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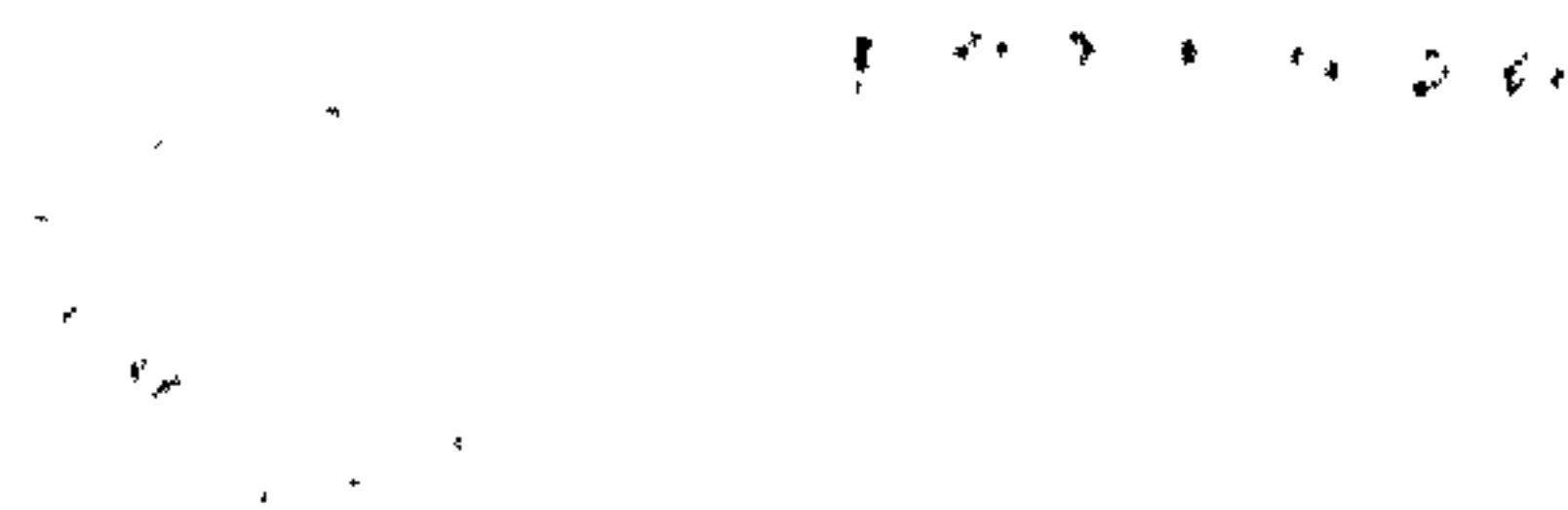
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**THE IMPACTS OF ENVIRONMENTAL FORCING  
ON THE DYNAMICS OF DEMERSAL FISHERY RESOURCES  
OF GHANA**

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## **DEDICATION**

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**FOR GOD AND GHANA**

***AFFECTIONATELY DEDICATED TO MY WIFE AND CHILDREN***

**and**

**TO THE MEMORY OF KWESI AND EFUA**

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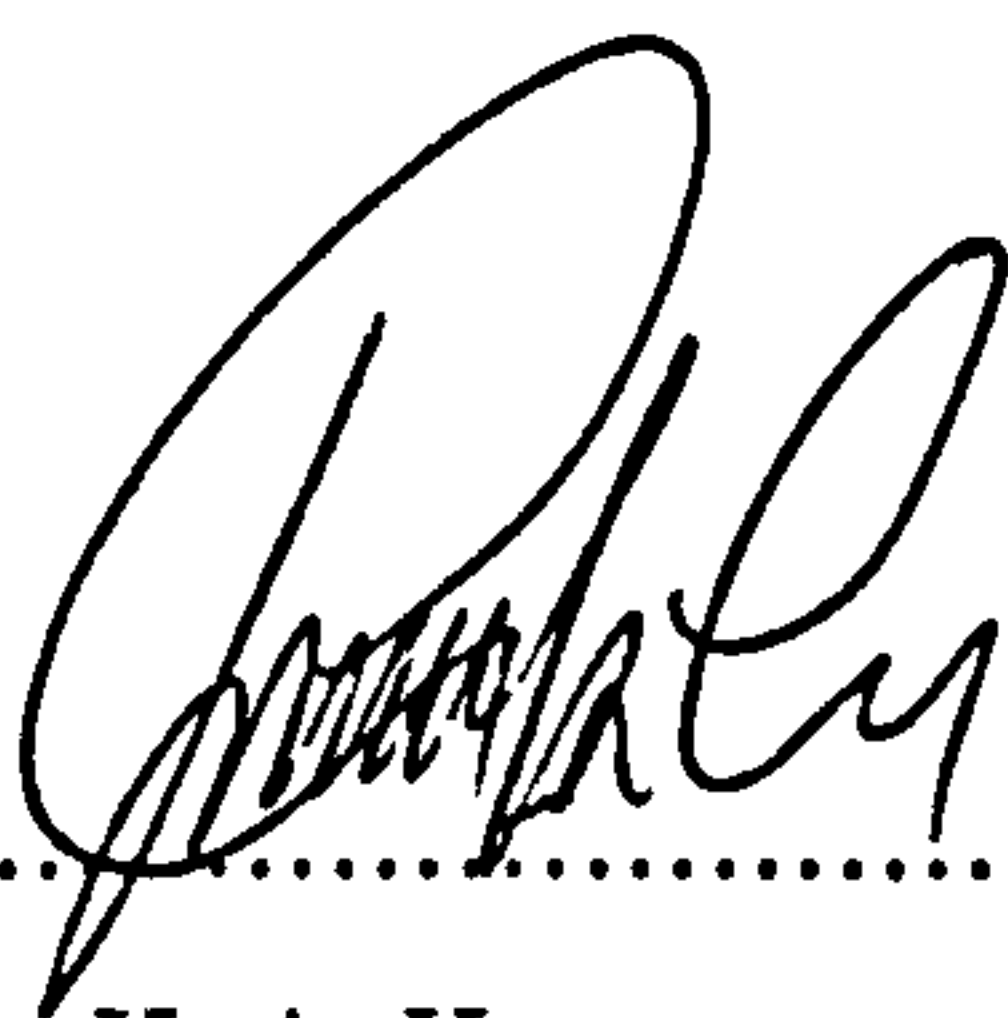
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MAY GOD LET HIS FACE SHINE UPON YOU ALL.

## DECLARATION

This thesis is the result of original research conducted by myself under the supervision of Professor Jacqueline M. McGlade. All sources of information have been appropriately acknowledged.

No part of this thesis has been submitted or is being submitted for a degree at any other university.



.....

K. A. Koranteng

## SUMMARY

The dynamics of demersal fish species assemblages and stocks on the continental shelf of Ghana, West Africa were investigated using data from trawl surveys conducted between 1963 and 1990, and in relation to marine environmental and near-shore forcing factors.

Time series analysis was used to examine the dynamics of the marine environment. Classification and ordination methods were used to identify fish assemblages and to identify factors that determine assemblage formation and dynamics. The response of the identified assemblages to changes in the Ghanaian shelf ecosystem were assessed.

Between 1964 and 1992, three distinct environmental time blocks (ETBs) in the continental shelf ecosystem off Ghana were recognised. In the first ETB (i.e. before 1972) sea surface and bottom temperatures were relatively high and salinity was low. The second ETB (1972 - 1982) was characterised by low temperatures, high but stable salinity, reduced rainfall and freshwater input into the sea. In the third ETB (1982 - 1992), the system bore a resemblance to the first block with rising temperatures and decreasing salinity.

Six fish species assemblages were identified, namely the supra-thermocline sciaenid and lutjanid assemblages, two sparid assemblages (shallow and deep elements), the deep shelf assemblage and the upper slope assemblage. During ETB1 and ETB3, the assemblages were easier to identify using ordination techniques, than during ETB2. Species diversity also decreased during ETB2 especially in waters between 10 and 50 m deep. This behaviour of the assemblages is attributed to the increase in abundance of *Balistes capriscus*, a species that dominated the ecosystem for nearly 20 years from about 1971, and the observed environmental changes.

The estimated density of demersal fish was higher in the upwelling season than in the thermocline season and decreased from 50 kg ha<sup>-1</sup> in 1963-64 to 32.4 kg ha<sup>-1</sup> in 1990. The density reached its lowest value of 22.5 kg ha<sup>-1</sup> in the period between 1973 and 1977.

The potential yield of the total demersal biomass (excluding triggerfish) is estimated to be 36,000 - 55,000 mt per annum. With landed catches exceeding 60,000 mt in some years, it is apparent that the resource is over-exploited. A number of policy options are discussed and recommendations for the management of the fishery are made.



## ABBREVIATIONS

|              |   |
|--------------|---|
| AESC (Hydro) | Architectural & Engineering Services Company (Hydrology Division)                 |
| AFR          | Assemblage Frame of Reference   |
| BFR          | Bathymetric Frame of Reference  |
| CPUE         | Catch per unit effort   |
| DCA          | Detrended Correspondence Analysis   |
| ETB          | Environmental Time Block  |
| FA           | Factor Analysis   |
| FAO          | Food & Agriculture Organization of the United Nations                             |
| FAQ          | Fleet Allocated Quota   |
| FMDA         | Fisheries Management and Development Act  |
| FRU          | Fishery Research Unit   |
| FRUB         | Fishery Research & Utilization Branch   |
| GRT          | Gross Registered Tonnage  |
| GTS          | Guinean Trawling Survey   |
| LME          | Large Marine Ecosystem  |
| MFRD         | Marine Fisheries Research Division  |
| MSD          | Meteorological Services Department  |
| MSY          | Maximum Sustainable Yield   |
| mt           | metric ton (i.e. tonne)   |
| ORSTOM       | Institute Français de Recherche Scientifique pour le Développement en Coopération |
| PCA          | Principal Component Analysis  |
| PNDCL        | Provisional National Defence Council Law  |
| TAC          | Total Allowable Catch   |
| UNCED        | United Nations Conference on Environment and Development                          |
| UNCLOS       | United Nations Convention on the Law of the Sea                                   |
| VRA          | Volta River Authority   |



**CHAPTER ONE:**

**GENERAL INTRODUCTION**

*We now come to the difficult and so far very obscure question,  
“What causes the irregularities in the .... fisheries... which have been observed from time  
immemorial?”  
..... This phenomena, like everything else in nature, must have its natural causes, which can be found  
.... only .... from scientific point of view.*

Georg Ossian Sars 1874

## 1.1 BACKGROUND

The principal objectives of this research are to examine spatial and temporal changes in the demersal fish stocks of Ghana, and to assess the impacts of the western Gulf of Guinea upwelling and other forms of environmental and near-shore forcing, and anthropogenic factors on the dynamics of the demersal fishery resources.

Many years ago, it was widely believed that the resources of the sea were infinite and that fishing could go on indefinitely. This notion is still present in some fishing communities, and in Ghana, this is reflected in the old adage of fisherfolks “sea never dry”; which literally means that there will always be fish in the sea. When a fishing season is bad, i.e. when catches are poor because the fish are not available, this is immediately attributed to the anger of the gods who are then quickly appeased with all forms of sacrifices.

In the same vein, ancient peoples saw the sea as being so large that they could not perceive that their activities could impinge upon it. With time, and sometimes after dramatic events and bitter experiences, we have come to realise that these notions about the sea are far from right. In Ghana, the near-collapse of the *Sardinella aurita* fishery after unusually high catch in 1972, and the recent apparent disappearance of the triggerfish (*Balistes capriscus*, Balistidae) from Ghanaian waters are examples of the inaccuracy in the “sea never dry” mentality. Elsewhere, the literature is full of records of boom and bust of fishery resources, the classical examples being the Peruvian anchoveta and the Californian sardine.

Human population growth throughout the world has resulted in mounting pressure on most natural resources and higher levels of industrial and domestic wastes finding their way into the sea. These have generally had an adverse effect on the resources of the sea. In addition, natural fluctuations in climate and other environmental factors can also induce changes in the state of natural resources. In renewable resources, this can potentially lead to rapid increases or decreases of stock abundance and/or shifts in resource distribution. Thus in nature, many populations are amenable to change with time and fisheries resources are no exception to this



general rule. It has been shown from patterns of deposition of fish scales in samples of ocean sediment, that a number of fish populations experienced periods of boom and bust even before the exploitation of these resources began (Soutar and Isaacs 1969; Devries and Percy 1982; Shackleton 1986).

Situated in the western Gulf of Guinea, which encompasses the area between Côte d'Ivoire and the Republic of Benin in West Africa (Figure 2.1), Ghana is endowed with rich fishery resources. However, over time, these resources also became part of the general trend of increasing exploitation and subsequent decline of fisheries resources around the globe. As the Ghanaian human population increased, there was a concomitant but natural increase in the demand for fish and fish products. The number of fishers also increased and fishing pressure was increased to satisfy the higher demand for fish. The consequences of these increases soon emerged, with average benefit to the fishers either stagnating or declining with time. Catches became erratic and landed sizes of prime fishes decreased (Mensah and Koranteng 1988).

However, it also became clear that fish, like all renewable natural resources, can be exploited sustainably if the resources are managed properly. Globally, it also soon became evident that natural processes in the sea are affected by the environment and that the sustainability of the fish communities also depends on the quality of the environment. To understand the fisheries, it is essential to understand the marine environment and the effect on fishery resources. The Fishery Research Unit (FRU) at Tema was established to conduct marine environmental and fisheries studies that would help the Government of Ghana in its desire to modernize the fishing industry and manage the fish resources. Between 1975 and 1995, FRU was known as the Research and Utilization Branch of the Fisheries Department (FRUB) but is now renamed the Marine Fisheries Research Division (MFRD) of the Fisheries Department.

This research was conducted within the auspices of MFRD, using data from their fishery survey cruises. The findings would be valuable contribution towards the work of the Division, especially as regards management of the demersal fishery.

## **1.2 MARINE ENVIRONMENTAL VARIABILITY AND FISHERY RESOURCES**

Various parts of the world experience regular annual and seasonal climatic changes (like summer and winter) and occasional climatic anomalies like droughts or unusually cold winters. Similar changes occur in the aquatic environment which may, or may not, be as a result of climatic changes. Examples of such climatic changes are the seasonal coastal upwelling in the Gulf of Guinea (FRU 1970; FRU/ORSTOM 1976; Philander 1979; Verstraete 1992) and El Niño/Southern Oscillation (ENSO) events in the eastern equatorial Pacific which occur with unpredictable periodicity (Cane 1983; Bakun 1996).

Walker (1987) has drawn some relationships between variability of sea surface temperature in the Benguela upwelling ecosystem (Southeast Atlantic) and atmospheric forcing. Similar observations have been made by Binet (1982) for the area off Ghana-Côte d'Ivoire and Arfi (1987) for the upwelling area off northwest Africa. Writing on the instability of ocean populations, Longhurst *et al.* (1972) concluded among other things that "the ocean is a restless and changing environment and that its changes may either be sudden and dramatic, or covert and sustained for very long periods".

Regarding marine living resources, all types of changes are important as the resources respond diversely to different effects on different time scales. A change in a pelagic ecosystem could suddenly lead to stock collapses (e.g. El Niño and Peruvian anchoveta), whereas changes in demersal fisheries, can occur over a relatively longer period of time. In the same way, stock recoveries can occur over various time scales (Cury 1995).

Mann (1993) gives an excellent review of the relationships between physical oceanography, food chains and fish stocks. Examples of fluctuations in yield as a result of changes in climate abound in the literature. Several case studies are given in Cury and Roy (1991) and Laevastu (1993). Many of these relationships have long been recognised by marine scientists. However, the search for appropriate relationships that will ultimately facilitate the forecasting of fisheries yield has been

the subject of research in many fisheries institutes around the world. In the West African region some of the recent studies on relationships between environmental parameters and fish resources are by Ofori-Adu and Koranteng (1993) off Ghana, Caverivière (1982) off Côte d'Ivoire, Coutin (1989) and Showers (1995) off Sierra Leone and Mennes (1984) off Morocco.

Globally, various studies have established some clear relationships between marine environmental changes, effects of near-shore forcing factors and the biology, distribution and abundance of demersal fish species. Some parameters shown to affect demersal fishery resources are: ocean currents (Rose and Leggett 1988), freshwater input into the ocean (Sutcliffe 1973; Sutcliffe and Muir 1977; Day *et al.* 1985; Drinkwater 1987; Binet and Marchal 1993; Halim *et al.* 1995) and local meteorological conditions like wind stress (Yanez-Arancibia *et al.* 1985; Rose and Leggett 1988). The importance of abiotic factors such as temperature (Mahon 1985; Bianchi 1991, 1992a; Perry & Smith 1994); oxygen (Mas-Riera *et al.* 1990; Overholtz & Tyler 1985; Kramer 1987); salinity (Overholtz & Tyler 1985; Yanez-Arancibia *et al.* 1985; Perry & Smith 1994) and nutrients (Yanez-Arancibia *et al.* 1985) have also been clearly demonstrated in the literature. In addition, the distribution of demersal fishery resources has also been linked with physical parameters like depth of the water (Williams 1968; Scott 1982; Koranteng 1984; Mahon, *et al.* 1984; Mahon 1985; Overholtz and Tyler 1985; Yanez-Arancibia *et al.* 1985; McManus 1986; Bianchi 1991, 1992a) and the type of sediment on the seabed (Longhurst 1969; Mahon *et al.* 1984; Mahon 1985; Yanez-Arancibia *et al.* 1985).

Given the increased knowledge of the linkages between resources and marine environmental parameters, it is essential to assess the effect of the observed environmental changes (especially in upwelling conditions) on the demersal fish resources of Ghana, hence this study.



## **1.3 A BRIEF INTRODUCTION TO THE STUDY AREA**

### **1.3.1 *Morphology of Ghana's coastal zone***

Ghana shares boundaries with the Republics of Togo on the east, Côte d'Ivoire on the west and Burkina Faso on the north. On the south is the Gulf of Guinea (Figure 2.1). The coastline of Ghana, measuring about 536 km long, stretches from longitude 3° 06' W to 1° 10' E and lies between latitudes 4° 30' and 6° 6' N (Figure 2.5.1).

Along the coast are long stretches of sandy beaches interspersed with rocky shores, estuaries and lagoons. Two large capes (Cape Three Points on the west and Cape St. Paul on the east) are important landmarks along the Ghanaian coastline. Most of the coconut trees that fringed the coastline and served as wind breakers, have been killed by the Cape St. Paul wilt disease in the last two decades, leaving long stretches of the shoreline rather bare. This situation has contributed to the problem of coastal erosion which is characteristic of this part of the African coast. Coastal erosion affects the fishing industry through the destruction fish landing sites. There is a sustained Government effort to protect the shoreline by constructing various sea defence structures.

There are 92 lagoons situated along the coast of Ghana (FOE 1994). Some of the lagoons are closed to the sea most part of the year whilst others are open to the sea all the time and are associated with rivers that flow all year round. These are classified as "closed" and "open" lagoons respectively (Boughey 1957). The lagoons and wetlands associated with them, serve as nursery grounds for many marine fish and crustacean species (Pauly 1976; Koranteng 1995).

Ghana has jurisdiction over 200 nautical miles (322 km) of exclusive economic zone (EEZ) having ratified the UNCLOS III convention on June 7, 1983 as the 3rd African country and the 6th State in the world to do so. The continental shelf of Ghana varies in width between about 13 km off Cape St. Paul and 80 km off Takoradi (Williams 1968; Koranteng 1980). The shelf narrows towards Togo and

also Côte d'Ivoire and usually drops sharply just after the 75 m depth contour, especially on the eastern and central parts (Koranteng 1984). The area of the continental shelf of Ghana (to the 200 m depth contour) is 23,700 km<sup>2</sup> (Koranteng 1984)

The ocean floor on the shelf has distinct areas of mud, hard rocks and mixed deposits (Figure 4.4). Generally, the area beyond 75 m deep is not safe for trawling, except towards the western side (Rijavec 1980; Koranteng 1984) where vessels can trawl in waters even deeper than 100 m (*personal observation*). According to Longhurst and Pauly (1987), the whole of the western coast of Africa from Mauritania to Cape of Good Hope, is dominated by terrigenous deposits except a small region off Ghana and Côte d'Ivoire. Citing other works, Longhurst and Pauly (1987) state further that along the coast of the Gulf of Guinea, linear fossil Holocene coral banks occur at the break of the slope around 150-180 m deep.

### **1.3.2 Climatic conditions in Ghana**

Ghana lies in the tropical equatorial belt and experiences high temperatures of between 25 and 35 °C with minimum variation throughout the year and for this reason, the difference in climatic conditions is due mainly to the amount and distribution of rainfall (Biney 1990). In southern Ghana, incorporating the coastal zone, there are two distinct wet seasons in the year - a major one in May - June and a minor one in August - September (Mensah 1991). Annual rainfall averages between 82 mm in the southeast and 215 mm in the southwest (Biney 1990; Mensah 1991). During the rainy seasons, the quantity of freshwater reaching the sea through rivers, increases considerably. According to Binet and Marchal (1993), the salinity of the usually warm tropical surface waters in the Gulf of Guinea, is lowered by river input during the rainy season.

The dominant wind in Ghana is the south-westerly monsoon. This is a relatively weak wind reaching a maximum speed of only 5 m s<sup>-1</sup> during boreal summer (Roy 1995).

### 1.3.3 Near-shore drainage pattern in Ghana

Several rivers, most of them taking source from within the country, enter the sea along the coast of Ghana either through coastal lagoons or extensive estuaries. The Volta River which originates from Burkina Faso and spans the entire length of Ghana on the eastern side, is the longest and most important river in the country. At Akosombo, 100 km from the mouth of the river is situated the giant Akosombo dam which was closed in 1964 for the generation of hydroelectricity. A second hydroelectric dam is situated 20 km downstream at Akuse and was completed in 1981.

Other important rivers are Tano, Ankobra, Pra and Densu (Figure 1.1). Tano enters the sea through the extensive Tando/Ehy lagoon system which separates Ghana and Côte d'Ivoire at the coastal belt.

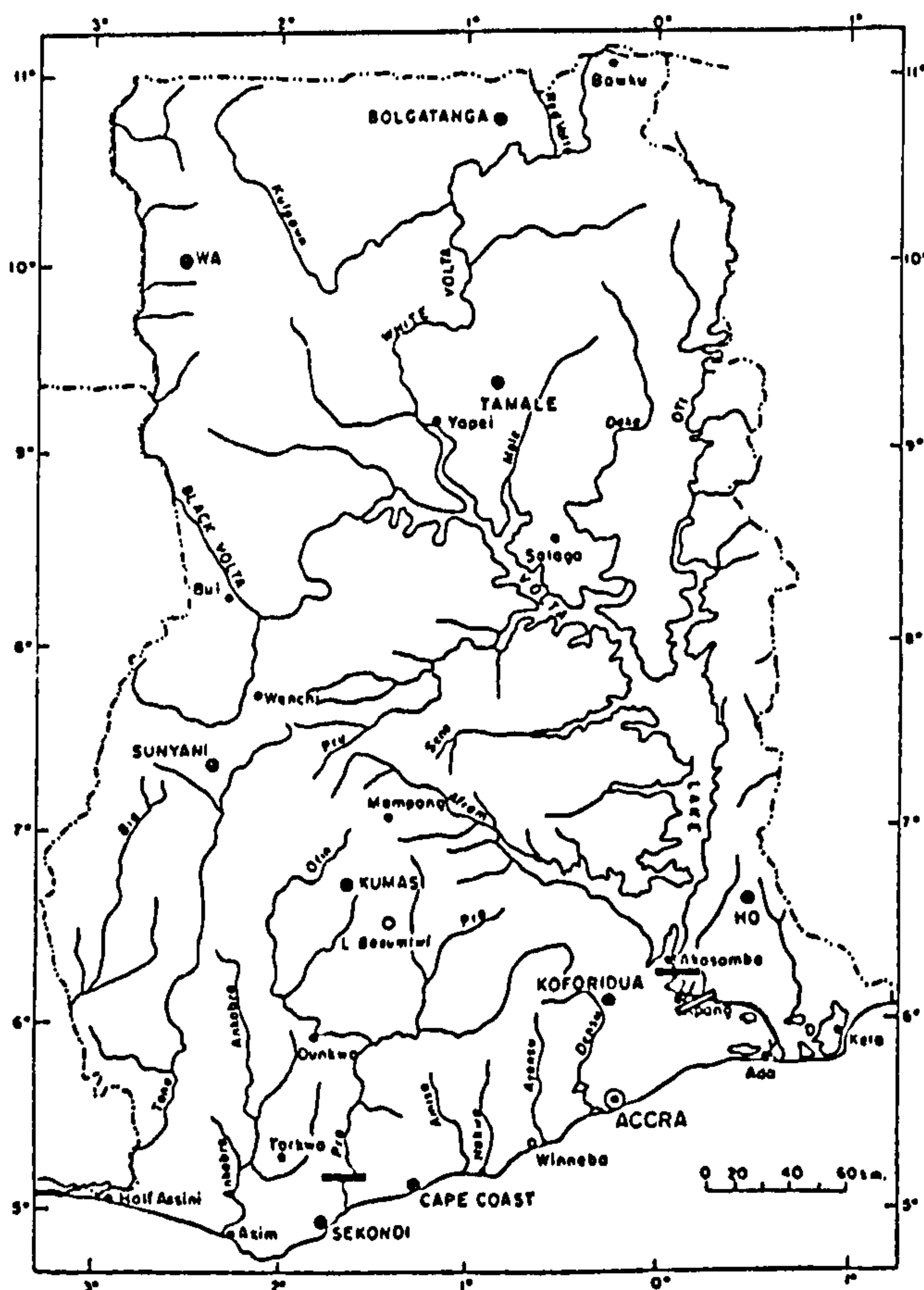



Figure 1.1: Map of Ghana showing drainage pattern. Centres from which river discharge data were used in this thesis are marked with 

## **1.4 THE FISHING INDUSTRY IN GHANA**

### **1.4.1 *The fisheries sector***

Fishing is an old way of life in Ghana, especially among coastal communities. Ghana is a leading fishing nation in Africa and Ghanaian fishers may be seen in several fishing communities in countries bordering the eastern Atlantic. In Ghana, there are important fisheries in some rivers, in the Volta lake (once thought to be the largest man-made lake in the world), in coastal lagoons as well as in the sea. The marine fishing industry provides over 87 percent of all fish produced in Ghana and constitutes one of the most important sectors of the nation's economy. In 1995, the 336,000 mt of fish landed by Ghanaian fishing crafts was valued at nearly 445 thousand million Ghanaian cedis (or about 250 million U.S. dollars) (MFRD unpublished data).

### **1.4.2 *Fishing fleets***

The marine fishing industry in Ghana, well described in various reports (e.g. FRU 1973; Bernacsek 1986; Mensah and Koranteng 1988), has three sectors, namely small-scale (or artisanal), semi-industrial (or inshore), and industrial. The number of canoes and motor fishing vessels in each of the fleets and for the period 1980 - 1992, are summarised in Table 1.1.

#### **1.4.2.1 The small-scale (or artisanal) sector**

In the artisanal sector, the dugout canoe is the fishing craft and various fishing gears are employed. The number of canoes operating actively in Ghanaian marine waters in the last two decades has been estimated at various times as between 6,000 and 8,000 units (Koranteng 1996); 8,641 were counted in the last census in 1995 (Quatey *et al.* 1997). About a half of these are propelled by outboard engines. The canoes measure 3 - 18 m long and 0.5 - 1.8 m wide (Doyi 1984). The fishing gears used in this sector include gilling and entangling nets (set and drifting), seine nets and handlines. The canoes operate out of 264 sites in 192 fishing villages



(Koranteng *et al.* 1993; Quatey *et al.* 1997) and produces between 65 and 80 % of the total catch of marine fish in Ghana (chapter 7).

The sector, employing between 90 and 109 thousand fishers (Koranteng and Nmashie 1987; Koranteng *et al.* 1993; Quatey *et al.* 1997), is by far the most important in Ghana. The sector is quite old and its nature has changed with time. The most significant changes are: (i) introduction of outboard motors, (ii) introduction of the purse seine net, and (iii) change from use of natural to synthetic netting materials.

The multiplicity of gears and the problem of migration of fishers that characterise the artisanal fleet make assessment of its catch and fishing effort rather difficult. Consequently, assessment of the stocks of fish that the fleet exploits is also difficult (Koranteng 1996).

#### 1.4.2.2 The Semi-industrial (or inshore) sector

The inshore (or semi-industrial) sector comprises of locally-built, wooden-hulled vessels measuring between 8 and 37 m long. There are also a few steel-hulled foreign-built vessels in this sector. For statistical purposes, the Fisheries Department of Ghana has put these vessels into two categories, namely those with lengths between 8 and 12 m and which undertake daily fishing trips and those over 12 m which are capable of staying at sea for up to 7 days. The vessels are powered by inboard engines of between 90 and 400 hp.

The inshore fleet developed rapidly from 2 vessels in 1948 to over 260 operational ones in 1984 (Mensah and Koranteng 1988; Koranteng 1996; Table 1.1). In the last decade, the inshore fleet has declined in importance as most of the vessels are old and hardly seaworthy; only 165 inshore vessels operated in 1996 (Table 1.1).

The inshore vessels use bottom trawl nets or purse seines depending on the season. The purse seine gear is used mainly during the upwelling season when sardinellas are the target species. For the rest of the year, the vessels that have strong



engines switch to bottom trawling. Presently, the inshore vessels operate from 8 coastal landing centres, namely Tema in the Greater Accra Region, Winneba, Apam, Mumford and Elmina in the Central Region and Sekondi, Takoradi and Axim in the Western Region.

The operation of these vessels, especially those measuring only up to 12 m, was severely affected by the disappearance of the triggerfish from this ecosystem towards the end of the last decade (Koranteng *et al.* 1994).

#### 1.4.2.3 The industrial sector

In the industrial sector large, steel-hulled foreign-built trawlers, shrimpers and tuna baitboats are used. Industrial vessels operate only from Tema and Takoradi where there are suitable berthing facilities.

The first industrial vessels were acquired about four decades ago principally for fishing in more productive distant waters (mainly off Angola and Mauritania). From mid 1970s, these vessels started fishing in home waters when countries claimed 200 miles of exclusive economic zone in accordance with relevant provisions of the third UN Conference on the Law of the Sea (UNCLOS III). In the last two decades, the number of industrial trawlers varied between 10 and 34 (Table 1.1).

Between 1969 and 1975, a shrimp fishery operated mainly in the Anyanui estuary and adjacent sea in the Volta Region of Ghana (Anon 1990). In 1970, as many as 18 shrimp vessels were in this fishery which eventually collapsed for various reasons including over-exploitation and the impact of the Volta dam at Akosombo on the hydrology of Anyanui estuary and the Keta lagoon (Anon 1990). In 1986, commercial shrimping was resumed with two vessels. The number of vessels increased rapidly thereafter and by 1995, as many as 17 industrial vessels were in the fishery (Table 1.1).

The numbers of tuna fishing vessels that operated in Ghanaian waters between 1980 and 1996 are also shown in Table 1.1.

### **1.4.3 Marine fishery resources exploited in Ghana**

There are fisheries for small pelagic species of the families Clupeidae, Scombridae and Engraulidae, and large pelagics of family Thunnidae. Exploited coastal demersal species include those of the families Sparidae, Sciaenidae, Lutjanidae and Penaeidae. The most important species of fish exploited in Ghana are listed in Table 1.2.

With the exception of the tuna fishing fleet, all vessels operate in about the same area, targeting the same species. This generates a considerable amount of conflict among the fleets, especially between the artisanal and the trawler fleets (including the shrimpers) with the latter very often destroying nets set by the former. The tuna baitboats also catch anchovies (*Engraulis encrasicolus*, Engraulidae) which they use as bait in their operations. Anchovies are also heavily exploited by artisanal purse seiners. Trend of landings by the various fleets and for the period 1972 - 1995 are shown in Table 1.3 and in Figure 1.2.

Table 1.1. Number of canoes and operational motor fishing vessels in Ghana, 1980 - 1996.  
(Sources: MFRD, Tema and Fisheries Department, Accra).

|                    | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|--------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Canoes of which    |      | 6938 |      |      |      |      | 8214 |      |      | 8052 |      |      | 8688 |      |      | 8641 |      |
| Beach seine        |      | 822  |      |      |      |      | 797  |      |      | 852  |      |      | 775  |      |      | 790  |      |
| Others             |      | 6116 |      |      |      |      | 7417 |      |      | 7200 |      |      | 7913 |      |      | 7851 |      |
| Inshore vessels    | 248  | 246  | 255  | 257  | 262  | 256  | 258  | 244  | 244  | 183  | 169  | 153  | 160  | 155  | 164  | 153  | 165  |
| Industrial vessels | 50   | 53   | 53   | 53   | 48   | 45   | 56   | 51   | 49   | 69   | 71   | 73   | 63   | 65   | 75   | 81   | 83   |
| of which           |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Trawlers           | 10   | 14   | 12   | 12   | 10   | 17   | 22   | 13   | 15   | 29   | 30   | 30   | 29   | 32   | 35   | 34   | 34   |
| Shrimpers          |      |      |      |      |      |      | 2    | 2    | 4    | 5    | 8    | 11   | 5    | 8    | 14   | 17   | 16   |
| Tuna fishing       | 40   | 39   | 41   | 41   | 38   | 34   | 32   | 36   | 30   | 35   | 33   | 32   | 29   | 25   | 26   | 30   | 33   |

Table 1.2. Important fishery species exploited in Ghana's EEZ

| Resource            | Families   | Species  |
|---------------------|--|--|
| Coastal Pelagic     | Clupeidae<br><br>Scombridae<br>Engraulidae<br>Carangidae   | <i>Sardinella aurita</i><br><i>Sardinella maderensis</i><br><i>Scomber japonicus</i><br><i>Engraulis encrasicolus</i><br><i>Decapterus rhoncus</i>   |
| Large Pelagic       | Thunnidae  | <i>Thunnus albacares</i><br><i>Thunnus obesus</i><br><i>Katsuwonus pelamis</i><br><i>Euthynus alletteratus</i><br><i>Istiophorus albicans</i><br><i>Xiphias gladius</i><br><i>Makaira nigricans</i><br><i>Tetrapturus albidus</i>  |
| Coastal demersal    | Sparidae<br><br>Haemulidae<br><br>Sciaenidae<br><br>Lutjanidae<br><br>Mullidae<br>Serranidae<br>Polynemidae<br>Penaeidae | <i>Pagellus bellottii</i><br><i>Sparus caeruleostictus</i><br><i>Dentex canariensis</i><br><i>Pomadasys incisus</i><br><i>Pomadasys jubelini</i><br><i>Brachydeuterus auritus</i><br><i>Pseudotolithus</i> spp.<br><i>Umbrina</i> spp.<br><i>Lutjanus fulgens</i> ,<br><i>Lukanus agennes</i><br><i>Pseudupeneus prayensis</i><br><i>Epinephelus</i> spp.<br><i>Galeoides</i> spp.<br><i>Parapenaeopsis atlantica</i><br><i>Penaeus notialis</i> |
| Deep water demersal | Sciaenidae<br>Ariommatidae<br>Geryonidae<br>Penaeidae  | <i>Penteroscion mbizi</i><br><i>Ariomma bondi</i><br><i>Geryon maritae</i><br><i>Parapenaeus longirostris</i>  |

Table 1.3. Total quantity of fish (pelagic and demersal; in mt) landed by Ghanaian fishing fleets, 1972-1995. Only fish caught in Ghanaian waters are included in this table.

| Year | Artisanal vessels | Inshore Fishing Vessels | Industrial Trawlers | Shrimp Fishing Vessels | Tuna Fishing Vessels | Total   |
|------|-------------------|-------------------------|---------------------|------------------------|----------------------|---------|
| 1972 | 153 691           | 30 342                  |                     |                        |                      | 184 033 |
| 1973 | 73 007            | 15 987                  |                     |                        | 24 717               | 113 711 |
| 1974 | 108 883           | 15 747                  | 3 505               |                        | 24 703               | 162 838 |
| 1975 | 134 395           | 17 091                  | 892                 |                        | 19 878               | 172 256 |
| 1976 | 118 455           | 16 981                  | 880                 |                        | 32 274               | 168 590 |
| 1977 | 151 391           | 20 045                  | 3 724               |                        | 35 435               | 210 595 |
| 1978 | 176 010           | 18 891                  | 6 400               |                        | 40 983               | 242 284 |
| 1979 | 139 960           | 21 571                  | 9 312               |                        | 44 739               | 215 582 |
| 1980 | 141 422           | 15 593                  | 2 782               |                        | 35 856               | 195 653 |
| 1981 | 149 823           | 16 735                  | 4 193               |                        | 45 173               | 215 924 |
| 1982 | 140 891           | 17 304                  | 8 049               |                        | 46 247               | 212 491 |
| 1983 | 137 027           | 19 686                  | 9 337               |                        | 40 029               | 206 079 |
| 1984 | 171 236           | 14 704                  | 7 257               |                        | 31 266               | 224 463 |
| 1985 | 159 898           | 17 980                  | 13 881              |                        | 34 407               | 226 166 |
| 1986 | 190 197           | 21 894                  | 14 077              |                        | 34 720               | 260 888 |
| 1987 | 261 452           | 14 931                  | 20 171              |                        | 33 465               | 330 019 |
| 1988 | 244 042           | 7 414                   | 16 042              |                        | 35 433               | 302 931 |
| 1989 | 220 878           | 12 657                  | 23 073              | 380                    | 32 294               | 289 282 |
| 1990 | 242 020           | 9 250                   | 26 589              | 726                    | 40 803               | 319 388 |
| 1991 | 215 847           | 7 357                   | 27 892              | 785                    | 37 795               | 289 676 |
| 1992 | 307 931           | 10 768                  | 20 933              | 386                    | 30 776               | 370 794 |
| 1993 | 257 237           | 5 230                   | 18 323              | 1 548                  | 36 856               | 319 194 |
| 1994 | 211 747           | 6 037                   | 18 966              | 2 442                  | 36 973               | 276 165 |
| 1995 | 210 659           | 6 371                   | 20 049              | 2 689                  | 33 905               | 273 673 |



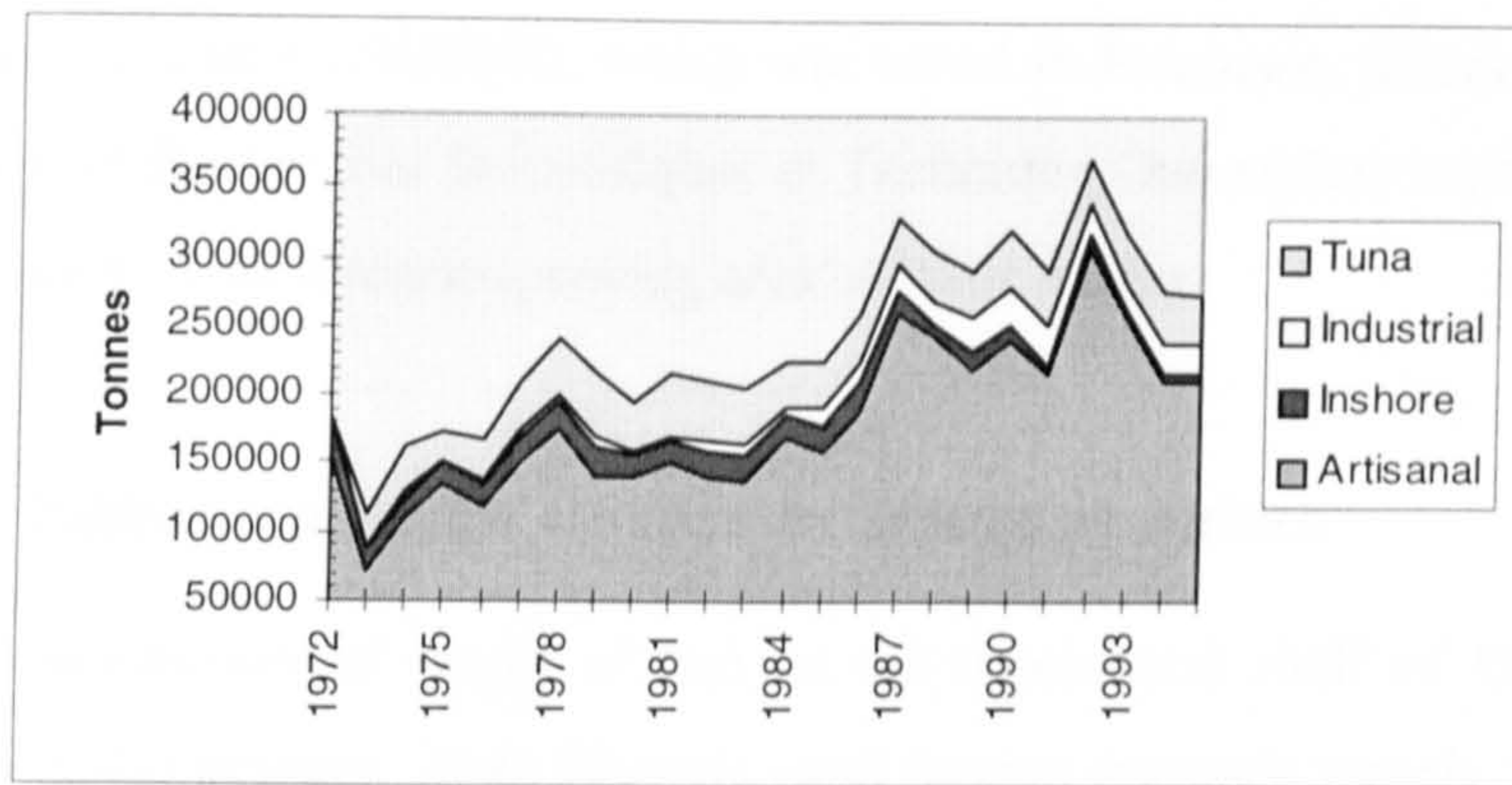


Figure 1.2. Trend of fish landings of Ghanaian fishing fleets, 1972 - 1995. The catch is made up of both pelagic and demersal fishes caught in Ghanaian waters.

## 1.5 SURVEYS OF DEMERSAL FISHERY RESOURCES

### 1.5.1 Background

Considering the fact that all natural resources are amenable to change and depletion if not exploited with care, it is essential that fish stocks are assessed periodically. According to Smith (1988), fluctuation in fishery yields in the mid 1880s led national governments to commission studies to determine the causes of the fluctuation. Inter-agency and international expeditions were undertaken to study the problem thus building the foundation for marine resource assessments (Smith 1988). All efforts on the subject were concentrated in the North Sea, mainly because the resources in the area were already being heavily exploited and also there were good statistics on the fisheries and scientists to carry out the investigations.

As modernised international fishing fleets roamed the oceans of the world it became necessary also to assess all the resources that these vessels were exploiting. Assessment of fishery resources in West African waters started with institutions established under colonial administrations. As fisheries in the then colonies were being 'developed' it was found expedient to assess the state of resources in order to take good decisions on exploitation levels and types and size of investment. In English-speaking West Africa, these studies were pioneered by scientists of the West African Fisheries



Research Institute (WAFRI), which was based in Freetown, Sierra Leone. ORSTOM (Offices de Recherches Scientifiques et Technique Outre-Mer) carried out most of the assessments in the French-speaking area of West Africa.

### **1.5.2 Fishery resource surveys in Ghanaian waters**

Assessment of stocks of fish on the continental shelf of Ghana began in the middle of this century. Both Ghanaian and foreign research vessels were utilized in the surveys. All surveys conducted before 1984, have been documented by van der Knaap (1985). The first documented survey was conducted in May-June 1956 by WAFRI (Salzen 1957) using the research vessel *R/V Cape St. Mary*. The objective of the survey was to explore the Ghanaian (then Gold Coast) continental shelf for potential trawling grounds. The survey was limited to a distance of 20 miles (32.2 km) on either side of the port of Tema. No estimate of stock size was given. Five years later, i.e. in April-July 1961, another survey was carried out on the continental shelf from Morocco to Ghana on a Polish research vessel *M/T Birkut* (Chrzan 1961). The survey revealed the characteristics of the stock-composition of fish in the West African shallow waters.

Between August 1963 and June 1964, the first comprehensive and most extensive survey in Ghanaian waters, and indeed, in the waters of West Africa (the Guinean Trawling Survey, GTS) was conducted under the auspices of the Scientific Committee of the Organization of African Unity (Williams 1968). The objective of the survey was to investigate the potential of demersal fish of the West African continental shelf in relation to the marine environment.

Following the establishment of the Fishery Research Unit in Ghana in 1962, the FAO assisted the Unit to undertake trawl surveys. A survey programme, the principal objective of which was to assess the demersal stocks, was executed in 1969-70 using the Unit's research vessel *R/V Research* (or *R/V 1*; Rijavec 1980). After the 1969-70 survey, mechanical problems on the research vessel could not permit sustained surveys until a new research vessel, *R/V Kakadiamaa* (*R/V 5*), was acquired in July 1979. In August 1979, the Ghanaian trawl survey programme was resumed.



Under the auspices of FAO (Food and Agriculture Organisation of the UN), the Government of Spain financed a trawl survey in the waters of Sierra Leone, Liberia, Côte d'Ivoire and Ghana in April 1990 (Ramos *et al.* 1990). The Guinea 90 survey was conducted by scientists of the Instituto Espaniol de Oceanografia in Malaga, Spain.

During the period under consideration some acoustic surveys were also carried out in Ghanaian waters and in the West African region with the primary objective of assessing pelagic resources. These surveys are also listed in van der Knaap (1985) except the recent ones by *R/V Cornide de Saavedra* in 1986 (Oliver *et al.* 1986) and *R/V Dr Fridtjof Nansen* in 1989 (IMR 1989).

In the baseline report for a European Development Fund (EDF)-assisted Fish Stock Monitoring Programme in Ghana in 1987, the results of the trawl surveys in Ghanaian waters were examined (Anon 1987; Mensah and Koranteng 1988). It was obvious that the demersal resources had declined but the causes were unclear.

Elsewhere, similar changes in demersal fish stocks and fisheries have been observed (e.g. Tiews *et al.* 1967; Pauly 1979; Sherman *et al.* 1981; Sherman 1991). Gulland and Garcia (1984) have documented changes that occurred in some Northwest African fisheries in the 1970s and early 1980s. Pereiro and Bravo de Laguna (1980) traced the increasing trend in the abundance of cephalopods off Northwest Africa and the concomitant decline of sparids.

In the face of increased fishing effort, changing climatic and environmental conditions, and the boom and bust of some species, it is essential that the response of demersal fishes to such ecosystem perturbations in Ghana's marine waters be properly investigated. This is essential in order to assess the current state of the resources and to help formulate and implement appropriate governance structures for the management of the resources.

## **1.6 FISH STOCK ASSESSMENT OBJECTIVES AND FISHERIES MANAGEMENT**

### ***1.6.1 How much fish may be caught?***

Traditionally, the question of “how much fish can be taken without destroying the stock” has been answered through the use of either the Surplus Production (or Yield) Model (SYM) or the Dynamic Pool Model (DPM). In spite of criticisms of these models (e.g. Larkin 1977), they have been used to establish “a sustainable yield” in a number of fish stocks and have provided the basis of management objectives for many fisheries.

The basic underlying assumption of both models is that as a renewable resource is cropped, the biomass grows back to equilibrium. Surplus production models (also called Schaefer models) further assume that biomass regeneration may be considered as a single process concerned only with inputs and outputs to the biomass of the population. To fit such a model requires only a time series of catch and fishing effort data. Dynamic pool models (also referred to as analytical or Beverton and Holt models) on the other hand, make a more realistic assumption that biomass regeneration is a combination of factors like tissue growth, mortality and reproduction and deal with each of these processes separately. DPM also requires knowledge of the age structure of the population. To fit such a model, which basically reduces to finding the optimum combination of age of entry into the fishery and fishing rate, requires good knowledge of the model components.

As fisheries science began in the temperate regions of the world, particularly in countries bordering the North Atlantic, the theories and methods developed were directed mainly towards managing fisheries in these areas, which tend to be based on very few species. The basic models treat the species as independent management units, rarely accounting for abiotic influences and explicitly excluding the complications of interspecific linkages (Sugihara *et al.* 1984). In later “improvements” of the models, other factors like recruitment variability and environmental randomness were accounted for (e.g. Beddington and May 1977; Schnute 1977; Walter 1978; Freon 1988). Various studies have pointed out the inadequacy of these single species-oriented models (e.g.

FAO 1978) and there is ample evidence to show that a multi-species (multi-stock) approach is a better option (May *et al.* 1979). After all, as Clark (1984) puts it “...most actual fisheries are multi-species in some sense”.

Methods that attempt to extend the single-species models to multi-species cases (Larkin 1963; Anderson and Ursin 1977; Pope 1979; May *et al.* 1979; Paine 1984) can only accommodate a few species as the interactions become mathematically impossible to unravel, and unfortunately at the expense of the biology (Pitcher and Hart 1982; Sugihara *et al.* 1984). Hilborn and Walters (1992) discuss some of these multi-species extensions to single species fisheries models.

### **1.6.2 Multispecies assessments**

Generally, the diversity of species is higher in tropical regions than in temperate areas (Gosline and Brock 1960; Rosenzweig 1995) and highest species diversities are observed in transition zones (Gulland and Garcia 1984). Consequently fisheries in tropical regions of the world tend to be multi-specific in which several species are caught in the same haul. In the bottom trawl surveys conducted in Ghanaian waters, for example, 187 species of fish belonging to 60 families were encountered in 1969-70 (Rijavec 1980), 171 species in 1979-80 (Koranteng 1981). As many as 40 different species could be caught in a single haul of 30 or 60 min duration. In the Guinean Trawling Survey, over 400 species were encountered (Williams 1968). Elsewhere in the tropics, a survey conducted on the shelf of Guyana in South America recorded over 200 fish species belonging to 72 families (Lowe-McConnell 1962 as cited in Lowe-McConnell 1987). Pauly (1979), citing other works, gives 341 species in Eastern Peninsular Malaysia, 230 species in Java Sea/South China Sea and 173 species in the Visaya Seas (Philippines). Gulland and Garcia (1984) quote 174 species in the Senegal-Mauritania area.

In the commercial trawl fishery, a large number of species contribute significantly to the landings. For example in the Gulf of Thailand, Pauly (1988) estimates that over 150 species make a significant contribution to the trawl fishery. The applicability of the single species-oriented fisheries models in such a situation is

debatable even though Pauly (1988) deduced from the results of a number of studies that the standard approaches were applicable to some extent to tropical fisheries.

With general lack of age-structured data, due mainly to the difficulty in aging tropical fish, the surplus production model is more widely used in the tropics than the dynamic pool model. However, the development of some length-based methods for fish population studies (e.g. Jones 1981; Pauly 1980a; Pauly and Morgan 1987; Rosenberg and Beddington 1988; Spare and Venema 1992) have circumvented the problem and some forms of the dynamic pool model have been used on tropical and multispecies fisheries (e.g. Murawski 1984; Mennes 1984; Koranteng and Pitcher 1987).

## **1.7 OBJECTIVES AND RESEARCH APPROACH**

The principal objectives of this research are stated above (section 1.1). Although the real impacts of the increase in fishing effort on the demersal fishery resources have not been adequately assessed, trends in landings and the results of the stock assessment surveys enumerated above show considerable change in the status of the fish resources. In the light of these and also changes in the environment, the research questions considered in this thesis are the following, which are related to particular chapters of the thesis in section 1.8:

1. What changes have occurred in the physical components of the ecosystem and in the climate?
2. Have demersal species assemblages in Ghanaian waters changed?
  - a. What are the contributing factors?
  - b. What is the ecological effect of the proliferation and subsequent decline of triggerfish in this ecosystem?
3. How are demersal fish distribution and abundance related to physical parameters of the ocean?
  - a. How do the species respond to seasonal and long-term changes in environmental factors?



4. Have the distribution and abundance of species truly changed in the last 30 years?
5. What has been the level of exploitation of the demersal fishery resources in Ghanaian waters and what is the current status of these resources?
6. How should the fisheries be managed to ensure sustainable exploitation in the face of environmental changes?

## **1.8 STRUCTURE OF THE THESIS**

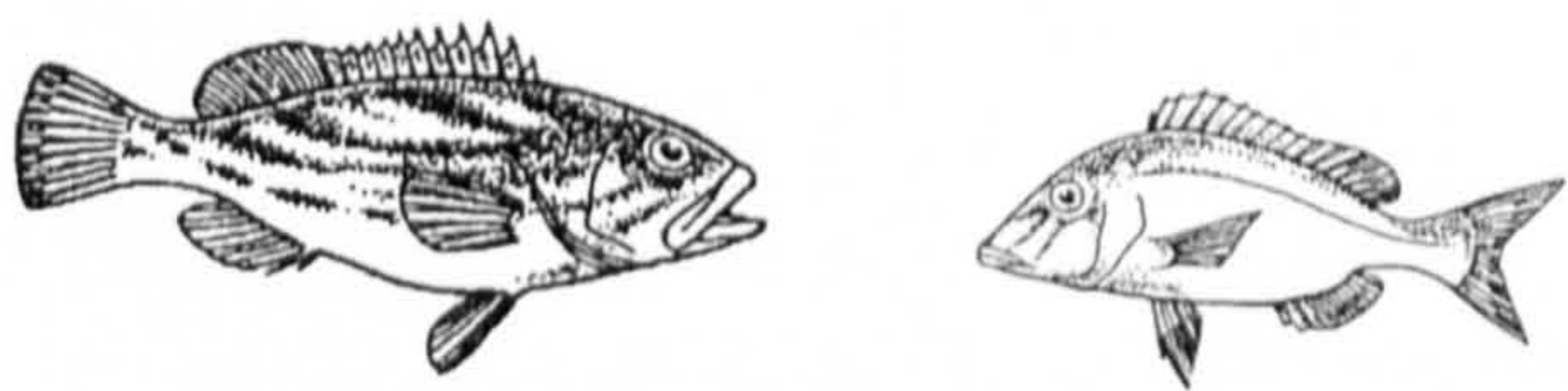
There are five distinct but interrelated parts in this thesis. This chapter (chapter 1) provides a general introduction to the thesis in which the objectives of the study are stated. The chapter also describes the study area, its fish resources and the fisheries. It includes review of key literature on environmental variability and fishery resources. A synopsis of fish stock assessment surveys (especially of demersal fish), carried out in Ghana and on fisheries management are also presented in this chapter.

Subsequent chapters address the research questions outlined above. Each includes a comprehensive literature review, sources of data and analytical methods used and also the main results.

Chapter 2 examines changes observed in the physical marine environment, especially those associated with the upwelling within the study area. Some of the changes relating to the biology and population dynamics of principal species in this ecosystem are also discussed in this chapter. Chapter 3 is a detailed analysis of spatio-temporal environmental and near-shore variability in the study area. The structure and dynamics of demersal fish species assemblages on the continental shelf and upper slope of Ghana are presented in chapters 4 and 5 respectively. Chapter 6 covers assessment of the demersal fish stocks in Ghana as well as changes at the stock, population and species (or family) levels. In chapter 7, management of the fish resources is examined and

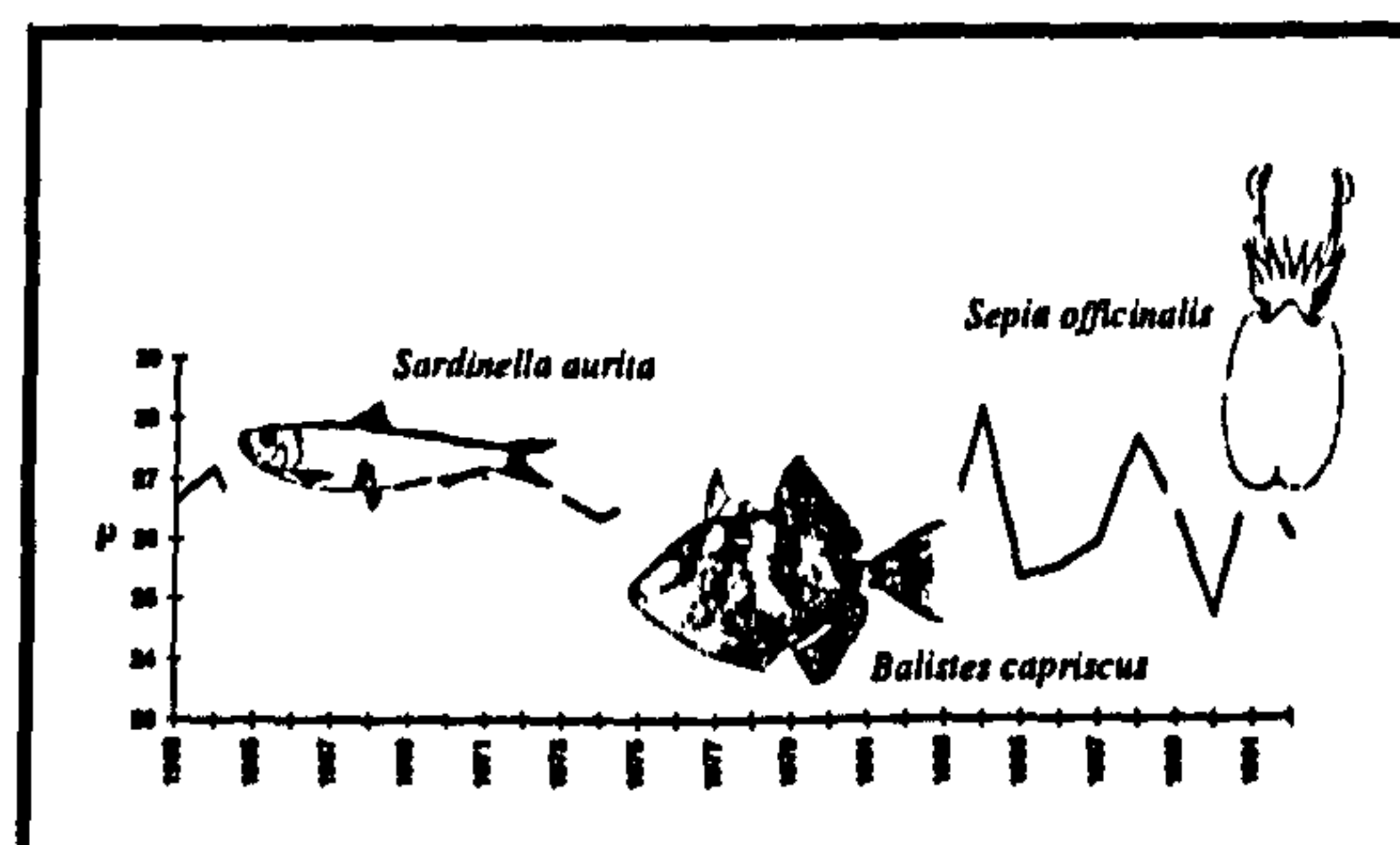


proposals for a management plan for demersal fisheries in Ghana are made. Finally, conclusions and suggestions for further research on demersal fish resources of Ghana are presented in chapter 8.



**CHAPTER TWO:**

**A REVIEW OF THE DYNAMICS  
AND FISHERY RESOURCES OF THE  
WESTERN GULF OF GUINEA COASTAL  
UPWELLING ECOSYSTEM**



## Chapter Summary

The western Gulf of Guinea is a unique subsystem of the Guinea Current large marine ecosystem. It appears to behave differently from other eastern ocean boundary upwelling ecosystems. In particular, the seasonal upwellings that occur in this ecosystem have increased in intensity and duration in the last decade, especially the secondary upwelling in the boreal winter. This upwelling has also intensified on the western side of both Ghana and Côte d'Ivoire around two large capes that are significant landmarks on this part of the West African coast. The mechanism causing the upwellings is not well understood, although recent evidence shows that wind may play a more important role in it than previously thought.

In the last decade, a change in the population dynamics of small pelagic fishes in this ecosystem, especially off Ghana and Côte d'Ivoire has been observed. There have been remarkable changes in the distribution, abundance and reproductive strategy of the round sardinella (*Sardinella aurita* Clupeidae). These have been attributed to the intensification of the minor upwelling.

There has also been significant rise and decline of some demersal fish populations in this ecosystem in the last decade. Most significant among these is the complete disappearance of triggerfish (*Balistes capriscus* Balistidae) from the sub-region where it had once accounted for over 60 % of total fish biomass assessed in bottom trawl surveys and about 83 % of total pelagic biomass assessed in acoustic surveys.

## 2.1 INTRODUCTION

The waters of the Gulf of Guinea are defined by the Guinea Current Large Marine Ecosystem (LME) (Sherman 1993). This LME extends from Bissagos Island in the north (Latitude 11° N, Longitude 16° W) to Cape Lopez in the south (Latitude 0° 41'S, Longitude 8° 45'E) (Binet and Marchal 1993) and includes the Exclusive Economic Zones (EEZ) of all countries between Guinea Bissau and Gabon (Koranteng *et al.* 1996) (Figure 2.1). The Guinea Current LME may be subdivided into three subsystems (Binet and Marchal 1993): the Sierra Leone - Guinea plateau subsystem stretching from Bissagos Island to Cape Palmas on the western part of



Côte d'Ivoire (i.e. Latitudes 16° W to 8° W); the Central West African (or western Gulf of Guinea) subsystem from Cape Palmas to Cotonou, Republic of Benin (Longitude 2° E) and the eastern Gulf of Guinea subsystem from Cotonou to Cape Lopez (Latitude 0° 41'S, Longitude 8° 45' E). Ghana is located in the western Gulf of Guinea subsystem which is characterized by a seasonal coastal upwelling.

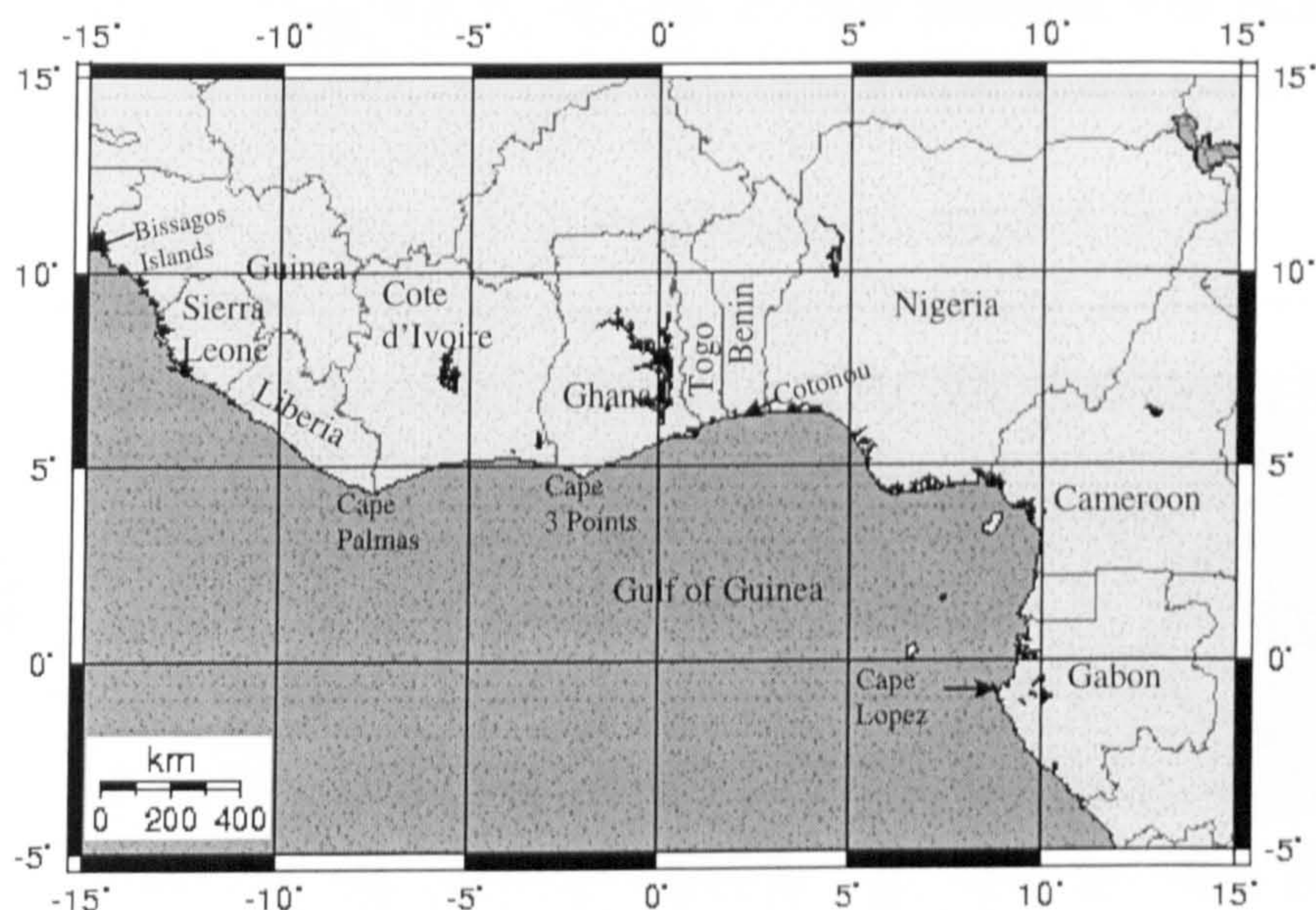


Figure 2.1. Map of West Africa showing areas and landmarks mentioned in the text

Off Ghana and Côte d'Ivoire, two upwelling seasons, major and minor, occur annually with differing duration and intensities. Small pelagic fisheries in the area are sustained by this upwelling (FRU/ORSTOM 1976; Mendelssohn and Cury 1987; Pezennec and Koranteng (1997). The most important fish species in the small pelagic fishery are round sardinella (*Sardinella aurita*, Clupeidae), flat sardinella (*Sardinella maderensis*, Clupeidae), chub mackerel (*Scomber japonicus*, Scombridae) and anchovy (*Engraulis encrasicolus*, Engraulidae). In the last decade, total landings of small pelagic fish from this ecosystem are between 200,000 and 260,000 mt annually (Figure 2.2.2; Bard and Koranteng 1995).

