.14	2915.25±575.31	1663.52±572.42
pCO_2 (µatm)	72.44±30.56	98.00±48.27	511.69±526.42	1966.93±786.44
Aragonite saturation	4.43±1.72	2.60±0.94	1.59±1.10	0.51±0.26
Calcite saturation	6.67±2.60	3.99±1.43	2.44±1.69	0.78±0.40
Carbonate (µmol/kg)	333.52±18.73	157.48±55.93	133.07±38.00	31.95±16.17
Revelle factor	7.23±2.41	6.78±0.94	10.77±3.00	15.67±1.15
Nitrates (mg/l)	0.98±0.13	0.88±0.25	1.17±0.41	3.40±2.59
Phosphates (mg/l)	2.23±2.21	0.08±0.03	0.28±0.24	2.12±2.01
Sulphates (mg/l)	2050.00±176.78	5450.0±353.55	5400.00±0.00	6062.50±515.39
Silicates (mg/l)	9.73±8.03	2.23±1.96	4.90±0.64	22.78±19.23
Iron (mg/l)	0.12±0.08	0.11±0.00	0.20±0.07	0.23±0.12
Calcium (mg/l)	143.00±6.61	139.67±3.62	134.17±5.80	388.75±29.55
Magnesium (mg/l)	1400.00±141.42	2500.00±100	2075.00±106.07	2233.33±152.75

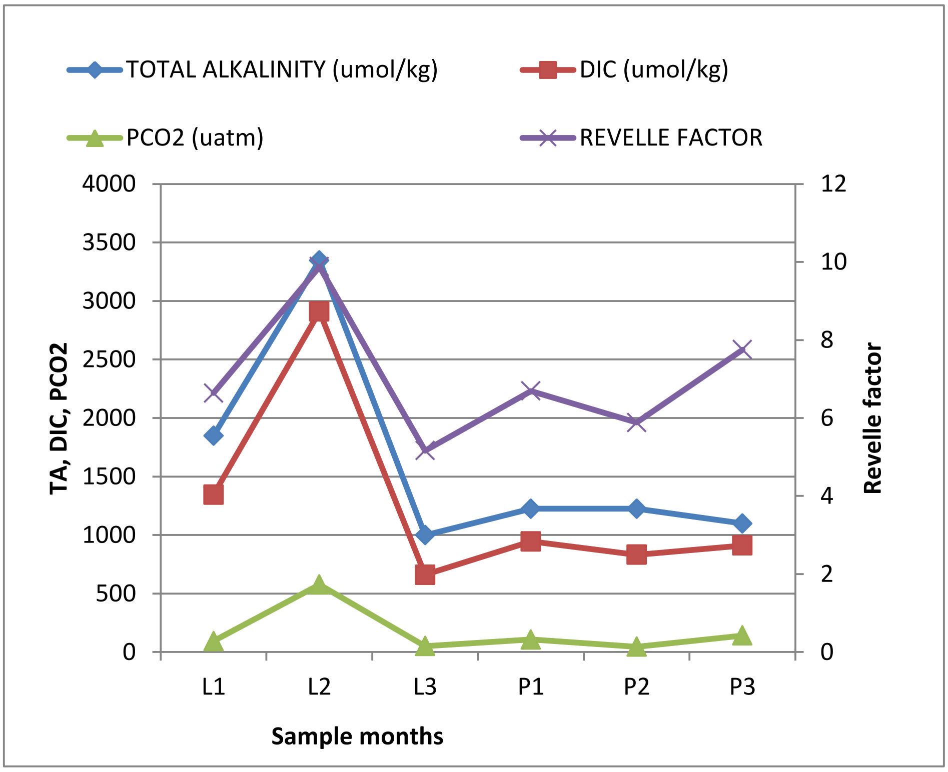

Figure 2: Trend of seawater carbonate chemistry parameters for the artisanal fishery during the lean and peak fishing seasons of year 2013.

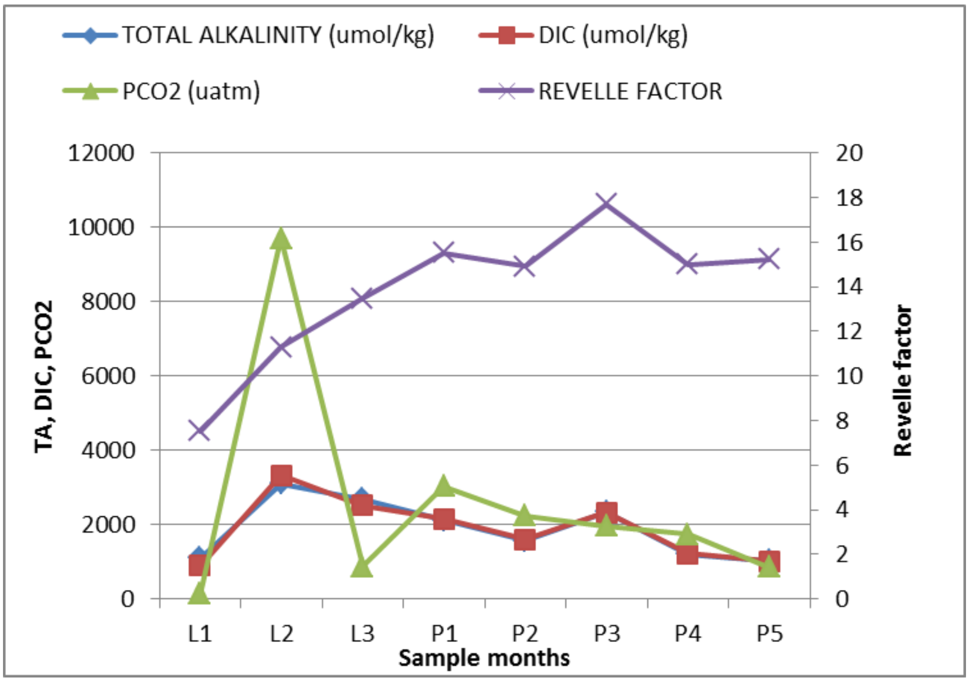

Figure 3: Trend of seawater carbonate chemistry parameters for the semi-industrial fishery during the lean and peak fishing seasons of year 2013.

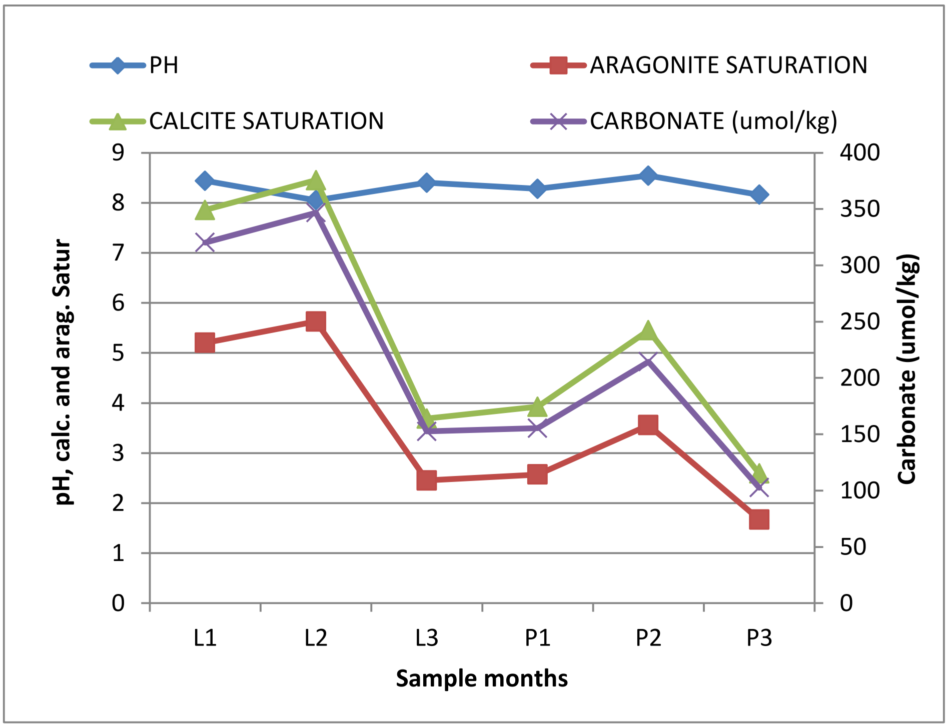

Figure 4: Trend of ocean acidification indicators for the artisanal fishery during the lean and peak fishing seasons of year 2013.

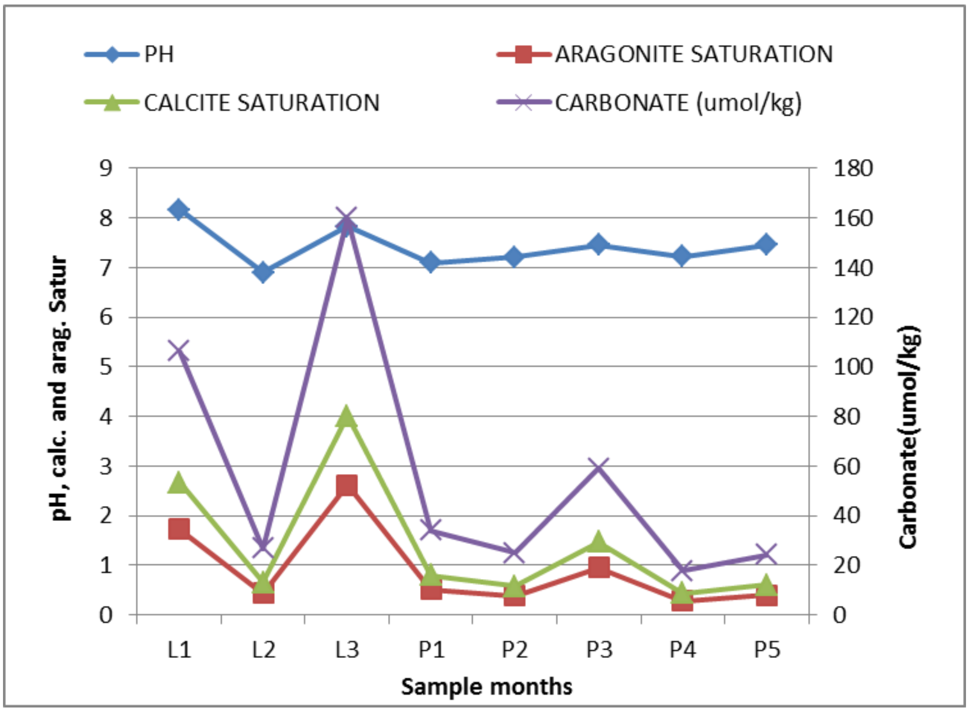

Figure 5: Trend of ocean acidification indicators for the semi-industrial fishery during the lean and peak fishing seasons of year 2013.

Legend

L1 = first month of lean fishing season

L2 = second month of lean fishing season

L3 = third month of lean fishing season

P1 = first month of peak fishing season

P2 = second month of peak fishing season

P3 = third month of peak fishing season

P4 = fourth month of peak fishing season

P5 = fifth month of peak fishing season

4.1.1 Significant Physico-chemical Parameters affecting Biological Variations

Out of the eighteen parameters measured, six parameters significantly (RELATE, $r = 0.955$, $p < 0.05$) explained best the variations observed in the biological data, using the BVSTEP method in PRIMER 6 to relate fish abundance and environmental data. These were total alkalinity, pH, carbonate ion concentration, nitrates, phosphates and the Revelle factor.

The Principal Components Analysis (PCA) performed with these parameters for species abundance for both sites and seasons yielded two principal components (eigenvalues > 1; Table 2) with a cumulative variance accounting for 79.8% of the total variation. Scores on PC1 were positively correlated with Revelle factor and nitrates but negatively correlated with pH and Carbonate ion concentration (Table 2). High scores on PC1 were thus associated with increasing Revelle factor and nitrates and decreasing pH and carbonate ion concentration. Both seasons sampled in the artisanal fishery loaded negatively on PC1 (Table 3), and thus inversely correlated with the scores on PC1.

Abundance and diversity in the artisanal fishery thus probably increases with decreasing pH and carbonate ion concentration and decreases with increasing Revelle factor and nitrates. Both seasons in the semi-industrial fishery except the third month of the lean season which was not significant ($P < 0.4$) loaded positively on PC1 (Table 3). Thus with the exception of month 3 sampled in the lean season in the semi-industrial fishery, abundances of species observed in all other seasons of the two fisheries probably increased with increasing nitrate levels and an increasing Revelle factor, while they decreased with decreasing pH and carbonate ion concentration. Scores on PC2 were positively correlated with nitrates and negatively correlated with total alkalinity. Thus scores on PC2 increased with increasing nitrates and decreasing total alkalinity. Three months in the lean season in the semi-industrial fishery loaded negatively on PC2 and two months in the peak season loaded positively on PC2 (Table 3). Thus, abundance and diversity observed in the lean season of the semi-industrial fishery reduced with increasing nitrate levels and increased with decreasing total alkalinity whereas abundances observed in the peak season increased with increasing nitrate levels and decreased with decreasing total alkalinity.

