AN ASSESSMENT OF THE VULNERABILITY OF GHANA'S COASTAL ARTISANAL FISHERY TO CLIMATE CHANGE

By

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ABSTRACT

Considering the fact that nearly 25% of the Ghanaian people live in the coastal zone and about 10% depend on the coastal fishery for livelihood, it is likely that any changes in the production of the fishery may impact on the socio-economic lives of the people. For the past four decades, climatic conditions have been found to be changing in the country. This period coincided with the conspicuous fluctuations in the landings of the most significant pelagic species exploited by the canoe fleet. This study provides an assessment of the influence of precipitation and sea surface temperature changes on yield and catch of Round Sardinella (*Sardinella aurita*), anchovy (*Engraulis encrasicholus*), Flat Sardinella (*S. maderensis*) and Guinea Shrimp (*Parapenaeopsis atlantica*). The abundance of these stocks is believed to be correlated with upwelling and sea surface temperature conditions and a local manifestation of global scale climatic changes is suspected to be taking place. It was hypothesized that climate as represented by sea surface temperature (SST) and precipitation affects either catchability or the population growth rate of each species. Forty years of climatological data (mean air temperature and precipitation) were assessed; 38 and 33 years each of hydrological data (sea surface temperature and salinity) were then used to investigate the possible relation between climatic changes and species production. Forecasts of future climate scenarios were made, and stock dynamics were simulated with an environmentally coupled dynamic surplus production model. Stock production and, to a lower extent, catchability were found to be closely tied to climatological factors. Lower catch rates of the Round Sardinella coincided with years of higher SST and the reverse was true for the anchovy. For the shrimp and flat sardine, precipitation was found to have the most substantial effect on production and total annual catchability. It was concluded that changes in climate directly affect the productivity of the ecosystem as well as its catchability and most importantly, the population growth rate of the species. For sustainable management of the fishery resources, it is imperative that climatic and hydrological parameters be incorporated into fishery management models.

TABLE OF CONTENTS

1.0 Introduction

LIST OF FIGURES

List of Plates

LIST OF TABLES

LIST OF APPENDICES.

1.0 INTRODUCTION

Increasing fishing effort on marine stocks has major impacts on the short-term dynamics and sustainability of the fish populations (Bakun, 1993; King 1995). Availability and distribution of the short-lived small pelagics, the tuneids and shrimp, have also been related to environmental changes, particularly variations in the ocean climate.

Precipitation, river-runoff and salinity have been found to be vital determinants of penaeid shrimp abundance (Condrey and Fuller, 1992). Sea surface temperature (SST) influences the distribution and availability of tuneids (Bages and Fonteneau, 1980; Sharp, 1992) and the seasonality and productivity of the fisheries such as those in the Gulf of Guinea upwelling areas (McGlade *et al*. 2002). However, fisheries management policies and practices are usually based on catch effort dynamics with little consideration of the ecosystem variations. Thus, the local effects of a change in global climatic conditions are likely to go unnoticed and would affect the most heavily exploited stocks in developing countries such as Ghana which have coastal communities with a high dependence on them (Glantz, 1992; IPCC, 2001).

1.1 Rationale of This Study

The exact cause-effect relationships between climate and stock variability are poorly understood because the relationship is difficult to define. Some studies relating the productivity to environmental factors have been undertaken for the Gulf of Guinea. Koranteng and McGlade (2002), Hardman-Mountford and McGlade (2002) Demarcq and Aman (2002) and Arfi *et al*. (2002) analysed how the dynamics of commercial stocks relates to the patterns in SST. The seasonal nature of the fishery and its close association to upwelling and SST has been confirmed. This could, however, be explained either in terms of species movement/migration to the fishing area occurring along a climatic gradient or more favourable conditions for population growth or both. Since little has been done to clarify this relationship, an attempt is made in the present study to assess which of these mechanisms is more applicable for the Ghanaian fishery.

1.2 Objectives of the Study

The ultimate objective of this thesis is to investigate the relationship between climate and the catch per unit effort (CPUE). Pertinent questions to ask in this regard would be:

- What have been the trends in landings of the main commercial fish stocks for the past 30 – 40 years?
- What have been the past climatic conditions?
- What historical relationships have been or can be established between the climate variability and fish yield?
- Which models have been used in similar studies and to what extent can they be used to predict future marine yields in Ghana?

It is expected that the answers to these questions would help to achieve the following specific objectives:

To assess the potential impact of climate change on the coastal fishery using existing historical climate data,

To forecast the dynamics of the main commercial stocks for 5- 20 years ahead in the absence of increases in fishing effort,

To develop possible adaptation options that can be integrated into management, and conservation of the living aquatic resources, and

To provide a basis for country –wide studies that can produce an input to Ghana's Second National Communication under the United Nations Framework Convention on Climate Change (UNFCCC).

2.0 DESCRIPTION OF THE FISHERY AND COASTAL CLIMATE

The Republic of Ghana is situated in West Africa along the Greenwich meridian between latitudes 4.5 ^{o} N, 11.5 ^{o} N and longitude 3.5^o W, 1.3^o E. To the East, West and North are the Republic of Togo, La Côte d'Ivoire and Burkina Faso respectively. The total area of 238,540 km^2 is washed to the South by the Gulf of Guinea. The population is estimated at 19.7 million and growing at a rate of about 3% per annum, with about 10% being almost entirely dependent on the marine fishery for livelihood (Quaatey, 1996; Republic of Ghana, 2000).

2.1 Natural Resources and the Economy

The vast array of renewable and non-renewable resources includes precious minerals (gold, diamond, copper and manganese), forests, fisheries, game and wildlife. Over 50% of the GDP is provided by the agricultural sector, which includes crops, Forestry and Fisheries. The main crops cultivated and consumed locally are rice, coffee, cassava, peanuts, corn, sheanuts while those cultivated for export are cocoa and coffee. Other exports include gold, timber, bauxite, aluminium and tuna (Isaka *et al*. 2002).

2.1.1 The Fisheries Sub-sector

Though contributing only about 3% to national GDP and 5% of Agricultural GDP, Fisheries provide about 65% of the animal protein intake of the entire populace. Like in all tropical countries, fish species diversity is high with about 447 in the marine waters, 227 in the inland waters and 19 species produced in aquaculture. Aquaculture activities are still yet to obtain a sound footing and the inland fisheries constitute only 16% of the total annual production. The marine fishery is, thus, the mainstay of the sub-sector and has been a significant non-traditional export since the introduction of the Economic Recovery Program in 1984 (Quaatey, 1996). The area of operation for this is the Eastern Central Atlantic Fishing Area (CECAF), which spans most countries in the sub-region. The coastline is 528 km long with an Exclusive Economic Zone (EEZ) of over 218,000 km^2 and a continental shelf of 23,700 km^2. With most of the country's major rivers emptying into the sea, Ghana's coastal fishery is the 4th most productive of 36 countries in the Atlantic. Three main fleets exploit it: Artisanal (over 70% of total marine catch), Inshore or Semi-industrial and the Deep-Sea or

Industrial, which can be categorised into the large trawlers and the Tuna vessels (Table 2.1).

Table 2.1 Fleets Exploiting the Coastal Fishery in Ghana (Anakwah and Santos 2002, Isaka *et al.* 2002).

Fleet	Vessel Type/Size	Target Species	Gear Type
Artisanal	Canoe, up to 8 m	Anchovy, Sardines, Mackerels, Guinea Shrimp, Burrito	Drift Nets, Purse Seine
Semi-Industrial	Small Boats, 8-37 m	Anchovy, Sardines, Mackerels, Burrito, Other Demersals	Purse Seine, Trawls
Industrial: Large Trawlers	Large Steel Vessels over 35 m	Sardines, Chub Mackerel, Horse Mackerel, Shrimp, Cephalopods	Trawls
Tuna	Large Vessels over 30 m	Skipjack, Yellowfin, Bigeye	Pole and Line, Long Lines, Purse Seine, Fish Aggregation Devices

2.2 Importance to Coastal Communities

The coastal zone is characterised by rivers, lagoons and marshes connecting to the ocean. The major rivers are flooded during the rainy season and empty into the sea. Though it forms only about 7% of the nation’s land area, the coastal area houses most of the major cities and towns: Accra (the capital), Tema (main harbour and industrial city,) Sekondi-Takoradi (Harbour city), Cape Coast, Elmina and Ada (tourist centres). It is, therefore not surprising that about a quarter of the populace (about 21 districts in 4 of the country’s 10 regions) reside here. It is also home to numerous productive lagoons. Majority of the people lives in rural communities where the major occupation is fishing and they are organised into about 200 fishing villages and nearly 300 landing beaches. Thus there is a high dependence on fisheries (currently open access) for food and livelihood. Employment has been created for several thousands of people in the industry such as processors, traders, exporters, boatbuilders and the middlemen who supply communities in the hinterlands.

The tuna fleet is the most important foreign exchange earner followed by the industrial shrimpers but as far as fish yield, employment and livelihood are concerned, the Artisanal fleet plays a dominant role. The stocks exploited are the Round Sardine, Flat Sardine, Anchovy, Chub Mackerel and Frigate mackerel. The first four are usually used to characterise the canoe fleet (small pelagics) since they are the most common and constitute over 60% of the landings. Others are the Guinea shrimp, Sea Breams, and Burrito. The tunas are mostly Yellowfin, Bigeye and Skipjack (Quaatey, 2002).

The Ghanaian canoe fleet has for a long time been a good example of how African indigenous fisheries can successfully develop to a modern stage. Fishing is done by the fishermen way beyond the national boundaries in spite of many economic difficulties. The fishing methods and gear that they have introduced have strongly influenced the kind of fisheries found there for example, in Sierra Leone and Guinea (Dykhuizen and Zei, 1970).

2.3 Biology of the Target Species of the Artisanal Fleet

Most of these fish stocks are shared along the subregion and in the fishing area and are believed to follow a migratory pattern along upwelling areas. However, the most noticeable aggregation areas are the Ghana-Ivorian shore (Dykhuizen and Zei, 1970).

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2.3.1 Sardinella aurita

Commonly called the Round Sardinella, this species belongs to the order Clupeiformes of the family Clupeidae and the class Actinopterygii (Plate 1). It is locally called 'Eban' or 'Kankama'. It is usually found in marine pelagic waters of 0-350m depths especially in West Africa. It is distributed in subtropical a climate (46°N-36°S) that is in the Black and Mediterranean Seas, in the Eastern Atlantic as well as in the Western Atlantic. Spawning occurs during the upwelling seasons. It is a highly schooling fish usually associated with the inshore shelf area and having a diurnal migratory feeding pattern. Its typical diet is mainly composed of zooplankton and copepods. It is classified by the FAO as highly commercial and used locally for food as well as for live-bait in tuna fishing in CECAF. The size distribution in Ghana has been estimated as 5-15cm for the beach seine and 18cm for the ring net (Anakwah and Santos, 2002). It is fished mainly by beach seiners and to some extent, poli operators during the two main seasons, July to September (main) and for about three weeks in January/February. These fish are believed to be sensitive to changes in temperature and salinity (Koranteng, 1999).

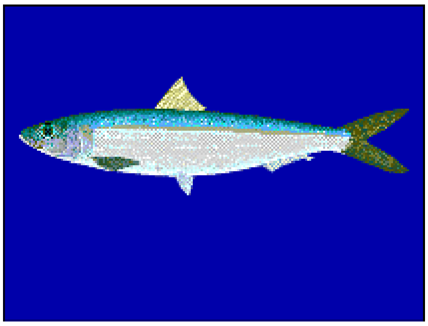

Plate 1 *Sardinella aurita* (Round Sardinella) Source: Froese and Pauly (2002)

2.3.2 Sardinella maderensis

The flat Sardinella (as it is usually called) belongs also to the class Actinopterygii and order Clupeiformes of the Clupeid family (Plate 2). To the local people, it is 'Antebo', 'Adruku' or 'Antar'. It is also a marine pelagic of the tropical eastern Atlantic from Gibraltar to Angola. It thrives at a depth of 80m and below by feeding on fish larvae and plankton. Breeding occurs in the warm season (July to September) and it is used locally for food and live bait. There is a strong schooling behaviour in coastal waters of 24°C with diurnal migration for a diet of fish larvae and zooplankton. Their movements are also correlated with seasonal upwelling (Froese and Pauly, 2002). It is also on the FAO list of highly commercial species and seems to be more tolerable to changes in temperature and salinity than *S. aurita* (Mensah and Koranteng 1988).

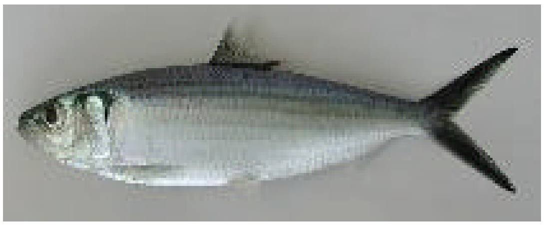

Plate 2 *Sardinella maderensis* (Flat Sardinella) Source: Froese and Pauly, (2002).

2.3.3 *Scomber japonicus*

This is a marine pelagic commonly called the Chub Mackerel. It occurs in waters up to 300m deep in subtropical climates (60°N-55°S). It is locally referred to as 'Saman' and belongs to the family Scombridae, order Perciformes and Class Actinopterygii (Plate 3). It shows strong schooling behaviour even with other species and also migrates diurnally to feed mainly on copepods. It is also reported as one of the stocks that could be affected directly or indirectly by climate change (Rothschild, 1996).

Plate 3 *Scomber japonicus* (Chub Mackerel) Source: Froese and Pauly (2002)

2.3.4 *Engraulis encrasicolus*

The anchovy is another marine pelagic found in the eastern north and central Atlantic between 62°N and 19°S. It also occurs in brackish water. It is locally called 'Bornu or 'Keta school boys'. It belongs to the family Engraulidae, order Clupeiformes and class Actinopterygii (Plate 4). Breeding occurs during the warm months. It is migratory and schooling occurs in saline waters. The diet is mainly composed of plankton. They can thrive in salinities of 5-41ppt and in certain regions, migrate into lagoons, estuaries and lakes during spawning. It is also classified by the FAO as highly commercial.

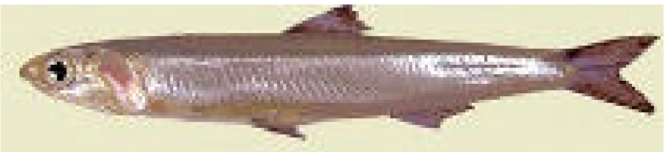

Plate 4 *Engraulis encrasicolus* (Anchovy) Source: Froese and Pauly (2002)

2.3.5 *Parapeneospsis atlantica*

This species of shrimp is commonly called the Guinea shrimp or the Brown Shrimp by virtue of its brownish greyish colour. However, it turns a beautiful red after cooking and is the main species caught off the West African coast. Spawning occurs in the ocean but tides and wind driven currents carry the individuals into estuaries. Most brown shrimp are caught in July-August and have a maximum life span of 18 months. They are common on muddy bottoms and feed mainly on detritus, small plants and animals. Generally, larval stages are spent in coastal estuaries, lagoons or mangrove areas where there is more food and safety while adulthood is spent in the sea. They thrive in sandy bottoms at depths between 10 m and 40 m. They are hypothesised to use changes in water temperature and salinity associated with cold fronts to elicit a passive behavioural response in combination with a diel activity cycle (Horton *et al*. 1997). They have an Lmaxof 17cm for females and 12cm for the males.

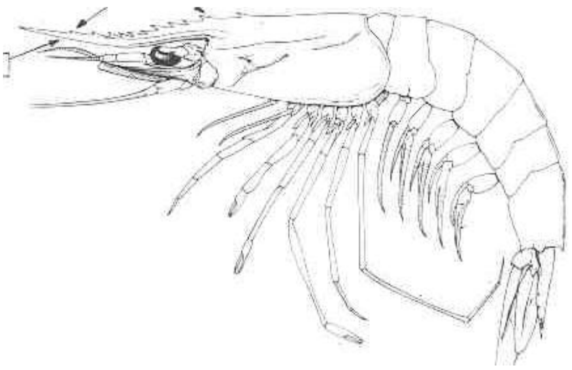

Plate 5 Guinea shrimp (*Parapenaeopsis atlantica*) Source: FAO 1986

2.4 General Trends in Production of the Fishery

Over the past two to three decades, increasing national population, especially in the coastal communities, has led to increasing fishing effort and a subsequent increase in yield. Thus the harvest of all the species has been increasing. Figure 2.1 depicts a summary of the total marine production for the past forty years. Closer examination of the fishing effort for the main fleet (canoe) however does not show such a considerable increase in the number of fishing vessels relative to the number of years under review. Thus, the increased effort could be attributed to increases in the number and efficiency of the gear and fishing methods rather than in the number of vessels (Anakwah and Santos, 2002). The number of fishermen has increased with the introduction and development of motorization, longer fishing time at sea and the use of more specialised gear) resulting in increasing stress on the resource.

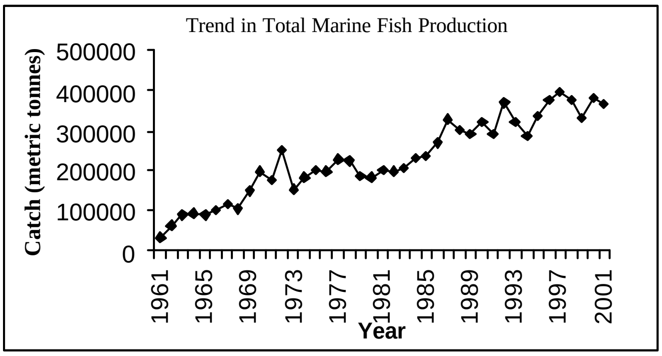

Figure 2.1 Summary of Total Marine Fish Production (1961-2001) Source: MFRD, Ghana.

Table 2.2 Trend of Variation in the Canoe Fleet -1969-2001. Source, Anakwah and Santos (2002), MFRD (2002). *Unavailable data

Year	Canoes	Outboard Motors	% Motorization
1969	8728	*	*
1973	8238	*	*
1977	8742	*	*
1981	6983	3698	53.3
1986	8214	4250	51.7
1989	8052	4631	57.5
1992	8688	4262	49.1
1995	8641	5076	58.7
1997	8610	5139	61.2
1999	8895	*	*
2001	9981	*	*

The fishery has exhibited high fluctuations, especially the *S. aurita* that constitutes over 50% of the annual landings. Its amount and availability seem to determine the annual production of the fishery. There are corresponding yearly fluctuations in catch and catch per unit effort (CPUE). Unusually high catches were recorded in 1972 due to availability of the fish. However, a poor landing was recorded in the ensuing years attributed mainly to overfishing and anomalous climatic conditions (Koranteng, 1991). Generally, the small pelagics are believed to be overexploited in spite of the recent increases in landings (Mensah and Quaatey, 2002).

2.5 Climate and Hydrology

Like in other coastal West African nations, the coastal climate is equatorial with considerable differences in the amount and seasonal distribution of precipitation. The average daily maximum temperature across the sub-region varies between 27-29°C in August–September and 31-33°C in February-March. Temperatures are generally high across the entire nation ranging from 18 to 40°C in the North and 24 to 30°C in the South. The Guinea current flows offshore from the west to the east as a continuation of the Equatorial counter Current. There is a persistent South West Monsoon modified by land and sea breezes in the coastal area. This monsoon reinforces the Guinea current, which is also modified by the harmattan. There may be some spatial variation with respect to diurnal and annual ranges due to distances from the modifying effect of the sea breeze. However, there is little variation of temperatures throughout the year. Upwelling of cold waters (22-25°C) occurs in late June-July to September-early October and during the Harman. Otherwise, sea surface temperatures typically vary between 27-29°C (Allersma & Tilman, 1993).

Rainfall is highest in the south and decreases towards the North to about 1100mm.