In the demersal fishery, several high-valued species are exploited. The most important of these belong to the families Sparidae, Lutjanidae, Haemulidae,



Serranidae and Sciaenidae. Total annual landings were between 40,000 and 80,000 mt in the last decade (Figure 2.2.2; FAO 1996).

In this chapter, knowledge about the western Gulf of Guinea coastal upwelling is reviewed and the observed changes in the marine environment, as they affect pelagic fisheries are examined. The stage is then set for detailed analysis of spatio-temporal changes in the demersal fisheries associated with changes in the marine and climatic environment and effects of near-shore forcing factors.

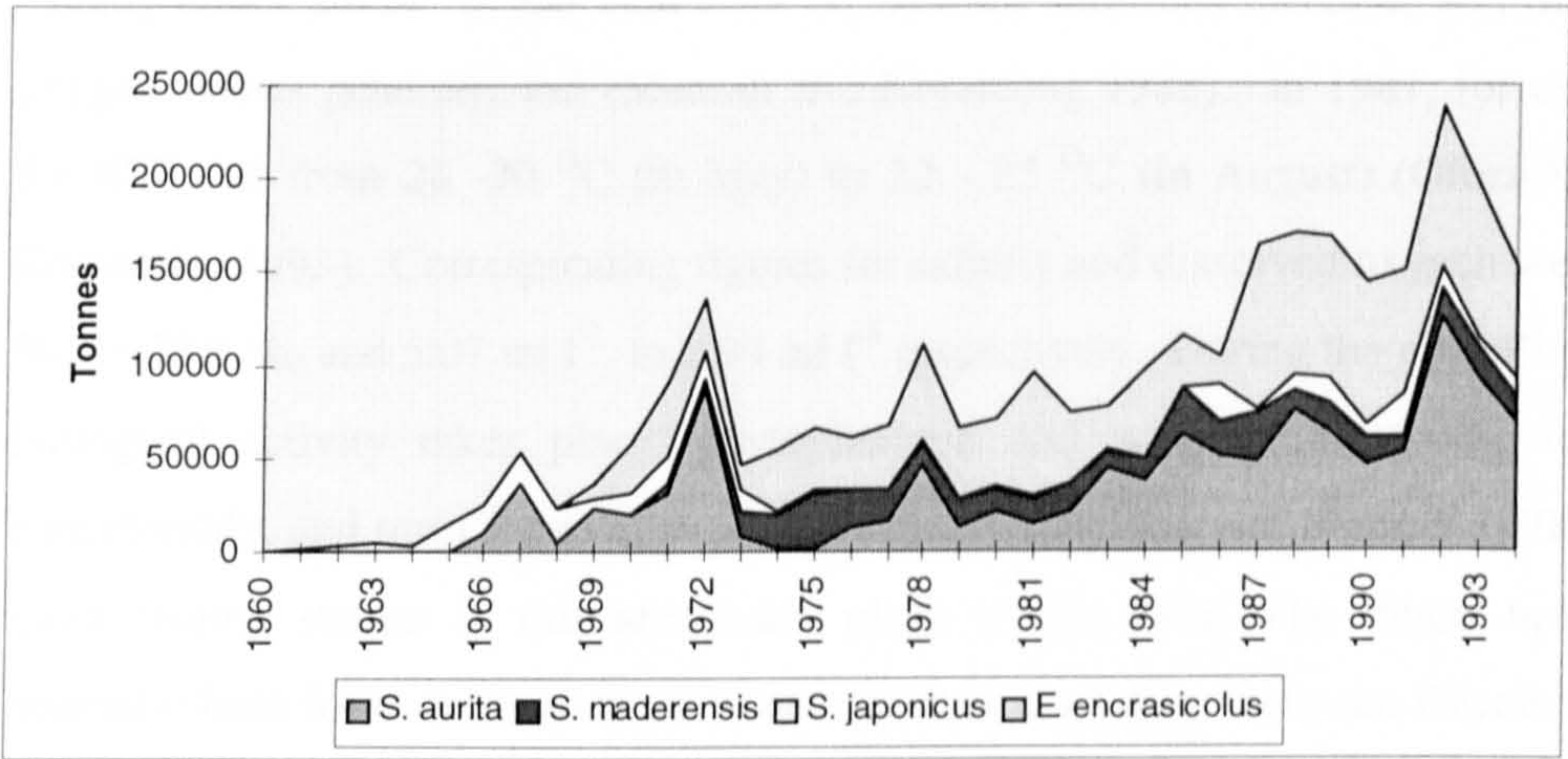


Figure 2.2.1. Total landings of the four principal small pelagic species from Ghana's coastal waters, 1960 - 1994.

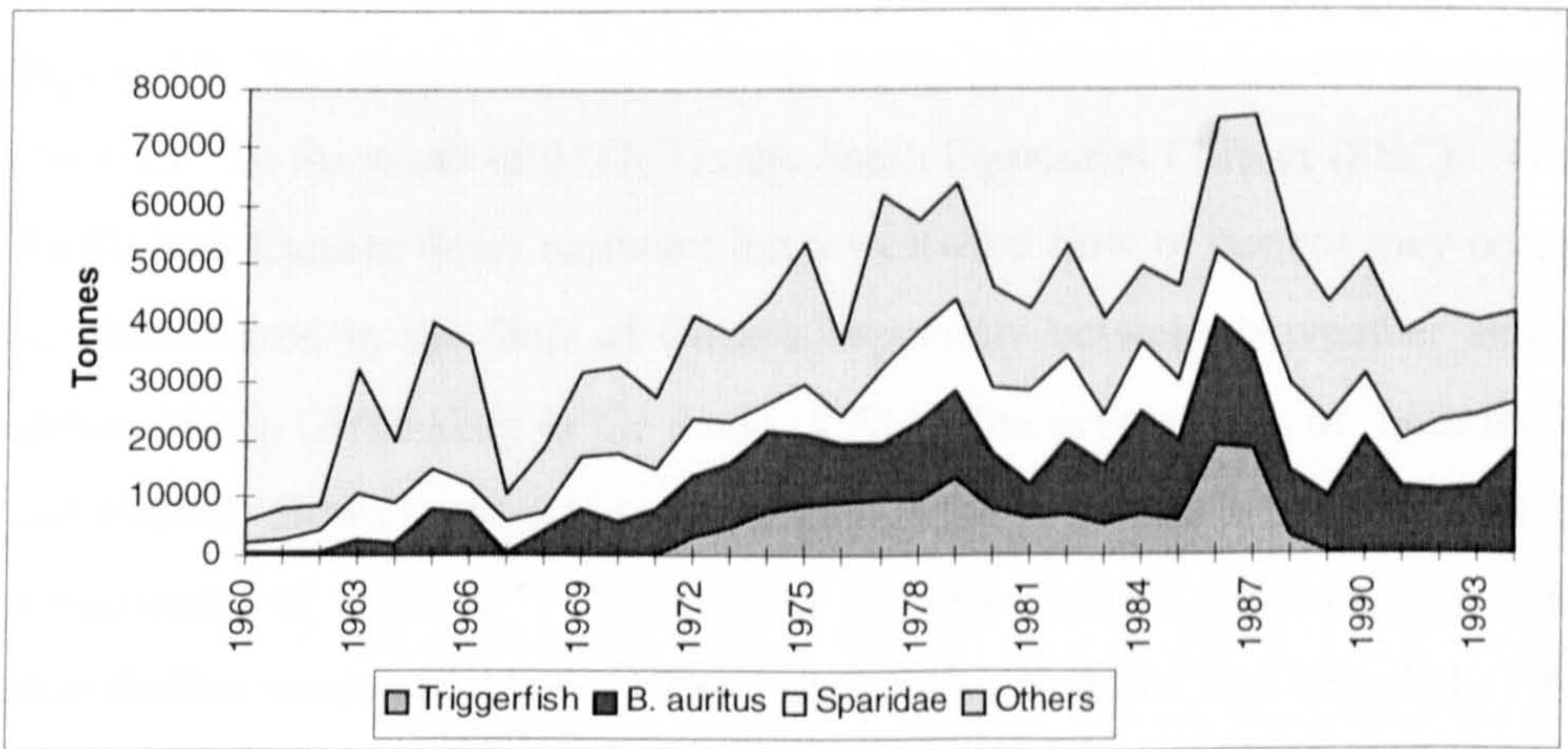


Figure 2.2.2. Total landings of selected demersal species and family from Ghana's coastal waters, 1960 - 1994.



## **2.2 GENERAL CHARACTERISTICS OF THE UPWELLING IN THE WESTERN GULF OF GUINEA**

The coastal hydrography of the Gulf of Guinea is generally divided into four regimes: a short cold season in December - January (minor upwelling), a long warm season between February and June, a long cold season between July and September (major upwelling) and a short warm season in October - November (Longhurst 1962). The seasonal cycle of sea surface temperature is portrayed in Figure 3.5.

In the major upwelling season, sea surface temperatures (SST) which are usually about 27-29 °C fall below 25 °C, surface salinities increase, and dissolved oxygen values generally fall (Mensah and Koranteng 1988). In 1981, for example, the SST fell from 28 -30 °C (in May) to 22 - 25 °C (in August) (Ofori-Adu and Koranteng 1993). Corresponding figures for salinity and dissolved oxygen were 34.6 ‰ to 35.9 ‰ and 5.07 ml l<sup>-1</sup> to 2.94 ml l<sup>-1</sup> respectively. During the upwelling, high biological activity takes place; phytoplankton and zooplankton production rise considerably, and most fishes spawn at this time (Houghton and Mensah 1978). The main fishing season in this area takes place at this time. The minor upwelling normally lasts for only about three weeks (occurring anytime between December and March) during which sea surface temperatures usually fluctuate between 26 and 27.5 °C (Mensah and Koranteng 1988).

The surface and subsurface circulation in the Gulf of Guinea are depicted in Figure 2.3. The Guinea Current (GC) is fed by the North Equatorial Counter Current (NECC). To the south of it (GC) is the South Equatorial Current (SEC). Generally, the Guinea Current flows eastward but a westward flow of current may occasionally be encountered in the Gulf of Guinea, especially between November and January (Anon 1996). According to the Anon (1996), “the average rate of both the easterly and westerly flows is about 0.4 m s<sup>-1</sup> although the usual rate is 0.8 m s<sup>-1</sup> and reaching a maximum of 1.0 m s<sup>-1</sup>”. The current has less strength and constancy off Ghana than further westward (Anon 1996). According to Binet and Marchal (1993) and Binet (1995), the Guinea Current extends only to the 25 m depth offshore and is

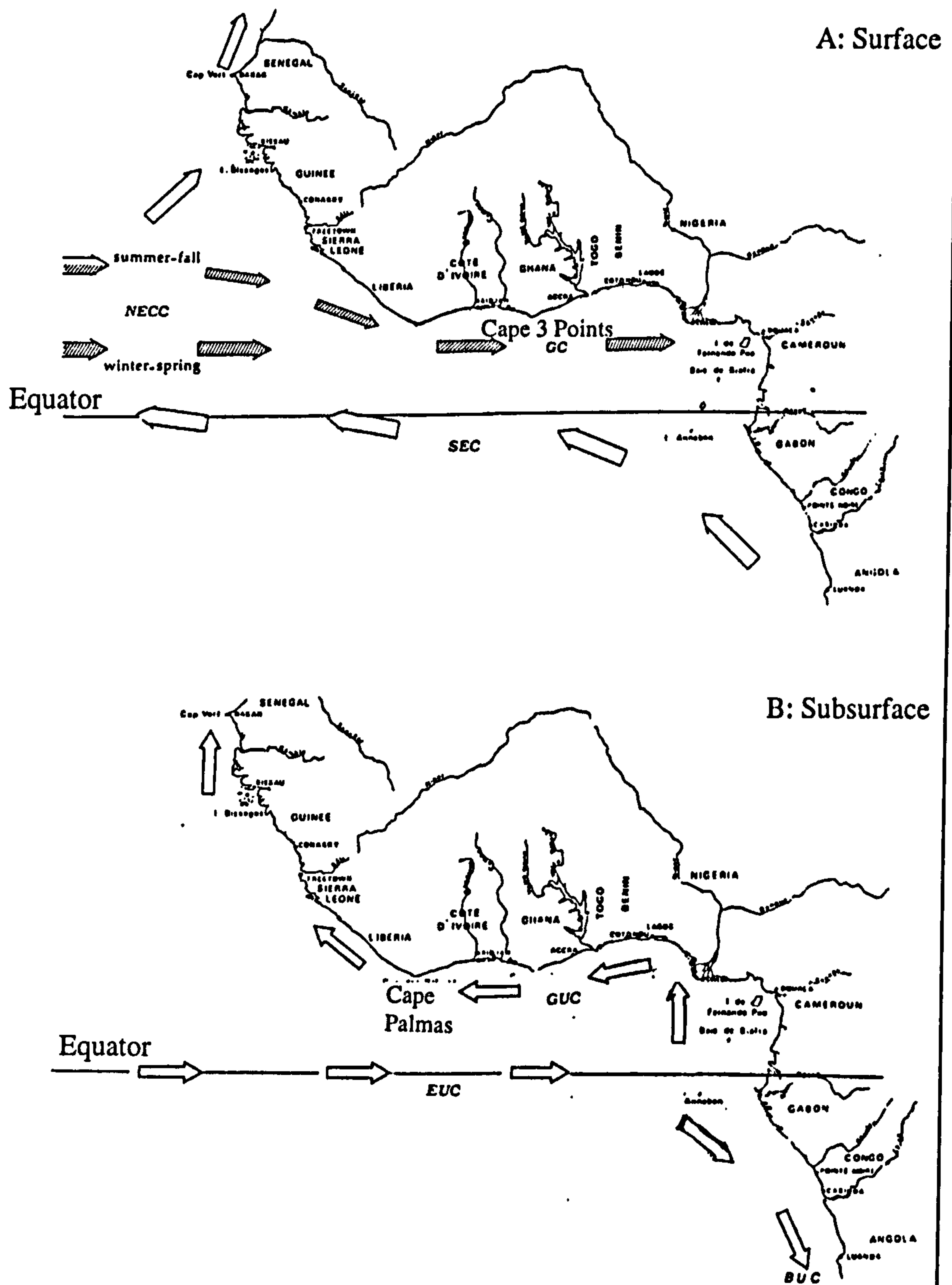


Figure 2.3. Surface and subsurface circulation in the eastern tropical Atlantic. The symbols are: GC - Guinea Current; GUC - Guinea Under Current; SEC - South Equatorial Current; NECC - North Equatorial Counter Current; EUC - Equatorial Under Current and BUC - Benguela Under Current. (Modified from Binet and Marchal 1993)

shallower closer inshore. It overlays the Guinea Under Current, GUC which flows westward.

This structure of surface and subsurface circulation is similar to what obtains in other upwelling areas (Binet 1991). Bakun (1978), also draws some similarities between the Gulf of Guinea upwelling ecosystem and other eastern ocean boundary upwelling systems like the Canary and Benguela current ecosystems lying to the north and south respectively of the Gulf of Guinea. These similarities include the appearance of cool sea temperatures near the coast and the high productivity of coastal fisheries. The peculiarities of the western Gulf of Guinea coastal upwelling system include the orientation of the coastline (zonal rather than meridional) and its proximity to the equator. It is also a seasonal upwelling.

The driving mechanisms of the upwelling in the western Gulf of Guinea are not well understood. However, the numerous studies on the system have shown that it is not of the classical wind-driven, Ekman type that characterizes other eastern boundary upwelling ecosystems (Houghton 1976; Bakun 1978). This is because the dominant wind in the area, the southwesterly monsoon, has a low speed and generally lacks seasonality (Verstraete *et al.* 1980). It blows almost parallel to the coastline and has a maximum speed of about  $5\text{ m s}^{-1}$  which occurs between June and September (Roy 1995; Ghana Meteorological Services Department unpublished data). There is a weakening and brief reversal of the wind in December/January. In Ekman-type upwelling, the movement of water near the sea surface is in response to the direct action of the wind. This is represented by the Ekman transport which is the component of ocean flow that responds to the forces exerted by the stress of the wind on the sea surface (Bakun 1996; Figure 2.4.1).

The cause of the upwelling off Ghana and Côte d'Ivoire has at one time or the other been attributed to:

- i. evaporation (FRU 1970; Pople and Mensah 1971),
- ii. eastward current (Ingham 1970; Marchal and Picaut 1977; Bakun 1978), and
- iii. remote forcing by coastally trapped Kelvin waves (Moore *et al.* 1978;

Servain *et al.* 1982; Picaut 1983).

#### i. Evaporation

An interdisciplinary National Committee on Oceanographic Research (NCOR), which was set up in Ghana purposely to study the upwelling, concluded that it (the upwelling) was caused by evaporation through a mixing process (FRU 1970). The committee reached this conclusion because during the period of study in 1970, SSTs fell from 25 to 19 °C in three days, meteorological conditions were calm, no marked inshore currents were recorded and there were no prevailing winds capable of blowing surface waters offshore (Pople and Mensah 1971). It was noted that such winds rather occurred at other times of the year when there was no upwelling.

#### ii. Currents

In the first of two hypothesis attributing the cause of the upwelling to currents, Ingham (1970) postulated that intensification of the Guinea Current increases the upward slope of the thermocline towards the coast (Figure 2.4.2) and this produces conditions favourable for the occurrence of an upwelling. In the second hypothesis, Marchal and Picaut (1977) argued that the dynamic interaction between the flow of the Guinea Current and the two large capes (Cape Palmas and Cape Three Points) leads to a rise in the thermocline downstream and accumulation of water upstream (Figure 2.4.3). The authors argued that these would create favourable upwelling conditions, especially on the eastern side of each cape.

#### iii. Remote forcing

The remote forcing hypothesis postulates that on reaching the African continent, an equatorial Kelvin wave generated by the seasonal onset of the wind in the western part of the Atlantic basin is reflected as a trapped coastal Kelvin wave which then propagates poleward along the coast (Moore *et al* 1978; Figure 2.4.4). Picaut (1983) showed that the SSTs recorded at several coastal stations along the West African coast exhibited a phase lag that was in consonance with the remote forcing hypothesis.



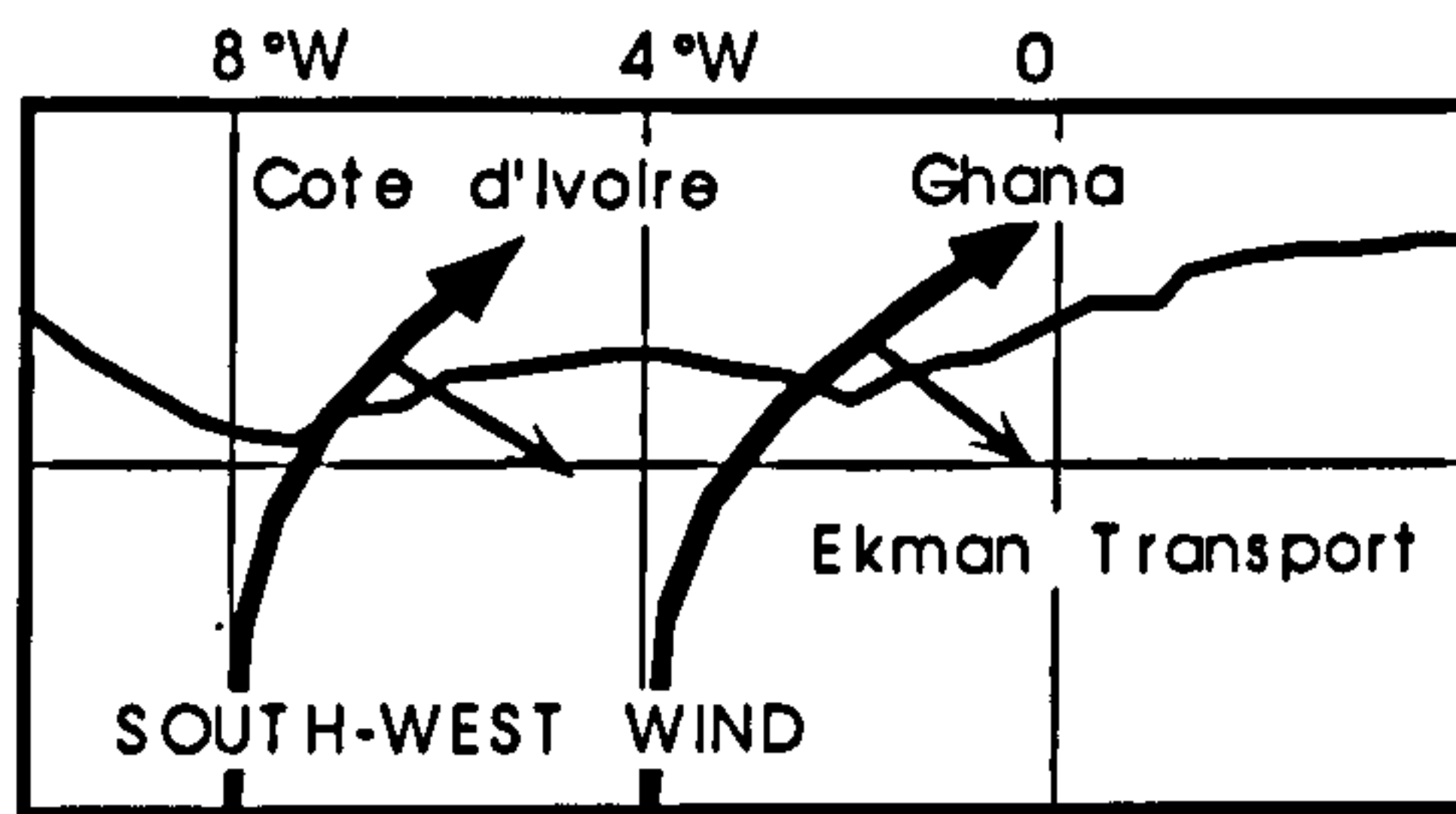


Figure 2.4.1. Diagram showing offshore Ekman transport created by the south-westerly wind regime in the Gulf of Guinea.

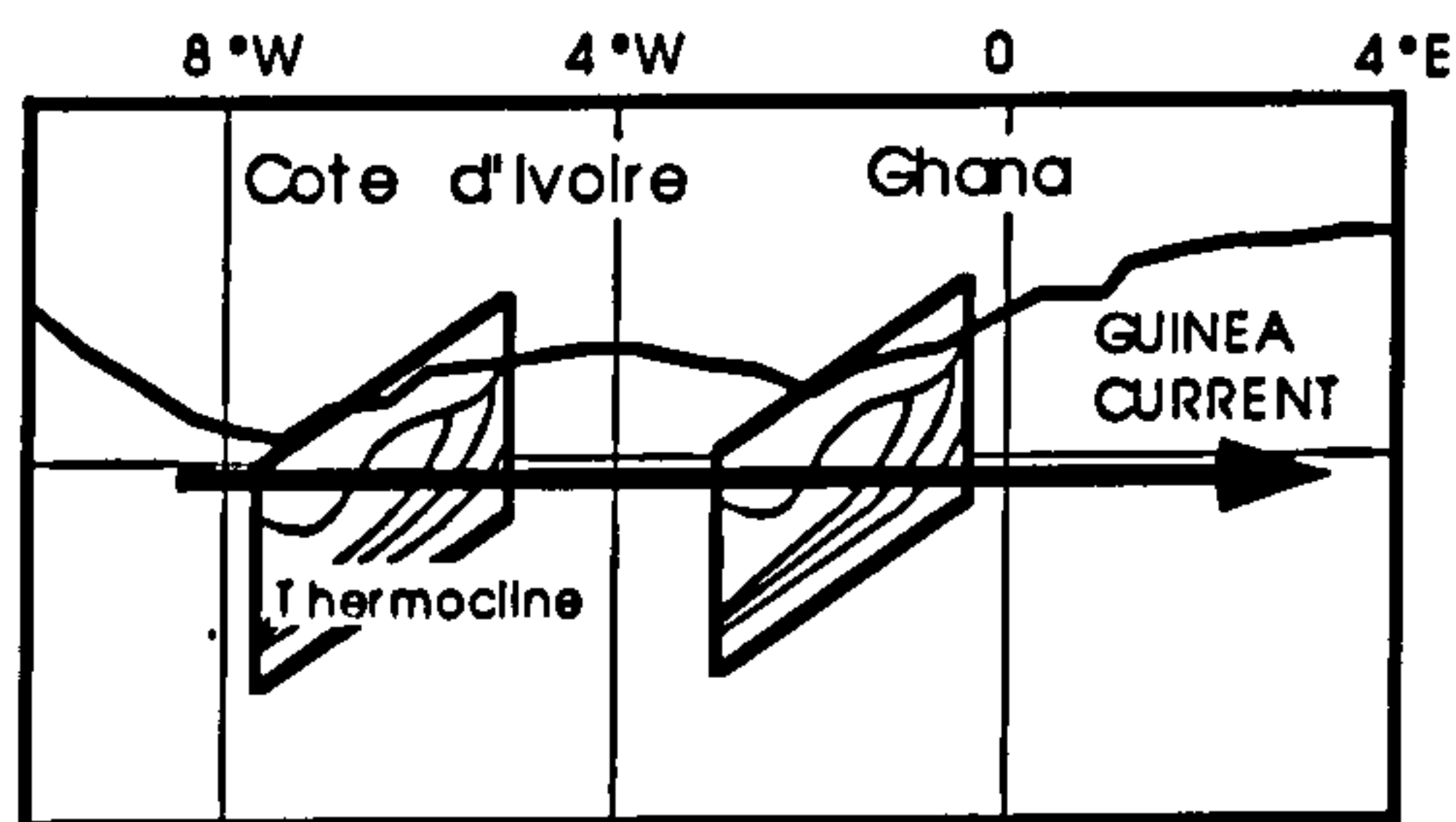


Figure 2.4.2. A schematic diagram of coastal upwelling induced by the eastward flow of the Guinea Current.

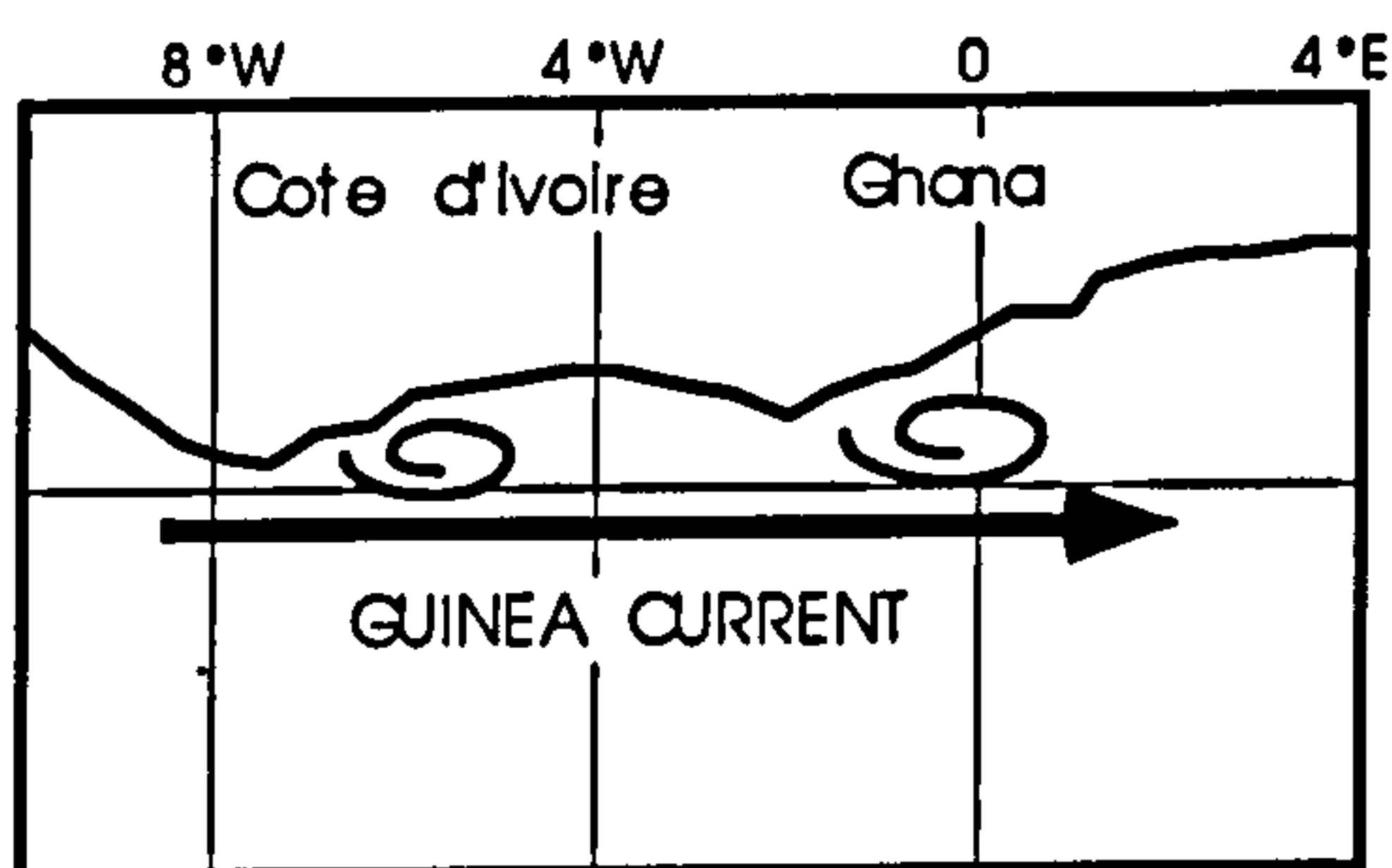


Figure 2.4.3. A schematic diagram of the "cape effect" induced by the eastward flow of the Guinea Current as described by Marchal and Picaut (1997).

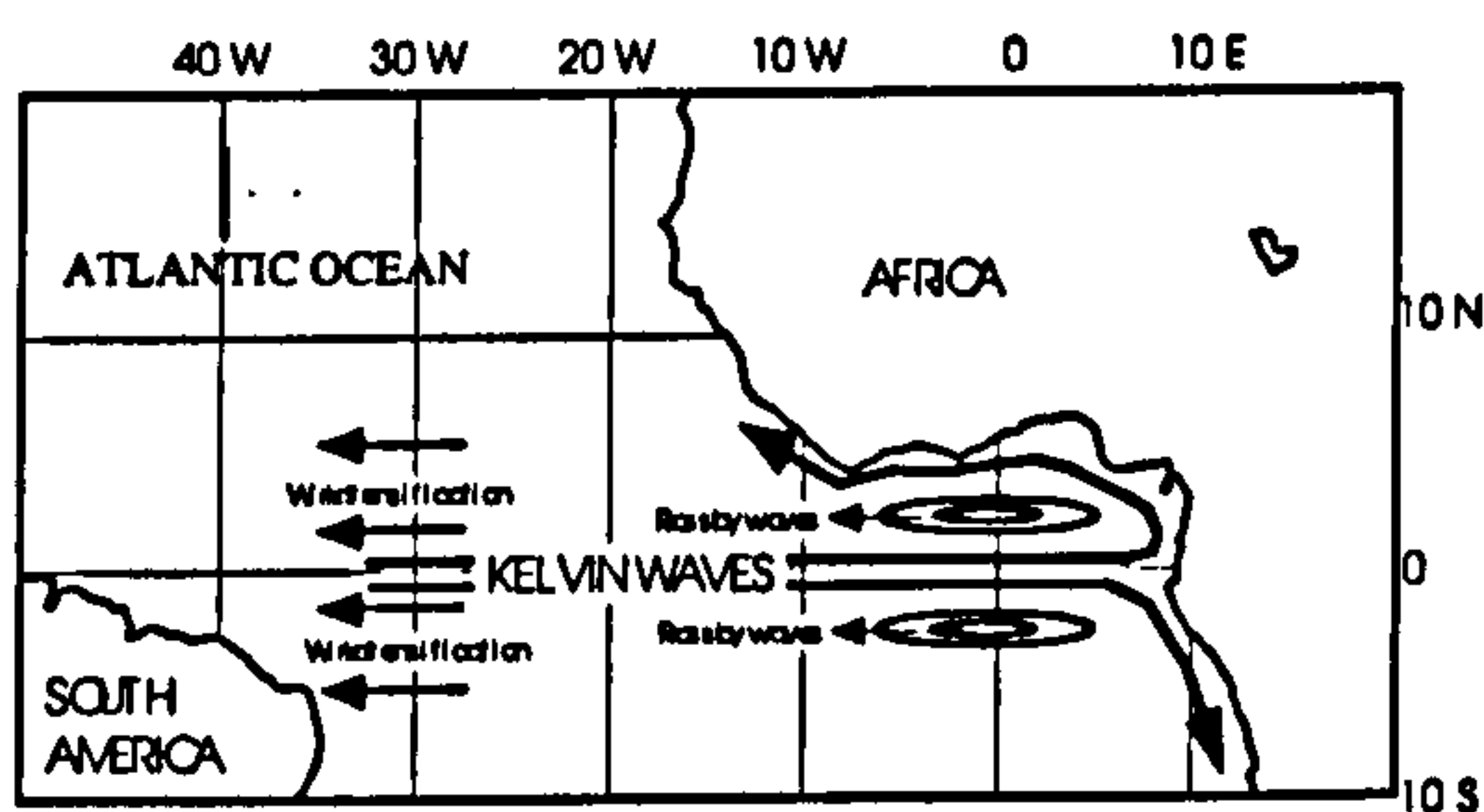


Figure 2.4.4: Schematic diagram of the remote forcing of the summer upwelling in the Gulf of Guinea (after Moore *et al.* 1978).

Figures reproduced with permission from Roy (1995).



Examining each of these hypothesis in detail Roy (1995) concluded that the upwelling off Ghana and Côte d'Ivoire may be caused by a combination of factors, but singled out wind as a possible prominent factor in the case of the minor upwelling. The author stated further, that the intensification of the Guinea Current in January-February is also considered to be an important contributing factor to the occurrence of the winter (minor) upwelling.

## 2.3 STUDYING THE DYNAMICS OF THE UPWELLING

As the prevailing south-westerly winds in the western Gulf of Guinea are usually weak and do not have significant relationship with the cooling of surface waters (as discussed above) the dynamics of the upwelling off Ghana and Côte d'Ivoire have been studied using mainly the analysis of sea surface temperature (e.g. FRU/ORSTOM 1976; Cury and Roy 1987; Mendelssohn and Cury 1987; Arfi *et al.* 1991; Koranteng and Pezennec 1997). Since 1963 (in Ghana) and 1978 (in Côte d'Ivoire), sea surface temperature (SST) is recorded daily at 13 locations along the nearly 1100 km long Ghana-Côte d'Ivoire coastline (Figure 2.5). To assess the quality of the upwelling, an upwelling index of the form

$$I = (26 - t) \times N \quad \dots 2.1$$

where **I** is the index for a fortnight; **t** is the mean of temperatures lower than 26 °C within the fortnight, and **N** is the number of days in the fortnight for which temperatures were less than 26 °C, is used (FRU/ORSTOM 1976; Arfi, *et al.* 1991). This index takes into account both the duration and intensity of the upwelling. Values of the index for the major and minor upwelling seasons are usually calculated separately. Figure 2.6 shows trend of the index during the major and minor upwelling for two coastal stations in Ghana (Keta and Takoradi) and two in Côte d'Ivoire (Tabou and Abidjan).

## 2.4 RECENT OBSERVED CHANGES IN UPWELLING CONDITIONS

The dynamics of the coastal upwelling and the consequences on fisheries, especially small pelagic fish, have been the focus of a number of studies on the ecosystem off Ghana and Côte d'Ivoire. Major results that have evolved from these studies are as follows:

- i. Major upwelling conditions were relatively stable in the past two decades with no apparent trend in the series of the major upwelling index (Arfi *et al.* 1991; Pezennec 1994). From Figure 2.6, it appears there was a weakening of this upwelling off Tabou (on the extreme west) and Keta (on the extreme east) between 1976 (or 1978 in the case of Tabou) and 1991.
- ii. There was intensification of the minor upwelling, especially on the western side of both Ghana and Côte d'Ivoire (Arfi *et al.* 1991; Pezennec and Bard 1992; Koranteng and Pezennec 1997). Figure 2.6 also shows that the intensification was more pronounced in Côte d'Ivoire than in Ghana where the minor upwelling is usually less intense.
- iii. Using data from the COADS data set (Woodruff *et al.* 1987), Pezennec and Bard (1992) and Pezennec (1994) showed that sea surface temperature recorded in offshore areas during the major upwelling season increased in the last two decades whilst the minor upwelling temperatures decreased.

Other recorded changes in the ecosystem and coastal zone of the sub-region and which could affect the fish and fisheries are as follows:

- i. There was a general reduction in annual total rainfall in the sub-region (Mensah 1991; Koranteng and Pezennec 1997) following the general pattern of declining rainfall amounts in sub-saharan Africa in the 1970s and 1980s (Lamb *et al.* 1986).
- ii. As a consequence of the above, there was substantial reduction in the amount of fresh water input into the sea from rivers (Mahé 1991; Mensah 1991). Another cause of this reduction is the construction of many hydro-electric and irrigation dams on a number of rivers that end up in the Gulf of Guinea.



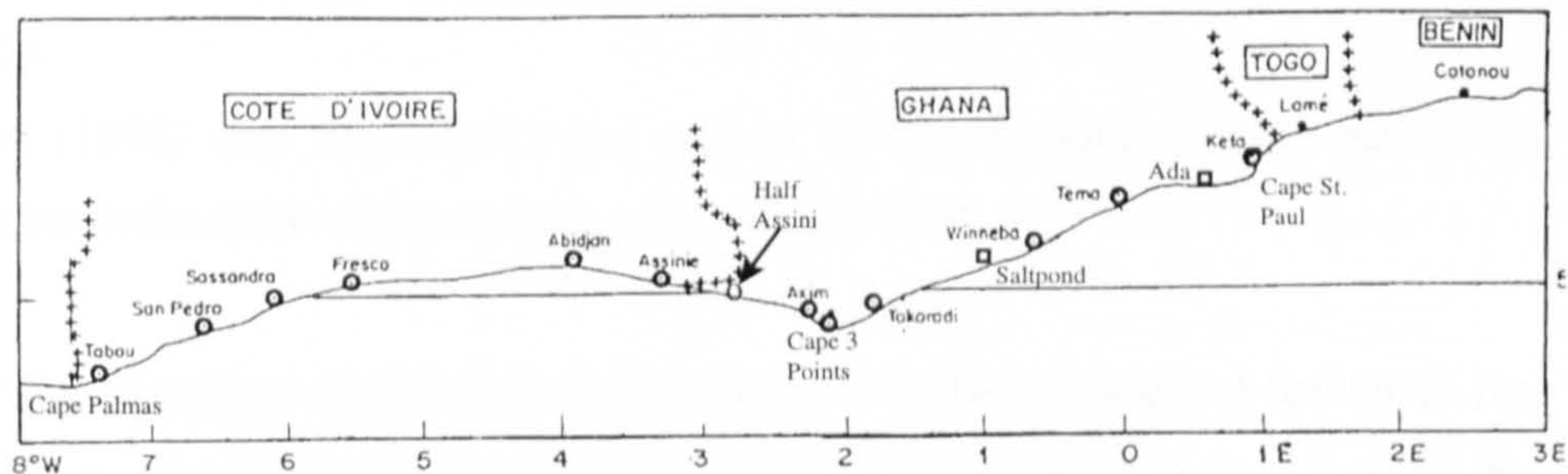


Figure 2.5: Sites in Ghana and Cote d'Ivoire at which sea surface temperature is recorded daily (modified from Koranteng and Pezennec 1997). Figure also shows other stations for meteorological observations (■)

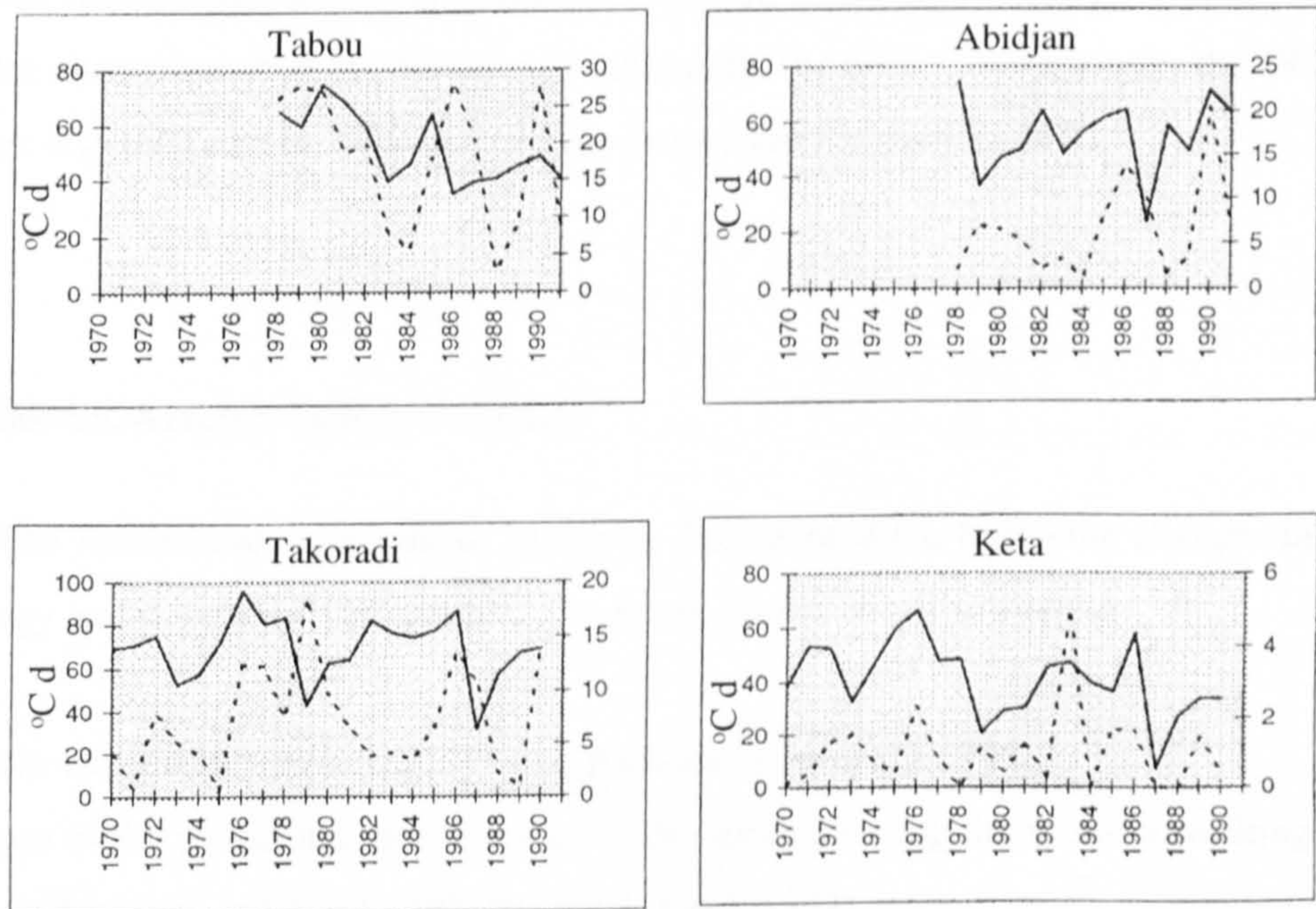


Figure 2.6: Series of the upwelling index for Tabou and Abidjan (Cote d'Ivoire) and Takoradi and Keta (Ghana). Left axis is for major upwelling (—) and right axis is for minor upwelling (- -). Data for figures were taken from Pezennec (1995)

- iii. Following from the above, there was increase in salinity of shelf waters (Binet 1995).
- iv. Binet (1995) also noted that there appears to be alterations in the pattern of currents in the Gulf of Guinea between 1978 and 1985.

The first three of these recorded changes have been discussed further in the next chapter. As regards the fourth, Binet (1995) related the latitude of flow of the North Equatorial Counter Current (NECC), which feeds the Guinea Current (Figure 2.3), to the position of the Inter-Tropical Convergence Zone (ITCZ). Citing Philander (1986), Binet (1995) noted that the interannual change in the migratory pattern of the ITCZ would induce similar deviations in the latitudinal flow path of the NECC. Binet (1995) noted further that as the average February-April latitude of the ITCZ was farther south than usual between 1978 and 1985, this would have resulted in similar displacement of the NECC and ultimately, the GC. Consequently, the GC was nearest to the coast in 1978 and farthest away from the coast in 1985.

## 2.5 IMPLICATIONS FOR FISHERIES

The studies mentioned above have also documented the following changes in the biology and population dynamics of *Sardinella aurita* in the sub-region:

- i. increase in total landings (Figure 2.2.1; Bard and Koranteng 1995),
- ii. increase in the abundance and landings of the species during the minor upwelling period (Pezennec and Bard 1992, Pezennec 1994, 1995),
- iii. increase in modal size of landed *S. aurita* (from between 15-18 cm in the 1960s and early 1970s (FRU/ORSTOM 1976) to 18-24 cm in the 1980s in Côte d'Ivoire (Pezennec 1994) and from 14-17 cm to 17-21 cm in Ghana (Quaatey 1993)) and
- iv. changes in reproductive strategy of the fish with increased spawning activities outside the main upwelling period (Quaatey 1993; Pezennec 1994; Pezennec and Koranteng 1997).



These changes have been attributed mainly to the intensification of the minor upwelling (Pezennec and Bard 1992; Pezennec 1994; Pezennec and Koranteng 1997), increase in salinity of shelf waters (Binet 1995) and changes in meteorological and other oceanographic conditions like reduction of rainfall, acceleration of winds and alteration of current patterns (Binet 1995).

The other three major small pelagic species in this ecosystem did not undergo such significant changes in biomass and biology. For example, even though landings of anchovy (*Engraulis encrasicolus*) also increased in the period under study, it was not in the same magnitude as that of the round sardinella. There was no marked increase in the landings of the flat sardinella, and chub mackerel landings have always been in pulses without any definite pattern (MFRD unpublished data).

On coastal demersal fish and fisheries, changes that have been noted are as follows:

- i. dramatic increase in the abundance and landings of triggerfish (*Balistes capriscus*) between 1973 and 1988 (Ansa-Emmim 1979; Caverivière 1991),
- ii. increase in the biomass and catch of globefish (*Lagocephalus laevigatus*, Tetraodontidae) and cuttlefish (*Sepia officinalis*, Sepiidae); the importance of the globefish was short-lived but the cuttlefish is still (1997) prominent in the landings of trawlers (MFRD unpublished data).

To give an idea about some of the changes that have occurred in the demersal fishery, Table 2.1 gives the twelve most abundant species recorded in four trawl surveys conducted in Ghanaian waters (Koranteng 1991). Some of the biomass flips that have been observed in this ecosystem are reflected in the table. For example, in stock assessment surveys conducted before 1979 (Williams 1968; Rijavec 1980) only a few specimens of triggerfish were caught and the bigeye grunt (*Brachydeuterus auritus*, Haemulidae), was the most abundant species recorded. In 1979-80, the demersal component of triggerfish assessed in bottom trawl surveys was put at 99,000 mt (or 57.2 kg ha<sup>-1</sup>) and accounted for about 62 percent of the total estimated demersal fish biomass in Ghanaian coastal waters (Koranteng 1981). Only a few



specimens of triggerfish were caught in the Guinea 90 bottom trawl survey in April 1990 (Ramos 1990).

The proliferation of triggerfish in the Gulf of Guinea in the 1970s and its total domination of the ecosystem were described by Bakun (1995) as “one of the most phenomenal episodes in the history of fish population dynamics”. Initially, the explosion of the triggerfish biomass was thought to be the main cause of the decline of the round sardinella fishery (FRU/ORSTOM 1976).

Trawling for demersal fishes in Ghanaian waters began about 50 years ago. The build up of the local trawler fleet resulted in increased landings of demersal fish (Figure 2.2.2). The deployment of large industrial trawlers in Ghanaian waters (chapter 1) marked the beginning of the apparent over-exploitation of demersal fishery resources in these waters. Although the real impact of the increase in fishing effort on the fish resources has not been adequately assessed, trends in landings and the results of stock assessment surveys indicate significant changes in the fishery, including species composition of catches.

## 2.6 CONCLUSION

The upwelling zone off Ghana and Côte d'Ivoire is unique in the Guinea Current large marine ecosystem and is different from other upwelling areas. The duration and intensity of the two seasonal coastal upwellings that occur in this ecosystem have changed in the last two decades.

Significant changes in the biology and population dynamics of small pelagic fishes, notably that of *Sardinella aurita* in this ecosystem have been attributed mainly to the increasing impact of the minor upwelling on the ecosystem. In the demersal fishery, the extent that the recorded changes in upwelling conditions and other near-shore and environmental factors have caused or affected changes in distribution, abundance and population dynamics of species like triggerfish, globefish and cuttlefish has not been critically assessed. This is the focus of this thesis.

Table 2.1. The 12 most abundant species recorded in selected trawl surveys in Ghanaian waters (From Koranteng 1991)

| Order | 1969-70                       | 1979-80                         | 1981-82                    | 1989-90                        |
|-------|-------------------------------|---------------------------------|----------------------------|--------------------------------|
| 1     | <i>Brachydeuterus auritus</i> | <i>B. capriscus</i>             | <i>B. capriscus</i>        | <i>B. auritus</i>              |
| 2     | <i>Chromis lineatus</i>       | <i>P. bellottii</i>             | <i>B. auritus</i>          | <i>P. bellottii</i>            |
| 3     | <i>Pagellus bellottii</i>     | <i>B. auritus</i>               | <i>P. bellottii</i>        | <i>P. prayensis</i>            |
| 4     | <i>Dentex canariensis</i>     | <i>S. caeruleostictus</i>       | <i>P. prayensis</i>        | <i>S. caeruleostictus</i>      |
| 5     | <i>Sepia</i> sp.              | <i>D. canariensis</i>           | <i>S. caeruleostictus</i>  | <i>Trachurus</i> sp.           |
| 6     | <i>Sparus caeruleostictus</i> | <i>P. prayensis</i>             | <i>D. canariensis</i>      | <i>C. lineatus</i>             |
| 7     | <i>Dactylopterus volitans</i> | <i>E. aeneus</i>                | <i>E. aeneus</i>           | <i>D. canariensis</i>          |
| 8     | <i>Trachurus</i> sp.          | <i>Caranx rhoncus</i>           | <i>Umbrina canariensis</i> | <i>E. aeneus</i>               |
| 9     | <i>Pseudupeneus prayensis</i> | <i>Chromis chromis</i>          | <i>P. arenatus</i>         | <i>D. volitans</i>             |
| 10    | <i>Balistes capriscus</i>     | <i>Pomadasys incisus</i>        | <i>Dentex angolensis</i>   | <i>Sepia</i> sp.               |
| 11    | <i>Epinephelus aeneus</i>     | <i>Priacanthus arenatus</i>     | <i>Sepia</i> sp.           | <i>P. arenatus</i>             |
| 12    | <i>Galeoides decadactylus</i> | <i>Chloroscombrus chrysurus</i> | <i>C. crysurus</i>         | <i>Lagocephalus laevigatus</i> |



### **CHAPTER THREE:**

## **SPATIAL AND TEMPORAL ENVIRONMENTAL VARIABILITY IN GHANA'S SHELF WATERS**

*"..... the ocean is a restless and changing environment;  
its changes may either be sudden and dramatic, or  
covert and sustained for very long periods..."*

**Alan Longhurst and others 1972**

## Chapter Summary

Several physical parameters of the continental shelf ecosystem of Ghana and near-shore environmental parameters were examined. These include sea surface temperature, bottom temperature, salinity and dissolved oxygen collected from coastal stations, the Tema hydrographic transect, trawl surveys and from the COADS database.

The time series of each environmental parameter was decomposed into its trend, seasonal variation and remainder, and also standardised anomalies of the parameter were calculated. Where there was more than one series of the same parameter, a composite index was calculated and its behaviour was examined.

The trend of temperatures, both surface (coastal) and bottom, exhibited a phase of decline from the beginning of the series until 1976/77 when a reversal (of the trend) occurred. Temperature began to rise again until the end of the series. This pattern of behaviour of the temperature and the other parameters resulted in the division of the observational period into three blocks, namely before 1972, from 1972 to 1982 and after 1982.

In the first block, SST (both coastal and offshore) and bottom temperature (SBT) declined, coastal salinity was low, rainfall was above average and the discharge of the Pra and Volta rivers were more than the average for the entire period. The second block was a cold one with less than average SST and SBT. The mixed layer was narrow with the thermocline remaining shallower than its average position. Coastal and bottom salinity (measured at 100 m deep) were relatively high but the seasonal variation was minimal. The phase was also characterised by reduced rainfall. In the final phase, temperatures were high, salinity was low and erratic and rainfall was close to normal. Thus, the second environmental time block was a period of significant change in the physical components of the ecosystem of the Ghanaian shelf waters which has not been so elaborately documented in the literature.

### 3.1 INTRODUCTION

It has long been recognized that environmental parameters influence the rates at which biological processes proceed (Hjort 1914). In the marine environment these could determine the type and quantity of species that colonise certain places or are associated with specific water masses. Various studies have underscored the



importance of factors like temperature, oxygen, ocean currents, freshwater input into the ocean and local meteorological conditions on the distribution and abundance of fish populations. Numerous correlations between landings of given species and environmental factors have been reported, and the variations in catches have often been attributed to climatic changes (Hjort 1914; Sutcliffe 1973; Sutcliffe and Muir 1977; Pauly and Tsukayama 1987; Drinkwater 1987; Pauly *et al.* 1989a; Laevastu 1993; Bakun 1996). Laevastu (1993) also brings into focus the importance of weather on fish behaviour (including schooling and migration) through its effect on the ocean.

The principal objective of this chapter is to assess the nature and types of changes that have occurred in the physical parameters of the marine ecosystem off Ghana and in the local climate. It involves examination of variability and trends in physico-chemical parameters of the marine and atmospheric environments and in near-shore forcing factors. Emphasis is on events in the last three decades during which the stocks of fish in Ghana's shelf waters were also assessed. The emerged patterns are used to direct the analysis of the fish catch data obtained from stock and catch assessment surveys.

The basic drawback in this type of work is the time scales over which the various processes occur, are measured or analysed. Effort has been made in this work, to harmonize the time scales over which the various components are analysed, however, in some situations a wider range in the series has been considered in order to reveal intrinsic but covert trends.

### **3.2 DATA ACQUISITION**

Several data types were used in this work; however, except where indicated otherwise, most of the data were assembled from records available at the Marine Fisheries Research Division (MFRD) of the Fisheries Department, Tema, Ghana.



### **3.2.1 Sea surface temperature recorded at the coast**

Daily recording of sea surface temperature (SST) was begun at Tema in 1962 by MFRD, and later in the decade at other six stations (Figure 2.5.1). The recording sites have been described by Ofori-Adu (1986) and their approximate locations are given in Appendix 3.1.

The coastal temperature is measured with a mercury-in-glass thermometer immersed for about five minutes in a sample of water collected in a plastic bucket; the recorder wades through the water to knee deep before fetching the water sample. Recording is done twice a day, between 7 and 9 o'clock in the morning and between 1 and 2 o'clock in the afternoon. Following the practice at the MFRD, only morning temperatures were used in this work. The inventory of data used in the analyses are presented in Appendix 3.1.

### **3.2.2 Offshore sea surface temperature**

Offshore SSTs were extracted from the Comprehensive Ocean Atmosphere Data Sets (COADS; Woodruff *et al.* 1987) using the CD-ROM produced by the Climate and Eastern Ocean Systems (CEOS) project (Bakun *et al.* 1994 ) and the CODE program (Mendelsshon and Roy 1996). The COADS database was created from marine surface observations made from 1854 to 1992 on various platforms including ships of opportunity and moored buoys. The raw data are screened and harmonized before incorporating them into the database (Woodruff *et al.* 1987). Sub-sets of the data were extracted for 4 areas off Côte d'Ivoire - Ghana between latitudes 1 and 6° N and from longitude 7° W to 1° E for the period 1946 to 1992. The areas are shown in Figure 3.1.

### **3.2.3 Coastal salinities**

From the water samples collected by the recorders for temperature measurement, sub-samples are taken and sent to the MFRD laboratories in Tema for the determination of salinity using an inductive salinometer. Collection of salinity records from stations other than Tema was discontinued in 1982, hence only Tema salinities were used in this work.

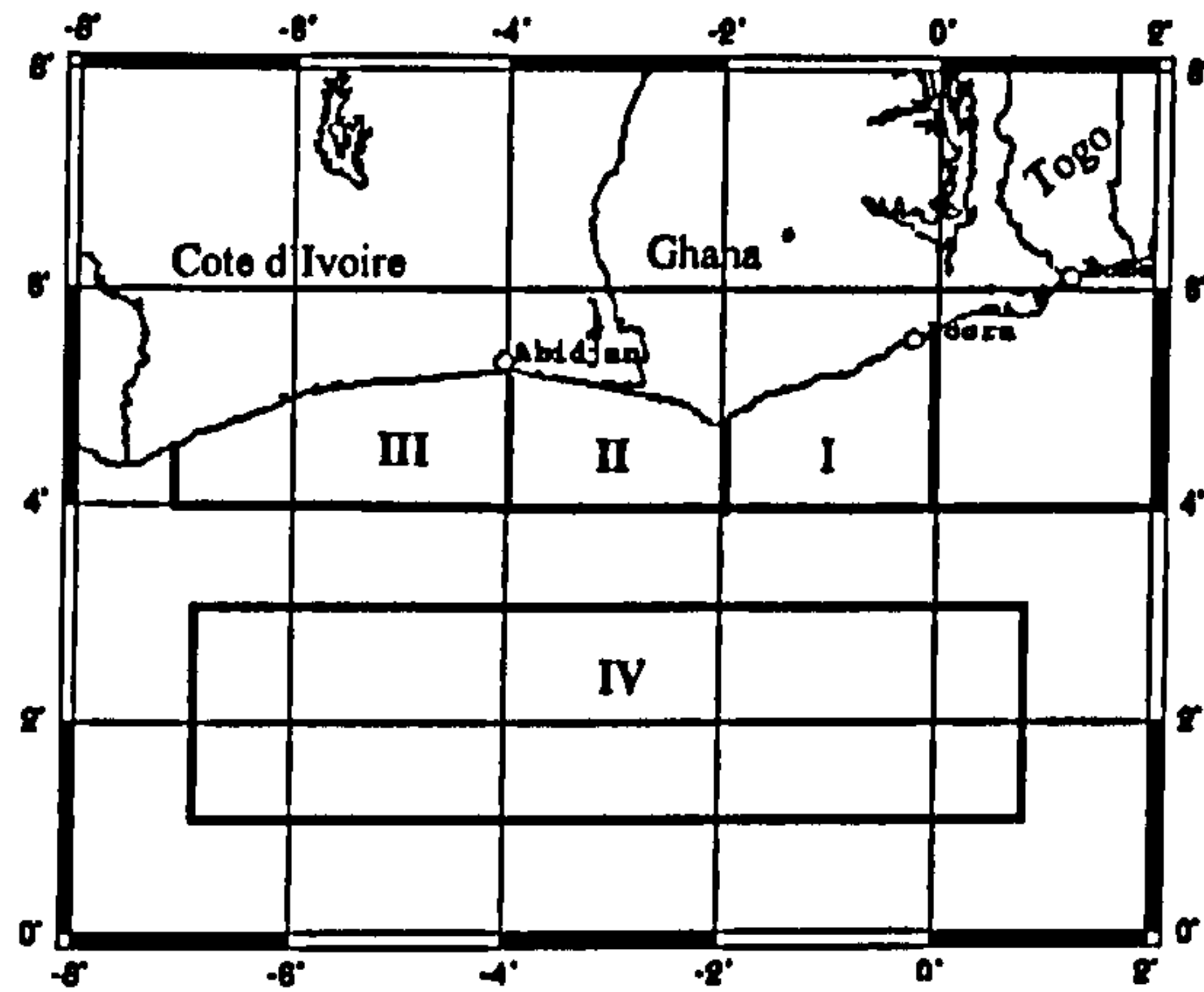


Figure 3.1: Areas for which data were extracted from the COADS database

### 3.2.4 Data collected on the Tema hydrographic transect

Since 1968 the MFRD has run a weekly hydrographic survey on a transect off Tema. This transect is almost perpendicular to the coastline and has four stations on it (Figure 3.2). These are stations A1, A2, B and C the approximate positions and depths of which are given in Appendix 3.2. The parameters measured on the transect and which were used in this work are temperature, salinity and dissolved oxygen.

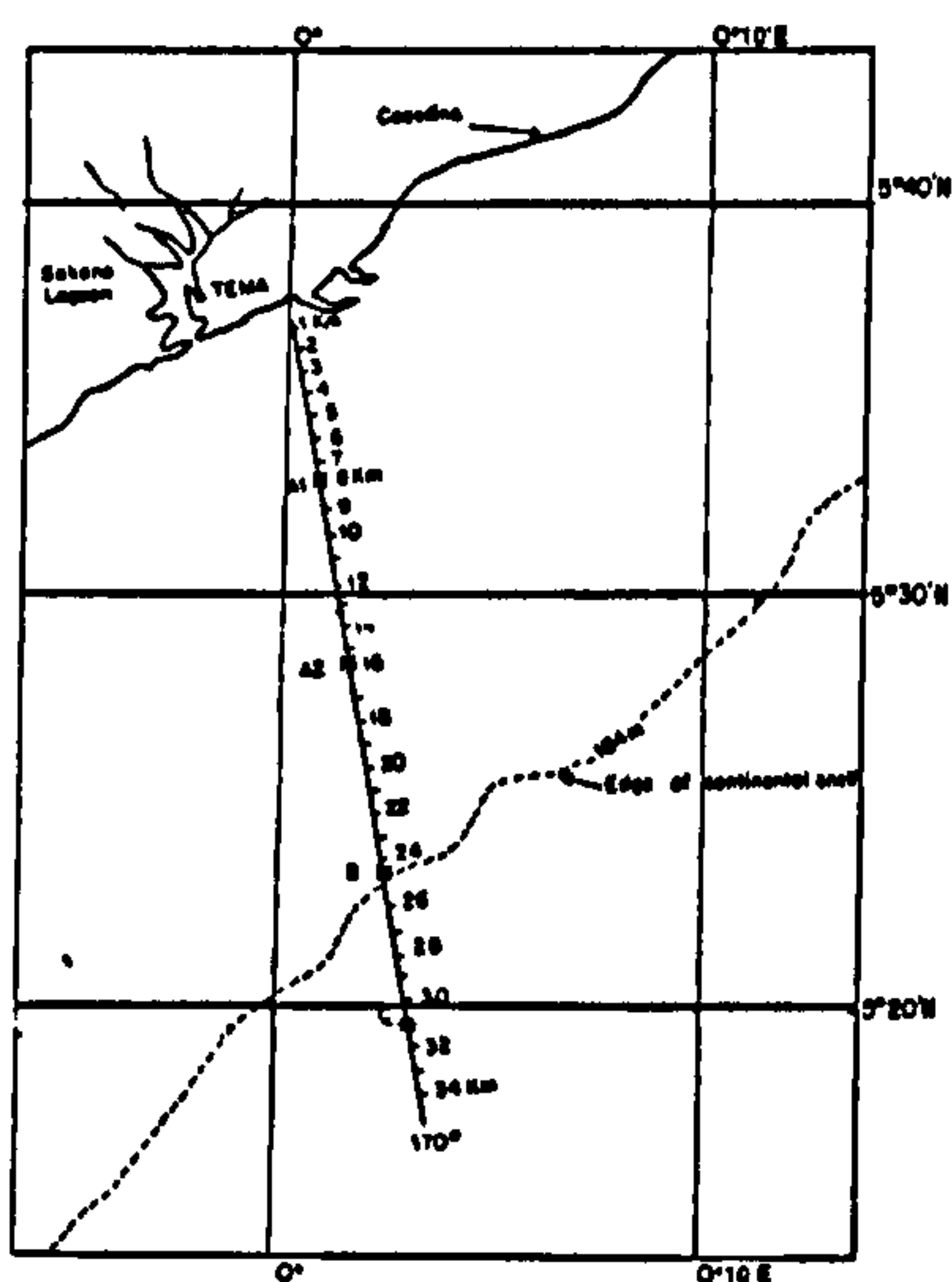


Figure 3.2:

Coastline and shelf off Tema showing the location of the hydrographic transect.