Table 2: Summarised PCA values on Physico-chemical parameters that relate with species abundance in the two fisheries for both seasons.

Variables	PC1	PC2
Total alkalinity (µmol/kg)	0.235	-0.684*
pH	-0.504*	0.204
Carbonate ion concentration (µmol/kg)	-0.458*	-0.168
Nitrates (mg/l)	0.396*	0.505*
Phosphates (mg/l)	0.293	0.378
Revelle factor	0.489*	-0.255
Eigenvalue	3.42	1.37
% variance explained	56.9	22.8
Cummulative % variance	56.9	79.8

Values with * are significant at 5% significance level.

Table 3: Principal component scores for fishery/season which loaded on selected principal components.

	Principal Component scores	
Fishery/Season	PC1	PC2
Teshie-M1Lean	-1.1*	0.36
Teshie-M2Lean	-0.64*	-1.66*
Teshie-M3Lean	-1.95*	0.71*
Teshie-M1Peak	-1.48*	0.21
Teshie-M2Peak	-2.12*	0.14
Teshie-M3Peak	-1.30*	0.04
Tema-M1Lean	-1.29*	0.13
Tema-M2Lean	1.97*	-1.28*
Tema-M3Lean	0.16	-1.46*
Tema-M1Peak	1.43*	-1.38*
Tema-M2Peak	2.15*	0.31
Tema-M3Peak	2.14*	-0.18
Tema-M4Peak	3.43*	2.41*
Tema-M5Peak	-1.40*	1.64*

Values with * are significant at 5% significance level.

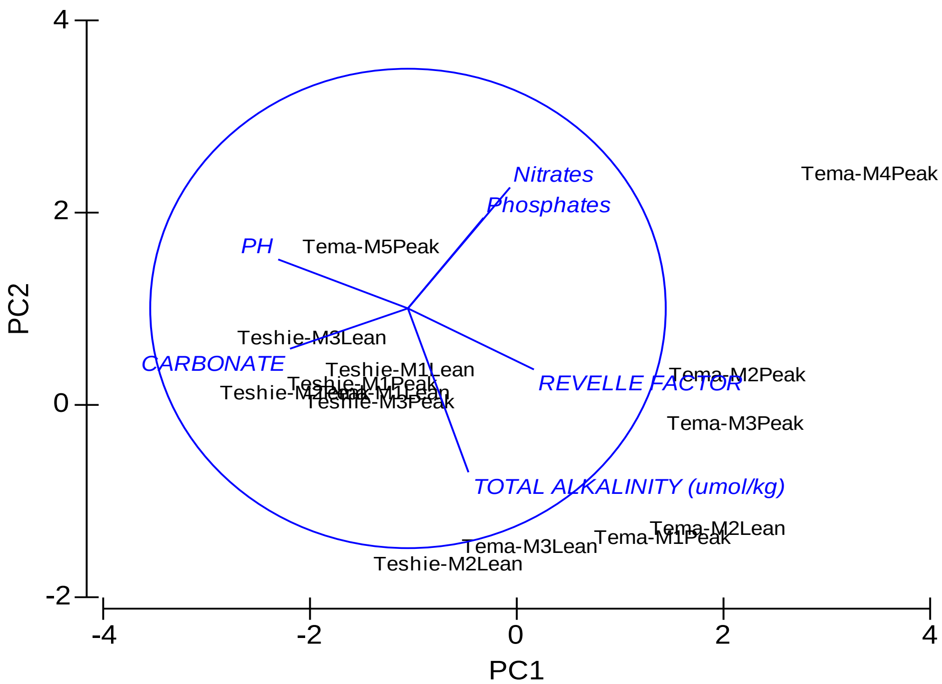

Fig. 6: PCA showing relationship between fishery and seasons sampled and the six principal variables.

4.2 Species Composition and Abundance

A total of 218,376 specimens representing 41 species from 22 families were recorded at the end of the study from both artisanal and semi-industrial fisheries (Table 4). 25 species from 14 families were recorded in the lean season while 28 species from 17 families were recorded in the peak season for the artisanal fishery whereas 13 species from 7 families for the lean season and 12 species from 8 families for the peak season were recorded for the semi-industrial fishery. Out of the 41 species identified, 9 of them, namely *Caranx crysos, Decapterus rhoncus, Ethmalosa fimbriata, Sardinella maderensis, Brachydeuterus auritus, Scomber japonicus, Sepia officinalis, Sphyraena sphyraena* and *Ephippion guttifer* were found in both fisheries in either of the two seasons. *Decapterus rhoncus* was however the only species present in both seasons for both fisheries.

Table 4: Occurrence of fish species in the artisanal and semi-industrial fisheries at Teshie and Tema respectively during the lean and peak fishing seasons of year 2013.

No	Family	Species	Common name	Occurrence			
				AFL	AFP	SFL	SFP
1	Bothidae	*Scyacium micrurum*	Flounder	x	x	√	x
2	Carangidae	*Caranx crysos*	Blue runner	√	x	√	√
3		*Caranx hippos*	Jack mackerel	√	√	x	x
4		*Chloroscombrus chrysurus*	Atlantic bumper	√	√	x	x
5		*Decapterus punctatus*	Round scad	x	x	√	√
6		*Decapterus rhoncus*	False scad	√	√	√	√
7		*Selene dorsalis*	African moonfish	√	√	x	x
8		*Trachinotus ovatus*	Pompano	√	√	x	x
9		*Trachinotus teraia*	Terai pompano	√	√	x	x
10		*Selar crumenophthalmus*	Bigeye scad	x	x	√	√
11	Clupeidae	*Ethmalosa fimbriata*	Shad	√	√	√	x
12		*Illisha africana*	Long finned herring	x	√	x	x
13		*Sardinella aurita*	Round sardinella	x	x	√	√
14		*Sardinella maderensis*	Flat sardinella	√	√	√	x
15	Cynoglossidae	*Cynoglossus senegalensis*	Senegal left-eyed tongue sole	√	√	x	x
16	Dactylopteridae	*Dactylopterus volitans*	Flying gurnard	x	x	x	√
17	Dasyatidae	*Dasyatis margarita*	Daisy sting ray	√	√	x	x
18	Drepanidae	*Chaetodipterus lippei*	Black spadefish	x	√	x	x
19		*Drepane africana*	African sicklefish	x	√	x	x
20	Muglidae	*Mugil cephalus*	Flathead grey mullet	√	x	x	x

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Table 4 continued

21	Penaiedae	*Penaeus notialis*	Pink shrimp	x	√	x	x
22	Polynemidae	*Galeoides decadactylus*	Common threadfin	√	√	x	x
23	Pomadasydae	*Brachydeuterus auritus*	Burrito	√	√	√	x
24	Portunidae	*Callinectes sapidus*	Blue swimming crab	√	√	x	x
25	Priacanthidae	*Priacanthus arenatus*	Atlantic bigeye	x	x	x	√
26	Rhinobatidae	*Rhinobatos rhinobatos*	Common guitarfish	x	√	x	x
27	Sciaenidae	*Pseudotolithus brachygnatus*	Small mouth croaker	√	x	x	x
28		*Pseudotolithus senegalensis*	Cassava croaker	√	√	x	x
29		*Pseudotolithus typus*	Long neck roaker	√	x	x	x
30		*Pteroscion peli*	Boe drum	√	√	x	x
31	Scombridae	*Auxis thazard*	Frigate tuna	x	x	√	√
32		*Orcynopsis unicolor*	Plain bonito	x	√	x	x
33		*Scomber japonicus*	Chub mackerel	√	x	√	√
34		*Scomberomorus tritor*	Spanish mackerel	x	√	x	x
35	Sepiidae	*Sepia officinalis*	Common cuttlefish	√	√	x	√
36	Soleidae	*Bathysolea albida*	Rock sole	x	√	x	x
37	Sparidae	*Boobs boops*	Bogue	x	x	√	√
38	Sphyraenidae	*Sphyraena sphyraena*	Barracuda	√	√	√	x
39	Stromateidae	*Stromateus fiatola*	Butterfish	√	√	x	x
40	Tetraodontidae	*Ephippion guttiffer*	Prickly puffer	√	√	x	√
41		*Lagocephalus laevigatus*	Smooth puffer	√	√	x	x
Total	Number of Families = 22	Number of species = 41		25	28	13	12

Legend: √ = present. x = absent. AFL = Artisanal fishery lean season AFP = Artisanal fishery peak season SFL = Semi-industrial fishery lean season SFP = Semi-industrial fisherypeak season

Selene dorsalis and *Brachydeuterus auritus* were the most abundant species in the artisanal fishery with relative abundances of 34.72% and 23.38% respectively, as shown in Table 5. In the lean season, *S. dorsalis* accounted for half of the fish catch composition with a relative abundance of 50.98% followed by *B. auritus*. *B. auritus* however dominated in the peak season with a relative abundance of 26.56% over 24.48% for *S. dorsalis*. New species were also recorded in the peak season such as *Bathysolea albida, Rhinobatos rhinobatos, Chaetodipterus lippei, Orcynopsis unicolor*, and *Penaeus notialis*, which were hitherto not recorded in the lean season, in relative abundances of 0.04%, 0.04%, 0.09%, 0.62% and 2.83% respectively. *Callinectes sapidus*, a crustacean, which was in relative abundance of 0.04% in the lean season increased to 3.54% in the peak season. The differences between the relative abundances of species in the two seasons in the artisanal fishery were however found to be not significant (Kruskal-Wallis H test, df=1, $P > 0.05$).

As shown on Table 6, *Decapterus punctatus* was the most abundant species for the semi-industrial fishery with a relative abundance of 45.35%. In the lean season, it accounted for 30.79% of fish catch, with *Sardinella aurita* following with 19.81% as the next dominant species. In the peak season, *Decapterus punctatus* constituted 46.41% of fish catches and 40.94% for *Sardinella aurita*. Together, these two species dominated the entire catches in the peak season with a relative abundance of 87.35%. *Brachydeuterus auritus*, which hitherto in the lean season constituted 19.25% relative abundance and the third dominating species, was not observed at all in the peak season. This was the same for species such as *Sardinella maderensis, Scyacium micrurum, Ethmalosa fimbriata and Sphyraena sphyraena*, which were observed in the lean season but not observed in the peak season.

Table 5: Species composition and relative abundance of species found in the artisanal fishery for year 2013.

Species observed	Abundance in lean season (numbers)	Relative abundance in lean season (%)	Abundance in peak season (numbers)	Relative abundance in peak season (%)
Bathysolea albida	0	0.00	2	0.04
Brachydeuterus auritus	522	18.33	1202	26.56
Callinectes sapidus	1	0.04	160	3.54
Caranx hippos	78	2.74	16	0.35
Chaetodipterus lippei	0	0.00	4	0.09
Chloroscombrus chrysurus	82	2.88	320	7.07
Cynoglossus senegalensis	3	0.11	4	0.09
Dasyatis margarita	15	0.53	8	0.18
Decapturus rhoncus	4	0.14	20	0.44
Drepane africana	0	0.00	52	1.15
Ephippion guttiffer	5	0.18	4	0.09
Ethmalosa fimbriata	5	0.18	4	0.09
Galeoides decadactylus	138	4.85	116	2.56
Illisha africana	0	0.00	344	7.60
Lagocephalus laevigatus	31	1.09	14	0.31
Mugil cephalus	4	0.14	0	0.00
Orcynopsis unicolor	0	0.00	28	0.62
Penaeus notialis	0	0.00	128	2.83
Pseudotolithus brachygnatus	10	0.35	0	0.00
Pseudotolithus senegalensis	13	0.46	92	2.03
Pseudotolithus typus	5	0.18	0	0.00
Pteroscion peli	10	0.35	634	14.01
Rhinobatos rhinobatos	0	0.00	2	0.04

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Table 5 continued

Sardinella maderensis	10	0.35	8	0.18
Scomber japonicus	20	0.70	0	0.00
Scomberomorus tritor	0	0.00	2	0.04
Selene dorsalis	1452	50.98	1108	24.48
Sepia officinalis	10	0.35	24	0.53
Sphyraena sphyraena	336	11.80	114	2.52
Stromateus fiatola	15	0.53	2	0.04
Trachinotus ovatus	51	1.79	110	2.43
Trachinotus teraia	28	0.98	4	0.09
Total	2848	100	4526	100

Species that were not available in the lean season but observed in the peak season include *Sepia officinalis*, *Ephippion guttifer*, *Priacanthus arenatus* and *Dactylopterus volitans*, with relative abundances of 0.29%, 0.33%, 0.18% and 0.03% respectively (Table 6). The differences between the relative abundances of species in the two seasons in the semi-industrial fishery were however found to be not significant (Kruskal-Wallis H test, df=1, $P > 0.05$).