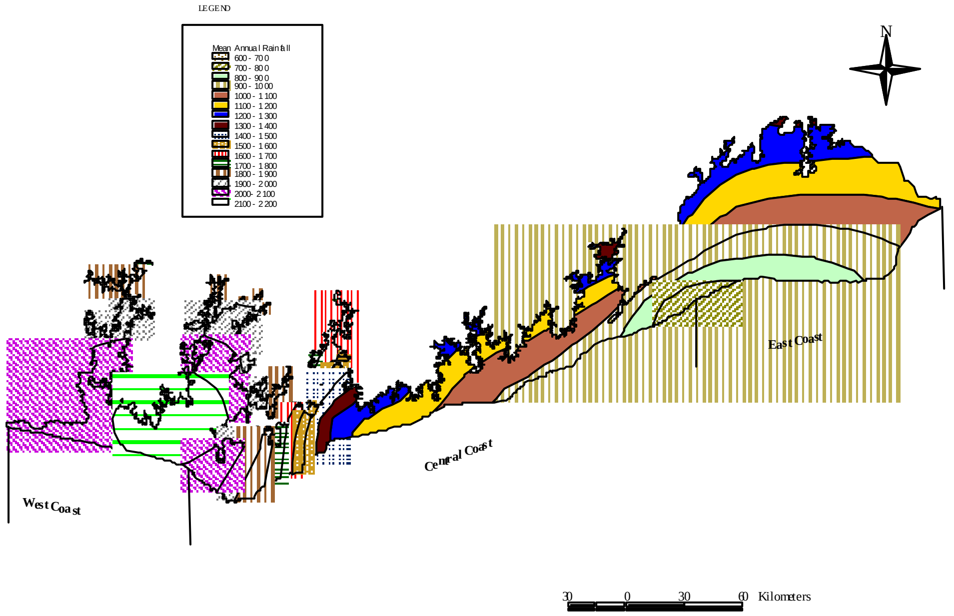

Figure 2.2 Distribution of Rainfall along the Coastal Zone of Ghana. Source: Meteorological Services Division, Accra.

There are two main regimes:

(a) A double maxima with peaks from May to August and September to October (areas south of 8^o30 N and including the coastal zone as in Figure 2.2)

(a) A single maximum from May to October with a long dry season from November to May (excluding the coast but encompassing the major rivers which drain into the sea).

According to Allersma & Tilman (1993), rainfall patterns are strongly related to the pattern of river flow and sediment transport into the sea. The coastal current is weak but the meeting of fresh river water and saline seawater gives rise to currents. Mensah (1991) attributed the overlap of the main fishery of the Ghana-Ivorian coast (*Sardinella aurita)* with this period as follows: Since organic nutrients and elements consumed during photosynthesis in the sea are replenished by river run-off, precipitation can be said to be positively related to the productivity of coastal ecosystems.

3.0 LITERATURE REVIEW AND BACKGROUND THEORY

3.1 Short Overview of Climate Change Activities in Ghana

After ratifying the United Nations Framework Convention on Climate Change (UNFCCC) on December 5, 1995 a number of activities have been carried out in line with Ghana’s commitment to the UNFCCC. These include the preparation of an inventory of greenhouse gases (GHGs), impact assessments for water resources, agriculture, and the coastal zone. Others are the possible abatement options in the forestry and energy sectors and the development of future national scenarios. The occurrence of climate change was observed in the form of sea level rise, coastal erosion and a general increase in GHG emissions. A warming rate of $0.2^{o}C$ per decade and 5.4% decrease in rainfall was observed for the whole nation (Republic of Ghana, 2000). Using General circulation Models (GCMs), scenarios were developed up to 2100 for national air temperatures and precipitation. However, the Fisheries sub-sector was not covered in these assessments and there are currently no predictions for the sea surface temperature (Republic of Ghana, 2000).

3.2 The Coastal Climate and Its Interaction with the Fishery

The Guinea current, blows from Guinea-Bissau in the north of the sub-region to Angola in the South, and has a weak link with local winds. According to Quaatey (1996), seasonality is exhibited on the coastal waters, which are dominated by a seasonal upwelling occurring twice a year. At this time, water temperatures typically drop below $25^{o}C$. The major upwelling lasts about three months (late June or early July to late September or early October). The minor one occurs in January, February or March for not more than three weeks. The only exception to this trend was in 1986 when it lasted for 10weeks.

The two seasons are characterised by decreases in SST, increases in salinity and decrease in dissolved oxygen. The mixing of cold and nutrient rich lower layers with water surface layers enhances productivity. The increased population of phyto and zooplankton leads to increased production of higher taxa, particularly fish. For the rest of the year, a strong thermocline exists which fluctuates in depth between 10 and 40m. The coastal climate has been linked to the abundance and availability of pelagic stocks by several authors including Mensah and Koranteng, 1988, Mensah, 1991, FAO, 1997.

Oceans are an integral and responsive component of the climate system with important physical and biogeochemical feedback to the climate. The atmosphere and oceans store and exchange energy in the form of heat and moisture, with the oceans being the largest reservoir of moisture. They are more effective heat absorbers than land and ice surfaces and better heat reservoirs than land. Hence, oceans can alter atmospheric conditions and the weather. Kawasaki (1992) observed that increased concentration of greenhouse gases (Carbon Dioxide, Water Vapour, Methane, Nitrous Oxide and Chlorofluorocarbons) and, hence, global warming could increase sea surface temperatures or distort the rainfall pattern. It could also intensify wind stress on the sea with a resultant acceleration in coastal upwelling. Climatic factors affect the biotic and abiotic elements that influence the numbers and distribution of fish species. The abiotic elements include water temperature, salinity, nutrients, sea level and current conditions while biotic factors include food availability and presence and species composition of predators and competitors. Water temperatures can directly affect spawning and survival of juveniles as well as fish growth (Laevastu and Hayes, 1981).

Sea temperature, on the other hand, affects the biological production rate and, hence, food availability in the ocean, which is a powerful regulator of fish abundance and distribution (IPCC, 2001). A summary of the interactions between the climate and the biotic and abiotic environments of fish as depicted by Glantz (2002) is shown in Figure 3.1

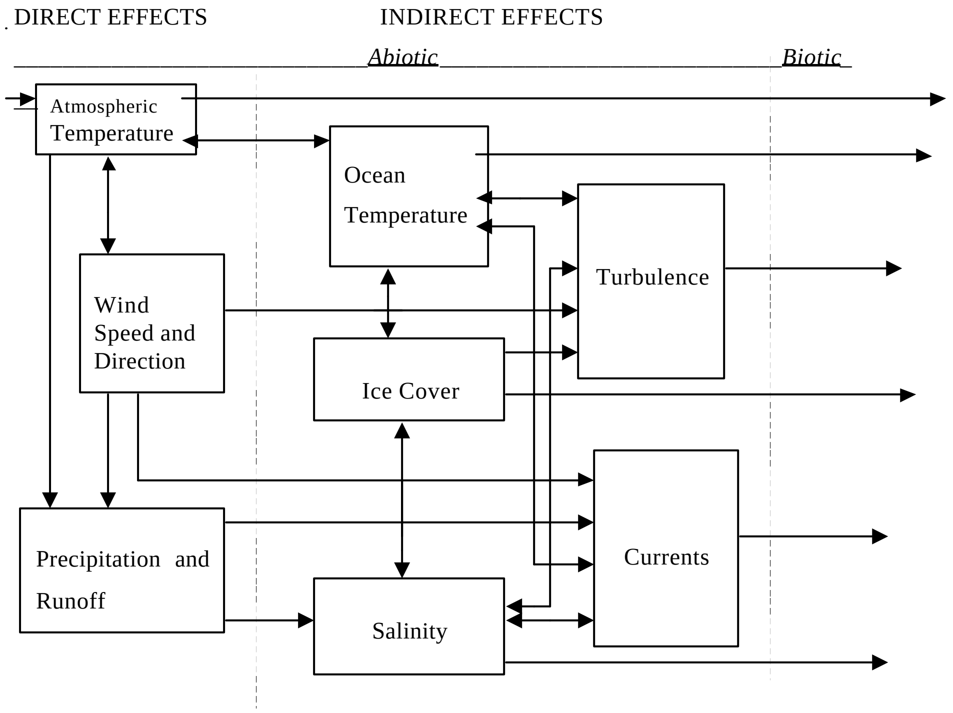

Fig. 3.1 The Major Climatic Pathways Affecting the Abiotic Environment of Fish (Glantz, 2002)

3.3 The Influence of Upwelling

Besides fishing effort, the coastal upwelling is believed to be the most significant factor affecting the Sardinella fishery in Ghana. Inter annual variations in upwelling at the coast creates fluctuations in biological production in coastal ecosystems by enhancing spawning and recruitment. Long term changes in upwelling trend related to global warming are expected to impact either positively or negatively on fisheries in coastal fish production.

According to Koranteng (1991), years of higher upwelling indices seem to coincide with those of high yield for the Sardinella fishery in Ghana when studied with models that take into consideration both the period and intensity of upwelling. Variability in upwelling trends also leads to variability in production of the Central West African Upwelling i.e.: Côte-d'Ivoire, Ghana, Nigeria, Togo and Benin (McGlade *et al.*, 2002). Models used by Cury and Roy (1987) to analyse the annual fluctuations in the CPUE of La Côte d'Ivoire indicated that the fishing effort accounts for 18% of the CPUE variability while the upwelling indices for the previous and current years accounted for 40%. The seasonal coastal upwelling periodically modifies the physico-chemical parameters of the water masses and controls the biology of the subsystem.

Mensah (1991) observed a correlation between the dominant rainfall pattern, river discharge and sediment transportation and zooplankton production. This rainfall pattern always precedes the major upwelling, which produces outbursts of fish yield. The upwelling seems to provide a favourable habitat and occurs spontaneously with spawning near Cape Three Points (Roy, 1996). Though the dynamics of upwelling systems appear to be different and not clearly defined, wind stress is believed to be an important cause. Binet (1997) noted that Sardinella catches are related to along-shore wind stress of the year except during the early months of larval life. Increased wind stress induces enrichment favourable for larval survival except immediately after hatching when turbulence and offshore advection induce adverse effects. It would therefore be expected that warmer years with higher sea surface temperatures would be characterised by increased number of eddies at Cape Three Points. With spawning occurring in this region, the enlarged turbulent structures would enable the survival of a large number of larvae.

Verstraete (1983) also detected a linkage between the upwelling event, mean sea level and dynamic height of the sea. Just before the start of the major upwelling, there is a simultaneous drop in mean sea level and dynamic height at Tema and Takoradi. It has been suggested that the changes in the Sardinella populations in the last decade could have been induced by long-term environmental fluctuations (Roy, 1993). According to Bakun (1993), the dramatic changes in the pelagic fish yield in the Gulf of Guinea could either be a result of global scale climatic effects that could lead to intensification of coastal upwelling, or of teleconnections to the Pacific El Nino Southern Oscillation (ENSO) system. However, each of these causes suggests differing scenarios for the future of the local fishery and would require further research for adequate scientific basis to choose between them.

3.4 SST- Related Studies in the Gulf of Guinea Large Marine Ecosystem (GOGLME) Fishery

In his analysis of the ocean environment, Mendelssohn (1988) observed that salinity, SST and wind (North-South) have a strong long-term memory component. He suggested that SST might even be an infinite variance series since it seems to reflect the essential processes that affect fish dynamics. However, Aman (1999) pointed out that measurements of only SST do not adequately describe the rise of the thermocline during the upwelling season. Nevertheless, SST is often used to quantify the upwelling.

Observations of remotely sensed SST data and the mean percentage of cloud contamination showed a close relation between atmospheric and oceanographic processes, which are subject to high variability (Hardman-Mountford and McGlade 2002). This was reflected in the seasonal feature of the fishery and suggests the possible presence of a 3-5year El Nino cycle and to some extent, the forcing of SST by global scale climate interactions.

3.5 Climate Models

General Circulation Models or Global Climate Models (GCMs) are computer simulations of the earth's surface and atmosphere. The latter is divided into grids. Fundamental equations describing the conservation of mass, energy and momentum, for each grid are solved. They numerically simulate changes in climate as a result of slow changes in some boundary conditions (such as the solar constant) or physical parameters (such as the greenhouse gas concentration). They can be run long enough to learn about the climate in a statistical sense that is, the means and variability and to predict future climatic condition (Kattenberg *et al*., 1995; Spencer, 2001).

Several types of GCM are used differently to model the different components of the climate: 3DAtmospheric models (AGCM), 3D Ocean models (OGCM), Atmospheric chemistry models, Regional Climate Models, Carbon cycle models and coupled Atmosphere Ocean models (AGCM+OGCM). The most common are the AOGCMs that can be used for the prediction and rate of change of future climate. They are also used to study the variability and physical processes of the coupled climate system as in this study. For example, an accurate coupling could be used to simulate the ENSO (Kerr, 1984; Berger *et al*. 1989).

Generally, simulating interannual variability in the presence of an annually varying sun continues to be a difficult problem. Although some models reproduce interannual SST variability and others reproduce the annual cycle, reproduction of the full spectrum of variability remains elusive. (Since the annual cycle is an average over all the variability present in the system [i.e., the average of all Januarys, Februarys, etc.], the annual cycle is not independent of interannual variability.)

The basic problem with these models is that is that the processes that determine the annual cycle appear to be different from the processes that determine the interannual variability. In particular, interannual SST variability in the Pacific is believed to be dependent on wind-driven thermocline variations with heat fluxes at the surface acting mainly to damp the interannual perturbations. Annual variations of SST depend critically on heat flux variations at the surface and therefore depend in an essential way on radiative and cloud feedback. The presence of low-level stratus clouds exhibit a positive feedback to SST at low tropical SSTs and therefore induce a special sensitivity. In existing GCMs, these are poorly dealt with. Also, vertical mixing is poorly represented in the current generation OGCMs used for tropical studies is believed to have affected the simulated SST in the eastern equatorial Pacific, where the changes in the wind stress play a key role in causing annual SST variability (Sloane and Tesche, 1991; Houghton, 1997; Schnur 2002).

In the literature reviewed so far, no SST predictions for the Gulf of Guinea by these models were obtained. Thus, in the present study, an attempt was made to extract patterns from historical climate data and to forecast the main trends for the next 20 years. Uncertainty of the future trends was suggested by the utilization of confidence intervals.

3.6 Hypotheses

It is imperative to investigate further the effects of other climatic components on the other small pelagics and to forecast the possible effects on future productivity. Based on the current review and the observations of Anakwah and Santos (2002) showing the SST to have a positive effect on the CPUE of the anchovy and a negative one on the round sardine, we could hypothesise that:

(i) The climatic conditions affect the distribution of the fish thereby affecting their catchability, or

(ii) The climatic conditions affect other aspects of the biology such as the growth rate of the population

The present study will investigate which of these two hypotheses is more applicable to the fish populations and would be useful in an ecosystem-based approach to management. The analytical method utilized to test the hypotheses was a fishery model, which could account for the additional effects of climatic variables. Different climatic variables were included separately and the model adopted to reflect changes in the catchability (and thus distribution) or in the rate of population growth. The fishery resources considered were those exploited by the canoe fleet and considered most important)

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4.0 MATERIALS AND METHODS

4.1 Study Area

The study was based on the 565 km shoreline of Ghana. All the data used were secondary and based on records from national collection points also used in regional research and distributed along the entire coastline (Figure 4.1).

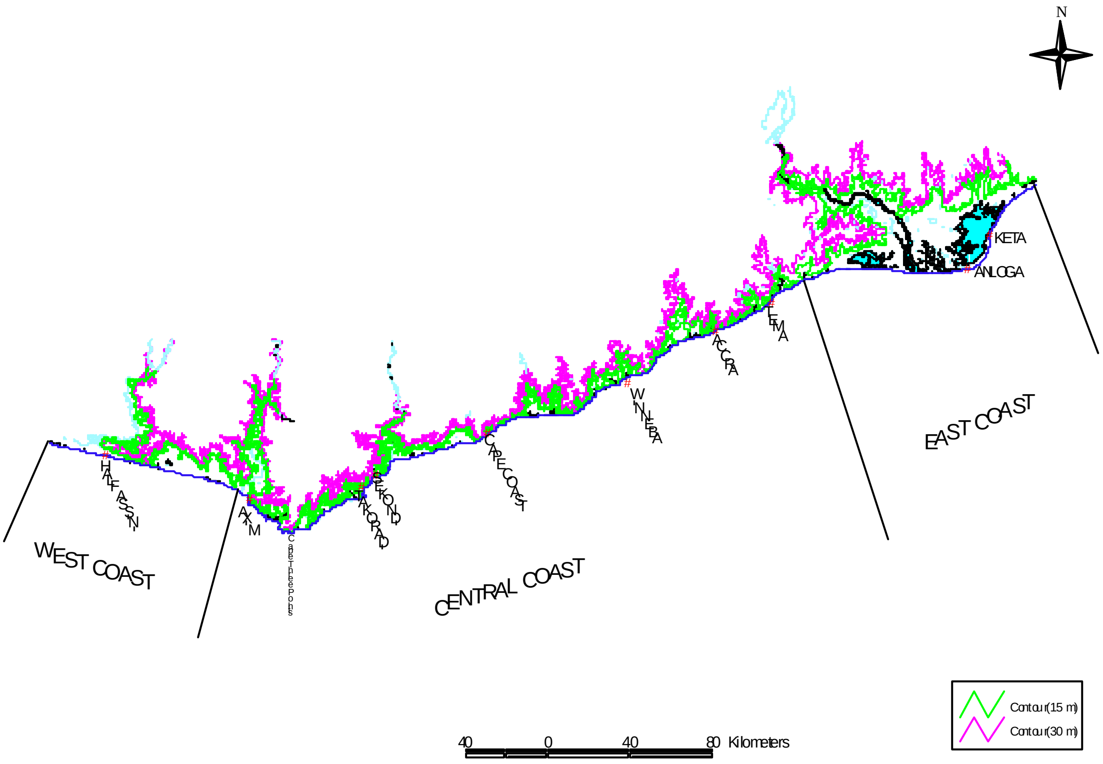


Figure 4.1 A map of the Ghanaian Coastline Showing the Climate and Fisheries Research Stations Source: M.S.D. Accra, Ghana

4.2 Data Required and Collected

Meteorological data in the form of precipitation (PPN), maximum, minimum and mean air temperatures on land (MAT), sea surface temperatures (SST), salinity and river run-off were required. For the fishery, all records of catch and effort data were required.

The daily records of the maximum and minimum air temperatures from 1960-2001 were obtained from the electronic database of the Meteorological Services Department, Accra. Daily readings of precipitation and the mean air temperature from 1961-2001 were also obtained from the same source. The values were measured at six coastal stations along the coast as depicted in Figure 4.1. These six stations are Accra, Ada, Tema, Takoradi, Axim and Saltpond (Nkansah, 2002). Daily records of SST (1963-2001) and Salinity (1968-2001) were obtained from data files of the Marine Fisheries Research Division (MFRD), Tema. These readings were taken at eight stations: Keta, Tema, Winneba, Takoradi, Cape Three Points, Axim, Half Assini and Elmina (Quaatey, 2002).

The annual landings (metric tonnes) and average price per kilo for the canoe and shrimp fisheries were compiled from the MFRD's annual summaries of Marine Fish Production from 1961 to 2001 (MFRD, 2001). The best record of fishing effort was culled from past reports and technical papers of the Department (Quaatey, 2002).

All the data obtained are considered authentic and are used by the organisations responsible for both national and international studies.

4.3 Analysis Materials

Annual means for the air temperatures, salinity and sea surface temperature were computed and put into a time series database created in MS Excel together with the total of all readings for the precipitation, fish catch and the effort. The Multivariate Statistical Software for Canonical Community Ordination in MS Windows (CANOCO 4) and the Biomass Dynamic Model were used in the analysing the meteorological and fishery data respectively.

4.4 Methodology

4.4.1 Biological and Economic Production of stocks

The general production trend and annual revenue obtained by species was assessed and the most significant stocks identified. The catch, effort and SST data was filtered and smoothened by comparison with the most recently used data analysed by Anakwah and Santos (2002) and from the same source.

4.4.2 Meteorological data

The investigation of past climatic trends was performed by means of correlation analyses of the MAT, SST and PPN and Salinity. The salinity value for 1995, which was unavailable, was interpolated by finding the average of the preceding and following years.