### **3.2.5 Environmental parameters measured during trawl surveys**

During the trawl surveys conducted by MFRD (chapter 6), SSTs are measured *in situ* with a continuous temperature recorder mounted on the research vessel. In addition, temperature is obtained from thermometers mounted on Nansen reversing bottles. Before the commencement of trawling, or immediately after the net had been hauled in, two Nansen reversing bottles are deployed, one at the surface and the other at the bottom of the sea. After 7 minutes, the bottles are retrieved and the thermometers (main and auxiliary) read. The necessary corrections are applied to obtain the true water temperature.

Water samples are also taken from the Nansen reversing bottles for the determination of dissolved oxygen and salinity at the MFRD laboratory.

Hydrographic records for trawl surveys conducted before 1979 could not be located for this work.

### **3.2.6 Climatic data**

Rainfall (monthly total) and air temperature data recorded at coastal stations in Ghana where MFRD also takes temperature and salinity measurements, were obtained from the Meteorological Services Department of Ghana (MSD) at Legon. The stations and periods for which data were compiled for this work are indicated in Appendix 3.3.

### **3.2.7 River discharge data**

Data on discharge rates of the Volta and Pra Rivers, measured at the last of recording stations towards the sea (Figure 1.1), were obtained from the Hydrology Section of the Architectural and Engineering Services Company of Ghana (AESC-Hydro) and the Volta River Authority (VRA). The two rivers were selected because of their size and also for the completeness of the data on their flow. Volta is the largest river in Ghana with a catchment area of 390,510 km<sup>2</sup> (at Akosombo), 43 %

of which is within Ghana and Pra is the second largest river with catchment area of 22, 818 km<sup>2</sup> at Beposo (AESC-Hydro unpublished data).

The Volta data covers the period 1950 - 1992 and the Pra data is for 1963 - 1992. Between May 1964 and December 1981, the Volta flow data are measurements of plant discharge at the Akosombo power generating plant and between December 1981 and 1992, they represent Akuse plant discharge (also see section 1.3.3).

### **3.3 DATA ANALYSES**

#### **3.3.1 *Sea surface temperature and upwelling index***

Monthly averages of the sea surface temperature recorded daily at the seven coastal stations were calculated. Each missing value in the daily records of SSTs was replaced with the average of the preceding and ensuing day. Where there were no records at the station for the whole month, an average of the preceding and ensuing months was used. Because of the eight years of missing information from Half Assini, the series was left out of most of the analyses.

An upwelling index UI, was defined as

$$UI = T_o - T_b \quad \dots 3.1$$

where  $T_o$  is the monthly mean offshore SST from COADS (in area IV of Figure 3.1) and  $T_b$  is the monthly mean coastal SST. A similar index was used by Wooster *et al.* (1976), Roy (1992), Nykjær and Van Camp (1994) and Cole (1997). For each coastal station, monthly UI values were calculated and plotted. Also for each coastal station, annual mean SST and annual mean UI were calculated as the mean of the monthly values. Overall monthly values of SST and UI were calculated by averaging the monthly data over the stations.



The values of the upwelling index were summarized by season, using January - March as the minor upwelling season, April - June as the first warm season, July - September as the major upwelling season and October - December as the second warm season in the year. The minor and major upwelling indices for each coastal station were plotted against years.

### **3.3.2 Time series analysis of environmental parameters**

Each time series of coastal and offshore sea surface temperature was decomposed to obtain the trend and seasonal variation using an additive model of the form:

$$Y_i = T_i + S_i + R_i \quad \text{.... 3.2}$$

where  $Y_i$  are the observed SST,  $T_i$  is the trend,  $S_i$  is the seasonal component and  $R_i$  represents the remainder random elements of the series after the trend and seasonal variation have been accounted for. This model assumes that the seasonal variation in each series is independent of any possible trend that the series will exhibit and that these are independent of the randomness in the system. The series of coastal salinity, subsurface temperature, dissolved oxygen and salinity were similarly treated. The analysis was carried out using STL (Cleveland *et al.* 1990) and state-space statistical models (Shumway and Stoffer 1982; Shumway 1988; Mendelssohn and Durand 1997).

“STL is a Seasonal-Trend decomposition procedure consisting of a sequence of smoothing operations that employ locally weighted regression or Loess” (Cleveland *et al.* 1990). In the estimation procedure, the set of values for each month of the year is treated as a sub-series. The output is composed of an inter-annual component common to all the sub-series, a seasonal component and a residual component. A detailed mathematical treatise of the method may be found in Cleveland *et al.* (1990). The STL analyses were done with the S-PLUS for windows computer software (MathSoft 1995).

From the time series, the state - space analysis obtains the components of the model by solving the equation “using a combination of the Kalman filter and maximum likelihood methods” (Schwing *et al.* 1997). Details of the statistical techniques used in this method are given by Schwing and Mendelssohn (1997) and Mendelssohn and Durand (1997). The program used was written by Dr. Roy Mendelssohn of Pacific Fisheries Environment Group, National Marine Fisheries Service, California, USA.

### 3.3.3 Time series of environmental anomalies

Following Laevastu (1993) and Becker and Pauly (1996), standardized departures of the monthly averages of each environmental parameter (e.g. SST) were calculated from

$$X_j = \frac{r_j - \bar{r}}{s} \quad \dots 3.3$$

where  $r_j$  is the monthly mean value of the parameter, and  $\bar{r}$  and  $s$  are the mean and standard deviation respectively of the series. Such standardized departures (or anomalies) are distributed with a zero mean and a variance of one (1).

A 13-point moving average was applied as a low-pass filter to remove the seasonal variation in the time series of anomalies (Chatfield 1996). The values of the filter were calculated from

$$s_m(x_t) = \frac{\frac{1}{2}x_{t-6} + x_{t-5} + x_{t-4} + \dots + \dots + x_{t+4} + x_{t+5} + \frac{1}{2}x_{t+6}}{12} \quad \dots 3.4$$

where  $x_{t-6}$  to  $x_{t-1}$  are six values lower than  $x_t$  and  $x_{t+1}$  to  $x_{t+6}$  are six values higher than  $x_t$ . The use of average value of  $x_{t+6}$  and  $x_{t-6}$  avoids giving twice as much weight to the month appearing at both ends of the 13-point moving average (Chatfield 1996).

### ***3.3.4 Vertical temperature profile of continental shelf waters of Ghana***

Temperature values recorded weekly at station B on the Tema hydrographic transect between 1968 and 1992 were examined. The monthly mean depth of the thermocline, represented by the depth of the 21 °C isotherm (Merle 1978; Koranteng and Pezennec 1997) was calculated.

The temperature values recorded close to the bottom of the sea at stations A1 (30 m), A2 (50 m) and B (100 m) were further examined using time series analysis. Each series was decomposed as described above. Salinity and oxygen values measured at station B were similarly analysed.

### ***3.3.5 Temperature, salinity and dissolved oxygen data collected during trawl surveys***

Temperature, salinity and dissolved oxygen data collected during the trawl surveys were summarised by month, depth zone and sector following the trawl survey design (chapter 6). On the assumption that the seabed was flat, contour maps of the parameters were produced for May and August 1981 and 1989. These two years were chosen because there were sufficient data for both upwelling and thermocline periods and also the surveys in these years have been used in the investigation on structure and dynamics of species assemblages (chapters 5 and 6).

### ***3.3.6 River discharge and climatic factors in the coastal zone***

#### ***3.3.6.1 River discharge data***

Data on the flow of Pra River at Daboasi and Volta River at Senchi/Akosombo and Akuse were analysed. The discharge data are in cubic meters per second (cms or m<sup>3</sup> s<sup>-1</sup>). Flow anomalies for each series were also examined as described above.

### 3.3.6.2 Rainfall

Rainfall data for five coastal meteorological stations (Ada, Tema, Saltpond, Takoradi and Axim, Figure 2.5) were examined in time and in space. Each series was plotted on a year - month space. Annual total rainfall was calculated for each station. From this data set, standardized departures were calculated and a rainfall index was calculated as:

$$X_j = \frac{1}{N_j} \sum_{i=1}^{N_j} \frac{r_{ij} - \bar{r}_i}{s_i} \quad \dots 3.5$$

In this equation,  $r_{ij}$  is the total rainfall for year  $j$  at station  $i$ ,  $\bar{r}_i$  and  $s_i$  are the mean and standard deviation respectively of the  $i^{\text{th}}$  station's series of annual rainfall data, and  $N_j$  is the number of stations with complete records in year  $j$ . Thus information from all five stations were combined in this index. A similar index was used to monitor rainfall in the Sahel region of West Africa (Kraus 1977; Katz 1978; Lamb *et al.* 1986). Statistical properties of the rainfall index are examined by Kraus (1977) and its viability as a suitable index for tracking spatial distribution of rainfall is discussed by Katz and Glantz (1986).

### 3.3.6.3 Other climatic parameters

Air temperature anomalies were calculated from the data collected at the five meteorological stations. Each series of anomalies was plotted together with the smoothed values. The five series of air temperature anomalies were combined using equation 3.5

From the COADS database monthly means of scalar wind speed were extracted from area I (i.e. 1° E-2° W, Figure 3.1) together with the meridional (north-south) and zonal (east-west) components of the wind. Anomalies of the scalar wind speed were calculated. Annual means of each component of the wind were calculated, plotted against year and a linear regression line (of wind speed over year) was fitted following the obvious significant rising trend exhibited in each data series.



## **3.4 Results**

### **3.4.1 *Sea surface temperature and upwelling index***

Quarterly (seasonal) means of SSTs for the coastal stations are presented in Table 3.1. Figures 3.3.1 - 3.3.6 give graphical representation of monthly mean SST recorded at Keta, Tema, Winneba, Takoradi, Cape Three Points and Axim respectively. The plots show the spatial differences in cooling between Keta on the east and Axim on the west with Cape Three Points, Takoradi and Tema experiencing more intense cooling than the rest of the littoral. Monthly means (averaged over stations) and annual means (averaged over months) of SSTs are shown in Figure 3.3.7 and 3.3.8 respectively.

Table 3.2 gives quarterly mean upwelling index (UI) values for the six coastal stations. Monthly and annual means of the UI are shown in Figures 3.4.1 and 3.4.2 respectively. Figures 3.4.3 and 3.4.4 show UI values for the major and minor seasons respectively. The outstanding nature of the cooling off Takoradi, during both minor and major upwelling, is also evident from these figures. The seasonal pattern of cooling is portrayed in Figure 3.5 (all stations combined). Evolution of major and minor upwelling index for each coastal station is depicted in Figures 3.6.1 - 3.6.4.

#### **3.4.1.1 Time series analysis of SSTs**

The extracted trend from the decomposition of the coastal SST series using the state-space model are presented in Figures 3.7.1 - 3.7.6. The trends are similar in all the series except at Winneba which differed a bit. Each trend exhibits a period of decline of mean SSTs (signifying cooling), from the beginning of the series to the mid-1970s and warming thereafter. Off Cape Three Points (Figure 3.7.5), the change was more gradual than at the other stations with average temperatures remaining cold for nearly a decade. The Axim series (Figure 3.7.6) showed a more erratic change than the others. In all the series, the decrease in temperature in the 1990s is also noteworthy, especially in the Axim series.

To assess the significance of the decline or rise in temperature, a linear regression of the derived trend values was fitted on time (years) to each phase of the Tema series as an example. The results (Figure 3.8), show highly significant ( $p < 0.001$ ) change in temperature in both the descending and ascending arms (i.e. 1963 - 1975 and 1975 - 1992).

From the plot of the seasonal component of each series (Figures 3.7.7 - 3.7.12), it is possible to follow the intra-annual (seasonal) variation in sea surface cooling. Within each year, the lowest point on the graph corresponds to the peak of cooling (major upwelling) and the highest point corresponds to the peak of warming. Between these are points corresponding to the first cold period in the year (January/February) and the warm period towards the end of the year (October/November).

The trend component of the COADS SSTs for the three inshore areas are presented in Figure 3.9. These series, being longer, also provide information on the behaviour of SSTs in the study area in the years preceding the commencement of the Ghana coastal SST series.

Table 3.1 Quarterly means of coastal SST (°C) recorded at the indicated centres  
(1,2,3, and 4 indicate four quarters of the year), 1963 - 1992

| Month | Keta |      |      |      | Tema |      |      |      | Winneba |      |      |      |
|-------|------|------|------|------|------|------|------|------|---------|------|------|------|
|       | 1    | 2    | 3    | 4    | 1    | 2    | 3    | 4    | 1       | 2    | 3    | 4    |
| 1963  |      |      |      |      | 26.7 | 28.4 | 23.8 | 27.5 |         |      |      |      |
| 1964  |      |      |      |      | 26.6 | 28.2 | 21.5 | 25.0 |         |      |      |      |
| 1965  |      |      |      |      | 26.6 | 28.0 | 23.1 | 26.9 |         |      |      |      |
| 1966  |      |      |      |      | 27.3 | 26.8 | 23.0 | 26.8 |         |      |      |      |
| 1967  |      |      |      |      | 26.9 | 27.0 | 20.4 | 25.8 |         |      |      |      |
| 1968  |      |      |      |      | 26.6 | 27.6 | 25.3 | 27.4 |         |      |      |      |
| 1969  | 27.4 | 27.9 | 23.2 | 26.8 | 27.5 | 28.0 | 22.1 | 26.5 |         |      |      |      |
| 1970  | 27.6 | 27.7 | 23.5 | 27.6 | 27.2 | 27.5 | 22.8 | 27.1 | 25.8    | 26.8 | 21.7 | 26.9 |
| 1971  | 27.6 | 27.9 | 22.5 | 26.6 | 26.8 | 28.2 | 21.8 | 26.3 | 26.7    | 27.6 | 21.7 | 26.8 |
| 1972  | 27.1 | 27.5 | 22.6 | 26.9 | 26.7 | 27.7 | 21.9 | 27.4 | 26.6    | 26.5 | 22.3 | 27.3 |
| 1973  | 27.3 | 27.6 | 24.6 | 27.4 | 27.3 | 27.8 | 23.1 | 27.3 | 27.1    | 27.9 | 23.8 | 27.2 |
| 1974  | 27.1 | 28.2 | 23.0 | 26.5 | 26.8 | 28.6 | 22.4 | 26.1 | 27.3    | 28.3 | 23.8 | 27.0 |
| 1975  | 27.1 | 27.5 | 22.1 | 26.7 | 27.3 | 27.6 | 21.2 | 26.5 | 28.1    | 27.4 | 22.2 | 26.9 |
| 1976  | 27.1 | 26.8 | 21.7 | 25.5 | 27.0 | 26.9 | 20.9 | 25.6 | 27.1    | 26.9 | 22.0 | 26.2 |
| 1977  | 26.9 | 26.8 | 22.4 | 26.3 | 27.0 | 26.6 | 21.3 | 26.2 | 27.1    | 26.7 | 23.1 | 26.9 |
| 1978  | 27.2 | 27.0 | 22.9 | 26.8 | 27.2 | 27.2 | 21.7 | 26.8 | 27.5    | 26.8 | 22.8 | 27.0 |
| 1979  | 26.7 | 27.7 | 25.0 | 27.5 | 26.1 | 27.6 | 24.6 | 27.5 | 26.7    | 27.6 | 23.3 | 27.9 |
| 1980  | 27.3 | 27.2 | 24.1 | 27.2 | 26.8 | 26.9 | 23.4 | 27.0 | 27.3    | 27.3 | 23.4 | 27.2 |
| 1981  | 27.0 | 27.7 | 24.0 | 27.9 | 26.9 | 27.6 | 23.3 | 28.0 | 27.3    | 27.7 | 23.8 | 28.2 |
| 1982  | 27.9 | 27.8 | 23.0 | 26.9 | 27.7 | 27.3 | 21.4 | 26.6 | 27.7    | 27.4 | 22.2 | 27.0 |
| 1983  | 26.2 | 27.3 | 22.9 | 26.9 | 25.8 | 26.5 | 22.3 | 26.8 | 26.7    | 26.6 | 22.7 | 27.8 |
| 1984  | 27.7 | 27.8 | 23.4 | 27.0 | 28.1 | 27.9 | 22.3 | 27.4 | 29.2    | 28.4 | 23.6 | 27.4 |
| 1985  | 27.3 | 27.1 | 23.6 | 27.5 | 26.6 | 27.5 | 21.8 | 27.4 | 26.7    | 28.0 | 23.0 | 27.3 |
| 1986  | 27.0 | 28.1 | 22.2 | 26.7 | 26.6 | 28.0 | 20.9 | 26.1 | 27.5    | 28.0 | 22.3 | 26.7 |
| 1987  | 27.7 | 27.5 | 26.0 | 28.1 | 27.0 | 27.5 | 25.4 | 27.9 | 27.8    | 27.6 | 25.0 | 28.0 |
| 1988  | 28.2 | 28.2 | 24.3 | 27.9 | 27.8 | 27.7 | 22.9 | 27.6 | 28.2    | 27.5 | 24.1 | 27.7 |
| 1989  | 27.4 | 28.3 | 23.8 | 27.3 | 27.2 | 28.1 | 22.7 | 27.3 | 27.0    | 27.5 | 24.3 | 27.4 |
| 1990  | 27.5 | 27.6 | 23.8 | 27.9 | 26.5 | 27.0 | 22.7 | 27.5 | 26.3    | 25.6 | 23.5 | 27.2 |
| 1991  | 28.4 | 28.3 | 25.1 | 27.1 | 27.2 | 27.2 | 23.7 | 26.4 | 27.5    | 26.9 | 24.6 | 27.0 |
| 1992  | 26.9 | 27.7 | 24.3 | 27.4 | 26.8 | 27.2 | 22.8 | 27.5 | 27.2    | 27.1 | 23.5 | 27.2 |
| Mean  | 27.3 | 27.6 | 23.5 | 27.1 | 27.0 | 27.5 | 22.6 | 26.9 | 27.2    | 27.3 | 23.2 | 27.2 |

Table 3.1 continued

| Month | Takoradi |      |      |      | Cape Three Points |      |      |      | Axim |      |      |      |
|-------|----------|------|------|------|-------------------|------|------|------|------|------|------|------|
|       | 1        | 2    | 3    | 4    | 1                 | 2    | 3    | 4    | 1    | 2    | 3    | 4    |
| 1963  |          |      |      |      |                   |      |      |      |      |      |      |      |
| 1964  |          |      |      |      |                   |      |      |      |      |      |      |      |
| 1965  |          |      |      |      |                   |      |      |      |      |      |      |      |
| 1966  |          |      |      |      |                   |      |      |      |      |      |      |      |
| 1967  |          |      |      |      |                   |      |      |      |      |      |      |      |
| 1968  |          |      |      |      |                   |      |      |      |      |      |      |      |
| 1969  | 26.5     | 27.0 | 21.1 | 25.9 |                   |      |      |      | 28.3 | 28.5 | 24.7 | 27.2 |
| 1970  | 26.4     | 26.7 | 21.5 | 26.8 | 28.0              | 28.1 | 24.2 | 27.6 | 28.4 | 28.2 | 25.0 | 27.7 |
| 1971  | 26.6     | 26.9 | 21.3 | 25.5 | 26.9              | 27.6 | 22.1 | 26.6 | 27.5 | 27.7 | 23.7 | 27.1 |
| 1972  | 26.1     | 26.0 | 21.1 | 26.4 | 27.4              | 27.7 | 24.0 | 27.4 | 27.3 | 27.4 | 24.1 | 27.6 |
| 1973  | 26.5     | 26.7 | 22.6 | 26.7 | 27.8              | 28.5 | 23.9 | 27.0 | 28.1 | 27.9 | 24.5 | 27.5 |
| 1974  | 26.2     | 28.0 | 22.2 | 25.5 | 27.4              | 28.0 | 24.5 | 26.5 | 27.3 | 27.8 | 24.5 | 26.9 |
| 1975  | 27.0     | 26.7 | 21.3 | 25.4 | 27.6              | 27.4 | 21.9 | 26.1 | 27.5 | 27.3 | 23.9 | 26.5 |
| 1976  | 25.7     | 25.4 | 19.8 | 24.4 | 26.3              | 26.6 | 21.1 | 25.4 | 27.6 | 27.1 | 23.4 | 25.4 |
| 1977  | 25.4     | 25.6 | 20.0 | 25.6 | 26.4              | 26.8 | 21.4 | 26.6 | 27.0 | 27.4 | 24.7 | 27.5 |
| 1978  | 25.8     | 26.0 | 20.6 | 25.6 | 27.2              | 26.7 | 22.0 | 26.7 | 27.9 | 27.7 | 25.1 | 27.6 |
| 1979  | 24.8     | 26.6 | 23.2 | 26.7 | 26.7              | 27.3 | 24.0 | 27.3 | 28.7 | 28.4 | 25.7 | 27.8 |
| 1980  | 25.5     | 25.7 | 21.9 | 26.0 | 26.8              | 26.5 | 23.3 | 26.8 | 27.5 | 27.5 | 24.8 | 26.5 |
| 1981  | 25.8     | 26.4 | 21.8 | 26.6 | 26.9              | 27.4 | 22.7 | 27.7 | 27.8 | 27.5 | 24.8 | 28.2 |
| 1982  | 26.5     | 26.4 | 20.6 | 26.0 | 27.0              | 27.0 | 21.6 | 26.3 | 28.1 | 27.4 | 24.4 | 27.0 |
| 1983  | 26.2     | 25.7 | 21.0 | 26.2 | 26.8              | 26.7 | 23.0 | 27.1 | 27.8 | 27.9 | 25.0 | 27.7 |
| 1984  | 26.8     | 26.9 | 21.1 | 26.1 | 27.5              | 27.4 | 22.3 | 26.9 | 27.7 | 27.5 | 24.9 | 27.7 |
| 1985  | 26.1     | 26.6 | 21.0 | 26.0 | 26.6              | 27.4 | 22.1 | 26.6 | 28.3 | 27.8 | 24.6 | 27.4 |
| 1986  | 25.2     | 27.0 | 20.3 | 25.6 | 25.9              | 27.7 | 22.3 | 26.4 | 28.1 | 27.4 | 24.4 | 28.3 |
| 1987  | 25.5     | 26.7 | 23.9 | 27.1 | 26.6              | 27.6 | 24.9 | 27.7 | 28.4 | 28.1 | 25.5 | 28.0 |
| 1988  | 26.5     | 26.7 | 22.2 | 26.7 | 28.1              | 27.4 | 23.5 | 27.5 | 28.6 | 29.9 | 25.6 | 27.6 |
| 1989  | 27.1     | 27.2 | 21.6 | 26.4 | 27.8              | 28.0 | 22.9 | 27.4 | 28.1 | 27.6 | 25.4 | 27.4 |
| 1990  | 25.7     | 26.5 | 21.5 | 26.8 | 26.5              | 27.1 | 21.9 | 27.2 | 26.8 | 26.4 | 23.9 | 27.2 |
| 1991  | 26.5     | 26.7 | 22.9 | 25.3 | 27.0              | 26.8 | 23.7 | 26.3 | 27.4 | 27.7 | 25.0 | 26.8 |
| 1992  | 26.0     | 26.6 | 21.3 | 26.7 | 26.5              | 27.2 | 22.9 | 27.0 | 27.5 | 27.8 | 24.1 | 27.0 |
| Mean  | 26.1     | 26.5 | 21.5 | 26.1 | 27.0              | 27.3 | 22.9 | 26.9 | 27.8 | 27.8 | 24.7 | 27.3 |



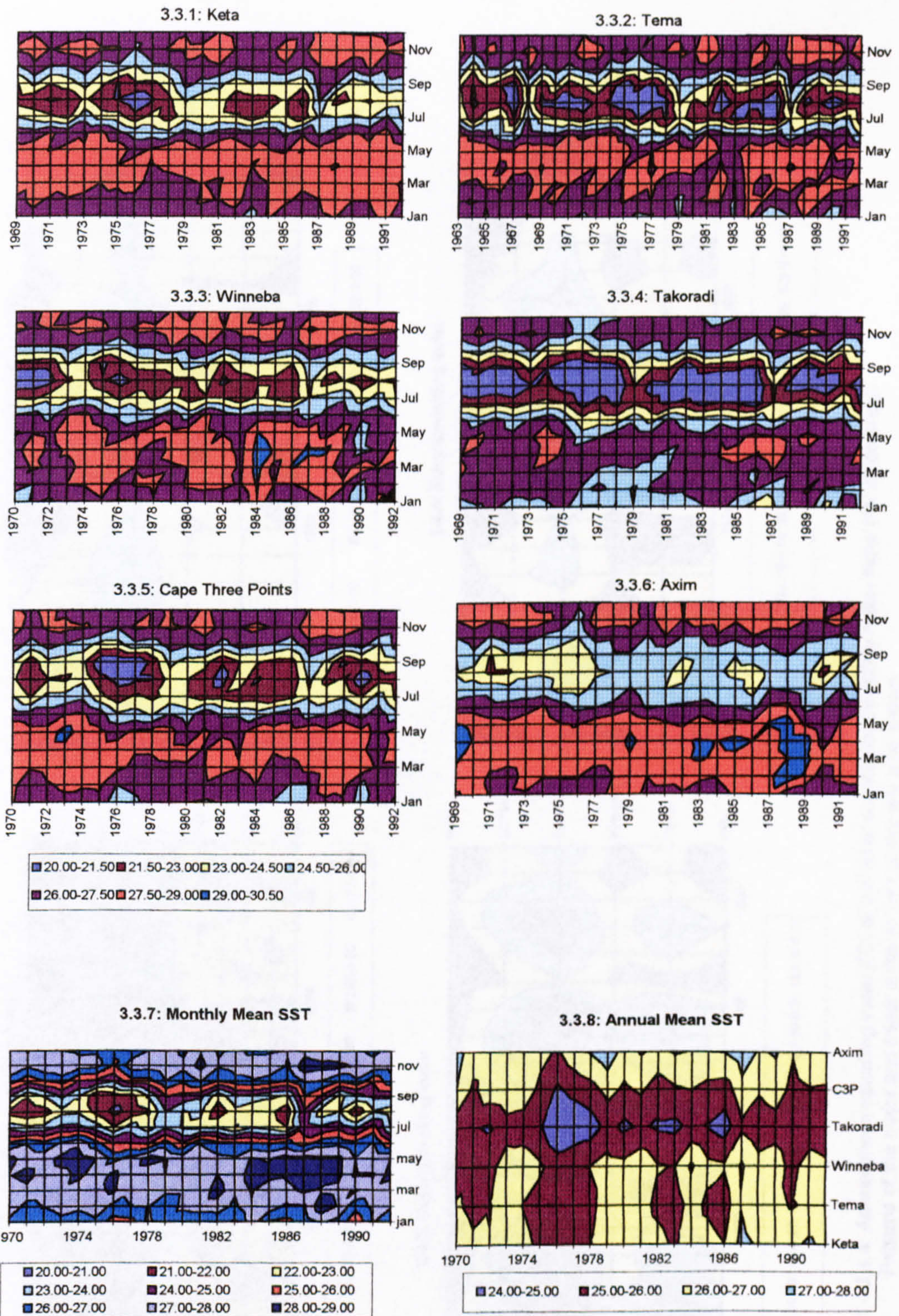
Table 3.2 Quarterly means of upwelling index (°C) from records at the indicated centres (1,2,3, and 4 indicate four quarters of the year), 1963 - 1992

| Month | Keta |      |      |       | Tema |       |      |       | Winneba |       |      |       |
|-------|------|------|------|-------|------|-------|------|-------|---------|-------|------|-------|
|       | 1    | 2    | 3    | 4     | 1    | 2     | 3    | 4     | 1       | 2     | 3    | 4     |
| 1963  |      |      |      |       | 2.01 | 0.12  | 3.19 | 0.03  |         |       |      |       |
| 1964  |      |      |      |       | 2.35 | -0.09 | 4.01 | 0.90  |         |       |      |       |
| 1965  |      |      |      |       | 1.34 | -0.03 | 2.48 | -0.30 |         |       |      |       |
| 1966  |      |      |      |       | 1.09 | 1.54  | 2.59 | 0.12  |         |       |      |       |
| 1967  |      |      |      |       | 1.92 | 0.96  | 4.92 | 0.59  |         |       |      |       |
| 1968  |      |      |      |       | 1.33 | 0.56  | 0.99 | -0.06 |         |       |      |       |
| 1969  | 1.59 | 0.71 | 2.18 | -0.55 | 1.52 | 0.61  | 3.22 | -0.24 |         |       |      |       |
| 1970  | 0.81 | 0.46 | 2.06 | -0.67 | 1.28 | 0.66  | 2.76 | -0.20 | 2.62    | 1.36  | 3.89 | 0.00  |
| 1971  | 0.51 | 0.76 | 3.17 | 0.17  | 1.35 | 0.43  | 3.91 | 0.51  | 1.47    | 1.08  | 3.97 | 0.05  |
| 1972  | 1.34 | 0.88 | 2.71 | 0.73  | 1.75 | 0.67  | 3.37 | 0.22  | 1.86    | 1.92  | 3.05 | 0.32  |
| 1973  | 1.85 | 1.09 | 1.81 | 0.03  | 1.84 | 0.81  | 3.30 | 0.14  | 2.03    | 0.80  | 2.62 | 0.25  |
| 1974  | 1.30 | 0.34 | 2.99 | 0.38  | 1.54 | -0.01 | 3.62 | 0.80  | 1.07    | 0.26  | 2.18 | -0.08 |
| 1975  | 1.54 | 1.20 | 3.76 | 0.23  | 1.34 | 1.10  | 4.68 | 0.45  | 0.55    | 1.29  | 3.64 | 0.04  |
| 1976  | 1.07 | 1.05 | 2.79 | 0.71  | 1.11 | 0.98  | 3.61 | 0.59  | 1.02    | 0.99  | 2.51 | -0.03 |
| 1977  | 1.00 | 1.05 | 2.92 | 0.73  | 0.84 | 1.24  | 4.02 | 0.83  | 0.80    | 1.10  | 2.28 | 0.21  |
| 1978  | 0.84 | 0.96 | 2.25 | -0.28 | 0.83 | 0.78  | 3.40 | -0.31 | 0.53    | 1.13  | 2.33 | -0.46 |
| 1979  | 1.88 | 0.57 | 0.80 | -0.23 | 2.50 | 0.69  | 1.16 | -0.20 | 1.85    | 0.70  | 2.45 | -0.59 |
| 1980  | 1.39 | 0.99 | 1.75 | -0.35 | 1.86 | 1.27  | 2.49 | -0.20 | 1.44    | 0.93  | 2.45 | -0.40 |
| 1981  | 1.24 | 0.73 | 1.92 | -0.30 | 1.29 | 0.82  | 2.64 | -0.41 | 0.94    | 0.74  | 2.11 | -0.53 |
| 1982  | 1.00 | 0.49 | 2.24 | -0.23 | 1.27 | 0.95  | 3.84 | 0.04  | 1.24    | 0.85  | 3.02 | -0.37 |
| 1983  | 2.43 | 1.52 | 2.35 | 0.46  | 2.79 | 2.36  | 2.98 | 0.54  | 1.89    | 2.17  | 2.61 | -0.45 |
| 1984  | 0.83 | 0.32 | 2.82 | 0.36  | 0.42 | 0.25  | 3.97 | -0.08 | -0.70   | -0.26 | 2.64 | -0.08 |
| 1985  | 1.20 | 1.40 | 2.38 | -0.36 | 1.88 | 1.02  | 4.14 | -0.31 | 1.73    | 0.46  | 2.99 | -0.21 |
| 1986  | 1.56 | 1.16 | 3.29 | 0.10  | 1.95 | 1.24  | 4.62 | 0.69  | 1.10    | 1.23  | 3.27 | 0.09  |
| 1987  | 0.50 | 1.29 | 0.91 | -0.16 | 1.22 | 1.24  | 1.46 | 0.00  | 0.45    | 1.14  | 1.82 | -0.10 |
| 1988  | 0.82 | 1.02 | 1.99 | -0.26 | 1.18 | 1.52  | 3.36 | 0.00  | 0.79    | 1.72  | 2.24 | -0.07 |
| 1989  | 1.18 | 0.39 | 2.99 | -0.06 | 1.32 | 0.57  | 4.12 | -0.01 | 1.54    | 1.24  | 2.53 | -0.08 |
| 1990  | 0.85 | 1.57 | 1.89 | -0.62 | 1.82 | 2.19  | 3.02 | -0.27 | 2.02    | 3.52  | 2.16 | 0.03  |
| 1991  | 0.50 | 0.38 | 0.93 | 0.07  | 1.63 | 1.45  | 2.33 | 0.71  | 1.33    | 1.78  | 1.43 | 0.14  |
| 1992  | 1.74 | 0.47 | 0.99 | -0.10 | 1.84 | 0.97  | 2.52 | -0.23 | 1.50    | 1.37  | 1.79 | -0.23 |
| Mean  | 1.21 | 0.87 | 2.25 | -0.01 | 1.55 | 0.90  | 3.22 | 0.14  | 1.21    | 0.87  | 2.25 | -0.01 |

Table 3.2 continued

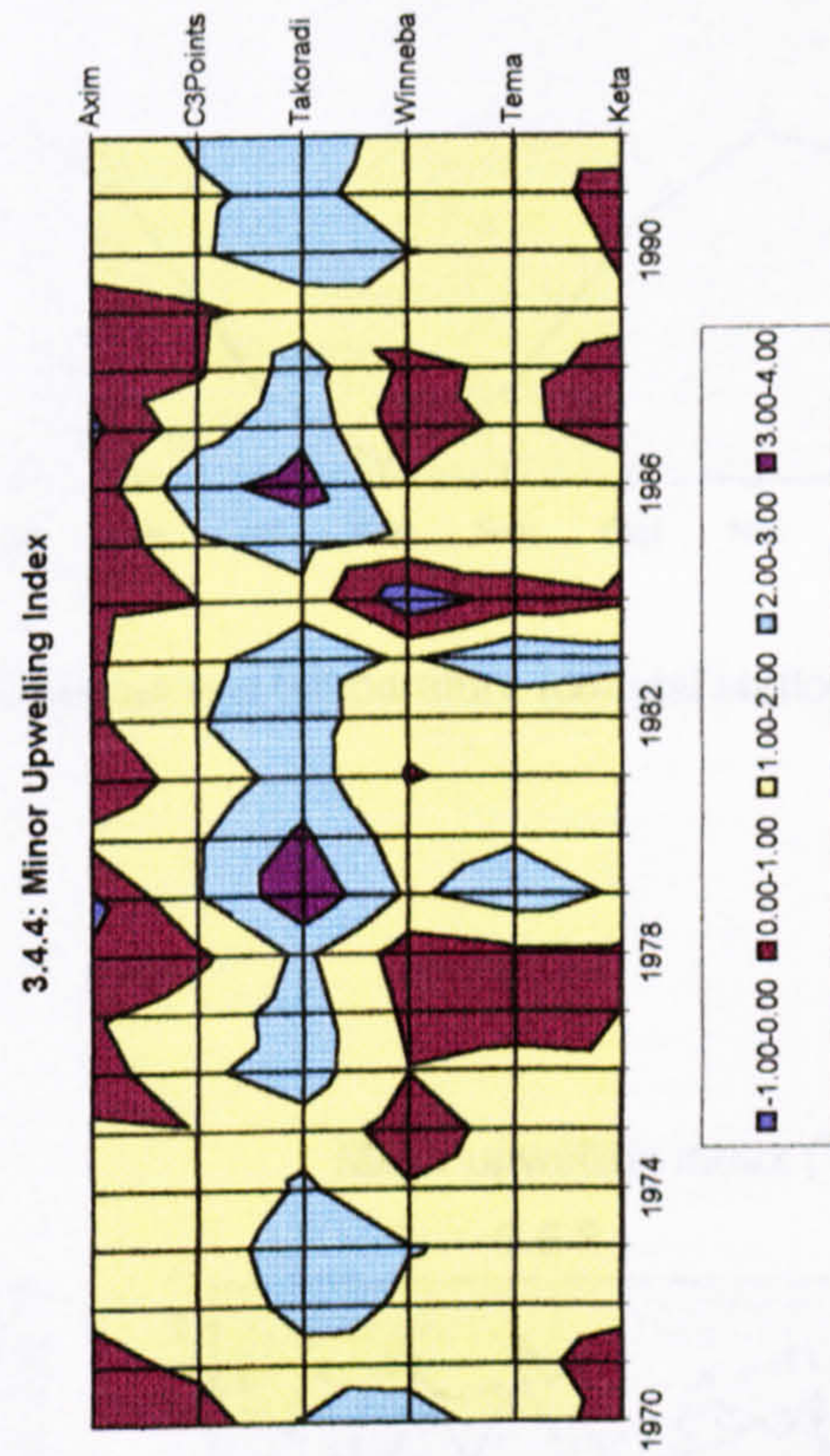
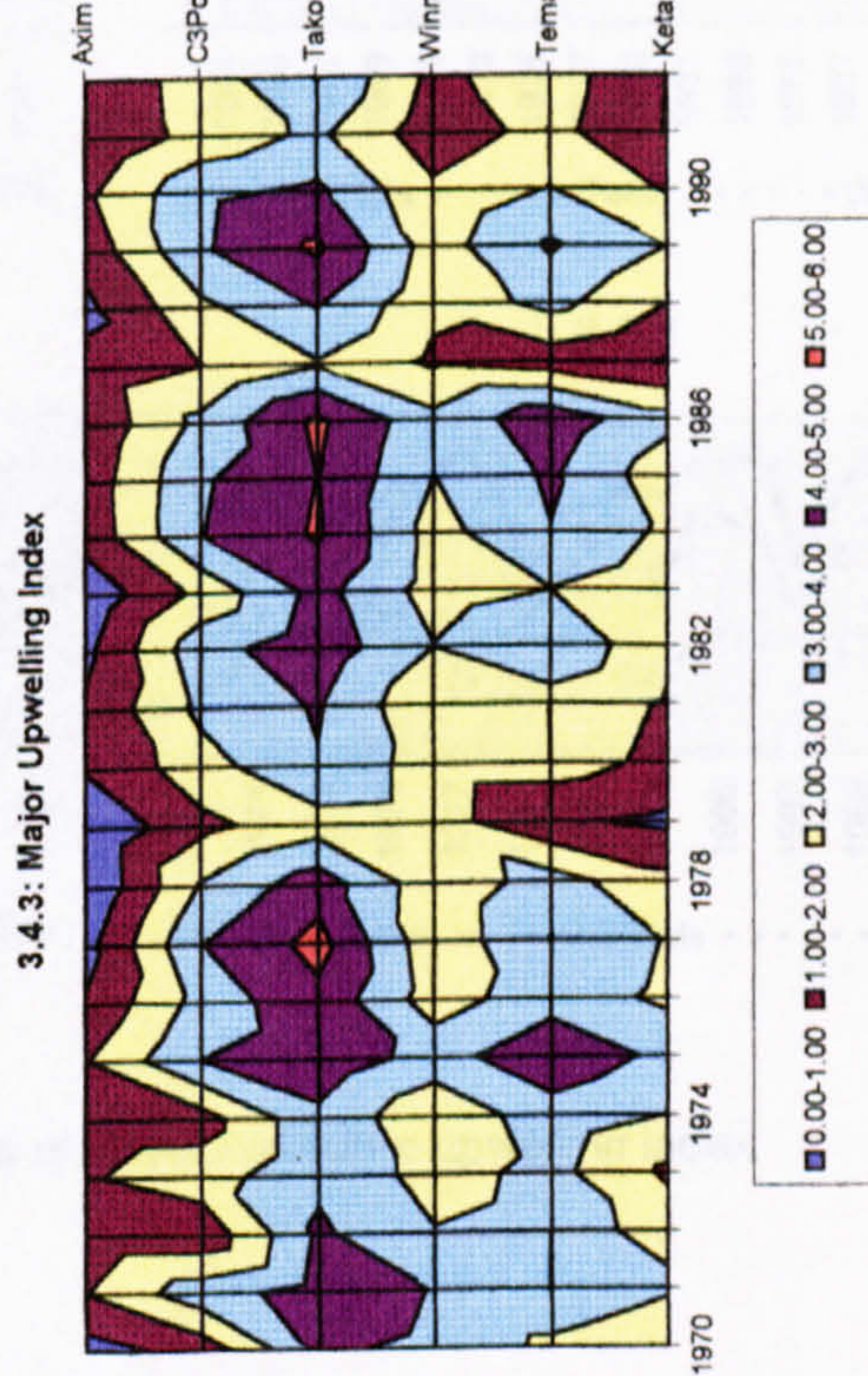
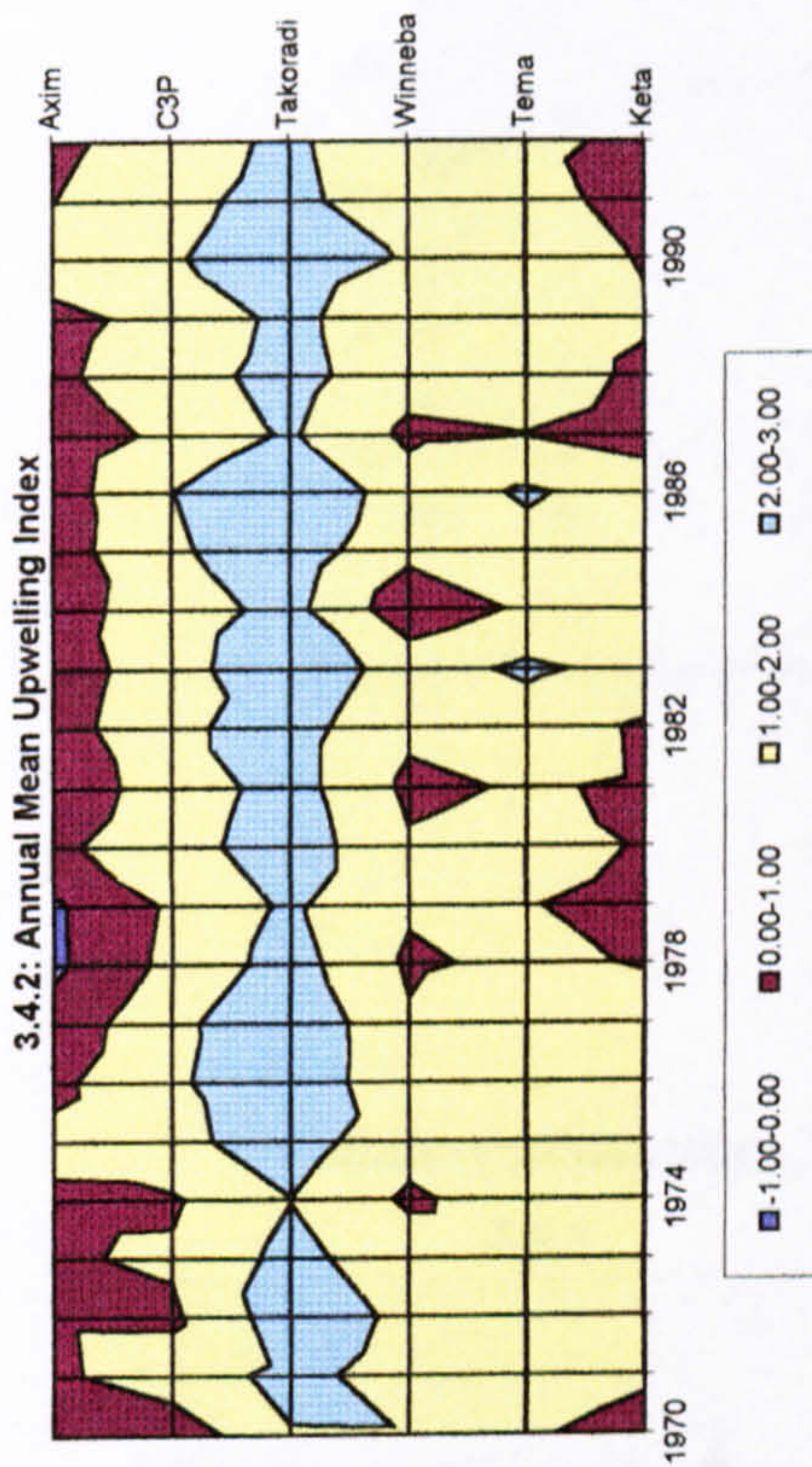
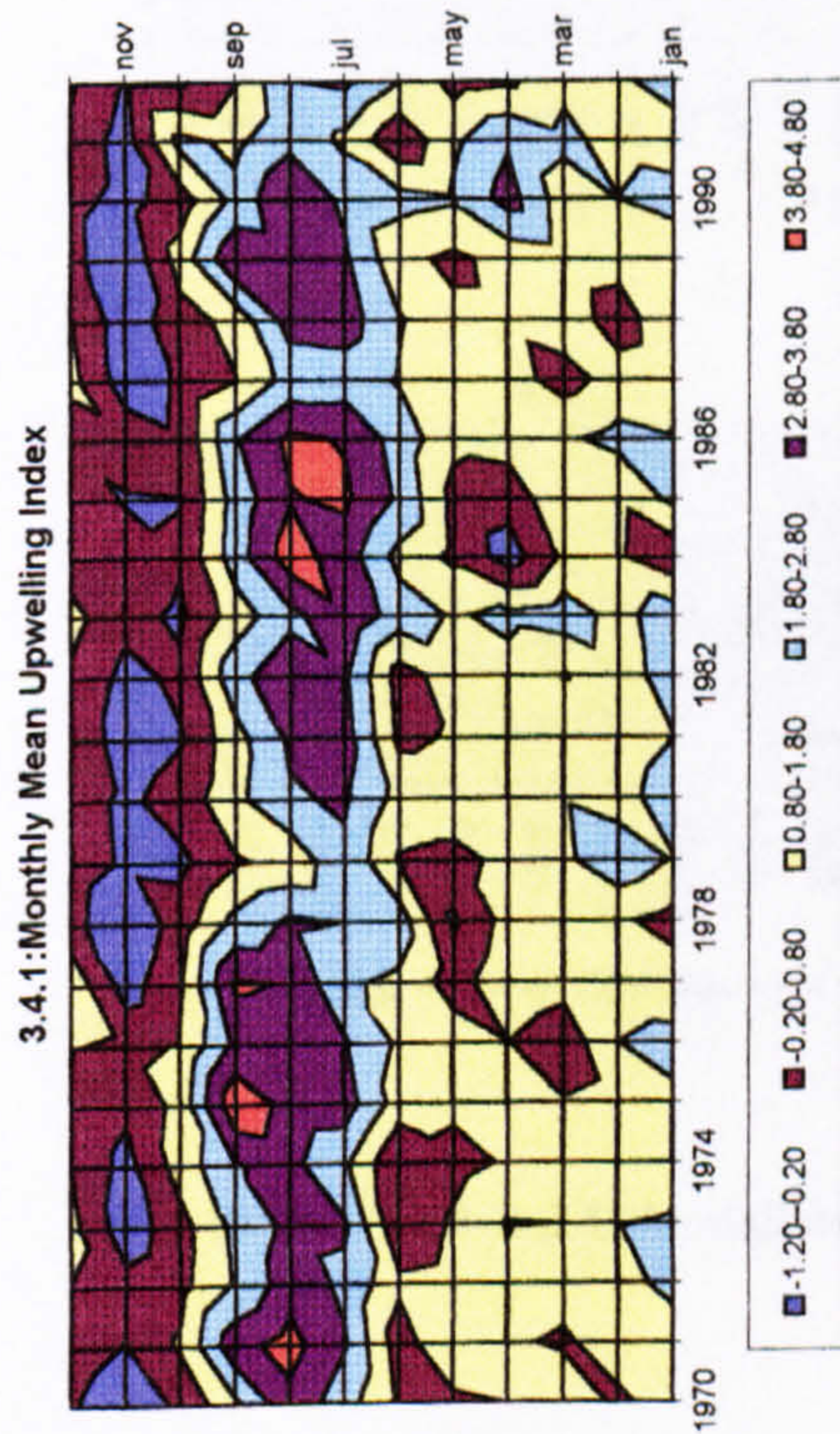
| Month | Takoradi |      |      |      | Cape Three Points |      |      |       | Axim  |       |      |       |
|-------|----------|------|------|------|-------------------|------|------|-------|-------|-------|------|-------|
|       | 1        | 2    | 3    | 4    | 1                 | 2    | 3    | 4     | 1     | 2     | 3    | 4     |
| 1963  |          |      |      |      |                   |      |      |       |       |       |      |       |
| 1964  |          |      |      |      |                   |      |      |       |       |       |      |       |
| 1965  |          |      |      |      |                   |      |      |       |       |       |      |       |
| 1966  |          |      |      |      |                   |      |      |       |       |       |      |       |
| 1967  |          |      |      |      |                   |      |      |       |       |       |      |       |
| 1968  |          |      |      |      |                   |      |      |       |       |       |      |       |
| 1969  | 2.47     | 1.63 | 4.27 | 0.37 |                   |      |      |       | 0.75  | 0.14  | 0.67 | -0.98 |
| 1970  | 2.05     | 1.46 | 4.08 | 0.18 | 0.41              | 0.14 | 1.37 | -0.63 | 0.02  | 0.01  | 0.54 | -0.75 |
| 1971  | 1.57     | 1.75 | 4.38 | 1.29 | 1.22              | 1.02 | 3.61 | 0.26  | 0.59  | 0.99  | 1.99 | -0.27 |
| 1972  | 2.43     | 2.47 | 4.17 | 1.25 | 1.04              | 0.75 | 1.28 | 0.28  | 1.23  | 0.98  | 1.20 | 0.07  |
| 1973  | 2.66     | 2.00 | 3.80 | 0.73 | 1.37              | 0.15 | 2.54 | 0.41  | 1.09  | 0.71  | 1.91 | -0.06 |
| 1974  | 2.17     | 0.54 | 3.79 | 1.40 | 1.00              | 0.56 | 1.56 | 0.42  | 1.13  | 0.73  | 1.49 | 0.05  |
| 1975  | 1.62     | 1.92 | 4.62 | 1.59 | 1.05              | 1.21 | 4.00 | 0.84  | 1.19  | 1.33  | 1.96 | 0.50  |
| 1976  | 2.44     | 2.46 | 4.72 | 1.75 | 1.84              | 1.31 | 3.38 | 0.80  | 0.52  | 0.74  | 1.10 | 0.80  |
| 1977  | 2.46     | 2.28 | 5.34 | 1.45 | 1.43              | 1.02 | 3.98 | 0.47  | 0.89  | 0.41  | 0.67 | -0.38 |
| 1978  | 2.19     | 2.00 | 4.56 | 0.89 | 0.81              | 1.30 | 3.10 | -0.19 | 0.09  | 0.23  | 0.03 | -1.07 |
| 1979  | 3.76     | 1.73 | 2.57 | 0.59 | 1.91              | 0.95 | 1.75 | -0.02 | -0.15 | -0.07 | 0.07 | -0.52 |
| 1980  | 3.17     | 2.49 | 3.94 | 0.76 | 1.89              | 1.70 | 2.57 | 0.04  | 1.25  | 0.72  | 1.07 | 0.29  |
| 1981  | 2.45     | 2.09 | 4.08 | 1.05 | 1.36              | 1.06 | 3.22 | -0.03 | 0.40  | 0.92  | 1.16 | -0.57 |
| 1982  | 2.46     | 1.90 | 4.60 | 0.70 | 1.95              | 1.24 | 3.63 | 0.38  | 0.84  | 0.82  | 0.78 | -0.27 |
| 1983  | 2.43     | 3.07 | 4.32 | 1.15 | 1.82              | 2.08 | 2.25 | 0.31  | 0.86  | 0.87  | 0.27 | -0.30 |
| 1984  | 1.71     | 1.21 | 5.12 | 1.20 | 0.98              | 0.71 | 3.97 | 0.38  | 0.78  | 0.62  | 1.32 | -0.35 |
| 1985  | 2.34     | 1.86 | 5.02 | 1.09 | 1.84              | 1.15 | 3.87 | 0.57  | 0.19  | 0.75  | 1.42 | -0.25 |
| 1986  | 3.41     | 2.23 | 5.20 | 1.17 | 2.71              | 1.53 | 3.28 | 0.42  | 0.44  | 1.88  | 1.18 | -1.50 |
| 1987  | 2.72     | 2.01 | 2.91 | 0.81 | 1.59              | 1.16 | 2.00 | 0.16  | -0.22 | 0.60  | 1.34 | -0.06 |
| 1988  | 2.46     | 2.51 | 4.05 | 0.95 | 0.88              | 1.80 | 2.78 | 0.18  | 0.41  | -0.74 | 0.73 | 0.06  |
| 1989  | 1.46     | 1.54 | 5.17 | 0.84 | 0.80              | 0.73 | 3.87 | -0.15 | 0.45  | 1.15  | 1.36 | -0.08 |
| 1990  | 2.67     | 2.61 | 4.20 | 0.48 | 1.87              | 2.00 | 3.78 | 0.04  | 1.52  | 2.71  | 1.81 | 0.10  |
| 1991  | 2.36     | 2.01 | 3.20 | 1.84 | 1.83              | 1.85 | 2.37 | 0.87  | 1.50  | 1.01  | 1.07 | 0.34  |
| 1992  | 2.67     | 1.60 | 4.05 | 0.57 | 2.17              | 0.97 | 2.42 | 0.30  | 1.20  | 0.34  | 1.25 | 0.30  |
| Mean  | 1.55     | 0.90 | 3.22 | 0.14 | 1.21              | 0.87 | 2.25 | -0.01 | 1.55  | 0.90  | 3.22 | 0.14  |





Figures 3.3.1 - 3.3.8: Monthly mean SST at the indicated coastal stations; overall means (all stations and all months) are also shown





Figures 3.4.1 - 3.4.4: Annual mean upwelling index ( $^{\circ}\text{C}$ ) at indicated centres and monthly mean index (for all centres). Patterns of the major and minor index at the centres are also shown.



