UNIVERSITY OF CAPE COAST

ANALYSIS OF CLIMATE VARIABILITY IMPLICATIONS FOR SARDINELLA FISHERIES IN GHANA

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BY

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Thesis submitted to the Department of Fisheries and Aquatic Sciences, College of Agriculture and Natural Sciences, School of Biological Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Integrated Coastal Zone Management

NOVEMBER 2018

DECLARATION

Candidate's Declaration

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

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

Name: ……………………………………………………………………

Supervisors' Declaration

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

Principal Supervisor's Signature ………………………. Date ……………

Name: ………………………………………………………………………

Co-Supervisor's Signature………………….. Date …………………

Name: ………………………………………………………………….

ABSTRACT

Over the years, marine fish production in Ghana has been on a downturn. The dwindling has been ascribed mainly to illegal fishing practices with less attention given to the possible effects of climate variability. This study sought to evaluate the impact of climatic variability on the sizes of Sardinella fish species, *S. aurita* and *S. maderensis,* captured by fishermen operating in Ghana's marine waters. The effect of climate variability on these fish stocks was evaluated through its effects on the strength of coastal upwelling as measured using changes in sea surface temperature (SST) and wind stress as proxies. The optimum length (22.6 cm) of *S. aurita* was found to be statistically significant with SST ($P<0.0001$), while an optimum length of 21.8 cm was also found for wind stress ($P<0.0001$). Also, local knowledge indicates that individual sizes of Sardinella species have decreased over the years (approx. 30 years). This finding confirms the results from the empirical aspects of the study. The results also show that the decrease in length of Sardinella species leads to low profitability of the fish trade, with its attendant impact on income. In conclusion, Sardinella fishery in Ghana is indeed collapsing and climatic variations due to sea surface temperature and wind stress are major contributing factors to the relatively smaller sizes of *S. aurita* landed in Ghana. This effect has implications for deepening poverty among local fishers and fish traders of these species. There is therefore the need to incorporate this impact of climate variability in fisheries management strategies in Ghana. It highlights the urgent need to consider these aspects of climate variability in adaptation planning in fishing communities for poverty alleviation in coastal areas of Ghana.

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DEDICATION

To Dr. K. A. Dankwa for being my anchor

TABLE OF CONTENTS

Content Page

LIST OF FIGURES

Figure Page

LIST OF TABLES

LIST OF ACRONYMNS

$CaCO_3$	Calcium Carbonate
CO	Carbon Dioxide
FAO	Food and Agriculture Organisation
FMP	Fisheries Management Plan
GBRMP	Great Barrier Reef Marine Park
GIPC	Ghana Investment Promotion Centre
GNCCP	Ghana National Climate Change Policy
ITCZ	Intertropical Convergence Zone
MESTI	Ministry of Environment Science, Technology and Innovation
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
SFMP	Sustainable Fisheries Management Project
SL	Standard Length
SST	Sea Surface Temperature
TL	Total Length
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar

CHAPTER ONE

INTRODUCTION

Background to the Study

Trends in the global climate

Climate is the average atmospheric conditions over a long period of time usually 30 years and beyond (Yankson, Acheampong & Asare, 2017; NASA, 2014). These atmospheric conditions include temperature, precipitation (Rainfall) and storm. They are the most frequently used indicators of climate (Yankson et al., 2017). Trends in these climate indicators have been observed and reported by many science-based organisations and institutions such as the National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA) all of the United States of America. In Figure 1, there is a clear trend of increase in global atmospheric temperature as well as increase in atmospheric carbon dioxide concentrations over a century and three decades (1880-2010). Figure 2 also shows a trend in annual global precipitation over a period of 115 years (1900-2015).

Climate change therefore is the change in average weather conditions over a long period of time for at least three decades (IPCC, 1996; NASA 2014). It is characterized by increase in the earth's average temperature as a result of emissions of greenhouse gases in the environment (Kaddo, 2016). Over the years there have been theories and empirical studies highlighting the causes of climate change as well as the real and potential threats.

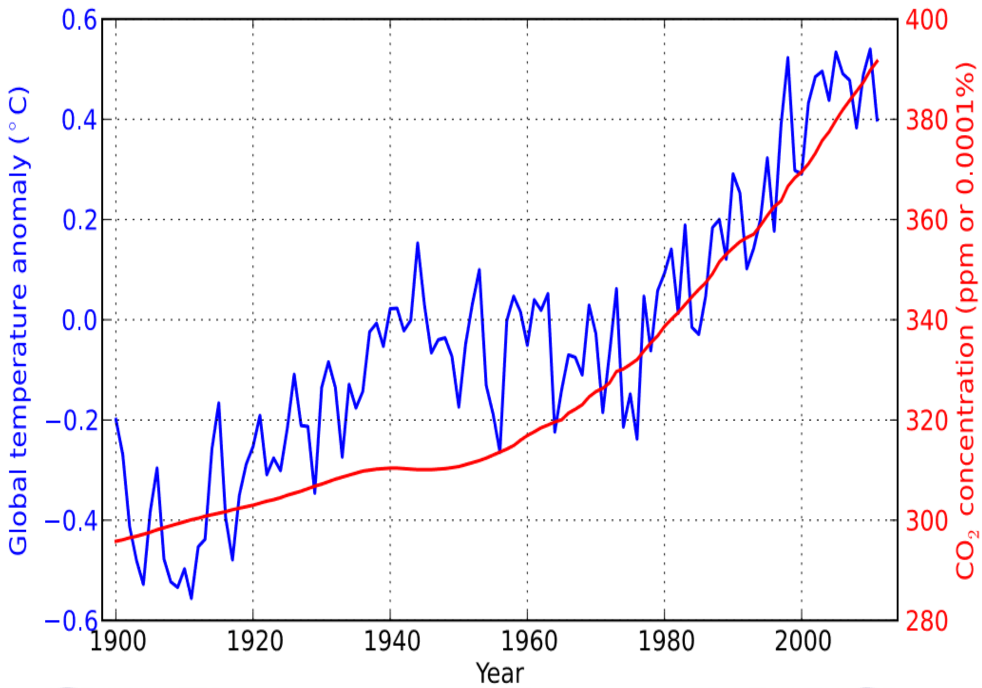

Figure 1. Trends in global temperature anomaly and atmospheric carbon dioxide concentrations.
(Source: https://www.geo.vu.nl/~gwerf/_plots/climate/T_CO2.pdf accessed on 5th September, 2018)

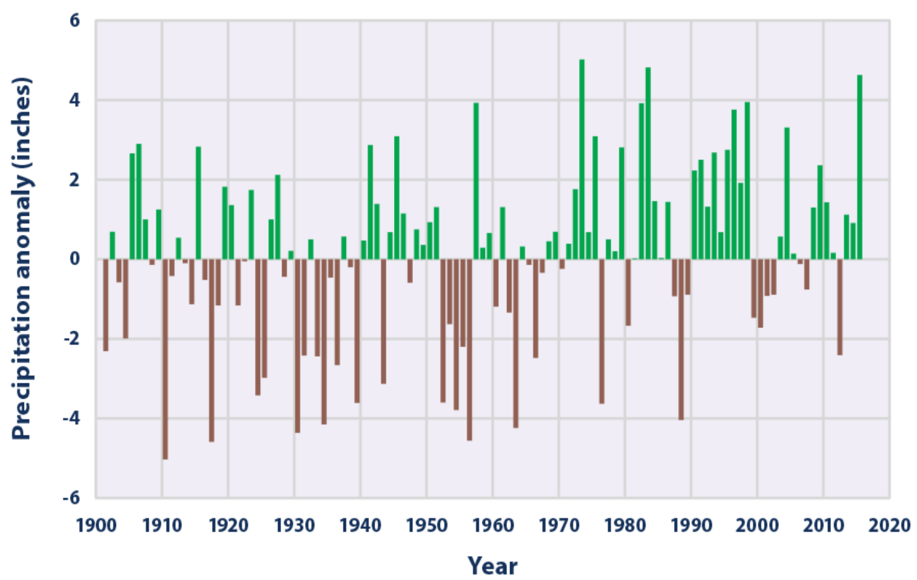

Figure 2: Trends in annual global precipitation from 1900-2016.
(Source:https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-precipitation#ref1 accessed on 5th September, 2018)

Causes of global climate change

Over the years there have been theories and empirical studies highlighting the causes of climate variability. There are three fundamental drivers of climate variability. They are: “the amount of solar radiation entering the earth’s atmosphere, the fraction of the solar radiation that is reflected back towards space, and the amount of radiation emitted by the earth towards space” (Yankson et al., 2017).

There are both natural and anthropogenic induced factors that trigger these drivers of climate variability. The natural factors include: volcanic eruptions, radiations from, the sun and internal climate fluctuations (El Niño and La Niña), (Crowley, 2000; US Global Change Research , 2009). However, climate variability is mainly caused by human activities such as the burning of fossil fuel and deforestation (UNFCCC, 1992). These activities release greenhouse gases including methane, halocarbons, and carbon dioxide (CO_2) which, according to United States Global Change Research (2009) and Kaddo (2016), is the most dominant greenhouse gas causing changes in climate, into the Earth’s atmosphere. These gases end up causing temperatures on earth to rise.

Effects of climate on global fisheries production

The CO_2 emissions and their associated change in the climate impact on marine ecosystems particularly, ocean acidity (Orr et al., 2005), sea surface temperature (Pörtner & Knust, 2007), surface wind events (Bakun, 1992) and ocean circulations (Ottersen, Kim, Huse, Polovina & Stenseth, 2010).

Consequently, it has been projected that variations in climate affects the physiological behaviour and development of marine organisms in many different ways (Merino et al., 2012) including the growth and production of many fish species (Barange & Perry, 2009). For instance, it has been reported that small pelagic populations are prone to considerable fluctuations caused by environmental variability which include temperature, wind, acidity and food (Bakun, 1996; Cury & Roy, 2002), essentially due to their relatively short life cycle (2–3 years) (Diankha et al., 2015).

Although the ocean is the largest carbon sink on earth and absorbs one third of the CO_2 emission in the atmosphere, this role in turn increases the hydrogen ions in the ocean which results into making the ocean more acidic (Hoegh-Guldberg & Bruno, 2010). Acidity of the ocean, affects unique ecosystems such as coral reefs and organisms especially shell fishes. This is because these organisms form their shells through a process called calcification and calcium carbonate ($CaCO_3$) is a requirement to complete this process. However, the process is chemically hindered or slowed down due to the acidic nature of the water (Orr et al., 2005; Hoegh-Guldberg & Bruno, 2010).

Fossa, Berllerby and Jakobsen (2011) pointed out that ocean acidification can affect fisheries through recruitment because the eggs and larvae are likely to be vulnerable to change in pH. Heinrich & Krause (2017) in a research carried out in Norway, concluded that the Norwegian fisheries industry is at risk due ocean acidification. In that same publication, they identified that 68% of selected countries they worked on were at either moderate or high vulnerability risk to ocean acidification.

Temperature has been found to be an important factor for the growth and survival of organisms. It influences fish species at different stages and survival of their lifecycles (Diankha et al., 2015). For instance, during spawning, at the development and survival of the egg stages and larvae as well as influencing distribution, aggregation, migration and schooling behaviour of juveniles and adults (Laevastu and Hayes, 1981 in Diankha, 2015). For example, in the North-eastern USA, Fogarty, Incze, Hyhoe, Mountain & Manning (2008) discovered that increasing water temperatures over the past four decades accounted for the general decline of Atlantic cod (*Gadus marhua*). They further found out that in the Gulf of Maine, the general increase in the water temperature also affects the survival of the Atlantic od in their early life stages. Wiafe, Yaqub, Mensah and Frid (2008) suggested that temperature could be responsible for the long-term decline in zooplankton biomass in the Gulf of Guinea. These zooplanktons play very important role in the transfer of energy from the lowest trophic level to the next.

The likely effect of climate variability on marine fish production in Ghana

This work focuses on the effect of climate variability on the marine fisheries of Ghana. The production of this fishery is mainly based on the capture of fish from the coast of Ghana which is part of the Gulf of Guinea - a large marine ecosystem - extending from Cape Roxo in Guinea Bissau to Cape Lopez in Gabon (Mensah & Quaatey, 2002). It is one of the world's very productive marine systems due to the annual occurrence of upwelling, i.e., the upward movement of dense, colder and nutrient-rich water to the surface of the ocean to power primary production and subsequently increased production of higher-level organisms including fish, in the region (Ukwe, Ibe, Alo & Yumkella, 2003).

Generally, there are two main types of this upwelling phenomenon: the coastal and equatorial upwelling, with the coastal upwelling being the dominant type in the Gulf of Guinea region (Addison, 2010). In the Gulf of Guinea, two periods of upwelling (major and minor) occur each year making the upwelling in this ecosystem different and interesting to study. The major upwelling occurs between July and September, whereas the minor upwelling normally only lasts for about 3 weeks during January and February, although it has been known to occur any time between December and March (Roy, 1995; Koranteng1998). According to Wiafe et al. (2008), the upwelling region of the Gulf of Guinea extends from the coast of La Cote d'Ivore to Benin. Ghana's coast is therefore within the upwelling region of the Gulf of Guinea.

The causes of upwelling phenomenon in the Gulf of Guinea are not well understood. Two main causes are however suspected: thermo-haline circulation and wind-driven Ekman Transport (Colin, 1988 in Djagoua et al., 2011; Djagoua et al, 2011; O'Brien, Adamec & Moore, 1978; Murtugudde et al., 1999). Thermohaline circulation is the part of the ocean circulation that involves warm, saline surface water flowing northward and the cold, dense water flowing southward at depth in the Atlantic basin the warm, saline surface water flows into high latitudes of the Northern Hemisphere where it is cooled and sinks to depth (Stouffer et al., 2006). Thermohaline circulation is susceptible to alteration when climate changes. Climate variability, as known, is associated with increase in SST. This increase in temperature is likely to hinder its occurrence as it requires difference in bottom and surface water temperatures to make the circulation occur. Ekman transport on the other hand is the horizontal mass transport associated with a wind stress applied on the ocean surface (Wenegrat & Thomas, 2017). Changes in sea surface temperature and wind stress over a long period of time, is probable to alter or hinder the occurrence of upwelling as these climatic factors tend to be the drivers of the upwelling.

The upwelling in the Gulf of Guinea has a significant effect on the abundance of pelagic fish, especially, Sardinella fishery (Bakun, 1992; Koranteng, 1998; Wiafe & Nyadjro, 2015) and on the rainfall distribution along the western African coast and the sub-Saharan countries (Lamb, 1978).

Problem Statement

Sardinella are small pelagic fishes of different species of which two main species *S. aurita* (round sardinella) and *S. maderensis* (flat sardinella) are exploited in the Gulf of Guinea. The round and flat sardinella are highly migratory. They migrate from the north to the south and vice versa, they migrate from Mauritania in North-Eastern Atlantic through to Angola in the South (Boely et al., 1979) (Figure 3). The optimal temperature interval for spawning of both species is between 18 ºC and 21.14 ºC (Ettahiri, Berraho, Vidy & Ramdani, 2003).

Sardinella fishery is one of the most important fisheries worldwide. Many of its species which include *Sardinella aurita*, *S. maderensis*, *S. fimbriata*, *S. gibbosa* occur in tropical and subtropical ocean and coastal water bodies (Lawson & Doseku, 2013). *S. aurita* and *S. maderensis* are among the most abundant small pelagic species in Africa with more than two million tons of catch per year (Ahmed, Benzer & Elahi, 2016). In terms of food and nutritional security in terms of animal protein, these two *Sardinella* species are strategic products for African populations (FAO, 2010). These species are of high commercial importance. They are marketed fresh, frozen, smoked, salted, dried, canned and at times used as bait in fishing.

In the 1970s, Sardinella fishery reached points of near collapse but bounced back from the mid-1980s, where there was remarkable increase in abundance in the West Gulf of Guinea (Bard & Koranteng, 1995; Mensah, Koranteng, Bortey & Yeboah, 2006). From this period, landings of Sardinella have been declining time to time similar to the decline of most pelagic resources worldwide which is linked with the changes in the marine environment (Bard & Koranteng, 1995). Along the Gulf of Guinea, countries including Cote d'Ivoire, Ghana, Togo and Benin are considered to be fully exploiting these *Sardinella* species. Koranteng (1991; 1995) recounts that they can constitute about 40% of annual marine landings in Ghana of which *S. aurita* is most abundant (Mensah & Quaatey (2002).

Figure 3: The Migration path of *Sardinella* species from Mauritania to Angola

There have been several studies suggesting that fisheries production across the globe are in crisis (for example, see Asiedu & Nunoo, 2013, Merino et. al., 2012 and Pershing et. al., 2015). Many researchers have attributed the decline in fisheries productivity to overfishing (Buchsbaum, Pederson & Robinson, 2005; FAO, 2010), population growth, high demand for fisheries products (Asiedu & Nunoo, 2013) and global climate fluctuations (Buchsbaum et al., 2005). Interestingly, although *Sardinella* species are among the most abundant small pelagic species in West Africa coasts (FAO, 2010), they are among the global threatened fisheries. Sardinella productivity has been recorded to be declining at an alarming rate in the Gulf of Guinea (see Atta-Mills, Alder & Sumaila, 2004; Lazar et al., 2017). A major threat to the productivity of Sardinella fisheries has been identified as climate variability.

In the last 3 decades, significant changes have occurred in the biological and physical components of the Gulf of Guinea marine ecosystem and in near shore forcing factors that could have an effect on species aggregations in the sub-region (Koranteng, 1998). On this basis, Merino et al. (2012) projected that variations in climate over years will affect fish production as well as fisheries-based economies. Decline in Sardinella landings have been recorded in Ghana. Figure 4 shows a decline in landings of round and flat sardinella from 10,983 (2000-2004) tonnes to 3,248 tonnes in (2010-2014).