However, Pearson's correlation allows only pairwise analysis of variables. For a simultaneous analysis of all climatic variables (common time-series 1972-2001), a multivariate analysis was called for. The data were log transformed and analysed with the Multivariate Statistical Software for Canonical Community Ordination in MS Windows (CANOCO 4, ter Braak & Smilauer 1998). Linear models and correlation matrices were utilised in the ordination by means of Principal Component Analysis (PCA). The relationships among climatic variables with and without the effect of the annual trends (year as a covariate), and with the temperature of the previous year as the explanatory variable were assessed. The aim was to find a parsimonious set of environmental variables that adequately described the past climate. The selected variables were later combined with catch rate data into a fishery-environmental model.

4.5 Fishery Models

The stock dynamics were simulated using a biomass-dynamic model with observation error estimation (Hilborn & Walters 1992; Haddon 2001). The exploited population was assumed to grow according to the (logistic) Schaefer model described by the following difference equation:

$$B_{t+1} = B_t + rB_t(1-\frac{B_t}{K}) - C_t \qquad \text{...Equation 1}$$

where B_t is the biomass of the stock in year t, r is the population growth rate (i.e. the difference between birth and death rates), K (or Bmax) is the maximum population size, and C_t the yield in year t.

The basic information required to fit the model was a time-series of yield (C_t) and effort (E_t) for that fishery. The biomass of the stock was projected forward from the first year in the series, given an estimate of the initial biomass (BI or B_0). The observed catch per unit effort (*cpue*) was assumed to be linearly related to the abundance of the stock through a constant catchability term q:

$$\hat{I}_t = cpue_t = \frac{C_t}{E_t} = qB_t$$

The caret symbol is used because an index of abundance is estimated from the model. It is the difference between an estimated I (=qB_t) and the observed I (=C_t/E_t) that is used to fit the model to reality. The observation error assumes that the model exactly describes the population dynamics but that the observations were made with error:

$$\hat{I}_t = \frac{\hat{C}_t}{E_t} = qB_t e^e$$

This implies that the residual error (e) is multiplicative and log-normally distributed with a constant variance.

In the base model, the catchability variable was sometimes modified to reflect the effect of increasing fishing effort with the relation:

$$q_t = q_0 q_{inc}^t \quad \text{………………………………………………………….. Equation 2}$$

where q_t is the catchability in year t and q_0 is the catchability in the first year of the series. Catchability could therefore show annual proportional increases. For a 0% increase in catchability q_{inc} =1, and for a 5% per annum increase q_{inc}=1.05. The values of q_t were estimated using the closed-form procedure of Haddon (2001) because the model is easier to fit when it has fewer directly estimated parameters. The classical performance estimators derived from this model were the maximum sustainable yield (MSY), the corresponding effort (E_{MSY}) and the instantaneous fishing mortality rate at MSY, F_{MSY}. All these estimators should be regarded as long-term averages rather than unique (constant) values for the population.

4.5.1 The Fit of the Model

The base model utilised here includes five parameters B_0, r, K, q_0 and qinc from which the values of interest for fishery management are calculated. The model parameters were obtained using lognormal residuals by two alternative methods: the least-squares criterion

$\min \sum_t \ln\left(\frac{I_t}{\hat{I}_t}\right)^2$ and the log-likelihood criterion

$LL = -\frac{n}{2}(Ln(2p) + 2Ln(\hat{s}) + 1)$ for which n is the number of observations and

$$\hat{s}^2 = \sum_t \frac{(Ln\ I_t - Ln\ \hat{I}_t)^2}{n}$$

Similar results are obtained with both methods. The fits were performed using Solver in MS Excel.

4.5.2 Refinement of the Base Model (Covariates)

The time-series of catch and effort for the different species were relatively long and this allowed the inclusion of other explanatory variables (covariates) into the base model. The covariates that seemed more appropriate to include were the sea-surface temperatures (T, in ^{o}C) and precipitation (P, in mm), for reasons explained before. It was assumed in all formulations that linear changes in these environmental variables would result in proportional changes in the output.

Two hypotheses were tested in addition to the base model. Firstly that changes in the environmental variables would result in changes in the catchability of the fish, and thereby in the estimated cpue:

$$\hat{I}_t = B_t q_t e^{a(T_t - T_{\min})} e^{b(P_t - P_{\min})} \text{ ....Equation 3}$$

where T_t and P_t are the average temperature and total precipitation in year t *respectively*, T_{min} and P_{min} are the minimum values in the two series, and a and b are the rate parameters for temperature and precipitation, respectively.

The second hypothesis was that these environmental variables directly influenced the growth of the population rather than its catchability:

$$r_t = r_0 e^{a(T_t - T_{\min})} e^{b(P_t - P_{\min})} \text{ ....Equation 4}$$

where r_t is the annual growth rate of the population, which will thereby vary from year to year depending on the observed temperature, precipitation, or both, and r_0 is the rate at the origin (i.e. at T_{min}, P_{min} or the two combined). In relation to the base model, the fishery-environment model has one (e.g., a or b) or two (e.g., a and b) extra parameters, depending on the number of environmental variables included in the fit.

4.5.3 Selection of the Best Model

Analysis of residuals (estimated I versus observed I) after fitting the models was the most important tool in checking for acceptable error structure and model fit. Two criteria normally used to select robust and parsimonious models (Quinn and Deriso 1999) were also employed. The Akaike information criterion (AIC) is a means of selecting the best model, even when the models are not hierarchical (i.e. nested):

$$AIC = -2\ Ln\ LL + 2\ p$$

where Ln LL is the log-likelihood, and p is the number of model parameters. The AIC was calculated for candidate models, and the most parsimonious one was that with the lowest AIC. An alternative criterion is the Bayesian information criterion (BIC) defined as:

$$BIC = -2\ Ln\ LL + p\ Ln(n)$$

where n is the number of observations. The BIC forms an approximation to Bayes factors, an important consideration when the model is used for forecasting. The AIC tends to be a conservative criterion in that a model with more parameters results than when using the BIC, but the BIC is more likely to result in a parsimonious model.

5.0 RESULTS

5.1 Trends in Climatic Parameters

The analysis showed certain features of the climatic variables that may be attributed to naturally occurring variability or atmospheric warming. The summary of variations is shown in Appendix 1.

5.1.1 Temperatures

Both maximum and minimum air temperatures increased by 2.5 and 2.2°C respectively between 1960 and 2001 (Appendix 2A). Thus, MAT also increased by about 0.9°C and a positive autocorrelation with a significant lag of one year was observed. The highest MAT was recorded in 1998 (27.8°C) and the lowest in 1975 (26.3°C) as shown in Figure 5.1. Except for the marked decreases between 1972 and 1975, variability was generally low. An analysis of Variance indicated that the linear regression trend was statistically significant (p-value of 0.00009) as shown in Appendix 2B.

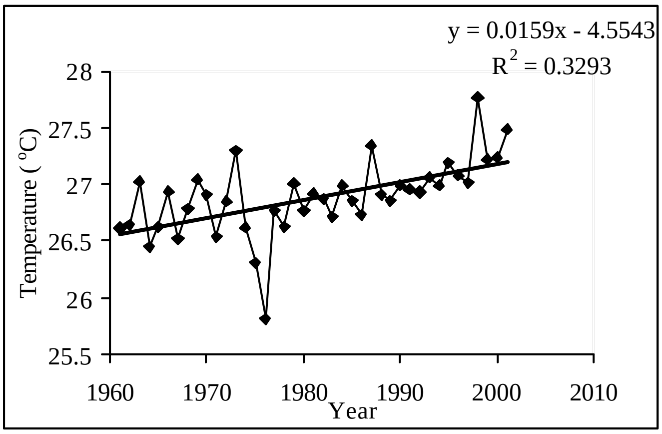


Figure 5.1 Trends in Mean Annual Air Temperature along the Coast of Ghana.

A comparison of the present SSTs with that used by Anakwah and Santos (2002) showed minimal variation between the two data sets. (Appendix 3B). The SST (Fig. 5.2) showed a higher variability with more frequent and greater inter-annual changes than the MAT. Cooling periods seemed to alternate with warm periods at an average cycle of two to four years but the most significant interannual change occurred between 1983 –84 and 1986-87. There was a slight but non-significant (p= 0.153) increase in SST with time (Appendix 3A).

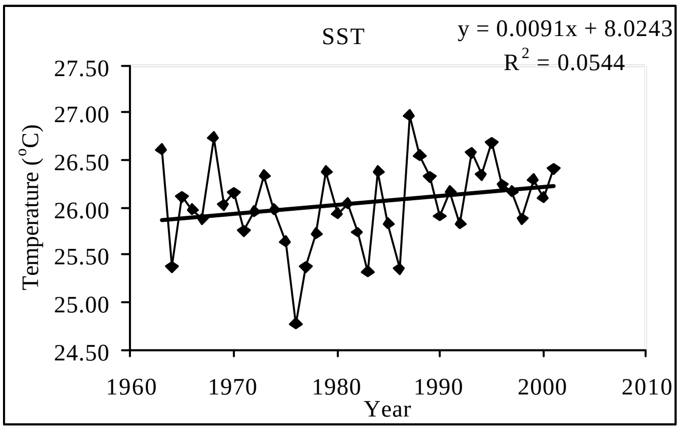


Figure 5.2 Trends in SST along the Coast of Ghana

5.1.2 *Salinity*

This data series was the shortest and poorest of the lot due to unavailability of historic readings. The value for 1995 had to be interpolated by finding the average of the readings for the previous and ensuing years. For the first two years, the readings were too low (31.10 & 32.95 ppt respectively), implying an almost impossible drastic increase from 1968-72 (Fig. 5.3). Between 1983 and 1996, there was no clear trend. A positive autocorrelation was, however, observed between 1970 and 1994 implying an expected increase in salinity over the years.

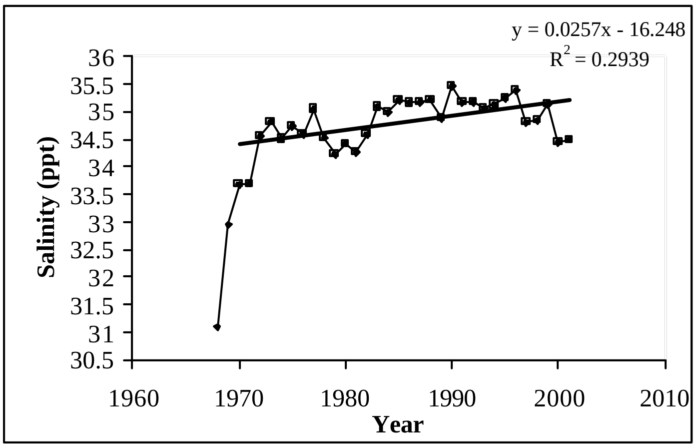


Figure 5.3 Salinity Observations (1968-2001)

5.1.3 *Precipitation*

The marked cyclical variation showed a positive autocorrelation with an apparent 6-year lag (Fig.5.4). The highest rainfall was recorded in 1968 (11426 mm) and the lowest in 1983 (3352.2 mm). The most significant decreases occurred in 1968-69 and 1997-98. A p-value of 0.009 implied a significant decreasing trend from 1961 to 2001(Appendix 4A).

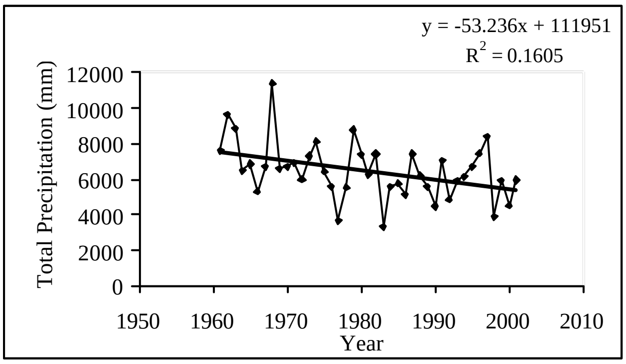


Figure 5.4 Precipitation Trend (1961 –2001).

The variability of the parameters described above is also observed in plots of annual deviations from the mean (Appendices 4B-5C). The seasonal trends mentioned in chapter 2 were reflected in the graphical summary of all the historic data (Appendices 6A – 7A).

5.2 Correlations among Climatic Variables

A strong positive correlation was observed between SST and MAT (Appendix 7B). SST was found to increase with increasing MAT (Fig. 5.5). Despite the fact that precipitation showed a decreasing trend as opposed to MAT, there is also a positive correlation between SST and precipitation (Fig. 5.6), though not as strong as that between MAT and SST. A negative correlation was observed between precipitation and salinity. In spite of SST and MAT being positively correlated, a slight negative correlation existed between the precipitation and air temperature (Figs. 5.7 –5.8).

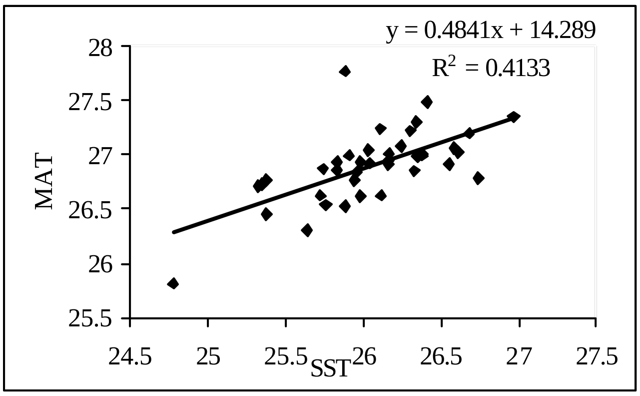


Figure 5.5 Variation of SST with MAT (1963-2001).

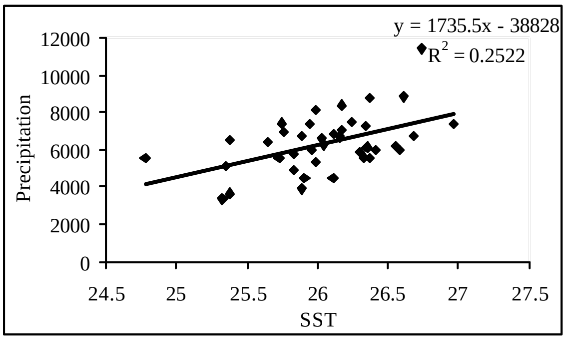


Figure 5.6 Variation of Coastal Precipitation with SST

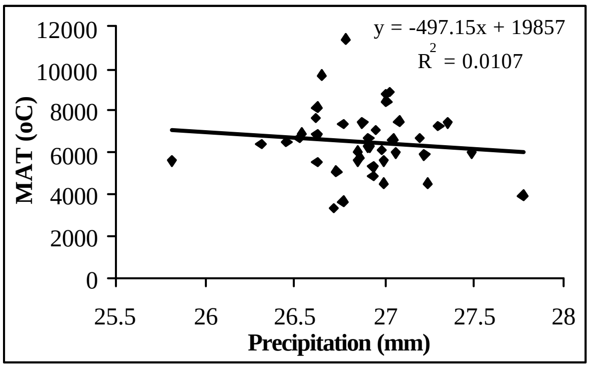


Figure 5.7 Variation of Precipitation with Mean Air Temperature

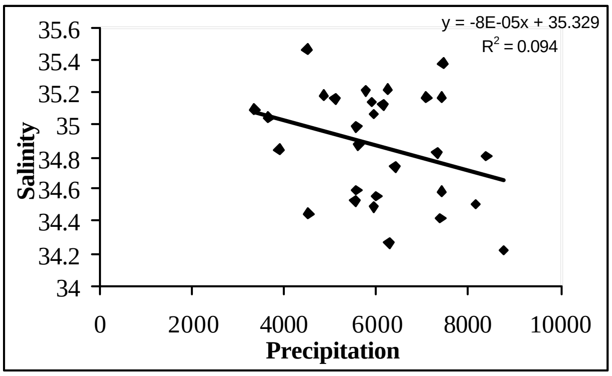


Figure 5.8 Variation of Salinity with Changes in Precipitation

These relationships were confirmed by the PCA and RDA in CANOCO 4 and are summarised in the multivariate analysis biplots (Figures. 5.9 – 5.12).

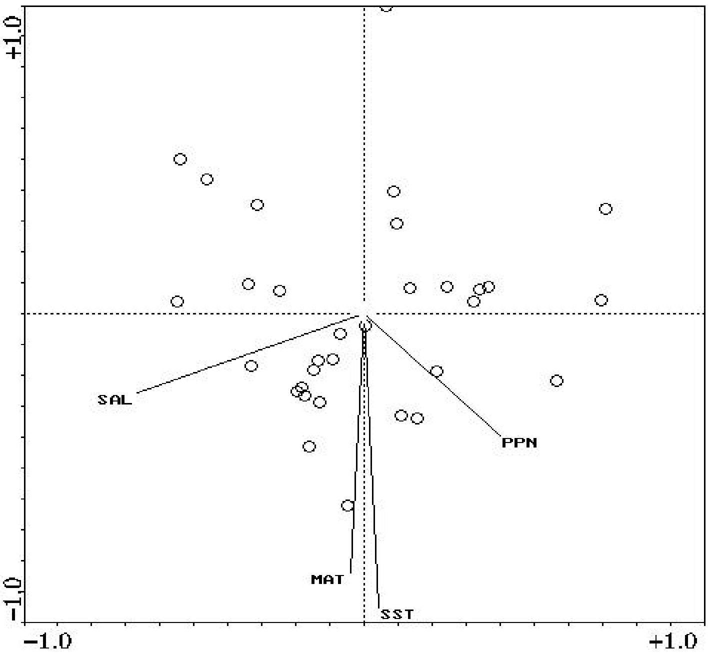


Fig 5.9 PCA Showing Correlation among Climatic Variables (Log-transformed Species from 1970 to 2001). SAL = Salinity, MAT = Mean Air Temperature, PPN = Precipitation, SST = Sea Surface Temperature

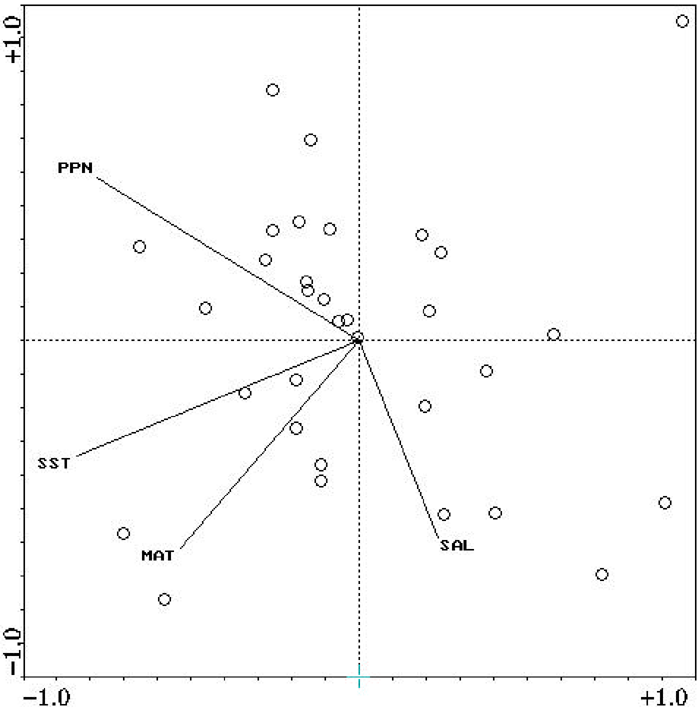


Figure 5.10 PCA Showing Correlation among Climatic Variables from 1970 -2001 (Log-transformed Series with Year as Covariate).