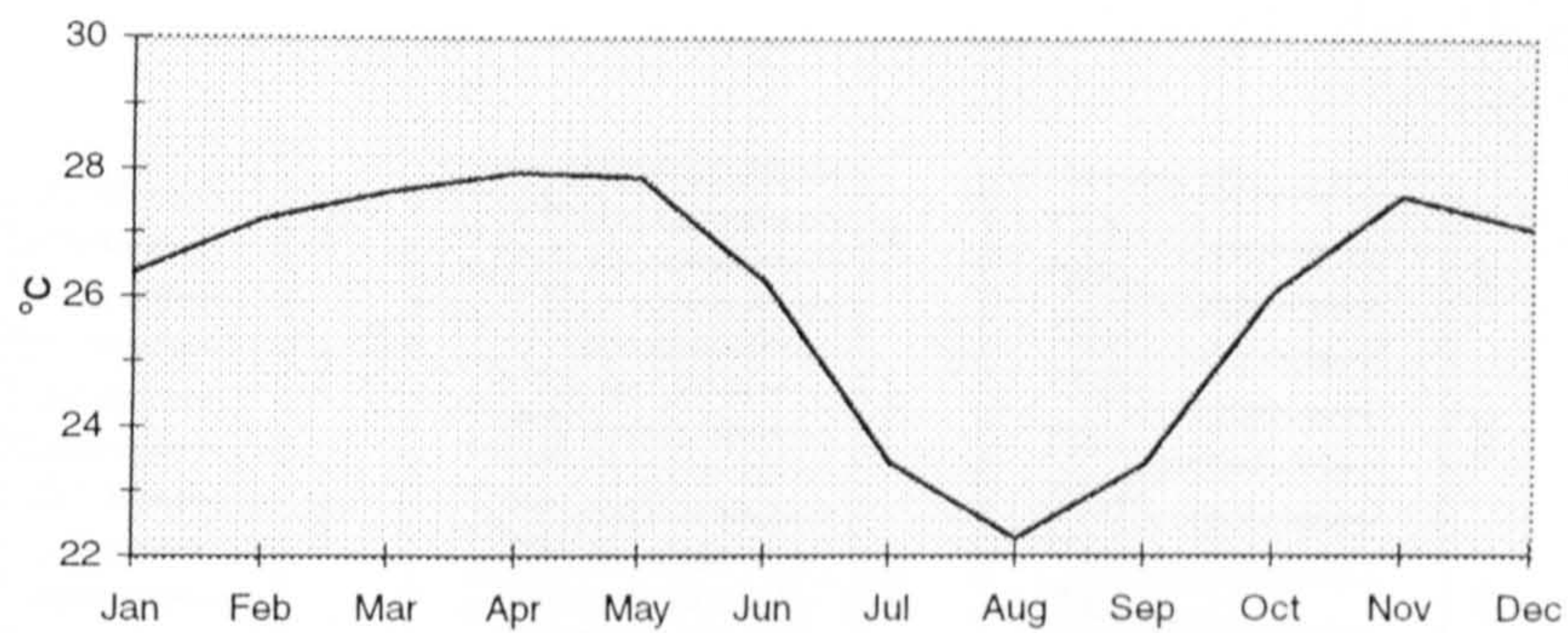


Figure 3.5. Seasonal cycle of sea surface temperature (coastal stations)

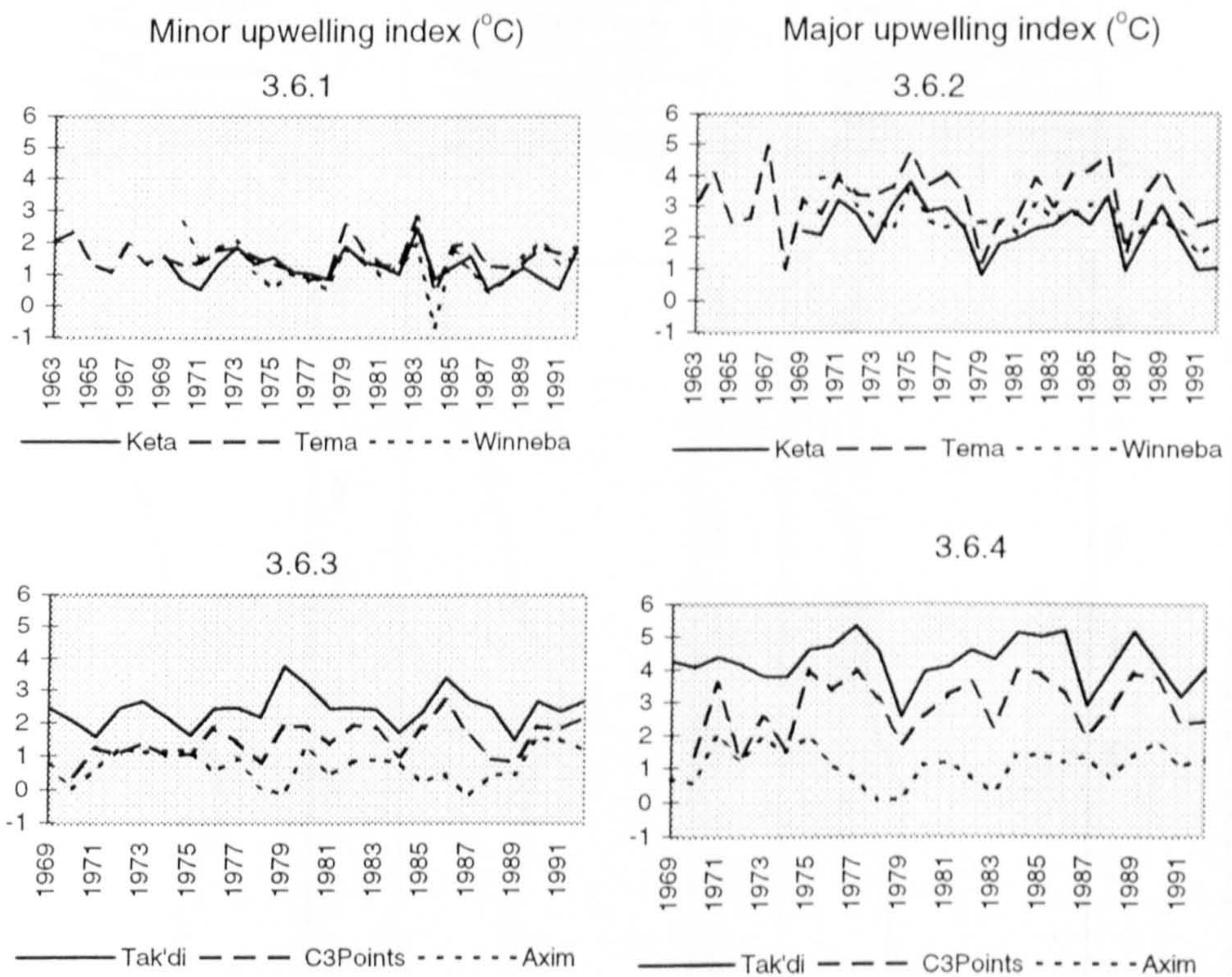


Figure 3.6.1-3.6.4. Annual means of major and minor upwelling index



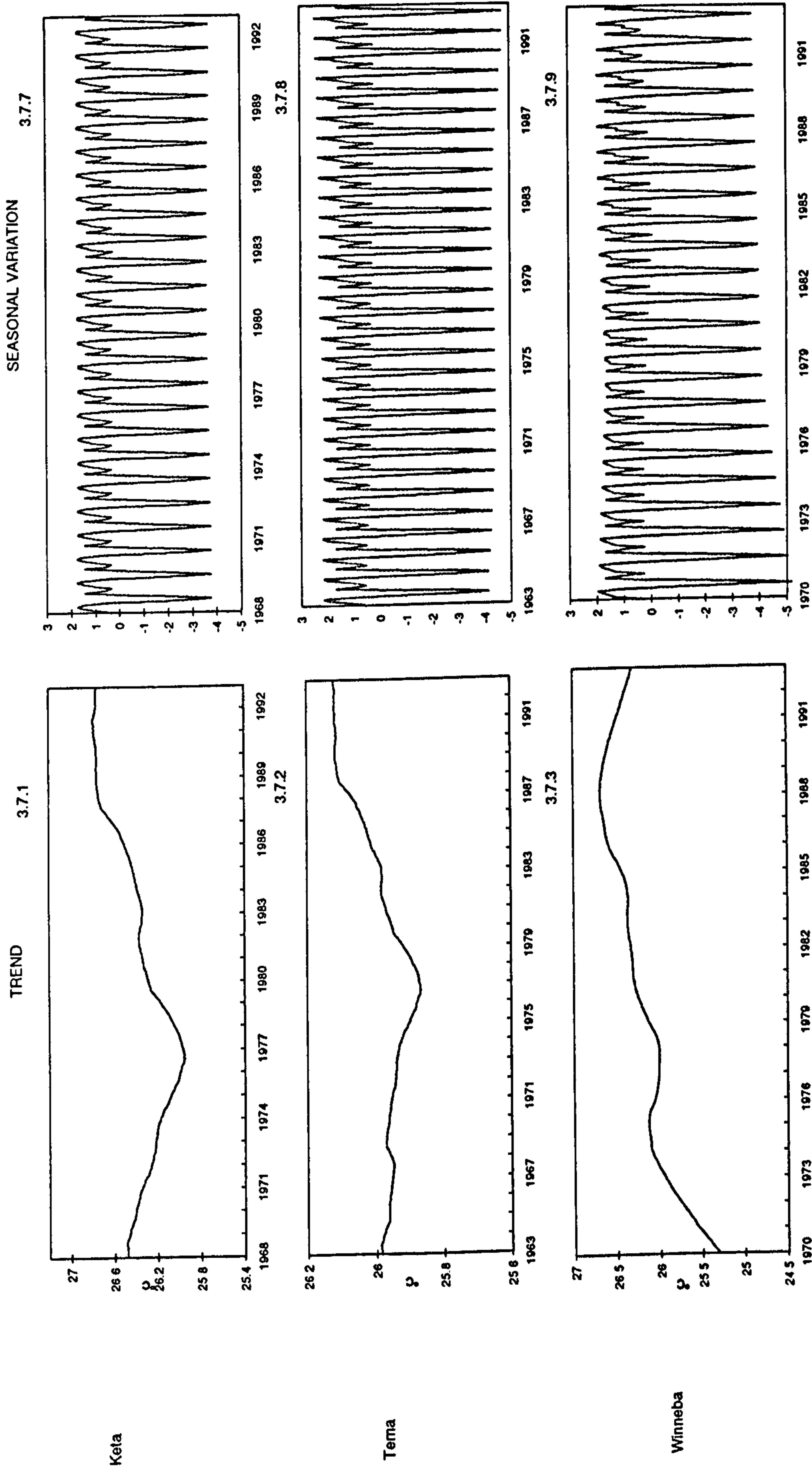


Figure 3.7. Trend (3.7.1 - 3.7.6) and seasonal variation (3.7.7 - 3.7.12) of sea surface temperature series at six coastal stations in Ghana

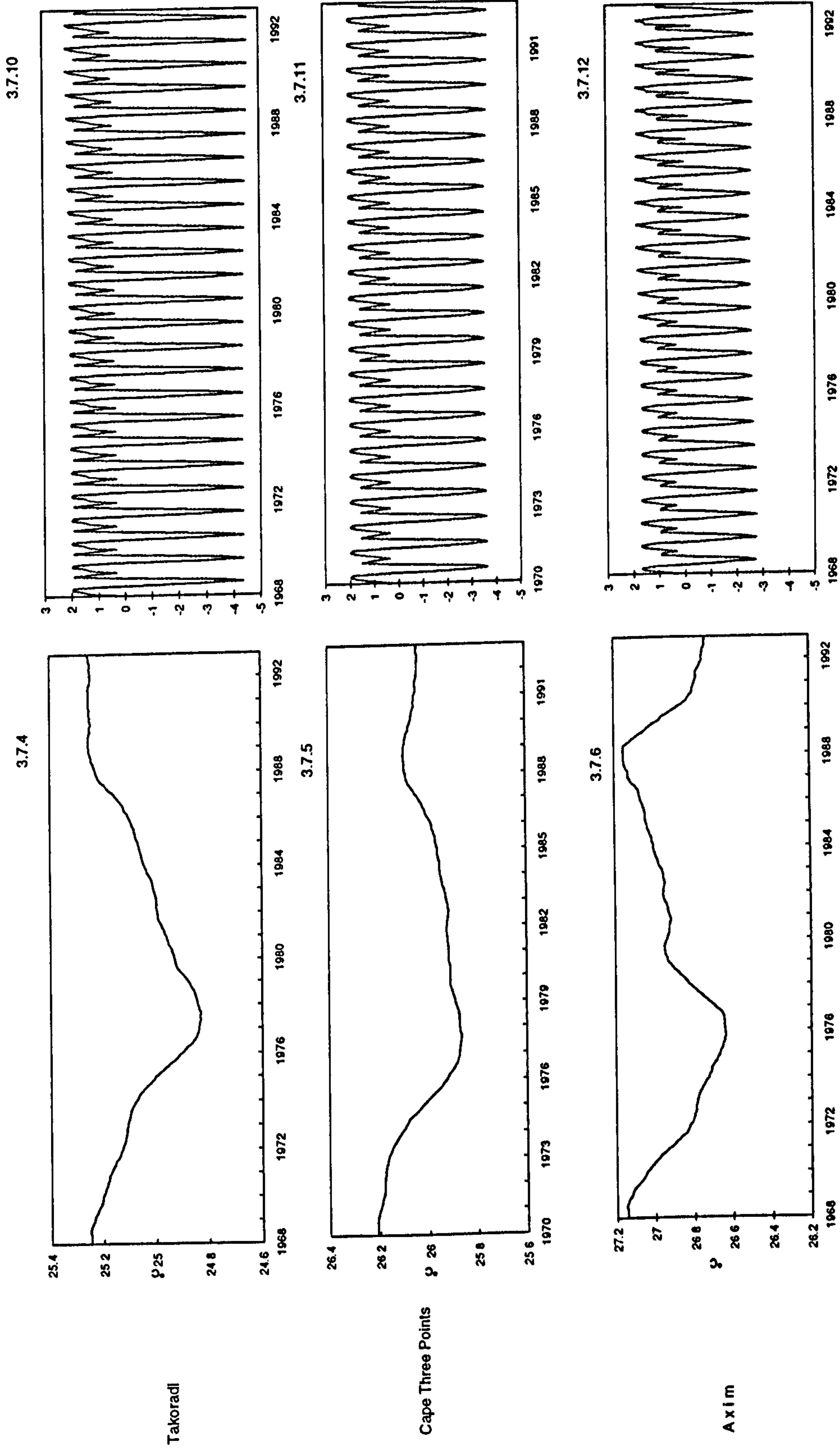
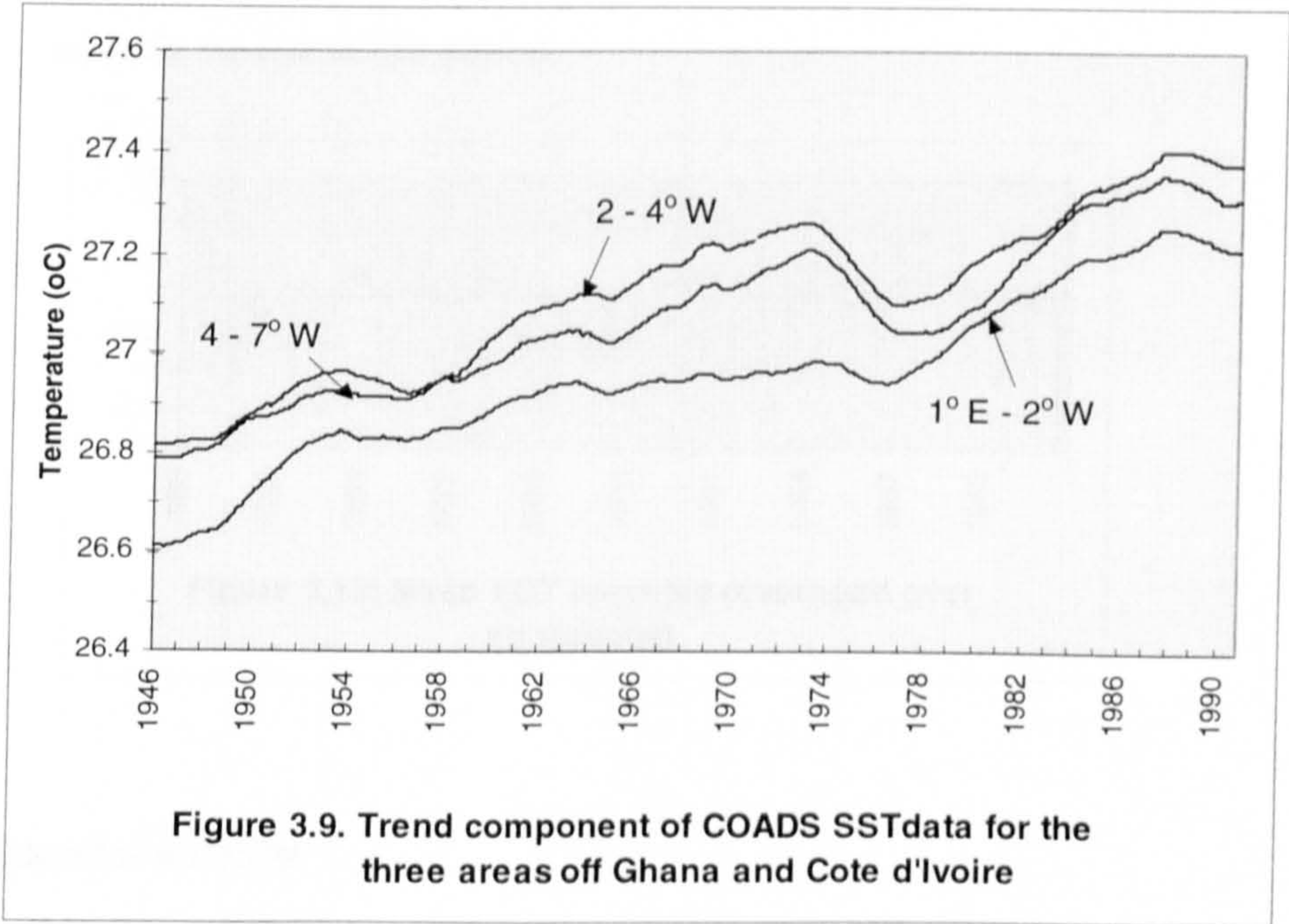
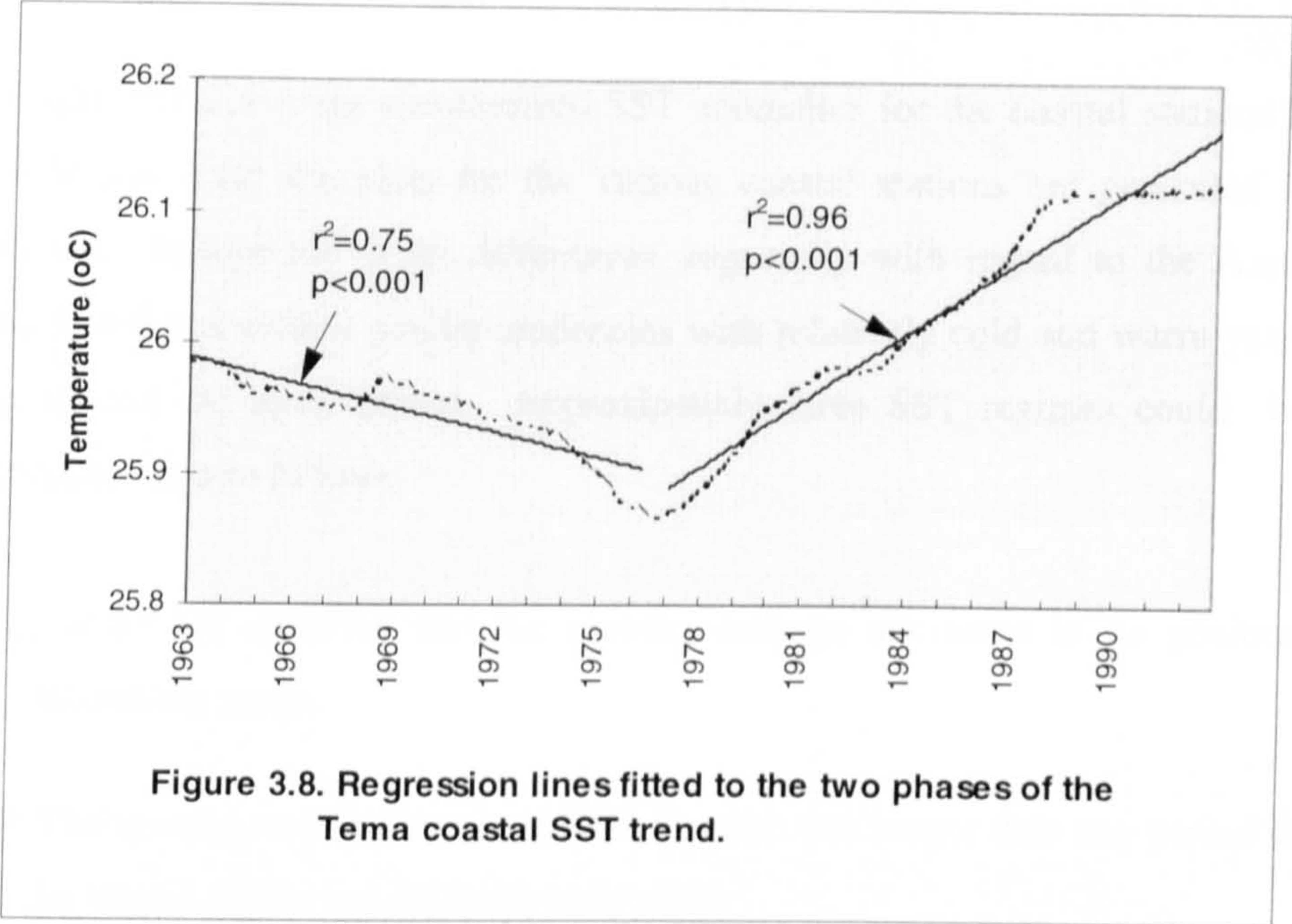


Figure 3.7. continued







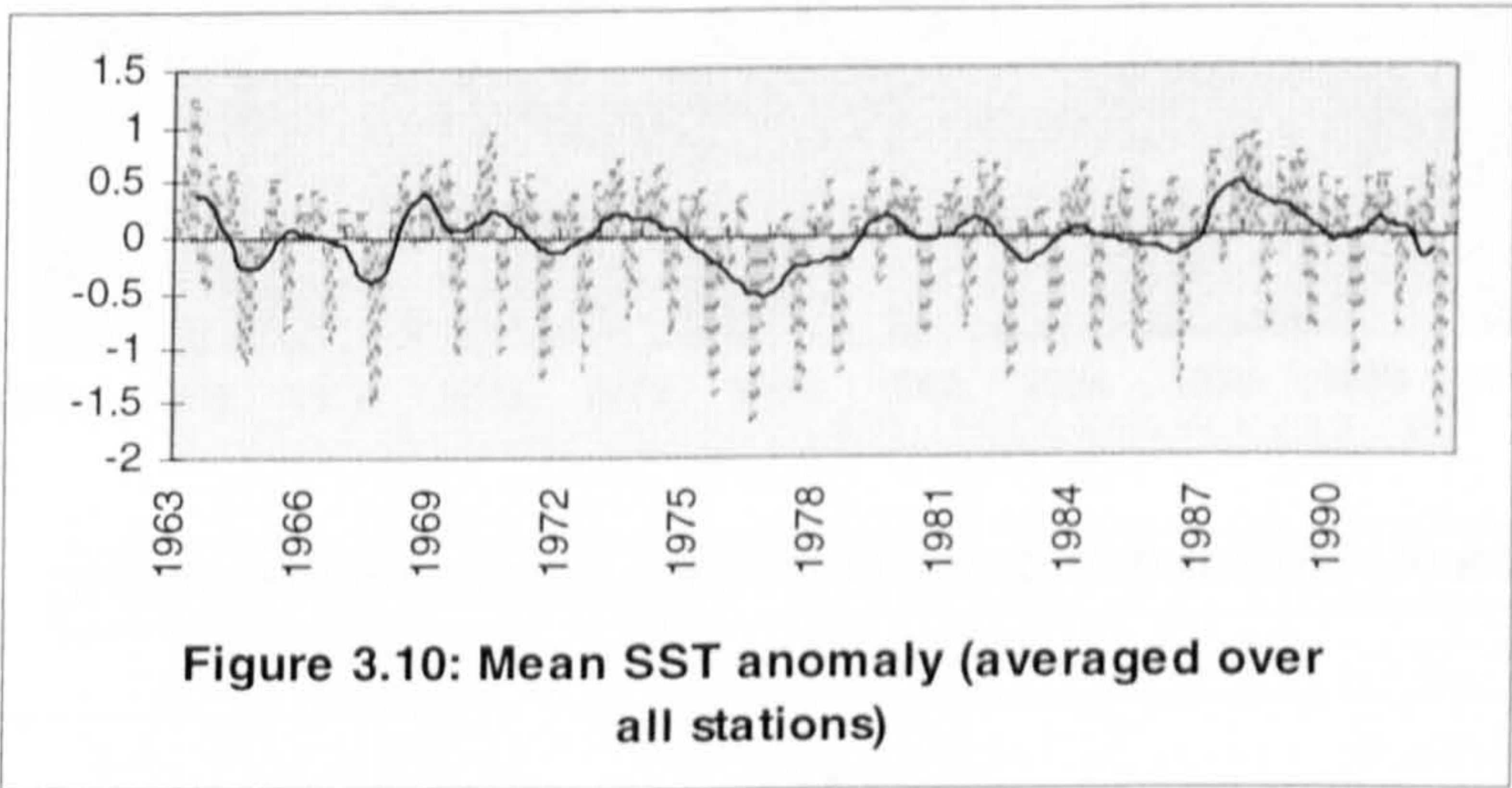
3.4.1.2 Sea surface temperature anomalies

A plot of the average standardized SST anomalies for the coastal stations is shown in Figure 3.10; the plots for the various coastal stations are presented in Appendix 3.4. Except for minor differences, especially with regard to the Axim series, the five series exhibit similar tendencies with relatively cold and warm years occurring around the same period. Approximately three SST regimes could be identified from these as follows:

Regime 1: SSTs are unsettled and the moving average alternates in its position around the mean.

Regime 2: The moving average remains below the zero line longer than any period in the series. These are relatively cold years.

Regime 3: SSTs are unsettled initially but the anomalies generally remain positive towards the end of this period.



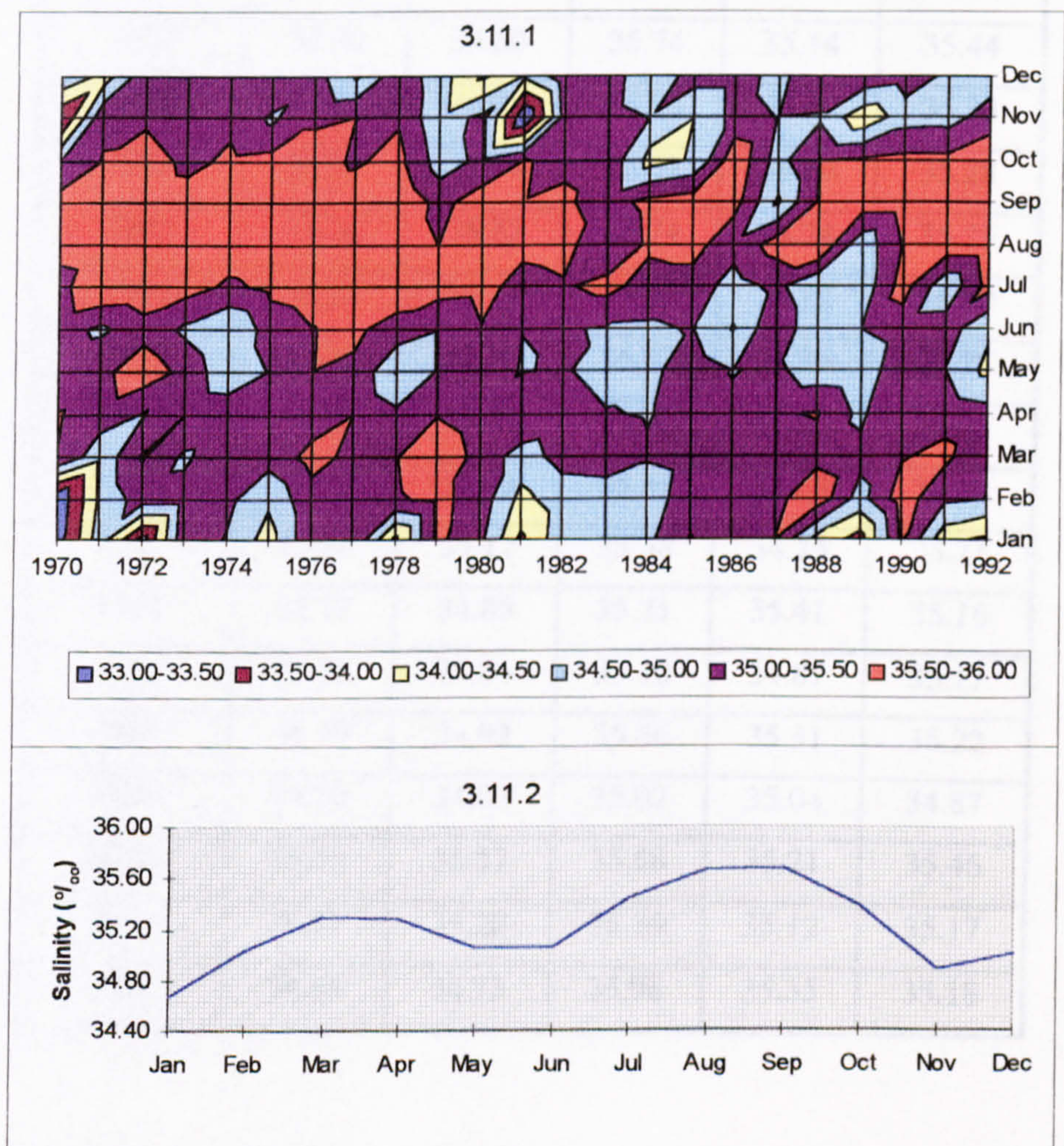
3.4.2 Coastal salinity

The seasonal means of Tema beach salinity for the period 1970 to 1992 are presented in Table 3.3. Major upwelling salinities were higher than those in the minor upwelling. Figure 3.11.1 is a plot of monthly mean salinity by year and Figure 3.11.2 depicts the seasonal variation averaged over the 23 years of observation (1970-1992). In Figure 3.12.1 - 3.12.4, the observed salinity series and components



are plotted against time (years). Figures 3.12.2 (trend) shows a period of rising salinity (up to about 35.45 ‰) between 1970 and 1978. Between 1978 and 1982, the salinity declined rapidly (to about 35.2 ‰ in 1982) and stabilised around this value until the end of the series.

From the behaviour of the seasonal component in Figure 3.12.3 (and as portrayed in Figure 3.11.2 as well), the distribution of coastal salinity also has two maxima and two minima (like the coastal temperature). The maxima correspond to the periods of coastal cooling (upwelling) and the minima correspond to the warm periods.

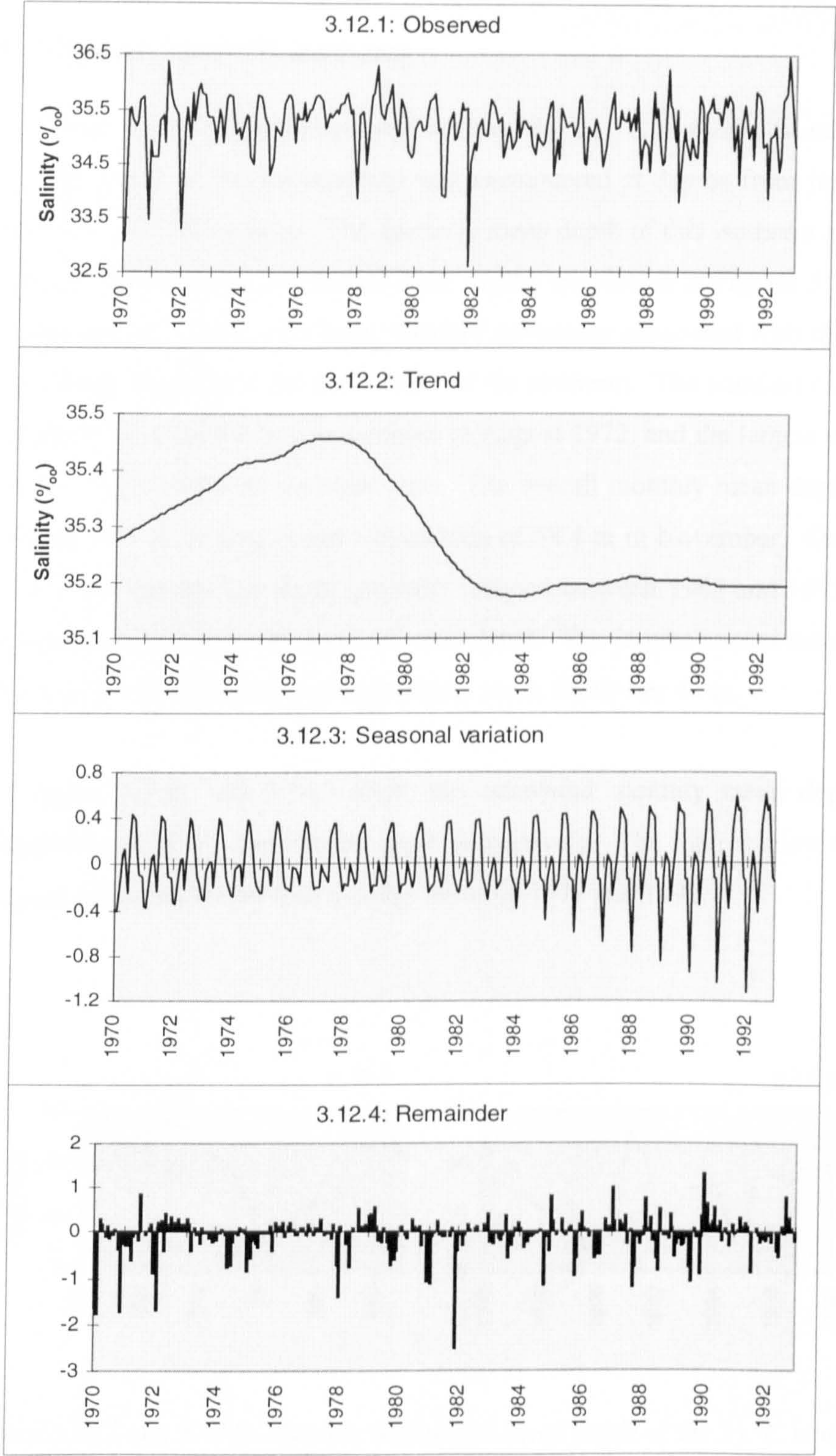


Figures 3.11.1 and 3.11.2: Monthly mean (3.11.1) and seasonal variation (3.11.2) of Tema coastal salinity (‰).



Table 3.3: Monthly means of coastal salinity recorded off Tema, 1970-1992

| Year | Ja - Ma | Ap - Ju | Jy - Se | Oc - De | Mean  |
|------|---------|---------|---------|---------|-------|
| 1970 | 33.93   | 35.35   | 35.57   | 34.48   | 34.83 |
| 1971 | 34.68   | 35.20   | 35.92   | 35.08   | 35.22 |
| 1972 | 34.68   | 35.36   | 35.88   | 35.51   | 35.36 |
| 1973 | 35.16   | 35.25   | 35.73   | 35.20   | 35.33 |
| 1974 | 35.16   | 34.82   | 35.63   | 35.40   | 35.25 |
| 1975 | 34.69   | 35.13   | 35.71   | 35.34   | 35.22 |
| 1976 | 35.44   | 35.42   | 35.75   | 35.43   | 35.51 |
| 1977 | 35.40   | 35.50   | 35.74   | 35.14   | 35.44 |
| 1978 | 34.91   | 34.98   | 35.96   | 35.49   | 35.33 |
| 1979 | 35.74   | 35.18   | 35.52   | 34.69   | 35.28 |
| 1980 | 35.26   | 35.25   | 35.74   | 34.74   | 35.25 |
| 1981 | 34.34   | 35.15   | 35.49   | 34.22   | 34.80 |
| 1982 | 34.95   | 35.14   | 35.57   | 35.36   | 35.25 |
| 1983 | 34.88   | 34.93   | 35.32   | 35.23   | 35.09 |
| 1984 | 34.87   | 34.93   | 35.51   | 34.63   | 34.98 |
| 1985 | 35.34   | 35.17   | 35.58   | 34.75   | 35.21 |
| 1986 | 35.17   | 34.85   | 35.21   | 35.41   | 35.16 |
| 1987 | 35.38   | 35.34   | 35.10   | 34.87   | 35.17 |
| 1988 | 35.19   | 34.92   | 35.46   | 35.31   | 35.22 |
| 1989 | 34.60   | 34.83   | 35.02   | 35.04   | 34.87 |
| 1990 | 35.59   | 35.37   | 35.68   | 35.21   | 35.46 |
| 1991 | 34.97   | 35.20   | 35.39   | 35.12   | 35.17 |
| 1992 | 34.64   | 34.73   | 35.98   | 35.35   | 35.18 |



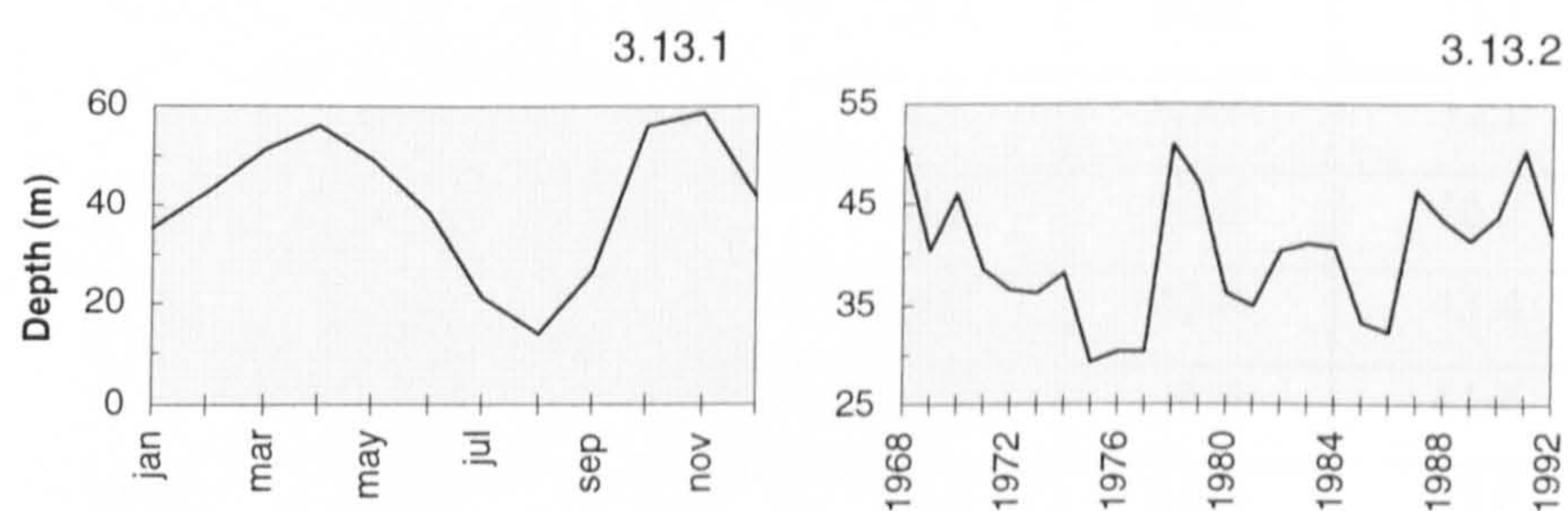
Figures 3.12.1 - 3.12.4: Observed values and components of Tema coastal salinity series, 1970 - 1992



3.4.3 Depth of the 21 °C isotherm

During the weekly hydrographic cruises, the 21 °C isotherm (used here to represent the depth of the thermocline) was encountered at depths from just below the surface to over 100 m deep. The quarterly mean depth of this isotherm are given in Table 3.4. The monthly and annual mean depths are plotted in Figures 3.13.1 and 3.13.2 respectively. There were large standard deviations associated with the means signifying large variation in the mean depth of the isotherm. The smallest calculated monthly mean depth of 4.0 m was recorded in August 1972, and the largest was 65.5 m recorded in November of the same year. The overall monthly mean depth had a minimum of 14.1 m in August and a maximum of 58.4 m in November. On annual basis, the mean thermocline depth generally reduced between 1968 and 1975 where the shallowest mean depth (29.4 m) was calculated. The largest annual mean depth (51.0 m) was in 1978 and the long-term annual mean depth was 41 m.

Figures 3.14.1 and 3.14.2 show the calculated monthly mean depth and decomposed trend of the thermocline depth respectively. The figures show that the thermocline remained deeper than average between 1977 and 1992.



Figures 3.13.1 and 3.13.2: Monthly and annual mean depth of the 21 °C isotherm

Table 3.4. Quarterly mean depth of the 21 °C isotherm measured at Station B on the Tema hydrographic transect, 1968 - 1992

| Year | Ja - Ma | Ap - Ju | Jy - Se | Oc - De | Mean* |
|------|---------|---------|---------|---------|-------|
| 1968 | 60.4    | 58.2    | 39.1    | 50.4    | 50.8  |
| 1969 | 43.2    | 43.9    | 20.0    | 57.9    | 40.4  |
| 1970 | 52.6    | 49.6    | 26.5    | 61.6    | 46.2  |
| 1971 | 58.2    | 53.1    | 16.2    | 43.9    | 38.5  |
| 1972 | 40.1    | 34.6    | 18.6    | 53.3    | 36.7  |
| 1973 | 36.8    | 57.1    | 26.9    | 48.1    | 36.1  |
| 1974 | 31.6    | 54.4    | 18.6    | 40.0    | 38.1  |
| 1975 | -       | 43.6    | 10.1    | 47.3    | 29.4  |
| 1976 | 30.0    | 27.8    | 15.9    | 46.9    | 30.4  |
| 1977 | 34.3    | 47.5    | 15.3    | 31.8    | 30.2  |
| 1978 | 48.8    | 49.0    | N.O.    | 50.2    | 51.0  |
| 1979 | 39.9    | 70.8    | N.O.    | 47.7    | 47.2  |
| 1980 | 46.7    | 39.0    | 19.5    | 61.4    | 36.1  |
| 1981 | N.O.    | 36.0    | 27.2    | 54.3    | 34.8  |
| 1982 | 42.6    | 60.7    | 15.0    | 57.1    | 40.6  |
| 1983 | 39.9    | 35.4    | 24.3    | 57.0    | 41.1  |
| 1984 | 58.8    | 48.4    | 15.6    | 53.9    | 40.7  |
| 1985 | 32.7    | 37.5    | 17.1    | 50.2    | 33.1  |
| 1986 | 43.6    | 40.9    | 4.7     | N.O.    | 32.2  |
| 1987 | N.O.    | N.O.    | 33.8    | 52.5    | 46.3  |
| 1988 | 52.3    | 51.7    | 29.8    | 47.8    | 43.4  |
| 1989 | 42.8    | 55.8    | 21.3    | 46.0    | 41.4  |
| 1990 | 31.1    | 43.3    | 22.0    | 64.0    | 43.8  |
| 1991 | 47.6    | 53.4    | N.O.    | 53.1    | 50.4  |
| 1992 | 37.3    | 39.0    | 28.6    | 63.8    | 42.1  |
|      |         |         |         |         |       |
| Mean | 43.0    | 48.0    | 20.8    | 52.2    | 41.0  |

\* Annual mean (weighted with number of samples per month); N.O. = 'no observation'.



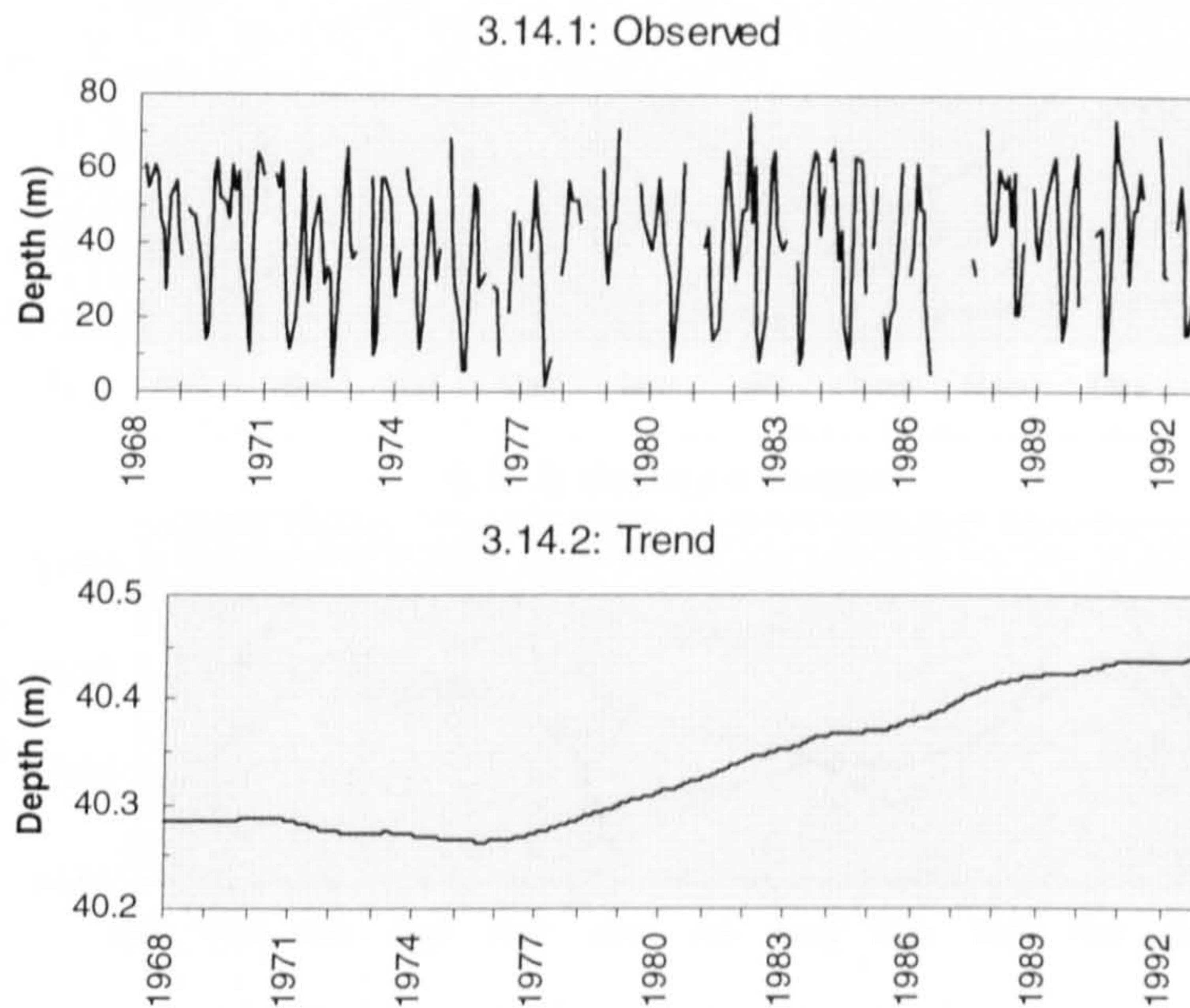


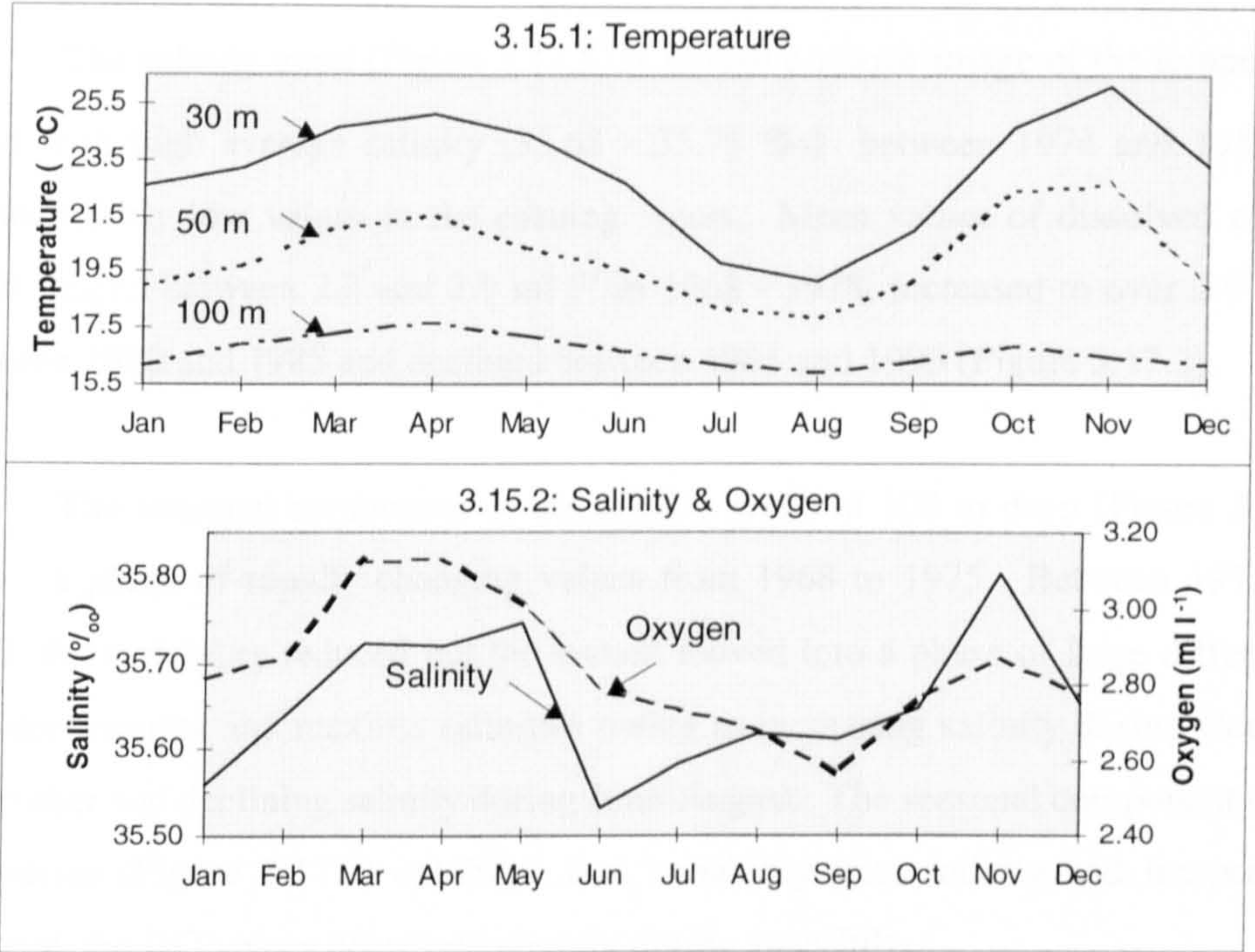
Figure 3.14.1 and 3.14.2: Observed and trend of the 21 °C isotherm depth recorded at 100 m off Tema, 1968 - 1992.

#### 3.4.4 Sub-surface environmental parameters

Monthly mean values of bottom temperature recorded at station A<sub>1</sub> (30 m deep), A<sub>2</sub> (50 m deep) and B (100 m deep) on the Tema hydrographic transect are plotted in Figure 3.15.1. The figure depicts the seasonal variation in water temperature at the indicated depths; these are similar to variation of SST. At 30 and 50 m deep average temperatures were higher in October/November than in April/May whereas the April/May temperatures were higher than October/November temperatures at 100 m deep. In all cases the lowest mean temperature was in August.

Monthly means of salinity and dissolved oxygen values at station B are shown in Figure 3.15.2. Whereas salinity had the lowest value in June, the lowest oxygen value occurred in September. Quarterly means of temperature, salinity and dissolved oxygen at Station B are given in Table 3.5.





Figures 3.15.1 and 3.15.2: Mean values of temperature, salinity and dissolved oxygen measured at 100 m deep off Tema. Mean temperature at 30 and 50 m deep are also shown in Figure 3.15.2

The trend and seasonal components from the decomposition of the time series of bottom temperature are presented in Figures 3.16.1 - 3.16.6. Each series of subsurface temperatures exhibited two phases of change in almost the same pattern as has been described for the SST series from coastal stations. The seasonal variation in the temperature data at 30 m and 50 m deep was rather uniform throughout the period of investigation (Figures 3.16.4 and 3.16.5). On the contrary, an increasing secondary warming (October - December) and declining minor upwelling temperatures are exhibited in the series recorded at 100 m deep. This phenomenon is not visible in the series from 30 and 50 m deep. It is essential to note also that the variability in temperature decreases from shallow to deep waters. Whereas departures of temperature from the mean value varied between -4 and +3 at 30 m deep the corresponding values were between -1 and 1 at 100 m deep signifying a more stable environment at this depth.



The salinity trend (Figure 3.17.5) is almost a mirror image of the temperature trend with high average salinity (35.65 - 35.75 ‰) between 1974 and 1982 and comparatively low values in the ensuing years. Mean values of dissolved oxygen (DO) ranged between 2.8 and 2.9 ml l<sup>-1</sup> in 1968 - 1978, increased to over 2.9 ml l<sup>-1</sup> between 1980 and 1985 and declined between 1985 and 1990 (Figure 3.17.2).

The seasonal component of the salinity series at 100 m deep (Figure 3.17.6) shows a phase of rapidly changing values from 1968 to 1975. Between 1975 and 1980, the variability reduced but the system moved into a phase of large differences between minima and maxima salinities owing to increasing salinity during October-December and declining salinity during June-August. The seasonal component of the DO series (Figure 3.17.3) exhibited less variability than salinity and temperature although the DO values decreased slightly during June/July.

Temperature, salinity and dissolved oxygen anomalies at 100 m were also examined; the results are shown in Appendix 3.5.

Table 3.5: Quarterly means of environmental parameters recorded at 100 m deep off Tema (Hydrographic station B)

| Year | Temperature °C |       |       |       |      | Salinity ‰ |       |       |       |       | Dissolved oxygen ml l <sup>-1</sup> |       |       |       |      |
|------|----------------|-------|-------|-------|------|------------|-------|-------|-------|-------|-------------------------------------|-------|-------|-------|------|
|      | Ja-Ma          | Ap-Ju | Jy-Se | Oc-De | Mean | Ja-Ma      | Ap-Ju | Jy-Se | Oc-De | Mean  | Ja-Ma                               | Ap-Ju | Jy-Se | Oc-De | Mean |
| 1968 | 16.7           | 17.5  | 16.1  | 16.1  | 16.6 | 35.53      | 35.67 | 35.43 | 35.76 | 35.60 | 3.39                                | 3.14  | 2.52  | 2.89  | 2.99 |
| 1969 | 17.1           | 17.6  | 16.1  | 16.5  | 16.8 | 35.69      | 35.17 | 35.34 | 34.84 | 35.26 | 3.25                                | 3.50  | 2.57  | 2.76  | 3.02 |
| 1970 | 17.0           | 17.4  | 16.2  | 16.1  | 16.7 | 34.85      | 35.92 | 35.82 | 35.69 | 35.57 | 2.92                                | 3.01  | 2.46  | 2.56  | 2.74 |
| 1971 | 17.2           | 17.6  | 16.1  | 16.5  | 16.8 | 35.73      | 35.82 | 35.77 | 35.66 | 35.74 | 2.77                                | 3.04  | 2.59  | 2.53  | 2.73 |
| 1972 | 16.2           | 16.8  | 15.9  | 16.2  | 16.3 | 35.77      | 35.70 | 35.55 | 35.93 | 35.74 | 3.00                                | 2.86  | 2.55  | 2.99  | 2.85 |
| 1973 | 17.3           | 16.8  | 16.6  | 16.2  | 16.7 | 35.10      | 35.72 | 35.73 | 35.70 | 35.56 | 2.98                                | 2.78  | 3.22  | 2.54  | 2.88 |
| 1974 | 16.2           | 17.2  | 15.9  | 15.6  | 16.2 | 35.70      | 35.73 | 35.69 | 35.69 | 35.70 | 2.58                                | 2.79  | 2.54  | 2.57  | 2.62 |
| 1975 | 15.4           | 16.8  | 15.7  | 16.2  | 16.0 | 35.62      | 35.75 | 35.68 | 35.57 | 35.66 | 2.81                                | 3.08  | 2.55  | 2.58  | 2.76 |
| 1976 | 15.7           | 16.0  | 15.7  | 16.2  | 15.9 | 35.76      | 35.67 | 35.77 | 35.72 | 35.73 | 2.41                                | 2.70  | 2.42  | 2.49  | 2.50 |
| 1977 | 16.5           | 16.9  | 15.9  | 15.6  | 16.2 | 35.80      | 35.79 | 35.70 | 35.69 | 35.75 | 3.05                                | 2.75  | 2.53  | 3.26  | 2.90 |
| 1978 | 16.3           | 16.3  |       | 16.2  | 16.3 | 35.85      | 35.88 |       | 35.75 | 35.83 | 3.67                                | 2.96  |       | 3.20  | 3.28 |
| 1979 | 17.1           | 18.5  |       | 15.9  | 17.2 | 35.85      | 36.07 |       | 35.70 | 35.87 | 2.95                                | 3.73  |       | 2.56  | 3.08 |
| 1980 | 16.7           | 16.4  | 15.7  | 17.0  | 16.5 | 35.86      | 35.79 | 35.56 | 35.90 | 35.78 | 2.84                                | 2.76  | 2.84  | 2.85  | 2.82 |
| 1981 |                | 16.4  | 16.1  | 16.3  | 16.3 |            | 35.78 | 35.82 | 35.83 | 35.81 |                                     | 3.29  | 2.69  | 2.86  | 2.95 |
| 1982 | 17.0           | 17.6  | 16.2  | 16.8  | 16.9 | 35.84      | 35.95 | 35.85 | 35.79 | 35.86 | 3.09                                | 3.13  | 2.99  | 3.03  | 3.06 |
| 1983 | 16.8           | 16.4  | 16.8  | 17.0  | 16.8 | 35.74      | 35.70 | 35.51 | 35.62 | 35.64 | 3.20                                | 2.94  | 3.27  | 3.29  | 3.17 |
| 1984 | 17.4           | 17.7  | 15.9  | 16.9  | 17.0 | 35.54      | 35.47 | 35.96 | 35.75 | 35.68 |                                     | 3.42  | 2.70  | 3.08  | 3.06 |
| 1985 | 17.1           | 17.0  | 16.1  | 16.7  | 16.7 | 35.85      | 35.63 | 35.49 | 35.66 | 35.66 | 3.21                                | 2.89  | 2.79  | 2.85  | 2.93 |
| 1986 | 16.9           | 17.1  | 15.8  |       | 16.6 | 35.46      | 35.37 | 35.24 |       | 35.36 | 2.67                                | 2.96  | 2.59  |       | 2.74 |
| 1987 |                |       | 16.5  | 17.1  | 16.8 |            |       | 35.82 | 35.79 | 35.80 |                                     |       | 2.48  | 2.69  | 2.59 |
| 1988 | 17.5           | 17.7  | 17.0  | 16.7  | 17.2 | 35.67      | 35.44 | 35.18 | 35.78 | 35.52 | 2.97                                | 2.76  | 2.66  | 2.73  | 2.78 |
| 1989 | 16.8           | 18.3  | 16.6  | 16.6  | 17.1 | 35.52      | 35.46 | 35.12 | 35.63 | 35.43 | 2.67                                | 2.96  | 2.35  | 2.61  | 2.65 |
| 1990 | 16.8           | 17.3  | 16.3  | 17.7  | 17.0 | 35.75      | 35.73 | 35.51 | 36.16 | 35.79 | 2.54                                | 2.57  | 2.31  | 2.93  | 2.59 |
| 1991 | 17.7           | 17.6  |       | 16.5  | 17.3 | 35.56      | 35.71 |       | 35.67 | 35.65 | 2.66                                | 2.74  |       | 2.73  | 2.71 |
| 1992 | 17.0           | 17.3  | 16.4  | 18.3  | 17.2 | 35.67      | 35.29 | 35.78 | 35.79 | 35.63 | 2.74                                | 2.65  | 2.79  | 3.60  | 2.94 |
| Mean | 16.8           | 17.2  | 16.2  | 16.5  | 16.7 | 35.64      | 35.68 | 35.61 | 35.71 | 35.66 | 2.92                                | 2.97  | 2.65  | 2.84  | 2.85 |



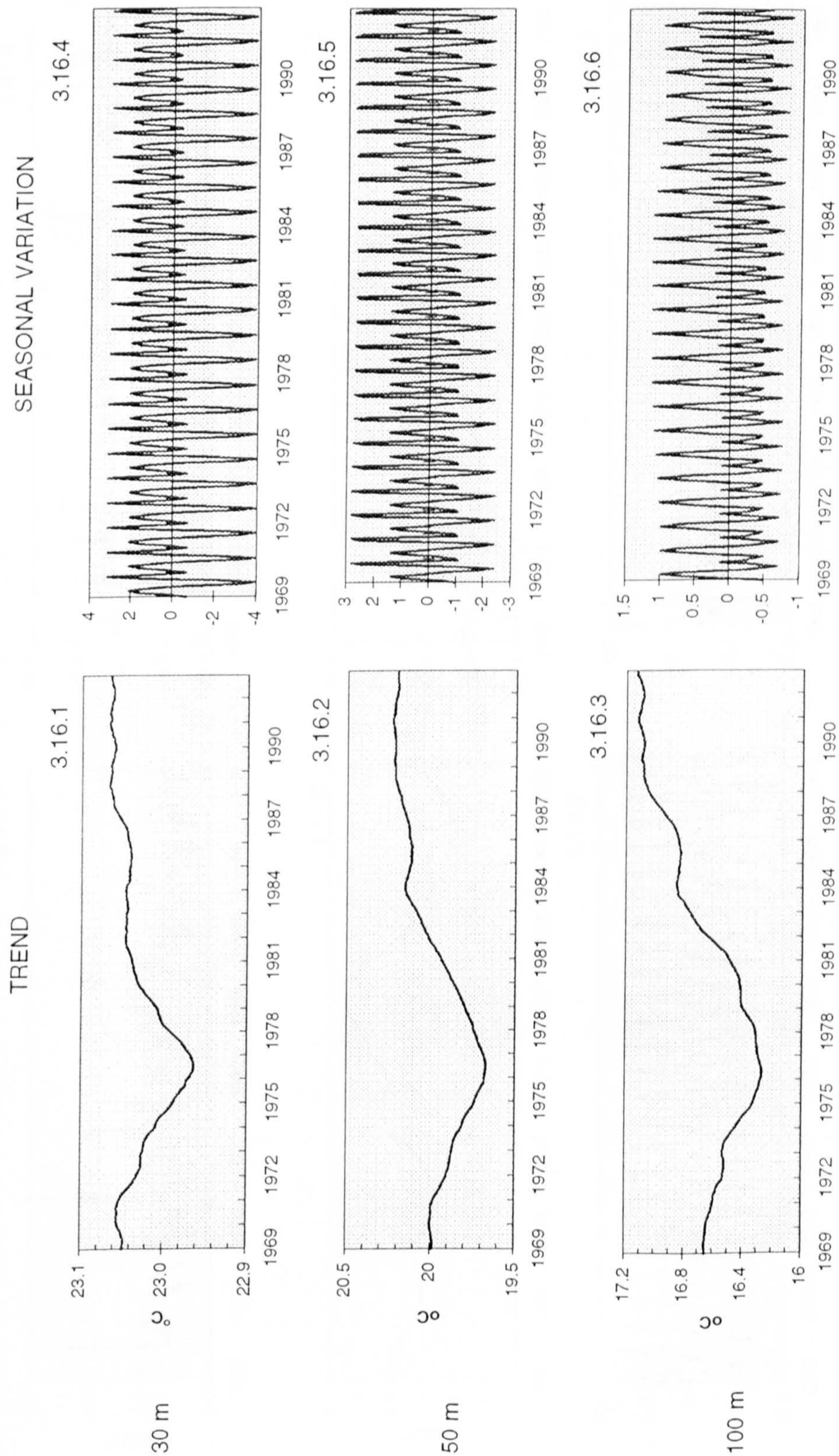


Figure 3.16: Trend and seasonal components of temperature values at 30, 50 and 100 m deep off Tema



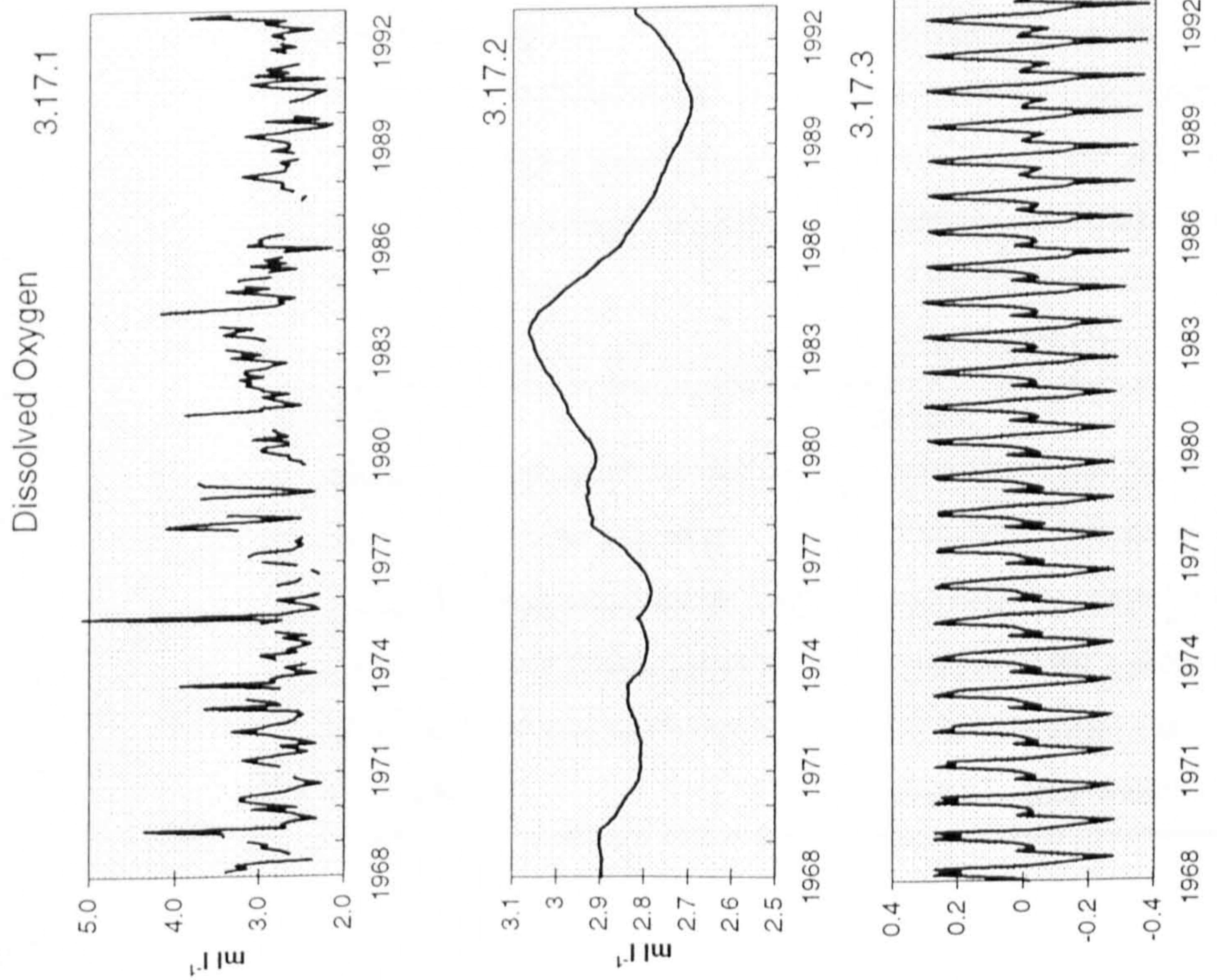


Figure 3.17. Observed values, trend and seasonal component of dissolved oxygen and salinity at 100 m deep on the Tema hydrographic transect



### 3.4.5 Environmental observations made during trawl surveys

Contours of the surface and bottom temperatures, salinity and dissolved oxygen measured during the trawling surveys in May (warm season) and August (cold season) 1981 and 1989 are shown in Appendices 3.6.1 - 3.6.16. The information contained in these plots are summarised in Table 3.6.

Table 3.6 : Summary of information contained in contour plots of environmental data collected during trawl surveys

|                         | 1981   | 1989   |
|-------------------------|--|--|
| May<br>(warm<br>period) | <u>Surface temperature</u><br>- varied between 27.8 and 29.0 °C<br>- inshore temperatures decreased from east (28.8 °C) to west (27.8 °C).<br>- there were pockets of relatively warmer water (29.0 °C) at various distances from the coast. | <u>Surface temperature</u><br>- varied between 28.4 and 30.0 °C,<br>- temperatures increased from east to west and away from the shore line.   |
|                         | <u>Bottom temperature</u><br>- contours run parallel to the coastline with temperatures decreasing with depth (28 - 18 °C).  | <u>Bottom temperature</u><br>- area divides into 4 (east and west off Cape Coast and above and below 45m deep); temperatures (20.0-30.0 °C) increase away from the divide.                                   |
|                         | <u>Salinity</u><br>- salinity is between 35.0 - 36.5 ‰<br>- there appears to be a salinity gradient (longitudinal divide) off Saltpond / Cape Coast; salinity decreases both east and west of the gradient.                                  | <u>Salinity</u><br>- most of the area has salinity of 35.0-35.5 ‰; salinity decreases towards the eastern and western borders of the country.<br>- off Keta, salinity decreases rapidly towards deep waters. |

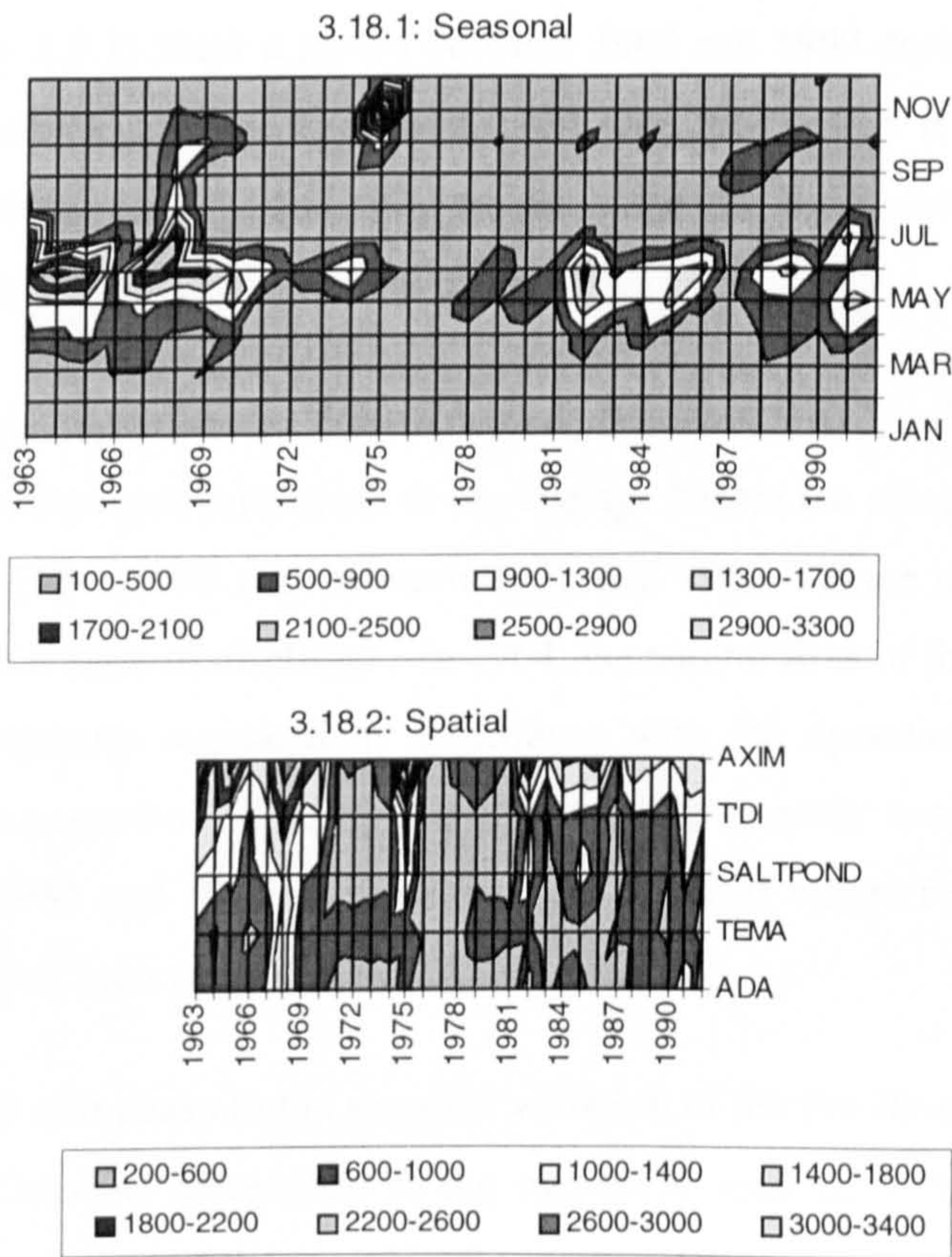
|                         |   |  |
|-------------------------|---|--|
| May<br>(continued)      | <u>Dissolved oxygen</u><br>- contours run approximately parallel to coastline,<br>- values decrease as depth increases,<br>- values are between 3.0 - 6.0 ml l <sup>-1</sup> .  | <u>Dissolved oxygen</u><br>- general reduction as depth increases but contours veer towards deep waters almost dividing off Saltpond.<br>- values are between 3.0 - 5.5 ml l <sup>-1</sup> . |
| August<br>(cold period) | <u>Surface temperature</u><br>- increases with distance from land (23.0 - 26.5 °C) with pockets of cold water at the east and west ends.  | <u>Surface temperature</u><br>- generally increases away from land (21.5 - 25 °C), with presence of pockets of water of different temperatures.  |
|                         | <u>Bottom temperature</u><br>- decreases as depth increases (24.0 - 17.0 °C) and away from two epicentres (Cape Three points on the west and Cape St. Paul on the east).  | <u>Bottom temperature</u><br>- decreases with depth (20.5 - 17.5 °C),<br>- contours run approximately east-west.   |
|                         | <u>Salinity</u><br>- a salinity divide off Saltpond; the salinity is completely uniform (35.8-36.0 ‰) west of the divide, on the east salinity decreases with depth (36.2-35.6 ‰) but not in any clear pattern (there are pockets of water masses with different salinity).             | <u>Salinity</u><br>- relatively high salinity (35.0-36.4 ‰),<br>- irregular distribution; large pockets of water of different salinity present.  |
|                         | <u>Dissolved oxygen</u><br>- decreases from land to deep waters (4.5 - 2.5 ml l <sup>-1</sup> ) and away from the two capes,<br>- there are pockets of water masses with different oxygen concentration,<br>- large section of the survey area has DO of 2.5 - 3.0 ml l <sup>-1</sup> . | <u>Dissolved oxygen</u><br>- area divided longitudinally off Winneba and by DO concentration of 2.5 ml l <sup>-1</sup> with low values towards the west.                                     |



3.4.6 Variation in near-shore and atmospheric forcing factors

3.4.6.1 Rainfall in the coastal zone

The total annual rainfall for Ada, Tema, Saltpond, Takoradi and Axim (Figure 2.5.1) for the years 1963 - 1992 are presented in Appendix 3.7 and Figure 3.18.1 is a two-way plot (year by month) of the total for the five stations. The figure shows a prolonged period of rains in 1968. Figure 3.18.2 shows total annual rainfall for the stations (summed over months). For all the stations combined, annual and monthly totals are presented in Figures 3.19.1 and 3.19.2 respectively. Figure 3.19.1 shows the decline of rainfall in the first half of the period of study (especially between 1968 and 1981) and the gradual rise in the second half, and Figure 3.19.2 shows the two rainy seasons (major in May-June and minor in October).