The dominant family observed in the artisanal fishery was Family Carangidae, with a relative abundance of 44.39% (Fig. 7). Families which had two or more species recorded together with the dominant family represented 61.95% relative abundance, while the other families such as Pomadasydae, Sepiidae, Polynemidae, Portunidae, made up 38.05% relative abundance. Family Carangidae was also the dominant family in the semi-industrial fishery, with a relative abundance of 48.78%. Family Carangidae, Family Clupeidae and Family Scombridae made up 95.27% total relative abundance in the semi-industrial fishery (Fig. 8).Others, comprising of families Bothidae, Dactylopteridae, Pomadasydae, Priacanthidae, Sciaenidae, Sepiidae, Sphyraenidae and Tetraodontidae made up 4.73% total relative abundance.

Table 6: Species composition and relative abundance of species found in the semi-industrial fishery during the lean and peak fishing seasons of the year 2013.

Species observed	Abundance in lean season (numbers)	Relative abundance in lean season (%)	Abundance in peak season (numbers)	Relative abundance in peak season (%)
Auxis thazard	375	2.62	222	0.11
Boops boops	516	3.60	5046	2.57
Brachydeuterus auritus	2760	19.25	0	0.00
Caranx crysos	78	0.54	296	0.15
Selar crumenophthalmus	171	1.19	1538	0.78
Dactylopterus volitans	0	0.00	50	0.03
Decapturus punctatus	4416	30.79	91278	46.41
Decapturus rhoncus	720	5.02	4424	2.25
Epipphion gutiffer	0	0.00	650	0.33
Ethmalosa fimbriata	180	1.26	0	0.00
Priacanthus arenatus	0	0.00	348	0.18
Sardinella aurita	2841	19.81	80520	40.94
Sardinella maderensis	1515	10.56	0	0.00
Scomber japonicus	744	5.19	11710	5.95
Scyacium micrurum	12	0.08	0	0.00
Sepia officinalis	0	0.00	580	0.29
Sphyraena sphyraena	12	0.08	0	0.00
Total	14340	100	196662	100

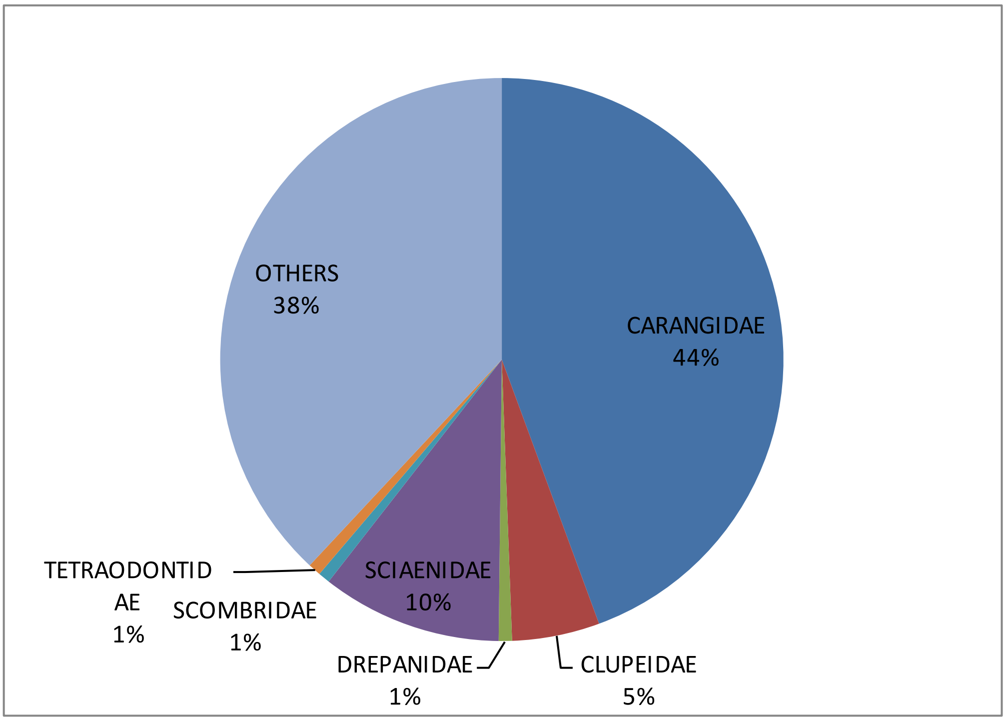

Fig. 7: Relative abundance of various fish families in the artisanal fishery.

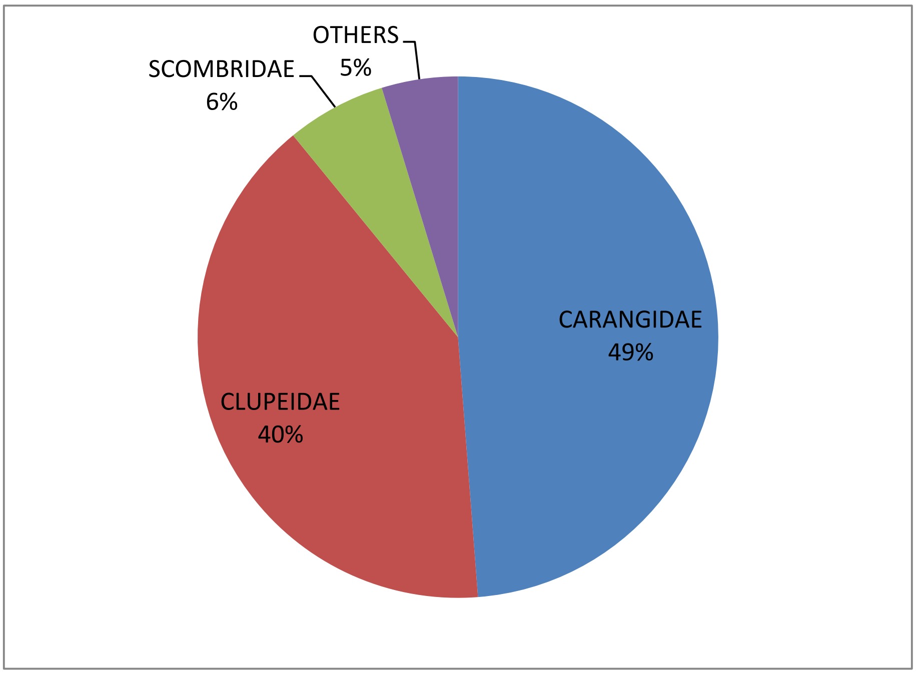

Fig. 8: Relative abundance of various fish families identified in the semi-industrial fishery.

4.2.1 Shellfish abundance

A total of two crustacean species; *Callinectes sapidus* and *Penaeus notialis*, from families Portunidae and Penaeidae respectively and one mollusc species *Sepia officinalis* from family Sepiidae were identified in the artisanal fishery. *Sepia officinalis* was also identified in the peak season of the semi-industrial fishery but none in the lean season. No crustaceans were identified either in the lean or peak seasons of the semi-industrial fishery. During the lean season in the artisanal fishery, the crustacean and molluscan abundance was generally low as compared to that from the peak season (Table 7). *Peneaus notialis* was not observed at all during the lean season, but was present during the peak season in large quantities. In total, the shellfish species from the artisanal fishery accounted for 0.39% of total catch in the lean season and 6.90% in the peak season, whereas that from the semi-industrial fishery accounted for only 0.29% of the total catch during the peak season.

Table 7: Abundance and relative abundance of crustaceans and molluscs in the artisanal fishery.

			Lean season		**Peak season**	
No.	Family	Species	Abundance	Relative Abundance (%)	Abundance	Relative abundance (%)
1	Portunidae	*Callinectes sapidus*	1	0.04	160	3.54
2	Penaeidae	*Penaeus notialis*	0	0.00	128	2.83
3	Sepiidae	*Sepia officinalis*	10	0.35	24	0.53
Total			11	0.39	312	6.90

Diversity indices

Number of fish species observed ranged from 12 in the peak season of the semi-industrial fishery to 28 in the peak season of the artisanal fishery (Table 8). Thus, the peak season of the semi-industrial fishery was the least species rich with only 12 species, while the peak season of the artisanal fishery with 28 different species had the highest number of species. In the artisanal fishery, ecological diversity indices measured (Margalef, Pielou, Shannon-Weiner and Simpson indices) were all higher in the peak season as compared to the lean season. However in the semi-industrial industry, although abundance (average number of individuals) was higher in the peak season than the lean season, all diversity indices measured were lower in the peak season. The combined diversity scores indicate that the peak season of the artisanal fishery was the most diverse (15) and the peak season of the semi-industrial fishery the least diverse (4) season and fishery. The scores also revealed that the total number of species identified did not necessarily relate to species diversity, as the lean season of the artisanal fishery had a higher number of species but lower diversity as compared to the lean season of the semi-industrial fishery (Table 8).

Table 8: Ranked diversity indices for both seasons in both fisheries [Highest score = 4 and least score = 1, in brackets].

	Fishery/Seasons			
Diversity indices	AFL	AFP	SFL	SFP
Shannon-Weiner	1.26(2)	1.93(4)	1.31(3)	0.87(1)
Pielou	0.53(2)	0.65(3)	0.67(4)	0.51(1)
Simpson	0.56(2)	0.78(4)	0.66(3)	0.45(1)
Margalef	1.82(3)	2.59(4)	0.72(2)	0.43(1)
Number of species	24	28	13	12
Total ranking value (4×4=16)	9	15	12	4

Legend

AFL = Artisanal fishery lean season

AFP = Artisanal fishery peak season

SFL = Semi-industrial fishery lean season

SFP = Semi-industrial fishery peak season

4.2.2 Relationship between environmental variables and species abundance

A Canonical Correspondence Analysis further explained the relationship between the six identified principal variables and fish species that occurred in the seasons and fisheries. For the lean season of the artisanal fishery, the first two axes cumulatively explained 100% of the variation found in species abundance as a result of the selected environmental variables, with axis 1 alone accounting for 91.3% of the variation. The first ordination axis reflected species with a gradient related to pH, nitrates and phosphates on the positive end of the axis and Revelle factor, total alkalinity and carbonate ion concentration on the negative end. The second axis had pH and nitrates on the positive end and phosphates, Revelle factor, total alkalinity and carbonate ion concentration on the negative end (Fig. 9). The species *Sphyraena sphyraena* related well with Revelle factor and total alkalinity but showed a negative relation with pH and nitrates (Fig. 9). The other dominant species identified in this fishery did not seem to be influenced by any of the variables. For the rare fish species (species with relative abundance lesser than 1%) identified in this fishery during the lean season, *Ephippion guttiffer* was identified to relate well with pH (Fig. 10).

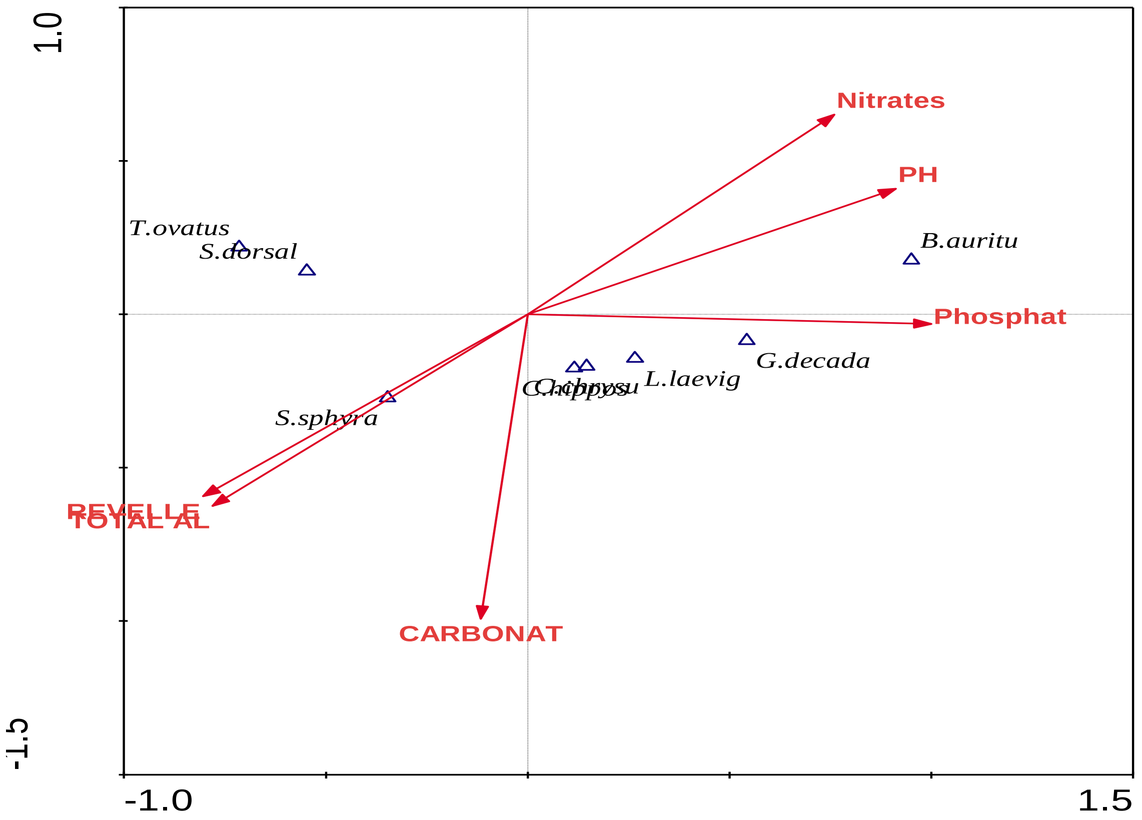

Fig. 9: CCA biplot showing relationship between dominant fish species identified in the lean season of the artisanal fishery.