Socio-economic implication of the effects of climate variability

Fishing is an essential source of livelihood in many developing nations, particularly for low-income families in coastal areas (Clause & York, 2008). It is regarded as a way of life for some people (Bard & Koranteng, 1995) and for others, it is a source of income as well as a source of animal protein (FAO, 2010). In West Africa, some developing countries according to (Neiland, 2006), export fish to Europe and other developed countries serving as a source of foreign exchange for these countries. In 2003 alone, fish exported from West Africa to European Union was worth €642 million.

Atta-Mills et al. (2004) gave an in-depth description of the cultural and economic importance of artisanal fisheries in Ghana. Their work as well as that of Koranteng (1998) opined that the decline of Ghana's marine fish production since 1992 is due to the reduction in landings of Sardinella species especially the *S. aurita*. For a period of four years, 1992 to 1996, when Ghana's marine fisheries production started declining to date, Atta-Mills et al. (2004) noted that 100,000, jobs accounting for 20% of the national labour force, was affected. This underscores, without exaggerating, the importance of marine fisheries and for that matter Sardinella fishery in Ghana.

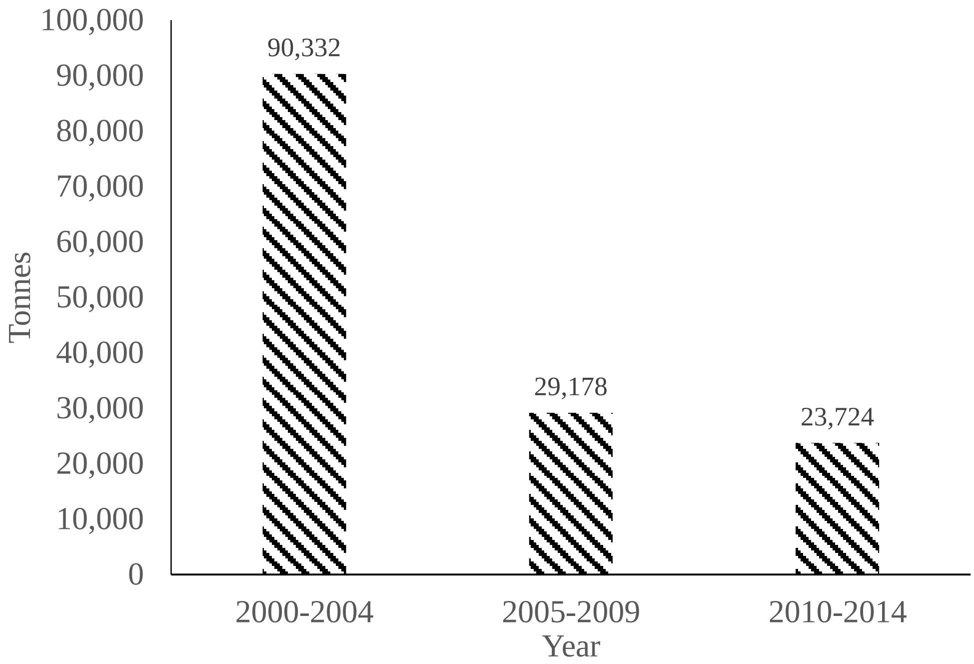

Figure 4: The landings of Sardinella in Ghana from 2000 - 2014
(Data source: Sustainable Fisheries Management Project)

These problematic issues are elaborated in the following sections.

Gaps in scientific knowledge on Sardinella production vis-à-vis the effect of climate change

Fisheries scientists have so far exhibited knowledge on the effects and potential effects of climate change on fish production. Most often than not, these researchers compare total landings of the fish species under study to changes in ambient conditions such as temperature and salinity. For example, see works by Aggrey-Fynn (2007) on *Balistis capriscus* and Koranteng (2001) on Sardinella species in the Gulf of Guinea. These methods are good. However, they do not capture the effect of climate variability on the organisms at the individual level i.e. how exactly climate variability can affect each fish (probably considering an aspect of the biology of the fish).

Climate change adaptation: inadequate use of indigenous Ghanaian knowledge on impacts 0f climatic variations

Indigenous people who live close to the natural resources, observe the activities around them and are first to identify any changes and adapt to them (Gyampoh, Amisah & Idinoba, 2009). Most coastal fishing communities in Ghana, for example, regard fishing as part of their culture and as such the people take note of periodical environmental occurrences seriously. This makes them conscious of every significant change in their microclimate which may affect the resources they depend on. They interpret and react to climate variability impacts in creative ways, drawing on traditional knowledge as well as new technologies to find solutions, which may help society at large to cope with the impending changes (Byg & Salick 2009). These regardless, little attention has so far been given to local knowledge on climate variability, its causes and potential effects on fisheries.

Justification

The strength of upwelling responsible for Ghana's marine fish production is thought to be driven by the effect of SST and wind stress. Evidence (Addison, 2010; Wiafe & Nyadjro, 2015) suggests that these two physical conditions are affected by global climate variability. Also, change in sea surface temperature and wind stress which results in upwelling, have direct and indirect impact on Sardinella productivity. Although certain researches such as Wiafe et al. (2008) has found that climate change has effect on copepods, which are major food source for Sardinella species, a gap in literature exists in the understanding of the likely effect of climate variability, through upwelling, on the total fish production in the Gulf of Guinea with focus on the individual fishes.

Aim and objectives

The main aim of this study was to evaluate the impact of climate variability on Ghana's Sardinella fisheries through its effect on coastal upwelling by using sea surface temperature and wind stress as proxies for the strength of upwelling. The study focuses on how these proxies are likely to affect the growth, specifically length-at-age, of the *Sardinella* species.

The specific objectives were:

1. To determine the effect of climate-induced changes in
    I. sea surface temperature on length-at-age of *Sardinella* species
    II. wind stress on the length-at-age of *Sardinella* species
2. To evaluate the potential impact of climatic variability on the market prices and sizes of *Sardinella* species
3. To investigate traditional understanding of climate variability and its influence on fisheries resources.

Hypotheses

1. Climate-induced changes of sea surface temperature have no influence on the length-at-age of *Sardinella* species
2. Climate-induced changes in wind stress have no influence on the length-at-age of *Sardinella* species
3. Climatic variations have no influence on the market prices of *Sardinella* species

Significance of the Study

The outcome of this research will contribute to better policy formulation and decision making in the area of fisheries and coastal zone management in Ghana. It would also to provide relevant scientific baseline data on which further studies on this issue may be grounded.

Delimitations

During the study, fish samples were obtained from four major fish landing sites along the coast of Ghana. This was to ensure that all populations in the fish stock were well represented as the *Sardinella* species are migratory.

Limitations

Fish samples were collected over a period of nine (9) months. It would have been ideal if they were collected for 12 months in order to cover all the seasonal variations with a year. This was largely due to logistical and financial constraints.

CHAPTER TWO

LITERATURE REVIEW

Chapter 1 clearly discusses the effect of global climate variability on the productivity of marine fisheries. This aspect of the thesis mainly focuses on the effect of climate variability on other sectors and systems crucial for the livelihood and economies of artisanal fishing communities.

The Effects of Climate Variability on Coastal Ecosystems

Coastal ecosystems include a diverse set of habitat types, encompassing marine, estuaries, coastal interface, mangroves, terrestrial and freshwater environments (Robbins, 2009; GBRMP, 2012; Alejandro, Meiner, Bowen & Anson, 2015). Coastal ecosystems are among the most productive, yet highly threatened systems in the world. The continued increases in temperature, sea level rise, altered weather patterns, ocean currents, and atmospheric carbon dioxide (CO_2) concentrations affect the physical and biological characteristics of coastal systems, modifying their ecosystem structure and functioning (Yanda, 2013). It is widely acknowledged that the coastal and marine environments are undergoing drastic changes as a result of both natural and anthropogenic induced factors (Nicholls & Cazenave, 2010; Michel and Pandya, 2010). For instance, between 1961 and 2003, global ocean temperature rose by 0.10°C from the surface to a depth of 700 m; the increase has also been observed on the global ocean heat content from the surface to a depth of 3,000 m (Bindoff et al., 2007). Such an increase and the resulting thermal expansion have been linked with the rise of global mean sea level; that is observed to rise at an estimated projection of 9 to 88 cm between 1990 and

2100, with a central value of 48 cm (Klein, Nicholls & Thomalla, 2002). It is predicted that changed patterns of SST and precipitation and rise in sea level may have significant temporal and spatial impacts on fisheries (Alusa & Ogallo, 1992) especially, coastal nations (Vergara, 2008; Michel & Pandya, 2010).

Effect of climate change on wetlands

Wetlands cover 6% of the world's land surface and contain about 12% of the global carbon pool, playing an important role in the global carbon cycle (IPCC, 1996; Ferrati, Canziani & Moreno, 2005). They provide many environmental services, including serving as hydrological buffers; human settlement protection through flood control; protection of the coastal region; help in mitigating storm impacts; control of erosion; conservation and replenishing of coastal groundwater tables; reduction of pollutants; regulation and protection of water quality; retention of nutrients, sediments, and polluting agents; sustenance for many human communities settled along the coast; and habitats for waterfowl and wild life (Bergkamp & Orlando, 1999; Erwin, 2009).

It is estimated that the total global value of services provided by coastal areas and wetland ecosystems is 15.5 trillion USD yr^{-1} being 46% of the total value of services that global ecosystems are estimated to provide (Costanza et al., 1997). It is generally understood, however, that increases in temperature, sea-level rise, and changes in precipitation will degrade those benefits and services. These changes will likely affect waterfowl that are dependent wetlands as habitats, and may contribute to desertification processes (Bergkamp & Orlando, 1999).

More so, such changes may also result in the loss of important brackish water habitats. Migratory and resident fish species as well as other living organisms may lose important staging, feeding, and breeding grounds, which are difficult to replace under competing demands for scarce land (Vergara, 2008). These deteriorations of wetland habitat, may result in impacts on commercially important fish species, seriously affecting the sustainability of fisheries.

Impact of climate variability on mangroves

The mangrove ecosystems are the inter-tidal and super-tidal muddy shores found in bays, lagoons and estuaries and form an important component of our natural ecosystems. They are dominated by woody halophytes which are highly adapted with continuous water courses, swamp and backwaters (Pinto, 1986). Mangroves feed and breed an amazing diversity of economically and ecologically important flora and fauna (Walters et al., 2008, Valiela et al., 2009). Mangroves are important nursery grounds and breeding sites for fish, crustaceans, birds, reptiles, mammals, and many other semiterrestrial and estuarine organisms; they help to ameliorate coastal erosion and the impacts of extreme events, such as tsunamis and cyclones (Kennedy, Twilley, Klepas, Cowan & Hare, 2002). Also, mangroves contribute to global climate mitigation efforts through CO_2 sequestration, provide resources for household activities and livelihoods for coastal communities, who are usually marginalized in terms of economy (Mukherjee, Dicks, Koedam & Guebas, 2014).

With the present trends of global warming, climate related factors are affecting the survival of mangrove ecosystems. Increasing temperature, increasing atmospheric CO_2, change of precipitation patterns, frequency and intensity of tropical storms and most importantly sea level rise are the main climate change driven factors that are affecting mangrove ecosystems and livelihood (McLeod & Salm, 2006). Sea level rise is a major potential climate change threat to mangrove ecosystems, because mangroves are sensitive to changes in inundation duration and frequency as well as salinity levels that exceed a species-specific physiological threshold of tolerance (Friess et al., 2012). He et al. (2007) has opined that increasing flooding duration can lead to plant death at the seaward mangrove margins as well as shifts in species composition (Gilman, Ellison, Duke and Field, 2008), ultimately leading to a reduction in productivity (Castañeda-Moya, Twilley & Rivera-Monroy, 2013) and ecosystem services. High temperature influences the ability of mangroves to assimilate CO_2 as a result of the limitations to biochemical reactions (Ball, Cowan & Farquar, 1988) and freeze plant tissue leading to vascular embolism, dehydration, or cellular rupture (Krauss et al., 2008). Furthermore, high temperatures increase evaporation rates, which can result in salinity increases; the synergistic impacts of salinity and aridity have been established to influence species diversity, size, and productivity of mangrove forests (Smith & Duke 1987; Ball & Sobrado, 2002).

Impact of climate variability on lagoons

A coastal lagoon is a "shallow coastal water body separated from the ocean by a barrier, connected at least intermittently to the ocean by one or more restricted inlets" (Anthony et al., 2009). Coastal lagoons are highly productive ecosystems contributing to the overall productivity of coastal waters by supporting a variety of habitats, including salt marshes, seagrasses and mangroves (Weisenberger & Chouinard, 2015). They provide essential societal values, habitat for many fish species, shellfish species, and feeding grounds for variety of organisms including birds and reptiles (Harris et al., 2004). Lagoons have relatively low flushing rate which makes it more favourable habitats for phytoplanktons and most aquatic plants (Anthony et al., 2009).

It is predicted that global climate change will have adverse effect on the physical structure, ecological characteristics and societal services of lagoons (Kennedy, Twilley, Klepas, Cowan & Hare, 2002; Anthony et al., 2009; Schroeder & Castello, 2010). Rise in sea level causes lagoons to retrieve landward resulting in steeper and narrower barrier profiles and shorten the length of existing inlets (Bird, 1994). When this happens, it is likely to increase the barriers' flushing rate (Zimmerman, 1981). As seawater inundates lagoon ecosystems, salinity is likely to increase, resulting in alteration of species composition (Mackenzie, Gislason, Möllmann & Köster, 2007). Also, rise in sea temperature reduces light penetration to submerged aquatic vegetation in lagoons, reducing photosynthetic potentials of the primary producers and changing nutrient dynamics making the lagoons more prone to eutrophication (Lloret, Marin & Marín-Guirao, 2008).

Changes in atmospheric temperatures strongly influence the temperature of slow-moving, shallow water bodies such as coastal lagoons (Turner, 2003). Change in temperature affects dissolved oxygen concentrations, as well as the physiology of lagoon organisms, species' range and patterns of migration (Turner, 2003). This is because, many marine species live close to their thermal threshold, with the slightest alteration in temperature can have impacts on their viability (Tomanek & Somero, 1999). Also, lagoons are prone to increase in the colonization of invasive species that may thrive in warmer waters (Stachowicz et al., 2002). Increase in lagoon temperature is likely to decrease dissolved oxygen concentrations which will affect the aerobic biota, with benthic communities expected to be stressed (Anthony et al., 2009). Increase in temperature has been recorded to change the phenology of lagoon processes. For instance, changes in atmospheric temperature has affected the timing and route of migrating birds that stops over lagoons (Gatter, 1992). Evidence of change in plankton phenology has been observed by Edward and Richardson (2004) with zooplankton becoming more active in the year following relatively warm weather.

Impact of climate change on coral reefs

Coral reefs are ecosystems typically found in shallow waters of the intertropical zone. Corals are named "engineering organisms", while the reef is considered "biogenic" because they are the result of biological activity. Coral reefs therefore represent ecosystems that have been built by their own inhabitants (Allemand et al., 2004; Goldberg, 2013). Coral reefs are found in only a small percentage of global oceans, between 0.08 and 0.16 %, but they shelter about one third of the marine species known today. This ecological success is due to a symbiosis between a coral and an intracellular microalga, commonly called zooxanthellae (Allemand et al., 2004).

Increasing ocean temperature might have significant adverse effects on coral reefs. The reefs are very important resources for humans and marine species, as they provide habitats to plants and animals, and protection of coastal areas from storm and wave damage; and they act as attractive scenery for tourism activities along the coast (Pallewatta, 2010). The increasing ocean temperature might lead to coral bleaching, whereby zooxanthellae that live within the coral in a symbiotic arrangement die and finally, in turn, so does the coral. Likewise, ocean acidification has been observed to affect coral reefs as it corrosive to coral growth; and it is predicted that "by the middle of the next century, the process of coral calcification will decrease to the level where erosion will be greater than new growth" (Kennedy et al., 2002; Pallewatta, 2010). Such situations would have devastating impacts on the coastal communities that have some kinds of dependences11 on coral reefs, as the reefs "constitute the basis of food security and incomes for many coastal people" (Muthiga et al., 2008).

Effects of Climate Variability on Agriculture

Artisanal fishermen in the fishing industry operates mostly in the bumper season where there is abundant of fish and operates less during the lean season. During the lean season, it is believed that some Ghanaian artisanal fishermen venture into agriculture to earn a living (Asiedu & Nunoo, 2013). Therefore, whatever that affects agriculture would affect the artisanal fishermen.

The agriculture sector both contributes to climate variability and is equally affected by changing climate (Aydinalp & Cresser, 2008). Agriculture is weather and climate dependant (Wreford, Moran & Adger, 2010) and climate is an important factor of agriculture productivity (Aydinalp & Cresser). The Intergovernmental Panel on Climate Change (IPCC) has predicted that the world's agriculture faces a serious decline within this century due to global warming. Generally, agricultural productivity for the entire world is projected to decline between 3 and 16 % by 2080 but developing countries are to suffer an average of 10 to 25% decline in agricultural productivity by the same period (IPCC, 2007).

Climatic change could affect agriculture in several ways such as quantity and quality of crops in terms of productivity, growth rates, photosynthesis and transpiration rates, moisture availability (Wreford et al., 2010; Mahato, 2014). Mahato (2014) categorized the effect of climate in three ways. Firstly, increased atmospheric CO_2 concentrations can have a direct effect on the growth rate of crop plants and weeds. Secondly, CO_2-induced changes of climate may change levels of temperature, rainfall and sunshine that can influence plant and animal productivity. Also, rises in sea level may lead to loss of farmland by inundation and increasing salinity of groundwater in coastal areas. An atmosphere with higher CO_2 concentration would result in higher net photosynthetic rates (Cure & Acock, 1986). Higher concentrations may also reduce transpiration (i.e. water loss) as plants reduce their stomatal apertures, the small openings in the leaves through which CO_2 and water vapor are exchanged with the atmosphere.

Livestock are also affected by climate change effects, basically, in two ways. The quality and amount of forage from grasslands may be affected and there may be direct effects on livestock due to higher temperatures (Adams et al., 1998). Indirectly, higher feed prices as a result of climate variability is likely to drive prices up. For example, it has been experimented that beef prices will be 60% higher with climate variability and no CO_2 fertilization for crops (Nelson et al., 2009). The overall consequences of agriculture's contribution to climate variability, and of climate change's negative impact on agriculture, are severe and is projected to have a great impact on food production and may threaten the food security (Mahato, 2014).