Figures 3.18.1 and 3.18.2: Seasonal and spatial variation of rainfall (in mm) in the coastal zone of Ghana, 1963 - 1992



The mean rainfall anomalies (rainfall index) for the coastal area of Ghana are shown in Appendix 3.8. The plot splits the period of investigation into three phases namely; a phase of over average rainfall between 1963 and 1970, a second phase of below average rainfall between 1971 and 1983 (except 1975 and 1982) and a final phase between 1984 and 1992 during which rainfall was generally close to the long-term average.

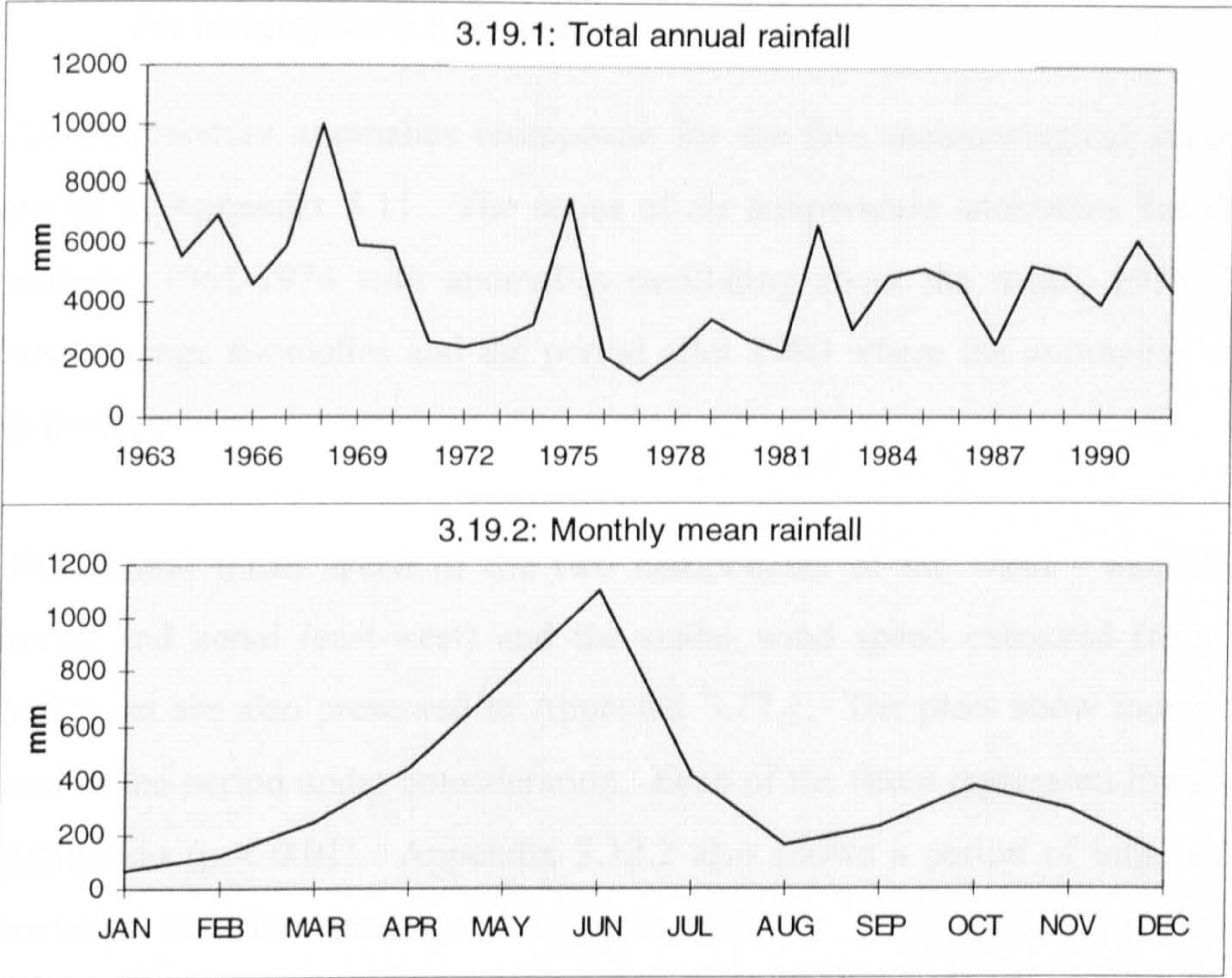
#### 3.4.6.2 Discharge rate of the Volta and Pra Rivers

Appendices 3.9.1 and 3.9.2 give the monthly mean discharge rate of the Volta River at Senchi/Akuse and the Pra River at Daboasi respectively. Annual and monthly mean discharge rates for both rivers are shown in Figures 3.20.1 and 3.20.2. The series for the Volta River was split into two, i.e. the period before the closure of the Akosombo dam and period after. The anomalies of the Pra River discharge (Appendix 3.9.1) show a period between 1963 and 1969 during which the discharge rate was above average except in 1964 and 1967 when it slipped to just below average. Between 1970 and 1979 the discharge rate was below average and in 1980 - 1992 the rate oscillated about the mean.

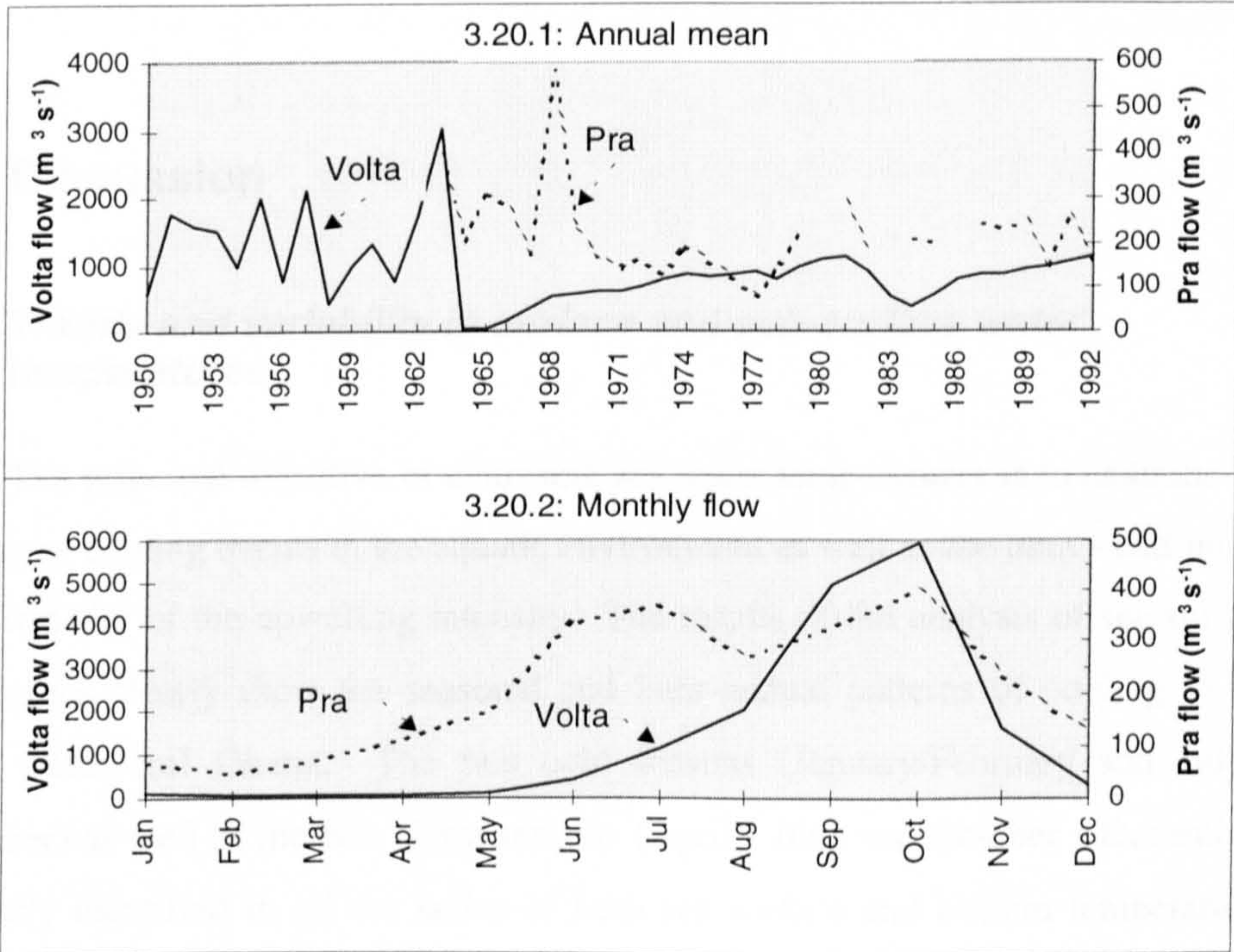
With regard to the Volta River (Appendices 3.10.2 and 3.10.3), discharge rate anomalies were generally close to the average before the closure of the dam in 1964, except in 1954, 1956 and between 1958 and 1962. There are alternating years of high and low rates of discharge. In 1964, the natural flow of the river was interrupted and subsequently regulated in accordance with the operation of the hydroelectric plant at Akosombo. The discharge increased steadily between 1965 and 1982. Between 1983 and 1986, the rate declined again to values below average but there was a gradual increase until 1992.

The two peaks in the seasonal variation of the Pra River discharge rate (June-July and October) correspond to the two rainy seasons, with the second peak due mainly to rains up country. The discharge rate of the Volta River has one peak (September-October; Figure 3.20.2). The monthly discharge rate after impoundment is between  $715$  and  $725 \text{ m}^3 \text{ s}^{-1}$ .





Figures 3.19.1 and 3.19.2: Annual total and monthly mean rainfall in the coastal zone of Ghana, 1963 - 1992



Figures 3.20.1 & 3.20.2: Annual and monthly mean discharge rates of the Volta and Pra Rivers. (Note: Akosombo dam on the Volta was closed in 1964)

### 3.4.6.3 Air temperature and wind

Air temperature anomalies (composite for the five meteorological stations) are presented in Appendix 3.11. The series of air temperature anomalies has three phases namely; 1961-1974 with anomalies oscillating about the mean, 1975-1979 with below average anomalies and the period after 1980 where the anomalies were generally positive.

The annual mean speed of the two components of the wind - meridional (north-south) and zonal (east-west) and the scalar wind speed extracted from the COADS data set are also presented in Appendix 3.12.1. The plots show increasing wind speed in the period under consideration. Each of the fitted regression lines was highly significant ( $p < 0.01$ ). Appendix 3.12.2 also shows a period of large inter-annual variation in scalar wind speed anomalies (1946 - 1971), a second period of reduced variation with generally positive anomalies (1972 - 1985) and finally a period of large positive anomalies with large inter-annual changes from 1986 to 1992.

## 3.5 Discussion

### ***3.5.1 Trends and variability in surface and sub-surface water temperatures***

The principal objective of analysing sea water temperatures is to examine the warming or cooling events in the aquatic environment as well as the inter - and intra - year variability of the upwelling intensity. The results of the analysis of sea surface temperatures clearly show the seasonal and inter-annual patterns of cooling in the coastal waters off Ghana. The two cold seasons (January/February and July - September) as well as the two warm seasons (April - June and October - December) are clearly identified in all the series of both sea surface and bottom temperatures (Figures 3.3 - 3.5 and 3.15.1).



These results agree with all previous observations and conclusions about the upwelling ecosystem in the Gulf of Guinea (e.g. Longhurst 1962; FRU/ORSTOM 1976; Arfi *et al.* 1991; Koranteng and Pezennec 1997). However, in the past, emphasis has been on seasonal differences in upwelling condition, but in this thesis some more light has been thrown on spatial differences. Furthermore, the pattern of low temperature in 1975-79 bounded by years of relatively high temperatures has not been described in the literature.

The upwelling index for the major cold season and minor cold season portray somewhat different pictures. The index shows pulses of weakened major upwelling at all stations, especially those on the eastern side (Figure 3.6.2). The years of weak major upwelling were 1968, 1973, 1979 and 1987 (Figures 3.6.3 and 3.6.4). Except for these years, there is no clear direction of change in the index for the major upwelling. However, the consistent reduction of the major upwelling index at Axim, between 1975 and 1979, is prominent in Figure 3.6.4.

There was gradual increase in the intensity of the minor upwelling between Winneba and Axim (i.e. towards the west). The periods of weak minor upwelling are slightly different from those of the major upwelling (except in 1979 and 1987 off Axim). Also, unlike the major upwelling, there are no visible decadal occurrences in the minor upwelling (Figures 3.6.1 and 3.6.2). In 1984, the minor upwelling was very poor, especially on the east.

The extracted trend from each series of SSTs followed a similar behaviour (Figures 3.7.1-3.7.6). The period of decline of the coastal SSTs, from the beginning of the series (1963, 1969 or 1970) to the mid-1970s, and a subsequent rise, are in phase with the behaviour of SSTs in the longer series obtained from the COADS database (Figure 3.9). The series of offshore SSTs (from COADS areas I-III, Figure 3.1) show a general increase since 1946 with relative decline in 1954-55, 1964-65, 1975-76 and 1987-88 and appear to follow decadal changes. The change in 1975-76 was the most pronounced within the 47-year period, and this was picked up in the coastal sea surface and bottom temperature series used in these analyses.

Also evident from the plot of the seasonal component of the SST series (Figure 3.7.7-3.7.12) is the intensification of the minor upwelling and increased secondary warming from mid-1980s. These events have been picked up more clearly in the time series decomposition analysis than the upwelling index and also appear clearest in the Axim series. The change in seasonal variation is not very evident from the COADS data, implying less significant change in the intensity of the two upwelling events in offshore areas. This is understandable as the upwelling is coastal.

It is essential at this stage to state the limitation in the COADS data, namely the low numbers of observations used in computing the monthly mean temperatures. In some months, especially in the early years of the series, there were as few as 6 observations. The months with such few observations could not be ignored in the analysis as this would have meant having to estimate the value anyway. Observations improved considerably in the critical period of this investigation, i.e. 1963 - 1992.

The seasonal variation in the sub-surface (bottom) temperatures is similar to that at the surface; temperature is minimum during the upwelling months and maximum during the warm periods (Figure 3.15.1). The difference in the pattern of cooling between the shallow stations (30 and 50 m deep) and the deep station (100 m) would imply that the inshore and offshore areas of the shelf may be subjected to different temperature-controlling processes. It is also evident that the deeper part of the shelf is a relatively more stable environment than the shallow areas (Figure 3.16). This creates spatial heterogeneity (by depth zone) of bottom temperatures that could affect the movement and availability of demersal fishes.

There is a correspondence between periods of low annual mean coastal sea surface temperature (SSTs) and bottom temperatures (SBTs) (Figures 3.7 and 3.16). Within the period of investigation, there appears to be a pattern of decadal changes in temperatures although the events (intense cooling or warming) do not occur with the



same intensity. For example, with the exception of Axim all areas consistently recorded relatively low SSTs (25-26 °C) between 1975 and 1979 and 1986-87 (Appendix 3.4). The corresponding periods in the SBTs were 1974-78 and 1985-87 (Appendix 3.5.1).

The series of sub-surface temperature data at 100 m deep shows striking features that are not exhibited in the same manner in the coastal SST series or the shallow water (30 m and 50 m) series. These are (referring to Figure 3.16):

- i. the consistently increasing temperatures during the second warm season (i.e. October/November) between 1975 and 1992,
- ii. the general reduction of temperatures during the minor upwelling period signifying an intensification of this upwelling, and
- iii. slight increases in temperatures during the main warm season signifying a relative weakening of the major upwelling.

Thus, it appears that the overall increase in oceanic water temperature may be due mainly to the warming at the end of the year.

It is important to note that infrequent perturbations in the environment (as observed with anomalies of SSTs) affect the internal dynamics of the system (Margalef 1986; Baird *et al.* 1991). These events would also have significant impacts on the behaviour of some species of fish, especially on their growth, distribution and abundance as have been described by Pezennec and Bard (1992), Pezennec (1994) and Pezennec and Koranteng (1997) for *Sardinella aurita* (chapter 2). The difference in cooling between the eastern and the western parts in inshore shelf waters has been cited as contributing significantly to the observed differences. Several examples of such relationships between the environment and population dynamics of fishery resources, may be found in the literature (e.g. Koranteng and Pitcher 1987; Pauly and Tsukayama 1987; Pauly *et al.* 1989b; McGlade 1990; Roy 1992).

### **3.5.2 SST anomalies and interconnections with other climatic events**

Each series of standardized SST anomalies, including the combined series, exhibited time blocks of sustained large (positive or negative) anomalies interspersed with blocks of relatively small but irregular oscillations of the anomaly about the mean (Appendix 3.4 and Figure 3.10). The onset and duration of the cold or warm events are not perfectly synchronized at all the coastal stations (Appendix 3.4); however there are some visible patterns common to all five stations. Between 1963 and 1992, there were years with relatively cold water (1975 - 1979), others with warm water (1987 - 1992) and two time blocks (before 1975 and 1980 - 1986) of relatively unsettled but close to average sea surface temperatures. 1975-76 was the peak of the cold events and 1987 was the warmest of the warm years.

From the anomalies and decomposition of both coastal and offshore (COADS) SSTs, years of significant cold or warm events in Ghanaian coastal waters were identified (Table 3.7). The table also shows years of strong Pacific El Niños in the last four decades, and years of Atlantic Niños. There is some indication in the table that warm temperature conditions in the Pacific (El Niño) are nearly associated with cold temperature conditions in the Atlantic (also see Bakun 1996). For example, 1983 was a relatively cold year in the Atlantic but one of the strongest Pacific El Niños ever recorded occurred that year. Also, there is usually a rapid rise of temperatures as occurs in El Niño years, following the period of cooling. This is exemplified by the 1984 Atlantic Niño which followed the 1983 cold year.

Possible interconnections between El Niño in the Pacific and Atlantic Niños have been discussed by Shannon *et al.* (1986), Hisard (1988) and Bakun (1996). It has been observed that El Niño in the Atlantic lagged El Niño in the Pacific by one year (Bakun 1996). Such interconnection is exemplified by the eastward movement of positive SST anomalies from the Brazilian coast towards the Angolan and Namibian coasts during the 1984 warm events in the Atlantic (Hisard 1988).



Table 3.7: Pacific El Niños, Atlantic Niños and years of unusual climatic events in the Gulf of Guinea in the last forty years (Sources: Hisard 1988; Bakun 1996, and present study)

| Gulf of Guinea<br>warm years | Gulf of Guinea<br>cold years | Pacific<br>El Niños years | Atlantic Niños<br>years |
|------------------------------|------------------------------|---------------------------|-------------------------|
| 1953-54                      |                              |                           |                         |
|                              | 1955-56                      | 1957-58                   |                         |
| 1962-63                      |                              | 1963-64                   |                         |
|                              | 1964-65                      |                           | 1963                    |
|                              |                              | 1965-66                   |                         |
|                              |                              | 1972-73                   |                         |
| 1973                         |                              |                           |                         |
|                              | 1975-77                      |                           |                         |
|                              |                              | 1982-83                   |                         |
|                              | 1983                         |                           | 1984                    |
|                              | 1985-86                      | 1986-87                   |                         |
| 1987-88                      |                              |                           |                         |

Appendix 3.13 shows smoothed standardized anomalies of coastal sea surface temperature measured at Cananea (south of Sao Paulo) in Brazil (25° S, 47° 55' W) (Patricia Sunye-Sfair<sup>1</sup>, *pers. comm.*) Also shown are SST anomalies for Tema (Ghana; 05° 35' N, 00° 04' E). The figure shows similar specific cold and warm events in the two series but the Tema series usually lags behind the Cananea series. This is very clear in some years but not in others. For example, the years of sustained cold SSTs that occurred off Tema between 1975 and 1978 is also seen in the Cananea series but for 1973 - 76. Similarly, the warm events of 1987 - 89 off Tema occurred during 1985 - 87 off Cananea.

There is also a rising trend in the decomposed Cananea SST series (Appendix 3.14) which also shows reversals of SST similar to what has been described for the various Ghanaian series. Considering the fact that Tema and Cananea are about 5400 km apart (across the Atlantic), perhaps the temperature

<sup>1</sup> Patricia Sunye-Sfair is graduate student at ORSTOM-Brest, France.

events described in this thesis could be generalised for the whole Tropical Atlantic basin with some time lags.

### **3.5.3 Trends and variability in surface (coastal) and sub-surface salinity off Tema**

The period between 1970 and 1978 was characterized by high coastal salinities between July and October each year (Figure 3.11.1). This pattern changed in the 1980s where such high salinities were limited to August/September and occasionally October, neither did they occur every year.

The derived trend from the series of coastal salinity (Figure 3.12.2) shows that there were basically two long-term salinity regimes during the period 1970-1992, namely a period of relatively high salinities between 1970 and 1980 with a peak in 1977-78 and one of low salinity between 1981 and 1992. The sub-surface salinity trend (Figure 3.17.5), also shows two long-term salinity regimes. These are, the period of high mean values (35.65 - 35.75 ‰) between 1974 and 1982, and one of comparatively lower values (< 35.5 ‰) in the ensuing years. The regime of high salinity lasted longer (until about 1984) at 100 m deep than at the coast (Figures 3.12.2 and 3.17.5) signifying the general resilience of the deep-water environment. Coastal salinity was also generally lower than the salinity at 100 m deep.

From some patchy data available at MFRD for all the coastal recording stations, the annual mean coastal salinity was found to be extremely low between 1968 and 1970. The low salinity could be the result of the high rainfall during those years (Figures 3.18 and 3.19) and the resultant increased river outflow (Figure 3.20.1; Pra River series). Surprisingly, the reduction of salinity was reflected even more strongly in the trend of sub-surface salinity at 100 m deep (Figure 3.17.5) than the coast. This portrays the extent of effect of freshwater input into coastal waters where the less saline river water eventually reaches the bottom through processes like tides, currents and internal waves (Drinkwater 1987; Halim *et al.* 1995). Off Tema, the 100 m depth contour is less than 25 km from shoreline (Figure 3.2).



Some relationships between river discharge and/or rainfall and salinity have been established in other regions. Examples are Halim *et al.* (1995) for the eastern Mediterranean and Laane *et al.* (1996) for the Irish Sea and English Channel. Mahé (1991, 1997) attribute the relatively low salinity of ocean waters in the Gulf of Guinea to the outflow of large rivers ending up in the sub-region.

The seasonal variation of coastal salinity as depicted in figure 3.11.2, is almost a mirror image of the seasonal variation of coastal sea surface temperature (Figure 3.5) in that when SSTs decrease, the coastal salinity increases and vice versa. This is a consequence of cold, more saline sub-surface water reaching the surface of the sea during the upwelling periods. At 100 m deep, the relationship is less clear as salinity is also relatively low during the upwelling period (Figure 3.15) probably through the circulation of surface and bottom water in the upwelling.

The seasonal component of the Tema coastal salinity series (Figure 3.12.3) shows a period before 1974 that was characterized by wide but decreasing range of salinity between cold and warm periods. The difference between the maxima and minima narrowed in the mid-1970s to early 1980s as a result of reduction in both maxima and especially minima of salinity. From about 1984, the system returned to the state of wide maxima - minima differences in coastal salinity due both to a rising of the maxima and lowering of minima of salinity. This large seasonal variation in salinity with continuous reduction of salinity in the warm season, could be an important factor influencing the biology and population dynamics of some fish species. The seasonal component of the sea bottom salinity series (Figure 3.17.6) shows a pattern similar to that of the coastal salinity. In addition, this series also shows that between 1985 and 1992, there was a drastic reduction of salinity during June/July (i.e. at the onset of the major upwelling). In the same period, the salinity occurring during the last quarter of the year gradually increased.

Taking clues from the observation that the salinity anomaly that occurred in the Northern North Atlantic in 1971-73, depressed recruitment in a number of deep-water fish stocks (Cushing 1988, 1990; Mertz and Myers 1994), one can expect that

the nature of salinity changes, as have been described in this work, could affect the distribution and abundance of some demersal fish species in coastal waters in the Gulf of Guinea.

#### ***3.5.4 Vertical structure of shelf waters as indicated by the depth of the 21 °C isotherm***

From Figure 3.13.1, the intra-annual mean depth of the 21 °C isotherm followed the seasonality of coastal cooling with the thermocline rising to the surface during the cold months and staying deep during the warm months. Within the period of investigation (1968-1992), the annual mean depth of the 21 °C isotherm was around 41 m (Figure 3.13.2; Table 3.4).

Between 1968 and 1970, the thermocline stayed deeper than its long-term mean depth of 41 m indicating warm years in the marine climate. Except for the relatively warm years of 1978/79, the thermocline mean depth in 1971-86 was generally shallower than the long-term average.

Houghton (1983) estimated that between 1959 and 1981 the shallowest depth of the thermocline, in an area off western Ghana to Côte d'Ivoire (i.e. 3° W - 6° W and 1.5° N to 1.5° S), was about 12 m. This occurred in 1975 and the 20 °C isotherm was considered as proxy for the thermocline. In the same study, the minimum monthly mean depth of the thermocline was estimated to be about 29 m (occurring in August) and the maximum was 70 m occurring in April (also compare Table 3.4 and Figure 3.13).

The thermocline, which is a rapid discontinuity of temperature in the water column, acts as a physical barrier to the transfer of nutrients between the surface and the bottom of the sea. This acts like the density discontinuity layer (or pycnocline which is related to temperature and salinity balance in the sea), which affects the vertical distribution of chemicals that contribute to the biology of the seas (Lalli and Parsons 1993). The discontinuity layer could also pose as a barrier to the vertical

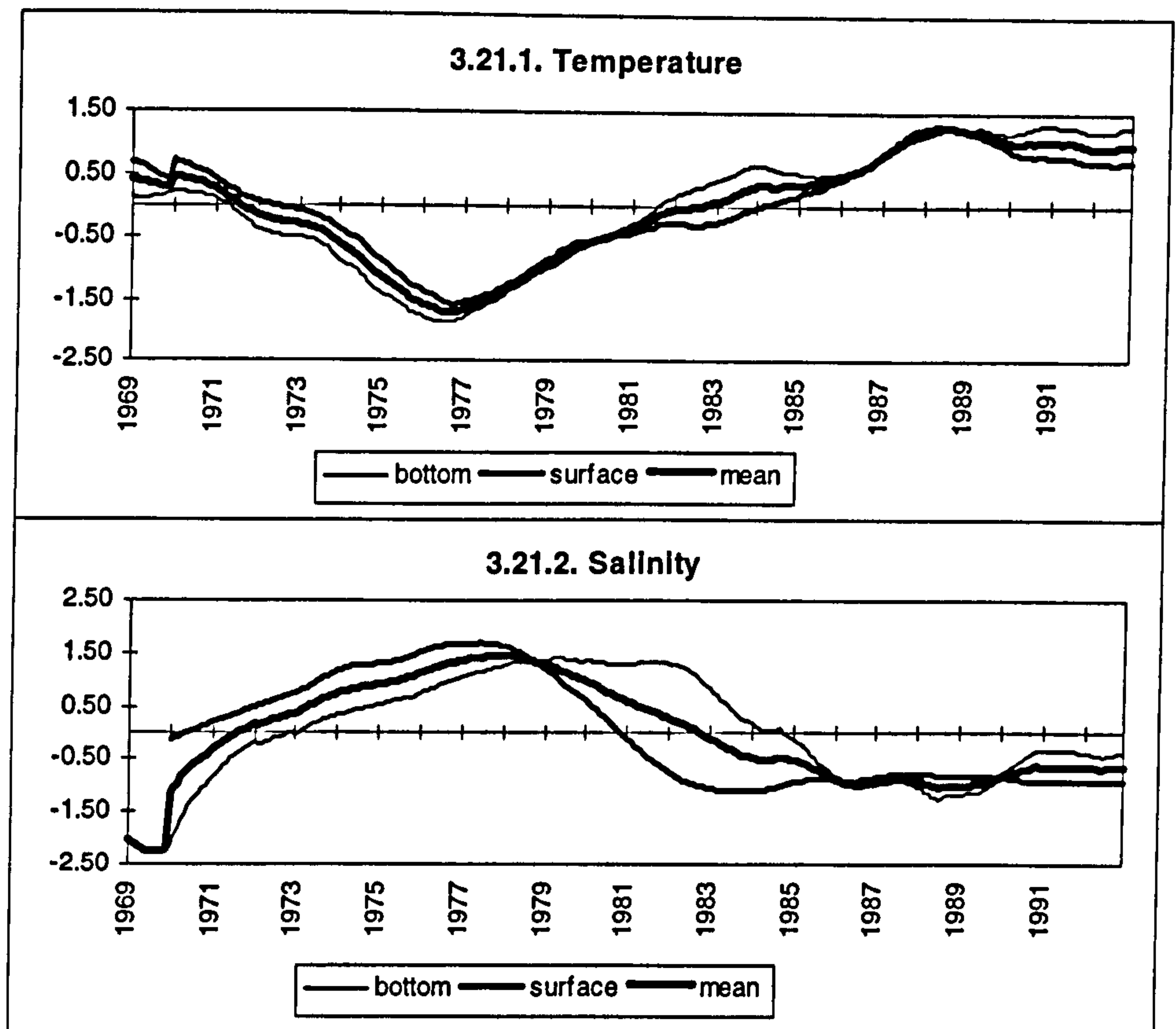


migration of some species of fish. As this could affect the catchability of some species, especially in shallow waters, it has the potential to affect the results of bottom trawl surveys.

### ***3.5.5 Environmental time blocks in Ghana's coastal zone and shelf waters***

It is obvious from the results and foregoing discussion that in the period under consideration (i.e. between 1963 and 1992), there were distinct time blocks within which the marine waters in the Gulf of Guinea experienced different environmental conditions. Although these environmental blocks were identifiable from all the temperature, salinity and dissolved oxygen series that were analysed and also in the depth of the thermocline, they were not synchronized. There were differences in the series with regard to the onset and cessation of the various environmental conditions.

For the purposes of subsequent analyses in this work, it was essential to define the boundaries of the environmental time blocks. To do this, new temperature and salinity anomalies were calculated using the monthly values of the decomposed trend of each series as the data values. The mean and standard deviation of the trend were used in the calculation and standardization of the anomalies. The resultant anomalies for the bottom and surface temperatures are shown in Figure 3.21.1 and Figure 3.21.2 shows corresponding plots for salinity. Each series is a composite of all the available series for that parameter (e.g. the bottom temperature line represents the trends at 30, 50 and 100 m). The period under consideration was then clearly divided into three regimes, namely the period until 1972, 1972-1982 and 1982-1992 (using the mean values).



Figures 3.21.1 & 3.21.1: Plots showing time blocks of environmental parameters in Ghana's coastal waters

There is a remarkable synchrony between the temperature and salinity results and some interesting features are revealed in these results with regard to the events of the sardinella and triggerfish fisheries in this ecosystem. In the case of the sardinella, the environmental regimes closely match the relatively 'healthy' phase of the stock before the high landings of 1972; the 'collapsed' phase between 1973 and 1982 and the recovered or 'prosperous' phase between 1983 and 1992 (see Figure 2.2.1 and also Pezennec 1994). The environmental regimes also match the years of appearance and disappearance of *Balistes capriscus* in this ecosystem. Proliferation of the species started around 1972-1973, and flourished in the mid-to-late 1970s until mid - 1980s. Its decline was observed between 1987 and 1988 (Koranteng *et al.* 1994, also see Figure 2.2.2). Incidentally, these results lead to an ecological conundrum, i.e. if *Balistes capriscus* has preference for warm water (Ansa-Emmim 1979; Koranteng



1981; Caverivière 1982), why then did it flourish during the relatively cold regime only to decline when the waters 'warmed' up? This is discussed in chapters 4 and 5.

### ***3.5.6 Spatial distribution of temperature, salinity and dissolved oxygen on the continental shelf of Ghana in two environmental time blocks***

The objective of this analysis is to examine the pattern of distribution of surface and sub-surface environmental parameters during each of the identified time blocks in the changing environment and to compare the situation between the warm and the cold seasons. The year 1981 is towards the end of the first time block and 1989 is part of the second block. In addition, trawl surveys in these two years are included in the investigation of fish community structure and dynamics (chapter 4).

The following conclusions could be drawn from Appendices 3.6.1 - 3.6.16 and the information contained in Table 3.6. There are some clear similarities as well as differences between the two seasons (May and August) and the two years 1981 and 1989. For example, in both years, there was general reduction of sea surface temperature from east to west in May which is in agreement with pattern of coastal SSTs. However, this change was not uniform as may be seen, for instance, during the warm season in 1989 when there appeared to be a longitudinal division of the shelf into two - east and west. In addition, pockets of surface water with different temperatures were encountered during both cold and warm seasons and in both years. This data set clearly indicates a more intense coastal upwelling in 1989 than in 1981, agreeing very much with the data from coastal stations (Figure 3.6).

The bottom temperature charts also show that 1989 was generally cooler than 1981 although the spatial distribution of temperatures was different in the two years, especially during the cold season. Whereas the temperature contours in 1989 showed a clear reduction of temperatures as depth increased, the pattern was less clear in 1981.

On bottom salinity, there was a general division between the eastern and the western parts of the Ghanaian continental shelf. In addition there was a narrow salinity range in the cold season than in the warm. This may be the result of intense mixing of water masses during the upwelling period. Dissolved oxygen values generally decreased with depth except in May 1989 when the pattern was not so clear and there also appeared to be a division between the eastern and the western parts of the shelf. During the cold season the difference in DO values between the deep and the shallow areas was reduced.

From the plots, it appears that the sea area under investigation may not be large enough to reveal clear patterns in the distribution of the environmental parameters. Another possible source of significant variation in the distribution of the parameters is the duration of measurements. Each survey took between three and five weeks to complete, which is a very long time for environmental observations, especially in an upwelling ecosystem such as the western Gulf of Guinea. The following summarises the temporal and spatial distribution of the environmental parameters measured during the trawl survey.

- i. There appears to be clear differences in the physico-chemical properties of sea water along the continental shelf (inshore to offshore) and from east to west. Longitudinally, the area could be divided into three, namely eastern, central and western with each area usually having water masses of distinct characteristics. In the central part, the continental shelf is much wider (up to 80 km wide) than in the other sectors. The differences in the physico-chemical properties may be a consequence of this difference in shelf width which will reflect the effect of deep-water currents on the shelf and the area of space for such influence. The effect of the Volta River on the east and large rivers like Pra and Ankobra on the west could also be considered. The central part of the coastal zone does not have rivers of such size.
- ii. Within these broad divisions on the shelf, parcels of water masses with relatively



different properties were also encountered, especially during the upwelling period. This phenomenon could have substantial effect on the distribution and abundance of fishes having different environmental preferences.

### **3.5.7 Trends and variability in near-shore and atmospheric forcing factors**

#### **3.5.7.1 Rainfall**

The following may be deduced from the analysis of the rainfall data:

- a. Except for the exceptionally high rainfall in May-August, 1968 and October/November, 1975, the total rainfall recorded at the five stations generally declined between 1963 and 1978 (Figure 3.19.1); between 1979 and 1992 total rainfall increased slightly,
- b. There are two peaks of rainfall in a year, a major one in June and a minor one in October (Figure 3.19.2); this is in agreement with the rainfall pattern 1 described by Mensah (1991),
- c. Amount of total rainfall increased from east to west with Axim recording the highest rainfall in the period under consideration (Figure 3.18.2),

The rainfall index was able to detect the decline of rainfall in Ghana (within the period of investigation) which is in agreement with the general pattern of declining rainfall in sub-Saharan Africa as reported by Lamb (1982) and Lamb *et al.* (1986).

An inverse relationship between rainfall and upwelling has been observed in all eastern ocean boundary current systems (Binet 1982, 1995). This is because during the cold season, lower atmospheric layers are cooled by the presence of upwelled waters, and this prevents the development of vertical clouds which cause rain (Binet 1995).

### 3.5.7.2 Effect of freshwater input into coastal waters

In general, one sees a reduction of freshwater input into the Ocean from the Pra and Volta Rivers within the period of study. From 1970, the rate of discharge of the Pra River declined until 1979-80 when a modest reversal of the trend was observed (Figure 3.20.1). However, this was short-lived as the flow quickly declined again. Since its impoundment, the flow rate of the Volta River gradually increased as power generation from the dam increased. This reached high values in 1980-81. The decline in 1983-86 was due to the drought that occurred in sub-Saharan West Africa at that time (Lamb *et al.* 1986) and which resulted in reduced flows of almost all rivers ending up in the Gulf of Guinea (Mahé 1991).

Freshwater input into coastal waters directly influence salinity, retention of nutrients and productivity (Halim *et al.* 1995; Mahé 1997). Substantial amount of nutrients like phosphates and nitrates originating from domestic and agricultural effluents and which are required for primary production, are carried into the sea through river outflows. Thus, variation of freshwater input into the sea can have repercussions on marine life. For example, it has been suggested that the distribution and abundance of *Sardinella aurita* in the western Gulf of Guinea are affected by freshwater input into the sea (Binet 1995). Similarly, Caverivière (1991) related the variation in abundance of *Balistes capricus* in the western Gulf of Guinea to river discharge through the effect of the latter on ocean salinity. Sutcliffe (1973) noted good correlation between river discharge into the Gulf of St. Lawrence, Canada, and landed catch of lobsters 9 years later. In Iceland, the main spawning grounds of rich fish stocks are areas affected by freshwater input (Mann and Lazier 1996). Gammelsrod (1992) found that catch rate of shrimp (*Penaeus indicus*) in Mozambique (Southeast Africa) is positively correlated with discharge rate of the Zambesi river.

Therefore, the building of dams on rivers which reduces the amount of nutrients reaching the sea affects the productivity of the oceans. Also there is a change in the flow regime that marine living resource are adapted to and this could



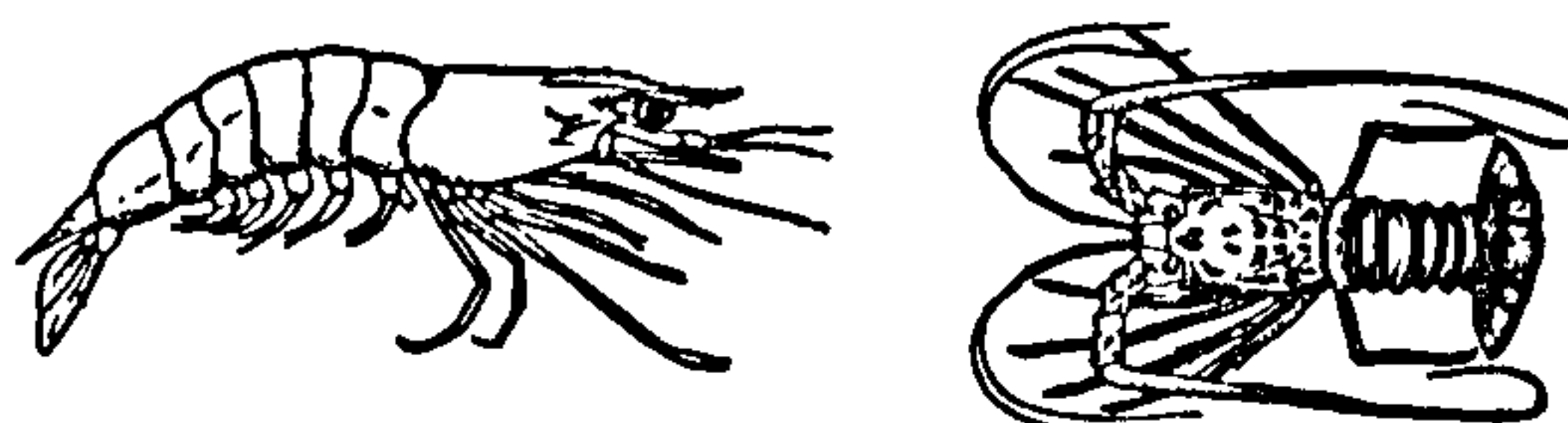
affect the state of the resources down in the estuary. For example, the collapse of the shrimp fishery in the Volta estuary (Ghana) was partly attributed to the damming of the Volta at Akosombo (see chapter 6). Mann and Lazier (1996) have documented similar impact of hydrologic changes on biological systems in the Black Sea, San Francisco Bay and the Mediterranean Sea among others.

### 3.5.7.3 Trends and variability in air temperature and wind regimes off Ghana

Some biological production in the sea may be affected by weather and climatic fluctuations (Laevastu 1993; Mann and Lazier 1996). For example, air temperature variation could be a significant factor in surface cooling that characterizes coastal upwelling. Bakun (1996) discusses various ocean - atmosphere connections from the perspective of considering the ocean and atmosphere in an integral system.

The importance of wind in the functioning of upwelling systems is known (e.g. chapter 2). For example, as the wind blows across the surface of the sea, it causes the water to move in the same direction. The direction of flow is altered by Coriolis effect and eventually becomes perpendicular to the direction of the wind (effect known as Ekman transport).

Therefore, one could expect that the intensification of wind speed off Ghana - Côte d'Ivoire would affect the state of the marine environment, especially the minor upwelling for which wind appears to play a very significant role in its cause (Roy 1992; chapter 2).



## **CHAPTER FOUR:**

### **STRUCTURE OF DEMERSAL FISH ASSEMBLAGES ON THE CONTINENTAL SHELF AND UPPER SLOPE OFF GHANA**

*"As for the truth, no man has known it Nor shall he know ...  
And even if by chance he were to utter  
The final truth, he would himself not know it  
For all is but a woven web of guesses ...".*

*..... Xenophanes, 5<sup>th</sup> century BC*



## Chapter Summary

Using two-way indicator species analysis and detrended correspondence analysis, species on the continental shelf and upper slope of Ghana were put into six assemblages. These assemblages are comparable to those described thirty years ago from recurrent species analysis and for the whole Gulf of Guinea.

There are clear faunal discontinuities around 30 m, 100 m and 200 m depth with the first ecotone closely related to depth and the thermocline, the second to drastic shelf drop, and the third to division between shelf and slope fish assemblages. The structure of the assemblages is determined primarily by depth and sediment type the latter of which is more important when considering short depth gradient as was the case in the MFRD surveys. The dynamics of the assemblages are influenced by physico-chemical parameters of the water masses, mainly temperature, salinity and dissolved oxygen.

Examination of the composition of the three shallow - to - mid shelf assemblages showed that a number of species remain faithful to their assemblages over time. It was found also that the lutjanid assemblage is more stable than previously thought.

## 4.1 INTRODUCTION

### 4.1.1 Objectives

The specific objectives of this chapter are:

- i. to establish assemblage units of demersal fish species on the continental shelf and upper slope off Ghana,
- ii. to determine the factors that determine fish community structure on Ghana's shelf, and
- iii. to assess the effects of environmental parameters on the structure of the assemblages.

Defining the aggregation of species in the ecosystem is the basis for managing species by the management unit approach (Tyler *et al.* 1982; Mahon 1985). The

structure of species assemblages for several exploited fish stocks around the world has been established. Examples are Oviatt and Nixon (1973) in Narragansett Bay (USA), Hoff and Ibara (1977) in southeastern New England (USA), Gabriel and Tyler (1980) on the continental shelf of Oregon (US Pacific coast) and Mahon (1985) on the Scotian shelf of Atlantic Canada. Others are Yáñez-Arancibia *et al.* (1985) in the southern Gulf of Mexico, Mahon and Smith (1989) also on the Scotian shelf and Blaber *et al.* (1994) in the Gulf of Carpentaria in Australia. Bianchi (1992a) carried out similar studies in six areas around the world, namely the area between the Gulf of Tehuantepec in Mexico to Gulf of Papagayo in Costa Rica, Congo and Gabon, Angola, between the mouths of Orinoco and Maroni Rivers on the northern coast of South America, North-western Indian Ocean and the continental shelf of East Africa.

In the Gulf of Guinea, Fager and Longhurst (1968) and Longhurst (1969) worked out the assemblage structure of demersal species on the continental shelf using data from the Guinean Trawling Survey (Williams 1968). Villegas and Garcia (1983) attempted to map demersal fish communities on the continental shelf of selected countries in the Gulf of Guinea using data and information from surveys that have been conducted in the sub-region.

These studies have shown, *inter alia*, that:

- a. depth is a principal factor that determines assemblage structure although other factors like sediment type, temperature and salinity can also influence the structure (e.g. Bianchi 1992a),
- b. the structure of the assemblage can change with time (e.g. Gomes *et al.* 1995),
- c. seasonal changes can occur in the assemblage structure due to differential migration of the component species of the assemblage (Villegas and Garcia 1983; Overholtz and Tyler 1985),

In this part of the thesis, the research questions posed are as follows:

- i. What is the pattern of distribution of demersal (bottom-dwelling) fish on the continental shelf and upper slope off Ghana?



ii. What factors determine the distribution of fish in these assemblages?

It was not my intention to re-invent Longhurst's (1969) classification but rather to clarify the information in order to contribute to the debate on the subject and to throw light on the dynamics of the assemblages during the last three decades. This last objective is treated in more detail in chapter 5.

#### **4.1.2 'Community', 'assemblage' and 'population'**

In its simplest sense, 'community' is used in ecology to describe a group of plants and/or animals living together in a given area. Various definitions of the term are found in the literature; these include:

- i. "... a group of populations of plants and animals in a given place " (Krebs 1985),
- ii. "... an assemblage of species populations which occur together in space and time" (Begon *et al.* 1990),
- iii. "... an organized body of individuals in a specified location " (Southwood 1988).

Magurran (1991) considers the three definitions as a good representation of the concept of community in ecological literature. It is essential to point out that whereas 'community' applies to a group of plants and animals (Krebs 1985), 'assemblage' implies that the populations and species are of the same phyla. Bianchi (1992a) uses the words as synonyms to indicate "an association of coexisting species with similar environmental tolerance, possibly trophic relationships, but not totally interdependent". This approach has generally been followed in this thesis, however, the more appropriate word 'assemblage' has been used more often than 'community'.

In a related issue, 'population' is used in this thesis to denote a group of individuals of a single species. The degree of interactions among the populations or individuals within the community vary from one community to another and the structure and function of the community "...result from direct and indirect interactions that tie members of the community together in a web" (Ricklefs 1990).

### 4.1.3 'Demersal', 'pelagic' and 'semi-pelagic' species

In a general fisheries sense, 'demersal' applies to species that live on, or close to the bottom of the sea and are caught mainly with bottom trawls. They are benthos-feeding animals (Longhurst and Pauly 1987; Bianchi 1992a). On the other hand, 'pelagic' refers to species living off the bottom and caught mainly with mid-water trawls or purse seines. There are also species, usually referred to as 'semi-pelagic' (or 'benthopelagic'), that are intermediate between these two categories of fishes.

In the study of coastal fisheries, it is difficult to put the species into these broad categories. According to Longhurst and Pauly (1987), it is even "... not satisfactory to attempt a formal separation between pelagic and benthopelagic fish in tropical fish resources...". This is because several fish species that may be classified as pelagic also occur in large quantities in demersal trawls. A typical example is triggerfish, *Balistes capriscus*. Being of a "reef-fish genus" (Bianchi 1992b), the species is described as "... basically demersal" (Longhurst and Pauly 1987), but is generally classified as semi-pelagic (Ansa-Emmim 1979; Caverivière 1982). In FAO's (Food and Agriculture Organization of the United Nations) Field Guide to Commercial Marine Resources of the Gulf of Guinea (Schneider 1990), the habitat of triggerfish is recorded as "... sandy and rocky bottoms, to 60 m depth". This habitat description gives the impression that *B. capriscus* is a bottom-dwelling (i.e. demersal) fish. However in stock assessment surveys conducted in the Gulf of Guinea, the biomass of the species recorded in acoustic surveys was much higher than the biomass recorded in bottom trawl surveys. For example in June 1981, the pelagic biomass of *B. capriscus* in Ghanaian waters, estimated in an acoustic survey, was 310,000 mt (Stromme 1983). The corresponding figure in a 1981-82 bottom trawl survey was 96,000 mt (Koranteng 1984).

A number of species included in the analyses presented in this chapter are in the same situation whereby one cannot say with certainty whether they are demersal or pelagic. This is particularly the case with species in shallow waters. In deep waters, substantial quantities of true pelagic fish may be caught during a bottom trawl



net's transit to and from the bottom (Rijavec 1980; Koranteng 1984). During trawling, the high-opening nets that were used in these surveys (chapter 6) would also catch species that are normally off the bottom. In this chapter, all fish species - pelagic, demersal, semi-pelagic (or benthopelagic) have been included in the analyses bearing in mind the fundamental meaning of community or assemblage.

## 4.2 COMMUNITY ORGANIZATION AND STATISTICAL METHODS FOR DEFINING STRUCTURE IN ECOLOGICAL DATA

In community studies, the ecologist is faced with the problem of assessing the distribution of animal or plant populations along environmental gradients. The distribution may take many forms. In addition, and using the example of a hypothetical distribution of species in communities, the communities could be "closed" whereby community edges - ecotones - would be quite distinct and associated with clear environmental gradients or "open" with species distributed at random and the community boundaries difficult to identify (Figure 4.1; Ricklefs 1990). However, in nature, one may find a combination of these community structures with a number of factors, biotic and abiotic, providing the mechanisms for such species aggregation.

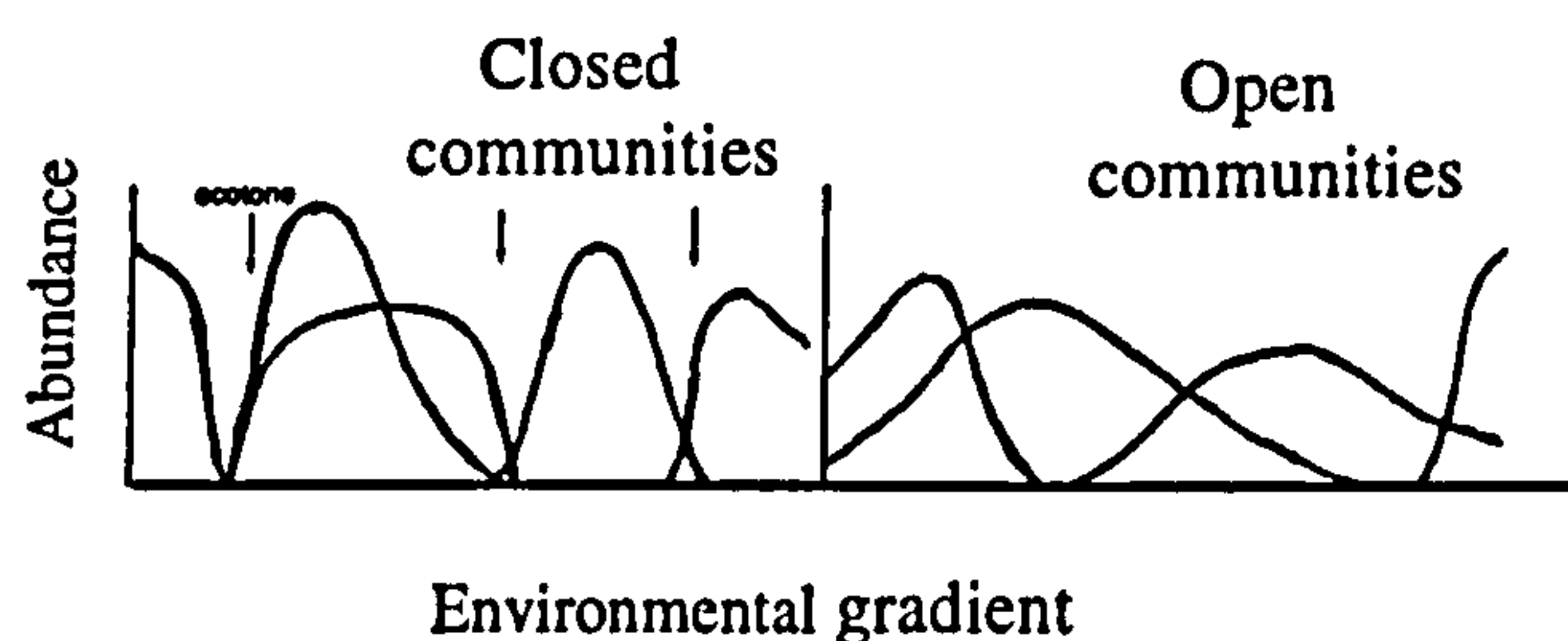


Figure 4.1: Unimodal distribution of a number of species in hypothetical communities; sharp changes in environmental gradient (ecotones) are also shown (modified from Ricklefs 1990)

#### **4.2.1 Methods for determining structure**

Since the structure of many fish assemblages can only be assessed by making inferences from catches, proxies such as habitat or physical and chemical factors in the environment are used to group fish. In a review of methods for such grouping, Fager (1957) pointed out the problem of subjectivity of an ecologist's selection and concluded that this can be reduced if the grouping is based on a defined index of affinity. Fager (1957) proposed a procedure for the determination of recurrent species groups which was intended to remove the subjectivity element and also to make the results repeatable. The method was further developed by using the geometric mean of the proportion of joint occurrences as an index of affinity based on records of presence and absence (Fager 1963). This method was applied to the Guinean Trawling Survey data from which the assemblages of demersal fish species in the Gulf of Guinea were determined (Fager and Longhurst 1968; Longhurst 1969).

Generally, community ecologists employ a number of multivariate statistical methods to organize data with a view to determining any structure in them and developing an understanding of the communities involved. Such data are analyzed by a 'methodological triad' consisting of direct gradient analysis, ordination and classification (Gauch 1994; Jongman *et al.* 1995).

Direct gradient analysis, also known as canonical ordination (ter Braak 1991) is used to display the distribution of organisms along gradients of important and recognized environmental factors (Gauch 1994). The ordination axes are constrained to be a linear combination of the environmental variables (ter Braak 1991). Redundancy analysis and canonical correspondence analysis are examples of direct gradient analysis. In ordination, sites are arranged along axes on the basis of data on species composition. A suite of observed variables are reduced to axes which are linear combinations of the original variables. These methods, also referred to as indirect gradient analysis, would also search for major gradients in the species data even where there are no environmental variables associated with the data (ter Braak 1991). They arrange the species data according to theoretical environmental



variables. Principal component analysis (PCA), factor analysis (FA), multidimensional scaling (MDS) and correspondence analysis (CA) are examples of ordination methods. Classification, on the other hand, is the assignment of entities to known classes or groups. Cluster analysis is one such method (van Tongeren 1995).

Cluster analysis is widely used in fish community studies to identify groups of species (e.g. Gabriel and Tyler 1980; Strauss 1982; Gabriel and Murawski 1985). Usually, a classification diagram (dendrogram) is produced which is also intended to reveal the hierarchical relationships among the groups. There are numerous choices and stopping rules in the use of this technique. These include the order of classification, i.e. hierarchical or non-hierarchical, the method of linking the groups and defining the linkage - similarity or dissimilarity of sites and the mode of handling the sample, i.e. divisive or agglomerative. These choices introduce a high degree of subjectivity in the use of the method. In addition, cluster analysis has the following major drawbacks:

- i. production of miscellaneous clusters from 'left-overs' referred to as 'chaining' where objects may be added to groups that they do not belong to at all, and
- ii. the difficulty in relating the sample dendrogram with the species dendrogram, thus making it difficult to match species groups with sample groups.

Within the broad categories of the multivariate statistical methods noted above, community ecologists have a variety of options to choose from in the analysis of community data. Gauch (1994) gives an excellent review and evaluation of multivariate statistical methods and their use in ecological work. Each of these methods may be sensitive to specific aspects of structural variation (Pielou 1975; Magurran 1991) and has particular advantages or disadvantages. However, as the results of multivariate analysis of community data are to help improve the ecologist's understanding of spatial variability of community structure in relation to the environment, the choice of suitable multivariate statistical methods for the analysis of such data must involve the examination of the underlying assumptions in the

methods with respect to the response of natural resources to changes in their environment. This response takes the form of a Gaussian curve (Gauch and Whittaker 1976; Fasham 1977) as depicted in Figure 4.1. Under such a model, the abundance of a species in response to changes along an environmental gradient has a single mode or optimum. Many multivariate statistical methods (e.g. FA) assume a linear structure for such a relationship, i.e. the abundance of a species either increases (or decreases) with change in state of the environmental variable. This choice of model has an adverse effect on the results of the analysis. For example, in a research that examined the influence of environmental factors on the distribution of juvenile fish off Nova Scotia, Canada, Horne and Campana (1989) showed, that PCA and FA were unable to define distinct gradients in the biological ordination, and the authors attributed this to the linearity assumption used in these techniques.

Correspondence analysis (CA; also known as reciprocal averaging, RA, dual scaling or *analyse factorielle des correspondances* by the French school), is an ordination method which does not assume a linear relationship in response but rather assumes the more appropriate unimodal Gaussian curve (Digby and Kempton 1987, ter Braak 1991; Jongman *et al.* 1995). Consequently, this method is very popular among community ecologists as it is also robust against the effect of sampling errors and sample clusters (Fasham 1977). From a suite of environmental variables, CA constructs 'theoretical variables' (axes) that best explain the variation in the species data. It does this by choosing the best values for the sites that maximize the dispersion of the species scores (ter Braak 1995). The derived axes are decorrelated with respect to each other thereby ensuring that later axes carry new information (ter Braak 1995). In the absence of environmental data, CA extracts the ordination axes from the species data alone.

Unfortunately, correspondence analysis also has two defects, namely the 'arch effect' and compression of the ends of the first axis (Hill 1974; Gauch 1994). The first defect implies that the second ordination axis is usually a quadratic function of the first (or primary) axis resulting in spurious ordination. In the second defect, the



degree of separation on the primary axis depends on the position of the segment along the axis. Hill and Gauch's (1980) suggested an improvement on the method, called Detrended Correspondence Analysis (DCA), which overcomes the two major problems of CA.

To handle the first problem, the improvement involves dividing the primary axis into a number of segments and then adjusting the scores on the secondary axis within each segment (of the primary axis). The scores are normalized to have a zero mean (Gauch 1994). The second problem is solved by re-scaling "... to expand or contract small segments along the species ordination axis such that species turnover occurs at a uniform rate along this axis and, consequently, that equal distances in the ordination correspond to equal differences in species composition" (Gauch 1994).

The method of "detrending by segments" has been criticized by Pielou (1984) who warns that "DCA's over zealous correction may sometimes lead to the unwitting destruction of ecologically meaningful information" and by Minchin (1987) on the grounds of instability in the result. However, Bianchi (1992a) points out that the stated problems of detrending by segments "is true only when the number of samples is small compared to the number of segments chosen for detrending and also for short gradients". On this score, the more stable method of detrending by polynomials, which has also been examined by Hill and Gauch (1980) has been revisited. In this method of detrending, the second axis is not only decorrelated with the first axis but is also with its square (ter Braak 1995). This method of detrending retains ecological information which might be destroyed when detrending by segments (Jongman *et al.* 1995; ter Braak 1995).

In spite of the stated improvements on the method of correspondence analysis, Greenstreet and Hall (1996), citing Clarke and Ainsworth (1993) and Warwick and Clarke (1993), concluded that "of all suitable ordination methods, multidimensional scaling (MDS) appears to be emerging as a relatively robust method". The robustness of the method in such analysis was also acknowledged by

Sheppard (1995). Unlike DCA which analyses a sample-by-species data matrix, MDS operates on a matrix of dissimilarity values between sites with the original species composition data replaced by this matrix. However, Jongman *et al.* (1995) caution that it is unclear what response models the method can cope with.

With the modifications indicated above and the attractiveness and advantages of assuming a unimodal response curve, the method of ordination by detrended correspondence analysis (DCA) was used in this work, and with detrending by second order polynomials. Two ecology programs, TWINSpan (Hill 1979) and CANOCO (ter Braak 1991) were used to analyse the data.

TWINSpan is a cluster analysis program that also performs ordination of the sites and species. It uses a divisive cluster analysis algorithm to classify the samples and correspondence analysis to perform the ordination. This property of TWINSpan has made it one of the most widely used programs in community ecology (van Tongeren 1995). TWINSpan “first constructs a classification of the samples (stations records), and then uses this classification to obtain a classification of the species according to their ecological preferences. The two classifications are then used together to obtain an ordered two-way table that expresses the species’ synecological relations as succinctly as possible” (Hill 1979). In this output, sites are arranged in columns according to their properties with similar stations appearing close to one another. These form clusters that are characterized by their diversity, total biomass or other ecological features. The species are arranged in rows according to the same criteria.

Two-way Indicator species Analysis (TWIA) which is the underlying principle of TWINSpan, identifies ‘differential species’ the presence of which can be used to identify particular environmental conditions (Hill 1979). The ‘differential species’ idea is a qualitative one, and so TWINSpan uses the levels of abundance of the species to define a scale that provides a quantitative alternative of this concept. This is referred to as ‘pseudospecies cut levels’ (Hill 1979).