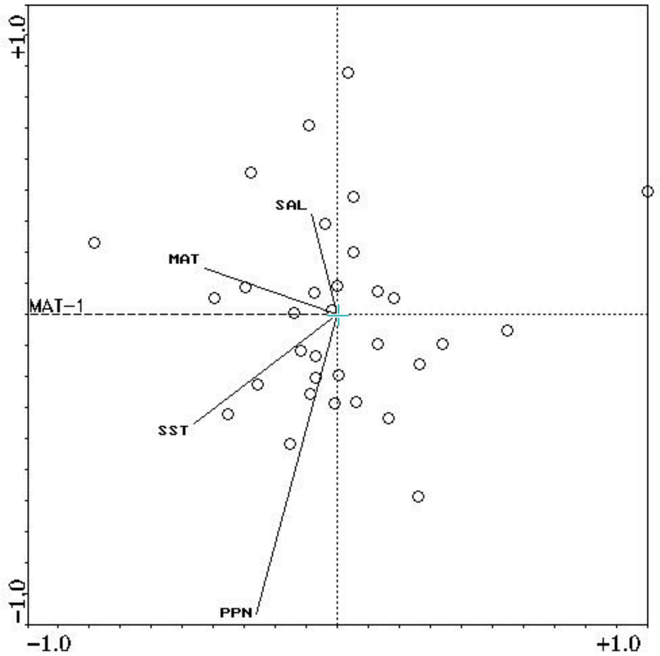


Figure 5.11 RDA Showing Correlation among Climatic Variables (Log-transformed Data with the Previous Year’s Temperature (MAT-1) as an Explanatory Variable).

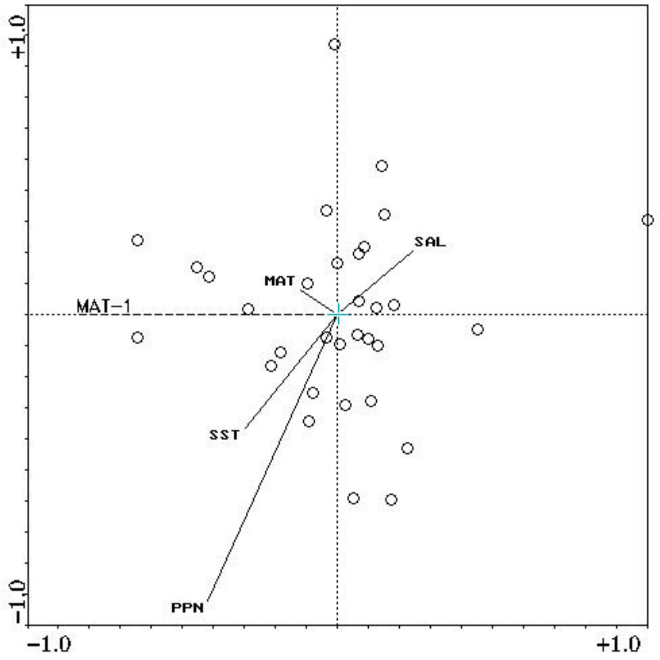


Figure 5.12. RDA Showing Correlation among Climatic Variables (Log-transformed Data with Year as a Covariate to Filter the Annual Trends.

The pattern of residuals remained the same even after removal of the major time trends (figure 5.11- 5.12). SST showed a strong positive correlation with the MAT and PPN showed a strong negative correlation with salinity. Simultaneously, years of high SST and MAT corresponded to years of higher salinity. These correlations were also observed in plots of the seasonal variability (Appendices 6A-7A). The mean air temperature of the previous year also seemed to determine the magnitude of the parameters in the current year. The higher the MAT in the previous year, the higher the current SST and precipitation and the lower the salinity and MAT.

5.3 Projected Climatic Scenarios

Forecasts for the next 20 years indicated that a continual decrease in the precipitation would result if the current climatic trend were maintained (Figure 5.13). By 2021, the precipitation could fall to an average value of 4361 cm with 6005 and 2718 cm being the upper and lower 95% confidence limits respectively.

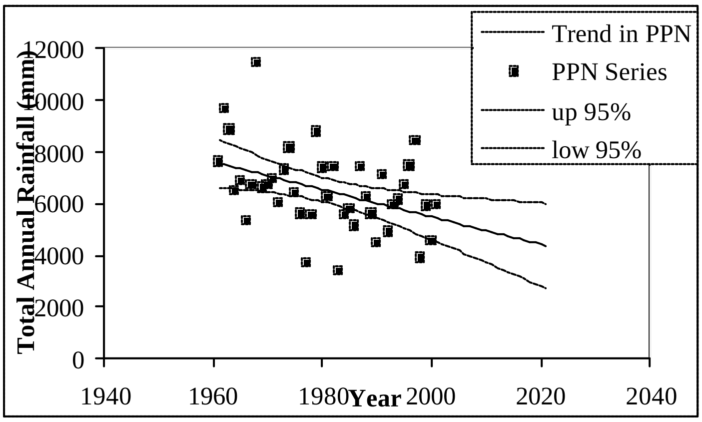


Figure 5.13. Projected Rainfall for the Coast of Ghana for 2002 – 2021, Based on Regression of Historical Data (1961 – 2001).

For the forecasts of SST two scenarios could be envisaged:

(a) The observed increasing trend could not be statistically demonstrated owing to undue variability of the historical data (type II statistical error). In the case of type II error, avoidance, the regression line could be extrapolated (Figure 5.14). There is considerable uncertainty about future values in year 2021 with the confidence limits varying from 25.9 to 26.9 ^{o}C (95% lower and upper confidence limits). The best estimate for 2021 would be 26.40 ^{o}C.

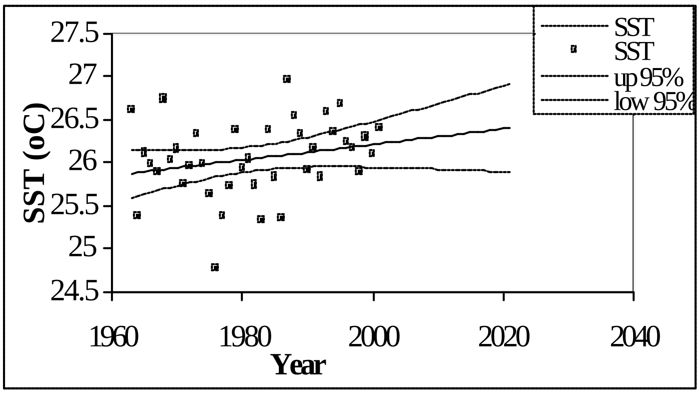


Figure 5.14 Projected SST Scenario for the Coast of Ghana for years 2002 –2021 Based on Regression of Historical Data (1961-2001)

(b) If the mean trend of historical is rejected to avoid type I statistical error, the mean of the historical data can give an indication of the expected mean temperature in the future. (5.15).

For 2021, the expected mean SST is 26.1°C with the 95% lower and upper confidence limits of 26.2 and 25.9°C (5.15).

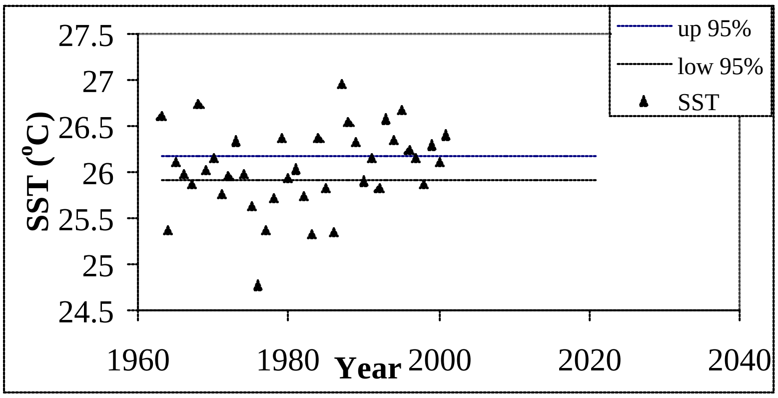


Figure 5.15 Projected Mean SST Scenario for the Coast of Ghana Based on Regression of Historical Data (1961 –2001).

5.4 Production Trends of the Canoe Fishery

The most significant contributors to revenue were the round sardine, flat sardine and anchovy (decreasing order of significance). Of the average annual revenue obtained from the five species under study between 1980 and 2001 (C46,939,615), the Round Sardinella, Flat Sardinella, Anchovy, Chub Mackerel and Guinea Shrimp constituted 57%, 24%, 11%, 7% and 1% respectively. The most significant stock in terms of yield was the Anchovy followed by the Round Sardinella, Flat Sardinella, Chub mackerel and the Guinea Shrimp (Figures 5.16 - 5.17). The prices of each species and revenues obtained are summarised in Appendix 13.

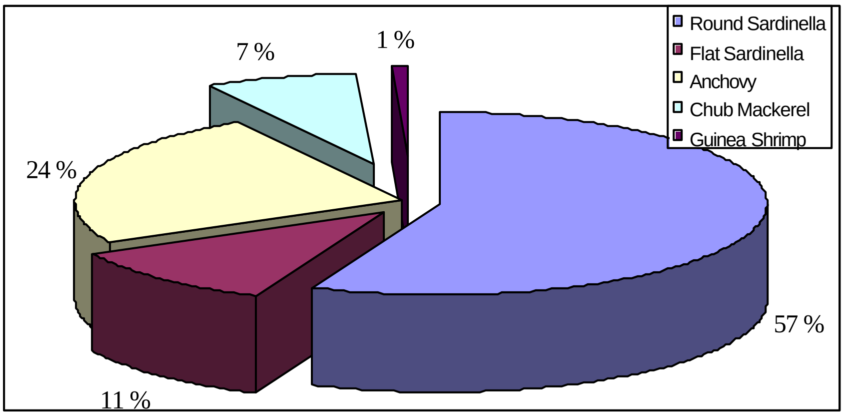


Figure 5.16 Relative Significance of the Five Species in Terms of Revenue to the Canoe Fleet (1980 –2001)

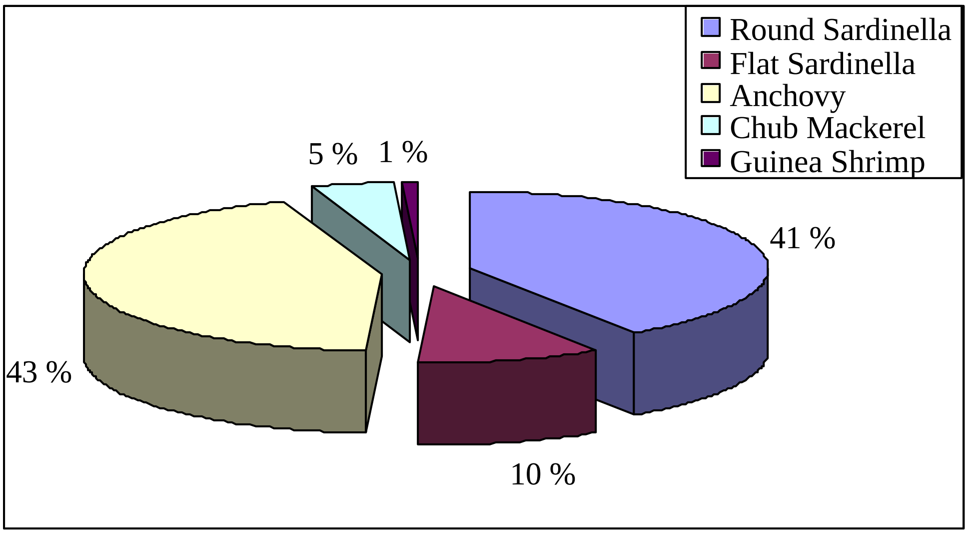


Figure 5.17 Relative Significance of the Five Species in Terms of Yield to the Canoe Fleet (1980-2001)

5.5 Dynamic Production Model

The effect of fishing effort coupled with climate on the catch dynamics were best observed for the anchovy, Round Sardinella and Flat Sardinella. The observed parameters are presented in Tables 5.1-5.3.

The first fit performed concerned the base model. Climatic forcing was introduced in the CPUE-based model and r-based models. In the CPUE based models, the base model was combined with a function (equation 3) that modified catchability and thereby expected CPUE in terms of SST, PPN or both (CPUE f (T, P)). Another family of models utilised these covariates to change the population growth rate (rf (T,P)) in agreement with equation 4, combined in the base model. This gave rise to seven models fitted to each species.

Table 5.1 Production Model Estimates for the Anchovy (1974 –2001)

Parameter	r	K	MSY	qinc	a	b	AIC	BIC
Base model	0.13	1,010,162	32447	1.04	0	0	45.47961	52.14064
CPUE f (T)	0.12	1036443	30502	1.05	0.028246	0	48.23129	56.22452
CPUE f (T, P)	0.12	1036581	30498	1.03	0.02983	9.66E-07	49.11555	58.44098
CPUE f (P)	0.13	1012795	32976.74	1.04	0	1.3E-05	47.26677	55.26
r f (T)	0.05	679641.7	7869.94	1.01	1.690865	0	31.74402	39.73725
r f (T, P)	0.38	206581.3	19563.63	0.96	0.954672	-5.5E-06	33.64584	42.97127
r f (P)	0.00	2042.547	0.18	1.11	0	-0.00293	42.28003	50.27326

Table 5.2 Production Model Estimates for the Round Sardinella (1973 –2001)

Parameters	r	K	MSY	qinc	a	b	AIC	BIC
Base model	0.36	620953	56174	1.17	0.00	0.00	59.50	66.34
CPUE f(T)	0.36	626315	56022	1.17	-0.04		61.28	69.48
CPUE f(T, P)	0.35	630736	55677	1.16	0.15	-9E-05	62.08	71.65
CPUE f(P)	0.35	630736	55189	1.17	0.00	-3E-05	60.73	68.93
r f(T)	1.50	3551752	1331907	0.98	-1.02	0.00	41.68	49.88
r f(T,P)	1.50	8650234	3243838	0.98	-0.86	-2.3E-05	42.81	52.38
r f(P)	0.68	712838	121477	1.01	0.00	-7.9E-05	47.86	56.06

Table 5.3 Production Model Estimates for the Flat Sardinella (1972 –2001)

Parameter	r	K	MSY	qinc	a	b	AIC	BIC
Base model	0.336	500,000	42058	1.04	0	0	46.91	53.57
CPUE f (T)	0.336	500,000	42058	1.04	0.0073	0	48.90	56.89
CPUE f (T, P)	0.336	500,000	42058	1.04	0.028	-1.57E-05	51.28	60.60
CPUE f (P)	0.5	600000	75000	1.00	0	2.97E -06	51.41	59.41
r f (T)	0.322	549959	44245	0.99	0.115	0	44.43	52.42
r f (T, P)	5.99E-05	405489	6.073	1.04	0.028	-1.6E-05	36.81	46.13
r f (P)	0.5	600000	75000	0.97	0	0.00203	35.43	43.42

In most cases the introduction of climatic variables improved the fit of the fishery model and this was reflected in both the distributions of residuals and fit statistics such as AIC and BIC (Figures 5.18-5.26). The increase in efficiency fishing effort (technological creep) was reflected in values of qinc > 1.

The Anchovy showed the highest variability in CPUE and sensitivity to climatic changes. Runs of the r-based model had MSY, BI, qinc, K and r, which showed much greater variation compared to the CPUE-based model. Catch rates could increase variably from 2.8% (for CPUE-base model) to about 169% (for r-based model) as a result of a 1^{o}C increase in temperature. Precipitation seemed to have a minimal positive effect on the production of the CPUE of anchovy and a slight negative effect on catches of the r-based model. The stock level fell gradually between 1974 to 1986 after which it shot from about 80000 to nearly 200000 mt by 1990. In 1992, it reduced to about 120000mt. Between then and 1999, there was little variation about 150000 mt until an eventual reduction to 117391 mt in 2001 (Figures 5.18-5.20). By virtue of the observed fluctuations the stock could not be described as an increasing or decreasing one. It would be more appropriate to call it a variable stock that responds to current climatic conditions.

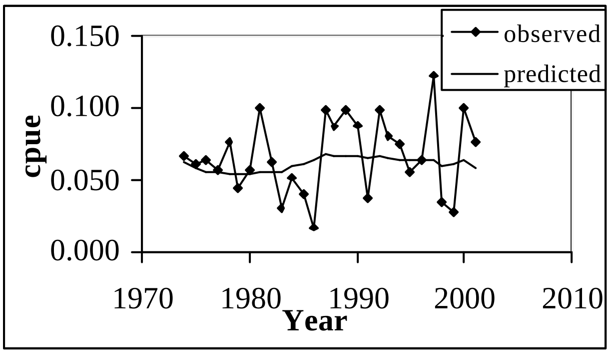


Fig. 5.18 Best Fit of the CPUE-based Model for the Anchovy (1974 –2001)

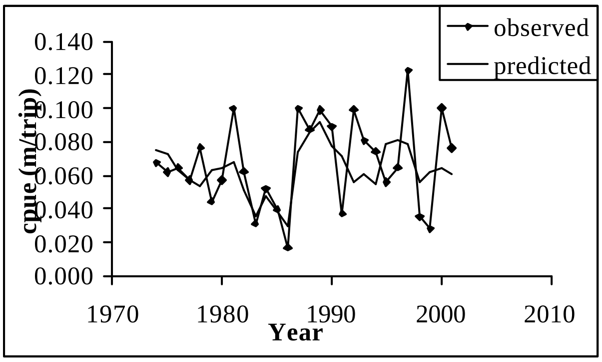


Figure 5.19 Best Fit of the r-based Model for the Anchovy (1974 –2001)

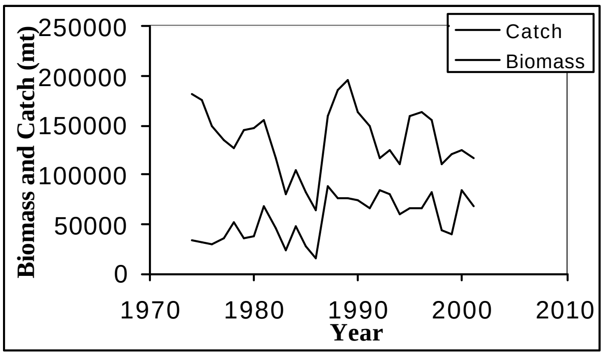


Figure 5.20 Catch & Biomass Curves of the r-based Model for the Anchovy (1974 – 2001).

For the round Sardinella, good fits were obtained for the two climate-forced models

The r and qinc did not show wide variation between the two models under different climatic scenarios. However, SST seemed to have a negative effect on CPUE. Increasing the temperature by 1^{o} resulted in a 4.2% (CPUE-based model) and 102% reduction in the catch rates for the r-based model. Precipitation seemed to have a very minimal negative effect on catch rates in both models.

After the near-collapse in 1973, biomass and catch showed an almost parallel steady increase with little variation until the early nineties. A major peak was observed for both in 1992 followed by a decreasing trend with the exception of a lower peak in 2000. The biomass then declined to 233664 mt in 2001 (Figs. 5.21 -5.23). These variations were indicative of the matured fishery in which a further increase in effort could deplete the stock.

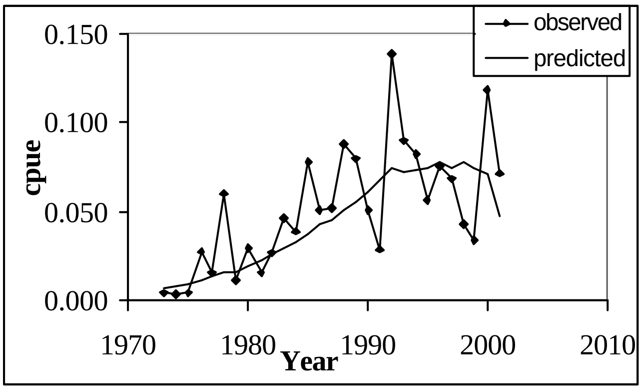


Figure 5.21 SST-Dependent Fit for the Round Sardinella in the CPUE- based model (1973-2001).

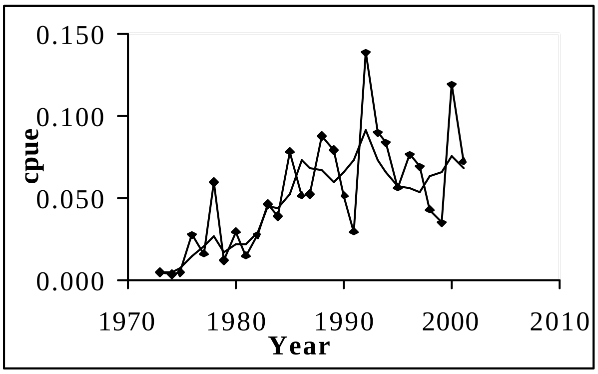


Figure 5.22 Best Fit for the Round Sardinella in the r-based Model (1973-2001).