Influence of Climate Variability on Pests and Diseases Outbreaks

The effect of global climate variability and spread of diseases in both plants and animals is well recognised by several authorities including the Food and Agriculture Organisation (FAO, 2010). These effects are discussed in the following sections.

Climate Variability Effect on Plant and livestock Diseases

Interactions between temperature and CO_2 are recognised as a key determinant in plant damage from pests in the future, and interactions between CO_2 and precipitation are also likely to be important (Stacey & Fellow, 2002). Changes in temperature and precipitation regimes due to climate variation may alter the growth stage, development rate and pathogenicity of infectious vectors, and the physiology and resistance of host plants (Mboup et al., 2012). It can also affect disease management by altering efficacy of biological and chemical control options (Coakley, Scherm & Chakraborty, 1999). Some significant changes that will likely influence the severity of plants disease under elevated CO_2 are lowered nutrient concentration, leading to the partitioning of nitrogen from photosynthetic proteins to metabolism that is limiting to plant growth (Chakraborty et al., 1998). Elevated CO_2 is expected to increase canopy size and density, resulting in greater biomass of high nutritional quality, combined with higher microclimate humidity (Wreford et al., 2010). These changes will likely promote foliar diseases such as rusts, powdery mildews, leaf spots, and blights (Manning and Tiedemann 1995; Coakley et al., 1999).

Moisture can also impact both host plants and pathogens in various ways. Some pathogens such as apple scab, late blight and several vegetable root pathogens are more likely to infect plants with increased moisture content because forecast models for these diseases are based on leaf wetness, relative humidity and precipitation measurements (Coakley et al., 1999).

With respect to animal diseases, especially livestock, climate variability has been shown to be potentially life-threatening to livestock as it decreases productivity and conception rates (IPCC, 2007). Studies have shown that the spread of animal diseases from low to mid-latitudes is occurring today. Example is the bluetongue disease that affects cattle and sheep that is spreading from the tropics to the mid-latitudes including France and UK (Wreford, Mora & Adger, 2010). Sudden changes in climate, such as severe weather events, often results in large losses to stock in confined cattle lots, as they have no prior conditioning to this event (Mader, 2003). High temperatures and droughts are likely to induce increases in mortality, yield, and conception rates, for animals that are not accustomed to higher temperatures (IPCC, 2007). Easterling et al. (2007) found a strong relationship between droughts and animal death, especially in Africa and Mongolia.

Assimilations of animal energetics and nutrition have shown that high temperatures put a ceiling on milk production, regardless of feed intake. Extreme events and weather are predicted to have far greater impact on animal productivity than associated with average changes in climate (IPCC, 2007).

Human diseases

Warming oceans and a changing climate are resulting in extreme weather patterns which have brought about an increase in both new and re-emerging infectious diseases. The intense weather patterns are generating extended rainy seasons in some parts of the world and others, extended period of droughts (Epstein & Dan, 2011a). These extended seasons are creating climates that are able to sustain disease causing organisms for longer periods of time, allowing them to multiply rapidly, and also creating climates that are allowing the introduction and survival of new vectors (Epstein & Dan, 2011b).

The greatest threat to human beings is mosquito-borne diseases which include malaria, elephantiasis, dengue fever, yellow fever and rift valley fever (McMichael, Woodruff & Hales, 2006). Research has shown higher prevalence of these diseases in areas that have experienced high flooding and drought (Paul, 2001; Hunter, 2006). Flooding creates more standing water for mosquitoes to breed and these vectors are able to feed more and grow faster in warmer climates. As the climate warms over the oceans and coastal regions, warmer temperatures are also creeping up to higher elevations allowing mosquitoes to survive in areas they had never been able to before (McMichael et al., 2006). The warming oceans are becoming a breeding grounds for toxic algae blooms and cholera (Paul, 2001; Epstein & Dan, 2011a). As the nitrogen and phosphorus levels in the oceans increase, the cholera bacteria that lives within zooplankton emerge from their dormant state (Epstein & Dan, 2011a). The changing winds and changing ocean currents push the zooplankton toward the coastline, carrying the cholera bacteria, which then contaminate drinking water, causing cholera outbreaks (McMichael et al., 2006). As flooding increases there is also an increase in cholera epidemics as the flood waters that are carrying the bacteria are infiltrating the drinking water supply (Michael & Jeremy, 2008).

The American Heart Association (2009) statistics have shown evidence of climate sensitivity for several cardiovascular diseases, with both extreme cold and extreme heat directly affecting the incidence of hospital admissions for chest pain, acute coronary syndrome, stroke, and variations in cardiac dysrhythmias, though the reported magnitude of the exposure-outcome associations is variable. There is also evidence that heat amplifies the adverse impacts of ozone and particulates on cardiovascular disease (Fouillet et al., 2006).

Effect of Climate Varibility on Coastal Infrastructure

The expected change in global climate will significantly impact on coastal settlements and infrastructure in diverse ways (Lewsey, Cid & Kruse, 2004; Neumann et al., 2014). Transportation, infrastructure, water and tourism are sectors sensitive to climate extremes (Almeida & Mostafazi, 2016). The expected damage to infrastructure for selected climate variability phenomena, for example high precipitation, cyclones, sea level rise and inland flooding may result in coastal inundation, flood damage to homes and properties, and expedite the erosion of roads, ports and bridges (Fakhruddin, Babel & Kawasaki, 2015). However, coastal infrastructure is likely to be exposed to other climate variability hazards. For example, saltwater intrusion may be of particular concern for the numerous old dump sites and rubbish tips around the coast, and potential changes in wind speed and extreme storm events could cause damage or fatigue to structures (Nicholls & Cazenave, 2010).

The IPCC (2013) report shows that increased extreme rainfall will increase risk of flooding of coastal settlements and infrastructure. The flooding of electricity and water supply infrastructure along coastal areas may lead to power outages and contaminated water supply, and flooding of sewage works may put settlers out of action leading to risks to public health.

The effects of climate variability on rural coastal livelihood cannot be over emphasised. Rural coastal livelihoods are inherently dependent on all the different ecosystems discussed above. For example, mangrove does not only serve as nursery, spawning and breeding grounds for marine fishes. The local people harvest mangroves for their medicinal uses as well as for firewood to smoke fish (Aheto et al., 2016). Oyster, crabs and other shell fishes are also harvested in different forms from some of these ecosystems, especially, mangroves and lagoons.

CHAPTER THREE

MATERIALS AND METHODS

Sampling Sites

Data on the sizes of fish, their market prices, and indigenous understanding of climate varibility effects were collected from three coastal Regions in Ghana i.e. the Western, Central and Greater Accra Regions. Samples of round and flat *Sardinella* species were purchased from landings at the Tema Fishing Harbour in the Greater Accra Region, and the Elmina landing quay in the Central Region. In the Western Region, the fish samples were purchased at the Albert Bosomtwi-Sam Fishing Harbour in Sekondi and Half Assini fish landing site (Figure 5). Socio-economic data was also collected from all the four fish landing sites mentioned as well as from major fish markets in the regions. The fish markets include Agbogbloshie market in the Greater Accra Region, Mankessim and Elmina markets in the Central Region, and Sekondi market in the Western Region.

For this study, primary and secondary data were collected. Primary data was obtained from fish samples and feedback based on interviews and focus group interviews with fisherfolks at the various sampling sites. Secondary data were obtained from existing studies on growth of *Sardinella* species in Ghanaian waters, in addition to wind and temperature variability data over the past 30 years (1982-2017)

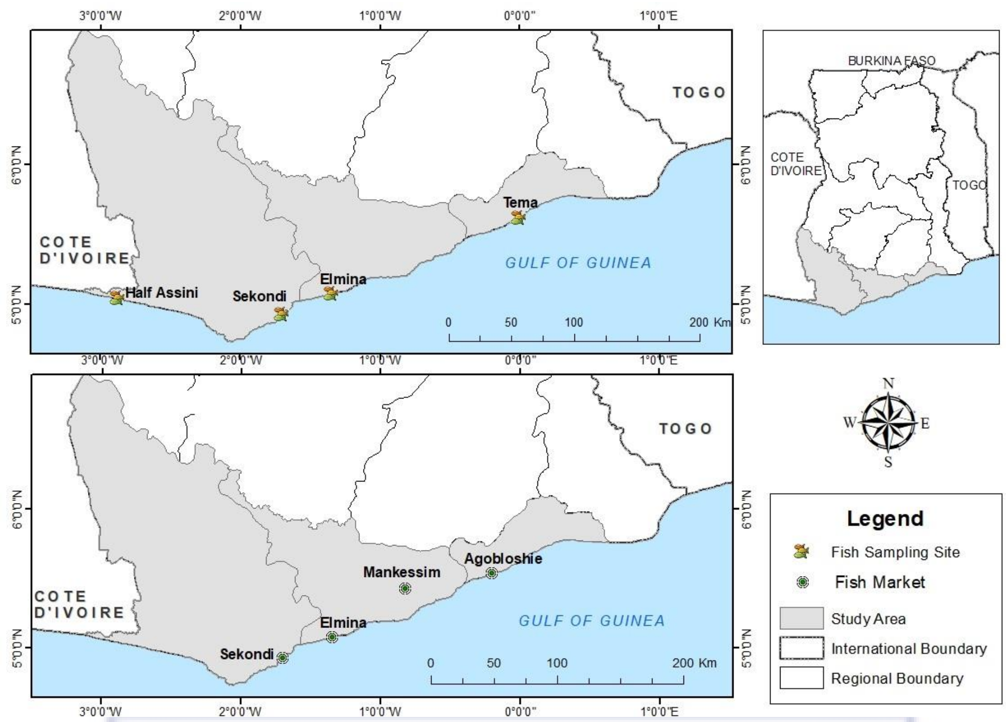

Figure 5: The study area showing various sampling locations of fish samples, and indigenous knowledge

Determination of Temperature and Wind Stress Anomaly Effects on *Sardinella* Species

To evaluate the effect of temperature and wind stress on growth (length) of individual fish species, the age of each fish sample was determined and compared to the average temperature and wind stress anomaly conditions the fish had experienced throughout its lifetime.

Determination of temperature and wind stress anomalies

In order to evaluate the effect of climate variability on the growth of the fish in this study, all the climate varibility induced temperature and wind stress anomalies experienced by the fish were determined. The calculation was done based on the procedure given by Rodriquez et al. (2012); described as the monthly variation from the mean temperature value over the period of 35 years studied.

First and foremost, wind stress had to be which was derived from the equation:

$\tau = C_d P_a U^2$(kg/ms) (Weisberg & Wang, 1997), where τ= wind stress; C_d= dimensionless drag coefficient (1.43×10^{-3}) ρ_a= density of air (1.225kgm^{-3}); U=wind speed above 10 metres.

Estimation of age of fish

The age each individual fish s was calculated using the equation below;

$t = t_{\circ} - \frac{1}{k} x \ln(1 - \frac{L}{L\infty})$……..........................1

In order to estimate the growth parameters (variables in equation 1) of each species, monthly length-frequency data were estimated using ELEFAN 1 routine in FiSAT II software (Gyanilo et al., 2005). Growth parameters that were analysed include asymptotic length (L_∞) and growth coefficient (K) of each of the two *Sardinella* species (Pauly, 1985). Based on the estimated L_∞ and K, longevity (t_{max}) and theoretical age at length zero (t_o) were estimated according to the following equations:

t_{max} = 3/ K (Pauly, 1984a) ……………………….2 and

Log_{10} (t_o) = 0.392 – 0.275Log_{10} L_∞ – 1.038 Log_{10} K (Pauly, 1979a) ….3 respectively.

Determination of length (l) of fish

Samples of *Sardinella* species were purchased from landings at the various sampling sites in the second and third week of each sampling month for nine consecutive months, starting from October, 2016 to June, 2017. Samples were immediately kept on ice and transported to the laboratory for further analyses.

Length measurement

In the laboratory, fish of the species *aurita* and *maderensis* were identified using Schneider, (1990). Basic morphometric parameters; total length (TL), fork length (FL) and standard length (SL) were measured to the nearest 0.1 cm using a fish measuring board (Figure 6) and values recorded. The body weight of each individual was also measured to the nearest 0.01g using a digital pocket scale and recorded (Figure 7).

Figure 6. Researcher measuring the length of fish samples in the laboratory

Figure 7: Weight measurement of a *Sardinella aurita* sample

Determination of Average Temperature Conditions

After estimating the age of an individual fish, the month and year of birth of the fish was inferred from the age of the fish (in months) and month of sampling. The average temperature and wind stress anomaly experienced by each fish was then determined. The averages were calculated by summing up the individual monthly temperature and wind stress anomaly data and then dividing it by the number of months the fish lived.

The relationship between the size of fish and climate indicators was then analysed. (See Data Analysis section for details of analysis).

Assessment of Traditional Knowledge on the Effect of Climate Variability on Fisheries

Focus group interview

In November and December 2016, pre-test of the draft interview guide (Appendix A) was carried out at Elmina, Sekondi and Half Assini. Fishermen were interviewed individually and in groups.

Artisanal and semi-industrial fishermen from Tema, Elmina, Half-Assini and Sekondi were interviewed in groups from April, 2017 to July, 2017. At each sampling site, 10 group interviews were conducted. Each group consisted of at least 5 fishermen and not more than 10 fishermen as recommended by Rabiee (2004). A total of 40 different groups were interviewed in line with suggestions made by Kitzinger (1995).

Prior to conducting an interview, the chief fisherman at the respective sampling sites was informed ahead of time to enable cooperation and to enhance effectiveness of the exercise. On the date of the interview, the respondents were duly briefed about the interview before the work was carried out. A semi-structured interview guide was used during the interview. General questions about the state of the Sardinella fishery were asked for answers. Respondents were asked to describe and elicit their opinions on the current state of the Sardinella fishery based on options provided.

They were also asked if there has been a change in size (referring to body length) of the Sardinella that were landed 10 years ago in relation to the time of study.

1. Influence of temperature and wind on the *Sardinella* species

Respondents were asked to state whether there was a relationship between the three factors mentioned above and the *Sardinella* species. They were also asked to state reasons, if any for their answers. Also, they were asked to state with reasons, if any whether *Sardinella* species had been influenced by temperature and wind over the period of years of their fishing experience.

2. Influence of temperature, wind and rainfall on upwelling

Respondents were asked to state with reasons if there was a relationship between temperature, wind and rainfall on the strength of upwelling as well as the productivity of the upwelling over the years of their fishing experience.

Each interview lasted between 35 and 90 minutes. All interviews were recorded and transcribed. The languages for communication during the interviews were Ewe, Fante, Ga and Twi. Figures 8 and 9 show some focus group sessions.

Figure 8: An interview session at Elmina fish landing site

Figure 9: A focus group interview with fisher folks at Tema fishing harbour

Estimation of the Effects of Climate Variability on Prices of Fish

A market surveys on smoked Sardinella fishes were conducted in four fish market centres in order to determine the relationship between sizes of Sardinella landed and market prices considering the fact that income generated from sales form a major source of livelihood for those involved. The fishes were priced per a hundred pieces so the price of one fish was calculated from the bulk price it was sold at. During the market survey, an interview guide was used to interact with the women. After each interview, samples of smoked Sardinella were purchased from the interviewee and labelled for measurement in the laboratory. Figures 10 and 11 show some sessions during market survey.

Figure 10: Market survey at Agbogbloshie market in Accra

Figure 11: Market survey at Mankessim market in the Central Region

In the laboratory, given the fact that it was impossible to differentiate between the two species of Sardinella they were treated as "*Sardinella* species". The standard length of each sample was measured to the nearest 0.5 centimetre. This is because, it was almost impossible to get the exact total or standard length of the smoked fish samples as the smoking process had deformed most of them in terms of length.

Figure 12: Measurement of a smoked *Sardinella* species

Data Analyses

The effects of temperature and wind stress anomalies

The relationships between fish length and climate change indicators were evaluated following a parsimonious approach by first testing for linearity before considering non-linear relationships. This was performed by fitting the data to the three-parameter power equation below (Sokal & Rohlf, 1981):

$$Y = aX^{b} + c \quad (1)$$

where Y was length of fish, X was the climate indicator being investigated and a, b and c were constants.

All data fitting procedures were done with Sigmaplot® for windows (V.10.0) using the automatic initial-parameter estimator function of the program. The standard error associated with b was used to test the null hypothesis that $b = 1$, i.e. a linear relationship between length of fish and climatic variability indicator (t-test, alpha = 0.05, df = n-3, where n is the number of data points) against the alternate hypothesis $b \neq 1$. If the null hypothesis could not be rejected, the relationship was considered to be linear, and least squares regression was used to determine the slope (a) of the line. a was then used as a measure for the effect of the climate variability indicator on the growth of the fish. Conversely, where $b \neq 1$, the length of the fish was considered to change allometrically with changes in the climate indicators. The change was considered to occur at slower rate than changes in the climate indicator when $b < 1$ as well as *vice versa*.

Evaluation of Traditional Knowledge on Climate Variability Effects

Data acquired through Focus group interview were evaluated by using graphs and frequency tables of some of the responses.

Feedback obtained from respondents were ranked based on importance or priority. Respondents were tasked to rank the effect of temperature, wind and rainfall on:

a. the intensity of upwelling (Physical factor)

b. the productivity (Biological factor)

Scores were based on the number of times each parameter was identified as more important. Ranking was done on cardboards, labelled and attached to their corresponding interview guides interview guide of each group. Ranks ranged from 1 to 3 where 1 is the highest and 3 the lowest rank. Scores were transformed to relative importance indices (RII) based on the formula (Zeng & Wang, 2002) :

$$RII = \frac{\Sigma W}{A * N}$$

Where:

W is the scores given to each factor by respondents, A the highest score which is 3 (in this study) and N the Number of respondents.