In ordination, the importance of each ordination axis is measured by the percentage of total variation in the data that it explains. The ordination axes are referred to as eigen vectors and the importance of each ordination axis is determined by its eigen value which is a measure of the dispersion of the species scores on the ordination axis. The first ordination axis explains the highest of the variation in the data with subsequent axes, having smaller eigenvalues, explaining less of the variation. Generally, the first two axes are sufficient to reveal important structure in the data (ter Braak 1995). However if the two eigenvalues are low and subsequent values are high, then the associated axes may be considered in the interpretation of the ordination and structure of the data. As a default in CANOCO, only the first four ordination axes are computed.

#### **4.2.2 Tests of assemblage association**

A few methods exist for testing the degree of association of the species within the assemblage. One such method is the correlation coefficient. The Pearson's product moment correlation coefficient between  $n$  pairs of two variables  $y_1$  and  $y_2$  is calculated from

$$r_{12} = \frac{\sum y_1 y_2}{(n-1)S_1 S_2} \quad \dots 4.1$$

where  $\sum y_1 y_2$  is their sum of product and  $S_1$  and  $S_2$  standard deviations of the two variables (Sokal and Rohlf 1995). The standard error ( $S_r$ ) of the correlation coefficient ( $r$ ) is

$$S_r = \sqrt{\frac{1-r^2}{n-2}} \quad \dots 4.2$$

(Sokal and Rolf 1995). The null hypothesis of no correlation between pairs of

observations is tested using Student's t-test with  $n-2$  degrees of freedom. For  $k$  environmental variables the degrees of freedom equals  $n-k-1$ . The t-value is calculated from

$$t_s = \frac{r - 0}{\sqrt{\frac{1-r^2}{n-2}}} = r \sqrt{\frac{n-2}{1-r^2}}. \quad \dots 4.3$$

(Sokal and Rolf 1995). In practice, the calculated  $r$  is compared with the critical value of  $r$  obtained from the table of distribution of correlation coefficient and for the appropriate degrees of freedom.

Similarities in the composition of the various assemblages are assessed using the Jaccard index,  $S_j$  (Southwood 1978; Magurran 1991) and the Similarity Ratio,  $S_r$  (Ball 1966). The Jaccard index measures how similar (or dissimilar) sites are in terms of variety of species found in them. The fewer species the sites have in common the smaller  $S_j$  will be (Magurran 1991). For two sampled sites (1 and 2),  $S_j$  is calculated as

$$S_j = \frac{c}{a+b+c} \quad \dots 4.4$$

where  $c$  is the number of species common to both sites,  $a$  is the number of species unique to site 1 and  $b$  is the number of species unique to site 2. The index is usually written as

$$S_j = \frac{c}{A+B-c} \quad \dots 4.5$$

where  $A$  is the total number of species at the first site and  $B$  is the corresponding number at the second site. To be adapted for use in this work, all stations in each assemblage were grouped and the assemblage treated as a 'site'.



The similarity ratio is basically, a quantitative equivalent of the Jaccard index (van Tongeren 1995). Following the notation of van Tongeren (1995), the similarity ratio for the comparison of two sites (i and j),  $S_{rij}$ , is calculated from:

$$S_{rij} = \frac{\sum_k y_{ki} y_{kj}}{\sum_k y_{ki}^2 + \sum_k y_{kj}^2 - \sum_k y_{ki} y_{kj}} \quad \dots 4.6$$

where  $y_{ki}$  is the abundance of the  $k^{\text{th}}$  species at site i,  $y_{kj}$  is its abundance at site j, and  $y_{ki} y_{kj}$  is the product of the abundance of the  $k^{\text{th}}$  species occurring at both sites.

### 4.3 MATERIALS AND METHODS

#### 4.3.1 *The data*

Between 1963 and 1992, a number of stock assessment surveys of the demersal fishery resources on the continental shelf and upper slope off Ghana were conducted. These surveys and data sets have been enumerated and described in detail in chapters 1 and 6. For the study of fish communities, the following data sets were used:

- i. subsets of the Guinean Trawling Survey (September 1963 and March 1964) data pertaining to the transects worked off Ghana (transects 27 - 33),
- ii. subsets of data from the Marine Fisheries Research Division (MFRD) surveys (1981-82 and 1989),
- iii. water temperature, salinity, and dissolved oxygen measured at depths trawled, and
- iv. depth sampled and nature of seabed (referred to in this work as bottom or sediment type).

The materials and methods used in the surveys including the survey design, survey procedures and compilation of the data are described in detail in chapter 6. The names of fishes follow Blache *et al.* (1970), Fischer *et al.* (1981) and Schneider (1990). Many of the names were cross-checked with entries in FISHBASE (FishBase 1996). For the MFRD survey data, only trips that covered the entire survey area (all sectors; see Chapter 6) were used. This was to avoid the problem of “over-weighting” as some areas were worked more often than others in accordance with the sampling design (Koranteng 1980). The relevant data were total catch (in weight) and number (MFRD surveys only) of each species in each haul. For hauls of 30 minutes duration (MFRD surveys), the catches were extrapolated to catch-per-hour of trawling.

The catch data were converted into the ‘Cornell condensed format’ (ter Braak 1991) that is required as input for TWINSpan and CANOCO. The NAN-SIS survey data logging program that was used as the repository for all the survey data has the facility to perform this conversion. The temperature was recorded at the time of sampling and generally after the trawl net had been hauled in. Salinity and dissolved oxygen were determined from sea water samples taken to the laboratory for analyses. Bottom type information was obtained from sediment maps produced during the GTS and also from similar ones used during Guinea 90 (Ramos *et al.* 1990). The descriptions of sediment types as used in the two surveys are as follows:

| <b>Bottom type</b> | <b>GTS</b>   | <b>GUINEA 90</b>      |
|--------------------|--|-----------------------|
| <b>Hard</b>        | predominantly sand, shell,<br>rock, gravel, coral, etc | sand-gravel-rock-grit |
| <b>Mixed</b>       | combination of hard and soft                           | sand-mud-grit         |
| <b>Soft</b>        | predominantly mud                                      | mud                   |



### **4.3.2 Analysis**

#### **4.3.2.1 Extracting assemblages of fish**

The analysis began with obtaining species groupings (assemblages) in the GTS data using the Two-way Indicator Analysis (TWIA) method implemented by TWINSpan and detrended correspondence analysis (DCA) incorporated in CANOCO. It was intended at this stage to see how many assemblages could be identified from the data and how these compare with the assemblages described by Fager and Longhurst (1968) and Longhurst (1969).

Considering the variation in sizes of the species in the analysis, weights were used for this and other analysis of assemblage structure instead of numbers. Bianchi and Hoisæter (1992) cautioned that the use of numbers in this kind of analysis would tend to overemphasize the importance of small-sized fishes in the community as these are normally caught in large quantities. They also showed that numbers and weights produce the same results, except in the case of short environmental gradients.

Thus, throughout this work the following pseudospecies cut levels were used: 0, 0.5, 5, 50 and 500. This implies that the numerals on the TWINSpan table output have the following meanings:

1:  $w < 0.5$ ;    2:  $0.5 < w < 5$ ;    3:  $5 < w < 50$ ;    4:  $50 < w < 500$ ;    5:  $w > 500$   
where  $w$  is weight of the species in kg.

The two GTS cruises were analysed together initially. Each data set was first analyzed with TWINSpan and the groups determined from examination of the two-way table in the output, the eigenvalues resulting from the ordination, and the indicator (or differential) species. A further ordination of the data by DCA was performed using CANOCO. In the latter analysis, each weight ( $x$ ) was converted to  $\log(x + 1)$  to stabilize the variance as a Gaussian relationship between species

abundance and each environmental variable was assumed. The environmental variables included in the analysis were depth sampled, type of sediment (hard, mixed or soft - a nominal variable), bottom temperature, salinity and dissolved oxygen. CANOCO assesses the importance of each environmental variable in the ordination by producing regression estimates and Pearson's product-moment correlation coefficient of ordination axes versus environmental variables.

Using the results of TWINSpan to label the sites, the DCA scores were plotted using the computer program CANODRAW (Smilauer 1992). CANOCO produces a solution file that is used as input file for CANODRAW. Outputs from CANODRAW include scatter diagrams of sites, species or environmental variables, bi-plot of any two of these and a tri-plot of all three.

The MFRD surveys were designed initially to cover depths between 10 and 75 m deep, however, hauls were made between 75 and 100 m occasionally. For the GTS results to be comparable to those of the MFRD, the GTS data were re-analysed using only hauls made between 10 and 75 m deep (i.e. up to the fourth station on each transect).

The MFRD3 (1981-82) and MFRD5 (1989) survey data were similarly analysed. A "standing" assemblage structure was defined from the combined data in each case. The species in each group were also obtained from the results of TWINSpan.

Unlike the sites (stations) in the ordination, species were not considered to belong exclusively to the groupings obtained from TWINSpan. An Index of Relative Importance was therefore defined to obtain the species that were most important in each assemblage. The index used was:

$$IRI = (\%W + \%N) \times \%F \quad \dots 4.7$$



where %W is the percentage contribution by weight, of each species in the assemblage, %N is the percentage contribution by numbers, and %F is the percentage of the number of times that the species occurred in hauls from the assemblage. This index was developed for work on feed and feeding of animals (Pinkas *et al.* 1971, as cited by Caddy and Sharp 1986). In the case of the GTS survey, numbers of fish caught were not readily available at the source from which data were obtained for this work. In this case, IRI was calculated from

$$\text{IRI} = \%W \times \%F \quad \dots 4.8$$

Species with IRI values of 50 or more in each assemblage were included in a short list of the most important species of the assemblage.

#### 4.3.2.2 Community association and temporal changes in assemblage formation

The significance of the correlation between species axes and environmental variables was examined using a Student's t-test on Pearson's product moment correlation coefficient. The statistical significance of each regression estimate given by CANOCO was also tested using the Student's t-test with  $n-k-1$  degrees of freedom. To obtain the mean of environmental parameters for each of the identified groups of stations (making up the assemblages of species), CANOCO was run again using only the stations in that group.

Seasonal and long-term temporal variation of the assemblages were investigated taking the GTS survey results as the baseline. In Ghanaian waters, GTS I was conducted in September 1963, i.e. towards the end of the upwelling season, and GTS II was in March, which marked end of the minor cold season and the beginning of the major warm season. Consequently, August (upwelling) and May (non-upwelling or thermocline) data for 1981-82 and 1989 MFRD surveys were used in

these analyses. As discussed later in this chapter (section 4.5), only three assemblages were extracted from the MFRD surveys for the purposes of comparison.

The Jaccard index and similarity ratios were also used to compare corresponding assemblages derived from the various surveys and also corresponding assemblages in the upwelling and non-upwelling seasons in the same survey.

## **4.4 RESULTS**

All descriptive information about fish species - e.g. depth found and habitat preference were summarized from Williams (1968), Blache *et al.* (1970), Fischer *et al.* (1981), Rijavec (1980), Koranteng (1984), Schneider (1990) and from personal observations made during the MFRD surveys. Appendix 4.1 is a list of all species encountered during the surveys - from GTS to Guinea 90 and used in these analyses. Some synonyms are also given, especially where the most preferred (or valid) name of the species had changed since GTS. Where the species was not identified, the genus name is given. Also shown are the species codes used in NAN-SIS and in the community ecology programs.

### **4.4.1 Community Structure**

Throughout this chapter 'station', 'haul' and 'site' have been used interchangeably to mean a sampling unit. In the sampling design, only one haul would be taken at each station on the same cruise and throughout the survey, a number of hauls would be taken at each station. In the GTS, some stations were intentionally repeated on the same cruise; this has been accounted for in the compilation of the data. 'Group' has also been used to denote a collection of hauls (or stations) making up an assemblage.



#### 4.4.1.1 Guinean Trawling Survey (all hauls)

Ninety-one hauls and 305 species (and species groups) were used in the analysis of this survey (Table 4.1). The hauls were made up of 45 from the first cruise (GTS I) and 46 from the second cruise (GTS II). Appendix 4.2.1 gives the 2-way output from TWINSpan having analyzed the entire GTS data.

Table 4.1: Number of hauls and species per survey used in the analysis of community structure

| Survey | Year    | Stations/hauls | Species |
|--------|---------|----------------|---------|
| GTS    | 1963-64 | 91             | 305     |
| GTS    | 1963-64 | 64*            | 247     |
| MFRD3  | 1981-82 | 139            | 150     |
| MFRD5  | 1989    | 109            | 136     |

\* with depth of 75 m or less

The first division of TWINSpan appears to have separated stations deeper than 100 m on mixed bottom, from those shallower than this. Unfortunately, even with a high eigenvalue of 0.464 at this division, there were no clear indicator species for this group of 15 hauls. However, from the TWINSpan output, *Paracubiceps ledanoisi* and *Chlorophthalmus atlanticus* appear to play this role. Both are deep-water species commonly found at 100 - 300 m deep on muddy bottoms. At the second level of divisions, this group of 15 stations was sub-divided into one of 4 stations (at depths ranging from 200 - 600 m) and another of 11 stations at depths between 100 and 400 m. The indicator species for the deeper group of stations was *Hymenocephalus italicus* which was generally caught in low quantities of about 0.5 kg hr<sup>-1</sup>. *H. italicus* is usually found in waters of 200 - 500 m deep.

The other 76 stations were subdivided into two groups, namely one (16 stations) in shallow waters (40 m deep or less) and on soft bottom and the other (60 stations) at 40 - 100 m deep. The indicator species in the first group were *Selene dorsalis* (= *Vomer setapinnis*) and *Galeoides decadactylus*. The first is a pelagic species found mainly in shallow waters and the second is a shallow water demersal species found on muddy grounds and sometime in estuaries. The 60 stations were further divided into two groups having membership of 25 and 35 stations. The group with 25 stations had *Balistes forcipatus* (= *B. punctatus*) and *Aluterus punctatus* as the indicator species. Both *B. forcipatus* and *A. punctatus* are coastal species and the latter is found mainly on sandy bottoms. From the CANOCO output, the prevailing sediment type for this group is mixed-to-hard. Other important species in this group were *Lutjanus agennes* and *Lutjanus fulgens*. *Dentex angolensis* and *Dentex congoensis* were the indicator species for the other group with 35 members.

At the next level, the groups just described above, were sub-divided. However it was not feasible to consider the separation of the group of 25 members as this appears to have resulted in the separation of hauls made in the first GTS cruise from those made in the second. The two sub-groups out of the 35 stations were one of 9 stations (in relatively shallower area) having the coastal and estuarine dwelling shrimp, *Penaeus notialis* and the ubiquitous *Brachydeuterus auritus* as the indicator species. The sparids *Dentex congoensis* and *Boops boops* and the smoothback angelshark, *Squatina oculata* characterized the other group of 26 members. All three species have wide depth distribution but were found mainly at depths of around 100 m.

Further divisions on the TWINSPAN output were found to be less meaningful than those considered. This gives the number of reasonably identified groups as six. Figure 4.2 is a dendrogram showing the clustering order of the station groupings (assemblages). The dendrogram shows that roughly, the six assemblages group in pairs. The first pair is made up of the first two assemblages in waters of 40 m or less deep, the second pair is on intermediate shelf at depths of 40 - 60 m and the third pair



of assemblages is found deeper (over 200 m deep).

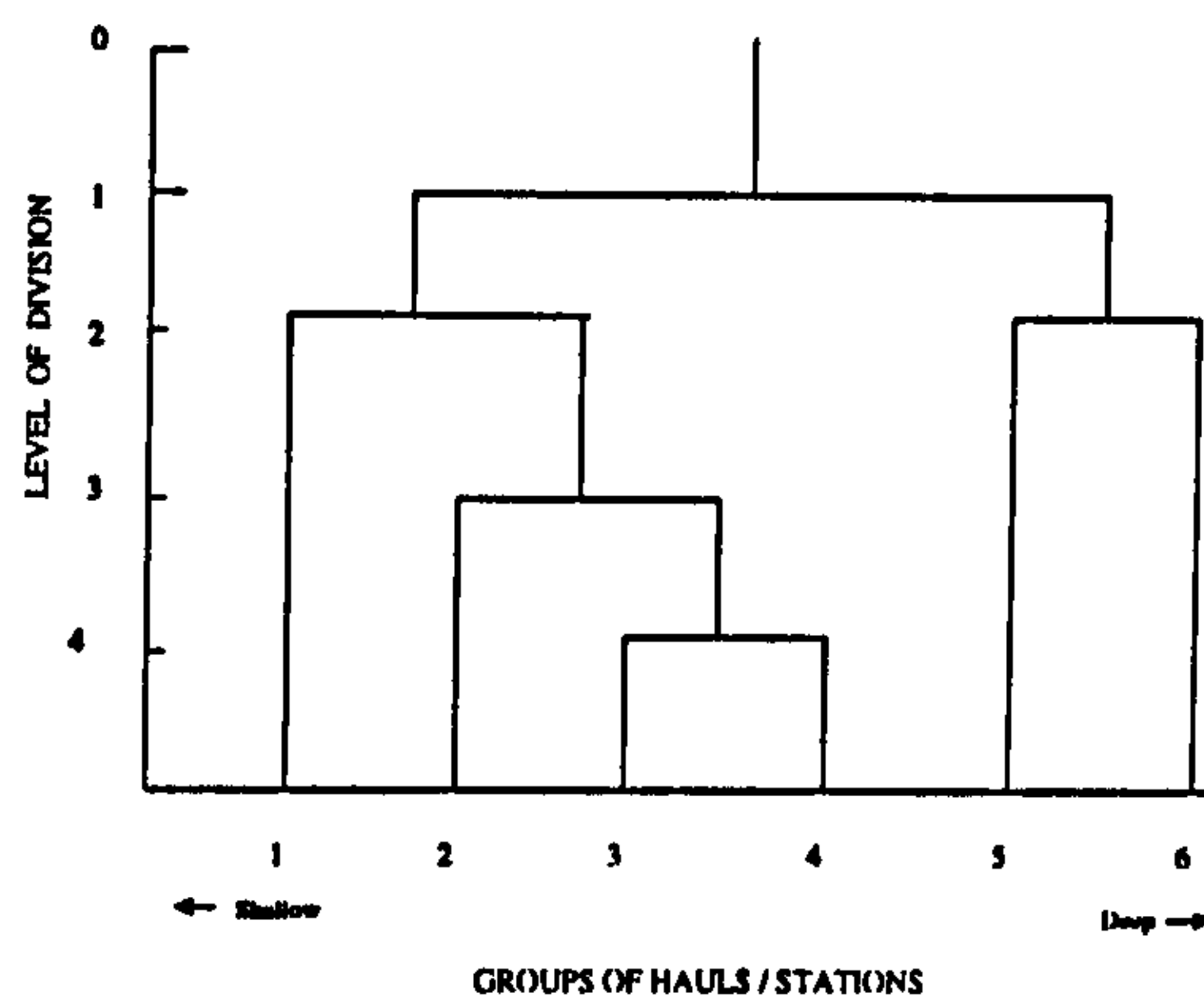


Figure 4.2: Dendrogram showing clustering order of groups of stations for the GTS data analysed with TWINSpan

Summary descriptions of the six assemblages are presented below. Depths and values of environmental parameters referred to in these descriptions are given in Table 4.5.1

#### Group/Assemblage 1.

This group is made up of 16 hauls/stations from both cruises, taken from muddy soft bottom at an average depth of 28 m. The average environmental temperature is 20.8 °C with salinity and dissolved oxygen values of 35.85 ‰ and 3.13 ml l<sup>-1</sup> respectively. The group is located along a narrow belt which widens considerably towards the west, close to the estuaries of the Ankobra and Pra Rivers (Figure 1.1), and towards the east around the Volta River estuary. The members are a mixture of pelagic species with large depth distribution and also coastal - estuarine demersal species. The most prominent of the species are *Selene dorsalis* and the eurybathic species *Brachydeuterus auritus* (which occurs in 94 % of the hauls in the group and accounts for over 34 % of the weight). Others are *Pseudotolithus senegalensis* and *Galeoides decadactylus*.

The species composition of this group and description of their preferred

environment coincide with a similar community found off Angola at average depth of 24 m and water temperature of 23 °C (Bianchi 1992b). Fager and Longhurst (1968) named this group the 'sciaenid community' having estuarine and shelf components. Considering the depths worked in the GTS, the group identified here is the shelf component.

### Group/Assemblage 2

A group of 25 hauls at a mean depth of 37 m and average temperature of 19.8 °C. Average salinity and dissolved oxygen are only slightly lower than the values for the first group being 35.82 ‰ and 2.98 ml l<sup>-1</sup> respectively. This group is normally found from between the mixed layer and upper thermocline layer (Longhurst and Pauly 1987). The sediment type is 'mixed-to-hard' with a couple of stations in the zones with soft bottom. The important species of the group are *Pagellus bellottii*, *Brachydeuterus auritus*, *Sparus caeruleostictus* and *Trachurus* sp. These account for nearly 44 % of the group's weight. Others are *Lutjanus fulgens* and *Lutjanus agennes*. The *Lutjanus* sp. give the group its name of 'lutjanid community' (Fager and Longhurst 1968). Longhurst (1969) remarked that this group does not have to be taken seriously as it is within the thermocline layer and contains many eurybathic species, perhaps suggesting that Longhurst expected the group to be very unstable.

### Group/Assemblage 3

Nine hauls constitute this group. These are located on soft-to-mixed sediment types at an average depth of 49 m (i.e. generally below the thermocline) and close to the two capes. The average temperature, salinity and dissolved oxygen values are 19.4 °C, 35.88 ‰ and 2.44 ml l<sup>-1</sup> respectively. The indicator species are *Brachydeuterus auritus* and *Penaeus notialis*, however the group also contains a large representation of sparids, with *S. caeruleostictus* topping the list. Other sparids are the deep-water, rocky bottom *Dentex angolensis* and *Dentex congoensis*. This group was named the sparid community (shallow element) by Longhurst (1969).



#### Group/Assemblage 4

Group 4, called the sparid community (deep element) by Longhurst (1969), is here made up of 26 stations/hauls from both cruises lying between 75 and 100 m deep (average 87 m). It is on hard-to-mixed bottom with low temperature of around 17.5 °C and low dissolved oxygen and salinity values of 2.74 ml l<sup>-1</sup> and 35.74 ‰ respectively. Like the previous group, it is dominated by sparids, especially deep water species *Dentex congoensis* and *Dentex gibbosus* and other mid-to-deep shelf species like *Epinephelus aeneus*, *Paracubiceps ledanoisi* and the semi-pelagic sparid *Boops boops*.

#### Group/Assemblage 5

There are 11 stations in this group stretching between 190 m and 245 m deep (average depth is 217 m). Three of the 11 stations are located on deep soft grounds. The mean values of environmental temperature, salinity and dissolved oxygen for this group are 14 °C, 35.41 ‰ and 2.23 ml l<sup>-1</sup> respectively. It is a deep continental shelf community (Longhurst 1969) lying well below the thermocline. The constituents of the assemblage are *Paracubiceps ledanoisi*, the benthopelagic cephalopod *Loligo* sp. and the deep water sciaenid *Pentheroscion mbizi*. Others are *Antigonia capros* and *Trachurus* sp. According to Longhurst (1969), this group has many taxa in common with assemblages at similar depths in mid-latitudes.

#### Group/Assemblage 6

Group 6 is made up of 4 stations with an average depth of 411 m and generally on mixed bottom, with low temperature of 11 °C, salinity of 35.37 ‰ and dissolved oxygen value of 2.07 ml l<sup>-1</sup>. The constituent species are all deep water fish mainly *Squalus fernandus* and *Centrophorus uyato* (deep water sharks), *Hypoclydonia bella*, and *P. ledanoisi*. These four species contribute over 75 % of the weight of the group.

Table 4.2.1 gives the correlation coefficient between pairs of the environmental variables depth, bottom temperature, salinity and dissolved oxygen.

Being a nominal variable, the three levels of sediment type could not be considered in these correlations. Correlation coefficient for the MFRD surveys are given in Table 4.2.2. As expected, depth correlated highly and negatively with bottom temperature and also with salinity. Salinity and temperature were also highly and positively correlated.

Table 4.2.1: Correlation coefficient between pairs of environmental parameters, GTS 1963-64 (Top half matrix is for all 91 stations and bottom for stations  $\leq 75$  m deep)

|                      | Depth | Temp. | Salinity | Oxygen | all stations |
|----------------------|-------|-------|----------|--------|--------------|
| Depth                | 1     | -0.85 | -0.68    | -0.34  | Depth        |
| Temp.                | -0.78 | 1     | 0.66     | 0.49   | Temp.        |
| Salinity             | -0.20 | 0.02  | 1        | 0.19   | Salinity     |
| Oxygen               | -0.18 | 0.34  | -0.18    | 1      | Oxygen       |
| stations $\leq 75$ m | Depth | Temp. | Salinity | Oxygen |              |

Table 4.2.2: Correlation coefficient between pairs of environmental parameters, MFRD surveys (Top half matrix is for MFRD3 and bottom for MFRD5)

|          | Depth | Temp. | Salinity | DO    | MFRD3    |
|----------|-------|-------|----------|-------|----------|
| Depth    | 1     | -0.63 | -0.36    | -0.42 | Depth    |
| Temp.    | -0.64 | 1     | -0.57    | 0.85  | Temp.    |
| Salinity | -0.01 | -0.11 | 1        | -0.37 | Salinity |
| DO       | -0.45 | 0.84  | -0.09    | 1     | DO       |
| MFRD5    | Depth | Temp. | Salinity | DO    |          |



Table 4.3 gives the correlation coefficients between the environmental variables and the four species ordination axes. All correlations with the first species axis, except those of bottom type, were significant at 1 % level; bottom type was significant on the second axis and there were no significant correlations with the third and fourth axes. In this ordination, the first two DCA axes explained 54.2 % of the total variation in the species-environment data. The total variation explained by the first four axes is only 56.7 % signifying that axes 3 and 4 carry very little additional information and that there is still substantial amount of variation in the data that has not been explained by the ordination.

Regression estimates of environmental parameters with the first two species axes are given in Table 4.4. Although none of the environmental parameters had significant regression estimates on the first two ordination axes, depth is still portrayed as the most important variable with the largest t-value on the first axis. Sediment types hard and mixed had largest values on the second axis.

Figure 4.3 is a plot of sites (hauls) in the DCA axis 1 against DCA axis 2 plane from the ordination results of CANOCO. Hauls in the same group (assemblage) are indicated by the same symbol and enclosed in an ellipse. Thus the six groups are shown. In this and similar plots, some points in the ordination are not shown. CANODRAW hides points that coincide with others that have already been positioned in the plane, or that lie on lines linking the coordinates of the environmental parameters with the origin or on the axes. The axes of the plot are from -1 to +1 as the scaling applied in CANOCO are correlations that always lie between -1 and +1. This is necessary to make all plots totally comparable and also to make it possible to superimpose them on one another. The figure also shows positions of the environmental variables in the ordination plane. The importance of each variable is 'proportional' to the length of line that links its coordinates to the origin.

Table 4.3: Pearson’s product-moment correlation coefficient r, of species axes 1 - 4 with bottom environmental variables.

|                             | Variable    | Species Axis 1 | Species Axis 2 | Species Axis 3 | Species Axis 4 |
|-----------------------------|-------------|----------------|----------------|----------------|----------------|
| GTS<br>(all hauls)          | Hard        | -0.13          | -0.29**        | 0.00           | 0.14           |
|                             | Mixed       | 0.13           | -0.14          | -0.00          | -0.02          |
|                             | Soft        | -0.02          | 0.43**         | 0.00           | -0.11          |
|                             | Depth       | 0.95**         | 0.01           | -0.03          | -0.06          |
|                             | Temperature | -0.81**        | 0.10           | 0.06           | 0.01           |
|                             | Salinity    | -0.64**        | -0.01          | 0.01           | 0.06           |
|                             | Oxygen      | -0.34**        | 0.11           | 0.08           | 0.17           |
|                             | Eigenvalues | 0.68           | 0.50           | 0.43           | 0.33           |
| GTS<br>(hauls at<br>≤ 75 m) | Hard        | -0.31**        | -0.02          | -0.04          | 0.15           |
|                             | Mixed       | -0.11          | -0.29*         | 0.11           | -0.11          |
|                             | Soft        | 0.44**         | 0.37**         | -0.09          | -0.03          |
|                             | Depth       | -0.51***       | -0.71***       | -0.11          | 0.08           |
|                             | Temperature | 0.47***        | -0.47***       | -0.08          | -0.09          |
|                             | Salinity    | 0.18*          | -0.07          | 0.06           | 0.33*          |
|                             | Oxygen      | 0.21*          | -0.19          | -0.14          | -0.05          |
|                             | Eigenvalues | 0.54           | 0.40           | 0.24           | 0.21           |
| MFRD3                       | Hard        | -0.49***       | 0.09           | 0.05           | 0.13           |
|                             | Mixed       | 0.30**         | 0.01           | -0.08          | -0.08          |
|                             | Soft        | 0.30**         | 0.13           | 0.05           | -0.08          |
|                             | Depth       | -0.29**        | 0.79***        | 0.01           | 0.09           |
|                             | Temperature | 0.23*          | -0.65***       | -0.12          | -0.06          |
|                             | Salinity    | -0.02          | 0.28           | 0.03           | 0.09           |
|                             | Oxygen      | 0.13           | -0.54***       | -0.14          | -0.03          |
|                             | Eigenvalues | 0.40           | 0.34           | 0.21           | 0.18           |
| MFRD5                       | Hard        | -0.29**        | -0.30**        | 0.08           | 0.09           |
|                             | Mixed       | 0.16           | 0.12           | -0.13          | 0.11           |
|                             | Soft        | 0.20*          | 0.26**         | 0.06           | -0.28**        |
|                             | Depth       | -0.42***       | 0.60***        | 0.22*          | -0.03          |
|                             | Temperature | 0.18           | -0.54***       | -0.13          | -0.01          |
|                             | Salinity    | 0.08           | -0.07          | 0.17           | 0.41***        |
|                             | Oxygen      | -0.02          | -0.47***       | -0.16          | 0.10           |
|                             | Eigenvalues | 0.46           | 0.36           | 0.26           | 0.20           |

\* r significant at 5% level; \*\* at 1% level; \*\*\* at 0.1 % level.



Table 4.4: Regression coefficient (x) and Student's t-value (t) on the first 2 DCA axes.

|             | GTS (all stations) |       |            |       | GTS (stations ≤ 75 m) |          |            |          |
|-------------|--------------------|-------|------------|-------|-----------------------|----------|------------|----------|
|             | DCA Axis 1         |       | DCA Axis 2 |       | DCA Axis 1            |          | DCA Axis 2 |          |
| Variable    | x                  | t     | x          | t     | x                     | t        | x          | t        |
| Hard        | -0.03              | -0.05 | -0.57      | -0.48 | -0.50                 | -3.95*** | -0.46      | -4.86*** |
| Mixed       | -0.02              | -0.05 | -0.47      | -0.40 | -0.50                 | -4.06*** | -0.46      | -4.93*** |
| Depth       | 0.92               | 1.27  | 0.07       | 0.03  | -0.40                 | -2.48*   | 0.90       | 7.32***  |
| Temperature | -0.05              | -0.06 | 0.06       | 0.03  | -0.02                 | 0.12     | 0.14       | 1.10     |
| Salinity    | 0.02               | 0.04  | -0.07      | -0.05 | 0.12                  | 1.15     | 0.08       | 1.07     |
| Oxygen      | -0.00              | -0.01 | 0.19       | 0.17  | 0.25                  | 2.32*    | 0.01       | 0.11     |

|             | MFRD3      |       |            |       | MFRD5      |         |            |          |
|-------------|------------|-------|------------|-------|------------|---------|------------|----------|
|             | DCA Axis 1 |       | DCA Axis 2 |       | DCA Axis 1 |         | DCA Axis 2 |          |
| Variable    | x          | t     | x          | t     | x          | t       | x          | t        |
| Hard        | -0.66      | -0.56 | -0.28      | -0.37 | -0.36      | -2.79** | -0.55      | -5.56*** |
| Mixed       | -0.26      | -0.22 | -0.11      | -0.14 | -0.22      | -1.63   | -0.17      | -1.68    |
| Depth       | -0.11      | -0.11 | 0.70       | 1.12  | -0.40      | -3.62** | 0.50       | 5.98***  |
| Temperature | 0.38       | 0.20  | -0.18      | -0.15 | 0.27       | 1.47    | -0.20      | -1.39    |
| Salinity    | 0.20       | 0.22  | -0.12      | -0.20 | 0.12       | 1.34    | -0.05      | -0.07    |
| Oxygen      | -0.13      | -0.09 | -0.12      | -0.13 | -0.42      | -2.70   | -0.09      | -0.08    |

The stations were plotted on the survey chart with hauls in the same group denoted by the same symbol and colour (Figure 4.4). The position of the points represents approximate locations of the trawls hauls. Summaries of salient properties of the groups identified in the Guinean Trawling Survey data are presented in Table 4.5.1. The table gives average values of the environmental parameters, indicator species and some of the important species of each assemblage. Table 4.6 gives a list of species with IRI value of 50 or more in each group.

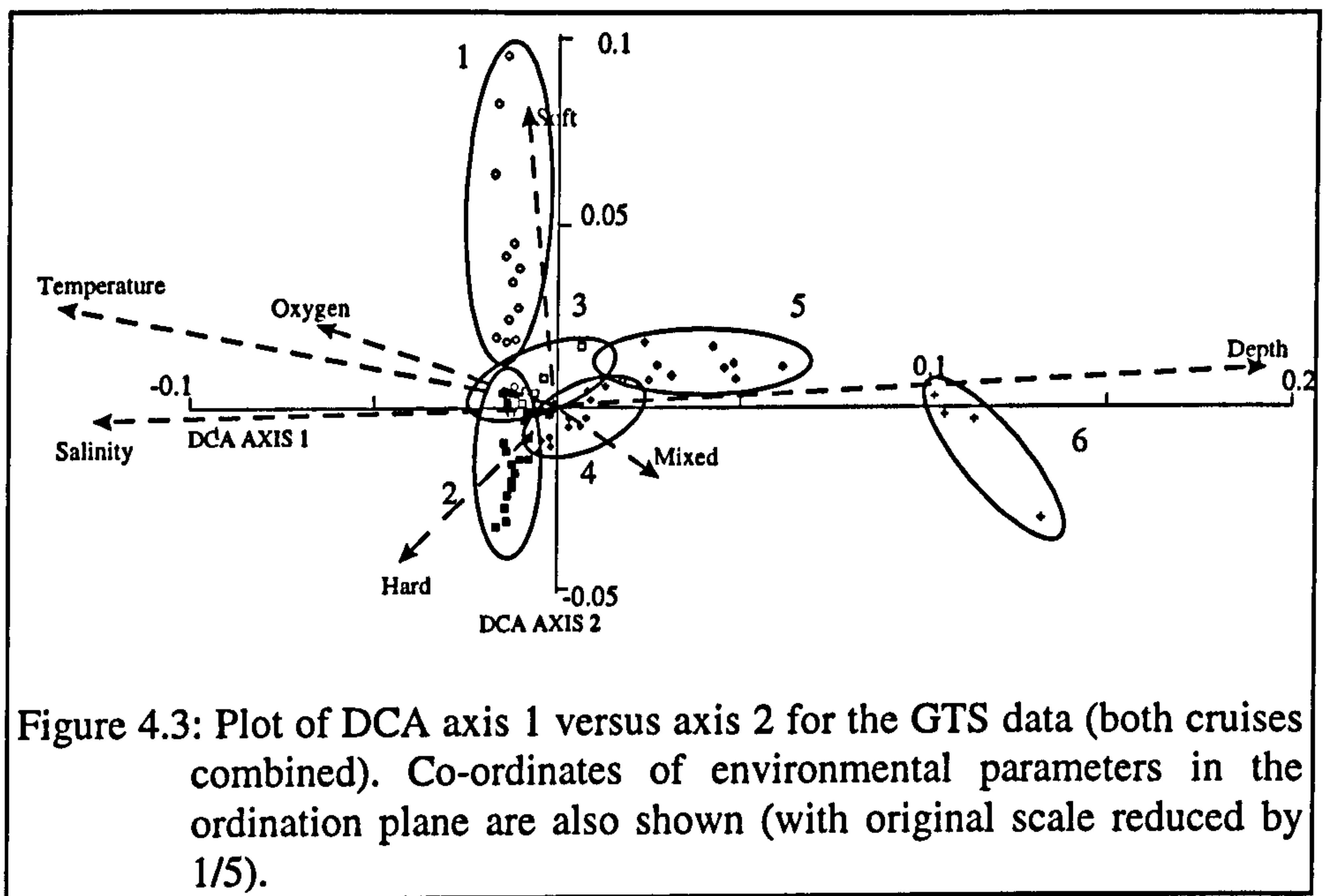


Figure 4.3: Plot of DCA axis 1 versus axis 2 for the GTS data (both cruises combined). Co-ordinates of environmental parameters in the ordination plane are also shown (with original scale reduced by 1/5).



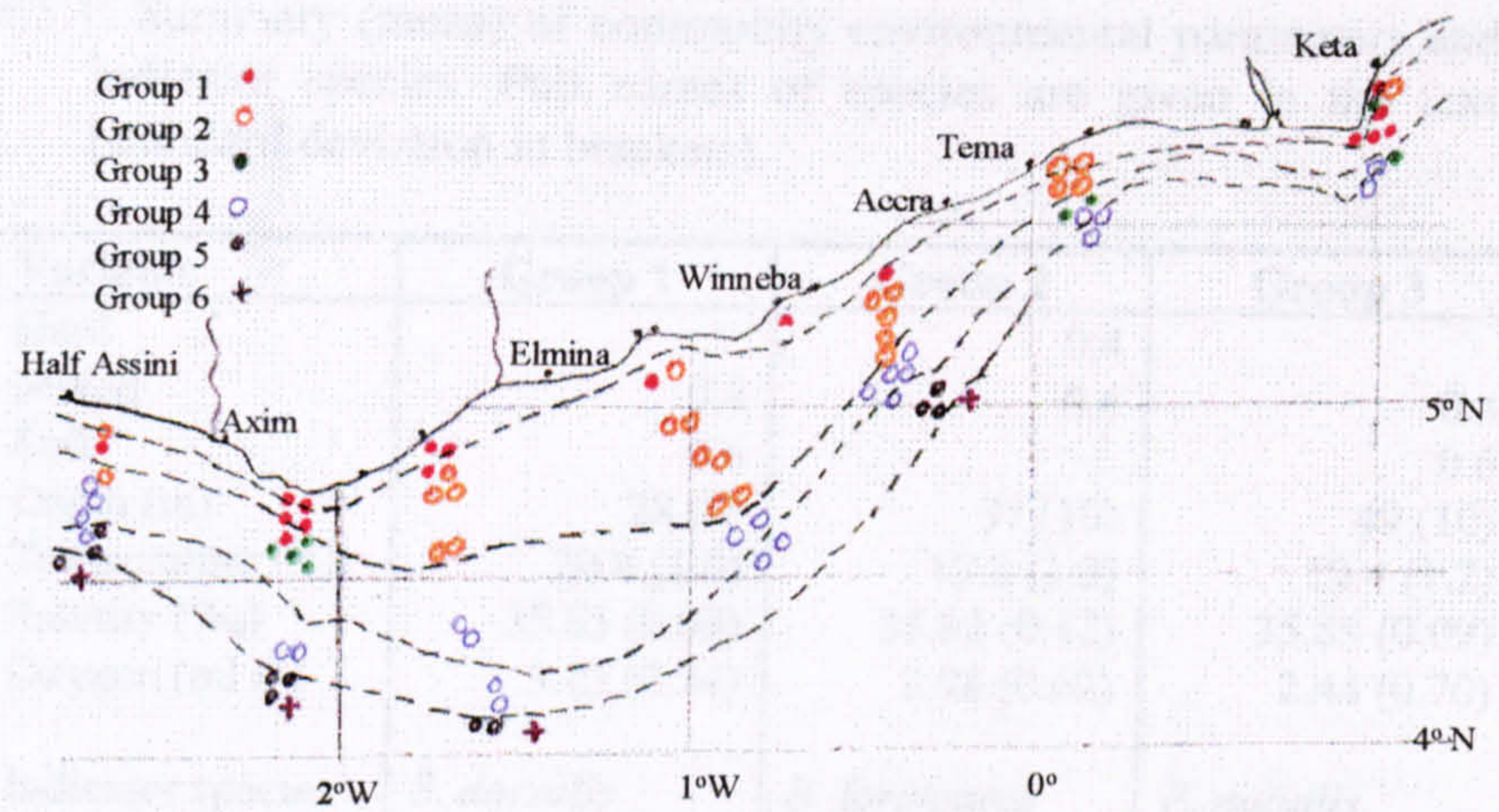


Figure 4.4: Grouping of trawl hauls (GTS I and GTS II)

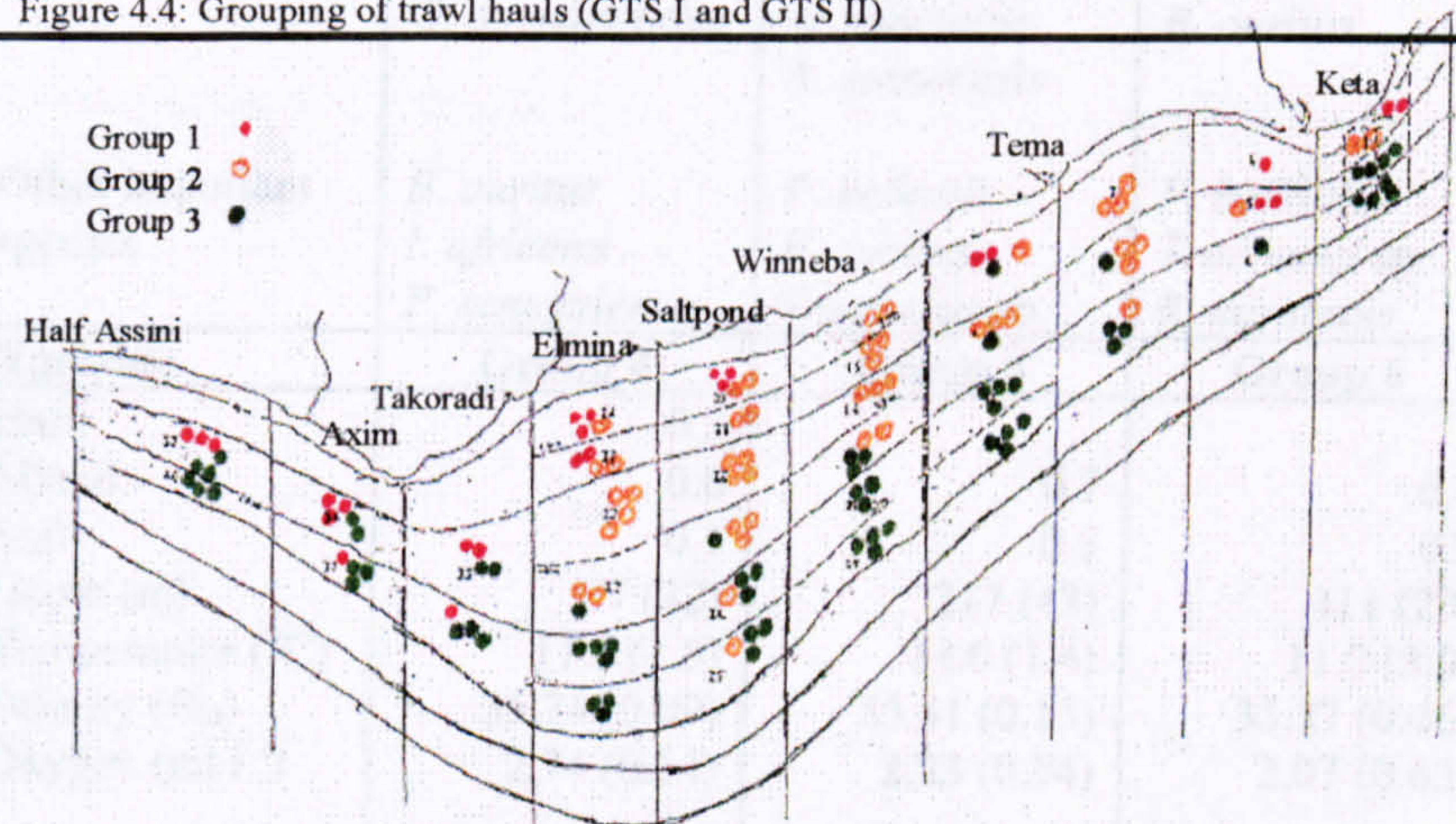


Figure 4.6: Grouping of trawl hauls, MFRD 3 (all cruises, survey design explained in chapter 6)

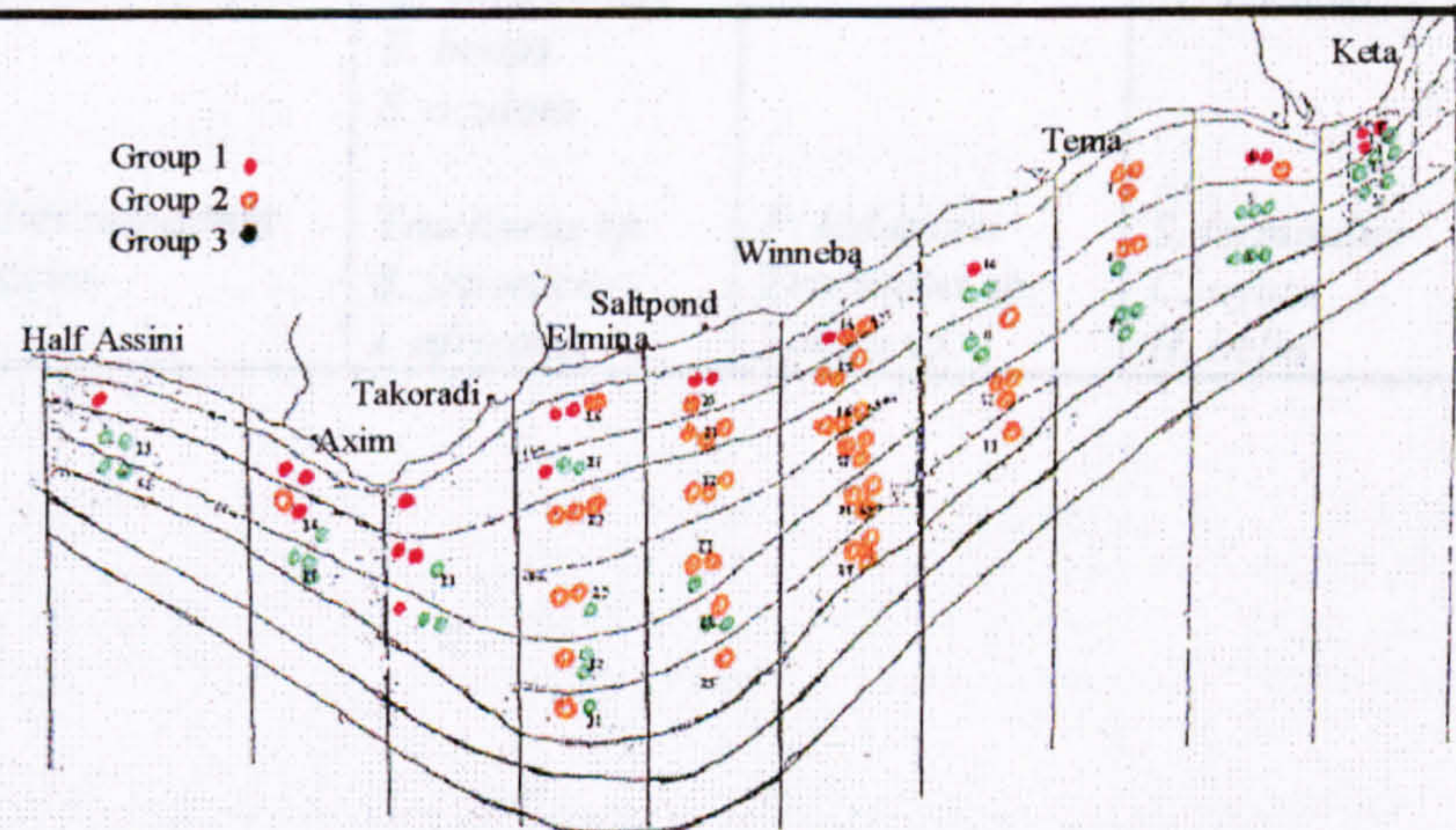


Figure 4.7: Grouping of trawl hauls, MFRD 5 (all cruises survey design explained in chapter 6)



Table 4.5.1: Summary (mean) of community environmental parameters and indicator species. Full names of species are given in the text (standard deviation in brackets).

| Survey | Variable                     | Group 1   | Group 2   | Group 3  |
|--------|------------------------------|---|---|--|
| GTS    | Hard                         |   | 0.4   |  |
|        | Mixed                        | 0.4   | 0.6   | 0.4  |
|        | Soft                         | 0.6   |   | 0.6  |
|        | Depth (m)                    | 28 (8)  | 37 (10)   | 49 (10)  |
|        | Temperature (°C)             | 20.8 (1.0)  | 19.8 (1.3)  | 19.4 (1.2)   |
|        | Salinity (‰)                 | 35.85 (0.09)  | 35.82 (0.12)  | 35.88 (0.09)   |
|        | Oxygen (ml l <sup>-1</sup> ) | 3.13 (0.74)   | 2.98 (0.62)   | 2.44 (0.70)  |
|        | Indicator species            | <i>S. dorsalis</i><br><i>G. decadactylus</i>                      | <i>B. forcipatus</i><br><i>A. punctatus</i><br><i>A. guineensis</i> | <i>P. notialis</i><br><i>B. auritus</i>                            |
|        | Other important species      | <i>B. auritus</i><br><i>I. africana</i><br><i>P. senegalensis</i> | <i>P. bellottii</i><br><i>B. auritus</i><br><i>Trachurus</i> sp.    | <i>P. bellottii</i><br><i>Trachurus</i> sp.<br><i>R. miraletus</i> |
| Survey | Variable                     | Group 4   | Group 5   | Group 6  |
| GTS    | Hard                         | 0.3   |   |  |
|        | Mixed                        | 0.6   | 0.7   | 0.8  |
|        | Soft                         | 0.1   | 0.3   | 0.2  |
|        | Depth (m)                    | 87 (32)   | 217 (43)  | 411 (23)   |
|        | Temperature (°C)             | 17.5 (1.3)  | 14.0 (1.4)  | 11.0 (3.0)   |
|        | Salinity (‰)                 | 35.74 (0.09)  | 35.41 (0.15)  | 35.37 (0.46)   |
|        | Oxygen (ml l <sup>-1</sup> ) | 2.74 (0.54)   | 2.23 (0.54)   | 2.07 (0.65)  |
|        | Indicator species            | <i>D. congoensis</i><br><i>B. boops</i><br><i>S. oculata</i>      |   | <i>H. italicus</i>   |
|        | Other important species      | <i>Trachurus</i> sp.<br><i>S. japonicus</i><br><i>I. africana</i> | <i>P. ledanoisi</i><br><i>Trachurus</i> sp.<br><i>Loligo</i> sp.    | <i>S. fernandus</i><br><i>C. uyato</i><br><i>H. bella</i>          |



Table 4.5.2: Summary (mean) of community environmental parameters and indicator species (only three assemblages considered)

| Survey                                     | Variable                     | Group 1  | Group 2  | Group 3   |
|--|------------------------------|--|--|---|
| GTS<br>(only<br>stations<br>≤75 m<br>deep) | Hard                         |  | 0.4  | 0.2   |
|  | Mixed                        | 0.4  | 0.6  | 0.5   |
|  | Soft                         | 0.6  |  | 0.3   |
|  | Depth (m)                    | 27 (8)   | 37 (10)  | 58 (31)   |
|  | Temperature (°C)             | 20.9 (1.0)   | 19.8 (1.3)   | 18.6 (1.4)  |
|  | Salinity (‰)                 | 35.85 (0.09)   | 35.82 (0.12)   | 35.81 (0.11)  |
|  | Oxygen (ml l <sup>-1</sup> ) | 3.20 (0.74)  | 2.99 (0.62)  | 2.69 (0.59)   |
|  | Indicator species            | <i>S. dorsalis</i><br><i>G. decadactylus</i>   | <i>B. forcipatus</i><br><i>L. atlanticus</i><br><i>A. monroviae</i><br><i>L. fulgens</i> | <i>D. angolensis</i><br><i>D. congoensis</i>  |
|  | Other important species      | <i>D. africana</i><br><i>P. senegalensis</i><br><i>P. jubelini</i>                       | <i>L. agennes</i>  | <i>P. ledanoisi</i><br><i>B. boops</i>  |
|  |                              |  |  |   |
| MFRD3                                      | Hard                         |  | 0.6  | 0.5   |
|  | Mixed                        | 0.7  | 0.4  | 0.4   |
|  | Soft                         | 0.3  |  | 0.1   |
|  | Depth (m)                    | 29 (10)  | 35 (10)  | 56 (10)   |
|  | Temperature (°C)             | 24.1 (2.8)   | 23.6 (3.6)   | 19.3 (2.0)  |
|  | Salinity (‰)                 | 35.70 (0.34)   | 35.56 (0.69)   | 35.88 (0.30)  |
|  | Oxygen (ml l <sup>-1</sup> ) | 4.53 (0.57)  | 4.45 (0.96)  | 3.53 (0.79)   |
|  | Indicator species            | <i>S. dorsalis</i><br><i>G. decadactylus</i><br><i>B. auritus</i><br><i>S. sphyraena</i> | <i>B. forcipatus</i><br><i>L. atlanticus</i>   | <i>D. angolensis</i><br><i>D. congoensis</i><br><i>Trigla</i> sp.<br><i>R. miraletus</i>    |
|  | Other important species      | <i>B. auritus</i><br><i>I. africana</i><br><i>P. senegalensis</i>                        | <i>L. goreensis</i><br><i>L. fulgens</i><br><i>A. fuscus</i>                             | <i>P. ledanoisi</i><br><i>B. boops</i>  |
|  |                              |  |  |   |
| MFRD5                                      | Hard                         | 0.1  | 0.7  | 0.3   |
|  | Mixed                        | 0.5  | 0.3  | 0.5   |
|  | Soft                         | 0.4  |  | 0.2   |
|  | Depth (m)                    | 28 (10)  | 41 (14)  | 52 (13)   |
|  | Temperature (°C)             | 23.0 (4.0)   | 22.0 (3.4)   | 20.0 (2.2)  |
|  | Salinity (‰)                 | 35.46 (0.97)   | 35.46 (0.34)   | 35.25 (0.60)  |
|  | Oxygen (ml l <sup>-1</sup> ) | 3.61 (1.33)  | 3.64 (1.09)  | 3.13 (0.70)   |
|  | Indicator species            | <i>S. dorsalis</i><br><i>B. auritus</i>  | <i>B. forcipatus</i><br><i>D. canariensis</i><br><i>L. fulgens</i>                       | <i>S. accraensis</i><br><i>D. angolensis</i><br><i>P. ledanoisi</i><br><i>D. congoensis</i> |
|  | Other important species      | <i>Cynoglossus</i> sp.<br><i>P. senegalensis</i><br><i>P. notialis</i>                   | <i>L. agennes</i><br><i>A. fuscus</i><br><i>L. atlanticus</i>                            | <i>S. pagrus</i><br><i>Trigla</i> sp.   |
|  |                              |  |  |   |

Table 4.6 : Total weight (W kg), percentage weight (%W) and frequency of occurrence (F, number of stations) of the main species in each group of stations; Guinean Trawling Survey, 1963-64.

|                                    |         |        |    |                                |         |        |     |    |
|------------------------------------|---------|--------|----|--------------------------------|---------|--------|-----|----|
| Group 1 (16 stations)              |         |        |    | <i>Raja miraletus</i>          |         | 66     | 0.6 | 23 |
| Species                            | W<br>kg | %<br>W | F  | Total                          | 9467    | 81.2   |     |    |
|                                    |         |        |    | Total (all species)            | 11657   |        |     |    |
| <i>Brachydeuterus auritus</i>      | 2616    | 34.2   | 15 | Group 3 (9 stations)           |         |        |     |    |
| <i>Serlene sorsalis</i>            | 544     | 7.1    | 13 |                                |         |        |     |    |
| <i>Galeoides decadactylus</i>      | 565     | 7.4    | 11 |                                |         |        |     |    |
| <i>Pseudotolithus senegalensis</i> | 586     | 7.7    | 10 |                                |         |        |     |    |
| <i>Ilisha africana</i>             | 620     | 8.1    | 7  |                                |         |        |     |    |
| <i>Sparus caeruleostictus</i>      | 313     | 4.1    | 9  | Species                        | W<br>kg | %<br>W | F   |    |
| <i>Pagellus bellottii</i>          | 235     | 3.1    | 10 |                                |         |        |     |    |
| <i>Drepane africana</i>            | 221     | 2.9    | 9  | <i>Sparus caeruleostictus</i>  | 569     | 17.0   | 9   |    |
| <i>Raja miraletus</i>              | 149     | 2.0    | 12 | <i>Brachydeuterus auritus</i>  | 771     | 23.1   | 6   |    |
| <i>Trichiurus lepturus</i>         | 152     | 2.0    | 10 | <i>Trachurus spp.</i>          | 444     | 13.3   | 7   |    |
| <i>Loligo sp.</i>                  | 250     | 3.3    | 6  | <i>Raja miraletus</i>          | 155     | 4.6    | 7   |    |
| <i>Pomadasys jubelini</i>          | 100     | 1.3    | 8  | <i>Priacanthus arenatus</i>    | 124     | 3.7    | 7   |    |
| <i>Pteroscion peli</i>             | 132     | 1.7    | 6  | <i>Epinephelus aeneus</i>      | 81      | 2.4    | 6   |    |
| <i>Epenephelus aeneus</i>          | 88      | 1.2    | 8  | <i>Pseudupeneus prayensis</i>  | 88      | 2.6    | 5   |    |
|                                    |         |        |    | <i>Sparus caeruleostictus</i>  | 62      | 1.9    | 5   |    |
| Total                              | 6571    | 85.9   |    | <i>Lepidotrigla cadmani</i>    | 59      | 1.8    | 4   |    |
| Total (all species)                | 7646    |        |    | <i>Loligo sp.</i>              | 32      | 0.9    | 6   |    |
|                                    |         |        |    | <i>Dentex congoensis</i>       | 58      | 1.7    | 3   |    |
|                                    |         |        |    | <i>Cynoglossus canariensis</i> | 34      | 1.0    | 5   |    |
|                                    |         |        |    | <i>Penaeus notialis</i>        | 22      | 0.7    | 7   |    |
|                                    |         |        |    | <i>Sardinella aurita</i>       | 39      | 1.2    | 4   |    |
|                                    |         |        |    | <i>Dentex angolensis</i>       | 38      | 1.1    | 4   |    |
|                                    |         |        |    |                                |         |        |     |    |
|                                    |         |        |    | Total                          | 2576    | 77.1   |     |    |
|                                    |         |        |    | Total (all species)            | 3343    |        |     |    |
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|----------------------|-------|------|--------------------------|------|------|---|
| Total                | 14084 | 83.8 | <i>Dentex angolensis</i> | 101  | 1.7  | 4 |
| Total (all stations) | 16812 |      | <i>Dentex congoensis</i> | 66   | 1.1  | 5 |
|                      |       |      | Total                    | 5019 | 84.6 |   |
|                      |       |      | Total (all stations)     | 5933 |      |   |

| Group 5 (11 stations)             |         |        |    | Group 6 (4 stations)              |         |        |   |
|-----------------------------------|---------|--------|----|-----------------------------------|---------|--------|---|
| Species                           | W<br>kg | %<br>W | F  | Species                           | W<br>kg | %<br>W | F |
| <i>Paracubiceps ledanoisi</i>     | 1567    | 26.4   | 10 | <i>Squalus fernandus</i>          | 501     | 47.5   | 2 |
| <i>Trachurus spp.</i>             | 1188    | 20.0   | 4  | <i>Hypoclydonia bella</i>         | 116     | 11.0   | 2 |
| <i>Antigonia capros</i>           | 431     | 7.3    | 8  | <i>Centrophorus uyato</i>         | 134     | 12.7   | 1 |
| <i>Loligo sp.</i>                 | 435     | 7.3    | 7  | <i>Paracubiceps multisquamis</i>  | 44      | 4.2    | 3 |
| <i>Pentheroscion mbizi</i>        | 333     | 5.6    | 7  | <i>Chlorophthalmus sp.</i>        | 41      | 3.9    | 2 |
| <i>Smaris macrolepidotus</i>      | 327     | 5.5    | 7  | <i>Chlorophthalmus atlanticus</i> | 71      | 6.7    | 1 |
| <i>Chlorophthalmus atlanticus</i> | 119     | 2.0    | 7  | <i>Carcharhinus signatus</i>      | 31      | 2.9    | 2 |
| <i>Paragaleus pectoralis</i>      | 265     | 4.5    | 3  | <i>Paracubiceps ledanoisi</i>     | 32      | 3.0    | 1 |
| <i>Paracubiceps multisquamis</i>  | 98      | 1.7    | 5  | Total                             | 970     | 92.0   |   |
| <i>Priacanthus arenatus</i>       | 88      | 1.5    | 5  | Total (all species)               | 1055    |        |   |

#### 4.4.1.2 GTS stations between 10 and 75 m deep

In TWINSPAN, the 64 stations lying between 10 and 75 m deep were first divided into two groups of 50 and 14 stations. This division separates shallow stations of generally 40 m or less from the others (Appendix 4.2.2). This group, having an average depth of 27 m, is characterized by *Selene dorsalis* and *Galeoides decadactylus*. Other important members of the group are *Drepane africana*, *Pseudotolithus senegalensis* and *Pomadasy jubelini*. All these are coastal species with preference for sandy and/or muddy bottoms.

At the next level of classification, the 50 stations are further divided into two. The first of these groups is made up of 28 stations and with a mean depth of 58 m. No clear indicator species are given in the TWINSPAN results but the two-way table output shows that *Dentex angolensis* and *Dentex congoensis* appear to play this role. The second of the two groups is intermediate between the two groups described

above and has an average depth of 37 m. The indicator species are *Lutjanus fulgens*, *Lutjanus goreensis*, *Lethrinus atlanticus*, *Balistes forcipatus* and *Acanthurus monroviae*. The first two species are of the family Lutjanidae which identifies the group.

The next step in the division appears to separate the hauls made in the first cruise from those made in the second, thus accounting for seasonal differences. Thus, this division and subsequent ones have been ignored. Consequently, three groups have been considered in this data set. The group characteristics, as obtained from CANOCO, are also summarised in Tables 4.4 and 4.5.2 and the order of grouping is shown as a dendrogram at the bottom of Appendix 4.2.2.

In this sub-set of the GTS data, correlation coefficient of all environmental parameters with species axis 1 are significant ( $p < 0.05$ ) except sediment-type 'mixed' which is significant on the second axis, together with depth, temperature and sediment-type 'soft' (Table 4.3). Depth and sediment type are also significant ( $p < 0.05$ ) on both axis 1 and axis 2. Oxygen is significant on axis 1.

#### 4.4.1.3 MFRD surveys of 1981-82

In the four surveys conducted between April 1981 and March 1982, 150 fish species were encountered. These include fin-fish, molluscs and crustaceans. The two-way classification of species and sampling stations obtained from TWINSpan is given in Appendix 4.3.