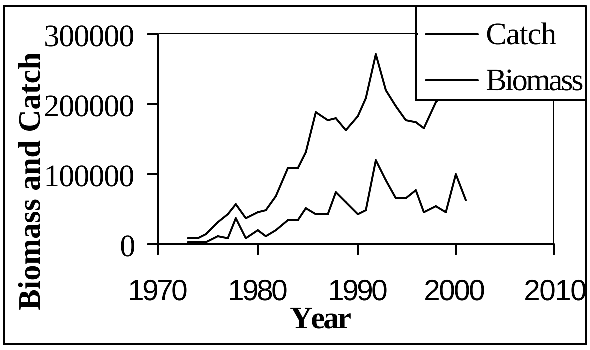


Figure 5.23 Catch & Biomass curves of the r-based Model for the Round Sardinella (1973 –2001).

However, for the CPUE –based model, the best fit was obtained with PPN as the covariate and suggests that precipitation had a greater effect on the distribution than the SST (Figure 5.24).

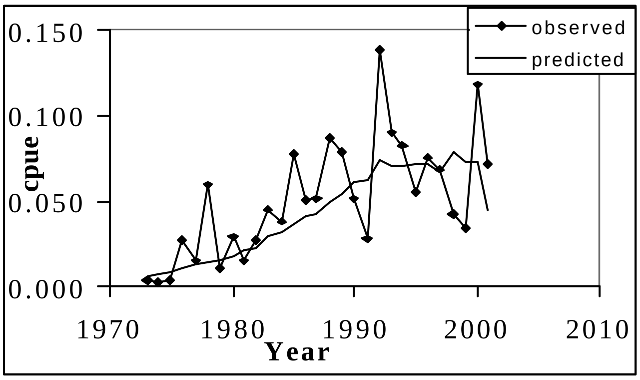


Figure 5.24 Best Fit of the CPUE-Based Model for the Round Sardinella (1973 – 2001).

The Flat Sardinella showed the least response to SST effects and the highest response to changes in precipitation. The catchability was best described with SST as covariate while the r-based model had the best fit when the population growth rate depended only on precipitation. Thus, distribution of the fish is more dependent on the temperature while the population growth rate is more influenced by precipitation. There seemed to be a general reduction in the CPUE. The highest was in 1976. This was followed by a sharp reduction the next two year and a more gradual continuation of the trend until 1985. There was a sharp increase to a peak in 1987. Thereafter the recorded peaks have been lower as observed in 1997 and 2000. The catch trends seem relatively constant and small when compared to the stock size. Peaks for the latter were recorded in 1974 and 1997 (Figs 5.25-5.27).

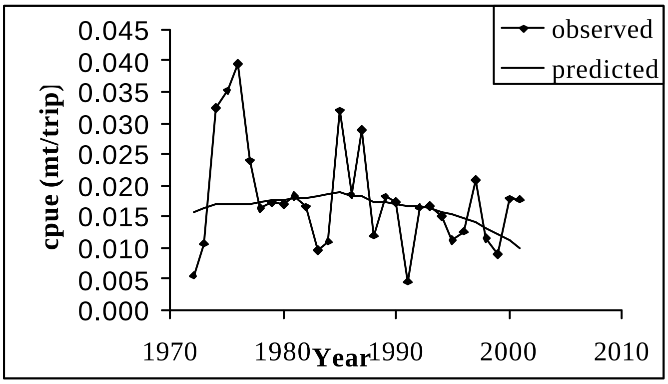


Figure 5.25 Best Fit of the CPUE-based Model for the Flat Sardinella (1972 –2001)

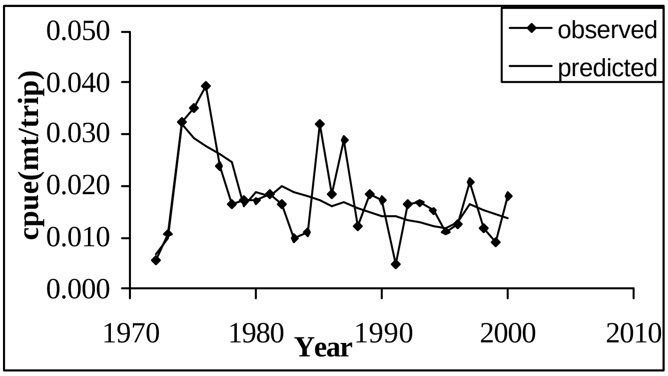


Figure 5.26 Best Fit of the Precipitation Dependent r-based Model for the Flat Sardinella (1972 –2001)

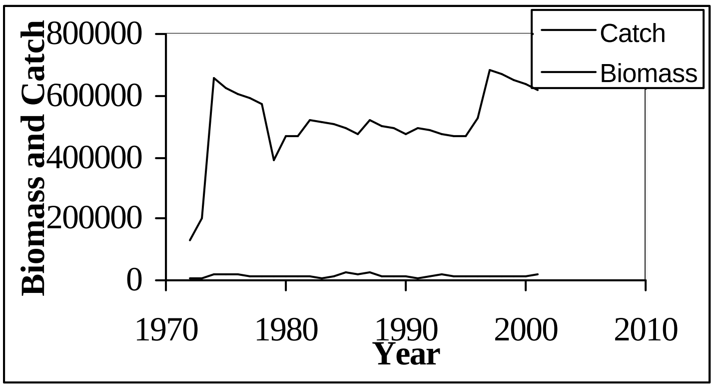


Figure 5.27 Catch & Biomass Curves of the r-based Model for the Flat Sardinella (1972 –2001).

The best fits for the shrimp *P. atlantica* were obtained for both models with precipitation as the only covariate (Appendix 12A). However, the second best fit was obtained with SST as covariate had little variation in the fit statistics from the best fit. Thus, temperature also seemed to significantly influence the catchability.

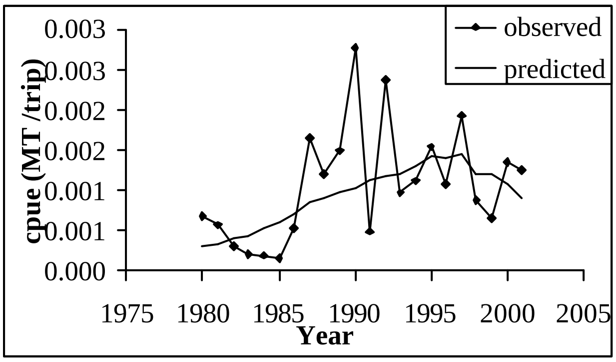


Figure 5.28 Best Fit of the CPUE-based Model for the Guinea Shrimp (1980-2001)

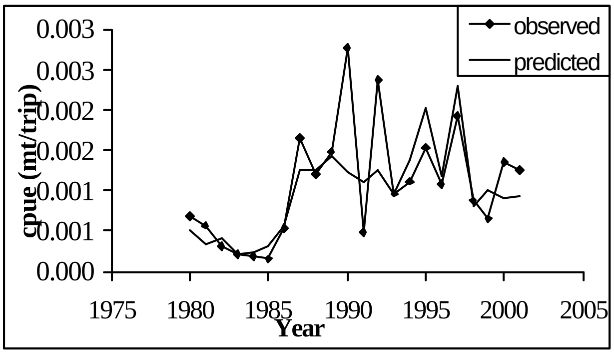


Figure 5.29 Best Fit of the r-based model for the Guinea Shrimp (1980-2001)

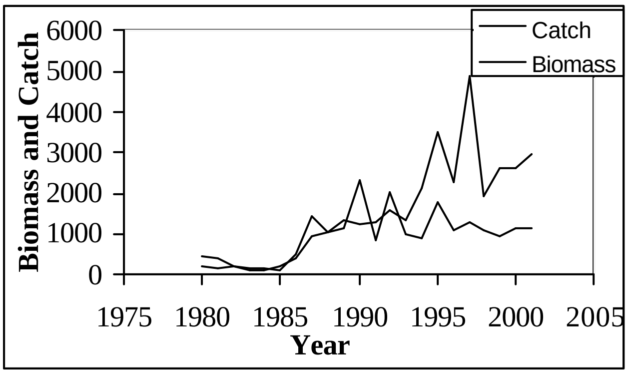


Figure 5.30 Catch-Biomass curves of the r-based model for the Guinea Shrimp (1980-2001)

The shrimp stock started from a low level of 193m in 1980 and increased steadily to 1336 in 1993. More drastic increases were then recorded until 1997(4867 mt) after which the stock level dropped to 1917 the following year. After this, there was a gradual increase to 2986 mt in 2001.

The fishery model for the Chub Mackerel with and without the inclusion of environmental variables seemed to be inappropriate to explain stock dynamics. This contrasts with results obtained with the small pelagics (Figures 5.31 –5.33).

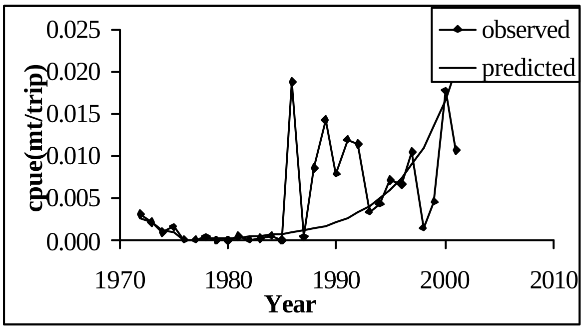


Figure 5.31 Best Fit of the CPUE-based production model for the Chub Mackerel (1972-2001)

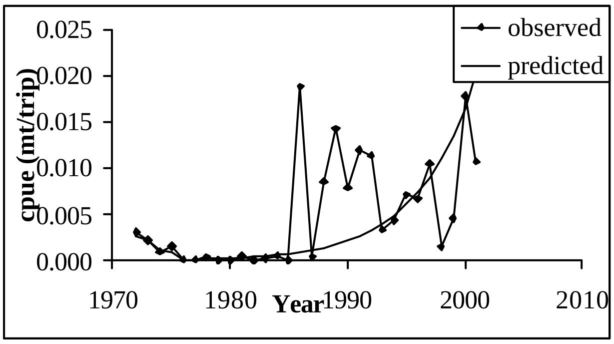


Figure 5.32 Best Fit of the r-based production model for the Chub Mackerel (1972-2001)

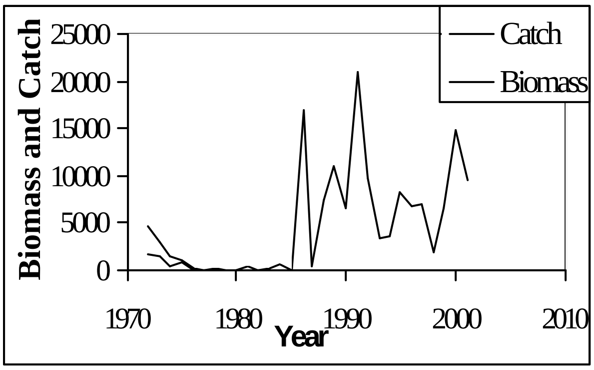


Figure 5.33 Catch & Biomass Curves of the r-based Production Model for the Chub Mackerel (1972-2001)

The MSY as simulated by each family of models denotes the MSY under particular conditions of SST and PPN. Thus to the MSY for the species could be estimated by finding the average value of the Year-specific MSYs obtained after inclusion of the

SST into the fishery model. The level of fishing of the two most significant stocks can therefore be judged from the number of times they have been overfished.

Thus, whereas the cpue-based models for the Anchovy state that the stock is overfished, the r-based model (the best fit) says that the MSY has only been overshot during nine out of the 28 years (Appendix 14). This occurred in the particularly in early years of the series until the 1980's when there was a marked decline in the stock (cool period). This implies that SST mostly causes variations in landings in spite of the overfishing component. For the Round Sardinella, the cpue-based models indicate overfishing while the r-based model shows that the MSY has never been reached. That is, the SST has mostly caused the variations in the landings (Appendix 15).

From all the observations obtained, climatic factors seemed to exert a significant influence on the production of the three most significant small pelagics and the shrimp. Catches varied from year to year depending on the magnitude of SST and precipitation influence. This means that the MSY for each stock is not a constant value but varies from year to year depending on the climatic condition.

6.0 DISCUSSION

The MAT and precipitation are the most significant indicators of change in the climate system. The SST and salinity seem to be direct responses of the ecosystem to variation of the former two factors. According to the multivariate analysis, years of higher SST should have corresponded to those of higher precipitation but this was not reflected in the rainfall pattern and forecasts.

6.1 Climatic Trends: Merely Local Changes?

The increases in the maximum, minimum and mean air temperatures may well be associated with the suspected trend for the sub-region or simply a result of long-term natural variability. The 0.5°C increase in average daily coastal temperatures was 50% lower than the value obtained for the national vulnerability assessment to climate change from 1961 to 1990 (Republic of Ghana, 2000). This could be attributed to the fact that the coastline falls under the coldest climatic zone.

The total decrease in precipitation (about 27.7%) was higher than the 20% observed for the whole country between 1961 and 1990. Again, this could be explained by the fact that the coastline is also the area with the highest precipitation. Although a decrease in rainfall has been projected for the inland areas, an almost contradictory increase has been predicted for the coast. This could be also be explained as follows:

1. The presence of the high forest zone near Axim implies a higher evapo-transpiration rate during warmer temperatures, which would be accompanied by higher rainfall (Republic of Ghana, 2000).
2. The ocean influences the coastal atmosphere by affecting its moisture content. With atmospheric warming come greater currents and intensified upwelling. This causes higher evaporation of water and hence increased rainfall (Brown *et. al.*, 1989).

However, there seems to be general conformity with predictions of overall or seasonal decreases in tropical areas as opposed to the reverse, which would occur at higher latitudes (IPCC, 2001).

Despite a clear warming trend for MAT and its correlation with SST, there was no significant warming of water temperatures. This could be a reflection of the 'Latent

Heat' effect. Oceans have a buffer effect that enables them to absorb and store heat much more effectively than the land. Thus heat uptake and loss result in a smaller surface temperature change than would occur on land. According to Banks and Wood (2002), SST is commonly useful in detecting changes in ocean climate because it provides a good signal-to-noise ratio. Its distribution is also a major factor influencing atmospheric circulation in the form of winds and precipitation (Brown *et. al.* 1989).

The alternating pattern in SST was in conformity with the findings of Hardman-Mountford and McGlade (2002) for the interannual SST variations in the entire Gulf of Guinea. Cooling occured from 1982 to 1986 and warming from 1987-1990 with exceptional warming in 1984. By virtue of the frequency of occurrence, the 3-year peaks were linked to El Nino events, particularly in 1984. The upwelling index showed a similar inverse pattern with a weak upwelling in 1984 and between 1987 and 1990. An interannual variability of 3year-frequency indicative of the Atlantic El Nino was observed to impact on the interannual upwelling intensity. The trend in SST anomalies in Cananeia - Brazil observed by Koranteng (1998) in Tema- Ghana at a lag of three years, and the pattern of anomaly in precipitation and river discharge in the Ghanaian inshore area (decline between 1970 and 1983), also show that climatic trends in the Atlantic could be related to the Pacific ENSO.
Thus, previous postulates of interaction of the global climate system with the coastal one under study could be acceptable.

6.2 Yield-Climate Interactions

The wide interannual variations for the individual species confirm that fishing effort alone does not account for the variations in CPUE. According to Koranteng (1991), the erratic fluctuations in abundance of the small pelagics are due to differences in the amounts of fish available to the fishermen, which in turn depend on coastal upwelling, rainfall, recruitment and migratory pattern of the fish. Mensah and Quaatey (2002) also reported that the increasing trend obtained for the small pelagics are due mainly to the intensity of upwelling. Hence, an assessment of and projections about the fishery cannot be made without due consideration of the climatic influences.

The output of the dynamic production models confirms that the coastal climate as quantified by the SST closely regulates the production of the fishery. The climate of the current year does not only affect the distribution of fish populations to fishing areas but also regulates to a greater extent, the processes affecting the growth and production. This accounts for the high year to year fluctuations. Optimum temperatures enhance spawning and larval growth. Good precipitation and runoff also regulate feeding and recruitment while primary productivity is enhanced by rainfall and river-runoff (Mensah, 1991). However, since responses of species to the environment differ, a consideration of abundance and dynamics is necessary for clarification of this relation.

6.2.1 Anchovy

Incorporating the SST factor into the models led to an increased production of the stock and also on catchability. In spite of the erratic changes in catch recorded, comparison of the a and b parameters for the two models in Table 5.1 show that the SST and precipitation affect the growth rate more than the catchability. SST changes seem to be the main factor behind the force behind the fluctuations. This is in conformity with observations by Allain *et al*. (2001). Warmer years are more favourable for the reproduction and growth of this species. More reproduction and growth would occur in warmer years leading to a healthier stock. To a smaller extent, migration would occur towards the shore thereby making the fish more likely to be caught by the gear. However, the effects on CPUE are minor when compared to those on the r (2.8% versus 102%). The second hypothesis was therefore more applicable to the stock.

6.2.2 Round Sardinella

This species obviously thrives under lower SST conditions. Lower stock production and MSY resulted from increases in the SST and vice-versa. The decreased catchability and stock growth rate under the effect of SST seemed to echo the observations of Koranteng and McGlade (2002). According to them, three distinct environmental time blocks occurred in the Gulf of Guinea between the sixties and the nineties: the period before 1972, 1973 to 1982 and 1982 to 1992. The first period was characterised by relatively high SST that decreased by the end of the period, the second by lower SSTs and high but stable salinity and the third by a rising trend in

SSTs. These time blocks are believed to have influenced the *S. aurita* fishery in Ghana and La Côte d'Ivoire as follows: a healthy phase before the high landings of 1972, a 'collapsed' phase from 1973 to 1982 and a phase of recovery from 1983 to 1992. These are clearly observed in the development of CPUE and stock biomass shown in Figures 5.21-5.24. The a components for the CPUE and r-based models (4% and 102%) also show that the population growth rate is much more variable to climate than the distribution. The second hypothesis is also more applicable to the round sardine than the first.

6.2.3 Flat Sardinella

The relative insensitivity of the stock to changes in SST (0.7%) as clearly reflected in the CPUE-based model indicates that the distribution and catchability of this species are hardly affected by changes in the ocean climate. The first hypothesis seems inappropriate to account for the changes in the production and can be rejected. On the other hand, the a component for the r-based model (11.5%) explains why this species thrives during the warm season and is more tolerable to changes in SST and salinity. The higher sensitivity of the r-based model to precipitation emphasizes the lower sensitivity of the growth rate to SST changes.

6.2.4 Guinea Shrimp and Chub Mackerel

Precipitation was the environmental variable that strongly influenced both the catchability and population growth rate of the guinea shrimp (Appendix 12A). Being an estuarine shrimp that spawns in the coastal lagoons and is washed out during adulthood into the ocean. Periods of higher precipitation are more favourable for its distribution or migration into the coastal fishing area. Increase in precipitation lead to higher river runoff and the washing of nutrients into coastal lagoons that harbour this species. Salinity is also regulated by precipitation. The fit statistics obtained with the SST as covariate also signify that the SST also affects the stock to some extent. Studies by Haas *et al.*, (2001) showed that 24% of the interannual variability in offshore catch of the brown shrimp (*Penaeus aztecus* Ives) was explained by environmental variables viz. water temperature, salinity, turbidity, river flow rate, acres of suitable habitat, and precipitation. Fifty-five percent of the remaining variation was accounted for by biological variables in the model that was used. Later, Haas *et al.*, (2001) confirmed that early juvenile abundance, salinity and temperature are the key regulators of adult abundance. Childers *et al.* (1990) found that climatological forcing has direct effects on estuarine flooding regimes and consequently affects inshore shrimp harvests while Agbesi (2002) detected that the influence of salinity is in itself not a significant factor but becomes essential when in combination with other factors like temperature and precipitation. Thus observed precipitation effects rightly describe its significance with respect to shrimp production

A stock assessment for the Chub mackerel based on the current analysis would be unrealistic. However, Perrotta *et al.*, 2001 indicated that this species migrates from coastal waters at higher SST values. Cury and Roy (2002) also observed a similar behavioural pattern in *S. japonicus* as that in *S. aurita.* Migration occurs to deeper waters during the warm season. Thus a lower abundance would be expected in a warming climate.