Information from market survey

Data on annual inflation rates in Ghana from 2012 to 2017 (data retrieved from http://data.worldbank.org/indicator/FP.CPI.TOTL.Z) was used to calculate the prices of the past ten years based on market prices in 2017 during the market survey.

Relationships between size of fish and market prices of the past were assessed using linear regression analysis.

CHAPTER FOUR

RESULTS

General Morphometric Characteristic of the *Sardinella* Species Studied

Two species of Sardinella: *S. aurita* and *S. maderensis* were collected every month during the sampling period. However, they were not always available at every sampling site during data collection.

Sardinella aurita

A total of 1,315 individuals of *S. aurita* were sampled. The minimum observed length was 8.1 cm with its corresponding weight 4.3 g. The maximum observed length was 26.4 cm with a weight of 149.2 cm. Figure 13 shows the total length frequency distribution of the species. Out of the 1,315 individuals, 755 representing 57.4% had their total length not exceeding 15.9 cm. The length frequency distribution exhibited a polymodal distribution with modes of 9.0 - 9.9, 13.0 - 13.9, 17.0 - 17.9, 20.0 – 20.9 and 22.0 - 22.9 cm.

Relationship between total length (TL) and body weight (BW) of *S. aurita* shown in Figure 14 can be described with the equation $BW=0.0135TL^{2.80}$. There was a strong relationship between TL and BW (r=0.89). The species exhibited isometric growth as the regression coefficient, *b*, was 2.8 and does not deviate from the theoretical value of 3.0.

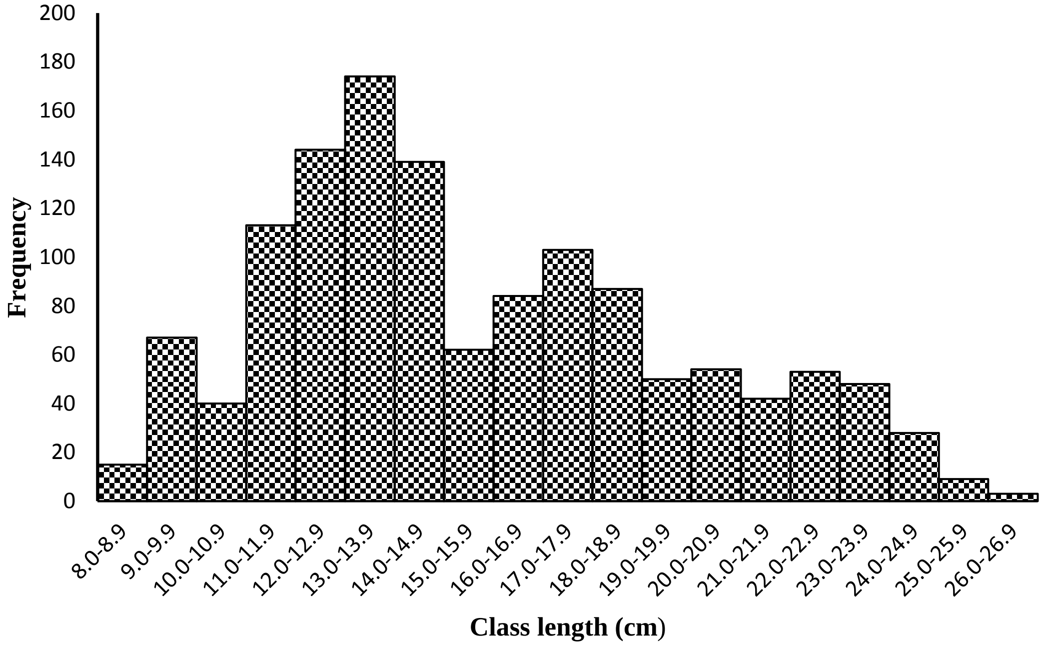

Figure 13: Length-frequency distribution *of Sardinella aurita* sampled along the coast of Ghana.

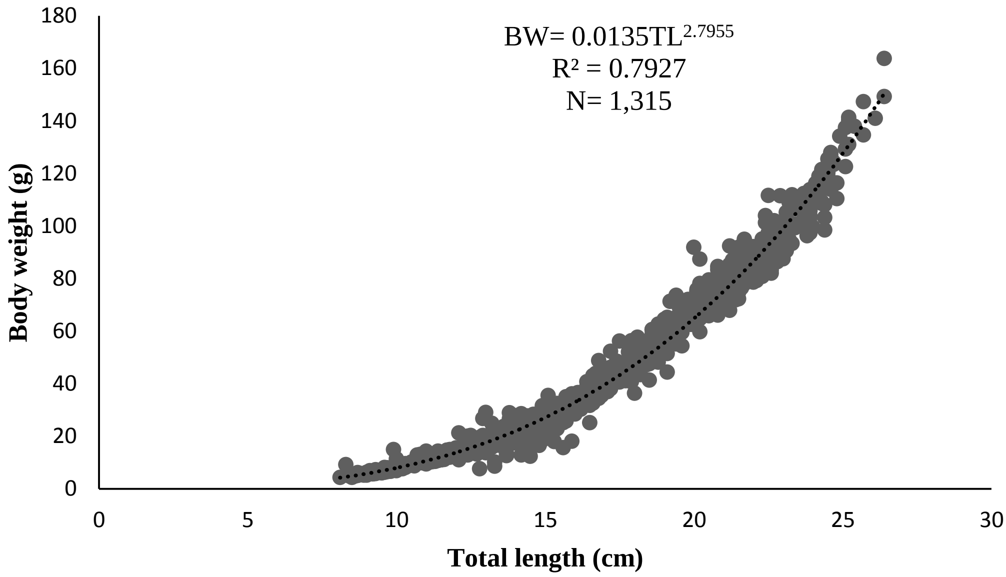

Figure 14: Length-weight relationship of *Sardinella aurita* sampled along the coast of Ghana.

Sardinella maderensis

At the end of data collection, a total of 2,489 individuals of *S. maderensis* were sampled. The total length of the samples ranged from 7.4 cm to 30.3 cm whereas the body weight ranged from 3.78 g to 232.25 g. Figure 15 shows the length frequency distribution of *S. maderensis*. The distribution is skewed to the right with a modal class of 14.0-14.9 cm. A total of 1,579 (63.5%) individuals of the pooled data did not have total lengths exceeding 15.9 cm.

The total length-bodyweight relationship of *S. maderensis* is shown in Figure 16. The relationship can be explained by the exponential equation: $BW=0.0073TL^{3.0591}$. The exponential coefficient of "*b*" is not statistically different from its hypothetical value of 3.0. The result also shows that there was a strong relationship between total length and body weight of the species. About 99 % of increase in weight was accounted for by respective increase in length of the fish.

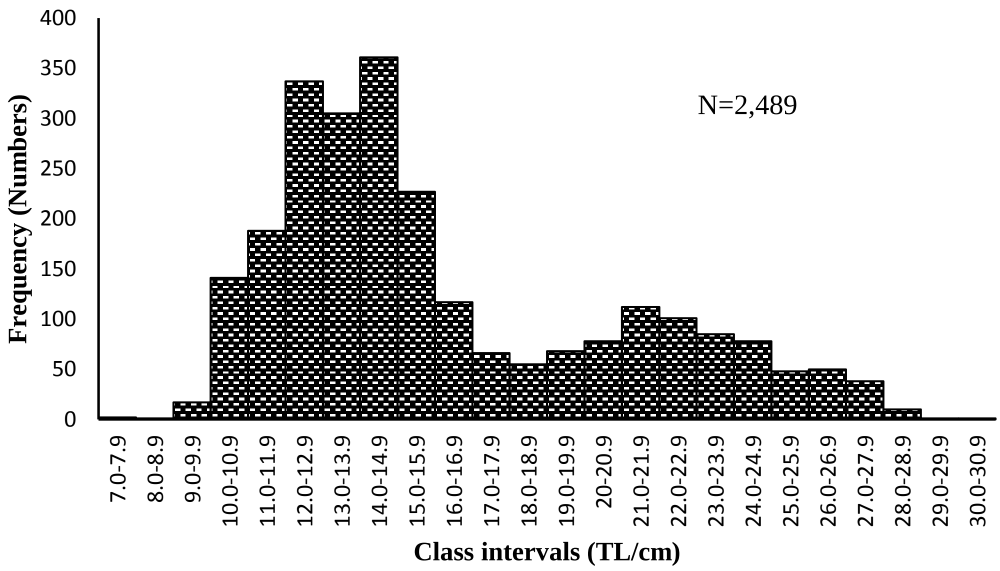

Figure 15. Length-frequency distribution of *Sardinella maderensis* sampled along the Coast of Ghana from October, 2016 to June, 2017

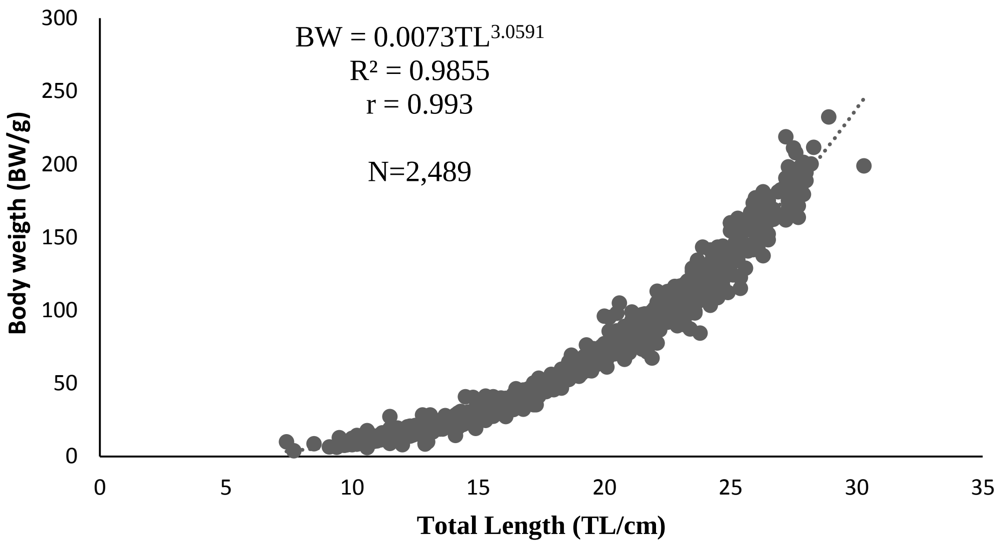

Figure 16: Relationship between total Length and body weight of *Sardinella maderensis* sampled in Ghana from October, 2016-June, 2017

Growth parameters

Growth parameters for each *Sardinella* species were estimated using the ELEFAN 1 routine of the FiSAT II software. The estimated growth parameters are shown in Table 1. The maximum observed length represented in the table as L_{max} was 26.4 cm for *S. aurita* and 30.3 cm for *S. maderensis*. The asymptotic length which is also referred to as L infinity ($L\infty$) was 27.3 cm and 31.01 cm (approximately, 31.0 cm) for *S. aurita* and *S. maderensis* respectively, the growth rate (K) of the S. aurita and S. maderensis stocks were estimated to be 0.62 yr^{-1} and 0.58 yr^{-r} respectively. Lastly, the longevity represented by (t_o) for *S. aurita* was -1.8 yr^{-r} and -1.69 yr^{-r} for *S. maderensis*. Therefore, the von Bertalanffy equation that describes the S. aurita stock in Ghana is:

$$L_t = 27.3 \{1 – \exp [–0.62 (t + 1.8]\}$$

S. maderensis stock in Ghana can also be described by the von Bertalanffy equation is:

$L_t = 31.01\{1 – \exp [–0.58 (t + 1.8]\}$

Table 1: *Estimated Growth Parameters for Sardinella Species*

Growth parameter	***S. aurita***	***S. maderensis***
L_{max} (cm)	26.4	30.3
$L\infty$ (cm)	27.3	31.01
K (yr^{-1})	0.62	0.58
t_o (yr^{-1})	-1.8	-1.69

Effect of Climate Variability on the *Sardinella* Species

The relationships between climate indicators (sea surface wind stress and temperature anomalies) and the length of *S. maderensis* were linear (i.e. $b = 1$ at $p < 0.05$). In contrast, it was predicted that the length of *S. aurita* changes allometrically at a slower rate ($b < 1$ at $p < 0.05$) than the climate indicators (Figures 17 and 18). However, for both species, the fit to the data was not significant, with r^2 being approximately ≤ 0.10 for all climate variability indicators investigated (Table 2). Based on these low r^2 values, it can be concluded that Equation 1 does reflect the growth response of the fish to climate variability effects.

Table 2*: Parameters of equation 1 as estimated for individual climate variability indicators*

Fish	Climate Effect	n	Coefficient	Mean Estimate	Std. Error	t	P	R-squared
S. aurita	Temp	37	c	17.2028	1.4342	11.9944	<0.0001	0.1019
			a	14.6625	7.3594	1.9923	0.0542	
			b	3.24E-07	3.42E-06	0.0946	0.9252	
	Wind stress	37	c	-8849885.8	93916202	-0.0942	0.9255	0.0871
			a	8849926.462	93916202	0.0942	0.9255	
			b	3.24E-07	3.42E-06	0.0946	0.9252	
S. maderensis	Temp	17	c	13.7901	0.8468	16.2841	<0.0001	0.0963
			a	-3696.599	49791.128	-0.0742	0.9419	
			b	3.1235	2.2107	1.4129	0.1795	
	Wind stress	17	c	22.9318	4.9641	4.6196	0.0004	0.0000
			a	1	10001.974	1.00E-04	0.9999	
			b	1	2197.8095	0.0005	0.9996	

A 3-parameter Gaussian description (Equation 2) was therefore used to determine the optimum climate condition (X_0) at which the fish are likely to grow to their optimum size (Yopt) (Table 3).

$$Y = Y_{opt} * \exp[-0.5*((X - X_0)/b)^\wedge 2] \quad (2)$$

Y represents length attained by the fish at the prevailing condition (X) of the climate; the parameter "b" describes the width of the response curve; see Figure 18 (Note: outliers – indicated as unshaded, open circles on the plots – were not included in the data analyses).

Table 3: *Parameters estimated for equation 2 for each fish and climate variability indicator. These parameters were used for the graphs.*

Fish	Climate Effect	n	Coefficient	Estimate	Std. Error	t	P	R-squared
S. aurita	Temp	37	Yopt	22.5795	0.6602	34.2000	<0.0001	0.4860
			b	0.1935	0.0224	8.6226	<0.0001	
			X0	0.1841	0.00127	14.4615	<0.0001	
	Wind stress	37	Yopt	21.8341	0.6182	35.3201	<0.0001	0.4804
			B	0.0005	5.11E-05	9.5871	<0.0001	
			x0	0.0007	3.34E-05	21.7292	<0.0001	
S. maderensis	Temp	17	Yopt	13.9648	1.1012	12.6815	<0.0001	0.1248
			B	0.6638	0.4971	1.3353	0.2031	
			X0	0.3041	0.1404	2.1658	0.0481	
	Wind stress	17	Yopt	14.0491	1.0277	13.6703	<0.0001	0.1103
			B	0.002	0.0012	1.6291	0.1256	
			x0	0.0005	0.0006	0.9053	0.3806	

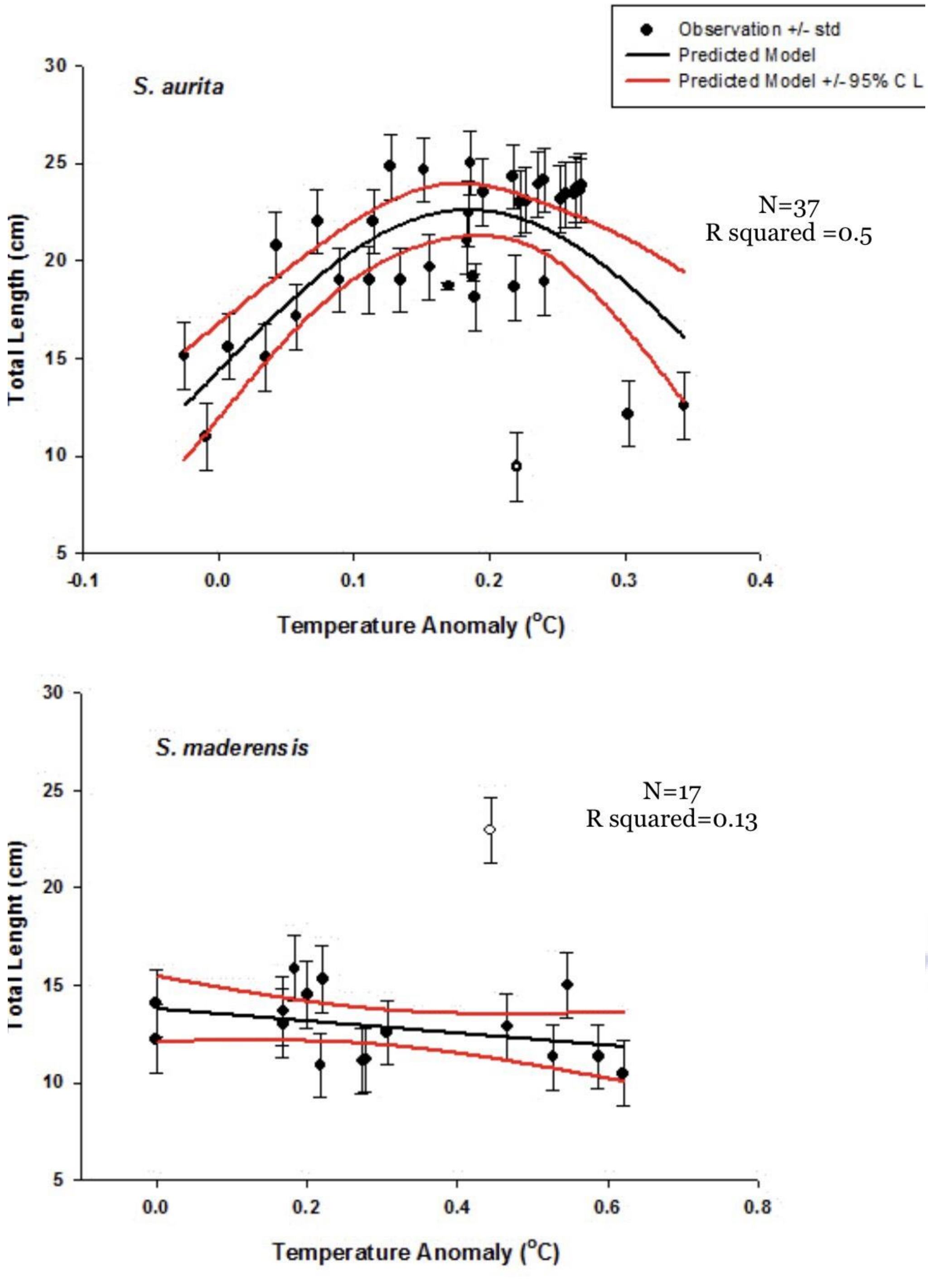

Figure 17: The effect of sea surface temperature anomaly on the total length of *Sardinella* species caught off the coast of Ghana from October, 2016 to June, 2017)