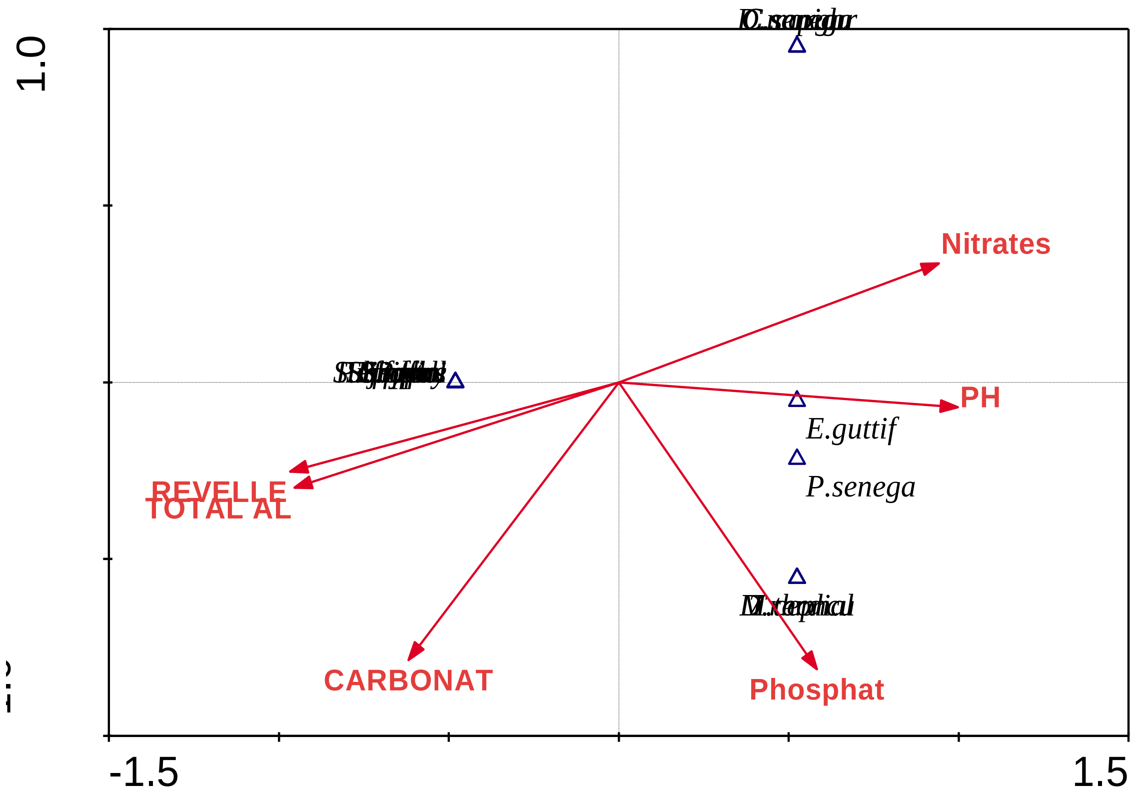

Fig. 10: CCA biplot showing relationship between rare fish species identified in the lean season of the artisanal fishery.

For the peak season of the artisanal fishery, the first two axes cumulatively explained 100% of the variation found in species abundance as a result of the selected environmental variables. The first ordination axis reflected species with a gradient related to Revelle factor, nitrates and phosphates on the positive end of the axis and pH, total alkalinity and carbonate ion concentration on the negative end. The second axis had pH, total alkalinity, carbonate ion concentration and nitrates on the positive end and phosphates and Revelle factor on the negative end (Fig. 11). The species *Chloroscombrus chrysusrus* related well with pH and carbonate ion concentration but showed a negative relation with nitrates, Revelle factor and phosphates (Fig. 11). *Drepane africana* however related well with Revelle factor and phosphates but showed negative relation with pH and carbonate ion concentration. For the rare fish species (species with relative abundance lesser than 1%) identified in this fishery during the lean season, *Sepia officinalis* was identified to relate well with pH (Fig. 12).

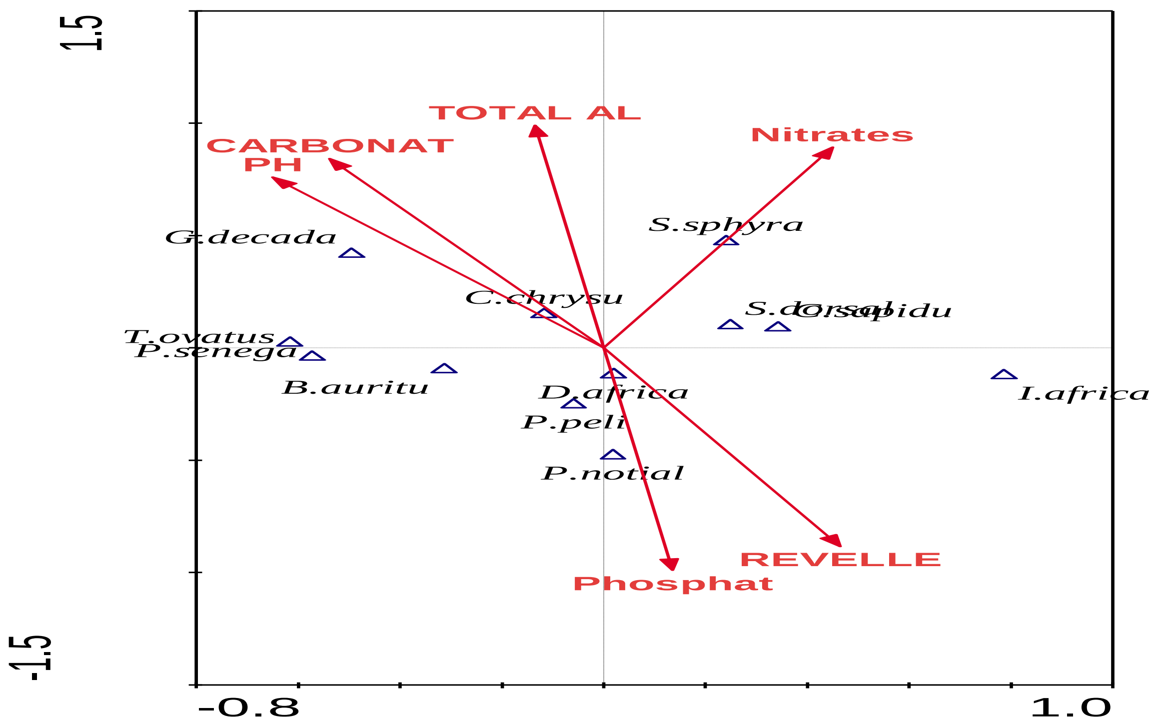

Fig. 11: CCA biplot showing relationship between dominant fish species identified in the peak season of the artisanal fishery.

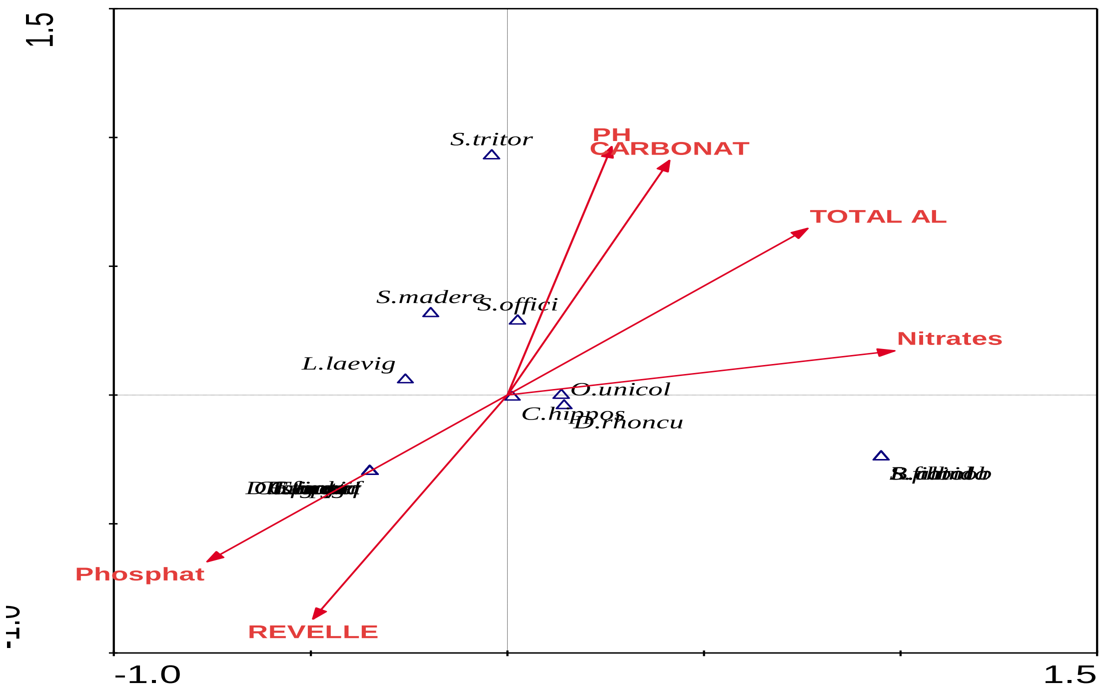

Fig. 12: CCA biplot showing relationship between rare fish species identified in the peak season of the artisanal fishery.

The first two ordination axes from the CCA cumulatively accounted for 100% of the variations of the species abundance from the environmental parameters in the lean season of the semi-industrial fishery. pH was found to be positive on the first axis and phosphates, nitrates, Revelle factor, total alkalinity and carbonate ion concentration on the negative end of the axis. On the second axis, total alkalinity, nitrates and phosphates were on the positive end while Revelle factor, pH and carbonate ion concentration were on the negative end. *Auxis thazard* related well with both total alkalinity and nitrates, while *Selar crumenophthalmus* related well with pH and carbonate ion concentration. *Sardinella maderensis* also related well with the Revelle factor (Fig. 13).

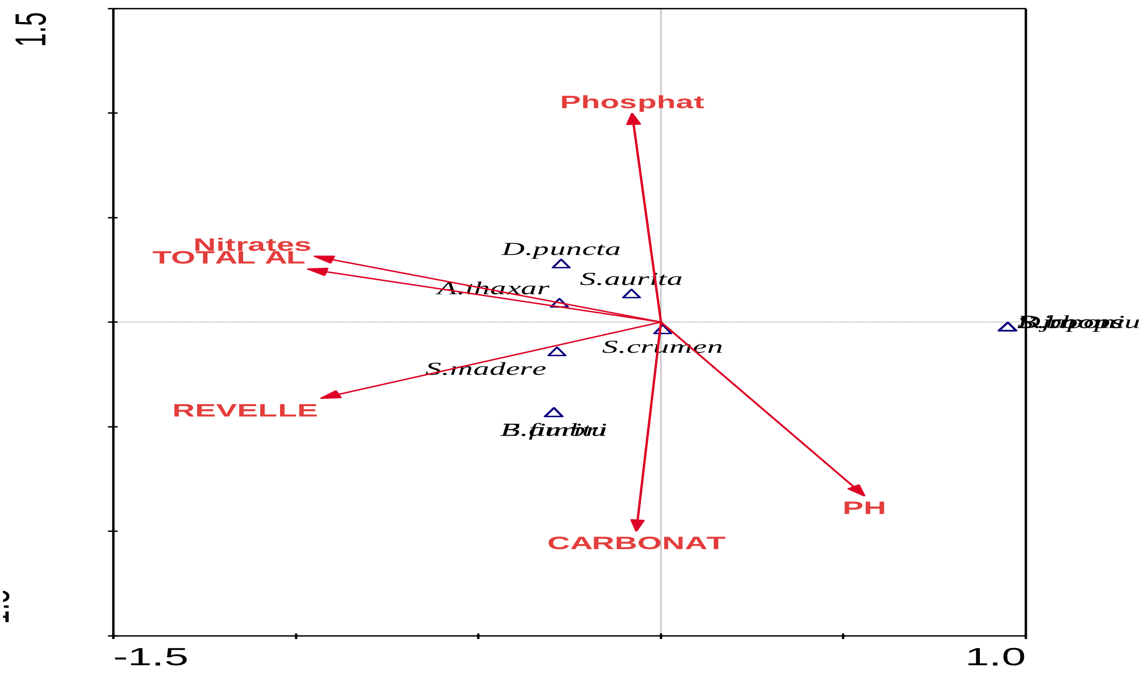

Fig. 13: CCA biplot showing relationship between dominant fish species identified in the lean season of the semi-industrial fishery.