6.3 Future Production

The differences in the CPUE-based models and the r-based models indicate that the influence of the climate is exerted more on the stock production than on the catchability. Cury and Roy (1987) studied the pelagic stocks off Côte d'Ivoire and suggested that the introduction of the SST into a Fox production model showed that the influence is exerted on the fish abundance rather than on their catchability. Thus the second hypothesis would be more acceptable than the first although the first is also applicable.

If the current trend of decrease in precipitation should continue, the yield is not expected to be affected significantly for the round sardine, flat sardine, anchovy and chub mackerel, though productivity will not be maximised. For the Guinea Shrimp, a decrease in precipitation is expected to result in a lower catch. If SST changes continue until a significant level, an increase in catch of the anchovy is expected while a decrease would be recorded for the chub mackerel, shrimp and most obviously in the round sardine. The flat sardine would record slight reductions in catch. Even if the fluctuations in SST remain insignificant, the various species populations are expected to exhibit variability according to the extent of their correlation with this variable. For the guinea shrimp, there seems to be an underexploitation. However, though usually harvested by the fleet, the stock seems to have been underestimated since there are also commercial shrimpers operating in the fishing area.

It is necessary to note the positive value of q_{inc} for all the species reflects the continuing increase in effeciency of the effort, which was recorded for the entire canoe fleet. Mensah and Quaatey (2002) suggested that the small pelagics in the CECAF are overexploited but are still recording high catches as a result of the intensity of the upwellings. This inference seems to have been based on the CPUE as reflected in the CPUE-based model of this study. According to Cury and Roy (2002) the patterns of SST indicate a shift in the timing and intensity of the major upwelling. The rate of warming between August and September seems to have intensified with a more pronounced shift in the SST drop between June and July. The minor upwelling is also believed to have intensified in favour of the round sardine. Cury and Roy's assessment of the SST patterns showed that this effect was unnoticeable in the monthly SST time series but its consequence has led to the greatest changes in the pelagic fishery observed between 1975 and 1995. Even for the demersals, this relation was observed and attributed to 'an environmental forcing event' related to climate variability, which occurred between the sixties and the nineties. With the observations of the current study, it is obvious that SST changes and upwelling impact more on the population growth rate thereby compensating for the any effect of overfishing. It can therefore be accepted that the influences of climate underplay the effect of fishing effort and should be seriously considered if any fishery is to be managed sustainably.

If these 'small' changes in the ocean climate (as measured by the SST) can induce such variability, then in the face of warming climate, the fishery would expected to experience changes which would impact on the biology of the species as well as on the socio-economic lives of its dependants. For the Round Sardine, Chub Mackerel and Shrimp, revenue would be expected to decrease while that for the Anchovy would be expected to increase. Small changes would be recorded for the flat sardine. In the face of changing precipitation, the guinea shrimp and the flat sardine would be most affected. The decreasing trend of precipitation implies that lower catches would be obtained for both species. These estimates are based on the assumption that pricing of the species and factors that determine it remain constant in the future. Further, it is assumed that the trends observed in this simple study of historical climate (a slight increase in SST and a significant decrease in the precipitation) are quantitative in nature. Should a climate change in the next 20 years bring about changes of predictive nature, such as reversal of ocean currents, these empirical fishery models would be poorly suited to forecast ecosystem changes.

6.4 Limitations of the Study

1. The major limitation in this study was the inability to obtain a longer time series for fish yield to match the climatic parameters. Most related studies have spanned longer periods for example but data series up to 50 years could not be obtained. A longer series of fishing effort and salinity to match that of the MAT and precipitation would have been more useful for assessing the historic fishery-climate relation.
2. Owing to the nature of the available data (catch rates) the fishery-environment models had simple logistic formulations.
3. The fish yield was not representative of the entire coast since it constitutes records from only 54 out of about 200 landing sites. Thus estimates for the MSY and CPUE may well be underestimated.
4. It would have been useful to underline the influence of precipitation by assessing the rate of river discharge into the sea. Data on this could not be obtained due to time and logistic constraints.
5. An exponential relationship was assumed between production and the climatic variables, which might not necessarily be true.
6. Complete monthly records of some of the meteorological data were not available for some stations and the averages were only based on readings for the other stations.
7. Good theoretical models for prediction of the climate in the sea, particularly in the Gulf of Guinea are still unavailable. Forecasts were based on simple empirical analysis of a short series of climate data.
8. The model parameters obtained in this are with uncertainty. The impact on future states of the stocks and corresponding catch rates, should be the target of simulation studies

7.0 CONCLUSION

7.1 Lessons

The facts discussed show that the stocks exploited by the canoe fishery are not completely immune to changes in the climate. The SST has quite a dramatic effect on the production of the coastal fishery and its minor interannual variations should never be dismissed as insignificant. The influence of precipitation is also essential and cannot be ruled out. An adverse effect on the ocean climate leading to changes in these factors would only add to the current problem of overfishing. Since variations in the stocks are subject to global climatic changes, management of the fishery would require a holistic approach with due consideration of the changes in the ecosystem.

7.2 Recommendations

The first step towards the solution from the scientific point of view would be to step up the monitoring of these and other selected environmental factors on a regular basis. Oceans and their ecosystems, as stated earlier are relatively 'conservative and regulative with respect to changes. A longer time is thus needed for observable responses to atmospheric forcing. This seems a tough challenge considering the lack of logistics and human resource demands of the management organisations in developing countries like Ghana. However, this and the previous studies undertaken in the Gulf of Guinea provide a firm grounding on which to base future studies.

With the current high dependence of coastal communities on the fishery it is tasking to effectively monitor catches completely let alone to introduce controls on the effort and the catch. However, funding by the government and international management organisations that recognise the importance of these shared *Sardinella* and Anchovy stocks could make this more practical. Innovation through research on the ecosystem should be strongly promoted while aquaculture activities are expanded to stabilise seafood and employment. The data, financial and human resource requirements of the Integrated Coastal Zones Management Program should be met to ensure the incorporation of fisheries management with other uses of the coastal area. Close co-operation with forestry, water and other resource managers will ensure the adequacy of management practices in all sectors affecting the fishery. Since most people in the fishing communities are ignorant of the problems accompanying overfishing and climate change, programmes of education and capacity building should be initiated in this regard.

Considering the uncertainties that still surround the stock-climate relation, the management policies should be flexible enough to adapt to potential changes in the resource and market conditions. This means that the exploitation of lesser-known species should be encouraged to ease the pressure on the main stocks.

REFERENCES

Agbesi E. N., 2002. Environmental Influence on Marine Pelagic Fish: Evidence from Bioeconomic Modelling. PhD. Department of Economics University of Portsmouth CEMARE, UK.

Allain G., P. Petitgas and Lazure P. 2001. The Influence of Mesoscale Ocean Processes on Anchovy (*Engraulis encrasicolus*) Recruitment in the Bay of Biscay Estimated with a Three-dimensional Hydrodynamic Model. *Fisheries Oceanography* Volume 10 No.2 pp. 151-163. Blackwell and Sons.

Allersma E. and M. K.W. Tilman, 1993. Coastal Conditions in West Africa- A Review in *Ocean and Coastal Management* Vol., pp 199- 240.

Aman A, 1999. A Multi-Data Approach to Assess the Spatio-Temporal Variability of The Ivorio-Ghanaian Coastal Upwelling, Ocean Circulation Science derived from the Atlantic, Indian and Arctic Sea Level Networks ed. Mitchum, G. 2000. No. 171 pp76-80

Anakwah E and. Santos J. 2002. Department of Aquatic Biosciences, Norwegian College of Fishery Science (NFU), University of Tromsø. Norway.

Arfi R, Bouvy M, and Ménard F. 2002. Environmental Variability in a Coastal station near Abidjan: Oceanic and continental influences *in* the Gulf of Guinea Large Marine Ecosystem. Environmental Forcing & Sustainable Development of Marine Resources. Eds. J. M. McGlade, P. Cury, K. A. Koranteng, N. J Hardman-Mountford. The Gulf of Guinea Large Marine Ecosystem. Environmental Forcing & Sustainable Development of Marine Resources. Ed. K. Shemann. Elsevier Series Amsterdam, Netherlands. 391pp

Bages, M. And A. Fonteneau, 1980. Catches of the Franco-Ivory Coast – Senegal Tuna Fleet, and Surface Temperatures in 1997. Meeting of the Standing Committee on Research and Statistics, ICCAT- Madrid, Spain. November. 1979.Collect-Vol-Sci-Pap-Iccat; Recl-Doc-Sci-Cicta; Colecc-Doc-Cient-Cicaa 9(1): 180-198.

Bakun, A., 1993. Global Climate Variations and Potential Impacts on the Gulf of Guinea *Sardinella* Fishery *in* Dynamics and Use of Sardinella Resources from Upwelling off Ghana and Ivory Coast. Eds. Bard, F. X.; Koranteng, -K. A.-eds. Paris France. Orstom 1995 pp 60-85.

Banks K. & R. Wood, 2002. Where to look for Anthropogenic Climate Change in the

Ocean, Journal *of Climate* Vol. 15, no. 8, pp. 879-891. American Meteorological Society, USA.

Berger A., R. E. Dickinson, John W. Kidson (1989) Eds. Understanding Climate Change. American Geophysical Union : International Union of Geodesy and Geophysics (IUGG) Vol .7, Washington. 187pp

Binet,-D..1997 Climate and pelagic fisheries in the Canary and Guinea currents 1964-1993: the role of trade winds and the Southern Oscillation *in* LONG-TERM-CHANGES-IN-MARINE-ECOSYSTEMS. -LES-CHANGEMENTS-A-LONG-TERME-DANS-LES-ECOSYSTEMES-MARINS Castel, -J.-eds. PARIS-FRANCE GAUTHIERS-VILLARS 1997 vol. 20, no. 1 pp. 177-190.

Brown J., A. Colling, D. Park, J. Phillips, D. Rothery & J. Wright, 1989. Ocean Circulation. Oceanography Course Series, The Open University, England. Ed. G. Bearman. Butterworth Heinemann, United Kingdom. 238 pp.

Childers DL, JW Day and RA Muller. Relating Climatological Forcing to Coastal Water Levels in Louisiana Estuaries and the Potential Importance of El Nino-Southern Oscillation Events *in* Climate Research. Oldendorf / Luhe [CLIM. RES.], Vol. 1, no. 1, pp. 31-42.

Condrey R. and D. Fuller, 1992. The US. Gulf shrimp Fishery. Ch. 5 *in* Climate Variability, Climate Change and Fisheries, ed. M. H. Glantz, Cambridge University Press, ISBN, UK. 450 pp.

Cury, P. And C. Roy, 1987. Upwelling et Peches des Espèces Pélagique Cotieres de la Cote d'Ivoire: Une approche globale. Oceanol. -Acta. 10 (3): 347-357

Cury P. and C. Roy, 2002. Environmental Forcing and Fisheries Resources in Côte d'Ivoire and Ghana: Did Something Happen? pp. 241-274 *In* McGlade J. M, Cury P, Koranteng K .A, Hardman-Mountford N.J, 2002 The Gulf of Guinea Large Marine Ecosystem. Environmental Forcing & Sustainable Development of Marine Resources. Ed. K. Shemann. Elsevier Series Amsterdam.

Demarcq H and Aman A .2002 A Multi-Data Approach for assessing the Spatio-Temporal variability of the Ivorian-Ghanaian Coastal Upwelling: Understanding Pelagic Fish Stock Dynamics *in* The Gulf of Guinea Large Marine Ecosystem. Environmental Forcing & Sustainable Development of Marine Resources. Eds. J. M. McGlade, P. Cury, K. A. Koranteng, N. J. Hardman-Mountford. The Gulf of Guinea Large Marine Ecosystem.

Environmental Forcing & Sustainable Development of Marine Resources. Ed. K. Shemann. Elsevier Series Amsterdam, Netherlands. 391pp

Dykhuizen P and Zei M, 1970.Clupeid Fisheries in the Eastern Atlantic. Information Report No.3, Fisheries Research Unit, Tema, Ghana

F.A.O. 1986. Guia Campo Para as Especies Comercais Marinhas de Aguas Salobras de Angola Fichas de Identificacao de Especies Para Actidades de Pesca. Organizacao das Nacoes Unidas Para a Agrucultura e a Alimentacao Rome.

FAO, 1997. Review of the State of the World Fishery Resources: FAO Fisheries Circular No. 920 FIRM/C920, Marine Resources Services, Fishery Resources Division, FAO, Rome.

Froese R. and D. Pauly. 2002. FishBase. World wide Web Electronic Publication. (www.fishbase.org)

Glantz, M: H., 1992. Climate Variability, Climate Change and Fisheries, Cambridge University Press, ISBN, UK. 450 pp.

Haas, HL, R. F Shaw. K A Rose, MC Benfield, WR Keithly 2001. Regression Analysis of the Relationships among Life-stage Abundances of Brown Shrimp (*Penaeus aztecus*) and Environmental Variables in Southern Louisiana, USA *in* Proceedings of the Gulf and Caribbean Fisheries Institute [Proc. Gulf Caribb. Fish. Inst.]. No. 52, pp. 231-241.

Haas HL, E C. Lamon III, KA Rose, RF Shaw, 2001. Environmental and Biological Factors Associated with the Stage-specific Abundance of Brown Shrimp (*Penaeus aztecus*) in Louisiana: Applying a New Combination of Statistical Techniques to long-term monitoring data. *Canadian Journal of Fisheries and Aquatic Sciences [Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat.]. Vol. 58, no. 11, pp. 2258-227*

Haddon, N., 2001. Modelling and Quantitative Methods in Fisheries. Chapman and Hall/CRC, USA

Hardman-Mountford, N. J. and J.M. McGlade 2002. Variability of Physical Environmental Processes in the Gulf of Guinea and Implications for Fisheries Recruitment. An Investigation Using Remotely Sensed SST. *In* The Gulf of Guinea Large Marine Ecosystem. Eds. J. M: McGlade, P. Cury, K: A. Koranteng & N. J. Hardman-Mountford. The Gulf of Guinea Large Marine

Ecosystem. Environmental Forcing & Sustainable Development of Marine Resources. Ed. K. Shemann. Elsevier Series Amsterdam, Netherlands. 391pp

HillBorn and Waters, 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman & Hall, London.

Horton R W., R F Shaw, J C Cope and C Benfield, 1997. Atmospheric Cold Fronts and Coastal Ocean-estuarine Physical Forcing as a Brown Shrimp (*Penaeus aztecus*) Recruitment Enhancement Mechanism. Midyear Meeting of the Southern Division of the American Fisheries Society. San Antonio, Texas. (www.sdafs.org/meetings/97sdafs/pollute/horton1.htm)

Houghton, J.T, 1997 An Introduction to simple climate models used in the IPCC Second Assessment Report, IPCC Technical paper; Vol. II

IPCC, 2001. Climate Change: Impacts Adaptation and Vulnerability. A Report of Working Group II. Technical Summary pp. 35 – 36, Summary for Policy Makers, pp. 11 – 12. (www.ipcc.org).

Isaka, D., S. O. Minta, V. Obeng and J Sackey, 2002 A Report on Ghana's Fisheries. Norwegian College of Fishery Science, University of Tromsø, Norway.

Kattenberg, -A. J.; Giorgi, -F.; Grassl, -H.; Meehl, -G.A.; Mitchell,-J.F.B.; Stouffer,-R.J., Tokioka, -T.; Weaver, -A. J.; Wigley, -T.M.L. Climate models— Projections of Future Climate *in* Climate Change 1995- The Science of Climate Change. Houghton, J. T.; Meira – Filho, L. G.; Callander, B. A.; Harris, N.; Kattenberg, A.; Maskell, Eds. Cambridge University Press, New York, USA

Kawasaki, T., 1992. Effects of Global Climate Change on Marine Ecosystems and Fisheries *in* Climate Change: Science, Impacts and Policy, Proceedings of the Second World Climate Conference, Ed. J. Jager and H. L. Ferguson, Cambridge University Press, U.K.

Kerr, R. A., 1984. Computer Models Gain on El Nino. Science Wash., Vol. 225, No. 4657, pp. 37-38

King M., 1995. Fisheries Biology, Assessment and Management. Fishing News Books, Oxford. 341pp.

Koranteng, K: A., 1991. Some Aspects of the *Sardinella* Fishery in Ghana. *in* Pêcheries Ouest Africaines Variabilité, Instabilité et Changement. Pp. 269 – 277 Editeurs Scientifique Philippe Cury et Claude Roy ORSTOM Ed. Institut

Français De Recherche Scientifique Pour Le Development Et Cooperation, Paris.

Koranteng, K.A.1999. Biodiversity Status and Threats on Demersal Fish Communities in continental Shelf Waters of the Gulf of Guinea *in* International-Workshop-on-status-of-the-freshwater; coastal; marine-living-resources-with-particular-emphasis-on-threats-and-options-in-coastal-areas, -15-18-november-1999-in-Montpellier,-France Vidy,-G.-(ed.); Albaret,-J.J.-(ed.); Baran,-E.-(ed.) Montpellier-France IRD 1999 pp. p. A.3.15-16.

Koranteng K.A and McGlade J .M, 2002. Physico-Chemical Changes in Continental Shelf Waters of the Gulf of Guinea and Possible Impacts on Resource Variability *in* the Gulf of Guinea Large Marine Ecosystem. Environmental Forcing & Sustainable Development of Marine Resources. Eds. J. M. McGlade, P. Cury, K. A. Koranteng, N. J. Hardmann-Mountford. Elsevier Series, Amsterdam, Netherlands. 391pp.

Laevastu T. and M. L. Hayes, 1988. Fisheries Oceanography and Ecology, 3rd Ed. Fishing News Books Ltd. England. 199 pp.

Marine Fisheries Research Division (MFRD), 2001. Summary of Total Marine Fish Production for Ghana. Fisheries Directorate of the Ministry of Food and Agriculture, Tema, Ghana

McGlade J. M, Cury P, Koranteng K .A, Hardman-Mountford N.J, 2002 The Gulf of Guinea Large Marine Ecosystem. Environmental Forcing & Sustainable Development of Marine Resources. Eds. J. M. McGlade, P. Cury, K. A. Koranteng, N. J. Hardmann-Mountford. Elsevier Series Amsterdam. 391p.

Mendelssohn, R. 1988 Relating Fisheries to the Environment in the Gulf of Guinea: Information, Causality and Long-Term Memory. *in* Pêcheries Ouest Africaines Variabilité, Instabilité et Changement. Pp. 269 –277 Editeurs Scientifique Philippe Cury et Claude Roy ORSTOM Ed. Institut Français De Recherche Scientifique Pour Le Developpement Et Cooperation, Paris

Mensah, M. A. and Koranteng, K. A., 1988. A Review of the Oceanography And Fisheries Resources in the Coastal Waters of Ghana, 1981 –1986. Marine Fisheries Research Report No. 8, Fishery Research Unit, 35pp.

Mensah M. A. & S.N.K Quaatey, 2002. An Overview of Fishery Resources and Fishery Research in the Gulf of Guinea. *in* The Gulf of Guinea Large Marine

Ecosystem. Environmental Forcing & Sustainable Development of Marine Resources. Eds. J. M. McGlade, P. Cury, K. A. Koranteng, N. J. Hardman-Mountford. The Gulf of Guinea Large Marine Ecosystem. Environmental Forcing & Sustainable Development of Marine Resources. Ed. K. Shemann. Elsevier Series Amsterdam, Netherlands. 391pp

Mensah, M. A.1991. The Influence of Climatic Changes in the Coastal Oceanography of Ghana *in* Pêcheries Ouest Africaines Variabilité, Instabilité et Changement. Pp. 67 –79. Editeurs Scientifique Philippe Cury et Claude Roy ORSTOM Ed. Institut Français De Recherche Scientifique Pour Le Developpement Et Cooperation, Paris

Nkansah A, 2002. Meteorological Services Department, Accra, Ghana.