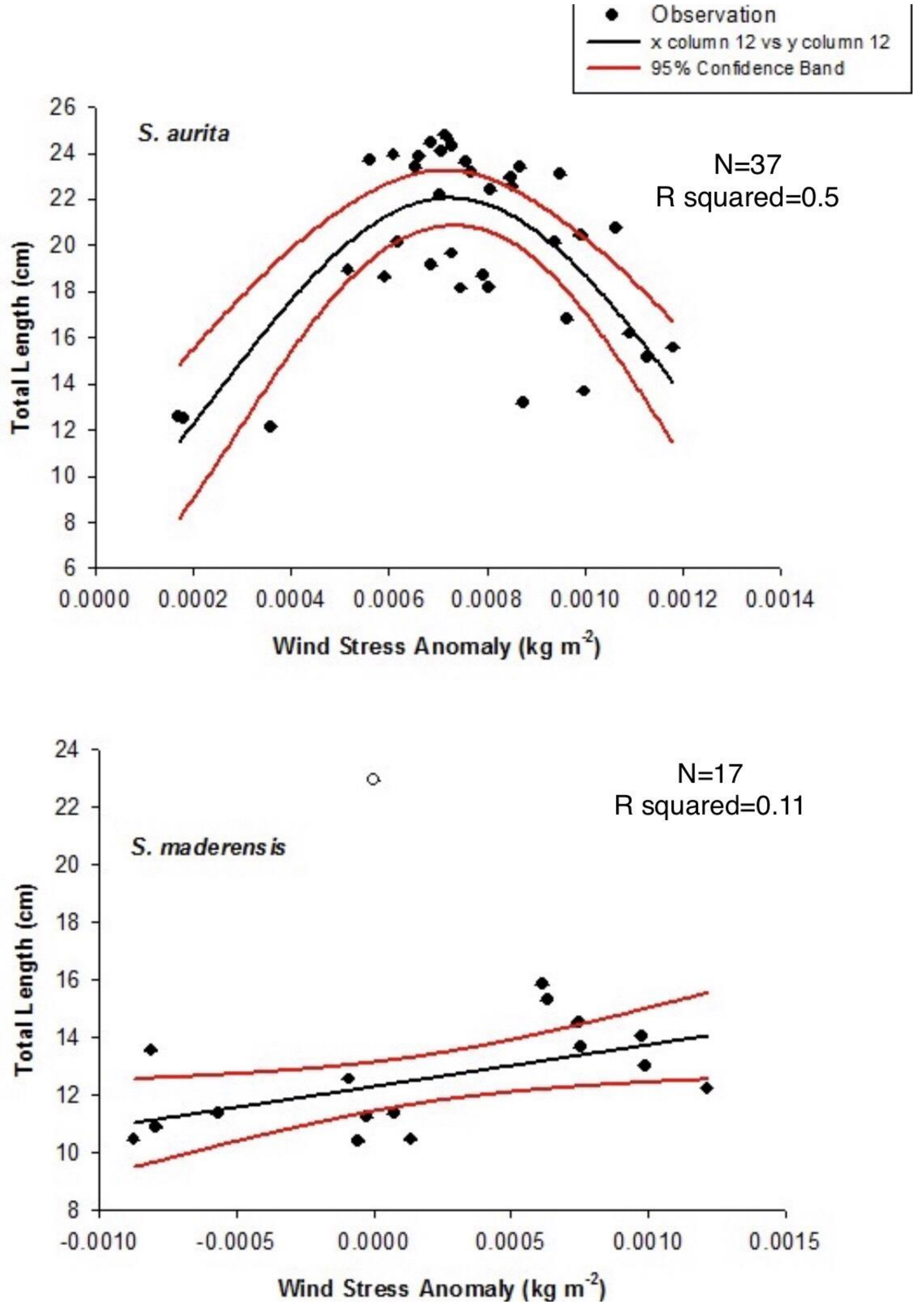

Figure 18: The effect of wind stress and total length of *Sardinella aurita* and *Sardinella maderensis* caught along the coast of Ghana from October, 2016 to June, 2017

Traditional Knowledge on the Effect of Climate Variability on Fisheries

This section describes from the fishermen's perspective, the state of the Sardinella fishery, influence of temperature and wind on Sardinella in terms of productivity, upwelling in Ghana, influence of temperature, wind and rainfall on upwelling.

Demography of fisherfolks

A total of 10 groups were interviewed at each study site. Group sizes ranged from 5 to 8 members. However, group size 5 dominated 23 out of 40 groups representing 57.5% (Figure 19). Group size 8 was the least with a frequency of 2 out of 40 groups representing 5%.

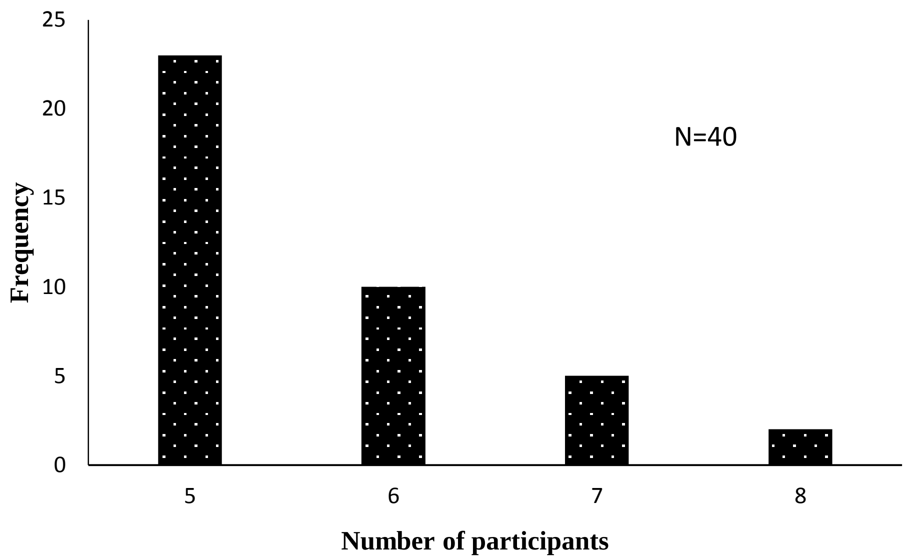

Figure 19: Distribution of various group sizes during the focus group interviews

The age of respondents ranged from 23 to 81 years. The modal age class of respondents is 40-50 years with frequency of 18 out of 40 representing 45% (Table 4).

Table 4: *Age class of respondents of focus group interviews held in four fish landing sites in Ghana*

Age class (years)	Frequency	Percent
20-30	2	5
30-40	14	35
40-50	18	45
Above 50	6	15
Total	40	100

Pair-wise ranking

Temperature was ranked highest (Tables 5 and 6) as the most important factor influencing productivity and upwelling. Wind had the least ranking in both cases.

Table 5: *Ranking of the importance of selected environmental variables on productivity from all 4 study areas*

Variables	RII	Rank
Temperature	0.517	1
Wind	0.017	3
Rainfall	0.442	2

Table 6*: Ranking of selected environmental variables the on upwelling from all 4 study areas*

	RII	Rank
Temperature	0.533	1
Wind	0.050	3
Rainfall	0.417	2

Perception of fisherfolks on state of the Sardinella fishery in Ghana

When asked to describe the current state of the Sardinella fishery with reasons, 62.5% representing majority (25 out of 40) of the respondents described it as "very bad", whilst, 13 of the respondents representing 32.5% said the Sardinella fishery is currently "bad". On the contrary, two respondents (5%) held opposing views. While one described the current state as 'good' the other said it has 'improved' (Figure 20).

All the respondents who described the fishery as bad or very bad (38 out of 40), attributed their answer to low yield with 34 of them giving further explanation to the low yield on illegal fishing practices, increased effort and effect of the oil rig. Only 4 out of the 38 did not explain further. Under the theme illegal fishing practises, light fishing (mostly combined with chemical), transhipment which is termed 'Saiko', pair trawling by foreign vessels were mentioned. Saiko was mentioned by all respondents at Elmina except one.

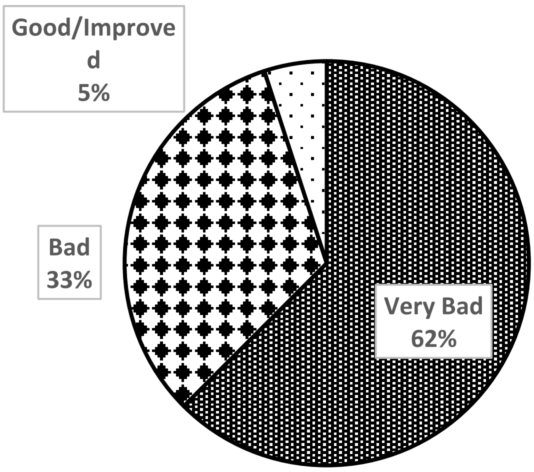

Figure 20: The impression of local fishing communities along the coasts of Ghana on the current state of Sardinella

Pair trawling was commonly mentioned by respondents in Tema. Light fishing was mentioned at all the four sampling sites even though Tema and Half Assini had almost all their respondents mentioning light fishing. However, one of the respondents mentioned nature as another reason apart from increased effect but did not further explain. Another respondent also mentioned deforestation as an additional reason aside increase in effort. Paraphrasing the statement, “some years ago, there used to be a lot of trees so it used to rain a lot but now, most of the trees have been cut down distorting the rainfall which brings a lot of fish”.

At Sekondi, eight out of ten groups interviewed were people involved in semi-industrial fishing using purse seine nets. Only one out of the 8 groups described the Sardinella fishery as “very bad”. Also, only one group out of the 8 groups mentioned light fishing as the reason behind the bad state of the Sardinella fishery. All the others blamed it on increased effort specifically increase in number of boats, more efficient tools and much larger nets.

Oil rig was mentioned at Half-Assini by 90% of the respondents there. Increase in fishing effort (mostly referring to number of trawling boats and size of nets and canoes), was common to respondents from Sekondi and Tema.

The two groups that described the fishery as good and improved were at Sekondi. The group which said the Sardinella fishery has improved, explained that previously, they used to land *S. aurita* during the upwelling season only but now they land it fortnightly throughout the year. They further explained that they get the Sardinella in large quantities just as they get during the ‘supposed’ upwelling season. The other group which said ‘good’ also explained that they get good catch throughout the year and they make more profit now than they used to make some years back because price of fish has increased in general.

From Figure 21, majority (85%) of respondents noted a decrease in the individual sizes of the Sardinella throughout their years of fishing experience. Others were of the view that there has not been a change in the sizes of the Sardinella. One respondent out of the 40 said the fishes have increased in size over the years. It should be noted that the respondents said the round Sardinella is the main *Sardinella* species they encounter regularly and as such, all their answers are based on their experience and observations of that species.

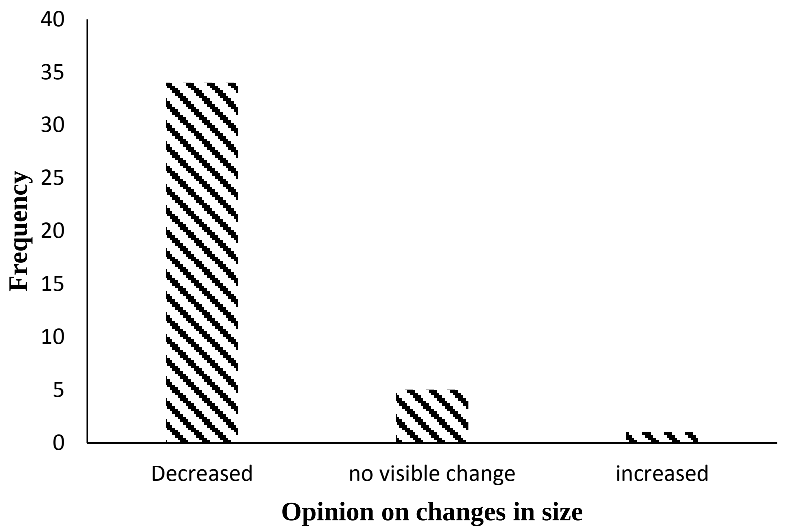

Figure 21: The opinion of the local stakeholders on recent changes in the sizes of Sardinella within Ghanaian coastal waters

Influence of temperature and wind on Sardinella

On temperature, majority of the respondents (36 out of 40) representing 90%, noted that there is a link between temperature and fish production. They gave two main reasons for their answer (Figure 22). These are:

- Some fishes prefer colder waters whereas others prefer warmer waters.
- "We get a lot of fish when the water is cold"

Some of the respondents who said they get a lot of fish when the water is cold further explained that when the water gets cold, Sardinella swim up to escape the extremely cold deeper waters that is why they get a lot of Sardinella during that period.

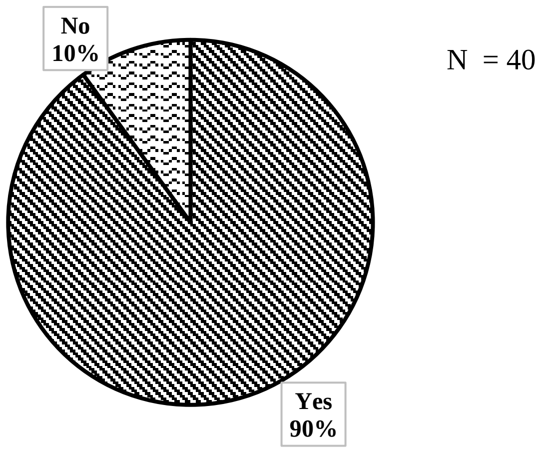

Figure 22: Opinion of local stakeholders on whether there is a link between temperature and fish production

The other four respondents who said they was no link between temperature and productivity of fish gave three different reasons for their answer:

1. "Quantity of fish we get depends on God" (Productivity is natural).
2. "We get fish all year round irrespective of the water temperature".
3. "When the water is extremely cold, we don't get a lot of fish".

In response to the question as to whether temperature has played or is playing a major role in the Sardinella fishery for the past decade or more, 24 out of 37 respondents agreed, whereas the remaining 13 did not think it is possible (see Figure 23). All respondents who agreed that temperature might have had a long-term effect on the Sardinella fishery, basically mentioned that temperature has increased over time (Table 7).

The remaining 13 groups who disagreed that temperature might have been having an effect on the Sardinella fishery also explained their answers (see table 8).