For the peak season of the semi-industrial fishery however, the first two ordination axes explained 97.6% of observed variations. Nitrates, phosphates, pH and carbonate ion concentration were found on the positive end of the first axis while Revelle factor and total alkalinity were found on the negative end. Revelle factor, total alkalinity and carbonate ion concentration were found on the negative end of the second axis while nitrates, phosphates and pH were found on the positive end. The species *Sardinella aurita* was found to relate well with pH, while Decapterus punctatus related well with Revelle factor and total alkalinity (Fig. 14). *Selar crumenophthalmus*, a rare species per abundance, was found to relate well with pH, while *Sepia officinalis* was partially related to carbonate ion concentration and the Revelle factor (Fig. 15).

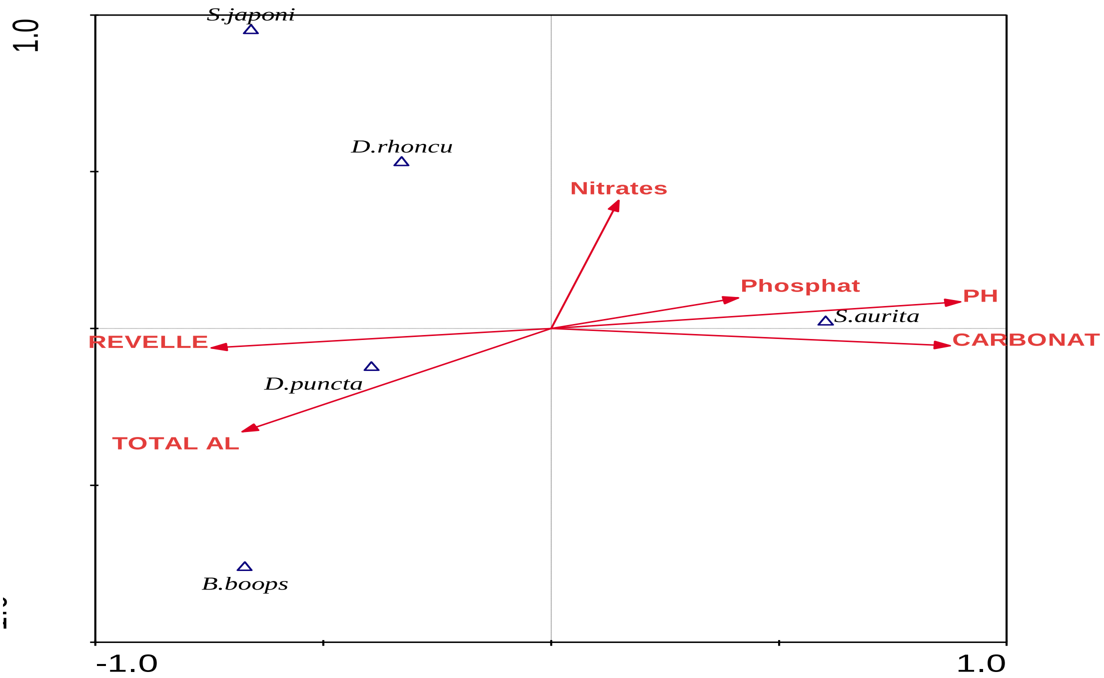

Fig. 14: CCA biplot showing relationship between dominant fish species identified in the peak season of the semi-industrial fishery.

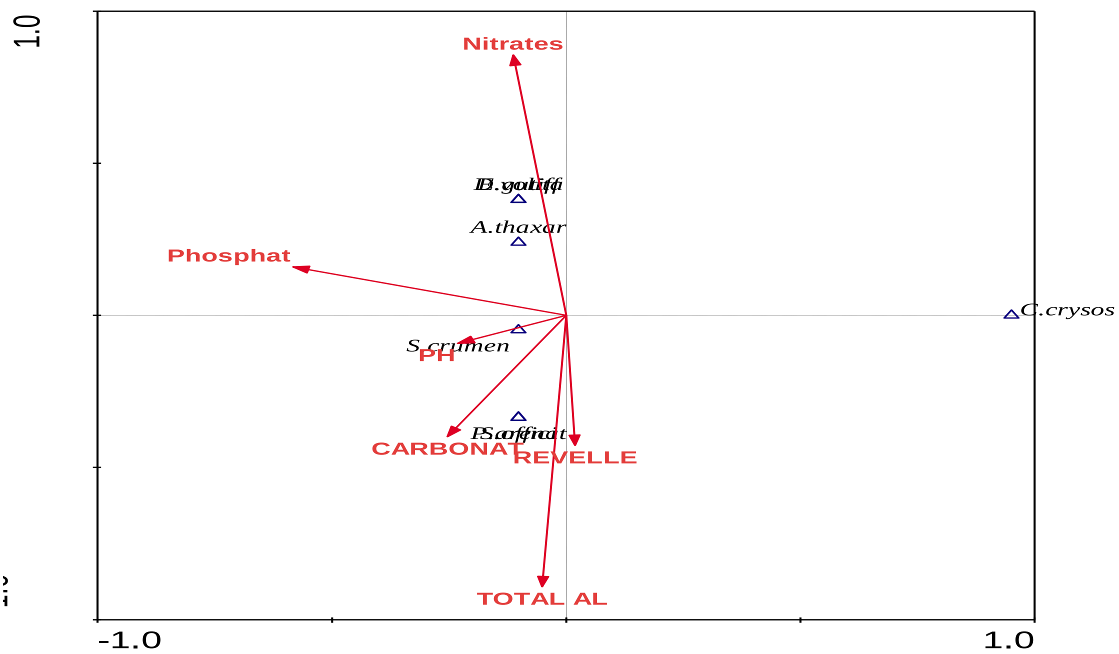

Fig. 15: CCA biplot showing relationship between rare fish species identified in the peak season of the semi-industrial fishery.

4.3 Ichthyoplankton Abundance

Larvae of fish found were mainly species of *Sardinella aurita* in both seasons. In the peak season, a large number of decapoda larvae, primarily of the family Peneaidae and Portunidae were observed, as well as larvae of the species *Scyacium micrurum* (Plate 6). A higher abundance was observed during the peak season as compared to the lean season (Figure 16). However these abundances were found to be not significant (Kruskal-Wallis H test, df=1, $P > 0.05$). A canonical correspondence analysis (CCA) of the abundance of these identified species with the principal environmental factors identified to influence biological variations revealed that the first two ordination axes accounted for 100% of variations in the larvae abundance. pH, phosphate and Revelle factor were found to be on the positive end of the first axes while carbonate ion concentration, total alkalinity and nitrates were found on the negative end. On the second axis, pH, carbonate ion concentration, total alkalinity and nitrates were found on the positive end and Revelle factor and phosphates on the negative end. Decapod species, consisting of species from the family Penaeidae and family Portunidae were found to relate well with Revelle factor (Fig. 17).

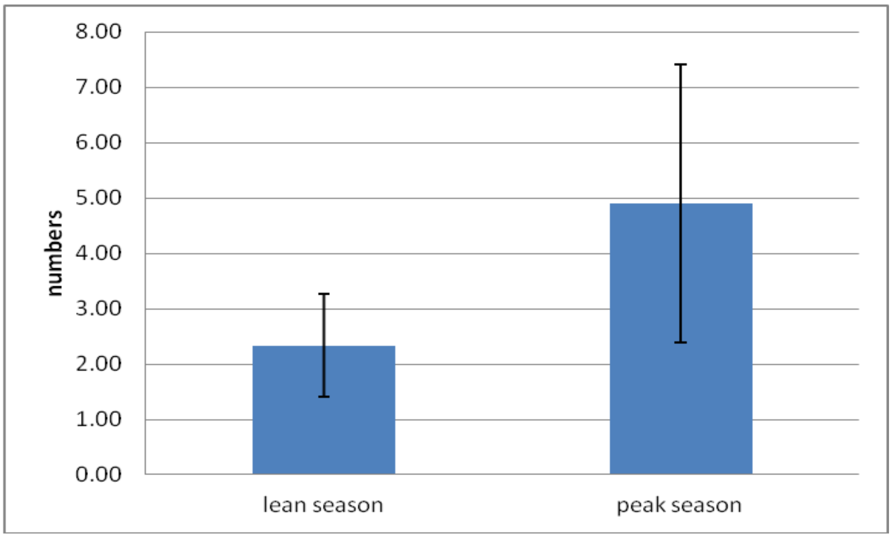

Figure 16: Seasonal means of total ichthyoplankton abundance in the artisanal fishery (error bars represent standard deviation).

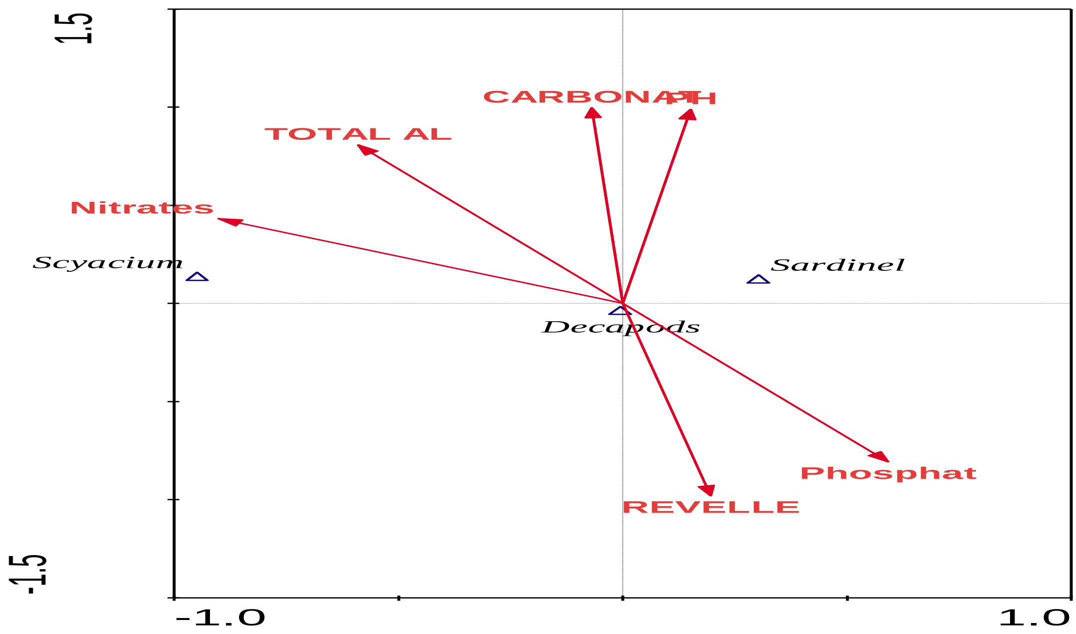

Fig. 17: CCA biplot of identified fish larvae in the peak season of the artisanal fishery.

4.4 Degree of Human Reliance on the Two Fisheries as Sources of Livelihoods

Table 9 presents summary statistics of role in household, educational level completed and primary occupation of respondents of the random interviews conducted to assess the degree of human reliance on the artisanal and semi-industrial fisheries. Both the lean and peak seasons of the semi-industrial fishery had a higher number of males as household heads as against women, except during the peak season in the artisanal fishery, which recorded a higher percentage of women as household heads. More than half of the respondents from the artisanal fishery during both seasons and from the semi-industrial fishery during the peak season had formal education from primary to the Junior High school (JHS) level. The respondents in the two fisheries were primarily fishermen and fishmongers. However, a greater percentage (58.7%) of respondents observed in the lean season of the artisanal fishery were involved in other fisheries related activities such as fish carriers, cold store operators or were traders within the fishing community.

Table 9: Demographic information of fisher folk community in study area in Ghana.

	Artisanal				Semi-industrial			
	Lean		**Peak**		**Lean**		**Peak**	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Role in the family								
Father	24	52.17	23	41.07	36	69.23	21	51.22
Mother	22	47.83	33	58.93	16	30.77	20	48.78
Total	46	100	56	100	52	100	41	100
Educational level completed								
JHS	25	54.35	32	57.14	21	40.38	24	58.54
SHS	8	17.39	2	3.57	15	28.85	7	17.07
Technical	1	2.17	0	0.00	1	1.92	0	0.00
No education	11	23.91	22	39.29	15	28.85	10	24.39
Total	46	100	56	100	52	100	41	100
Primary occupation								
Fisherman	7	15.22	25	44.64	26	50.00	21	51.22
Fishmonger	12	26.09	30	53.57	16	30.77	20	48.78
Other	27	58.70	1	1.79	10	19.23	0	0.00
Total	46	100	56	100	52	100	41	100

Freq. = Frequency

Table 10 presents the summary of descriptive statistics of respondents and their daily involvement in fisheries related activities as well as some demographics and household characteristics. Mean age of respondents observed in the artisanal fishery was about 41 years, ranging between 20 to 78 years (Table 10).