Perrotta RG, MG Vinas, Hernandez DR, Trigali L. 2001 Temperature conditions in the Argentine chub mackerel (*Scomber japonicus*) fishing ground: implications for fishery management Fisheries Oceanography [Fish. Oceanography.]. Vol. 10, no. 3, pp. 275-283

Quaatey, S. N. K., 1996. Report on the Synthesis of Recent Evaluations Undertaken On the Major Fish Stock in Ghanaian Waters, Marine Fisheries Research Division, Fisheries Directorate of the Ministry of Food and Agriculture, Tema, Ghana.

Quaatey S. N. K., 2002. Marine Fisheries Research Division, Fisheries Directorate of the Ministry of food and Agriculture, Tema, Ghana.

Quinn T. S. II and Deriso R. B.1999. Quantitative Fish Dynamics. Oxford Univerity Press. New York

Republic of Ghana, 2000. Ghana's Initial National Communication under the United Nations Framework Convention on Climate Change, Environmental Protection Agency, Accra- Ghana.

Rothschild, B. 1996. How Bountiful are Ocean Fisheries? *CONSEQUENCES*: 2. No1. (www. gcrio.ciesin.org/CONSEQUENCES/winter96/oceanfish.html)

Roy,-C..1993. The Cote-d'Ivoire and Ghana Coastal Upwellings Dynamics and Changes Dynamics-and-use-of-Sardinella-resources-from-upwelling-off-Ghana-and-Ivory-coast.-DYNAMIQUE-ET-USAGE-DES-RESSOURCES-EN Bard,-F.X.-eds.; Koranteng -K.A.-eds. Paris-France ORSTOM 1995 pp. 346-361.

Roy, C. 1996. An Upwelling Induced Retention Area off Senegal: A Mechanism to

Link Upwelling and Retention Processes in *South African Journal of Marine Science* 1998. Vol. 19 pp. 89-98.

Schnur R, 2002 Climatic Science: The forecast. *Nature* Vol.415, No.6871. pp 483-484.ccc Mac Millan publishers

Sharp G., 1992. Climate Change, the Indian Ocean Tuna Fishery, and Empiricism. Ch. 16 *in* Climate Variability, Climate Change and Fisheries, ed. M. H. Glantz, Cambridge University Press, ISBN, UK. 450 pp.

Sloane, Christine S and Tesche T.W, c1991, Atmospheric Chemistry: Models and Predictions for Climate and Air Quality, Lewis Publishers, 169pp

Spencer W., 2001. The Discovery of Global Warming: General Circulation Models of the Atmosphere Based on Edwards, P., 2000. A Brief History of Atmospheric General Circulation Modelling in General Circulation Model Development, Ed. David A. Randall, pp67-90. San Diego, CA: Academic Press

ter Braak CJF and Petr Smilauer, 1998. CANOCO Reference Manual and User's Guide to CANOCO for Windows. Software for Canonical Community Ordination (Version 4) Centre for Biometry, Wageningen, and Nederlands. pp15-301

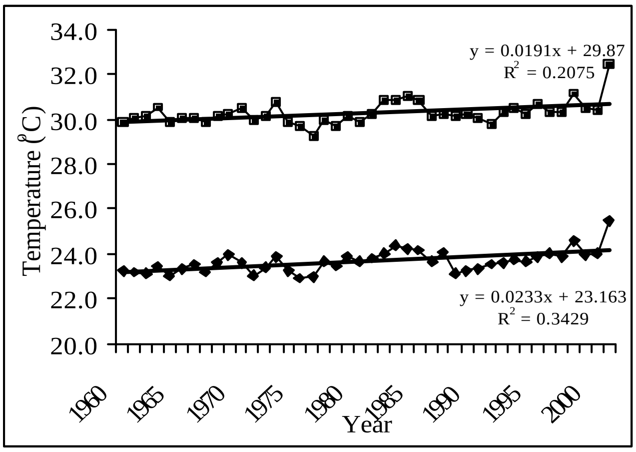
Verstraete, -J. -M.; Picaut, -J. 1983. Variation of Sea Level, Sea Surface Temperature and Dynamic Height along the Northern Coast of the Gulf of Guinea. OCEANOGR.-TROP. 1983. Vol. 18, no. 2, pp. 139-162

APPENDIX 1

Summary of Annual Variation in Climatic Variables Source MSD Database, MFRD, Ghana * Data Unavailable

YEAR	SST(°C	MAT(°C)	SALINITY (ppt)	PRECIPITATION (mm)	MINIMUM TEMPERATURE	MAXIMUM TEMPERATURE
1960	*	*	*	*	23.2	29.9
1961	*	26.6	*	7602.7	23.2	30.0
1962	*	26.6	*	9651	23.2	30.1
1963	26.6	27.0	*	8857.7	23.5	30.5
1964	25.4	26.5	*	6501.2	23.0	29.9
1965	26.1	26.6	*	6864.8	23.3	30.1
1966	26.0	26.9	*	5324.7	23.6	30.0
1967	25.9	26.5	*	6711.4	23.2	29.9
1968	26.7	26.8	31.10	11426.5	23.6	30.1
1969	26.0	27.0	32.95	6594.2	23.9	30.3
1970	26.2	26.9	33.67	6696.9	23.6	30.5
1971	25.8	26.5	33.69	6928.5	23.1	30.0
1972	26.0	26.8	34.56	6014.9	23.4	30.1
1973	26.3	27.3	34.82	7303.4	23.9	30.7
1974	26.0	26.6	34.51	8155.7	23.2	29.9
1975	25.6	26.3	34.73	6411.1	22.9	29.7
1976	24.8	25.8	34.59	5586.7	23.0	29.2
1977	25.4	26.8	35.05	3667.4	23.7	30.0
1978	25.7	26.6	34.53	5534.5	23.5	29.7
1979	26.4	27.0	34.22	8766.6	23.9	30.1
1980	25.9	26.8	34.42	7370.3	23.7	29.9
1981	26.0	26.9	34.27	6270.6	23.8	30.2
1982	25.7	26.9	34.59	7426.4	24.0	30.8
1983	25.3	26.7	35.09	3352.2	24.4	30.8
1984	26.4	27.0	34.98	5569.5	24.2	31.0
1985	25.8	26.9	35.21	5778.8	24.2	30.9
1986	25.4	26.7	35.16	5115.7	23.7	30.1
1987	27.0	27.3	35.17	7422.1	24.1	30.2
1988	26.6	26.9	35.22	6235.1	23.1	30.1
1989	26.3	26.9	34.87	5602	23.2	30.3
1990	25.9	27.0	35.46	4492.6	23.3	30.1
1991	26.2	27.0	35.17	7077.3	23.5	29.8
1992	25.8	26.9	35.18	4877.9	23.6	30.3
1993	26.6	27.1	35.06	5947.8	23.8	30.5
1994	26.4	27.0	35.12	6137.8	23.7	30.3
1995	26.7	27.2	*	6715.6	23.9	30.7
1996	26.2	27.1	35.38	7460.4	24.0	30.3
1997	26.2	27.0	34.81	8405.12	23.9	30.3
1998	25.9	27.8	34.84	3893.5	24.6	31.1
1999	26.3	27.2	35.14	5901.7	23.9	30.5
2000	26.1	27.2	34.45	4519.6	24.0	30.4
2001	26.4	27.5	34.49	5953.7	25.4	32.5

APPENDIX 2



Appendix 2A Trends in Maximum & Minimum Air Temperature

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.573844
R Square	0.329297
Adjusted R Square	0.3121
Standard Error	0.274785
Observations	41

ANOVA

	df	SS	MS	F	Significance F
Regression	1	1.445796	1.445796	19.14794956	8.76378E-05
Residual	39	2.944756	0.075507		
Total	40	4.390552			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-4.55428	7.18503	-0.63386	0.529874569	-19.0873623	9.978801023	-19.0873623	9.978801
X Variable 1	0.015871	0.003627	4.375837	8.76378E-05	0.008534649	0.023206857	0.008534649	0.023207

Appendix 2B Autocorrelation Analysis: Mean Air Temperature

APPENDIX 3

SUMMARY OUTPUT

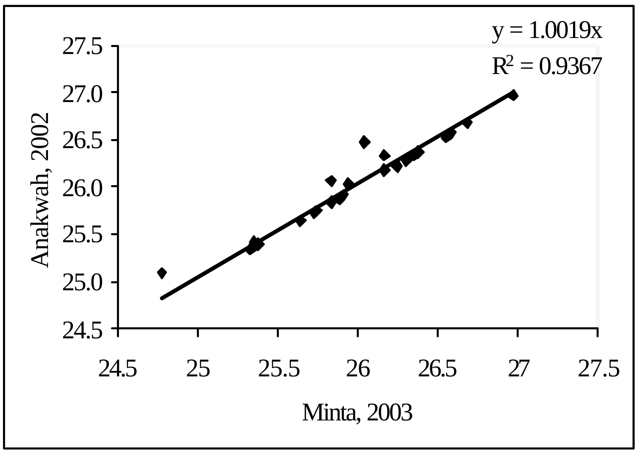
Regression Statistics	
Multiple R	0.23332
R Square	0.054438
Adjusted R Square	0.028882
Standard Error	0.437952
Observations	39

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.408572	0.408572	2.130174334	0.152863077
Residual	37	7.096679	0.191802		
Total	38	7.505252			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	8.024258	12.3502	0.649727	0.519882167	-16.99959529	33.04811107	-16.99959529	33.04811
X Variable 1	0.009094	0.006231	1.459512	0.152863077	-0.00353102	0.021719686	-0.00353102	0.02172

Appendix 3A Autocorrelation Analysis: Sea Surface Temperature



Appendix 3B Comparison of SST values used by Anakwah and Santos, 2002 & Minta, 2003, 1975-1999.

APPENDIX 4

SUMMARY OUTPUT

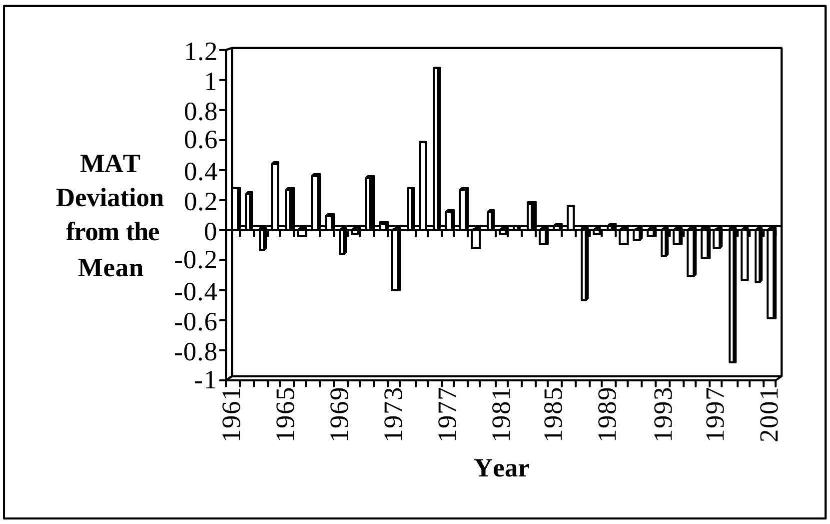
Regression Statistics	
Multiple R	0.400684
R Square	0.160548
Adjusted R Square	0.139023
Standard Error	1476.808
Observations	41

ANOVA

	df	SS	MS	F	Significance F
Regression	1	16267523	16267523	7.458871388	0.009429756
Residual	39	85057557	2180963		
Total	40	1.01E+08			

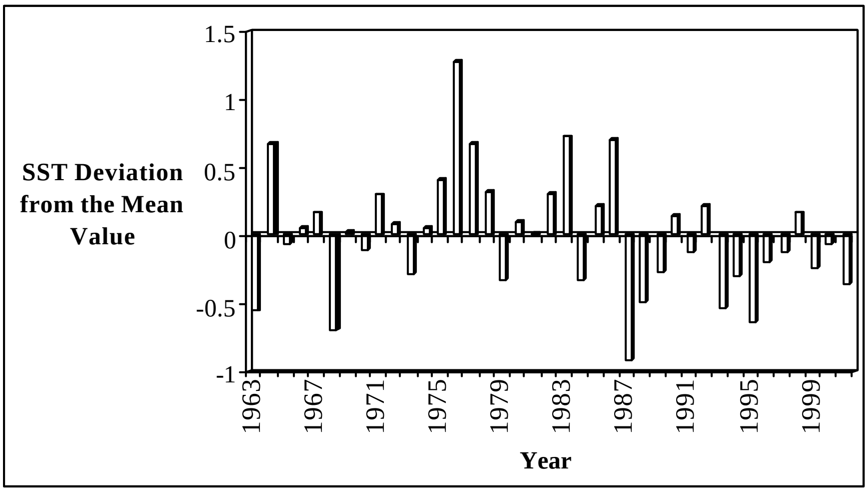
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	111951.2	38615.39	2.899135	0.006114997	33844.30409	190058.148	33844.30409	190058.1
X Variable 1	-53.2359	19.49253	-2.73109	0.009429756	-92.66324381	-13.80859591	-92.66324381	-13.8086

Appendix 4A Autocorrelation Analysis: Total Coastal Precipitation

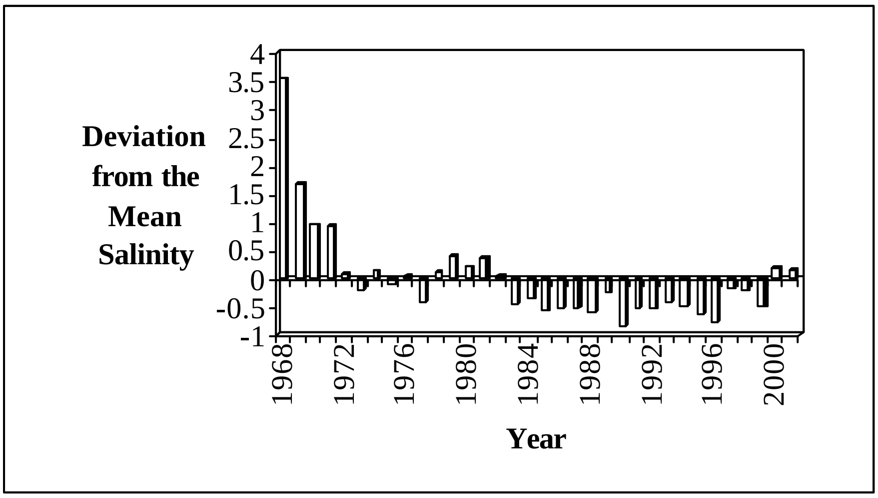


Appendix 4.B Fluctuations in Historic MAT

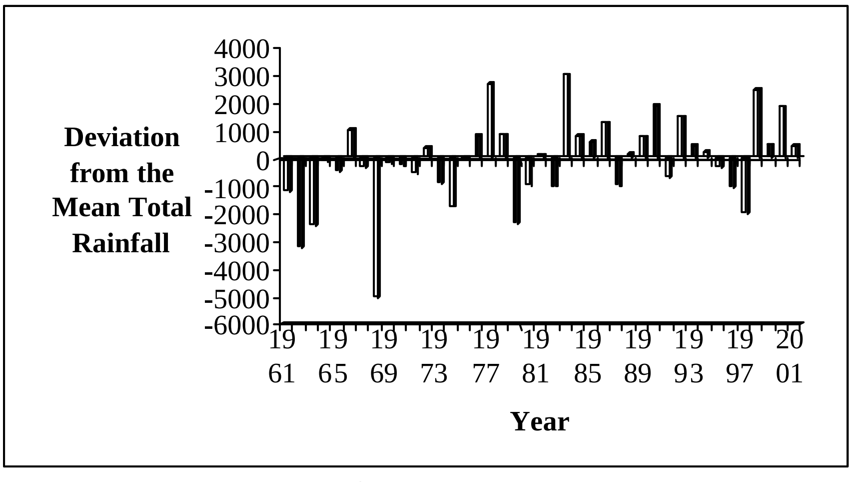
APPENDIX 5



Appendix 5A Fluctuations of Historic SST about the Mean

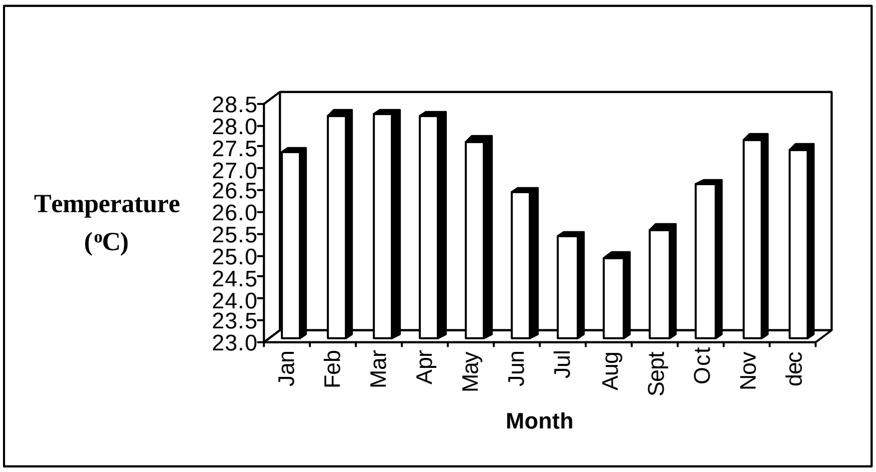


Appendix 5B Fluctuations of Historic Salinity about the Mean

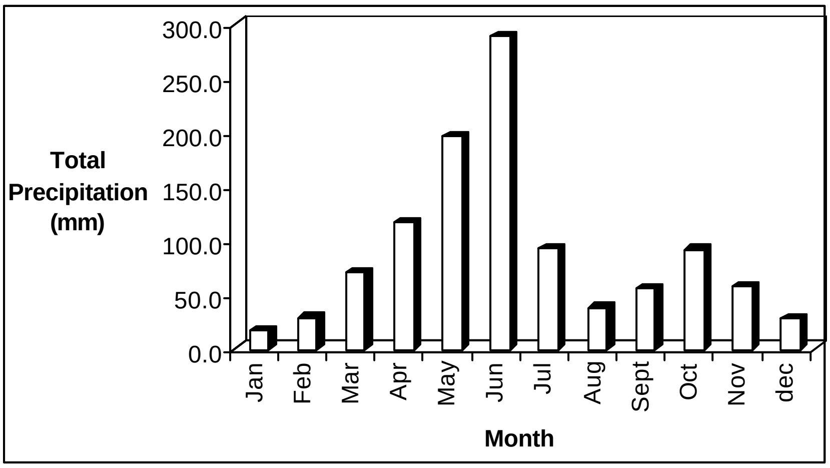


Appendix 5C Fluctuations of Historic Precipitation about the Mean

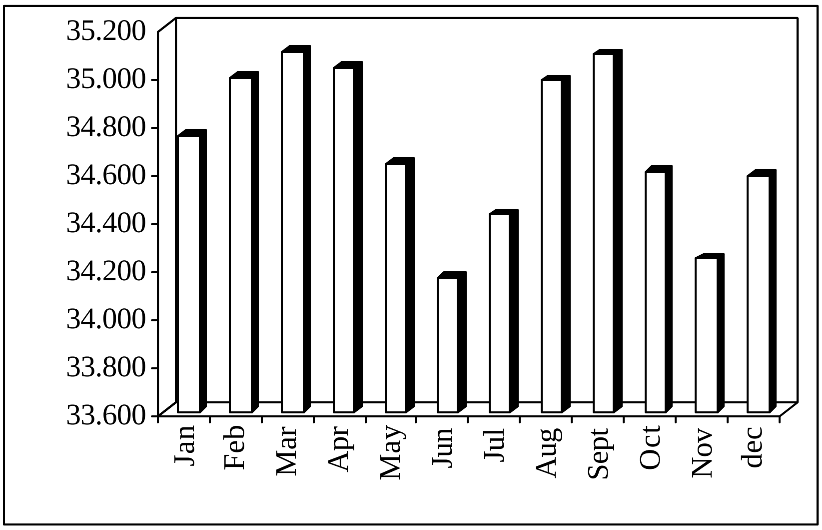
APPENDIX 6



Appendix 6A Seasonal Variation of MAT (based on 1961-2001)