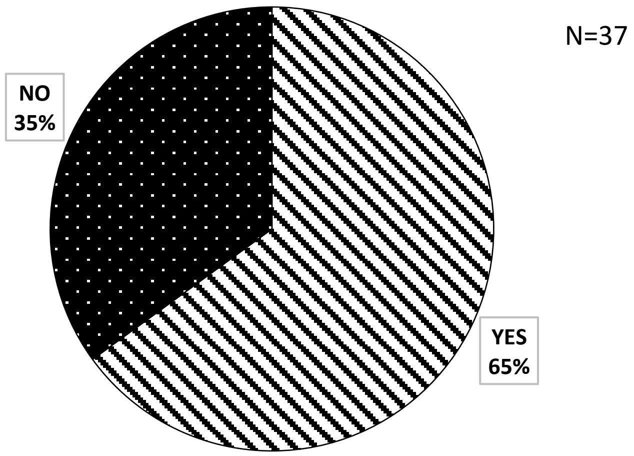

Figure 23: Perception of fisherfolks on the role whether temperature has played a role in Ghana's Sardinella productivity over the past decade and beyond

Table 7: *Opinion of fisherfolks to why temperature is playing a key role in the Sardinella fishery over the years*

Reason	**Frequency**
During upwelling period, water does not get as cold as it used to get some years ago.	3
Less rainfall over the years so water doesn't get as cold as it used to	3
temperature has increased gradually over the years and may not be favourable for productivity	18
Total	24

Table 8*: Opinion of fisherfolks on how temperature influences the productivity of Sardinella over the years*

Reason	**Frequency**
"Temperature is controlled by nature and has not changed over the years"	6
Seasons (rainy, dry) are still very distinct	3
Light fishing has made that possibility irrelevant	2
Pair trawling has made that possibility irrelevant	2
Total	13

With respect to wind, 24 groups out of 40 (representing 60% of the total sample size) agreed that there is a link between wind and the productivity of Sardinella. The remaining 16 groups thought otherwise. Those who agreed that there is a link between wind and the productivity of Sardinella gave one of the following reasons to explain their answer (Figure 24);

- During the period of strong winds, catch is low
- Strong winds precede upwelling period and thus bumper harvest
- It gets windy during the upwelling season and we get bumper harvest

The other 16 groups (40% of overall sample size) who thought otherwise gave one of the following reasons (Figure 25):

- "Irrespective of the wind, we still get fish"
- "Wind affects fishing operation and not productivity of fish"

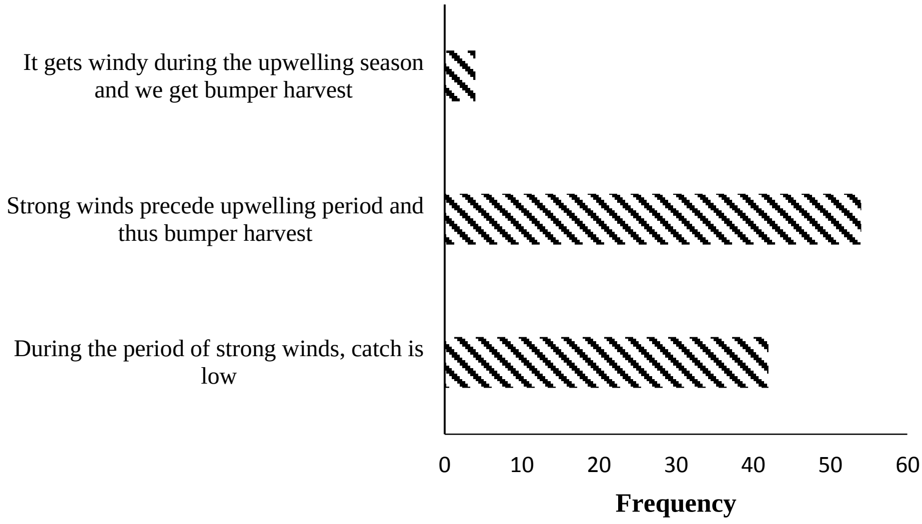

Figure 24: Opinion of fisherfolks of the coast of Ghana on how wind influences fish production

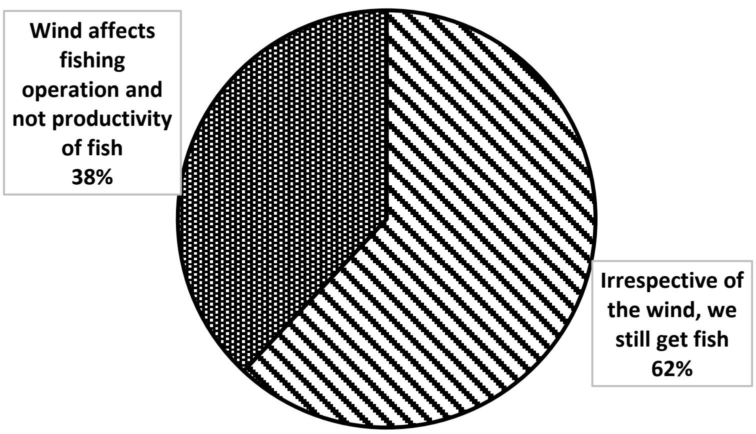

Figure 25: Impression of local fisherfolks of the coast of Ghana on why wind does not influence bumper harvest of fish

When asked if wind has played a role in the Sardinella fishery over the past decade or more, just a few (8 out of 24 groups, 33.33%) agreed. The remaining 16 groups disagreed. Seven out of the eight groups who agreed, explained that, winds have become increasingly stronger as the years go by and it could be a contributing factor to the decline in productivity of the

Sardinella fishery. The remaining one group did not answer the question. The 16 who disagreed gave one of the following reasons:

- "There has been no change in the nature and trend of wind"
- "Wind is controlled by the stars so is has always been consistent"
- "Wind does not affect overall productivity"

Upwelling

All respondents agreed that during the upwelling season there is bumper harvest of Sardinella. They however, gave at least one of the following reasons to explain why there is bumper harvest of Sardinella during the upwelling season. During upwelling,

- nutrient-rich water from deep sea comes to the surface of the water and Sardinella comes along with it because the nutrient is "their food";
- water reaches a low temperature which is favourable for Sardinella;
- Sardinella escape extremely cold deeper waters and they school closer to the coast; and
- the water contains "food" (nutrients) needed by Sardinella

A higher majority (92.5%) of the respondents described upwelling in recent times as "getting weaker". Most of them explained that they do not get as much yield as they used to get some years back during the period of upwelling. A few others were of the view that the upwelling is getting weaker because they do not see the "visible changes in the water" as they used to see (Figure 26).

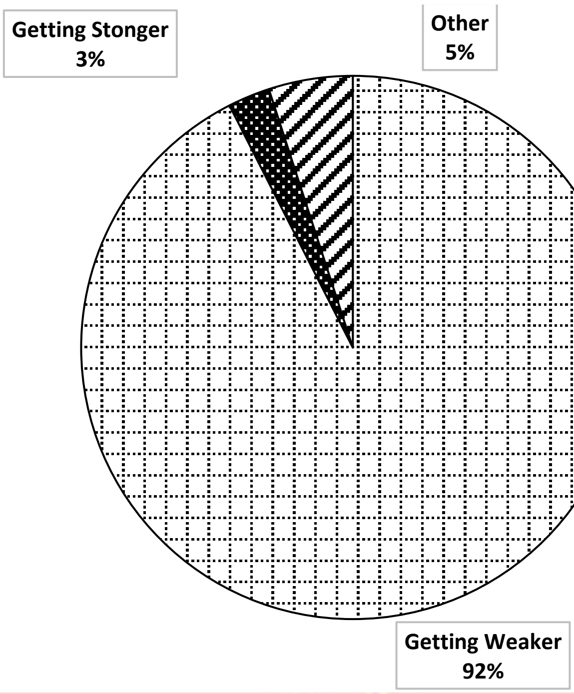

Figure 26: Fisherfolks' description of upwelling off the coast of Ghana in recent times

In response to the question "what causes upwelling?" most respondents listed at least one of the following factors: Rainfall, temperature and wind. None mentioned all three factors. Some respondents (27.5%) stated that upwelling is a natural occurrence (Figure 27).

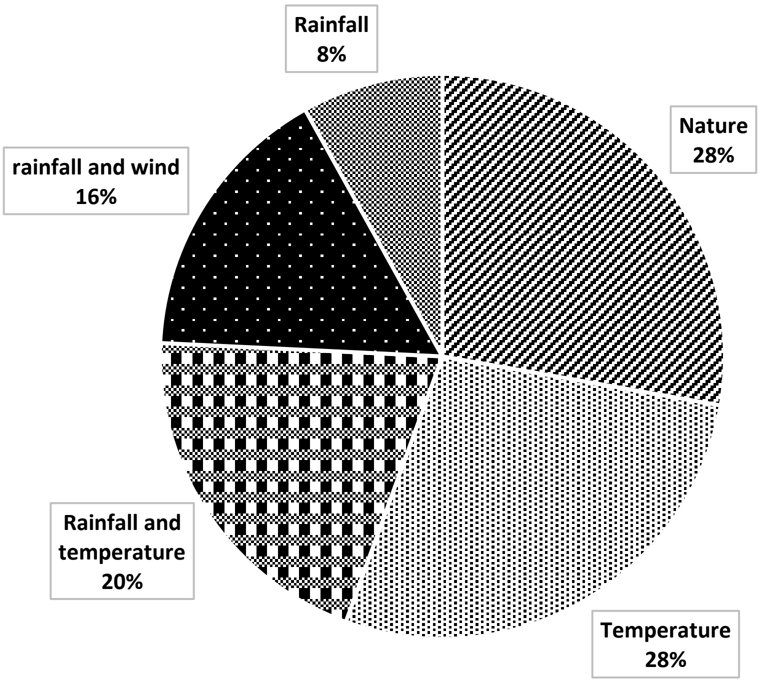

Figure 27: Causes of Upwelling off the coast of Ghana from the fisherfolks' perspective

All respondents agreed that there is a link between temperature and upwelling. Also, they all mentioned that during upwelling, water temperature drops. Some further explained that during upwelling season, the water is colder than all other seasons in the year.

Half of the sample size were of the view that, there is a link between upwelling and wind whereas the other half disagreed. Most (85%) of those who agreed, said that about a month before upwelling season begins, strong wind blow in the ocean. The remaining 15% said during upwelling, the wind is calm.

Majority of the respondents (82.5%) said there is a link between upwelling and rainfall. The rest did not agree. The former gave one of the following reasons to explain their answer.

- Rainfall brings in cold water which is favourable for Sardinella.

- Heavy rainfall (during the rainy season) in year, leads to bumper harvest during upwelling
- Rains bring nutrient-rich waters into the sea through lagoons and estuaries.

A total of seven respondents said there is no link between rainfall and upwelling. All of them but one explained that bumper harvest during upwelling does not depend on rainfall. The other respondent explained that, upwelling is a natural occurrence and thus it cannot be influenced by rainfall.

Impact of Climate Variability on Price of Fish

This result is based on the outcome from the market survey conducted as part of the research.

Demography of respondents during market survey

Overall, 40 smoked Sardinella sellers were interviewed, ten from each of the selected markets. Also, a total of 1,146 individuals of smoked Sardinella species were measured for their length and analysed. Of the 40 fish mongers that were interviewed, 21 (representing 53%) were single whereas the remaining 47% were married. Meanwhile, all interviewees had at least two children.

The primary occupation of all respondents is trading in smoked fish. None but one respondent however had a secondary occupation. Figure 28 shows that 50% of respondents have been in the business for more than 20 years. The same figure shows that only 2 out of the sample size have been in the business for less than 5 years.

Figure 28. Various year range of respondents in smoked Sardinella trade

Length-price relationship of Sardinella

A pooled data of length and prices of smoked fish samples from all the four markets during the survey is represented in figure 29. Generally, price increases as length also increases. The highest priced fishes were of length 19 cm and price \$0.25 whereas the lowest priced fishes were of length 8.5 cm with corresponding price of \$ 0.02. Similarly, there is no visible change in the trend seen in Figure 30 when the prices of fish for the past 5 years (2013-2017) were considered (Figure 29). In figure 29, all annual length-price seem to be following a similar trend. As length of fish, increases, price also increases over the years.

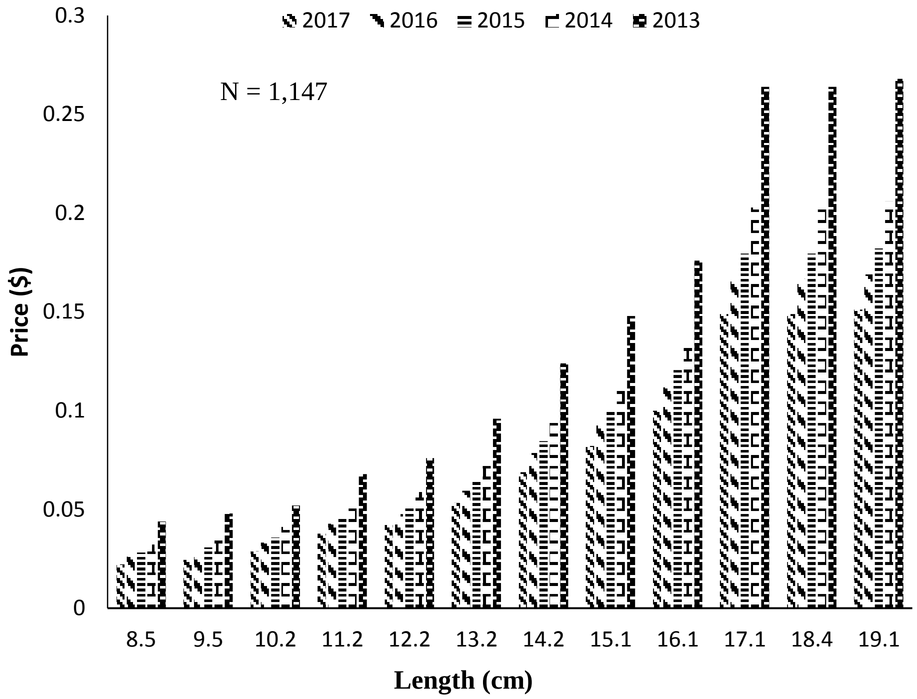

Figure 29. Length and prices of smoked Sardinella over a period of five years from 2013 to 2017

Perception of processed Sardinella traders on the fish and climate variability

Majority (72.5%) of respondents were of the view that the sizes of Sardinella species have decreased over time. The other respondents who made up 27.5% thought there has not been any change in the sizes of Sardinella species landed in Ghana over the years (Figure 29). When questioned on the consumer preference of sizes of smoked Sardinella, all respondents with the exception of 2 said there was market for all sizes (Figure 30). The only two respondents (representing 5%) who gave a different opinion on the consumer preference said consumers preferred smaller sizes of the smoked Sardinella.

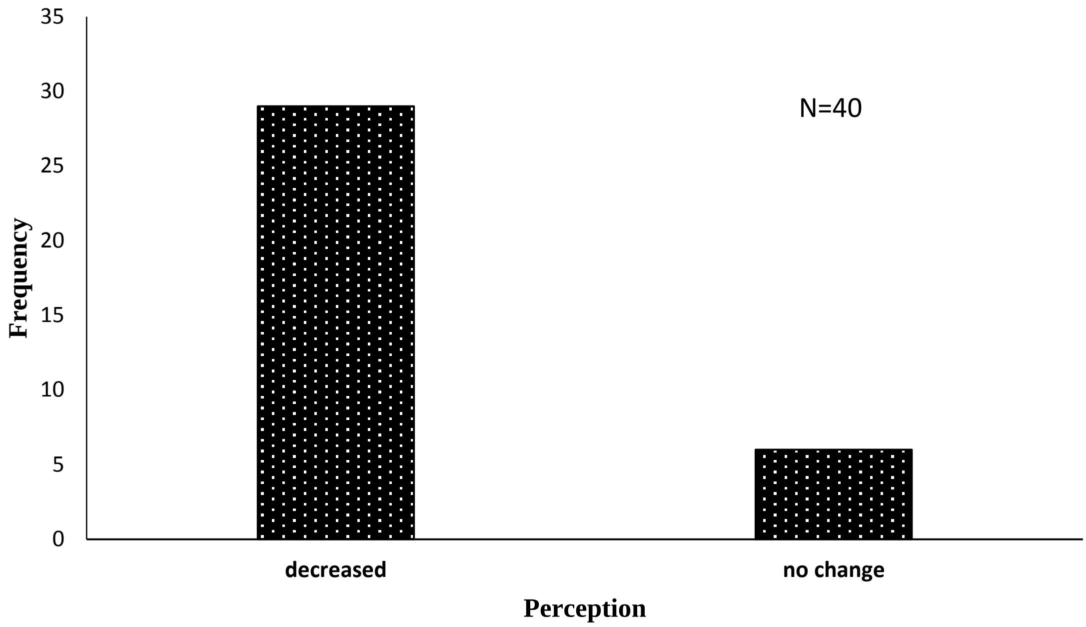

Figure 30: Perception of smoked Sardinella traders on sizes of Sardinella over the years

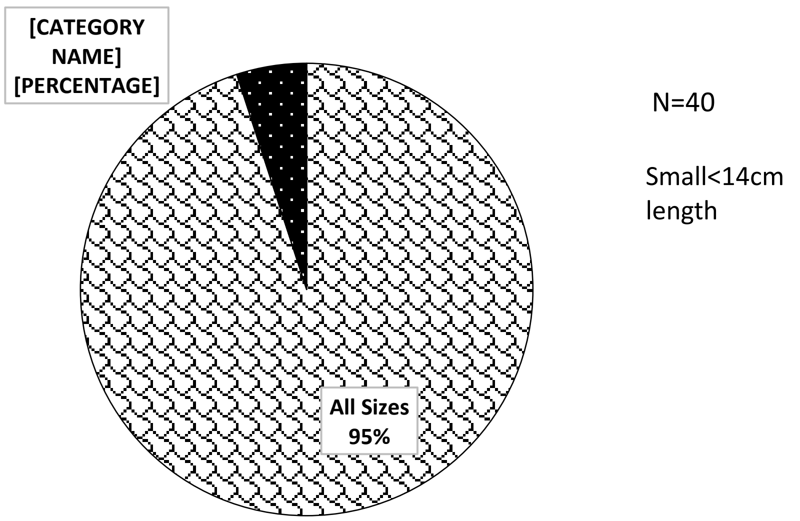

Figure 31: Consumer preference of sizes of smoked Sardinella from traders' perspective

Figure 32 shows that 50% of respondents said they make more profit on the smoked fish during the lean season i.e. non-upwelling season. They explained that during upwelling, consumers, knowing that the fish is in abundance always want it at a cheaper cost so they end up running at a loss. They however further explained that it is during the lean season they are able of recover the loss incurred during the upwelling season.

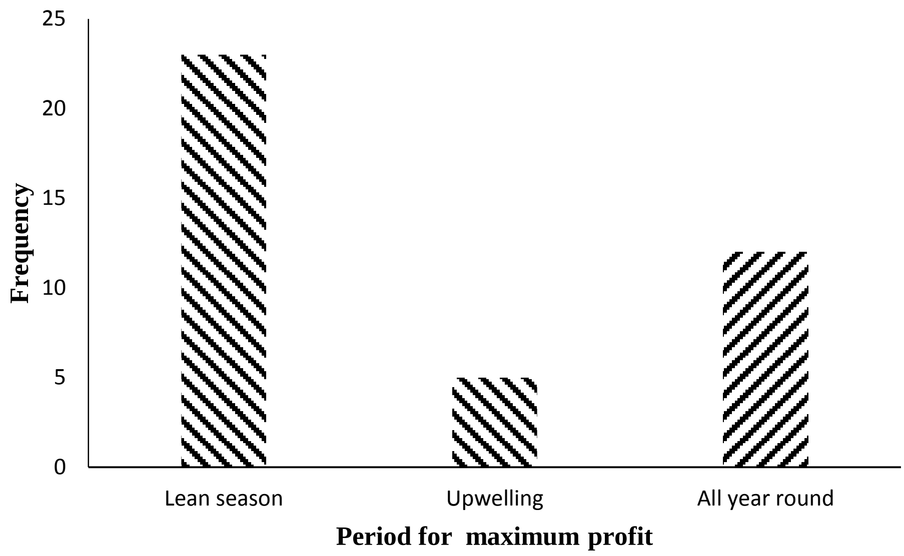

Figure 32: Seasons in a year for making maximum profit in the trade of smoked Sardinella

CHAPTER FIVE

DISCUSSION

This study sought to evaluate the impact of climate variability on the sizes of Sardinella species caught by fishermen operating in Ghana's marine waters. The effect of climate variability on fish was evaluated through its effects on the strength of coastal upwelling as measured by changes in sea surface temperature (SST) and wind stress as proxies. This chapter discusses the results in light of existing literature and the specific objectives of the study. Key areas discussed include morphometric and growth parameters of Sardinella species in Ghana (*S. aurita* and *S. maderensis*), empirical evidence for the effect of climate variability on the fish, local perception on climate variability and Sardinella fishery, and impact of climate variability on market price over the past five years.