Revenue per day from fisheries activities in the artisanal fishery (lean season) ranged from GH¢5 to GH¢550 per day with average revenue of about GH¢75. For the peak season of the artisanal fishery average revenue was about GH¢58, with about 23.21% earning GH¢10 a day, and as low as 1.79% earning larger sums. Maximum and mean revenues of GH¢1100 and about GH¢153per day were recorded in the lean season of the semi-industrial fishery.

Table 10: Summary statistics of respondents.

No.	Category	Description	Nos. encountered	Mean	Std. Dev.	Range
1.	Age (Years)					
		Artisanal lean	46	41.022	13.644	20 – 78
		Artisanal peak	56	40.661	11.578	20 – 70
		Semi-industrial lean	52	42.040	10.787	25 – 70
		Semi-industrial peak	41	38.659	11.821	25 - 75
2.	Daily revenue from fisheries activities (GH¢)					
		Artisanal lean	31	75.032	135.202	5 – 550
		Artisanal peak	56	57.821	94.806	5 – 600
		Semi-industrial lean	39	153.282	254.652	3 – 1100
		Semi-industrial peak	41	35.195	44.218	2 – 200
3.	Fish consumption (%)					
		Artisanal lean	46	79.239	26.541	15 – 100
		Artisanal peak	56	81.875	36.414	0 – 100
		Semi-industrial lean	52	87.000	13.994	50 – 100
		Semi-industrial peak	41	69.268	35.594	0 – 100
4.	Men in household involved with fisheries activities					
		Artisanal lean	46	1.282	3.430	0 – 20
		Artisanal peak	54	3.685	3.875	0 – 20
		Semi-industrial lean	52	0.346	0.590	0 – 3
		Semi-industrial peak	41	1.756	2.727	0 – 10
5.	Women in household involved with fisheries activities					
		Artisanal lean	46	0.870	1.454	0 – 7
		Artisanal peak	46	8.333	7.802	0 – 15
		Semi-industrial lean	52	0.308	0.729	0 – 3
		Semi-industrial peak	40	1.600	2.251	0 – 10
6.	Children in household involved with fisheries activities					
		Artisanal lean	46	0.152	0.631	0 – 4
		Artisanal peak	36	2.750	5.050	0 – 30
		Semi-industrial lean	52	0.096	0.409	0 – 2
		Semi-industrial peak	41	0.366	0.767	0 – 3

A greater number of men working with fisheries activities in the households of respondents were observed in the artisanal fishery than the semi-industrial fishery (Table 10). Both the lean season and the peak season of the artisanal fishery had a maximum of 20 men per household involved with fisheries related activities whereas maximum numbers of men observed for the semi-industrial fishery were 3 and 10 for the lean and peak seasons respectively. For number of women involved in fisheries related activities, a mean of 1 woman was recorded for the lean season of the artisanal fishery and 8 women in the peak season. A range of 4 to 30 children per household were observed to be involved in fisheries related activities and a range of 2 to 3 children per household observed for the semi-industrial fishery.

Table 11: Fish species preference of respondents during the lean and peak seasons.

	Artisanal				**Semi-industrial**			
	Lean		**Peak**		**Lean**		**Peak**	
Species	Freq.	Percent	Freq.	Percent	Freq.	Percent	Freq.	Percent
Auxis thazard	14	26.92	5	10.20	21	40.38	10	22.22
Chloroscombrus chrysurus	4	7.69	2	4.08	0	0.00	0	0.00
Cynoglossus senegalensis	1	1.92	1	2.04	0	0.00	0	0.00
Illisha africana	6	11.54	6	12.24	0	0.00	0	0.00
Pseudotolithus senegalensis	2	3.85	1	2.04	5	9.62	1	2.22
Pteroscion peli	1	1.92	1	2.04	0	0.00	0	0.00
Dentex canariensis	1	1.92	2	4.08	7	13.46	7	15.56
Sardinella sp.	4	7.69	4	8.16	0	0.00	4	8.89
Scomber japonicus	9	17.31	8	16.33	10	19.23	10	22.22
Scomberomeros tritor	2	3.85	1	2.04	0	0.00	0	0.00
Selene dorsalis	2	3.85	1	2.04	0	0.00	0	0.00
Sphyraena sphyraena	2	3.85	6	12.24	0	0.00	0	0.00
Trachurus trachurus	0	0.00	0	0.00	`1	1.92	1	2.22

Freq. = Frequency

Fish species preferred by respondents in both fisheries and seasons were mainly *Auxis thazard* of the family Scombridae, with the highest preference in the lean season of the semi-industrial fishery (40.38%). Other high rating species was *Scomber japonicus* also of the family Scombridae, with the peak season of the semi-industrial fishery recording the highest percentage of 22.22% and the peak season of the artisanal fishery recording the lowest preference of 16.33%.

Table 12: Regression results using the Tobit model.

	Marginal effects					
	Artisanal fishery		**Semi-industrial fishery**			
	Lean season	**Peak season**	**Lean season**	**Peak season**	**Pooled season**	**Pooled site**
Household Head	30.161*** (0.004)	-13.523*** (0.004)	-6.446*** (0.001)	5.802 (0.188)	-3.381* (0.087)	-3.762** (0.049)
Age	-0.314*** (0.005)	0 .409*** (0.000)	0.299*** (0.001)	1.038*** (0.000)	0.438*** (0.000)	0 .510*** (0.000)
Educational level completed	0.058** (0.049)	0 .002 (0.941)	0.049*** (0.009)	0 .061 (0.250)	0.030* (0.127)	0 .013 (0.491)
Major Occupation	-1.637 (0.393)	-15.990*** (0.000)	-1.333 (0.279)	-13.927*** (0.007)	-3.412** (0.017)	-4.708*** (0.001)
Household Income	-0.041*** (0.000)	-0.007 (0.559)	0.011*** (0.002)	0.268*** (0.000)	0.010* (0.112)	0 .016*** (0.006)
Men_Fish	0 .425 (0.174)	0 .227 (0.687)	0.649 (0.615)	0 .650 (0.721)	0 .087 (0.827)	0 .037 (0.924)
Female_Fish	-2.223*** (0.011)	1.658*** (0.014)	2.847* (0.075)	-2.430 (0.246)	0 .359 (0.502)	-0.020 (0.924)
Children_Fish	-0.924 (0.608)	-0.449 (0.233)	-7.927*** (0.004)	-7.717** (0.027)	0 .463 (0.265)	0 .298 (0.467)
Dummy Season					3.788 (0.158)	
Dummy Site						10.680*** (0.000)

Note: ***, ** and * implies significance at 1%, 5% and 10% respectively. Figures in parenthesis are the p-values and those above it represent the marginal effects.

From Table 12, household head was significant ($P < 0.01$) in determining the degree of human reliance for both the lean and peak season in the artisanal fishery and the lean season of the semi-industrial fishery. Age was also significant ($P < 0.01$) for both seasons of the artisanal and semi-industrial fisheries and in both the pooled sites and pooled seasons. The level of education completed by respondent was significant for the lean season of the artisanal fishery ($P < 0.05$) and the lean season of the semi-industrial fishery ($P < 0.01$). The household income for a respondent was also significant ($P < 0.01$) in determining degree of human reliance in the lean season of the artisanal fishery and both seasons of the semi-industrial fishery. The number of females involved in fisheries related activities in the household of a respondent was significant ($P < 0.01$) for both seasons of the artisanal fishery but not for the peak season of the semi-industrial fishery or the pooled season and site. The number of children involved in fisheries related activities was significant ($P < 0.05$) for both seasons of the semi-industry fishery but not significant ($P > 0.1$) for the artisanal fishery or the pooled season and pooled site. The number of males involved in fisheries related activities were however not significant ($P > 0.1$) in determining degree of human reliance in any of the two fisheries. Both the pooled season and pooled site were significant ($P < 0.1$) in determining the degree of human reliance when regressed with dummy variables. Pooled season was however significant at 10% whereas pooled site was significant at 1%.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Extent and magnitude of impacts of ocean acidification on abundance and diversity of fish species using physico-chemical parameters

pH

pH is the greatest indicator of ocean acidification (Bates *et al.*, 2012). Decreasing pH correlates with an increase in acidity of the oceans as a result of increased absorbance of carbon dioxide from the atmosphere (Armstrong *et al.*, 2010). Mean values of pH recorded from Teshie in the peak season (8.33±0.19) increased over that of the lean season (8.30±0.21). This is in contrast to the occurrence of ocean acidification, and also in contrast to the findings from Tema where the pH values recorded decreased in the peak season (7.29±0.16) from mean values in the lean season (7.63±0.65). Findings from the semi-industrial fishery are in agreement with work done by Bates (2007) and Bates *et al.* (2012), who both recorded a decrease in seawater pH over extended periods of time, thus, an occurrence of acidity of the oceans may be identified with the semi-industrial fishery.

However, unlike the semi-industrial fishery which fish offshore in a minimum zone depth limit (MZDL) of above 30 m (FAO, 2004), the artisanal fishery operates at the nearshore which is usually below this 30 m depth. The nearshore environment is noted to be vastly and directly influenced by many factors from land such as inputs of contaminants and nutrients from run-offs, waste products of animals and discharge systems (NOAA, 2009). These factors are, therefore, likely to confound pH levels and thus the evidence of ocean acidification. pH was found to be significant (RELATE, $P < 0.05$) in explaining variations in abundance and diversity for the two fisheries.

Calcite and aragonite saturation

The two crystalline forms of calcium carbonate ($CaCO_3$) are aragonite and calcite, with aragonite being more easily dissolved than calcite (Vezina and Hoegh-Guldberg, 2008). Calcite and aragonite saturation states both had declining trends in the artisanal and semi-industrial fisheries, although mean saturation states for calcite were higher in both seasons and fisheries as compared to aragonite saturation. Bates *et al.* (2012) observed a decreasing trend with calcite and aragonite saturation states in the North Atlantic Ocean. Feely *et al.* (2012) also observed an average decrease of 0.34% yr^{-1} in the saturation state of calcite and aragonite.

Generally above the saturation horizon of seawater, saturation states have a value greater than 1 and $CaCO_3$ does not readily dissolve. However below this depth, saturation state is less than 1 and $CaCO_3$ will readily dissolve (Royal Society, 2005). Although saturation state levels for the artisanal fishery in both seasons had a decreasing trend, values were above 1. Thus it can be said that such waters are supersaturated and above the threshold of acidification. However, with the observed decreasing trend and the continuous absorbance of anthropogenic carbon dioxide from the atmosphere, this justification is inconclusive. However, aragonite and calcite saturation level values of less than 1 were recorded for the peak season of the semi-industrial fishery (Table 1), indicating under saturation. It can thus be concluded that dissolution of $CaCO_3$ is on the onset in such waters, and as such calcifying organisms landed from this fishery would be heavily impacted. Aragonite and calcite saturation states were however not significant in explaining variations observed in the biological environments (RELATE, $P > 0.05$).

Carbonate ion concentration

Carbonate ion concentration had a decreasing trend in both the artisanal (320.28 µmol/kg – 102.61 µmol/kg) and semi-industrial fisheries (106.20 µmol/kg – 24.19 µmol/kg), with the peak seasons having lower mean concentrations than the lean seasons (Table 1). These are in line with results from Bates *et al.* (2012) and Beaufort *et al.* (2011) of recorded decreasing carbonate ion concentrations. Reduced carbonate ion concentrations raises the saturation horizon closer to the surface, giving room for increased under saturation. Bates *et al.* (2014) also documented a wealth of data from seven independent time series measurements of ocean carbonate chemistry and each of them alluded to a decreasing trend of carbonate ion concentration in oceanic waters. Carbonate ion concentration was found to have significant (RELATE, $P < 0.05$) influence on the abundance and diversity of fish species observed in both fisheries.

Total alkalinity

Decreasing trend of total alkalinity recorded in both seasons and fisheries (1848.34 µmol/kg – 1099.01 µmol/kg for the artisanal fishery; 1099.01 µmol/kg – 1032.37 µmol/kg for the semi-industrial fishery) indicate that the capacity of the ocean to neutralize acid is decreasing in the two study areas. Although oceanic alkalinity is said to be relatively stable, researchers have shown it to vary over time, especially through ocean acidification (Doney *et al.,* 2009). This is because total alkalinity is calculated from the ions in the ocean and thus a change in chemical composition which is evident now as a result of increasing anthropogenic carbon dioxide, would alter alkalinity. The decreasing trend thus observed is not out of place and only seeks to affirm the ongoing ocean acidification phenomenon. Moreover, since the carbonate chemistry of the ocean was changing as inferred from reducing carbonate ion concentrations, variation of total alkalinity in the study sites is no deviation. Total alkalinity was found to have significant (RELATE, $P < 0.05$) influence on the abundance and diversity of fish species observed in both fisheries.