The first dichotomy from TWINSpan separates what appears to be shallow-water stations (50 m or less) on mixed-to-soft bottom from deeper stations on the continental shelf. The indicator species of this first group are *Chloroscombrus chrysurus*, *Brachydeuterus auritus*, *Selene dorsalis* and *Sphyraena sphyraena*. These are pelagic or semi-pelagic species showing preference for coastal waters close to

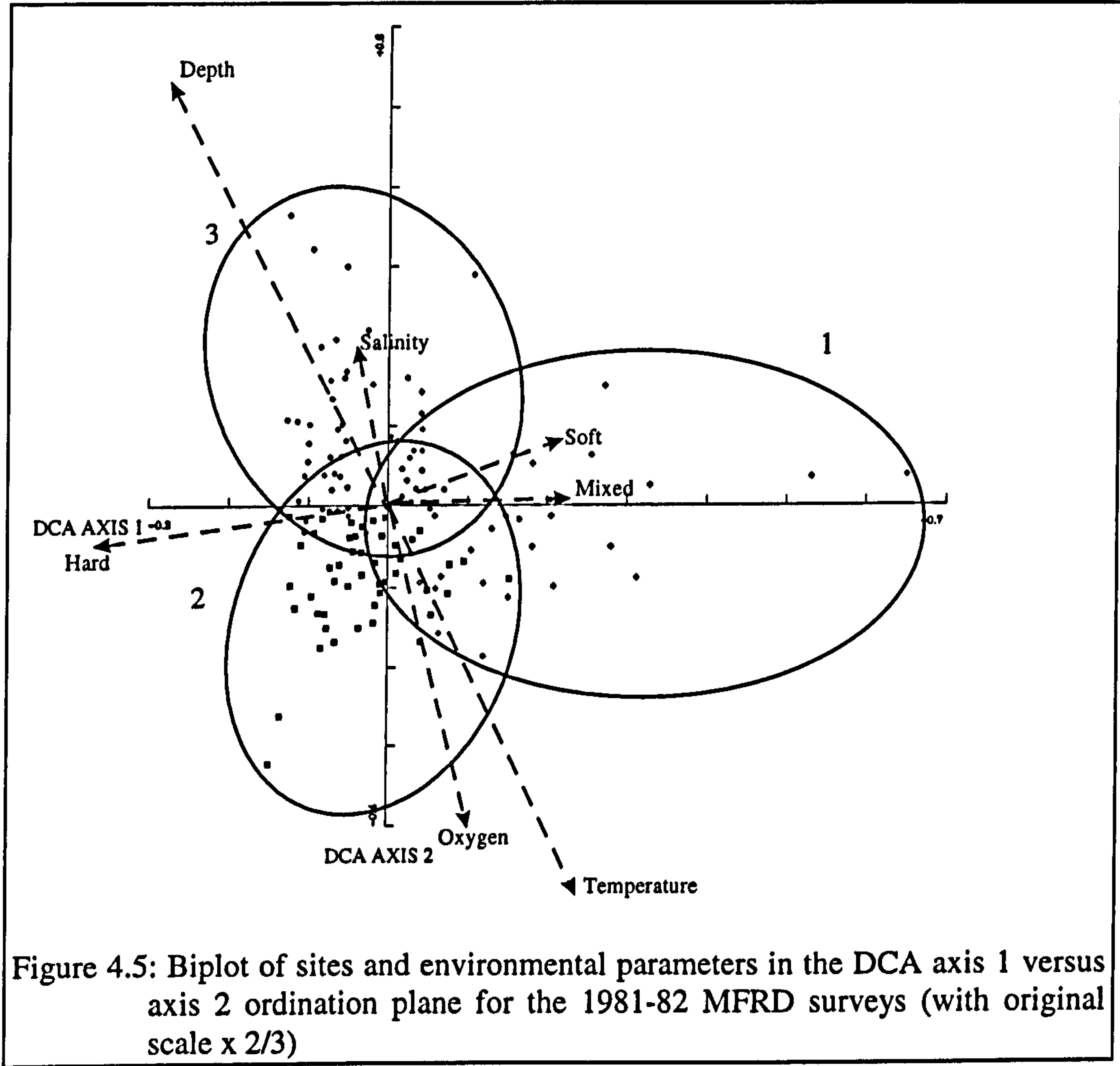


estuaries, and mixed sediment type. On the other side of the primary division, the indicator species are *Dentex canariensis* (a species with affinity for various types of bottoms on the continental shelf) and *Priacanthus arenatus* which is found mainly on rocky bottoms and down to 100 m deep.

At the second division, (level 2 of the TWINSpan output) the group of deep stations in the first dichotomy is divided into two, still separated by depth. The first of the two groups contains stations of mainly hard bottom whilst the second subgroup is of hard-to-mixed bottom types. The indicator species are *Balistes forcipatus* and *Lethrinus atlanticus* in the first group and *Dentex angoleis*, *Dentex congensis*, *Raja miraletus* and *Trigla* sp. in the second. The division of the shallow water group separated in the first dichotomy is not considered. This is because this division appears to have separated hauls taken on the first cruise (May 1981) from the others. Three groups are thus, considered. Appendix 4.3 also shows a dendrogram depicting the order of classification of the stations. Further ordination with CANOCO resulted in the species axes - environmental variables correlations in Table 4.3 and the group properties presented in Table 4.5.2.

Unlike the GTS data, sediment type is the most important factor in this data set with all three levels loading relatively higher than depth and physico-chemical parameters on the first species axis. On the second axis, depth emerges as the dominant factor with a correlation coefficient,  $r$  of 0.79 (Table 4.3). Bottom temperature and dissolved oxygen follow in importance with  $r$  values of 0.65 and 0.54 respectively. Table 4.4 gives regression estimates on the first two DCA axes, and the corresponding values of the Student's  $t$  distribution. None of the regression estimates is significant at the 5 % level. The four axes accounted for 56.3 % of the variation on the species - environment data. The first axis, representing sediment type, accounts for only 19.5 % of the total variation in the data, but results in a clear separation of the shallow water assemblage on soft - to - mixed bottom from the other groups. The second axis, representing depth, surprisingly accounts for about 35 % of the variation.

Figure 4.5 is a bi-plot of sites and environmental parameters. The results (groups) were also plotted on the survey chart as shown in Figure 4.6. As the depth zones on this map are not drawn to scale, the points mark the location of the stations in the sampling design (see chapter 6). The figure shows substantial overlap of the identified groups.





#### 4.4.1.4 MFRD surveys of 1989

One hundred and nine trawl hauls and 138 fish species were used in the TWINSPAN analysis for this survey. At the first dichotomy, 20 stations with an average depth of 28 m separate out from the others. This group on mixed-to-soft grounds, has *Selene dorsalis* and *Brachydeuterus auritus* as the indicator species whilst the other half of the dichotomy has *Pagellus bellottii*, *Dentex canariensis* and *Pseudupeneus prayensis* as the indicator species. At level 2 of the TWINSPAN two-way table (Appendix 4.4), the 89 stations on one side of the primary dichotomy are sub-divided into two, namely one with *Lutjanus fulgens*, *Balistes forcipatus*, *Dentex canariensis* and *Chaetodon* sp. as the indicator species and the other with *Serranus accraensis* and *Rhizoprionodon acutus* as the indicators species.

Divisions at the third and lower levels of the TWINSPAN output appear to be separating the data from the various cruises (seasons) and have therefore been ignored. Hence three groups at depths of between 28 and 63 m are considered here. The haul locations are shown in Figure 4.7.

Tables 4.3 and 4.4 also give the correlation coefficients and regression estimates respectively, obtained from this analysis. The correlations of sediment type (hard and soft) and depth with the first DCA axis are all significant at the 5 % level. On the second axis, the correlations of all the variables are significant, except the mixed sediment type and salinity which, surprisingly, is significant on the fourth axis. Sediment type (soft) is also significant on the fourth axis. In addition, unlike the previous surveys, the regression estimates for sediment type (hard), depth and dissolved oxygen at the bottom are significant on the first DCA axis with the first two also significant on the second axis. Consequently, the assemblages are separated almost equally on both DCA axis 1 and axis 2 (Figure 4.8).

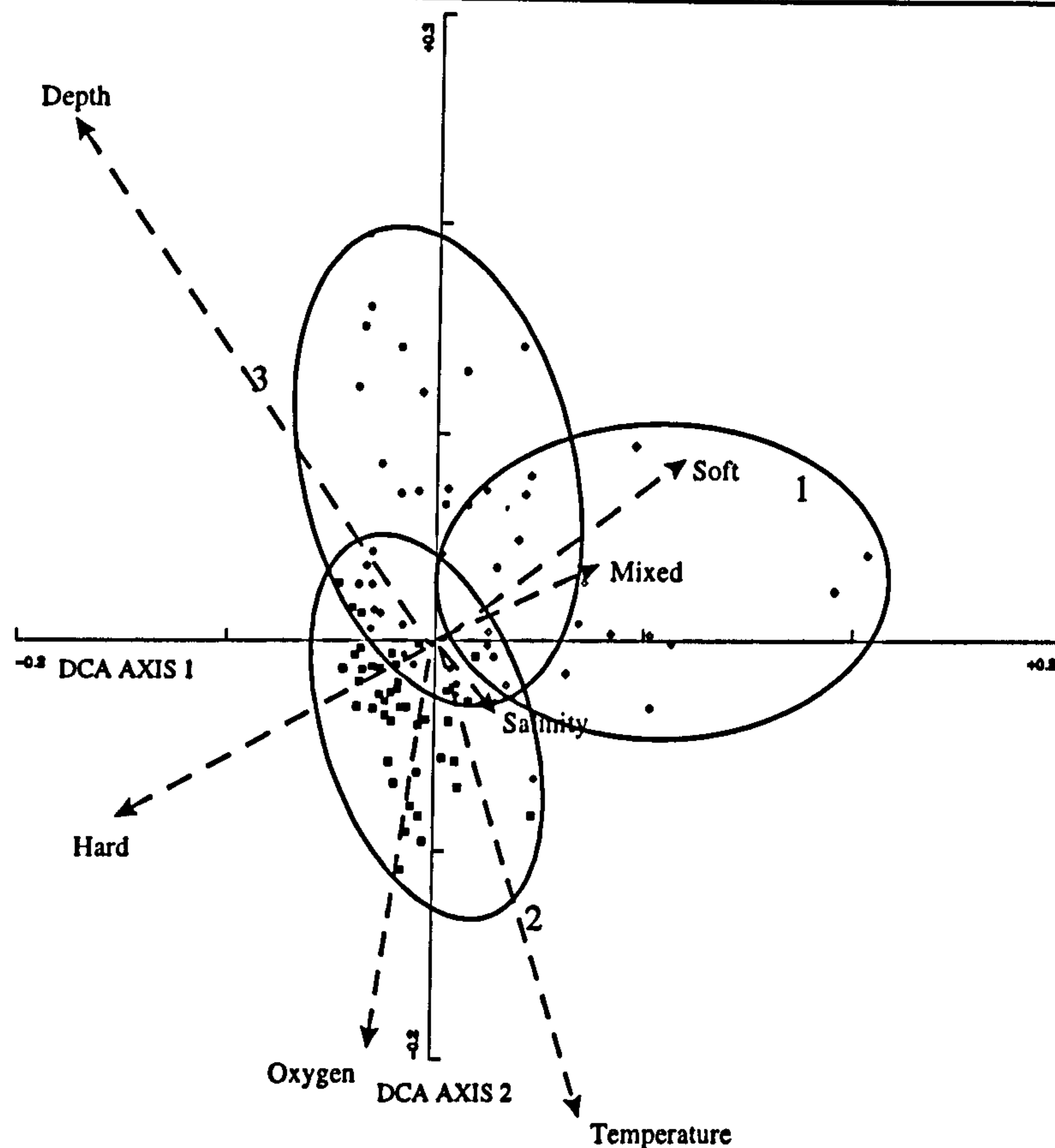


Figure 4.8: Biplot of sites and environmental parameters in the DCA axis 1 versus axis 2 ordination plane for the 1989 MFRD surveys; (with original scale x 1/3)

#### 4.4.1.5 Seasonal 'forms' of community structure

Table 4.7 gives the summary of group parameters obtained from analysing the data from the upwelling and non-upwelling (or thermocline) cruises of the three surveys. In the complete data set from the GTS, the mean depths of the positions of corresponding assemblages are higher in the warm season (GTS II) than in the upwelling season (GTS I). For hauls between 10-75 m, this is true only for the first



and second assemblages. In the MFRD surveys, assemblages 1 and 3 maintain almost the same depths in May and in August but the mean depth for assemblage 2 increases over the period (May to August) in MFRD3 but decreases in MFRD5.

The number of fish species caught during each survey cruise, classified according to assemblage, is given in Table 4.8. The number varies between 47 during the May cruise in 1982 and 150 for the September cruise of the GTS (1963). For each of the three groups identified from each cruise, a list of the most important species was prepared using the  $IRI > 50$  criterion (Tables 4.9.1 - 4.9.6). The percentage by weight contributed by these major species ranged between 65.7 (GTS II, March) and 97.7 (MFRD3, August). The percentage is slightly higher during the upwelling season than during the thermocline season, especially in assemblage 2. The number of species (and species groups) contributing to this percentage also varies between 8 (GTS II, group 1) and 23 (GTS I, group 2). In general the second assemblage has more species meeting the  $IRI > 50$  criterion than the other assemblages.

For each survey and for each assemblage, the list of species for the upwelling and thermocline seasonal cruises were compared (Tables 4.10.1- 4.10.3). This was to determine species that were present mainly during the upwelling period, those present in the thermocline period and those that were regularly present in the assemblage ('residents'). In these tables, the names in bold type face are those of the 'resident' species. The species at the upper part of each list (i.e. above the 'resident' species) are present mainly during the upwelling period and those below are present during the thermocline period. There are no visible patterns of relationships in group membership, except the low figures for the thermocline period during the GTS.

Table 4.7: Summary of group environmental parameters in seasonal surveys; standard deviation in brackets.

| Group  | Sediment   | Depth     | Temperature | Salinity     | Oxygen      |
|--|------------|-----------|-------------|--------------|-------------|
| <b>GTS I (September 1963)</b>                          |            |           |             |              |             |
| 1  | Soft       | 28 (7)    | 20.9 (1.0)  | 35.88 (0.09) | 3.10 (0.78) |
| 2  | Hard       | 43 (18)   | 19.7 (1.2)  | 35.86 (0.08) | 3.38 (0.49) |
| 3  | Mixed      | 64 (16)   | 18.2 (1.4)  | 35.78 (0.10) | 3.62 (0.71) |
| 4  | Mixed      | 109 (16)  | 16.7 (0.9)  | 35.68 (0.11) | 2.54 (0.26) |
| 5  | Mixed      | 228 (53)  | 14.4 (1.5)  | 35.46 (0.18) | 2.18 (0.26) |
| 6  | Mixed      | 284 (116) | 14.8 (0.7)  | 35.43 (0.17) | 3.35 (0.16) |
| <b>GTS II (March 1964)</b>                             |            |           |             |              |             |
| 1  | Soft       | 33 (10)   | 20.2 (1.2)  | 35.81 (0.05) | 2.98 (0.74) |
| 2  | Hard/mixed | 36 (11)   | 19.7 (1.6)  | 35.78 (0.13) | 2.75 (0.55) |
| 3  | Mixed      | 92 (36)   | 17.5 (1.2)  | 35.81 (0.10) | 2.68 (0.42) |
| 4  | Mixed/soft | 200 (-)   | 14.4 (0.5)  | 35.46 (0.02) | 2.25 (0.05) |
| 5  | Mixed      | 203 (4)   | 12.6 (1.4)  | 35.32 (0.13) | 1.74 (0.50) |
| 6  | Mixed      | 400(-)    | 9.8 (2.0)   | 35.29 (0.48) | 1.75 (0.14) |
| <b>GTS I (September 1963; stations within 10-75 m)</b> |            |           |             |              |             |
| 1  | Soft/mixed | 29 (8)    | 20.7 (1.0)  | 35.86 (0.86) | 3.26 (0.84) |
| 2  | Mixed/hard | 39 (9)    | 19.9 (1.0)  | 35.87 (0.07) | 3.41 (0.48) |
| 3  | Mixed/hard | 61 (14)   | 18.2 (1.3)  | 35.79 (0.10) | 2.64 (0.73) |
| <b>GTS II (March 1964; stations within 10-75 m)</b>    |            |           |             |              |             |
| 1  | Mixed      | 24 (5)    | 20.9 (0.53) | 35.78 (0.02) | 3.14 (0.16) |
| 2  | Mixed/soft | 41 (16)   | 19.5 (1.7)  | 35.79 (0.13) | 2.78 (0.56) |
| 3  | Mixed/soft | 50 (16)   | 19.2 (1.2)  | 35.84 (0.09) | 2.64 (0.55) |
| <b>MFRD3 (August 1981)</b>                             |            |           |             |              |             |
| 1  | Mixed/soft | 32 (7)    | 19.6 (1.3)  | 35.83 (0.28) | 3.28 (0.65) |
| 2  | Hard       | 45 (13)   | 18.1 (0.9)  | 35.90 (0.19) | 2.69 (0.19) |
| 3  | Mixed      | 59 (8)    | 17.6 (0.5)  | 35.79 (0.09) | 2.58 (0.16) |
| <b>MFRD3 (May 1981)</b>                                |            |           |             |              |             |
| 1  | Mixed/soft | 32 (9)    | 26.9 (1.2)  | 35.68 (0.21) | 4.75 (0.31) |
| 2  | Hard/mixed | 32 (8)    | 26.1 (2.3)  | 35.47 (0.56) | 5.10 (0.47) |
| 3  | Hard/mixed | 56 (7)    | 20.0 (1.8)  | 36.01 (0.25) | 4.04 (0.63) |
| <b>MFRD5 (August 1989)</b>                             |            |           |             |              |             |
| 1  | Mixed/soft | 36 (12)   | 18.9 (0.8)  | 35.51 (0.34) | 2.28 (0.74) |
| 2  | Mixed/hard | 31 (8)    | 19.4 (1.0)  | 35.30 (0.30) | 2.91 (0.73) |
| 3  | Hard/mixed | 55 (9)    | 18.2 (0.5)  | 35.38 (0.46) | 2.51 (0.19) |
| <b>MFRD5 (May 1989)</b>                                |            |           |             |              |             |
| 1  | Mixed/soft | 25 (7)    | 26.8 (2.4)  | 35.11 (0.30) | 4.58 (0.41) |
| 2  | Mixed/hard | 42 (15)   | 24.6 (2.8)  | 35.33 (0.41) | 4.62 (0.84) |
| 3  | Mixed/soft | 55 (9)    | 21.2 (0.8)  | 34.87 (0.87) | 3.73 (0.39) |



Table 4.8: Number of species and species groups in three assemblages recorded during surveys in thermocline and upwelling seasons

|              |             | Assemblage |     |    |                     |
|--------------|-------------|------------|-----|----|---------------------|
| Survey       | Season      | 1          | 2   | 3  | Average<br>(survey) |
| GTS<br>≤75 m | Upwelling   | 110        | 150 | 93 | 115                 |
|              | Thermocline | 143        | 110 | 83 | (26.7)              |
| MFRD3        | Upwelling   | 81         | 51  | 48 | 62                  |
|              | Thermocline | 47         | 65  | 77 | (15.1)              |
| MFRD5        | Upwelling   | 69         | 80  | 63 | 65                  |
|              | Thermocline | 55         | 74  | 51 | (11.1)              |

**Tables 4.9.1- 4.9.6:**

Total weight (W kg), percentage weight (% W), number of fish (N), percentage number (%N) and frequency of occurrence (F) of the most abundant species in the first three assemblages in each survey cruise, GTS I (September, 1963) - MFRD5 (August, 1989). The GTS data are from stations in the 10 to 75 m depths only.



**Table 4.9.1: GTS I (September 1963)**

**Group 1 (11 stations)**

| Species                           | W<br>kg | %<br>W | F  |
|-----------------------------------|---------|--------|----|
| <i>Brachydeuterus auritus</i>     | 1558    | 25.5   | 10 |
| <i>Selene dorsalis</i>            | 536     | 8.8    | 10 |
| <i>Pseudolithus senegalensis</i>  | 565     | 9.2    | 8  |
| <i>Galeoides decadactylus</i>     | 490     | 8.0    | 9  |
| <i>Ilisha africana</i>            | 575     | 9.4    | 6  |
| <i>Sparus caeruleostictus</i>     | 267     | 4.4    | 8  |
| <i>Drepane africana</i>           | 221     | 3.6    | 9  |
| <i>Pagellus bellottii</i>         | 176     | 2.9    | 7  |
| <i>Raja miraletus</i>             | 118     | 1.9    | 9  |
| <i>Loligo</i> sp                  | 249     | 4.1    | 4  |
| <i>Trichiurus lepturus</i>        | 139     | 2.3    | 7  |
| <i>Pomadasys jubelini</i>         | 100     | 1.6    | 8  |
| <i>Pteroscion peli</i>            | 124     | 2.0    | 5  |
| <i>Pseudolithus brachygnathus</i> | 200     | 3.3    | 2  |
| <i>Epinephelus aeneus</i>         | 64      | 1.0    | 6  |
| <i>Pseudolithus typus</i>         | 95      | 1.6    | 4  |
| Total                             | 5478    | 89.5   |    |
| Total (all species)               | 6121    |        |    |

**Group 2 (8 stations)**

| Species                       | W<br>kg | %<br>W | F |
|-------------------------------|---------|--------|---|
| <i>Pagellus bellottii</i>     | 772     | 17.6   | 8 |
| <i>Sparus caeruleostictus</i> | 406     | 9.3    | 8 |
| <i>Decapterus</i> sp.         | 340     | 7.8    | 6 |
| <i>Pseudupeneus prayensis</i> | 229     | 5.2    | 7 |
| <i>Trachurus</i> sp.          | 211     | 4.8    | 7 |
| <i>Scomber japonicus</i>      | 217     | 5.0    | 6 |
| <i>Priacanthus arenatus</i>   | 161     | 3.7    | 8 |
| <i>Dentex canariensis</i>     | 136     | 3.1    | 8 |
| <i>Brachydeuterus auritus</i> | 212     | 4.8    | 5 |
| <i>Epinephelus aeneus</i>     | 128     | 2.9    | 8 |
| <i>Loligo</i> sp.             | 138     | 3.2    | 7 |
| <i>Dactylopterus volitans</i> | 104     | 2.4    | 7 |
| <i>Acanthurus monroviae</i>   | 89      | 2.0    | 7 |
| <i>Lutjanus agennes</i>       | 79      | 1.8    | 7 |
| <i>Lutjanus fulgens</i>       | 73      | 1.7    | 7 |
| <i>Sardinella aurita</i>      | 93      | 2.1    | 5 |
| <i>Balistes forcipatus</i>    | 48      | 1.1    | 8 |
| <i>Fistularia villosa</i>     | 46      | 1.0    | 8 |
| <i>Trachinocephalus myops</i> | 67      | 1.5    | 4 |

|                          |     |     |   |
|--------------------------|-----|-----|---|
| <i>Pomadasys incisus</i> | 40  | 0.9 | 6 |
| Turtles                  | 108 | 2.5 | 2 |
| <i>Lutjanus dentatus</i> | 34  | 0.8 | 6 |
| <i>Raja miraletus</i>    | 25  | 0.6 | 8 |

|                     |      |      |
|---------------------|------|------|
| Total               | 3757 | 85.7 |
| Total (all species) | 4383 |      |

**Group 3 (12 stations)**

| Species                       | W<br>kg | %<br>W | F  |
|-------------------------------|---------|--------|----|
| <i>Scomber japonicus</i>      | 1843    | 22.5   | 9  |
| <i>Trachurus</i> sp.          | 1578    | 19.3   | 11 |
| <i>Sardinella aurita</i>      | 1329    | 16.2   | 6  |
| <i>Pagellus bellottii</i>     | 990     | 12.1   | 11 |
| <i>Epinephelus aeneus</i>     | 355     | 4.3    | 10 |
| <i>Dentex congoensis</i>      | 234     | 2.9    | 6  |
| <i>Boops boops</i>            | 193     | 2.4    | 6  |
| <i>Pseudupeneus prayensis</i> | 155     | 1.9    | 9  |
| <i>Priacanthus arenatus</i>   | 154     | 1.9    | 10 |
| <i>Raja miraletus</i>         | 150     | 1.8    | 9  |
| <i>Dentex angolensis</i>      | 99      | 1.2    | 4  |
| <i>Dentex gibbosus</i>        | 93      | 1.1    | 6  |
| <i>Sparus caeruleostictus</i> | 85      | 1.0    | 7  |

|                     |      |      |
|---------------------|------|------|
| Total               | 7257 | 88.6 |
| Total (all species) | 8191 |      |

**Table 4.9.2: GTS II**

**Group 1 (2 stations)**

| Species                          | W<br>kg | %<br>W | F |
|----------------------------------|---------|--------|---|
| <i>Brachydeuterus auritus</i>    | 748     | 81.3   | 2 |
| <i>Galeoides decadactylus</i>    | 43      | 4.7    | 1 |
| <i>Sphyræna</i> sp.              | 37      | 4.0    | 2 |
| <i>Pseudolithus senegalensis</i> | 21      | 2.3    | 1 |
| <i>Raja miraletus</i>            | 18      | 2.0    | 1 |
| <i>Pagellus bellottii</i>        | 17      | 1.8    | 1 |
| <i>Trichiurus lepturus</i>       | 12      | 1.2    | 1 |
| <i>Pteroscion peli</i>           | 8       | 0.9    | 1 |
| Total                            | 905     | 98.2   |   |
| Total (all species)              | 922     |        |   |

|                               |      |      |    |   |      |      |       |      |    |
|-------------------------------|------|------|----|---|------|------|-------|------|----|
| Group 2 (20 stations)         |      |      |    | <i>Epenephelus aeneus</i> 3105.41060.29       |      |      |       |      |    |
|                               |      |      |    | <i>Dentex canariensis</i> 1482.65711.110      |      |      |       |      |    |
|                               |      |      |    | <i>Pomadasys incisus</i> 911.68641.78         |      |      |       |      |    |
|                               |      |      |    | <i>Chloroscombrus chrysurus</i> 981.716423.25 |      |      |       |      |    |
| Species                       | W    | %    | F  | <i>Selene dorsalis</i> 821.44961.09           |      |      |       |      |    |
|                               | kg   | W    |    | <i>Galeoides decadactylus</i> 611.18521.77    |      |      |       |      |    |
| <i>Pagellus bellottii</i>     | 1293 | 20.0 | 20 | <i>Decapterus rhonchus</i> 671.23290.66       |      |      |       |      |    |
| <i>Trachurus</i> sp.          | 453  | 7.0  | 14 |   |      |      |       |      |    |
| <i>Sparus caeruleostictus</i> | 349  | 5.4  | 20 |   |      |      |       |      |    |
| <i>Priacanthus arenatus</i>   | 305  | 4.7  | 19 |   |      |      |       |      |    |
| <i>Brachydeuterus auritus</i> | 304  | 4.7  | 12 | Total482583.94839294.3                        |      |      |       |      |    |
| <i>Sardinella aurita</i>      | 300  | 4.6  | 13 | Total (all species)574951328                  |      |      |       |      |    |
| <i>Pseudupeneus prayensis</i> | 279  | 4.3  | 18 |   |      |      |       |      |    |
| <i>Epenephelus aeneus</i>     | 267  | 4.1  | 14 |   |      |      |       |      |    |
| <i>Dentex canariensis</i>     | 220  | 3.4  | 15 | Group 2 (12 stations)                         |      |      |       |      |    |
| <i>Dactylopterus volitans</i> | 122  | 1.9  | 19 |   |      |      |       |      |    |
| Total                         | 3892 | 65.7 |    | Species                                       | W    | %    | N     | %    | F  |
| Total (all species)           | 5926 |      |    |   | kg   | W    |       | N    |    |
|                               |      |      |    | <i>Dentex congoensis</i>                      | 891  | 11.5 | 1850  | 9.9  | 8  |
|                               |      |      |    | <i>Umbrina canariensis</i>                    | 2357 | 30.5 | 56    | 0.3  | 5  |
|                               |      |      |    | <i>Dentex canariensis</i>                     | 369  | 4.8  | 506   | 2.7  | 11 |
|                               |      |      |    | <i>Pagellus bellottii</i>                     | 165  | 2.1  | 1087  | 5.8  | 10 |
| Group 3 (11 stations)         |      |      |    | <i>Epinephelus aeneus</i>                     | 622  | 8.0  | 80    | 0.4  | 9  |
| Species                       | W    | %    | F  | <i>Brachydeuterus auritus</i>                 | 894  | 11.6 | 9834  | 52.7 | 1  |
|                               | kg   | W    |    | <i>Boops boops</i>                            | 574  | 7.4  | 388   | 2.1  | 6  |
| <i>Brachydeuterus auritus</i> | 1857 | 46.2 | 6  | <i>Sparus caeruleostictus</i>                 | 150  | 1.9  | 508   | 2.7  | 11 |
| <i>Pagellus bellottii</i>     | 421  | 10.5 | 10 | <i>Dentex angolensis</i>                      | 254  | 3.3  | 950   | 5.1  | 6  |
| <i>Sphyraena</i> sp.          | 205  | 5.1  | 6  | <i>Dentex gibbosus</i>                        | 184  | 2.4  | 317   | 1.7  | 8  |
| <i>Dentex congoensis</i>      | 187  | 4.7  | 5  | <i>Priacanthus arenatus</i>                   | 227  | 2.9  | 128   | 0.7  | 9  |
| <i>Sardinella maderensis</i>  | 163  | 4.1  | 2  | <i>Paracubiceps ledanoisi</i>                 | 318  | 4.1  | 86    | 0.5  | 7  |
| <i>Pseudupeneus prayensis</i> | 143  | 3.6  | 6  | <i>Pseudupeneus prayensis</i>                 | 56   | 0.7  | 620   | 3.3  | 7  |
| <i>Trachurus</i> sp.          | 124  | 3.1  | 5  | <i>Fistularia villosa</i>                     | 67   | 0.9  | 218   | 1.2  | 10 |
| <i>Epinephelus aeneus</i>     | 111  | 2.8  | 7  | <i>Trachurus</i> sp.                          | 30   | 0.4  | 520   | 2.8  | 5  |
| <i>Priacanthus arenatus</i>   | 107  | 2.7  | 8  | <i>Balistes capriscus</i>                     | 78   | 1.0  | 282   | 1.5  | 6  |
| <i>Pentheroscion mbizi</i>    | 106  | 2.6  | 4  | <i>Chromis lineatus</i>                       | 195  | 2.5  | 230   | 1.2  | 4  |
| <i>Sparus caeruleostictus</i> | 104  | 2.6  | 4  | <i>Dactylopterus volitans</i>                 | 60   | 0.8  | 182   | 1.0  | 7  |
| <i>Dentex angolensis</i>      | 74   | 1.8  | 5  | <i>Rhizoprionodon acutus</i>                  | 68   | 0.9  | 22    | 0.1  | 6  |
| Total                         | 3602 | 89.8 |    | Total   | 7560 | 97.7 | 17864 | 95.8 |    |
| Total (all species)           | 4021 |      |    | Total (all species)                           | 7737 |      | 18648 |      |    |

Table 4.9.3: MFRD3 (AUGUST 1981)

|                               |         |        |       |        |    |                               |         |        |      |        |   |
|-------------------------------|---------|--------|-------|--------|----|-------------------------------|---------|--------|------|--------|---|
| Group 1 (16 stations)         |         |        |       |        |    | Group 3 (8 stations)          |         |        |      |        |   |
| Species                       | W<br>kg | %<br>W | N     | %<br>N | F  | Species                       | W<br>kg | %<br>W | N    | %<br>N | F |
| <i>Brachydeuterus auritus</i> | 1640    | 28.5   | 25874 | 50.4   | 13 | <i>Pagellus bellottii</i>     | 496     | 23.2   | 4320 | 41.7   | 7 |
| <i>Pagellus bellottii</i>     | 718     | 12.5   | 9384  | 18.3   | 16 | <i>Pseudupeneus prayensis</i> | 213     | 10.0   | 1706 | 16.5   | 8 |
| <i>Sparus caeruleostictus</i> | 555     | 9.6    | 3352  | 6.5    | 15 | <i>Dentex canariensis</i>     | 315     | 14.8   | 730  | 7.0    | 8 |
| <i>Pseudupeneus prayensis</i> | 286     | 5.0    | 3115  | 6.1    | 12 | <i>Sparus caeruleostictus</i> | 264     | 12.4   | 822  | 7.9    | 7 |
| <i>Balistes capriscus</i>     | 184     | 3.2    | 1006  | 2.0    | 15 | <i>Balistes capriscus</i>     | 93      | 4.4    | 786  | 7.6    | 5 |
| <i>Priacanthus arenatus</i>   | 258     | 4.5    | 462   | 0.9    | 10 | <i>Epenephelus aeneus</i>     | 165     | 7.7    | 24   | 0.2    | 6 |
| <i>Sepia</i> sp.              | 329     | 5.7    | 339   | 0.7    | 8  | <i>Fistularia villosa</i>     | 47      | 2.2    | 238  | 2.3    | 8 |
|                               |         |        |       |        |    | <i>Boops boops</i>            | 24      | 1.1    | 368  | 3.5    | 5 |
|                               |         |        |       |        |    | <i>Sepia</i> sp.              | 51      | 2.4    | 70   | 0.7    | 7 |



|                               |      |      |       |      |   |                                   |      |      |      |      |    |
|-------------------------------|------|------|-------|------|---|-----------------------------------|------|------|------|------|----|
| <i>Lutjanus fulgens</i>       | 44   | 2.1  | 152   | 1.5  | 5 | <i>Priacanthus arenatus</i>       | 51   | 2.0  | 400  | 4.1  | 9  |
| <i>Acanthurus monroviae</i>   | 50   | 2.3  | 124   | 1.2  | 3 | <i>Chloroscombrus chrysurus</i>   | 27   | 1.1  | 306  | 3.1  | 11 |
| <i>Dentex gibbosus</i>        | 29   | 1.4  | 62    | 0.6  | 5 | <i>Lutjanus fulgens</i>           | 167  | 6.6  | 182  | 1.8  | 5  |
| <i>Rhizoprionodon acutus</i>  | 60   | 2.8  | 12    | 0.1  | 3 | <i>Decapterus</i> sp.             | 16   | 0.6  | 766  | 7.8  | 4  |
| <i>Dactylopterus volitans</i> | 19   | 0.9  | 46    | 0.4  | 6 | <i>Acanthurus monroviae</i>       | 127  | 5.0  | 163  | 1.7  | 5  |
| <i>Priacanthus arenatus</i>   | 21   | 1.0  | 46    | 0.4  | 5 | <i>Fistularia villosa</i>         | 32   | 1.3  | 128  | 1.3  | 9  |
| <i>Lutjanus goreensis</i>     | 62   | 2.9  | 10    | 0.1  | 2 | <i>Acanthostracion guineensis</i> | 49   | 1.9  | 244  | 2.5  | 5  |
| <i>Trigla</i> sp.             | 8    | 0.4  | 66    | 0.6  | 5 | <i>Epenephelus aeneus</i>         | 63   | 2.5  | 28   | 0.3  | 6  |
| <i>Distodon speciosus</i>     | 14   | 0.7  | 28    | 0.3  | 5 | <i>Lagocephalus laevigatus</i>    | 48   | 1.9  | 52   | 0.5  | 6  |
| <i>Chaetodon luciae</i>       | 9    | 0.4  | 96    | 0.9  | 3 | <i>Chaetodon</i> sp.              | 11   | 0.4  | 138  | 1.4  | 6  |
|                               |      |      |       |      |   | <i>Dactylopterus volitans</i>     | 20   | 0.8  | 58   | 0.6  | 7  |
| Total                         | 1985 | 93.0 | 9706  | 93.6 |   | Total                             | 2213 | 87.1 | 8971 | 90.9 |    |
| Total (all species)           | 2135 |      | 10370 |      |   | Total (all species)               | 2542 |      | 9866 |      |    |

Table 4.9.4: MFRD3 (MAY 1981)

Group 1 (4 stations)

| Species                            | W<br>kg | %<br>W | N    | %<br>N | F |
|------------------------------------|---------|--------|------|--------|---|
| <i>Brachydeuterus auritus</i>      | 98      | 12.4   | 3770 | 39.5   | 4 |
| <i>Chloroscombrus chrysurus</i>    | 107     | 13.5   | 2366 | 24.8   | 4 |
| <i>Serlene sorsalis</i>            | 93      | 11.7   | 434  | 4.5    | 4 |
| <i>Sparus caeruleostictus</i>      | 89      | 11.3   | 350  | 3.7    | 4 |
| <i>Galeoides decadactylus</i>      | 88      | 11.1   | 280  | 2.9    | 3 |
| <i>Elops senegalensis</i>          | 52      | 6.6    | 178  | 1.9    | 3 |
| <i>Sphyraena sphyraena</i>         | 32      | 4.0    | 564  | 5.9    | 2 |
| <i>Pseudotolithus</i> sp.          | 64      | 8.1    | 8    | 0.1    | 2 |
| <i>Balistes capriscus</i>          | 20      | 2.6    | 126  | 1.3    | 4 |
| <i>Pseudotolithus senegalensis</i> | 40      | 5.1    | 40   | 0.4    | 2 |
| <i>Ilisha africana</i>             | 8       | 1.0    | 324  | 3.4    | 2 |
| <i>Dentex canariensis</i>          | 20      | 2.5    | 58   | 0.6    | 2 |
| <i>Engraulis encrasicolus</i>      | 1       | 0.1    | 386  | 4.0    | 1 |
| <i>Pteroscion peli</i>             | 4       | 0.5    | 124  | 1.3    | 2 |
| <i>Scyacium micrurum</i>           | 4       | 0.6    | 112  | 1.2    | 2 |
| <i>Epenephelus aeneus</i>          | 8       | 1.1    | 8    | 0.1    | 3 |
| Total                              | 730     | 92.1   | 9128 | 95.6   |   |
| Total (all species)                | 793     |        | 9544 |        |   |

Group 2 (13 stations)

| Species                       | W<br>kg | %<br>W | N    | %<br>N | F  |
|-------------------------------|---------|--------|------|--------|----|
| <i>Sparus caeruleostictus</i> | 440     | 17.3   | 1877 | 19.0   | 13 |
| <i>Dentex canariensis</i>     | 344     | 13.5   | 1264 | 12.8   | 11 |
| <i>Pseudupeneus prayensis</i> | 211     | 8.3    | 1144 | 11.6   | 12 |
| <i>Pagellus bellottii</i>     | 109     | 4.3    | 502  | 5.1    | 12 |
| <i>Sepia</i> sp.              | 168     | 6.6    | 308  | 3.1    | 11 |
| <i>Balistes forcipatus</i>    | 137     | 5.4    | 463  | 4.7    | 9  |
| <i>Lethrinus atlanticus</i>   | 157     | 6.2    | 573  | 5.8    | 6  |
| <i>Scyacium micrurum</i>      | 34      | 1.4    | 375  | 3.8    | 11 |

Group 3 (17 stations)

| Species                         | W<br>kg | %<br>W | N     | %<br>N | F  |
|---------------------------------|---------|--------|-------|--------|----|
| <i>Balistes capriscus</i>       | 1715    | 23.4   | 14926 | 28.4   | 12 |
| <i>Pagellus bellottii</i>       | 1516    | 20.7   | 8056  | 15.3   | 15 |
| <i>Pseudupeneus prayensis</i>   | 371     | 5.1    | 3312  | 6.3    | 15 |
| <i>Brachydeuterus auritus</i>   | 466     | 6.4    | 5866  | 11.2   | 5  |
| <i>Sparus caeruleostictus</i>   | 235     | 3.2    | 1126  | 2.1    | 15 |
| <i>Dentex canariensis</i>       | 306     | 4.2    | 828   | 1.6    | 12 |
| <i>Chromis lineatus</i>         | 396     | 5.4    | 3284  | 6.2    | 5  |
| <i>Chloroscombrus chrysurus</i> | 389     | 5.3    | 5794  | 11.0   | 3  |
| <i>Priacanthus arenatus</i>     | 128     | 1.7    | 1094  | 2.1    | 10 |
| <i>Pomadasy s incisus</i>       | 201     | 2.7    | 1258  | 2.4    | 7  |
| <i>Sepia</i> sp.                | 129     | 1.8    | 212   | 0.4    | 15 |
| <i>Epenephelus aeneus</i>       | 208     | 2.8    | 56    | 0.1    | 10 |
| <i>Sardinella aurita</i>        | 147     | 2.0    | 1492  | 2.8    | 6  |
| <i>Dentex gibbosus</i>          | 71      | 1.0    | 340   | 0.6    | 10 |
| <i>Serlene sorsalis</i>         | 104     | 1.4    | 246   | 0.5    | 7  |
| <i>Lepidotrigla</i> sp.         | 26      | 0.3    | 500   | 1.0    | 10 |
| <i>Raja miraletus</i>           | 57      | 0.8    | 122   | 0.2    | 12 |
| <i>Decapterus rhonchus</i>      | 64      | 0.9    | 690   | 1.3    | 4  |

|                     |      |      |       |      |  |
|---------------------|------|------|-------|------|--|
| Total               | 6530 | 89.2 | 49202 | 93.6 |  |
| Total (all species) | 7320 |      | 52580 |      |  |

Table 4.9.5: MFRD5 (AUGUST 1989)

Group 1(11 stations)

| Species                       | W<br>kg | %<br>W | N     | %<br>N | F |
|-------------------------------|---------|--------|-------|--------|---|
| <i>Brachydeuterus auritus</i> | 659     | 53.6   | 18138 | 63.1   | 9 |
| <i>Pagellus bellottii</i>     | 74      | 6.1    | 1190  | 4.1    | 9 |
| <i>Trichiurus lepturus</i>    | 50      | 4.0    | 1358  | 4.7    | 7 |
| <i>Pteroscion peli</i>        | 30      | 2.5    | 1848  | 6.4    | 5 |

|                                 |      |      |       |      |    |                                  |                               |      |       |       |      |    |
|---------------------------------|------|------|-------|------|----|----------------------------------|-------------------------------|------|-------|-------|------|----|
| <i>Lagocephalus laevigatus</i>  | 46   | 3.7  | 88    | 0.3  | 6  | Group 3 (15 stations)            |                               |      |       |       |      |    |
| <i>Sepia officinalis</i>        | 38   | 3.1  | 94    | 0.3  | 7  |                                  |                               |      |       |       |      |    |
| <i>Pentheroscion mbizi</i>      | 23   | 1.9  | 957   | 3.3  | 4  |                                  |                               |      |       |       |      |    |
| <i>Trachurus trecae</i>         | 26   | 2.1  | 716   | 2.5  | 4  |                                  | Species                       | W    | %     | N     | %    | F  |
| <i>Sparus caeruleostictus</i>   | 25   | 2.1  | 402   | 1.4  | 5  |                                  |                               | kg   | W     |       | N    |    |
| <i>Pomadasys jubelini</i>       | 42   | 3.4  | 648   | 2.3  | 3  |                                  | <i>Chromis</i> sp.            | 1091 | 25.2  | 25760 | 28.9 | 5  |
| <i>Serlene sorsalis</i>         | 16   | 1.3  | 374   | 1.3  | 6  |                                  | <i>Pseudupeneus prayensis</i> | 329  | 7.6   | 5572  | 6.3  | 14 |
| <i>Penaeus notialis</i>         | 17   | 1.4  | 198   | 0.7  | 7  |                                  | <i>Decapterus</i> sp.         | 454  | 10.5  | 13672 | 15.3 | 4  |
| <i>Trachinocephalus myops</i>   | 12   | 1.0  | 406   | 1.4  | 4  |                                  | <i>Pagellus bellottii</i>     | 127  | 2.9   | 3644  | 4.1  | 14 |
| <i>Rhizoprionodon acutus</i>    | 23   | 1.9  | 18    | 0.1  | 4  |                                  | <i>Epenephelus aeneus</i>     | 346  | 8.0   | 90    | 0.1  | 10 |
| <i>Galeoides decadactilus</i>   | 26   | 2.1  | 273   | 0.9  | 2  |                                  | <i>Dentex canariensis</i>     | 230  | 5.3   | 686   | 0.8  | 13 |
| <i>Pomadasys incisus</i>        | 6    | 0.5  | 106   | 0.4  | 7  |                                  | <i>Dentex congoensis</i>      | 403  | 9.3   | 14740 | 16.5 | 3  |
| <i>Priacanthus arenatus</i>     | 9    | 0.7  | 144   | 0.5  | 5  |                                  | <i>Anthias anthias</i>        | 209  | 4.8   | 9358  | 10.5 | 4  |
| <i>Pseudupeneus prayensis</i>   | 7    | 0.5  | 112   | 0.4  | 6  |                                  | <i>Sparus caeruleostictus</i> | 130  | 3.0   | 890   | 1.0  | 14 |
|                                 |      |      |       |      |    | <i>Dactylopterus volitans</i>    | 124                           | 2.9  | 722   | 0.8   | 13   |    |
|                                 |      |      |       |      |    | <i>Scomber japonicus</i>         | 275                           | 6.3  | 5762  | 6.5   | 2    |    |
| Sum                             | 1129 | 91.8 | 27070 | 94.2 |    | <i>Rhizoprionodon acutus</i>     | 104                           | 2.4  | 38    | 0.0   | 8    |    |
| Sum (all species)               | 1230 |      | 28749 |      |    | <i>Boops boops</i>               | 118                           | 2.7  | 3368  | 3.8   | 3    |    |
|                                 |      |      |       |      |    | <i>Sardinella aurita</i>         | 78                            | 1.8  | 1908  | 2.1   | 4    |    |
|                                 |      |      |       |      |    | <i>Fistularia villosa</i>        | 33                            | 0.8  | 322   | 0.4   | 13   |    |
|                                 |      |      |       |      |    | <i>Dentex gibbosus</i>           | 38                            | 0.9  | 122   | 0.1   | 9    |    |
| Group 2 (12 stations)           |      |      |       |      |    |                                  |                               |      |       |       |      |    |
| Species                         | W    | %    | N     | %    | F  | Sum                              | 4090                          | 94.4 | 86654 | 97.3  |      |    |
|                                 | kg   | W    |       | N    |    | Sum (all species)                | 4332                          |      | 89082 |       |      |    |
| <i>Brachydeuterus auritus</i>   | 1216 | 31.1 | 56886 | 60.8 | 8  |                                  |                               |      |       |       |      |    |
| <i>Pagellus bellottii</i>       | 285  | 7.3  | 4516  | 4.8  | 10 |                                  |                               |      |       |       |      |    |
| <i>Sparus caeruleostictus</i>   | 297  | 7.6  | 1576  | 1.7  | 12 |                                  |                               |      |       |       |      |    |
| <i>Trachurus trecae</i>         | 347  | 8.9  | 11862 | 12.7 | 4  |                                  |                               |      |       |       |      |    |
| <i>Pseudupeneus prayensis</i>   | 108  | 2.8  | 1456  | 1.6  | 12 |                                  |                               |      |       |       |      |    |
| <i>Dentex canariensis</i>       | 129  | 3.3  | 430   | 0.5  | 12 |                                  |                               |      |       |       |      |    |
| <i>Dentex canariensis</i>       | 160  | 4.1  | 806   | 0.9  | 8  |                                  |                               |      |       |       |      |    |
| <i>Chloroscombrus chrysurus</i> | 140  | 3.6  | 4014  | 4.3  | 5  | Table 4.9.6: MFRD5 (MAY 1989)    |                               |      |       |       |      |    |
| <i>Pomadasys incisus</i>        | 158  | 4.0  | 2242  | 2.4  | 5  | Group 1 (6 stations)             |                               |      |       |       |      |    |
| <i>Lagocephalus laevigatus</i>  | 97   | 2.5  | 242   | 0.3  | 10 | Species                          | W                             | %    | N     | %     | F    |    |
| <i>Lutjanus fulgens</i>         | 123  | 3.1  | 1026  | 1.1  | 5  |                                  | kg                            | W    |       | N     |      |    |
| <i>Fistularia villosa</i>       | 55   | 1.4  | 436   | 0.5  | 9  | <i>Brachydeuterus auritus</i>    | 135                           | 17.8 | 3320  | 48.8  | 4    |    |
| <i>Decapterus rhonchus</i>      | 69   | 1.8  | 600   | 0.6  | 7  | <i>Sparus caeruleostictus</i>    | 111                           | 14.6 | 516   | 7.6   | 5    |    |
| <i>Boops boops</i>              | 80   | 2.1  | 1450  | 1.5  | 3  | <i>Chloroscombrus chrysurus</i>  | 34                            | 4.5  | 579   | 8.5   | 4    |    |
| <i>Acanthurus monroviae</i>     | 75   | 1.9  | 62    | 0.1  | 5  | <i>Dasyatis</i> sp.              | 37                            | 4.8  | 79    | 1.2   | 5    |    |
| <i>Priacanthus arenatus</i>     | 68   | 1.7  | 552   | 0.6  | 4  | <i>Epenephelus aeneus</i>        | 52                            | 6.9  | 28    | 0.4   | 3    |    |
| <i>Trachurus</i> sp.            | 70   | 1.8  | 2568  | 2.7  | 2  | <i>Serlene sorsalis</i>          | 18                            | 2.4  | 92    | 1.4   | 5    |    |
| <i>Sepia officinalis</i>        | 38   | 1.0  | 80    | 0.1  | 7  | <i>Galeoides decadactilus</i>    | 28                            | 3.7  | 158   | 2.3   | 3    |    |
| <i>Balistes forcipatus</i>      | 35   | 0.9  | 106   | 0.1  | 6  | <i>Sphyraena sphyraena</i>       | 17                            | 2.2  | 140   | 2.1   | 4    |    |
|                                 |      |      |       |      |    | <i>Sardinella maderensis</i>     | 5                             | 0.7  | 281   | 4.1   | 3    |    |
| Sum                             | 3553 | 90.9 | 90910 | 97.1 |    | <i>Trichiurus lepturus</i>       | 20                            | 2.6  | 310   | 4.6   | 2    |    |
| Sum (all species)               | 3907 |      | 93618 |      |    | <i>Sepia officinalis</i>         | 21                            | 2.8  | 51    | 0.7   | 4    |    |
|                                 |      |      |       |      |    | <i>Drepane africana</i>          | 16                            | 2.1  | 46    | 0.7   | 5    |    |
|                                 |      |      |       |      |    | <i>Elops senegalensis</i>        | 36                            | 4.7  | 115   | 1.7   | 2    |    |
|                                 |      |      |       |      |    | <i>Torpedo</i> sp.               | 16                            | 2.0  | 37    | 0.5   | 4    |    |
|                                 |      |      |       |      |    | <i>Dentex canariensis</i>        | 21                            | 2.8  | 35    | 0.5   | 3    |    |
|                                 |      |      |       |      |    | <i>Grammoplites gruveli</i>      | 28                            | 3.7  | 70    | 1.0   | 2    |    |
|                                 |      |      |       |      |    | <i>Lutjanus fulgens</i>          | 18                            | 2.4  | 135   | 2.0   | 2    |    |
|                                 |      |      |       |      |    | <i>Eucinostomus melanopterus</i> | 8                             | 1.1  | 78    | 1.1   | 3    |    |
|                                 |      |      |       |      |    | <i>Pseudupeneus prayensis</i>    | 4                             | 0.5  | 102   | 1.5   | 3    |    |



|                                 |      |      |       |      |    |                                 |      |      |       |      |   |
|---------------------------------|------|------|-------|------|----|---------------------------------|------|------|-------|------|---|
| <i>Penaeus notialis</i>         | 5    | 0.7  | 72    | 1.1  | 3  | Group 3 (9 stations)            |      |      |       |      |   |
| <i>Chilomycterus spinosus</i>   | 19   | 2.4  | 7     | 0.1  | 2  |                                 |      |      |       |      |   |
| <i>Pomadasys jubelini</i>       | 15   | 2.0  | 18    | 0.3  | 2  |                                 |      |      |       |      |   |
|                                 |      |      |       |      |    | Species                         | W    | %    | N     | %    | F |
| Total                           | 663  | 87.4 | 6269  | 92.1 |    |                                 | kg   | W    |       | N    |   |
| Total (all species)             | 759  |      | 6810  |      |    | <i>Pagellus bellottii</i>       | 714  | 32.7 | 10256 | 38.8 | 9 |
|                                 |      |      |       |      |    | <i>Sepia officinalis</i>        | 226  | 10.3 | 551   | 2.1  | 8 |
|                                 |      |      |       |      |    | <i>Trachurus</i> sp.            | 221  | 10.1 | 2323  | 8.8  | 3 |
| Group 2 (19 stations)           |      |      |       |      |    | <i>Brachydeuterus auritus</i>   | 63   | 2.9  | 1279  | 4.8  | 7 |
|                                 |      |      |       |      |    | <i>Dentex congoensis</i>        | 125  | 5.7  | 4150  | 15.7 | 2 |
|                                 |      |      |       |      |    | <i>Pseudupeneus prayensis</i>   | 63   | 2.9  | 836   | 3.2  | 7 |
| Species                         | W    | %    | N     | %    | F  | <i>Sparus caeruleostictus</i>   | 92   | 4.2  | 552   | 2.1  | 6 |
|                                 | kg   | W    |       | N    |    | <i>Lepidotrigla</i> sp.         | 54   | 2.5  | 1266  | 4.8  | 4 |
| <i>Pseudupeneus prayensis</i>   | 317  | 7.7  | 3037  | 13.3 | 18 | <i>Serranus accraensis</i>      | 23   | 1.0  | 439   | 1.7  | 7 |
| <i>Dentex canariensis</i>       | 430  | 10.4 | 1100  | 4.8  | 17 | <i>Chloroscombrus chrysurus</i> | 45   | 2.1  | 576   | 2.2  | 4 |
| <i>Sparus caeruleostictus</i>   | 321  | 7.8  | 1181  | 5.2  | 19 | <i>Lagocephalus laevigatus</i>  | 42   | 1.9  | 89    | 0.3  | 7 |
| <i>Dactylopterus volitans</i>   | 334  | 8.1  | 1286  | 5.6  | 17 | <i>Dactylopterus volitans</i>   | 48   | 2.2  | 136   | 0.5  | 5 |
| <i>Pagellus bellottii</i>       | 164  | 4.0  | 1648  | 7.2  | 16 | <i>Raja miraletus</i>           | 36   | 1.6  | 66    | 0.2  | 6 |
| <i>Fistularia villosa</i>       | 120  | 2.9  | 760   | 3.3  | 17 | <i>Balistes forcipatus</i>      | 29   | 1.3  | 95    | 0.4  | 6 |
| <i>Lethrinus atlanticus</i>     | 451  | 10.9 | 808   | 3.5  | 7  | <i>Fistularia villosa</i>       | 17   | 0.8  | 142   | 0.5  | 7 |
| <i>Lagocephalus laevigatus</i>  | 212  | 5.1  | 357   | 1.6  | 15 | <i>Serlene sorsalis</i>         | 35   | 1.6  | 126   | 0.5  | 4 |
| <i>Balistes capriscus</i>       | 162  | 3.9  | 617   | 2.7  | 14 | <i>Epenephelus aeneus</i>       | 34   | 1.6  | 11    | 0.0  | 5 |
| <i>Lutjanus fulgens</i>         | 168  | 4.1  | 404   | 1.8  | 11 | <i>Priacanthus arenatus</i>     | 27   | 1.2  | 178   | 0.7  | 4 |
| <i>Decapterus</i> sp.           | 31   | 0.8  | 1604  | 7.0  | 6  | <i>Scyacium micrurum</i>        | 13   | 0.6  | 128   | 0.5  | 7 |
| <i>Chloroscombrus chrysurus</i> | 135  | 3.3  | 1710  | 7.5  | 4  | <i>Umbrina</i> sp.              | 31   | 1.4  | 441   | 1.7  | 2 |
| <i>Chromis lineatus</i>         | 170  | 4.1  | 1459  | 6.4  | 4  | <i>Sphyraena sphyraena</i>      | 21   | 1.0  | 117   | 0.4  | 4 |
| <i>Trigla</i> sp.               | 65   | 1.6  | 533   | 2.3  | 10 | <i>Rhizoprionodon acutus</i>    | 21   | 1.0  | 10    | 0.0  | 5 |
| <i>Brachydeuterus auritus</i>   | 65   | 1.6  | 2550  | 11.2 | 3  |                                 |      |      |       |      |   |
| <i>Priacanthus arenatus</i>     | 58   | 1.4  | 304   | 1.3  | 13 | Total                           | 1981 | 90.6 | 23767 | 89.9 |   |
| <i>Sepia officinalis</i>        | 91   | 2.2  | 155   | 0.7  | 12 | Total (all species)             | 2186 |      | 26446 |      |   |
| <i>Epenephelus aeneus</i>       | 134  | 3.2  | 38    | 0.2  | 9  |                                 |      |      |       |      |   |
| <i>Sphyraena sphyraena</i>      | 19   | 0.5  | 536   | 2.3  | 5  |                                 |      |      |       |      |   |
| <i>Chaetodon</i> sp.            | 24   | 0.6  | 180   | 0.8  | 10 |                                 |      |      |       |      |   |
| <i>Balistes forcipatus</i>      | 44   | 1.1  | 102   | 0.4  | 8  |                                 |      |      |       |      |   |
| <i>Apsilus fuscus</i>           | 25   | 0.6  | 268   | 1.2  | 6  |                                 |      |      |       |      |   |
|                                 |      |      |       |      |    |                                 |      |      |       |      |   |
| Total                           | 3541 | 85.7 | 20637 | 90.4 |    |                                 |      |      |       |      |   |
| Total (all species)             | 4133 |      | 22840 |      |    |                                 |      |      |       |      |   |

**Tables 4.10.1 - 4.10.3.**

Table indicating seasonal membership of species in the various assemblages; names in bold type face are for species found in both seasons (resident) in the indicated assemblage, those at the top were found in the upwelling season only and those below were found in the thermocline season only.

**Table 4.10.1.**

**GTS I & II**

| Group 1   | Group 2  | Group 3   |
|---|--|---|
| <i>Drepane africana</i><br><i>Epenephelus aeneus</i><br><i>Ilisha africana</i><br><i>Loligo</i> sp.<br><i>Pomadasys jubelini</i><br><i>Pseudotolithus brachygnathus</i><br><i>Pseudotolithus typus</i><br><i>Sparus caeruleostictus</i> | <i>Decapterus</i> spp.<br><i>Fistularia villosa</i><br><i>Lutjanus dentatus</i><br><i>Pomadasys incisus</i><br><i>Lutjanus dentatus</i><br><i>Trachinocephalus myops</i><br><i>Acanthurus monroviae</i><br><i>Balistes forcipatus</i><br><i>Loligo</i> sp.<br><i>Lutjanus agennes</i><br><i>Lutjanus fulgens</i><br><i>Raja miraletus</i><br><i>Scomber japonicus</i><br>Turtles | <i>Dentex gibbosus</i><br><i>Raja miraletus</i><br><i>Sardinella aurita</i><br><i>Boops boops</i><br><i>Scomber japonicus</i>   |
| <i>Brachydeuterus auritus</i><br><i>Galeoides decadactylus</i><br><i>Pagellus bellottii</i><br><i>Raja miraletus</i><br><i>Trichiurus lepturus</i><br><i>Pseudotolithus senegalensis</i><br><i>Pteroscion peli</i>                      | <i>Brachydeuterus auritus</i><br><i>Dactylopterus volitans</i><br><i>Dentex canariensis</i><br><i>Epenephelus aeneus</i><br><i>Pagellus bellottii</i><br><i>Priacanthus arenatus</i><br><i>Pseudupeneus prayensis</i><br><i>Sparus caeruleostictus</i><br><i>Trachurus</i> sp.<br><i>Sardinella aurita</i>   | <i>Sparus caeruleostictus</i><br><i>Priacanthus arenatus</i><br><i>Epenephelus aeneus</i><br><i>Pagellus bellottii</i><br><i>Dentex congoensis</i><br><i>Trachurus</i> sp.<br><i>Pseudupeneus prayensis</i><br><i>Dentex angolensis</i> |
| <i>Sphyraena</i> sp.  |  | <i>Brachydeuterus auritus</i><br><i>Sphyraena</i> sp.<br><i>Pentheroscion mbizi</i><br><i>Sardinella maderensis</i>   |



Table 4.10.2.  
MFRD3 1981-82

| Group 1   | Group 2  | Group 3  |
|---|--|--|
| <i>Decapterus rhonchus</i><br><i>Pagellus bellottii</i><br><i>Pomadasys incisus</i><br><i>Priacanthus arenatus</i><br><i>Pseudupeneus prayensis</i><br><i>Sepia</i> sp.   | <i>Balistes capriscus</i><br><i>Boops boops</i><br><i>Brachydeuterus auritus</i><br><i>Chromis lineatus</i><br><i>Dentex angolensis</i><br><i>Dentex congoensis</i><br><i>Dentex gibbosus</i><br><i>Paracubiceps ledanoisi</i><br><i>Rhizoprionodon acutus</i><br><i>Trachurus</i> sp.<br><i>Umbrina canariensis</i>           | <i>Acanthurus monroviae</i><br><i>Boops boops</i><br><i>Chaetodon luciae</i><br><i>Dactylopterus volitans</i><br><i>Distodon speciosus</i><br><i>Fistularia villosa</i><br><i>Lutjanus fulgens</i><br><i>Lutjanus goreensis</i><br><i>Rhizoprionodon acutus</i><br><i>Trigla</i> sp. |
| <i>Balistes capriscus</i><br><i>Brachydeuterus auritus</i><br><i>Chloroscombrus chrysurus</i><br><i>Dentex canariensis</i><br><i>Epenephelus aeneus</i><br><i>Galeoides decadactylus</i><br><i>Selene dorsalis</i><br><i>Sparus caeruleostictus</i> | <i>Dactylopterus volitans</i><br><i>Dentex canariensis</i><br><i>Epenephelus aeneus</i><br><i>Fistularia villosa</i><br><i>Pagellus bellottii</i><br><i>Priacanthus arenatus</i><br><i>Pseudupeneus prayensis</i><br><i>Sparus caeruleostictus</i>   | <i>Balistes capriscus</i><br><i>Dentex canariensis</i><br><i>Dentex gibbosus</i><br><i>Epenephelus aeneus</i><br><i>Pagellus bellottii</i><br><i>Priacanthus arenatus</i><br><i>Pseudupeneus prayensis</i><br><i>Sepia</i> sp.<br><i>Sparus caeruleostictus</i>                      |
| <i>Elops senegalensis</i><br><i>Engraulis encrasicolus</i><br><i>Ilisha africana</i><br><i>Pseudolithus senegalensis</i><br><i>Pseudolithus</i> sp.<br><i>Pteroscion peli</i><br><i>Scyacium micrurum</i><br><i>Sphyraena sphyraena</i>             | <i>Acanthostracion guineensis</i><br><i>Acanthurus monroviae</i><br><i>Balistes forcipatus</i><br><i>Chaetodon</i> sp.<br><i>Chloroscombrus chrysurus</i><br><i>Decapterus</i> sp.<br><i>Lagocephalus laevigatus</i><br><i>Lethrinus atlanticus</i><br><i>Lutjanus fulgens</i><br><i>Scyacium micrurum</i><br><i>Sepia</i> sp. | <i>Brachydeuterus auritus</i><br><i>Chloroscombrus chrysurus</i><br><i>Chromis lineatus</i><br><i>Decapterus rhonchus</i><br><i>Lepidotrigla</i> sp.<br><i>Pomadasys incisus</i><br><i>Raja miraletus</i><br><i>Sardinella aurita</i><br><i>Selene dorsalis</i>                      |

Table 4.10.3.