Morphometric Parameters of the Sardinella Species

In this study two species of Sardinella i.e. *Sardinella aurita* (round Sardinella) and *Sardinella maderensis* (flat Sardinella) were identified. According to Nunoo, Asiedu, Kombat and Samey (2015), *S. aurita* and *S. maderensis* are the only species of Sardinella found in the Gulf of Guinea between La Cote d'Ivoire and the Republic of Benin. Both species were encountered at each of the four sampling sites. However, they were not always available during every data collection; an observation attributable to the migratory nature of the species.

Sardinella aurita

During the study, 1,315 individuals of *S. aurita* were encountered. This figure represents about 53% of *S. maderensis* which were encountered (n=

2,489). This could, however, be due to the fact that the round Sardinella species, as reported by Boely (1979); Houde & Fore (1973), have their peak spawning season from mid-June to September and that is the period where the species are most abundant even though they spawn all year round (see Brainerd, 1991). The low number of *S. aurita* could have been justified based on that since the data collection period did not capture the main upwelling season. However, Koranteng (1989; 1991) and Pezennec & Bard, (1992), stated that minor spawning season (minor upwelling) in Ghana-Cote d'Ivoire is as important as the major upwelling in terms of landings of the round Sardinella and this overthrows the argument. Also, during the focus group interview, some of the respondents, explained that the bumper season of round Sardinella is no longer significant as they get similar quantities of catch all year round. On that basis, it can be concluded that the round Sardinella were less abundant due to their general decline in abundance which is reported by the Fisheries Commission of Ghana (see FMP, 2015).

The maximum observed length of round Sardinella globally as documented by www.fishbase.org is 30 cm (TL). In this study, the recorded maximum length of 26.4 cm is comparable to figures obtained by Osei (2015) although lower than the documented value. According to Brainerd (1991) the maximum observed length of *S. aurita* in the western Gulf of Guinea is 25 cm. In that same work, Brainerd stated that the maximum observed length of this same species from Mauritania to Guinea as well as from Gabon to Angola (southern Gulf of Guinea) is 30 cm. This authenticates the length sizes of *S. aurita* species encountered in this study. Although the length-frequency distribution exhibited a polymodal trend, 57% of the total sample size of the species were below 16 cm in length. Brainerd (1991) as well as Quaatey and Maravelias (1999) reported that the species attains first maturity from 15 cm to 17 cm (this means that majority of the samples were juveniles).

The exponential equation, $BW=0.0135TL^{2.80}$, that describes the relationship between total length (TL) and body weight (BW) of *S. aurita* as shown in Figure 9 is comparable to results obtained by Osei (2015) which is $BW=0.0115TL^{2.90}$. There was a strong positive correlation (r=0.89) between total length (TL) and body weight (BW). Also, the regression coefficient, *b*, was 2.8 and does not deviate from the theoretical value of 3.0. Moutopoulos and Stergiou (2002) explained that the relationship between length and weight provides information on the growth pattern as well as the condition of the fish.

Sardinella maderensis

In this study a total of 2,489 individuals of *S. maderensis* were sampled which is 47% more than the quantity of *S. aurita* sampled. This finding confirms Osei's (2015) work where *S. maderensis* was slightly higher than *S. aurita*. Both reports, however, contradict studies by Bard & Koranteng (1995) stating that *S. aurita* is the target Sardinella species by fishermen in Ghana. An earlier study by Brainerd (1991) noted that *S. maderensis* commonly fished from Cote d'Ivoire to Nigeria, forming a major component of beach seine fishery in Ghana. These observations allude to the fact that *S. maderensis* is more abundant contrary to earlier reports, thereby making it equally important as the *S. aurita*. The modal length frequency of 14.0 -14.9 cm, confirming studies by Brainerd (1991) indicates that majority (about 63.5%) of individuals sampled were juveniles. The author noted that the beach seine fishery in Ghana commonly lands both adult and juvenile flat sardines. Also, considering the fact that *S. maderensis* spawns all year round, it is therefore not uncommonly to juveniles are landed. Reportedly, this species matures at 18 – 19 cm (see Gabche & Hockey, 1995).

Growth parameters

The asymptotic length which is also referred to as L infinity (L_∞) is the theoretical length which a fish attains assuming the fish grows continuously. In this study, the L_∞ for *S. maderensis* was 31.01 cm which is comparable to 29.5 cm found by Osei (2015) in Ghana; 30.3 cm in Senegal (Camarena-Luhrs, 1986 in Ba et al., 2016), 29.6 cm in Sierra Leone (Ba et al.), 32.5 cm Cameroon (Djama, Gabche & Njifonju, 1989). For *S. aurita*, the L∞ found in this study was 27.3 cm. Osei (2015) found 28.7 cm in Ghana and whereas Al-Beak (2016) reported a maximum length of 28.6 cm along the Sinai coast in the Mediterranean Sea.

Estimated growth rate (K) of *S. aurita* in this study was 0.62yr^{-1}. Osei (2015) in his work, he estimated the growth rate for this species to be 0.51 yr^{-1}. Tsikliras et al. (2005), also estimated the K of *S. aurita* in the north-eastern Mediterranean to be 0.51 yr^{-1}. This suggests that currently, the species grow at a relatively faster rate than as reported by those two other authors. These values are however similar than that which was estimated by Al-Beak (2016) as 0.18 yr^{-1}. Findings from this study suggests that *S. maderensis* grows at a relatively slower rate (K = 0.58) than *S. aurita*. This is quite different from Osei's (2015) findings which suggested the reverse. That regardless, there was no statistical difference between Osei's values and those of this study. Although these two species are of the same genius, it is not mandatory that they have the same growth rate. This is because, they each prefer different environmental conditions and definitely have variant genetic composition (Koranteng, 1989; Osei, 2015).

Empirical Evidence on the Effect of Climate Variability on Sardinella Species in Ghana

It has been established that south-westerly winds blow towards land, in the southern areas of Intertropical Convergence Zone (ITCZ), bringing moist air from the Atlantic Ocean intensifying the Guinea Current. The arrival of the moist air induces wet season and corresponding major coastal upwelling (Hagos & Cook, 2007 cited in Castro, Skrobe, Asare, & Kankam, 2017). Nonetheless, it is still unclear the role wind plays in the occurrence of upwelling in the Gulf of Guinea.

Projections of climatic conditions from this study indicate that climatic conditions significantly influence the growth patterns of *S. aurita* (R-squared = 0.5). On the contrary, the relationship between climate indicators and *S. maderensis* was not significant (R-square = 0.1) although sea surface wind stress and temperature anomalies were linear with growth of the species (see Figures 17 and 18). This result is similar to findings by Sabates, Martin, Lloret, and Raya (2006) that, there exists a significant positive relationship between round Sardinella landings and temperature anomalies in the western Mediterranean basin over a 50-year period.

Findings from the predicted model based on the data shows that the current optimum length of *S. aurita* is 22.6 cm at the prevailing SST of 0.18°C warmer than the mean temperature (25.8 °C) and 21.8 cm of wind stress anomaly 0.007 kg/m^2 of the 36 years under study. Superficially, the results show that more individuals obtain bigger body sizes when sea surface temperature deviate from the average (historical value of 25. 8 °C) by 0.25°C, an observation reported by about 80% of fisherfolks interviewed during the focus group interviews. Growth responses arising from temperature anomaly is expected on the basis that *S. aurita* spawns in Ghanaian waters when the sea surface temperature is well below 25°C (Roy, 1995; Zeeberg, Corten, Tjoe-Awie, Coca, Hamady, 2008). Accordingly, Zeeberg et al. (2008) noted that water temperature is the main factor that controls the migration and abundance of *S. aurita* in most parts of the world. This is largely due to the role of oceanographic conditions in the recruitment success of small pelagic fish stocks, particularly in the Gulf of Guinea. Another plausible factor for the weak relationship between growth response and climatic conditions recorded for the flat Sardinella may be attributed to the species ability to tolerate a wider range of temperature. In a similar study by Brochier et al. (2018), fishermen in Senegal associate the atmospheric conditions with the seasonal abundance and distribution of Sardinella.

Upwelling, which is largely responsible for productivity, distribution and abundance of Sardinellas particularly in the western Gulf of Guinea, has been associated with rainfall (see Koranteng, 1995). However, due to erratic rainfall patterns coupled with increased SST in recent times, there is a possible occurrence of weak upwelling resulting in low catches and smaller fish sizes. On the basis that sampling period covered the entire minor upwelling season but not major upwelling when the SST is known to drop, fish samples obtained contained higher numbers of *S. madarensis* in relation to *S. aurita*. This result is corroborated by local fishermen that *S. madarensis* prefer warm water (see Castro et al., 2017) . In the same vein, Castro et al. stressed that although *S. aurita* has higher commercial importance, than *S. maderensis* in terms of catch landings, the catches of *S. aurita* have significantly dropped in the past 15 years. Conversely, catch landings of *S. maderensis* have remained relatively constant given the fact that the species is caught all year-round whereas *S. aurita* is mostly caught during upwelling seasons. It is therefore postulated that increasing sea surface temperature, as well as, sea surface wind stress in recent times are accountable for the declining catch landings of *S. aurita*.

Premised on the above, it is imperative to establish a better understanding of the relationship between environmental variability and Sardinella population response to support fishery management at sub-regional scales.

Perception of Local Stakeholders on the Effect of Climate Variability on Fisheries

Fisheries are very complex systems as they are a combination of ecological and human systems. As such, it is difficult to fully understand human behaviours, beliefs and consequences of actions observed in these systems in addition to the variation often observed in natural systems (Castro et al., 2017).

To obtain a representative opinion of observations regarding impacts of climate variability on Sardinella fisheries, a total of 250 people participated in focus group interview. All the participants were male fishermen who were either active or retired fishermen. This criterion was used because in Ghana, women in the coastal regions do not go fishing and as such may not have sufficient information to contribute to the discussion. The modal group size of 5 also made it possible to have meaningful consensual interviews without much divergence within the groups. The views of local fishermen resulting from the focus group interviews constitute an important component of this study. This is due to the fact that about half of the respondents (45%) age between 40 – 50 years. This age class was critical as it gave the respondents the opportunity to experience possible climate change (a period of 30 – 35 years). Feedback from respondents could be relied upon on the basis that fishermen could start fishing at an early age of eight (personal communication).

Premised on the above, temperature, as confirmed during the focus group interviews (see Table 5 and 6), is the most important factor influencing upwelling and thus productivity of the Sardinella. This confirms empirical evidence over the years that temperature is a major cause of upwelling in the Gulf of Guinea system as noted by Addison (2010) and Wiafe and Nyadjro (2015). Rainfall ranked second by respondents, is closely associated with temperature in that, when it rains or during the rainy season temperatures are generally lower than during the dry season. This observation, though obvious, could account for rainfall being ranked as the second most important factor influencing upwelling in the Gulf of Guinea. Most of the respondents were convinced that temperature and rainfall were the factors that drive productivity of upwelling and for that matter the abundance of Sardinella species in the Gulf of Guinea. Castro et al. (2017) in their report on the scientific and local knowledge on Sardinella species in Ghana, came up with the findings from local knowledge that temperature and rainfall are the primary factors controlling Sardinella abundance. In that same report, it was noted that wind was not listed by fishermen as one of the primary drivers of upwelling.

Further communication with the respondents revealed that from their experiences in the fishing sector, they have come to know that upwelling occurs just when the rainy season is about ending – from July to early August. There were however two diverging opinions in explaining this phenomenon. One school of thought posits that during that time of upwelling, the ocean would have received enough nutrients from the freshwater inflow which then entices the fishes to swim up and closer to the continental shelf to feed. That is why biological productivity is at its peak during the upwelling season. The second school of thought on the other hand, explained that productivity is high during upwelling season because, that near shore waters are coldest in that time of the year due to the fresh water influx during the rainy season. It is further suggested that the fishes prefer colder waters all the time that is why during the dry season, the fishes go into deeper oceanic waters as it is colder in there. While these two scenarios hold some elements of truth, respondents still perceived wind (Table 6) as the least most important factor to influence the occurrence of upwelling in our system. According to them, just before upwelling occurs and during the upwelling season, there is nothing significant about the winds on the high seas and even on land. Though the views of these local fishermen lack substantial empirical basis, they maybe plausible even though it is still unclear the role wind plays in the occurrence of upwelling in the Gulf of Guinea.

Local perception of the state of the Sardinella fishery

Local fishermen and retired fishermen were interviewed to ascertain the status of the Sardinella fishery in terms of catch landings. Majority (95%) of respondents described the current Sardinella fishery in Ghana as very bad.

Whereas 90% of these respondents mentioned low productivity of the Sardinella landings in recent years as their reason for describing the fishery as very bad. This actually confirms various studies such as those of (Koranteng, 1991 and Atta-Mills et al., 2004). Those respondents further mentioned illegal fishing methods such as light fishing, using chemicals, pair trawling, transhipment popularly known in Ghana as ‘‘Saiko’’. This finding confirms reports by Koranteng, (1989); Koranteng (1991) and Nunoo et al. (2015) which attribute the decline in productivity of Ghana’s Sardinella fishery to illegal fishing methods and practices. Although in existence for a while the menace caused by fish transhipment has dire consequences on small pelagics particularly sardinella. At the Elmina landing quay, 90% of the respondents mentioned ‘Saiko’ as a major cause of decline in catch landings primarily because Elmina is one of the ‘hotspots’ where ‘Saiko’ fishes are landed and traded. Pair trawling as a poor fishing method was very popular among respondents at Tema and this is obvious since fishermen at Tema frequently the industrial boats they tend to see some of the illegal activities of such vessels at sea. At Half Assini, all the respondents mentioned two major causes of low productivity in the Sardinella fisheries- light fishing and offshore oil exploration. Interacting with the fishermen at Half Assini through this research, came up with findings that all fishing fleets were involved in light fishing. On the basis that Half Assini is not so far from Ghana’s Jubilee oil drilling fields, respondents complained that the protected zones around the oil rigs has become a sanctuary for fishes due to the lights on the rigs. According to them the lights used around the oil fields have drastically affected their catches; the reason many of them are involved in light fishing. The challenge of such poor fishing method is the imminent collapse of the Sardinella fishery which is the mainstay of Ghana's small pelagics. The signs of collapse are already visible to respondents who participated in this study.

Interestingly about 5% of the total number of respondents mentioned 'nature' and deforestation as the reasons why Ghana's Sardinella fishery has not been doing well over the years. Although 5% may seem insignificant, it nonetheless, gives an idea that at least some people know that these other reasons could be a cause. Probing further with these two groups to find out why they gave those reasons, the group which mentioned nature (hereafter referred to as Group N) explained that things are not the same as they were some years ago. The things they were referring to were weather conditions. One member of Group N explained that, many years ago, during July and August, the weather (on land) gets very cold and it is usually foggy in the morning but for some years now, it doesn't get as could as it used to be in the past. He recounts that it coincides with the low productivity of the upwelling season where bumper harvest is expected. Again, the other group (which will be to referred to as Group D) mentioned deforestation as the reason why the fisheries have become very bad as they described. Paraphrasing the explanation of Group D, "some years ago, there used to be a lot of trees so it used to rain a lot but now, most of the trees have been cut down distorting the rainfall which brings a lot of fish". The Royal Society (n.d) and UNFCC, 1992 stated deforestation as one of the main anthropogenic activities that cause climate variability. This means that at least some local people have some sort of knowledge about climate variability and its causes and effect. Indeed, Group D could have just mentioned deforestation and not give better explanation to it but linking it to rainfall, which of course introduces more nutrients from inland into the ocean and also influencing the temperature of the sea actually gives an indication that Group D had a good knowledge about climate variability and deforestation.

Describing the Sardinella fishery as good and improved was reported by only two (2) out of the 40 groups during the study. These respondents as stated in the results, were all from Sekondi and are semi industrial fishermen who use the purse seine nets. These fishermen are engaged in light fishing as discovered during the study. Their reason why the Sardinella fishery is improved or good, is that previously, they used to land *S. aurita* during the upwelling season only but now they land it fortnightly throughout the year. It can be deduced that this increase is because of the increased effort as well as light fishing. As these groups further explained that they get *S. aurita* in large quantities as much as they used to get or would get during the upwelling season. This is an indication that illegal fishing practices play a vital role in the decline in Ghana's Sardinella fishery.

Figure 21 shows that 85% of the total number of respondents have noted a general decrease in the sizes of Sardinella species that were landed from the time they entered the fishing industry till date. This observation is very crucial and important as it matches with the findings from the empirical studies of the work. Respondents expressed displeasure that it was very difficult to come by round Sardinella which has a length greater than the length of the palm (approximately 17 cm). Some of them recalled that they could get round Sardinellas that were as long as 30 cm. This observation was made by respondents who have retired from the fishing business as a result of aging. These respondents have over 30 years' experience in the job. The only group out of the lot which stated that the sizes of Sardinellas had increased were a group of quite young fishermen with less than a decade fishing experience. The comparison and contrast are a good indication that age and years of experience is a necessary factor to consider when dealing with issues relating to climate variability and local knowledge.