Revelle factor

An increasing trend of the Revelle factor values identified in both fisheries (6.64 – 7.75 for the artisanal fishery; 7.54 – 15.24 for the semi-industrial fishery) gives an indication that the capacity of Ghanaian waters to absorb carbon dioxide is diminishing. Bates *et al.* (2012) also identified increasing Revelle factors which implied waters of the North Atlantic were gradually losing capacity to absorb carbon dioxide from the atmosphere. The ocean's capacity to hold more carbon dioxide from the atmosphere is inversely proportional to the Revelle buffer factor (Egleston *et al.*, 2010), thus the higher the factor, the lower the capacity of the oceans. According to Gehlen *et al.* (2011), the most important direct feedback associated with ocean acidification is the changing of the Revelle buffer factor of the ocean by increasing its value. Thus, observed increasing trends of the Revelle factor from the study (6.64 – 7.75 for the artisanal fishery; 7.54 – 15.24 for the semi-industrial fishery) thus associates with an occurrence of ocean acidification in Ghanaian waters. Revelle factor was found to be significant (RELATE, $P < 0.05$) in explaining variations in abundance and diversity found in the two fisheries.

Two ocean acidification parameters (pH and carbonate ion concentration), two seawater carbonate chemistry parameters (total alkalinity and Revelle factor) and two nutrients (nitrates and phosphates) were identified by the Principal Components Analysis to significantly (RELATE, $r = 0.955$, $p < 0.05$) account for variances observed in the sampled sites. The influence of these parameters, especially those of the seawater carbonate chemistry and ocean acidification indicators tend to paint a positive trend of the possible occurrence of ocean acidification impacting abundance and diversity of fish species in the two sampled fisheries.

Diversity indices measured for the two fisheries indicate a higher species richness and diversity in the artisanal fishery over the semi-industrial fishery (Table 8), with the artisanal fishery exploiting a greater multi-species diverse assemblage. The artisanal fishery is operated at the nearshore environment, an environment usually used as breeding and nursery grounds for many species (Islam and Haque, 2004), thus, the diverse assemblage. Of the 33 fish species identified in the artisanal fishery, representing catches from the beach seine fishery, 28 species from 16 taxonomical families were identified by Aggrey-Fynn and Sackey-Mensah (2012) over a 17-month sampling period on the central coast of Ghana. Nunoo (2003) also identified 23 species from 11 taxonomic families over a 24-month sampling period on the eastern coast of Ghana.

Major species identified which accounted for about 85% of total catches such as *Brachydeuterus auritus, Selene dorsalis, Chloroscombrus chrysurus,* are in agreement with major species identified by Nunoo (2003) and Aggrey-Fynn and Sackey-Mensah (2012) in the artisanal fishery. However the species *Sardinella aurita*, which is usually known to be high in abundance especially during peak fishing seasons on the coasts of Ghana as a result of seasonal upwelling (Koranteng, 1995; Minta, 2003), had a lower relative abundance of 0.35% as compared to 13.1% found by Aggrey-Fynn and Sackey-Mensah (2012). Data from FAO show a general downwards trend of *Sardinella aurita* catches over the past ten years (Appendix E). This could be a contributory factor to observed lower catches of *S. aurita* in the artisanal fishery. Another limiting factor would be the short duration of sampling of this study (12 months) as compared to a 17-month sampling period of Aggrey-Fynn and Sackey-Mensah (2012).

Relations of fish species and indicators and parameters of ocean acidification from the CCA biplots revealed impacts of ocean acidification on abundance of species such as *Sardinella aurita*, *Sardinella maderensis*, *Selar crumenophthalmus*, *Chloroscombrus chrysurus*, *Auxis thazard*, *Ephippion guttifer* and *Sphyraena sphyraena*. *Sphyraena sphyraena* was positively related with total alkalinity in the lean season of the artisanal fishery (Fig. 9), indicating that as total alkalinity increased, abundance of this species increased and vice versa. Total alkalinity is a seawater carbonate chemistry parameter and as such a determinant of ocean acidification, thus, ocean acidification could be said to result in decreasing abundance of *Sphyraena sphyraena* in the artisanal fishery. With time, this could lead to a decreased diversity for this fishery.

In the peak season of the semi-industrial fishery, *Sardinella aurita* positively related to pH and carbonate ion concentration (Fig. 14). The decreasing trend in pH and carbonate ion concentration observed in the semi-industrial fishery (Fig. 5) thus relates to a decrease in abundance of the species *Sardinella aurita*. Odulate *et al.* (2014) also observed the abundances of *Sardinella aurita* to be influenced by pH levels in marine coastal waters of the Gulf of Guinea, Southwest Nigeria. *Selar crumenophthalmus*, *Chloroscombrus chrysurus* and *Ephippion guttifer* were also identified to relate positively with pH in Figures 15, 11, and 10 respectively. These findings underscore the evidence that ocean acidification as a result of decreased pH levels would impact fish species, as reported by authors such as Fabry *et al.* (2008); Doney *et al.* (2009) and Munday *et al.* (2009).

5.1.1 Impacts of Ocean Acidification on Shellfish Abundance

The relative abundance of shellfish was higher in the peak season as compared to the lean season in the artisanal fishery. Change in abundance could probably be influenced by increased pH and carbonate ion concentration as shown from the canonical correspondence analysis. *Sepia officinalis* was found to relate positively with pH from the CCA biplot (Fig. 12), implying a decrease in abundance of the species as pH decreased. Thus ocean acidification as a result of decreased pH would impact the abundance of *S. officinalis* and thus the diversity of the fishery. A decrease in abundance would result in a loss of the species over time and the fisheries that depend on them, thus reducing diversity and vice versa. Gutowska and Melzner (2009) also found linear relationships between mass of *S. officinalis* and pH, confirming that decreased concentrations of pH could result in the observed decreased abundance of the species. Also, since *S. officinalis* is a mollusc which makes use of calcium carbonate in the formation of its internal shell, decreasing carbonate ion concentration in its environment as evidenced by the results could also account for decreased abundance. In the semi-industrial fishery, abundance of *S. officinalis* was again influenced by carbonate ion concentration.

There was no clear evidence that ocean acidification was affecting the relative abundances and diversities of the shellfish species *Callinectes sapidus* and *Penaeus notialis* identified in the artisanal fishery, since these species did not relate with any of the ocean acidification indicators or the seawater carbonate chemistry parameters. Since these are calcifying organisms, the findings are in contrast to reports from Vezina and Hoegh-Guldberg (2008); Doney *et al.* (2009); Munday *et al.* (2009) and Barnard and Grekin (2010) which indicate that ocean acidification would impact negatively on calcifying organisms. However, Ries *et al.* (2009) has shown that this could occur, as their work on laboratory simulations revealed that marine calcifiers such as crustaceans may exhibit varied responses and further observed that *C. sapidus* did not exhibit any significant effects to ocean acidification. Although results for calcite and aragonite saturation states for the artisanal fishery show a decreasing trend with respect to the seasonal means (4.43 – 2.60 for aragonite saturation; 6.67 – 3.99 for calcite saturation; Table 1), none of the saturation states is yet below the value of 1, the value at which under saturation takes place according to Royal Society (2005). This could perhaps explain why the crustacean species were neither influenced by any of the seawater carbonate chemistry parameters nor ocean acidification parameters from the CCA. Thus ocean acidification could be a contributing factor to the observed abundances of molluscs but inconclusive for observed abundances of crustaceans in the artisanal fishery.

5.2 Impacts of Ocean Acidification on Ichthyoplankton Abundance

Ichthyoplankton abundance generally has a direct relationship with abundance of adult fish. Ichthyoplankton has also been identified to be more susceptible to ocean acidification and other environmental factors than adult fish (Sumaila *et al.*, 2011). Ichthyoplankton was found to be generally higher in the peak season than the lean season (Fig. 16). Sardinella larvae observed confirm the abundance of *Sardinella sp.* in coastal waters of Ghana usually linked with upwelling periods as documented by Koranteng, 1995; Minta, 2003 and Djagoua *et al.*, 2011. None of the ocean acidification indicators and parameters was found to relate with abundance of *Sardinella* larvae from the CCA biplot (Fig. 17), however, it is inconclusive to say that ocean acidification does not impact *Sardinella* larvae, and thus requires further investigation in the future.

Decapod larvae, mainly of families Peneaidae and Portunidae were however found to relate well with carbonate ion concentration, pH and the Revelle factor from the CCA biplot (Fig. 17). Species of these families which include Peneaus *notialis* and *Callinectes sapidus* identified in the artisanal fishery can therefore be said to susceptible to ocean acidification, and could thus be a factor to low abundances of adult *Peneaus notialis* and *Calinectes sapidus* species observed in the artisanal fishery (Table 5). The result is in support of the report from Vezina and Hoegh-Guldberg, 2008 and Doney *et al.*, 2009 which anticipates that larvae of calcifying organisms are highly susceptible to ocean acidification.

5.3 Degree of Human Reliance on the Two Fisheries as Sources of Livelihoods

The Tobit Regression analysis results revealed that the rate of fish consumption of a respondent per year as against other protein sources was influenced by some socioeconomic factors such as age, household head, occupation and household income. In both the lean and peak seasons of the semi-industrial fishery, age had a positive significant ($P < 0.01$) effect on the rate of fish consumption, indicating that as age of a person increases, rate of fish consumption increases. This could possibly be as a result of health consciousness and the fact that fish is a healthier choice over other sources of protein such as meat (Antonio, 2014). With the average age of respondents in this fishery being about 40 years (Table 10), this result could be expected. Ages in both the pooled season and the pooled site were positively significant ($P < 0.01$) to the rate of fish consumption, indicating that on the whole, age played a critical determining factor in fish consumption. These findings are in line with work done by Chrysohoou *et al.* (2007) who also found fish consumption to have a positive significant correlation with age.

The educational level completed by respondents for the lean seasons of both fisheries had a positive significant ($P < 0.01$) effect on the rate of fish consumption while the peak seasons of the fishery had no significant effect on rate of consumption. This implies that during the lean seasons, as level of education increased, rate of fish consumption also increased. This could be due to increased enlightenment with increased education on the benefits of consumption of fish such as protection against coronary heart disease death (Hu *et al.*, 2003; He *et al.*, 2004; Streppel *et al.*, 2008). Work by Wennber *et al.* (2012) also confirms that as educational level of a person increases, fish consumption increases and vice versa.

Household income for both seasons in the semi-industrial fishery had a positive significant ($P < 0.01$) effect on rate of fish consumption, indicating that as a person's household income increases, rate of fish consumption per year in comparison to other protein sources also increases. Household income in the pooled season and pooled site also had positive significant ($P < 0.01$) effects on the rate of fish consumption, indicating little effects of seasonal and geographical differences on rate of fish consumption. However, in the lean season of the artisanal fishery, as household income of a person increased, fish consumption decreased. This could be explained by the fact that household heads in that fishery diverted household income as it came in to other sources of protein aside fish, especially since fish was generally scarce and expensive during the lean season (Gordon *et al.*, 2011).

The number of women involved in fish activities in household for the peak season of the artisanal fishery and lean season of the semi-industrial fishery both had positive significant ($P < 0.10$) effects on the rate of fish consumption, implying that the higher the number of women in household directly or indirectly involved with fisheries activities, the higher the fish consumption of the household. Women are basically seen as the managers of a household, especially in terms of feeding among others (Gillespie and Mason, 1991). Households with women in fisheries activities such as fish mongering would thus have a greater likelihood of including fish in the daily diet. The degree of dependence of such households on fish and fisheries activities therefore also tends to increase. Per the summary statistics (Table 10), in both the lean and peak seasons in both fisheries, a minimum of 3 to a maximum of 15 women were involved in fisheries activities. These results are in agreement with that of Fay-Sauni *et al.* (2008), who studied the involvement of Nadorian women in fishing activities in Fiji. Her study concluded that the sale of produce from the fishing activities of the women contributed to household income and revenue was used for paying school fees of children as well as buying household necessities.

When the pooled season was regressed with a dummy variable, no significant ($P > 0.10$) effect was found on percentage fish consumption (Table 12). This implies that on the whole, differences observed within seasons may not be very important or significant in determining fish consumption and consequently the dependence of livelihoods on the fishery. On the other hand, when the pooled site was regressed with a dummy variable (Table 12), a positive significant ($P < 0.01$) effect was found on the percentage share of fish consumption. This implies that the type of fishery which pertained in a particular geographical site was necessary or significant in determining the percentage share of fish consumption and consequently the degree of human reliance.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The following conclusions were drawn from the study:

- Ocean acidification is possibly occurring in Ghanaian waters, as evidenced by decreasing pH, decreasing carbonate ion concentration, decreasing calcite and aragonite saturation states, decreasing total alkalinity and increasing Revelle factor.
- There is evidence that ocean acidification has impacts on the abundance and diversity of fish species landed by the artisanal and semi-industrial fisheries
- Although it is not clear whether ocean acidification parameters are impacting on abundance and diversity of adult species of crustaceans, there is evidence that this could occur with their larvae.
- In view of the fact that the livelihoods of the artisanal and semi-industrial fishers relied significantly on the fisheries, they would be directly impacted by changes in abundance and diversity of the fisheries if the phenomenon of ocean acidification continue to persist in our waters.