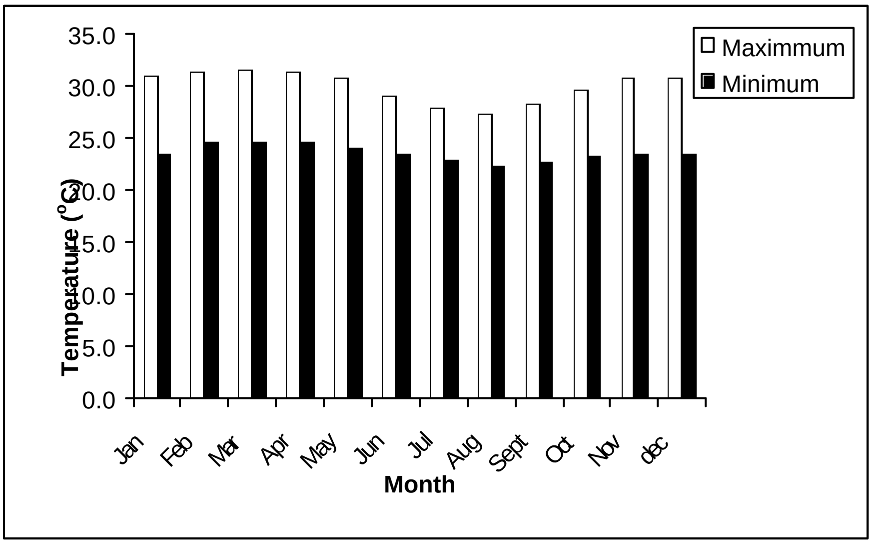


Appendix 6B Seasonal Variation of Precipitation (Based on 1961-2001)



Appendix 6C Seasonal Variation of Salinity (Based on 1968-2001)

Appendix 7



Appendix 7A Seasonal Variation of Maximum and Minimum Temperature (Based on 1960 – 2001)

Appendix 7B Results of Correlation Analysis for Climatic Variables Measured along the Coast of Ghana

Pearson Correlations

	SST	MAT	SAL	PPN
SST	1.000	**0.643**	-0.167	**0.502**
MAT		1.000	0.134	-0.103
SAL			1.000	**-0.593**
PPN				1.000

Pearson Probabilities

	SST	MAT	SAL	PPN
SST	0.000	**0.000**	0.317	**0.001**
MAT		0.000	0.424	0.536
SAL			0.000	**0.000**
PPN				0.000

APPENDIX 8

Appendix 8A. Regression Statistics for Precipitation Trend along the Coast of Ghana

Multiple R	0.400684
R Square	0.160548
Adjusted R Square	0.139023
Standard Error	1476.808
Observations	41

ANOVA

	df	SS	MS	F	Significance F
Regression	1	16267523	16267523	7.458871	0.00943
Residual	39	85057557	2180963		
Total	40	1.01E+08			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	111951.2	38615.39	2.899135	0.006115	33844.3	190058.1	33844.3	190058.1
X Variable 1	-53.2359	19.49253	-2.73109	0.00943	-92.6632	-13.8086	-92.6632	-13.8086

Appendix 8B Regression Statistics for SST Trend along the Coast of Ghana

Multiple R	0.233319847
R Square	0.054438151
Adjusted R Square	0.028882425
Standard Error	0.437952222
Observations	39

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.408572014	0.408572	2.130174	0.152863
Residual	37	7.0966795	0.191802		
Total	38	7.505251514			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	8.024257888	12.35019775	0.649727	0.519882	-16.9996	33.04811	-16.9996	33.04811
Year	0.009094333	0.006231079	1.459512	0.152863	-0.00353	0.02172	-0.00353	0.02172

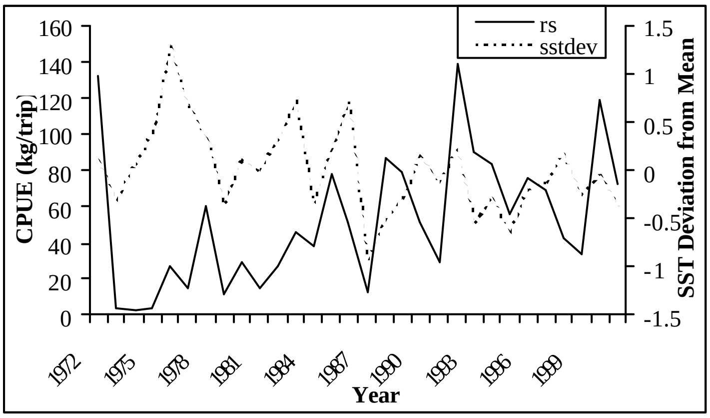
APPENDIX 9

Appendix 9 Annual Production of the Major Marine Stocks in Ghana. Source: MRFD

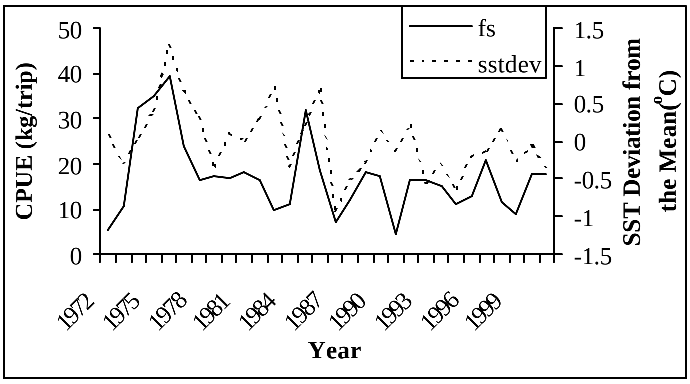
* Data Unavailable

Year	Species Catch (mt)					Effort (trips)
	Round Sardinella	Flat Sardinella	Anchovy	Chub Mackerel	Guinea Shrimp	
1972	71267.4	3001	*	1682.4	*	538751
1973	3074.5	7537.3	*	1543.3	*	698196
1974	1408.1	16110.9	33440.8	484.7	*	496180
1975	1931.1	18328.5	32172.1	832.7	*	520989
1976	12008.7	17472	28656.6	71.6	*	442201
1977	9581.6	14696	35042.9	93.3	*	613729
1978	40257.3	11069.5	51424.1	304.2	*	672414
1979	9247.4	14249.1	36675.9	51.8	*	827836
1980	19426.1	11310.1	37908.1	43.4	451.9	662540
1981	10066.5	12445.3	67535.5	327.4	385.8	676161
1982	20110.4	12378.3	46435	87.9	230.3	745190
1983	36299	7667.6	24392.3	194.9	163.4	787211
1984	34816.3	10077.1	47230.9	540.3	172.5	908052
1985	54072.5	22233.9	27590.3	45.2	106.8	695981
1986	45488.9	16633.5	15208.5	16865.7	482.6	897500
1987	45670.7	25479.2	87984.4	397.3	1455.4	3546324
1988	75851.5	10450.4	75902.3	7423.5	1039.8	867841
1989	61158.5	14097.7	76347.9	11035.8	1152.9	773203
1990	43166.5	14549	74668.1	6671.9	2326.4	839811
1991	50447	8206.7	65490	21028.5	865.2	1757136
1992	119514.7	14240.3	85384.4	9819.2	2042.4	860681
1993	90600.4	16797.1	81349.7	3455.5	977.9	1009118
1994	67565.6	12309.5	60519.3	3554.7	907.4	813104
1995	65597.5	13091.6	65496.7	8323.1	1798.3	1168906
1996	77866.2	13038.5	66552	6852.3	1104.5	1028128
1997	46383.9	14069.7	82723.6	7086.1	1303.1	674750
1998	54595.6	14770.3	44643.7	1972	1109.8	1269328
1999	48498.2	12850.1	39840	6572.9	922.3	1418903
2000	98864.7	14934.9	83500.8	14835.4	1130.6	834937
2001	64103.6	15853.4	68174.6	9574.3	1121.6	892534

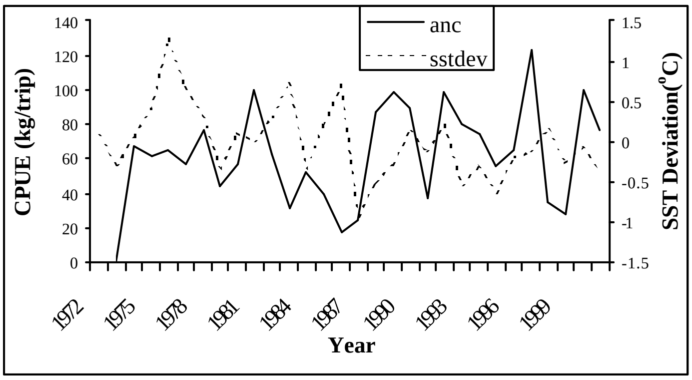
Appendix 10



Appendix 10A Fluctuation in Landings of Round Sardinella in Relation to SST Deviations from the Mean

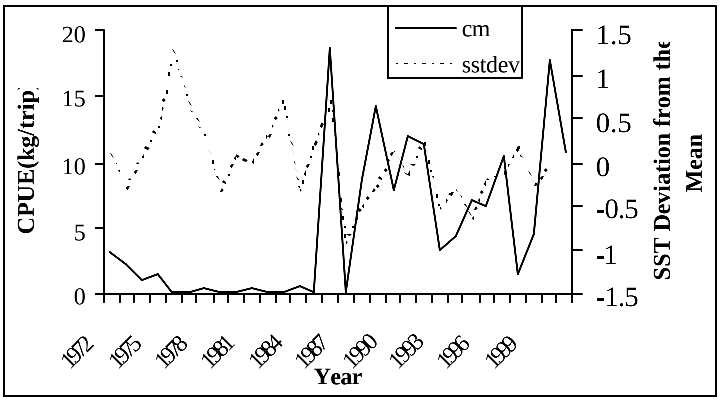


Appendix 10B Fluctuation in Landings of Flat Sardinella in Relation to SST Deviations from the Mean

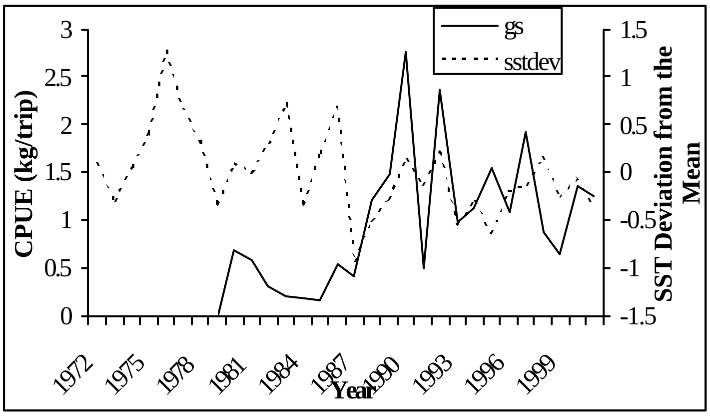


Appendix 10C Fluctuation in Landings of the Anchovy in Relation to SST Deviations from the Mean.

APPENDIX 11



Appendix 11A Fluctuation in Landings of the Chub Mackerel in Relation to SST Deviations from the Mean



Appendix 11B Fluctuation in Landings of the Guinea Shrimp in Relation to SST Deviations from the Mean

Appendix 11C Model Estimates for the Chub Mackerel (1972 – 2001)

Parameter	r	K	MSY	qinc	a	b	AIC	BIC
Basic	0.01	517112.8	1292.8	1.2235-	-		105.0598	110.5151
CPUE f(T)	0.3	50000	3750	1.2235	0-		107.0598	113.6061
CPUE f(T, P)	0.3	4000	3000	1.2235	0.1	0	109.6067	117.2439
CPUE f(P)	0.4	5000	500	1.2235-		0	107.0598	113.6061
r f(T)	0	33537.6	0	1.2235	0.4-		107.0598	113.6061
r f (T, P)	0	517112.8	0	1.2235	0.02	5.2546E - 05	109.06	116.70
r f (P)	0.7	22599	3954.8	1.2235-		0.000128	107.0598	113.6061

APPENDIX 12

Appendix 12A Model Estimates for the Guinea Shrimp (1980-2001).

Parameter	r	K	MSY	qinc	a	b	AIC	BIC
Basic	0.6	46086	6887	1	0	0	45.02	50.47
CPUE f(T)	0.7	23044	4033	1.713	0.07	0	52.71	59.26
CPUE f(T, P)	0.842	5387	1135	1.432	-0.72	0.000253	67.23	74.87
CPUE f(P)	0.7	23000	4025	1.717	0	0.00003	52.78	59.33
r f(T)	0.579	51476	7448	1.01	0.1	0	45.67	52.22
r f(T, P)	0.842	4387	924	0.9143	0.48	0.000076	35.25	42.89
r f(P)	0.881	3675	810	0.9026	0	0.000312	33.31	39.86

Appendix 12B Variation of Prices for the Main Stocks Harvested by the Ghanaian Canoe Fleet. * Data Unavailable Source: MFRD (2002)

Year	Price per Kilogram of Fish in Cedis (¢)				
	Round Sardinella	Flat Sardinella	Anchovy	Chub Mackerel	Guinea Shrimp
1980	7.7	7.9	2.5	22.8	7.7
1981	14.9	8.7	7.2	9.2	4.2
1982	6.0	5.5	2.0	11.7	7.2
1983	15.1	40.2	5.9	8.8	34.1
1984	28.1	37.7	0.7	38.9	50.5
1985	29.6	32.3	1.0	70.0	29.1
1986	30.4	28.9	1.8	108.2	24.0
1987	48.5	62.3	17.9	109.3	30.9
1988	99.3	93.1	31.9	83.0	85.5
1989	109.6	99.9	47.2	122.5	103.5
1990	89.5	111.0	50.8	133.4	74.4
1991	109.8	142.1	67.0	107	101.5
1992	99.9	127.6	62.7	130.5	58.6
1993	191.4	195.2	93.6	208.9	188.4
1994	*	*	*	*	*
1995	370.6	341.8	200.8	480.9	192.1
1996	522.2	524.5	264.9	532.5	413.1
1997	961.2	929.9	125.8	942.2	415.2
1998	741.8	621.5	344.8	875.9	869.3
1999	787.8	870.2	450.3	974.4	1087.2
2000	1400	1301.7	464.7	1274	1915
2001	2732.5	2134.2	1457.5	2600	1967.1

Appendix 13

Appendix 13: Contribution of the Main Small Pelagics and Guinea Shrimp to Annual Revenue of the Canoe Fishery Source: MFRD (2002)

Year	Annual	Revenue (¢)			
	Round Sardinella	Flat Sardinella	Anchovy	Chub Mackerel	Guinea Shrimp
1980	149581	89350	94770	990	3480
1981	149991	108274	486256	3012	1620
1982	120662	68081	92870	1028	1658
1983	548115	308238	143915	1715	5572
1984	978338	379907	33062	21018	8711
1985	1600546	718155	27590	3164	3108
1986	1382863	480708	27375	1824869	11582
1987	2215029	1587354	1574921	43425	44972
1988	7532054	972932	2421283	616151	88903
1989	6702972	1408360	3603621	1351886	119325
1990	3863402	1614939	3793139	890031	173084
1991	5539081	1166172	4387830	2250050	87818
1992	11939519	1817062	5353602	1281406	119685
1993	17340917	3278794	7614332	721854	184236
1994	18985934	3305101	8908441	1226016	172633
1995	24310434	4474709	13151737	4002579	345453
1996	40661724	6838714	17629625	3648828	456269
1997	44584205	13083414	10406629	6676523	541047
1998	40499038	9179741	15393148	1727275	964749
1999	38206882	11182157	17939952	6404634	1002725
2000	138410580	19440759	38802822	18900300	2165099
2001	175163087	33834326	99364480	24893180	2206299
Average (¢)	26403861	5242602	11420518	3476815	395819

APPENDIX 14

Calculation of the MSY for the Anchovy Using Annual Values Estimated by Incorporation of the SST Factor

Year	SST(^{0}C)	r_T	MSY_t	Catch (mt)	No. Of Years with Catch>MSY
1974	25.9833333	0.357331	60714.31	33440.8	
1975	25.6416667	0.200527	34071.7	32172.09	
1976	24.775	0.046318	7869.939	28656.6	1
1977	25.375	0.127747	21705.58	35042.9	1
1978	25.725	0.23087	39227.28	51424.1	1
1979	26.375	0.692923	117734.8	36675.9	
1980	25.9416667	0.333023	56584.02	37908.1	
1981	26.0416667	0.394373	67008.08	67535.5	1
1982	25.7416667	0.237469	40348.47	46435	1
1983	25.325	0.117391	19945.95	24392.3	1
1984	26.375	0.692923	117734.8	47230.9	
1985	25.8333333	0.277282	47113.03	27590.3	
1986	25.35	0.12246	20807.18	15208.5	
1987	26.9666667	1.884368	320173.7	87984.4	
1988	26.55	0.931522	158275.4	75902.3	
1989	26.325	0.636749	108190.3	76347.9	
1990	25.9083333	0.314772	53483.03	74668.1	1
1991	26.1666667	0.48719	82778.75	65490	
1992	25.8333333	0.277282	47113.03	85384.4	1
1993	26.5833333	0.985533	167452.3	81349.7	
1994	26.35	0.664242	112861.7	60519.3	
1995	26.6833333	1.16709	198300.8	65496.7	
1996	26.2416667	0.553062	93971.01	66552	
1997	26.1666667	0.48719	82778.75	82723.6	
1998	25.8833333	0.301743	51269.34	44643.7	
1999	26.3	0.610394	103712.2	39840	
2000	26.1083333	0.441431	75003.71	83500.8	1
2001	26.4083333	0.733099	124561.2	68174.6	
	Average	0.510939	86813.95	55081.8	Total No. Of times Catch>MSY=9

APPENDIX 15

Calculation of the MSY for the Round Sardinella Using Annual Values Estimated by Incorporation of the SST Factor

Year	SST	r_T	MSY_t	Catch(MT)
1973	26.34167	0.30552	271282.8	3074.5
1974	25.98333	0.439642	390374.9	1408.1
1975	25.64167	0.622024	552319	1931.1
1976	24.775	1.5	1331907	12008.7
1977	25.375	0.815517	724128.7	9581.6
1978	25.725	0.571544	507495.2	40257.3
1979	26.375	0.29535	262252.1	9247.4
1980	25.94167	0.458647	407249.8	19426.1
1981	26.04167	0.414351	367918.2	10066.5
1982	25.74167	0.56195	498976.7	20110.4
1983	25.325	0.858001	761852	36299
1984	26.375	0.29535	262252.1	34816.3
1985	25.83333	0.511993	454617.8	54072.5
1986	25.35	0.83649	742750.9	45488.9
1987	26.96667	0.16194	143792.7	45670.7
1988	26.55	0.247255	219546.8	75851.5
1989	26.325	0.310736	275914.1	61158.5
1990	25.90833	0.47444	421273.5	43166.5
1991	26.16667	0.364948	324051.6	50447
1992	25.83333	0.511993	454617.8	119514.7
1993	26.58333	0.239024	212238.3	90600.4
1994	26.35	0.302945	268996.4	67565.6
1995	26.68333	0.215939	191740.6	65597.5
1996	26.24167	0.338181	300283.8	77866.19
1997	26.16667	0.364948	324051.6	46383.9
1998	25.88333	0.486641	432107.3	54595.63
1999	26.3	0.318727	283009.6	48498.2
2000	26.10833	0.387224	343830.8	98864.7
2001	26.40833	0.285518	253522.1	64103.6
	AVERAGES	**0.465408**	**413253.6**	**45092.17**