Local perception influence of temperature and wind on Sardinella

Figure 22 shows that 90% of respondents from the four sampling sites were of the opinion that there is a link between temperature and fish production. They noted that some fish species prefer colder waters whereas others preferred warmer waters. According to them, during the dry season, when the temperature of the sea is relatively warm, there were some fish species that they were often landed. They mentioned tuna as one of such fishes. They also recounted that round Sardinella was the main fish species they land when the water temperature gets low. In addition to the round Sardinella was the Mackerels (Scomber species) among others. Fishermen exhibited their knowledge of the job as they gave several reasons to why *Sardinella aurita* is landed to its peak when the water temperature gets low. Their response is to Al-beak (2016) and Brainerd (1991) which says that round Sardinella, when not in its peak spawning season, go into deep oceanic waters. The fisherman's perspective has it that, round Sardinella are always in deep offshore waters because the water temperature there is favourable for them but they escape into shallower waters during the upwelling season as the deep waters gets too cold for them. Among these respondents, there was a divergence when they were to express their opinions on the possible long-term effect of temperature on fish production in Ghana (see Figure 23 and Table 7). All the three opinions given by fisherfolks who think temperature has a part to play in the Sardinella fishery over the years were linked to the decline in productivity of the fishery. How interesting it is to note that fisherfolks have observed a decline in sea temperature over the years and are able to see it as a plausible factor to the decline in Sardinella fishery as “less rainfall” was part of the three reasons they mentioned. Earlier in this discussion, it was noted that one group mentioned deforestation which they associated with less rainfall and thus increased sea temperature. On the other hand, those who perceived that there was no link between temperature and productivity/bumper harvest of Sardinella seemed to have said so because they wanted to defend their illegal fishing practices. This is because those respondents were the same people who said they have efficient gears to ‘chase’ the Sardinella species all year round irrespective of whether they were offshore or near shore. So, to such people, once they have all the tools to get the fishes, no environmental factors can be a hinderance or controlling factor of the quantities that are landed.

Respondents’ general response to the influence of wind on fish productivity and upwelling is that they do not think wind plays a significant role. Although 60% of overall respondents thought wind influences fish production (Figure 24), the explanation given by 42% of this 60% (10 out of 24), gives the impression that they do not understand the significance of wind in upwelling. Even though their explanation was that the catch is low when winds are strong, further interaction with them pointed out that wind hinders the fishing activity and not the organisms or the upwelling phenomenon.

According to them, when there are strong winds, it is difficult to go fishing hence they do not get fish during such periods. However, fish catch is good when they endure the weather and go fishing. This probably explains why those who thought wind does not influence fish productivity and upwelling gave those two reasons (Figure 25). For some to have said they get fish irrespective of the wind, supports the further explanation given by the 10 groups who said wind influences productivity with the reason that they get low catch when there are strong winds. Their answer is also not different from the rest (Figure 25) who said "wind affects fishing operation and not the production itself". What they simply mean was that going to sea when winds are strong can be difficult and dangerous so only few people go hence generally landing is poor on such occasions. Adding these 42% (10 groups) from Figure 24 to the sample size of Figure 25 gives a total of 26 groups out of 40 which represents 65% of the total sample size. This deduction is viable and can be related to the finding from Relative Importance Index where wind was ranked the least most important factor among temperature and rainfall which influences the physical component of upwelling the biological component (productivity) as well.

This notwithstanding, inference from Figure 24, where 54% (13 groups) of the sample size (24) related the influence of wind on occurrence and productivity of upwelling to strong winds that precede the upwelling season. These respondents explained that just before the upwelling season, strong winds occur. To them, it could be another environmental factor aside temperature controlling upwelling. This 54% in although accounts for only 32.5% of the overall sample size (40 groups), it is a very important outcome. It is suggestive that the local people are not all ignorant of the part wind plays in the upwelling mechanism and its productivity.

Unlike temperature, most respondents did not think that the wind has had a long-term effect of fish production in Ghana. This is obviously is not a surprise owing to their general reaction towards wind as discussed earlier. Some of the specific statements they made such as “there has been no change in the nature and trend of wind” and “wind is controlled by the stars so is has always been consistent” makes it clear that, there is no way the trends in wind have been altered and as such cannot be listed as a possible factor which has influenced productivity of the Sardinella fishery.

Local perception on the coastal upwelling and climate variability

During the ranking of environmental factors that influence the occurrence of upwelling as well as its productivity, fisherfolks have exhibited their knowledge on upwelling and its relationship with bumper harvest of Sardinella. They also made it clear that S. aurita is the main *Sardinella* species associated with the upwelling season. Castro et al. (2017) also reported that fishermen said *S. aurita* prefers cold water whereas *S. maderensis* preferred warm water.

In attempts to explain why there is bumper harvest of round Sardinella during upwelling, respondents based their explanations on temperature and nutrients as follows:

- Nutrient-rich water from deep sea comes to the surface of the water and Sardinella comes along with it because the nutrient is “their food”.
- Water reaches a low temperature which is favourable for Sardinella

- Sardinella escape extremely cold deeper waters and they school closer to the coast.
- The water contains "food" (nutrients) needed by Sardinella

This local/indigenous knowledge about upwelling and the abundance of Sardinella also has scientific evidence. For example, Wiafe et al. (2008), reported the abundance of Copepods during the upwelling season whereas Koranteng (1995; 2001) and Mensah and Quaatey (2002) also mentioned the significance of temperature to *Sardinella* species. Some of the respondents who mentioned 'nutrients' in the water further described the sea water during upwelling as "dirty" so "the fishes get blinded by the colour of the water and they cannot escape our nets". Others also talked about some kind of water which appears during upwelling. According to them, that water is "reddish" or "brownish" in colour and it contains different species of fish but dominated by Sardinella. Ga fishermen call this kind of water "*dade nsu*" whereas the Fantes and Ewes call it "*adom nsu*" and "*d3dohe*" respectively. According to Aggrey (2015), adom nsu is "brownish" sea water which prevails during the peak season of July through August "*adom nsu*" appears to be the comfort zone of particular fishes (Sardinella especially). These fishes therefore move in great shoals and hardly play any tricks when in these waters. "The presence of *adom nsu* signifies the peak of the season". At Half-Assini, according to one of the groups, in August referring to upwelling season, there are days when the sea becomes very rough and it can be seen that the water level 'rises up above the usual level'. They explained that after this occurrence they get bumper harvest. That group was made up of 6 fishermen whose average age is 60. Their years of fishing experience ranged from 44 years to 52 years. This observation noted by that particular group could actually be the physical evidence of the breaking of thermocline to allow colder nutrient-water from deep sea to come to the surface as described by Korso et al. (1991). Further interaction with fishermen on upwelling revealed that, the strength of upwelling has decreased over time (Figure 26). They related ‘weakness’ of upwelling to low productivity because from their perspective, strong upwelling means bumper harvest. Other fisherfolk could however, not discuss upwelling and its occurrence any further apart from noting that it is closely associated with bumper harvest. To them, upwelling is a natural occurrence and as such they have no idea what causes of influences its occurrence.

Based on the above, it can be concluded that the average fisherman in Ghana has a fair idea about the Sardinella fishery, environmental factors that influence the fishery as well as coastal upwelling.

Impact of Climate Variability on Market Prices of Fish

In the West African Region, fish is processed mostly through smoking, salting, cannery and frying. Most of the processing activities are highly dominated by women especially the informal ones (Samey, 2015). In Ghana about 80% of fish landed is smoked and the rest is either fried, sun dried or fermented (Mensah et al., 2006).

The comparison between prices of locally processed Sardinella and their length, indicates that price increases as the length of fish increases as represented in Figure 29. If climate variability is influencing the sizes of Sardinella landed in Ghana, then it translates that the value of the fish will keep decreasing over time. Fortunately, there is market for all sizes of Sardinella on the market (Figure 31). Based on this, it can be assumed that they will not incur losses. Meanwhile, interaction with respondent reveal that other factors such as cost of fuel influence the cost prices of the fish and this is having a great toll on their income. Assuming more bigger fishes are landed than the smaller sizes, the fishes will get better market value and of course increasing the profit margin. Also, a glance at Figure 29 tells shows that there is no much change in the price of fish over the five years reviewed (2013-2017). Sardinella, are generally, low priced fish (Atta-Mills et al., 2004; Koranteng, 1991) but are economically important due to the large quantities that are landed in the country.

Perception of processed fish traders on the fishery and climate variability

Fishmongers (all women) who were interviewed during this section of the research, opined that the individual sizes of Sardinella landed over the years have decreased in size whereas a few others thought there has not seen any change in size (Figure 30). That regardless, they admitted that there was market for all sizes of Sardinella that is landed although 5% of respondents were of the view that consumers preferred smaller sizes of smoked Sardinella species to that of bigger sizes (Figure 31). This observation could be the reason why fishermen keep landing juveniles of Sardinella as there is market for all sizes. In that regard, it will be a great challenge to policy makers as well as law enforcers to ensure that policies, laws and other measures that are proposed to revamp Ghana's Sardinella fishery will be heeded to. It would have been easier if the smaller sizes of Sardinella were not being patronized. Figure 32 illustrates that 50% of respondents admitted they make maximum profit during the lean season. However, they were quick to add that, in recent years, the profit they make, is used it to reimburse the losses incurred during the upwelling season where prices of smoked Sardinella are very low.

Generally, the women lamented over the losses they tend to incur. Some further explained that over 10 years ago, the business was ‘sweet’ because they made very good profit. Low profits and even running at a loss are not a good thing to write about. About half of the respondents are single mothers. Which means that they are fully dependent on returns made from their business for survival. Meanwhile, the primary occupation of all respondents is trading in smoked Sardinella and none but one of them had a secondary occupation. This means that, should the Sardinella fishery in Ghana collapse, livelihood that are directly dependant on this business are going to suffer a great deal.

Climate Variability Impacts: Implications for Coastal Livelihoods

The Ghana National Climate Change Policy [GNCCP] lists agriculture and food security systems as one of its strategic focus areas (MESTI, 2013). Under this strategic focus area, the policy identifies fishing from natural water bodies as one of the bases of Ghana’s agriculture and food production systems. According to the Ghana Investment Promotion Centre (GIPC, 2018), marine fisheries account for over 80% of fish consumed in Ghana with Sardinella constituting a majority of fish catch. As findings from this research indicate, climate is having a detrimental impact on the sizes Sardinella species in Ghana. Also, from this study, local knowledge confirmed a reduction in sizes of Sardinella. It is therefore suggestive that the effects of climate variability are a major contributing factor to the small sizes of Sardinella fishes landed in Ghana. On this premise, the impacts of climate variability is to be seriously considered in the management of round Sardinella fishery in Ghana, given that stakeholders in the fisheries industry have not duly acknowledged climate variability impacts as a major determinant in the recent crises in the Sardinella fishery.

The results of this research also show that smaller sizes of Sardinella are not profitable as compared to the larger sizes which have higher market value. Trends from the market prices of Sardinella over five years show no much difference in price of the species under study (Figure 29). Meanwhile, the bulk of their fish supply are of smaller sizes which may account for the less profit made on sales and losses incurred, as reported by the respondents. This has implications for poverty in the coastal regions. On the other hand, the GNCCP seeks to achieve national food security and poverty reduction as part of its key principles. Against this background, it is important that the Sardinella fishery be seriously considered in terms of revamping the industry as bid to alleviate poverty in coastal communities for national development.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Marine fisheries in Ghana has over the years been declining. Most often than not, the decline is attributed to bad fishing practices and methods. Little attention has, however, been given to the plausible contribution of climate variability, which is currently a global issue. This study therefore sought to evaluate the impact of climate variality on Ghana's Sardinella fisheries through its effects on coastal upwelling by using SST and wind stress as proxies for the strength of upwelling. This goal was meant to be achieved by: 1) investigating the effect of long term temperatures variations on the length-at-age of *Sardinella* species; 2) investigating the effect of long term variations in wind stress on the length-at-age of *Sardinella* species; 3) investigating traditional knowledge on climate variability and its influence on fisheries resources; and 4) establishing the relationship between sizes of Sardinella landed, climate variations, and market prices over the past years.

The effect of long-term variations in wind stress and sea surface temperature (SST) on the length-at-age of *Sardinella* species were investigated by back calculating the ages of each individual and finding the average temperature and wind stress conditions the individual experienced throughout its lifetime. SST and wind stress anomalies since 1981 were also calculated. Analysis of sizes of fish and climate induced indicators was performed. Traditional knowledge based on perception was investigated through focus group interviews involving fisherfolks from four different landing sites along the coast of Ghana.

Results from the research showed strong relationship (R-squared =0.5) between anomalies of climate indicators and sizes (length) *S. aurita*. Sizes for *S. aurita* decrease with increasing temperature above the optimum temperature of 25.8 ºC over a period of 36 years (1981-2017) whereas the relationship between anomalies of climate indicators and sizes (length) *S. maderensis* (flat Sardinella) was poor (R-squared =0.1). It was therefore concluded that prevailing climatic conditions influence the growth of round Sardinella species but is currently not statistically important to the growth of flat Sardinella.

Also, findings from traditional perceptive indicate that there is the awareness of relationships between *Sardinella* species and temperature in that, *S. aurita* prefers low temperatures and as such, its abundance largely depends on the temperature of the ocean and thus the upwelling season where temperature of the ocean drops significantly. On the other hand, *S. maderensis* is not responsive to temperature and that explains its abundance all year round. They also attested to the fact that temperatures have increased over the years and could also account for the poor landings of *S. aurita* in terms of abundance and size.

Furthermore, interaction with smoked fish traders confirms the major reduction in sizes of landed Sardinella species. They however did not see it as a threat to their business since there is market of all sizes of smoked Sardinella although they make more profit on the larger sizes. Their main concern was the low catch in Sardinella which could be a major threat to their source of income.

Conclusions

It was evident from this research that empirical studies shows a strong relationship between climate indicators and growth of *S. aurita* species. As such, due to the prevailing increase in SST and wind stress, the optimum length of *S. aurita* species in Ghanaian marine waters based on influence of SST is 22.6ºC and 21.8 for wind stress. On this basis, the first null hypothesis is rejected.

Secondly, traditional knowledge of fisherfolks confirms a strong relationship between water temperature, *Sardinella* species and upwelling but no important relationship between wind, *Sardinella* species and upwelling.

Also, the sizes of *Sardinella* species influences profitability. However, traders do not see the current small sizes of Sardinella which are landed as a threat to their business because, there is market for all sizes of smoked Sardinella. Based on this, the second null hypothesis stated is accepted.

Sardinella fishery in Ghana is indeed collapsing and climatic variations in sea surface temperature and wind stress are major contributing factors to the relatively smaller sizes of *S. aurita* landed in Ghana. If climate related effects on fisheries are not taken seriously and incorporated in fisheries and coastal management strategies in the country, the depleting stock of *Sardinella* species may never be solved likewise the issue of poverty reduction in fishery dependent livelihoods.

Recommendations

Grounded on the results from this research, the following recommendations are made:

Fisheries scientist who seek to investigate into climate variations and its effects on marine fisheries can consider this method but collect fish data over a longer period capturing at least two major upwelling seasons. Also, other climate indicators such as rainfall should be included in the work as rainfall is known to influence the occurrence of upwelling.

Detailed studies on the effect of climate variability on coastal upwelling in the Gulf of Guinea needs to be carried out. The volume of water which is upwelled yearly could be tracked from the past to the present to see if there has been any change. As reduction in volume could be associated with the total biological productivity of the upwelling.

Supplementary livelihoods need to be promoted and effectively implemented in coastal fishing areas as a way of reducing poverty in these fisheries dependant local economies while identifying strategies to address the effects of climate variability on Ghana's fisheries.

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APPENDIX

UNIVERSITY OF CAPE COAST

SCHOOL OF BIOLOGICAL SCIENCES

DEPARTMENT OF FISHERIES AND AQUATIC SCIENCES

A SURVEY OF TRADITIONAL KNOWLEDGE ON THE EFFECT OF CLIMATE VARIABILITY ON SARDINELLA FISHERIES IN GHANA

<u>INTERVIEW GUIDE</u>

SITE………………………………… DATE……………….

Biodata

Gender: Female /Male /Other

Age…………………. Number of children…………………….

Educational Background: none/ MSLC/SSS/O'LEVEL/other

Primary Occupation …………………………….

Secondary occupation…………………………….

General

1. How long have you been in the fishing industry? ....
2. Where are your fishing grounds?...
3. Do you live in this fishing community? Yes/No

2a) If yes, how long have you lived here? ....

2b) If no, where do you live? ....

4. How will you describe the *Sardinella* fishery since you entered the industry till date? a) good b) bad c) very good d) improved e) no change f) very bad

5. What is the reason behind your answer in question 4? ………………..

…………………………………………………………………………….

6. Comparing the sizes of *S. aurita* (Eban or Kankama) and *S. maderensis* (Antebo, Adruku, Antar) that used to be landed since you joined the industry till now, will you say they have: a) increased? b) decreased? c) no visible change? d) remained the same?

Climate Variability (Temperature, wind)

A. Do you think there is a link between temperature and fish production? **Yes/No**

B. What is the reason behind your answer to question 1? ………………

…………………………………………………………………………….

C. If your answer to ques 1 is yes, based on your personal observation of the local temperature over the past years, will you say temperature has played/ is playing a role in the *Sardinella* fishery in Ghana? **Yes/No**

3b) Please explain your answer to question 3…………………………………

D. Do you think there is a link between wind and fish production? **Yes/No**

E. What is the reason behind your answer to question 1?

………………………………………………………………………………

F. If your answer to ques 1 is yes, based on your personal observation of the local wind over the past years, will you say wind has played/ is playing a role in the *Sardinella* fishery in Ghana? **Yes/No**

3b) Please explain your answer to question 3………………………………

………………………………………………………………………………

Upwelling

I. How many times does upwelling occur in a year **a)** once **b)** twice **c)** other

II. How will you describe upwelling in the Ghanaian waters over the years? a) getting stronger **b)** getting weaker **c)** it hasn't changed **d)** other

III. Is there a link between upwelling and bumper harvest of *Sardinella*? **Yes**/**No**

IV. Explain your answer to question III ……………………………..…

V. What causes upwelling in the Ghanaian coastal waters? ………………………………………………………………………….

VI. Is there a relationship between temperature and upwelling? **Yes**/**No**

VI a) If yes, describe it

....

VII. Is there a relationship between wind and upwelling? **Yes**/**No**

VI a) If yes, describe it ....

VIII. Is there any another thing you want to share based on this questionnaire?