6.2 Recommendations

Based on the findings, the following are recommended for immediate action in the light of on-going ocean acidification and its impacts:

- Commence long term studies of ocean acidification and fish diversity in Ghanaian coastal waters.
- Develop a bioclimatic model to further predict future impacts of ocean acidification on fish diversity in Ghana.

- Undertake tissue analyses of fish species to ascertain the uptake of carbon by fish.
- Institute an ocean acidification observance programme to effectively monitor changes in seawater carbonate chemistry and ocean acidification parameters.
- Further studies and research on impacts of ocean acidification on ichthyoplankton to inform abundance of fish stocks.
- Fisher folks must be educated on alternative livelihoods to ensure upkeep of livelihoods in the face of occurring ocean acidification of coastal waters.
- Support from Government and Fisheries Ministry for the development of fish farming as an alternative source of fish should ocean acidification lower the abundance of marine fish.
- Need for improved methods of preventing post-harvest losses by institutional research and Ministry interventions in order to ensure increased supply of fish in the face of occurring ocean acidification.

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APPENDICES

APPENDIX A: Interview guide administered to fisher folks in the two fisheries

UNIVERSITY OF GHANA

DEPARTMENT OF MARINE AND FISHERIES SCIENCES

Mphil Research Topic: Impacts of Ocean Acidification on Diversity of Fish Species Landed by Artisanal, Semi-Industrial, and Culture Fisheries, and Livelihoods.

Rights: This study is solely linked to research purposes and all information given would be used only for such purposes, held in confidentiality and would not in any way affect the livelihood of the respondent, legal or any other rights.

Target: Adults living within the sampling area

INTERVIEWER:_____________________________________DATE:____________

DEMOGRAPHICS

1. Name of respondent ……………………………………………………………
2. What is your role in the family?……………………………………………
3. Age……………………………….....
4. Gender…………………………….
5. Education level completed (JHS, SHS, O level, A level, technical, training, degree, diploma, HND…………………………………………………………

6. What is your household size? (No. of dependants/ people in household which respondent heads)…………………………………………………….………

7. How many of your dependents are students? ....

8. What is the highest level of education of the eldest dependant? (JHS, SHS, O level, A level, technical, training, degree, diploma, HND)

9. Which tribe do you belong to/ mother tongue? ………………………………...

10. What is your Primary occupation? …………………………………………..

11. What is your Secondary occupation? ………………………………………..

12. What are the sources of income for your household? (Rank according to importance)

(i) ……………………..

(ii)…………………………………………………………………………

(iii)………………………………………………………………………..

13. How much revenue do you make from your involvement with fisheries activities per day? ………………………………………………………..

14. Has there been any change in your revenue over the past year?

Yes [ ] No [ ]

a. If yes, what are some of these changes and please give reasons?……………………………………………………………………....

b. What is the percentage change? ……………………………………………

RESIDENCY

15. Where do you normally reside? ………………………………………………

16. Permanent [ ] Seasonal [ ]

17. If permanent, how many years have you been staying at this location? …….

18. If seasonal, how many years have you been coming to this location?……….

19. If seasonal, where is your origin? ……………………………………………

20. Are there any particular months you reside here seasonally? ....

RELIANCE ON FISH SPECIES

21. Rank in order of importance your main source of protein, indicating percentage (%) of consumption:

Fish [ ] Meat [ ] Chicken [ ] Eggs[ ] Plant sources [ ]Other [ ]

22. What are your preferred types of fish consumed? (Rank in order of importance)

1.

2.

3.

4.

5.

23. Where do you get your regular source of fish? : *Artisanal [ ] Inshore [ ]* *Culture [ ] Unknown [ ]*

24. How many times in a week do you take fish in your food? ………………..

    b. How many pieces do you take per meal? [ ] Small/ medium/ large?

25. How much do you spend on fish consumption per day or week? ....

26. Has there been any change in this cost over the past year? Yes [ ] No [ ]

27. If yes, what are some of these changes and give reasons …………………….....

    b. What is the percentage change?

28. How many men in your household are involved with fisheries activities in the community?………………………………………………………………..

29. Please specify (Fisher, fish monger, boat builder, etc) ………………………..

30. How many women in your household are involved with fisheries activities in the community? …………………………………………………………..

31. Please specify (Fisher, fish monger, boat builder, etc) ………………………

32. How many children in your household are involved with fisheries activities in the community? ………………………………………………………….

33. Please specify (Fisher, fish monger, boat builder, etc) ………………………

ATTITUDES AND PERCEPTIONS

34. How would you describe current conditions of the fisheries resources in terms of catch?

    Very good (5) good (4) not good or bad (3) bad (2) very bad (1)

35. What are the top 5 major threats to the sustainability of coastal resources?

    (1) ....

(2) ………………………………………………………………………………

(3) ………………………………………………………………………………

(4) ……………………………………………………………………………

(5) ………………………………………………………………………………

WEALTH

Material style of the house

36. Do you own your own house? Yes [ ] No [ ]

37. If No, do you live in (a) Family House [ ] or (b) Rented House [ ]

38. Size of the house: Number of rooms…………………………………………..

39. For household materials:

40. Type of roof: Tile [ ] Aluminium [ ] Wood [ ] Thatch [ ] Slate [ ]

41. Type of outside structural walls: Tiled [ ] Brick/Concrete [ ] Stone [ ] Mud [ ] Thatch [ ] Grass [ ]

42. Windows: Glass[ ] Frame[ ] Open[ ] Louvres [ ] Wooden[ ] None[ ]

43. Floors: Tile[ ] Wooden[ ] Cement[ ] Mud[ ]

44. Access To Water: Piped[ ] Private Well/Borehole[ ] Public Well[ ] River [ ] Public pipe [ ]

45. Power: Mains[ ] Solar Power[ ] Battery[ ] None[ ]

THANK YOU FOR YOUR HELP

APPENDIX B: Ichthyoplankton data by individual months and average

Month	Number of eggs	Number of larvae	Total number of ichthyoplankton per 10ml	Total number of ichthyoplankton per 200ml (N)	Number of revolutions	Volume of seawater filtered (m3) (V)	Number of ichthyoplankton per m3 (V/N)
Lean season							
Jan	2	5	7	140	3571	427.1	3.05
Feb	0	6	6	120	2682	320.8	2.67
Mar	10	15	25	500	5349	639.7	1.28
Aver							2.33
S.d							0.93
Peak season							
Aug	0	6	6	120	2480	296.6	2.47
Sept	1	1	2	40	1863	222.8	5.57
Octo	1	2	3	60	3495	418.0	6.97
Nov	1	5	6	120	7470	893.4	7.44
Dec	0	25	25	500	8597	1028.2	2.06
Aver							4.90
Standard deviation							2.51

APPENDIX C: Kruskal-Wallis H test results for relative abundance

i. Artisanal fishery

Kruskal-Wallis test:

K (Observed value)	0.263
K (Critical value)	3.841
DF	1
p-value (Two-tailed)	0.608
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 60.84%.

ii. Semi-industrial fishery

Kruskal-Wallis test:

K (Observed value)	0.982
K (Critical value)	3.841
DF	1
p-value (Two-tailed)	0.322
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 32.18%.

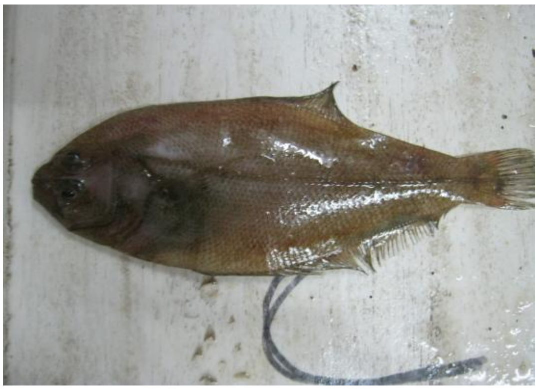
APPENDIX D: List of plates

Plate 1: Weighing of fish on the field using field hand scale KERN CH15K20

Plate 2: HANNA 9828 multi-parameter probe

Plate 3: Spectrophotometer DR800

Plate 4: Ichthyoplankton net



Scyacium micrurum

Scomber japonicus

Lagocephalus laevigatus

Chloroscombrus chrysurus

Trachinotus ovatus

Sardinella aurita

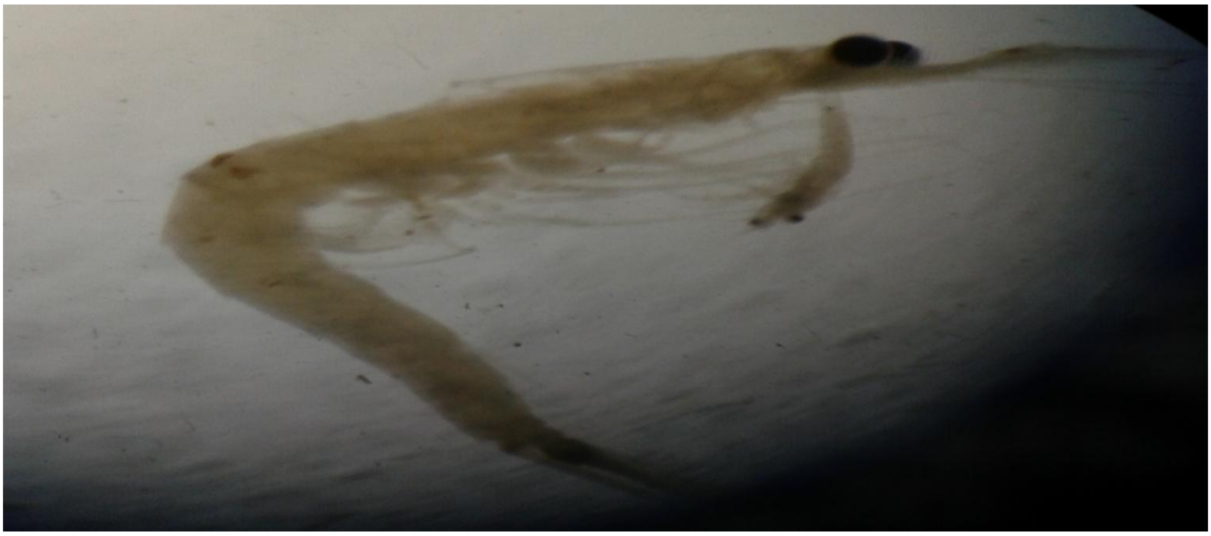
Sepia officinalis

Callinectes sapidus

Plate 5: Some identified fish species in the artisanal and semi-industrial fisheries

Larvae of *Scyacium micrurum* (Magnification 4x)

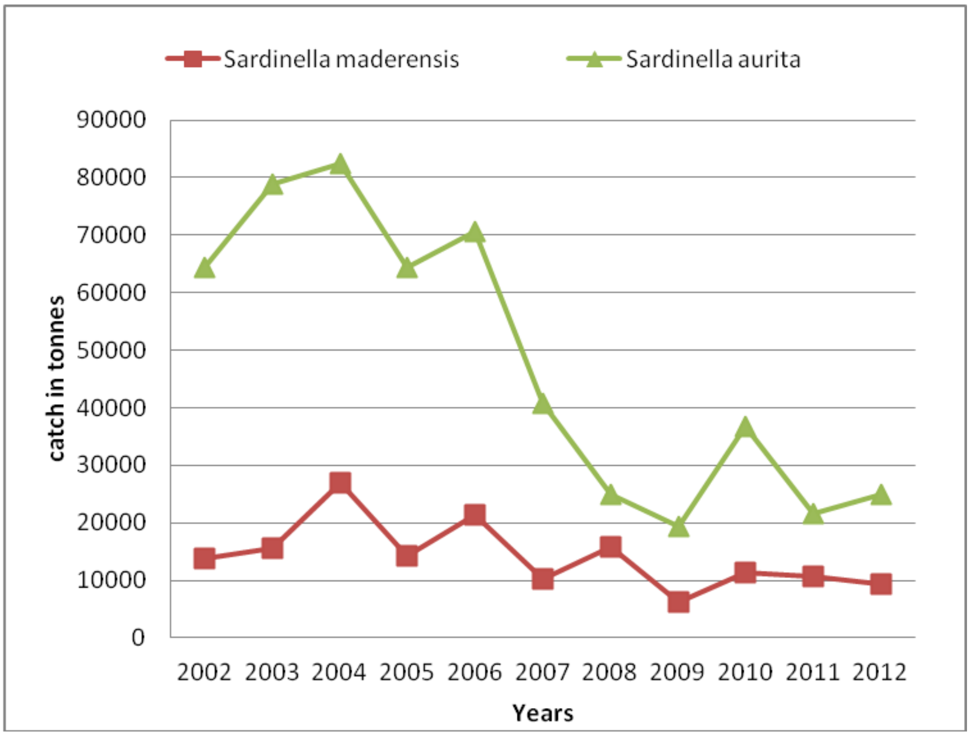
Larvae of *Sardinella aurita* (Magnification 4x)



Decapoda larvae (Magnification 4x)

Plate 6: Identified larvae in the artisanal fishery

APPENDIX E: Catch production of *Sardinella* species in Ghana



Source: www.fao.org