MFRD5 1989

| Group 1   | Group 2   | Group 3   |
|---|---|---|
| <i>Lagocephalus laevigatus</i><br><i>Pagellus bellottii</i><br><i>Pentheroscion mbizi</i><br><i>Pomadasy incisus</i><br><i>Priacanthus arenatus</i><br><i>Pteroscion peli</i><br><i>Rhizoprionodon acutus</i><br><i>Trachinocephalus myops</i><br><i>Trachurus trecae</i>   | <i>Acanthurus monroviae</i><br><i>Boops boops</i><br><i>Decapterus rhonchus</i><br><i>Pomadasy incisus</i><br><i>Trachurus sp.</i><br><i>Trachurus trecae</i>   | <i>Anthias anthias</i><br><i>Boops boops</i><br><i>Chromis sp.</i><br><i>Decapterus sp.</i><br><i>Dentex canariensis</i><br><i>Dentex gibbosus</i><br><i>Sardinella aurita</i><br><i>Scomber japonicus</i>  |
| <i>Brachydeuterus auritus</i><br><i>Galeoides decadactylus</i><br><i>Penaeus notialis</i><br><i>Pomadasy jubelini</i><br><i>Pseudupeneus prayensis</i><br><i>Sepia officinalis</i><br><i>Selene dorsalis</i><br><i>Sparus caeruleostictus</i><br><i>Trichiurus lepturus</i>   | <i>Balistes forcipatus</i><br><i>Brachydeuterus auritus</i><br><i>Chloroscombrus chrysurus</i><br><i>Dentex canariensis</i><br><i>Fistularia villosa</i><br><i>Lagocephalus laevigatus</i><br><i>Lutjanus fulgens</i><br><i>Pagellus bellottii</i><br><i>Priacanthus arenatus</i><br><i>Pseudupeneus prayensis</i><br><i>Sepia officinalis</i><br><i>Sparus caeruleostictus</i> | <i>Dactylopterus volitans</i><br><i>Dentex congoensis</i><br><i>Epenephelus aeneus</i><br><i>Fistularia villosa</i><br><i>Pagellus bellottii</i><br><i>Pseudupeneus prayensis</i><br><i>Rhizoprionodon acutus</i><br><i>Sparus caeruleostictus</i>  |
| <i>Chilomycterus spinosus</i><br><i>Chloroscombrus chrysurus</i><br><i>Dasyatis sp.</i><br><i>Dentex canariensis</i><br><i>Drepane africana</i><br><i>Elops senegalensis</i><br><i>Epenephelus aeneus</i><br><i>Eucinostomus melanopterus</i><br><i>Grammoplites gruveli</i><br><i>Lutjanus fulgens</i><br><i>Sardinella maderensis</i><br><i>Sphyraena sphyraena</i><br><i>Torpedo sp.</i> | <i>Apsilus fuscus</i><br><i>Balistes capriscus</i><br><i>Chaetodon sp.</i><br><i>Chromis lineatus</i><br><i>Dactylopterus volitans</i><br><i>Decapterus sp.</i><br><i>Epinephelus aeneus</i><br><i>Lethrinus atlanticus</i><br><i>Sphyraena sphyraena</i><br><i>Trigla sp.</i>  | <i>Balistes forcipatus</i><br><i>Brachydeuterus auritus</i><br><i>Chloroscombrus chrysurus</i><br><i>Lagocephalus laevigatus</i><br><i>Lepidotrigla sp.</i><br><i>Priacanthus arenatus</i><br><i>Raja miraletus</i><br><i>Scyacium micrurum</i><br><i>Sepia officinalis</i><br><i>Selene dorsalis</i><br><i>Serranus accraensis</i><br><i>Sphyraena sphyraena</i><br><i>Trachurus sp.</i><br><i>Umbrina sp.</i> |



A number of fish species are found in more than one assemblage, making some of the assemblages look similar to each. These similarities were assessed with the Jaccard index and the Similarity Ratio. In Table 4.11.1 calculated values of the Jaccard index of similarity between pairs of the six assemblages obtained from the combined GTS data are presented. Values of the index for pairs of surveys (GTS - MFRD5) for corresponding assemblages and between pairs of assemblages from the same survey are given in Tables 4.11.2 and 4.11.3. These have been computed for both upwelling and thermocline seasons. From the GTS I (upwelling) data, the first two assemblages are quite similar to each other ( $S_j = 0.45$ ) and in the warm season both assemblages 1 and 3 show equal similarity to assemblage 2. In the case of the MFRD surveys, assemblages 2 and 3 are similar during the upwelling whilst 1 and 2 are similar during the warm season. In general, the assemblages derived from data for the two MFRD surveys are similar to each other than to the GTS assemblages, especially during the warm period.

The calculated values of the Similarity Ratio are given in Tables 4.12.1 and 4.12.2. For the shallow, soft bottom assemblage (assemblage 1), the close similarity among the surveys in the upwelling season is quite remarkable especially between GTS and MFRD3, and between the two MFRD surveys. In the other assemblages (2 and 3), the GTS results are closer to the MFRD5 results than MFRD3. During the thermocline period, the two MFRD surveys are more similar to each other than to the GTS results. The inter-assemblage relationships are different in all three assemblages. During the GTS, assemblages 2 and 3 are closest to each other; in MFRD3 and MFRD5 it is 1 and 3 and 1 and 2 respectively.

Table 4.11.1. Jaccard index values between derived assemblages for the GTS 1963-64 (both cruises and all species included)

| Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 |         |
|---------|---------|---------|---------|---------|---------|---------|
| 1       | 0.45    | 0.32    | 0.35    | 0.19    | 0.13    | Group 1 |
|         | 1       | 0.30    | 0.36    | 0.26    | 0.11    | Group 2 |
|         |         | 1       | 0.36    | 0.18    | 0.09    | Group 3 |
|         |         |         | 1       | 0.16    | 0.07    | Group 4 |
|         |         |         |         | 1       | 0.04    | Group 5 |
|         |         |         |         |         | 1       | Group 6 |



Table 4.11.2: Jaccard's index of similarity between surveys for corresponding species assemblages. Figures above shaded diagonal are for the upwelling period, and those below are for the thermocline period.

| Group 1 |      |       |       | Group 2 |       |       |      | Group 3 |       |       |  |
|---------|------|-------|-------|---------|-------|-------|------|---------|-------|-------|--|
|         | GTS  | MFRD3 | MFRD5 | GTS     | MFRD3 | MFRD5 | GTS  | MFRD3   | MFRD5 |       |  |
| GTS     | 1    | 0.35  | 0.35  | 1       | 0.29  | 0.31  | 1    | 0.32    | 0.28  | GTS   |  |
| MFRD3   | 0.33 | 1     | 0.46  | 0.21    | 1     | 0.54  | 0.22 | 1       | 0.39  | MFRD3 |  |
| MFRD5   | 0.34 | 0.44  | 1     | 0.31    | 0.31  | 1     | 0.29 | 0.42    | 1     | MFRD5 |  |
|         | GTS  | MFRD3 | MFRD5 | GTS     | MFRD3 | MFRD5 | GTS  | MFRD3   | MFRD5 |       |  |

Table 4.11.3. Jaccard's index of similarity between pairs of assemblages for the same survey. Figures above shaded diagonal are for the upwelling period, and those below are for the thermocline period.

| Group | GTS  |      |      | MFRD3 |      |      | MFRD5 |      |      |
|-------|------|------|------|-------|------|------|-------|------|------|
|       | 1    | 2    | 3    | 1     | 2    | 3    | 1     | 2    | 3    |
| 1     | 1    | 0.27 | 0.35 | 1     | 0.45 | 0.37 | 1     | 0.43 | 0.33 |
| 2     | 0.45 | 1    | 0.35 | 0.36  | 1    | 0.35 | 0.45  | 1    | 0.37 |
| 3     | 0.40 | 0.41 | 1    | 0.36  | 0.46 | 1    | 0.39  | 0.46 | 1    |
|       | 1    | 2    | 3    | 1     | 2    | 3    | 1     | 2    | 3    |





## 4.5 DISCUSSION

### 4.5.1 Community structure

From the GTS data, the TWINSpan and CANOCO analyses have been able to identify the principal fish assemblages similar to those described by Fager and Longhurst (1968) and Longhurst (1969). A number of species are common to these assemblages, especially the first four. The occurrence of *Brachydeuterus auritus* and *Trachurus* sp. (*Trachurus trachurus* and *Trachurus trecae*) in many of the groups is notable. *B. auritus* features prominently in the first three assemblages and *Trachurus* sp. are important in groups 2-5 (4 groups) (Table 4.6). Longhurst (1969) describes *B. auritus* as a 'notoriously eurybathic' species.

The six groups identified in this work from the GTS data correspond to the following assemblages (as named by Longhurst):

Group 1: Sciaenid community

Group 2: Lutjanid community

Group 3: Sparid community (shallow part)

Group 4: Sparid community (deep part)

Group 5: Deep shelf community

Group 6: Upper slope community.

The class of species referred to as eurybathic or thermocline species by Longhurst (1969) is not isolated in this work; these are generally included in the second assemblage. Also the estuarine sciaenid community is perhaps not represented in these surveys.

The dendrogram produced from TWINSpan analysis of the GTS data (Appendix 4.2.1) shows that the six communities grouped in pairs, namely a pair in waters shallower than 40 m, a second pair in 40-100 m and the last pair in waters deeper than this. Off Ghana, the average thermocline depth is about 40 m (chapter 3). This means that the sciaenid and lutjanid assemblages are generally above the thermocline whereas the two sparid communities originate from within the



thermocline depth and stretch seaward. Obviously, the deep shelf and upper slope assemblages lie well below the thermocline layer.

From the plot of DCA axis 1 versus DCA axis 2 (Figure 4.3), it appears that the first two species assemblages are separated mainly by sediment type - the first on soft bottom and the second on hard bottom. Assemblages 3 and 4 are separated by both sediment type and depth. The last two assemblages are separated from the others by depth.

It is not clear how the choice of species included in the final list of Longhurst's assemblages (Appendix 4.5) was made, thus a direct comparison of the species lists in the two studies cannot be made. However, the species in the final list from this work fit in quite well with the descriptions given for species belonging to the various assemblages. The information on the site-environmental parameters bi-plot (Figure 4.3) also correspond with the habitat preferences of various species in the assemblages as described by Longhurst (1969), Williams (1968), Blache *et al.* (1970) and Schneider (1990).

After going through ordination, it is expected that similarities between assemblages in the same survey will be minimal and that groups that were farther apart would have only a few species in common. This is confirmed by the low values of the Jaccard index between groups obtained from the GTS data (Table 4.11.1). With a Jaccard index value of 0.45, groups 1 and 2 show closest similarity; the average index among the first four groups is 0.36. From the matrix of the Jaccard index, it appears that there are clear discontinuities in species composition of assemblages between assemblages 2 and 3 (~ 30 m deep), 4 and 5 (~ 100 m) and 5 and 6. The rather low similarity between assemblages 5 and 6 appears to suggest that the 200 m depth contour is a significant division (ecotone) between continental shelf and upper slope fish assemblages.

These results imply that it is possible to obtain comparable assemblages for

the purposes of examination of trends and variability in fish community structure using the methods employed in this work.

Because of the short range of depths worked in the MFRD surveys (10-75 m with occasional hauls taken between 75 and 100 m deep, see chapter 6), the five groups that were initially identified in the TWINSPAN analysis overlapped considerably. Thus, the three main assemblages that have been considered in this work should be sufficient to describe fish assemblages of the inner-to-middle shelf communities. The smaller-sized groups could be sub-groups as described by Fager and Longhurst (1968) and perhaps occupying different locations within the domain of the 'true' assemblages.

#### ***4.5.2 Environmental parameters and assemblage structure***

The observed correlations among the environmental variables are as one would normally expect (Tables 4.2.1 and 4.2.2). For example, in all the surveys depth correlates negatively with temperature, salinity and dissolved oxygen (DO). The significantly high correlation between depth, bottom temperature, bottom salinity and bottom dissolved oxygen and the first DCA axis and between sediment type and the second axis, for the GTS data (Table 4.3), show the importance of these parameters in the determination of the structure of the demersal species assemblages in the study area. With this data set, depth appears to be the most influential variable on the ordination. It is followed by bottom temperature, salinity and dissolved oxygen. These physico-chemical parameters are themselves closely related to depth in the oceans and change by seasons as discussed in the last chapter. Thus the upwelling, which appears to change the properties of water masses may also have effect on the structure of demersal species assemblages.

Sediment type then follows in importance being highly significant (1 % level) on the second DCA axis. This shows the importance of this feature, which like depth, is invariant with time (at least within the time frame under consideration).



In the MFRD surveys, sediment type is the most important factor determining assemblage structure. All levels of this variable are highly significant on the first DCA axis (Table 4.3). The second axis is dominated by depth and then temperature, dissolved oxygen and salinity. These results are rather different from the GTS results. It appears that with a long depth gradient, as was the case in the GTS, sediment type becomes secondary to depth as the principal factor influencing assemblage structure. On such a long depth gradient, the physico-chemical factors, which are correlated with depth, also become extremely important forcing factors on community structure. When the depth range is not wide, then the most important factor affecting community structure is the type of sediment on the seabed, relegating depth to a secondary position. As temperature and dissolved oxygen also then become important on the second axis in case of short depth gradient, it may be sufficient to regard depth and bottom sediment type as the principal forcing factors determining assemblage structure. It appears, therefore, that temperature, dissolved oxygen and salinity are important in the dynamics of the assemblages.

It is noteworthy that in the complete GTS data, the stations deeper than 100 m are always separated at the first level of dichotomy in TWINSpan (e.g. Appendix 4.2.1). This shows the extreme importance of the depth factor and especially the 100 m depth, on the organization of assemblages on the continental shelf and upper slope off Ghana. In this area, especially on the eastern side, the shelf drops sharply around this depth (Koranteng 1984). In the MFRD surveys and also in the 10-75 m subset of the GTS data, the first dichotomy in TWINSpan usually separates the shallow-water soft and muddy-bottom assemblage from the others (Appendices 4.2.2 - 4.4). The relative importance of sediment type in this case is thus portrayed here.

ter Braak (1991) cautions the use of the regression / canonical estimates obtained from CANOCO and suggests that they be utilized for exploratory purposes only. Consequently, in this work the regression coefficients are not considered at the same level of importance as the other statistics (e.g. correlation coefficient). In the complete GTS data, none of the calculated regression estimates are significant.

However, sediment type and depth become highly significant ( $P < 0.01$ ) on both DCA axes 1 and 2 when the stations deeper than 75 m are excluded from the analysis. No significant regression emerged from the MFRD3 data. As regards MFRD5, regression estimates of sediment type (hard) and depth are highly significant on both first and second DCA axes ( $p < 0.01$ ) (Table 4.4). With the exception of the MFRD3 survey, these results are compatible with the correlation coefficient analysis and they seem to reaffirm the importance of depth and sediment type on assemblage structure.

The results obtained in this study, in one way or the other, conform to results of similar studies undertaken elsewhere. For example, it has been shown by several authors (including Fager and Longhurst 1968; Mahon *et al.* 1984; Yanez-Arancibia *et al.* 1985; McManus 1986; Roel 1987 and Bianchi 1992a) that depth is the most important gradient along which faunal changes occur. Working on the entire GTS data collected from Guinea Bissau to Congo, Fager and Longhurst (1968) attributed assemblage boundaries in the Gulf of Guinea to thermal discontinuity and sediment type the latter of which also changed with depth. However, according to Longhurst and Pauly (1987), the general pattern or regular fish community replacement with depth in the Gulf of Guinea as clearly portrayed in Longhurst (1965; 1969) was disrupted off the upwelling coast of Ghana. The authors put it that “off Ghana, the distribution of species is much less easy to analyse, probably because of the existence of a variable oceanographic situation and species distribution that shift in response to it”.

According to Mahon *et al.* (1984), depth and sediment particle size contribute primarily to the first discriminant axis, temperature to the second and salinity equally to both axes to determine spatial and temporal patterns of groundfish on the Scotian shelf and in the Bay of Fundy (Canada). McManus (1986) noted depth-dependent changes in fauna between 20 and 90 m deep in the Samar sea, Philippines. Roel (1987) drew similar conclusion with the demersal fish assemblages off South West Africa (now Namibia) and Bianchi (1992a) noted consistent depth-dependent



changes in demersal assemblages at a number of locations in the tropical seas (including areas off Angola, Congo and Gabon, North-Western Indian Ocean and French Guyana to Suriname in South America). Yanez-Arancibia *et al.* (1985) concluded from their study in the Southern Gulf of Mexico, that factors influencing assemblage structure are mainly bathymetry, sediments, salinity and temperature.

The importance of sediment type on community structure is also well documented (e.g. in sources as cited above for depth). The emphasis in the present work is on the order of importance of these factors in determining the assemblage structure. It has been shown that with a long depth gradient, sediment type is only secondary to depth in determining structure of demersal fish assemblages. On a short depth gradient, sediment type takes precedence over depth.

The effect of physical characteristics of the water masses appears confounded with depth due to high positive or negative correlation between depth and these parameters. Nevertheless, it appears that the physico-chemical parameters play a major role in influencing assemblage dynamics, especially seasonal changes. For example, fluctuations in dissolved oxygen in the water can cause vertical or horizontal habitat changes in fishes (Kramer 1987). Off India, (Longhurst 1969) found that “oxygen-deficient water drives the stocks either very close inshore or into mid-water offshore”. In the Gulf of Guinea, the appearance of cold water with the onset of the seasonal upwelling is thought to make triggerfish move to surface waters and further offshore (Ansa-Emmim 1979). The effect of salinity on the movement of fish has been documented in the literature (e.g. the effect of the Great salinity anomaly in the North Sea (Cushing 1990)). Longhurst (1965) laid great emphasis on the role of temperature and the thermocline as “important biological and faunistic barriers”, concluding that in the Gulf of Guinea, the discontinuity of the fish fauna is associated with bottom temperature of around 20 °C.

As has been shown in chapter 3, associated with the global cooling in the Gulf of Guinea between 1972 and 1982, was a rise in salinity of both surface and

bottom sea water. Towards the end of this period, decrease in salinity and increase in seasonal fluctuation of this parameter may have contributed to the drastic decline of the stock of the triggerfish. As the species is said to prefer warm water (Ansa-Emmim 1979; Caverivière 1982), the boom and bust of its population in the Gulf of Guinea cannot be explained by changes in sea temperature but by salinity.

#### **4.5.3 Variability in assemblage formation**

Generally the number of species recorded during the GTS was much higher than the corresponding figures in the MFRD surveys. Although the differences in depth range sampled could be a factor, the incidence and use of genus names instead of species names were highest in the GTS data. As a result, only very obvious genus names could be completed during the compilation of the data in this work. This is because even where only two species of a particular genus were found in the area surveyed, one could not say with certainty which of the two species the genus name recorded refers to. For example, it was uncertain whether a record appearing as *Trachurus* sp. referred to *Trachurus trachurus* or *Trachurus trecae* even when one of these names had already appeared in the station record. *Trachurus* sp. could have been used also for young undersized specimens of this genus that could not be clearly identified.

Generally, only a few species achieved the  $IRI > 50$  criterion in assemblages 1 and 3 of the GTS (Tables 4.6, 4.9.1 and 4.9.2). This implies that only a few species (e.g. *Brachydeuterus auritus*) occur in large quantities in most of the hauls made in these assemblages. The situation is slightly different in the MFRD surveys even though one would expect a similar situation because of the abundance of triggerfish at the time of these surveys. Unfortunately, this does not quite show up in the results, one reason being that *B. capriscus* was generally most abundant during the last quarter of the year, i.e. October to November (Koranteng 1981,1984); a period that was not included in the analyses. Thus in the MFRD surveys, many species occur in moderate quantities and in many of the hauls thereby increasing the number of



species meeting the  $IRI > 50$  criterion (Tables 4.9.3 - 4.9.6). This state of affairs could also indicate a change in the population structure of the species belonging to these assemblages and possibly resulting from effects of environmental changes or exploitation.

The analyses carried out in this work on temporal and spatial patterns of community structure (using the first three assemblages and the three surveys) and involving the use of Jaccard's similarity index does not seem to have resulted in definite or clear assemblage dynamics over the time period under consideration. However, the calculated values of the Jaccard index (Tables 4.11.1 - 4.11.3) indicate that assemblages 2 and 3 showed closest resemblance to each other during the cold season and 1 and 2 in the warm season. The first situation could be due to fishes in assemblage 3 moving closer inshore during the upwelling and the second perhaps, due to assemblage 1 fishes moving away from shallow areas during the warm season (also see chapter 5). It is clear also that in general, the properties of the derived assemblages in the MFRD surveys are quite similar to each other and different from the GTS. This is true in both the upwelling and thermocline periods. In a way, this is expected considering the fact that the GTS was conducted 17 years before MFRD3 and at a time when commercial trawling on the continental shelf of Ghana and neighbouring countries was much less intense than was the case at the time of the MFRD surveys. There was also the case of increased abundance of triggerfish in the period of the MFRD surveys, especially during MFRD3.

The Jaccard index is based only on presence - absence information thereby giving equal weight to all species including rare ones. However, using only species that met the  $IRI > 50$  criterion in the analysis should give more credence to the results obtained. Corresponding analyses using the Similarity Ratio, which takes the abundance of the species into consideration, did not result in a clearer picture of the situation although the similarity between the two MFRD surveys came out clearly here as well (Tables 4.12.1 and 4.12.2). It appears therefore, that either these indices are unable to detect the relevant patterns in the nature of assemblage similarity among the surveys or between the two seasons or that there are no measurable

assemblage patterns in the information obtained from the three surveys.

Similar studies elsewhere have resulted in similar conclusions. For example, examining groundfish assemblage structure in relation to fishing in north-western North Sea over two time periods 1929-53 and 1980-93, Greenstreet and Hall (1996) concluded that the changes were rather subtle and were probably due to the relative abundance of rarer species.

The following observations were made from looking at Tables 4.10.1 - 4.10.3 which portray the occurrence of species in the various assemblages and in the two seasons:

- i. certain species were faithful to their groups over the 26 year period; these include *Brachydeuterus auritus*, *Galeoides decadactylus* and *Sparus caeruleostictus* in Group 1; *Dentex canariensis*, *Pagellus bellottii*, *Priacanthus arenatus*, *Pseudupeneus prayensis* and *Sparus caeruleostictus* in Group 2, and *Epinephelus aeneus* and *Pagellus bellottii* in Group 3,
- ii. the representation of *Lutjanus* species in the lutjanid assemblage reduced over the time period under consideration.

The reduced importance of *Lutjanus* species in the lutjanid assemblage is a significant observation which may reflect the pattern of exploitation of commercial fisheries (especially of demersal fishes) in Ghanaian waters and also the abundance of commercially exploited fish species. As an example, the occurrence of some *Lutjanus* species vis-a-vis that of *Balistes capriscus* were briefly examined. During the Guinean Trawling Survey, *Lutjanus agennes* was recorded in 17 out of the 25 hauls (i.e. 68 %) in assemblage 2. Occurrences of other lutjanids in the assemblage were: *L. fulgens*, 72 % and *Letrinus atlanticus*, 72 %. In the September cruise, both *L. agennes* and *L. fulgens* occurred in 88 % of the hauls in assemblage 2 and *L. dentatus* occurred in 75 % of the hauls. In GTS 2, each of the first three species was



recorded in at least 62 % of the hauls. During this time *B. capriscus* was insignificant in the catches.

In August 1981 when *B. capriscus* occurred in 50 % of the hauls in the second assemblage, none of the lutjanids made it to the list of the most abundant species which on this occasion accounted for 98 % of the total catch of fish in this assemblage. Instead, *L. fulgens* and *L. goreensis* appeared in the corresponding list in assemblage 3. When *B. capriscus* eventually also topped the list of important species in assemblage 3 in May 1981, no lutjanid was found in the list. A situation similar to what has been described for 1981-82 also occurred in 1989-90. It appears, therefore, that the presence of *B. capriscus* had an effect on the distribution and abundance of the lutjanids, especially in the lutjanid community. These and other changes and species interactions are further examined in chapter 5.

It is possible also that the apparent disorganisation of lutjanids may be associated with the destruction of their preferred habitat as a result of the activities of industrial trawlers. Longhurst (1969) associates lutjanids with "outlying patches of coral banks". The large industrial trawlers that have operated in Ghanaian waters since the early 1970s (chapters 6 and 7) could have destroyed these habitats. There is no information to verify this.

It was not possible to adequately cover spatial (mainly longitudinal) differences in assemblage structure in this work. The principal reason being the uneven sampling intensity between the sectors. During the GTS, the areas between 200 - 600 m deep on the eastern end (i.e. transects 32 and 33) were not worked on either cruise. In the MFRD surveys, the intensity of sampling was higher in the area between Cape Three Points and Tema (Greenwich Meridian) than the other areas. Nevertheless, it is essential to put into perspective some of the longitudinal differences observed in this work.

The deep-water assemblages (groups 4 - 6) derived from the March data give

some indication of the non-continuity of assemblages within the various depth strata. For example, both assemblages 4 and 5 have a mean depth of about 200 m but differ mainly in longitudinal location. Whereas assemblage 4 is located on the western side (transects 27 and 28) on soft-to-mixed bottom, assemblage 5 is located in the central part of the shelf (transects 29 - 31) mainly on mixed sediment type. The value of the Jaccard index of similarity between these two assemblages is 0.43 showing that they had many species in common including *Loligo* sp., *Paracubiceps ledanoisi* and *Antogonia capros*. In addition, assemblage 5 also has a good representation of the family *Triglidae*.

Such seemingly minor but important differences between the two assemblages at 200 m deep go to the heart of the matter concerning the existence of small sub-assemblages on the inner shelf with each sub-assemblage related essentially to an optimum sediment type. This offers additional justification for the merging of some of the sub-assemblages identified in the MFRD data.

However, as the major direction of change in assemblage boundaries was found to be linked with depth and sediment type (the latter of which also essentially changes with depth), the effects of these parameters on the structure of the assemblages may be confounded.

#### **4.5.4 Limitations of the methods and analyses**

Some of the methods that have been used in this work may be open to criticism. Firstly, the three surveys that have been compared in this work did not follow the same sampling design and methodology. The GTS followed a systematic sampling design and covered a wide depth range sampling at specified depths along line transects. The two MFRD surveys followed a different sampling design (stratified random). Unfortunately, much as this method of sampling is desirable for stock assessment purposes, the inconsistency in sampled depths on different cruises, introduces particular difficulty in using the same data for community studies. For



example, does a change in community parameters mean a real change resulting from movement of the community or due to sampling at different locations as a result of randomization?

As discussed in chapter 6, the survey vessels and survey gear also differed between the GTS and the MFRD surveys. Identification of the species at sea is another source of error in this kind of work. The same taxonomists were involved in all the MFRD surveys; but different taxonomists worked on the GTS.

In the compilation of the data, raising catch in half an hour to catch per hour (as applied to the MFRD survey data) only increases the total catch but does not account for the possibility of encountering different fish species within the extrapolated time. The timing of the surveys selected for the analyses does not permit perfect comparison of the results considering the effect of the upwelling on properties of the water masses. Comparing August (in MFRD) with September (in GTS) may not be too critical, but comparing May with March may be far from desirable. However, although it has been shown that the physico-chemical properties of the water masses are important in determining assemblage structure, and especially their dynamics, the problem is minimised since depth and sediment type, which are invariant over time, emerged as the most critical factors.

The effective number of divisions to be considered on the TWINSpan output to reveal the true and appropriate assemblages, presents a significant drawback of the method whereby no definite stopping rule is used and there is no concrete statistical test to evaluate the significance of successive divisions. In a way this is similar to the problem encountered in cluster analysis and which introduce subjectivity and uncertainty at the tail end of the analysis. The choice of number of divisions and minimum class size to divide presuppose having some prior knowledge about the assemblages in question. Therefore, the subjectivity element mentioned by Fager (1957) is in a way present in the analysis. In addition, the TWINSpan analysis is rather sensitive to the handling of certain options (e.g. the pseudospecies cut levels),

especially when analysing data with short environmental gradient (Bianchi and Hoisæter 1992). To minimize the possible effect of this factor, the cut levels that were carefully chosen after examination of the various data sets were kept throughout the analyses. It was found that the total number of samples (hauls) used in the TWINSpan analysis is very important as too few samples in the analysis would suppress the identity of some otherwise important communities.

The detrended correspondence analysis routine in CANOCO requires a large number of options including transformation of the data, weighting of species and samples and method of detrending. All these affect the results and to minimise such errors the input answers to all options were kept constant throughout the analyses.

Another source of variation is the description of sediment type as used in this work and originating from the GTS and Guinea 90 surveys. It looks as if the descriptions are rather too coarse and finer categorization which would more closely reflect the ecology of the food prey could be more appropriate for such analyses.

Missing from all these analyses is information on the availability (distribution and abundance) of the food for the fish. This is a significant omission. The fact that the four ordination axes generally explained less than 60 % of the variation in the data implies that other factors that have not been accounted for in the present analyses do influence the structure and dynamics of the assemblages. Prey availability and distribution could be examples of such additional factors. For example, it is known that *B. capriscus* feeds mainly on benthic invertebrates like molluscs and crustaceans (Totonese 1986). Therefore, it would be useful to find out how the abundance of these benthic invertebrates changed over time. This would be important information in understanding the change in biomass of *B. capriscus*.

Similarly, the inclusion of surface temperature in the model to serve as proxy for the upwelling could improve the results. However, this variable was omitted on the grounds of the established links in the trends and seasonal variation in both



surface and bottom temperatures as discussed in the previous chapter. The choice of the more 'surrounding' bottom temperature for the demersal assemblage was considered more appropriate and was done to reduce the number of variables in the model.



**CHAPTER FIVE:**

**COMMUNITY DYNAMICS OF DEMERSAL FISHES  
ON THE CONTINENTAL SHELF OFF GHANA**

*".....and yet in the long run  
the forces are so nicely balanced that  
the face of nature remains uniform for long periods of time....."*

Charles Darwin  
The Origin of Species, 1859



## Chapter Summary

Between 1964 and 1990, the structure of demersal species assemblages on the continental shelf of Ghana underwent significant change. During the first environmental time block (1964 - 1972), the assemblages are relatively easy to identify using ordination techniques, but in the second time block (1972 - 1982), the assemblages become difficult to separate (especially the lutjanid and sparid assemblages). In the final time block, the system bears the semblance of ETB1. This behaviour of the assemblages is due mainly to the sudden increase in abundance of *Balistes capriscus* at a time when climatic and near-shore forcing factors had resulted in an environment conducive for the low temperature, high salinity sparid community to which *B. capriscus* belongs.

Generally, species diversity, richness and evenness also declined during ETB2, especially in the shallow waters between 10 and 50 m deep.

The relative importance of sciaenids, lutjanids and sparids in three bathymetric frames of reference changed in response to the alterations in the ecosystem. As the assemblages get re-established following the decline of *B. capriscus*, the density of rays, cephalopods and soles increase especially between 30 and 50 m deep.

## 5.1 INTRODUCTION

### 5.1.1 Objectives

As a follow-up to the identification of the structure of demersal fish assemblages on the continental shelf and upper slope off Ghana (chapter 4), the primary objective in this chapter is to assess the stability of the identified assemblages through time given the observed changes in marine environment, climate and near-shore forcing factors as discussed in chapter 3. The research questions are:

- i. Have the assemblages of demersal fishes on the continental shelf off Ghana changed in the last 30 years?
- ii. What is the nature and pattern of change?
- iii. What are the possible factors and causes?

Long-term changes in fish assemblages have been attributed to a number of factors including over-exploitation of some of the species within the assemblage (Brown *et al.* 1973, 1976; Sherman *et al.* 1981) and climatic variations (Sutcliffe and Muir 1977). Studies on fish communities have shown that:

- a. spatial changes in the assemblage can occur with the whole assemblage performing inshore-offshore temporal migrations (e.g. Macdonald *et al.* 1984; Gomes *et al.* 1995), and
- b. dominance (or decline) of some species in the assemblage may result from exploitation (Brown *et al.* 1973, 1976; Burd 1978; Sherman *et al.* 1981; Overholtz and Tyler 1985) or differential response to changes in environmental forcing factors (Gulland and Garcia 1984; Overholtz and Tyler 1985; Macpherson and Gordo 1992).

The literature is rather inconsistent with respect to the persistence of fish species assemblages through time. One school of thought holds the view that marine fish communities are in constant motion and hold no memory that will enable them to return to a previous state (Beddington 1984; Sherman and Alexander 1986; Tyler *et al.* 1982). On the other side of the argument, Longhurst and Pauly (1987), for example, hold the view that "...one can assume that given sensitive management, or the relaxing of fishing pressure for some reason, tropical fish communities would tend to revert to the natural state ....." . McGlade (1989) believes that "...natural systems do recover from large environmental perturbations".

There are various publications supporting either side of the argument. For example, from theoretical considerations, Beddington (1984) showed that for exploited systems, multiple stable states of community structure are possible and therefore changes in structure are unlikely to be reversible. This is affirmed by Tyler *et al.* (1982) who discuss the apparent irreversibility of fish assemblage structure in the fisheries of the Great Lakes of Canada. This means that the perturbations induced by fishing activities, for example, could lead to irreversible changes in the structure of marine fish communities (Sherman and Alexander 1986)



Examining changes in demersal fisheries in the Gulf of Thailand, Tiews *et al.* (1967) and Pauly (1979) noted significant changes in species composition of catches, reflecting possible alteration in the structure of demersal fish assemblages in the area between 1963 and 1972. In the northwestern North Sea, Greenstreet and Hall (1996) reported long-term changes and between-area differences in the species composition of the demersal fish assemblage. The authors noted, however, that the differences were “.... rather subtle and most apparent in the dominance structure...”. This was further underlined in an analysis of the effects of the industrial fisheries on the North Sea ecosystem (Robertson *et al.* 1996).

Many assemblages have also been found to persist in structure and bathymetric or geographic boundaries through time (Overholtz and Tyler 1985; Fargo and Tyler 1991). Fargo and Tyler (1991) reported stable geographic boundaries of assemblages with time and Macpherson and Gordo (1992) noted high community stability in demersal fish species off southern Namibia. Similarly, Gabriel (1992) noted that membership of major species groups in the area between Cape Hatteras and Nova Scotia (Northwest Atlantic) was persistent in time although the response of species groups to fishery perturbations varied among groups.

Making inferences from Rijavec (1980) and Koranteng (1981), Villegas and Garcia (1983) concluded that the occurrence of the most frequent demersal species in Ghanaian waters were the same in 1979-80 as in 1969-70 indicating possible persistence of species assemblages in Ghanaian waters.

Between these two situations, Gomes *et al.* (1995), found different response in assemblage structure on the Newfoundland/Labrador shelf (Northwest Atlantic) over two time periods. Between 1978 and 1987, the assemblages remained relatively stable but entered a period of dramatic change thereafter.

These examples show that the behavior of fish communities is probably ecosystem-specific. Since the cited works in the Gulf of Guinea, both the resources and environment have undergone considerable changes as discussed above (chapters

1 - 3), however no study has examined long-term spatial and temporal changes or interrelationships among the fish assemblages in this ecosystem. For example, in order to be able to predict or detect changes due to human /natural processes in the demersal fishery of Ghana, there is a real need to examine the behaviour of fish assemblages in Ghana's shelf waters given the long-term changes in the marine environment and near-shore environmental forcing factors (chapter 3), the ecological changes resulting from the proliferation of triggerfish and the considerable increase in fishing effort on demersal fisheries resources in the last two decades (chapters 1 and 6). It is acknowledged, however, that it is often difficult, if not impossible, to separate natural fluctuations from those caused by anthropogenic factors like exploitation (Cushing 1980; Sissenwine *et al.* 1982).

### **5.1.2 Measurement of change in ecological communities**

The abundance of a species is measured by its population density or biomass which may change in response to variation in its environment or other forcing factors. To examine the nature and extent of changes that occur in an ecosystem at the level of ecological community, a community-based analysis is used. Gomes *et al.* (1995) suggest two alternative but complementary methods of monitoring such changes in time and space. In the first method, a community composition (assemblage) is defined and its spatial movement is followed through time. Gomes *et al.* (1995) describe this approach as Assemblage Frame of Reference (AFR). The other approach is to delineate an area and follow community succession within this frame over time. This is referred to as Geographic Frame of Reference (GFR).

As seen in chapter 4, distribution of species assemblages on the continental shelf off Ghana is dependent mainly upon depth and sediment type. In the area of investigation, both parameters are invariant over time and are linked to each other. Over most of the Ghanaian shelf, the sediment type changes almost uniformly with increasing depth; from soft, muddy grounds in shallow waters to hard or mixed bottom in deep waters. Associated with these depth-sediment type regimes are the three major species assemblages described in chapter 4, namely the sciaenid, lutjanid

and sparid assemblages found from the inner to middle part of the continental shelf. In this chapter, assemblage dynamics are investigated following the methods of Gomes *et al.* (1995). Depth ranges are considered in the geographic frame hence this is referred to as bathymetric frame of reference (BFR) in this work.

### **5.1.3 Species diversity**

A corollary of studies in community ecology is the examination of how species numbers (i.e. diversity) vary over time and in space. For many years now, ecologists have sought ways of describing the diversity of ecological communities and have come up with several indices aimed at capturing the diversity of a community by a single number. Magurran (1991) gives a review of some of the available indices and discusses the merits and applicability of each of them.

A diversity index provides a univariate measure of community association as opposed to the multivariate methods discussed in the chapter 4. Diversity indices broadly fall into three categories: those that characterise species richness (i.e. number of species in the community), those that assess evenness (how abundance is distributed among the species) and those that combine the two (Ludwig and Reynolds 1988; Magurran 1991). Because of differential response of individual species to environmental and ecosystem changes and to exploitation, species diversity is likely to change as a result of environmental changes (e.g. as described in chapters 3 and 4 for the Ghanaian shelf ecosystem) and exploitation (e.g. as discussed in chapters 6 and 7).

A fundamental variable required in the calculation of diversity index is the number of individual species either in the population or in the sample. In the study of fish populations, numbers of fish are extremely difficult to obtain; even the number of fish caught in one haul can only be estimated in sub-samples. Therefore, it was found appropriate in this work to use a diversity index that did not rely on numbers *per se*. Following Wilhm (1968), the Shannon Diversity Index (Shannon and Weaver 1963) calculated with weights of species instead of numbers, was used. The Shannon Diversity Index (also known as Shannon-Weaver Index - a misnomer



according to Magurran (1991)) is an example of an index that originated from information theory<sup>2</sup>, combining species richness and evenness. The index makes two assumptions, namely that individuals are sampled at random from a large population, and that all species are represented in the sample.

For  $s$  individual species in a sample, the Shannon Diversity Index is given by

$$H' = - \sum_{i=1}^s p_i \ln p_i \quad \dots 5.1$$

where  $p_i = \frac{N_i}{N}$ ,  $N_i$  is the number of individuals of the  $i^{\text{th}}$  species and  $N$  is the total number of individuals of all  $s$  species. The variance of  $H'$  is given by

$$\text{var}(H') = \frac{1}{N} \left[ \sum_{i=1}^s \frac{N_i}{N} \ln \frac{N_i}{N} - (H')^2 \right] \quad \dots 5.2$$

Wilhm (1968).  $N_i$  and  $N$  are population parameters which can be estimated from their corresponding sample parameters  $n_i$  and  $n$ . Thus the index becomes

$$H'' = - \sum_{i=1}^s \left( \frac{n_i}{n} \right) \ln \left( \frac{n_i}{n} \right) \quad \dots 5.3$$

When weights are used, the Shannon Diversity Index is calculated from

$$H'' = - \sum_{i=1}^s \left( \frac{w_i}{w} \right) \ln \left( \frac{w_i}{w} \right) \quad \dots 5.4$$

where  $w_i$  and  $w$  are the sample weights of the  $i^{\text{th}}$  species and the total respectively.

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<sup>2</sup> "... indices based on the rationale that the diversity, or information, in a natural system can be measured in a similar way to information contained in a code or message" (Magurran 1991)

Using Wilhm's (1968) approach, it is possible also to calculate species richness and evenness using weights. Margelef's (1958) richness index (R1) and Pielou's (1975) evenness index (J') were chosen among many possible indices. These are given by

$$R1 = \frac{s-1}{\ln(w)} \quad \dots 5.5$$

$$J' = \frac{H''}{\ln(s)} \quad \dots 5.6$$

where all symbols are as explained above.

## 5.2 MATERIALS AND METHODS

Subsets of the data collected in 10 surveys conducted in Ghana's coastal waters between March 1964 and April 1990 (see chapter 6) were analysed. Only surveys conducted during the main thermocline season (i.e. April - June) were included here, thereby eliminating seasonal differences. Data from the March cruise of the Guinean Trawling Survey were also included as done in chapter 4. The surveys were irregular in time and in space and unequal numbers of samples (hauls) were taken. The area covered was not the same in the various surveys, however care was taken to select cruises during which a large number of stations were worked.

### 5.2.1 *Assemblage Frame of Reference (AFR)*

On each set of data, TWINSpan was used to classify the stations as described in chapter 4. The indicator species for each assemblage were noted and the positions of the stations marked on the survey chart. On the basis of results obtained in chapter 4, clusters of points were demarcated to denote the locations of assemblages. These relative positions were compared from survey to survey.

### **5.2.2 Bathymetric Frame of Reference (BFR)**

In the second approach of looking at community change, the shelf area between 10 and 100 m was divided into three; namely 10-30, 31-50 and 51-100. From the results of the previous chapter, these depth ranges correspond to approximate locations of the sciaenid, lutjanid and sparid assemblages respectively. Although there are overlaps between these assemblages, the investigations were carried out using the defined bathymetric frame as the unit for comparison. Other considerations for the use of these divisions are the physical properties of the shelf waters as measured at locations along the Tema hydrographic transect (chapter 3), and the significance of depth zonation in fisheries management issues in Ghana (chapter 7).

In each bathymetric frame, the following investigations were conducted:

- i. species diversity: Shannon Diversity Index was calculated; evenness and species richness were also calculated,
- ii. yield of selected families, genera or species of fish were calculated; the list is given below:

1. Snappers (Lutjanidae and Lethrinidae)
2. Groupers (Serranidae)
3. Grunts (Haemulidae)
4. Croakers (Sciaenidae)
5. Seabreams (Sparidae)
6. Rays (Dasyatidae, Myliobatidae, Rhinobatidae, Torpedinidae)
7. Cephalopods (Octopodidae, Sepiidae and *Loligo* sp.)
8. Soles (Soleidae, Citharidae and Bothidae)
9. *Balistes capriscus*

Biomass parameters were obtained with the 'swept-area' method and other routines in NAN-SIS (also see chapter 6). As the surveys were conducted with different vessels and fishing gears, and as has been described in detail in chapter 6, the statistic used in this work is the calculated density of fish in kilograms per



hectare ( $\text{kg ha}^{-1}$ ). This parameter takes into consideration the speed of the vessel, the size of the survey net and the total catch in each haul.

Some cross-sectoral investigations were also conducted including examination of species diversity among the BFRs. The calculated values of diversity, evenness and richness indices were compared using analysis of variance. The use of this technique here is justifiable because Taylor (1978) showed that  $H''$ , for example, is normally distributed if calculated for a number of samples.

The correlation between abundance values of pairs of families (and *Balistes capriscus*) were calculated using Pearson's product-moment correlation coefficient and Kendall's coefficient of rank correlation ( $\tau$ )<sup>3</sup>. The latter coefficient appears to be more appropriate in this case (see footnote).

## 5.3 RESULTS

### 5.3.1 *Assemblage Frame of Reference and Identification of species assemblages*

In each of the data sets, the three main species assemblages described in chapter 4 (i.e. sciaenid, lutjanid and sparid) were identified. The sparid assemblage, as used here, is a mixture of the shallow and deep components described in chapter 4. Because of the considerable overlap of the three assemblages, discrimination among the groups was difficult at times. The results for each data set are described below.

April-June, 1970: Thirty hauls were used from a survey that followed systematic sampling along five transects (see chapter 6). There was a relatively clear

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<sup>3</sup> Kendall's coefficient of rank correlation ( $\tau$ ) is "...based on the probabilistic notion that correlation between variables  $x$  and  $y$  is strong if there is a high probability that an increase in  $x$  will be accompanied by an increase (or decrease) in  $y$ " (McPherson 1990). Unlike Pearson's coefficient which assumes a linear trend between the two variables,  $\tau$  only requires that the two variables "...should be either continually increasing or continually decreasing" (McPherson 1990).

demarcation of the areas occupied by the three assemblages and in line with the assemblage descriptions given in chapter 4. There were insufficient samples to clearly delineate the sparid assemblage.

April-June,1975: The results from an analysis of 22 hauls were used but were rather unclear. The sciaenid assemblage could be identified but the lutjanid and sparid assemblages appear mixed with the latter extending to the normal biotope of the former. The few hauls separated out in the TWINSpan analysis, representing the lutjanid assemblage, were grouped at two rather close locations.

April-June,1977: The 21 hauls used resulted in a structure quite opposite to that of 1975; the lutjanid assemblage appeared to be in the biotope usually occupied by the sparid assemblage.

April-June,1980: From the 30 hauls used in the analysis, the sciaenid assemblage separated out at the primary dichotomy and a slightly clearer separation between the lutjanid and sparid assemblages was obtained.

April-June,1981 and 1988: The results of the TWINSpan analyses for these years show a clearer separation of the three assemblages than in the previous year.

April-June,1989 and 1990: In the 1989 and 1990 data sets, all three assemblages were identifiable. The lutjanid assemblage appeared to occupy more space in 1989 than in 1990. Unfortunately, this comparison was inconclusive as there were only a few hauls in the 1990 data set compared to 1989.

The data sets in each Environmental Time Block (ETBs) (chapter 3) were combined; i.e. data for 1964 and 1970 were put into one group, those for 1975,1977, 1980 and 1981 in a second group and 1988 - 1990 in a third group. These grouped data were re-analysed. The assemblages derived from the results of the TWINSpan analysis are shown in Figures 5.1.1 to 5.1.3. In Figure 5.1.1 (ETB1), the sciaenid, lutjanid and sparid assemblages are identifiable even though the sample size is rather

small. In ETB2 (Figure 5.1.2), only the sciaenid assemblage is recognizable with the other two assemblages overlapping each other. A better separation of the assemblages is seen in Figure 5.1.3.

### **5.3.2 Species behaviour in the Bathymetric Frames of Reference**

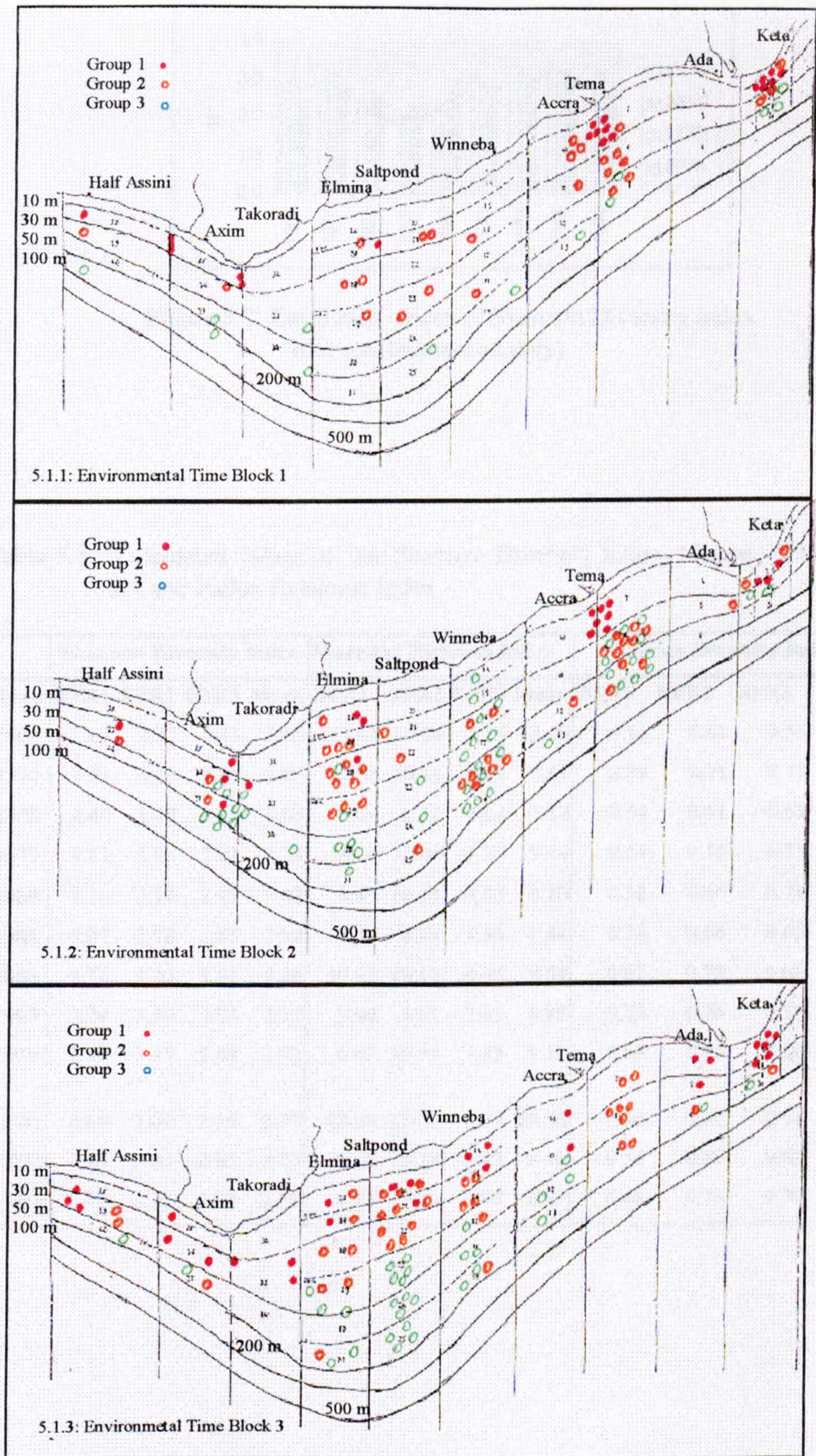
#### **5.3.2.1 Species diversity, Evenness and Richness in the BFRs**

The values of the Shannon Diversity Index ( $H''$ ) calculated for each bathymetric frame are presented in Table 5.1. All the values fall within the normal range of 1 - 3.5 (Magurran 1991). The trend of  $H''$  over the time period is shown in Figure 5.2. The table and figure show a decline in diversity between 1970 and 1977 in all sectors with lowest overall value obtained in 1977. The reduction is more pronounced in BFR1 and BFR2 with the second experiencing it in 1975. From 1980, diversity increased in all three bathymetric frames.

Analysis of variance of  $H''$  shows that the differences between the BFRs are not significant. On the other hand, the differences between years and Environmental Time Blocks (ETBs) are significant ( $p < 0.02$ ).

Species richness and evenness also changed within the observational period. During ETB1, the Margalef Richness Index ( $R1$ ) was relatively high in BFR1 and BFR2 (12.23 and 12.47 respectively), but these reduced drastically during ETB2.  $R1$  increased again in both frames during ETB3. The direction of change of  $R1$  in BFR3 is opposite that in the shallow frames increasing between ETB1 and ETB2 but decreasing slightly in ETP3. Pielou Evenness Index  $J'$  also decreased between the first two time blocks but increased during the third. The biggest decrease was in BFR2.





Figures 5.1.1 - 5.1.3: Grouping of trawl hauls in the three environmental time blocks (after ordination)



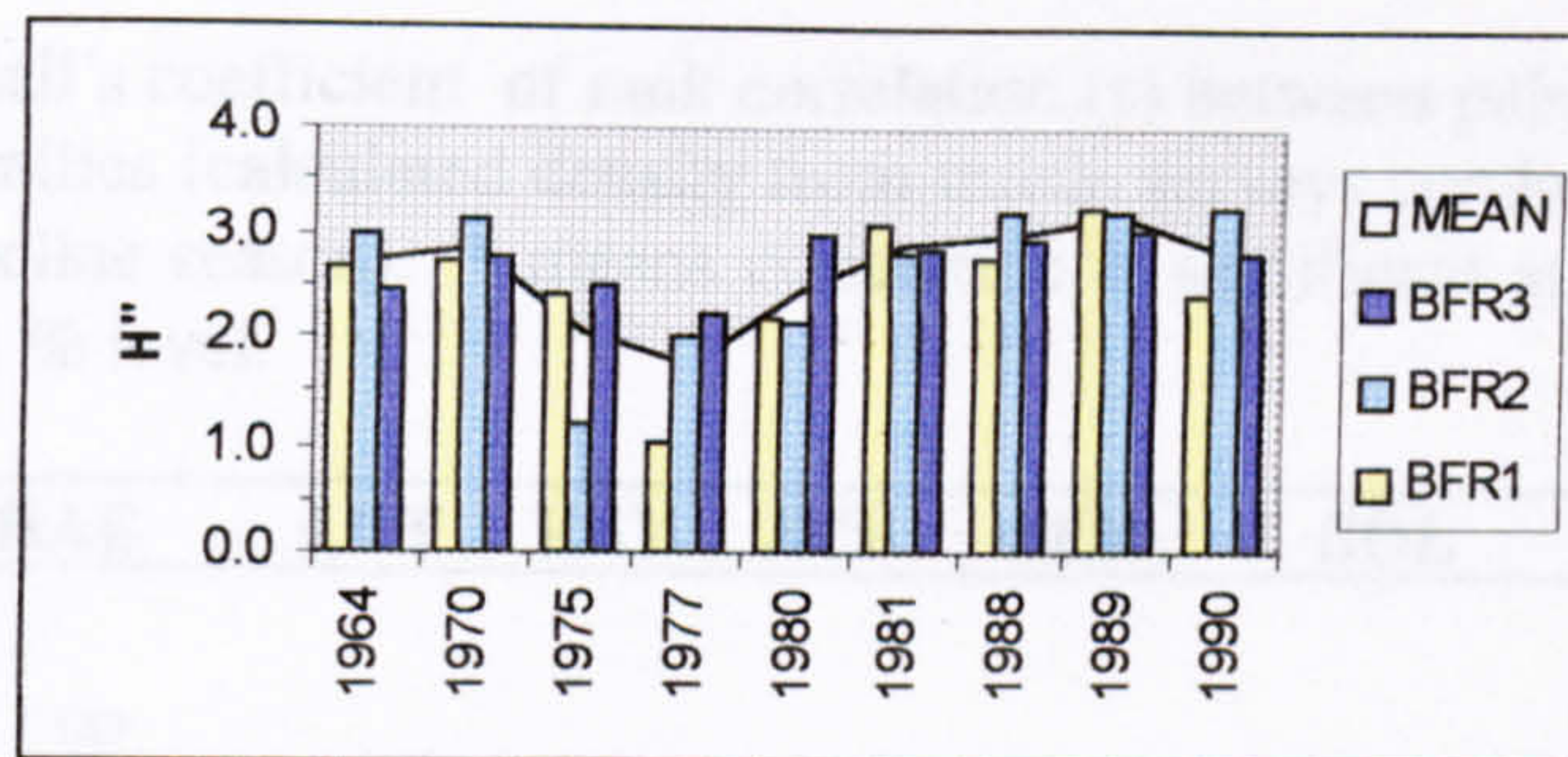


Figure 5.2: Calculated values of Shannon Diversity Index (thermocline season only)

Table 5.1. Calculated values of the Shannon Diversity Index, Margalef Richness Index and Pielou Evenness Index

| Year | Shannon Diversity Index |      |      |      | Margalef Richness Index |       |      |       | Pielou Evenness Index |      |      |      |
|------|-------------------------|------|------|------|-------------------------|-------|------|-------|-----------------------|------|------|------|
|      | BFR1                    | BFR2 | BFR3 | Mean | BFR1                    | BFR2  | BFR3 | Mean  | BFR1                  | BFR2 | BFR3 | Mean |
| 1964 | 2.67                    | 2.97 | 2.43 | 2.69 | 17.41                   | 14.84 | 8.25 | 13.50 | 0.53                  | 0.61 | 0.56 | 0.57 |
| 1970 | 2.71                    | 3.11 | 2.75 | 2.86 | 7.04                    | 10.11 | 5.69 | 7.61  | 0.74                  | 0.71 | 0.71 | 0.72 |
| 1975 | 2.40                    | 1.20 | 2.49 | 2.03 | 7.74                    | 6.15  | 7.62 | 7.17  | 0.64                  | 0.31 | 0.61 | 0.52 |
| 1977 | 1.01                    | 1.98 | 2.22 | 1.74 | 8.10                    | 10.06 | 9.25 | 9.14  | 0.24                  | 0.45 | 0.51 | 0.40 |
| 1980 | 2.16                    | 2.14 | 2.97 | 2.42 | 8.49                    | 10.48 | 8.33 | 9.10  | 0.52                  | 0.46 | 0.71 | 0.56 |
| 1981 | 3.07                    | 2.78 | 2.85 | 2.90 | 8.24                    | 8.41  | 8.68 | 8.44  | 0.74                  | 0.66 | 0.65 | 0.69 |
| 1988 | 2.75                    | 3.20 | 2.92 | 2.96 | 10.41                   | 10.12 | 8.09 | 9.54  | 0.62                  | 0.72 | 0.68 | 0.67 |
| 1989 | 3.24                    | 3.19 | 3.01 | 3.15 | 9.80                    | 9.01  | 7.83 | 8.88  | 0.75                  | 0.76 | 0.72 | 0.74 |
| 1990 | 2.40                    | 3.23 | 2.82 | 2.82 | 6.03                    | 10.57 | 7.75 | 8.12  | 0.66                  | 0.75 | 0.69 | 0.70 |
| ETB1 | 2.69                    | 3.04 | 2.59 | 2.77 | 12.23                   | 12.47 | 6.97 | 10.56 | 0.64                  | 0.66 | 0.64 | 0.65 |
| ETB2 | 2.16                    | 2.03 | 2.63 | 2.27 | 8.14                    | 8.77  | 8.47 | 8.46  | 0.54                  | 0.47 | 0.62 | 0.54 |
| ETB3 | 2.80                    | 3.21 | 2.92 | 2.98 | 8.75                    | 9.90  | 7.89 | 8.85  | 0.68                  | 0.74 | 0.70 | 0.71 |



Table 5.2. Kendall's coefficient of rank correlation ( $\tau$ ) between pairs of species and families (calculated density from trawls surveys conducted during thermocline season). \* means correlation is significant at 5 % level; \*\* at 1 % level.

|     | BAL    | HAE    | LUT   | RAY   | SCI   | SER    | SOL    | SPA    | CEP  |
|-----|--------|--------|-------|-------|-------|--------|--------|--------|------|
| BAL | 1.00   |        |       |       |       |        |        |        |      |
| HAE | -0.01  | 1.00   |       |       |       |        |        |        |      |
| LUT | 0.12   | 0.20   | 1.00  |       |       |        |        |        |      |
| RAY | -0.31* | -0.01  | -0.12 | 1.00  |       |        |        |        |      |
| SCI | -0.11  | 0.38** | -0.13 | 0.17  | 1.00  |        |        |        |      |
| SER | 0.12   | 0.10   | -0.01 | -0.06 | 0.23  | 1.00   |        |        |      |
| SOL | -0.05  | 0.04   | 0.06  | -0.11 | 0.06  | -0.16  | 1.00   |        |      |
| SPA | 0.06   | 0.18   | 0.05  | -0.08 | 0.28* | 0.50** | -0.04  | 1.00   |      |
| CEP | -0.09  | -0.03  | 0.07  | -0.03 | 0.03  | 0.02   | 0.50** | -0.36* | 1.00 |

### 5.3.2.2 Calculated densities in the BFRs

Figures 5.3.1 - 5.3.11 are bar graphs of calculated density (in  $\text{kg ha}^{-1}$ ) of sciaenids, lutjanids, sparids and other selected families of fishes in each BFR. In Figure 5.3.2, 'demersal' represents total demersal species excluding *Balistes capriscus*. The figures exhibit different patterns of change within the BFRs and between families. Whereas some groups of species like Cephalopods increased in density in all BFRs throughout the period, others (e.g. snappers, rays) exhibited different trends in the three bathymetric frames.

In each BFR, the average density of lutjanids, sciaenids, sparids and triggerfish were graphed in a pie chart (Figures 5.4.1 - 5.4.9). Each pie chart shows the percentage contribution of each group to the total density of the 4 groups only. The other species were ignored in these comparisons. There is one pie diagram for each ETP and BFR. These pie charts also display significant shifts in importance of the various groups between the environmental time blocks and depth zones.



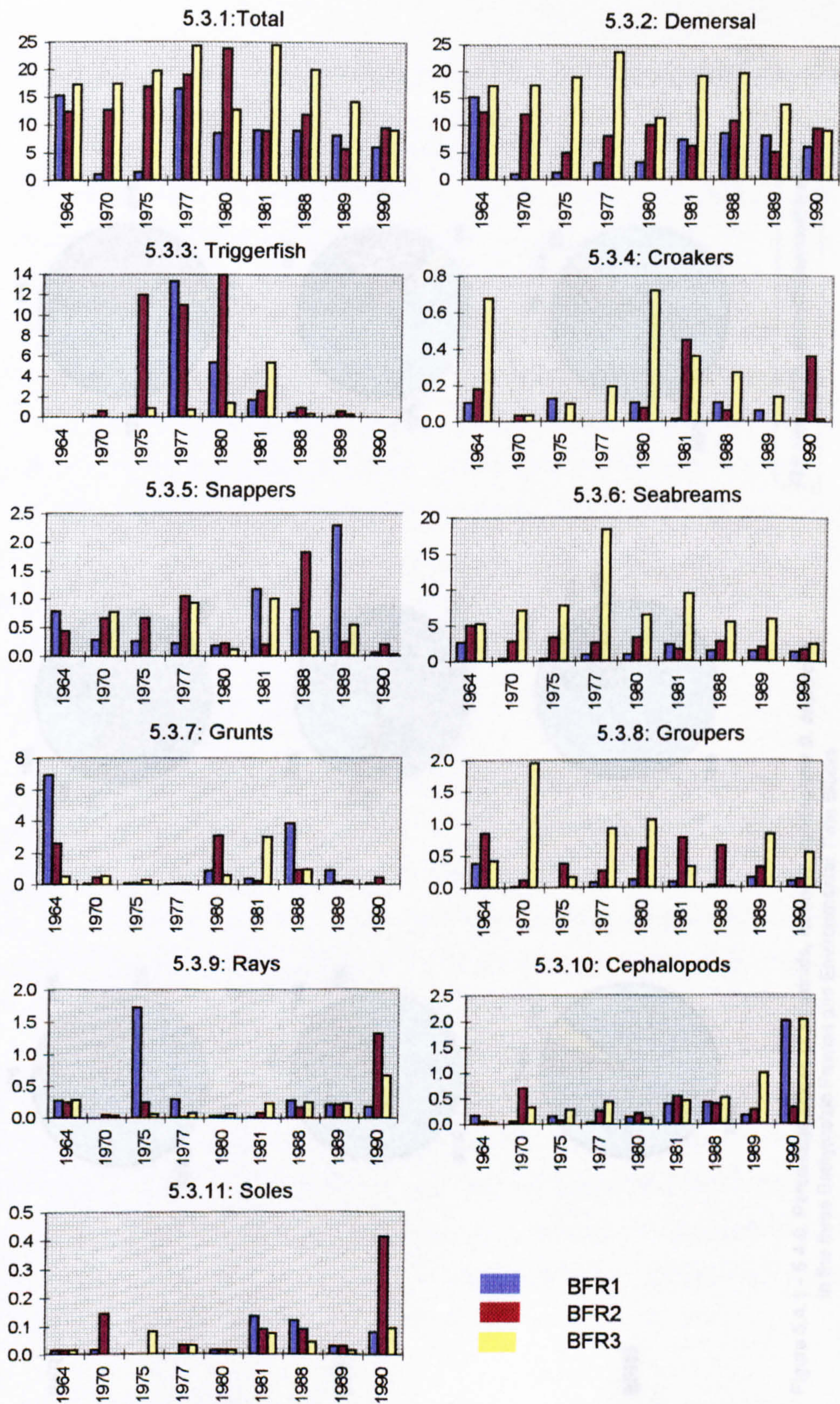
## 5.4 DISCUSSION

### 5.4.1 *Assemblage Frame of Reference and dynamics of species assemblages*

The results show that between 1964 and 1990, the structure of species assemblages on the inner to mid-continental shelf of Ghana underwent significant change; from relatively identifiable groupings during ETB1, through apparently inseparable assemblages (especially between the lutjanid and sparid assemblages) during ETB2 to a situation where the assemblages become identifiable again in ETB3. It is postulated here that the difference in assemblage structure is due mainly to the change in the ecosystem. As has been shown in chapter 3, 1972 marked the beginning of a period of relatively low temperature in the Gulf of Guinea maritime waters, a period that was also characterised by a rise in both coastal (surface) and bottom water salinity and dissolved oxygen. In 1972, the stock of *Sardinella aurita* in this ecosystem was heavily exploited and the resource severely depleted over the five ensuing years (chapter 2). Just before 1972, the proliferation of the population of *Balistes capriscus* in this ecosystem began. It appears then that these three events conjointly or singly affected the nature of species assemblages in Ghana's coastal waters.

Although it is difficult to tell which was the principal cause of the change, it is hypothesized here that the explosion of biomass of triggerfish, *Balistes capriscus* is a significant factor. It appears that the assemblages - especially the lutjanid and sparid - were destabilised with the advent of the triggerfish - a species that appears to have 'shared' the biotopes of the two assemblages, especially the lutjanid. With the decline of the triggerfish, which coincided with an overall lowering plus rapid seasonal fluctuations in salinity (chapter 3), the two assemblages appear to have re-established themselves. However, it cannot be said with certainty whether the system was returning, or had already returned, to its original state.





Figures 5.3.1 - 5.3.11. Calculated density ( $\text{kg ha}^{-1}$ ) of selected fish in the three Bathymetric Frames of Reference



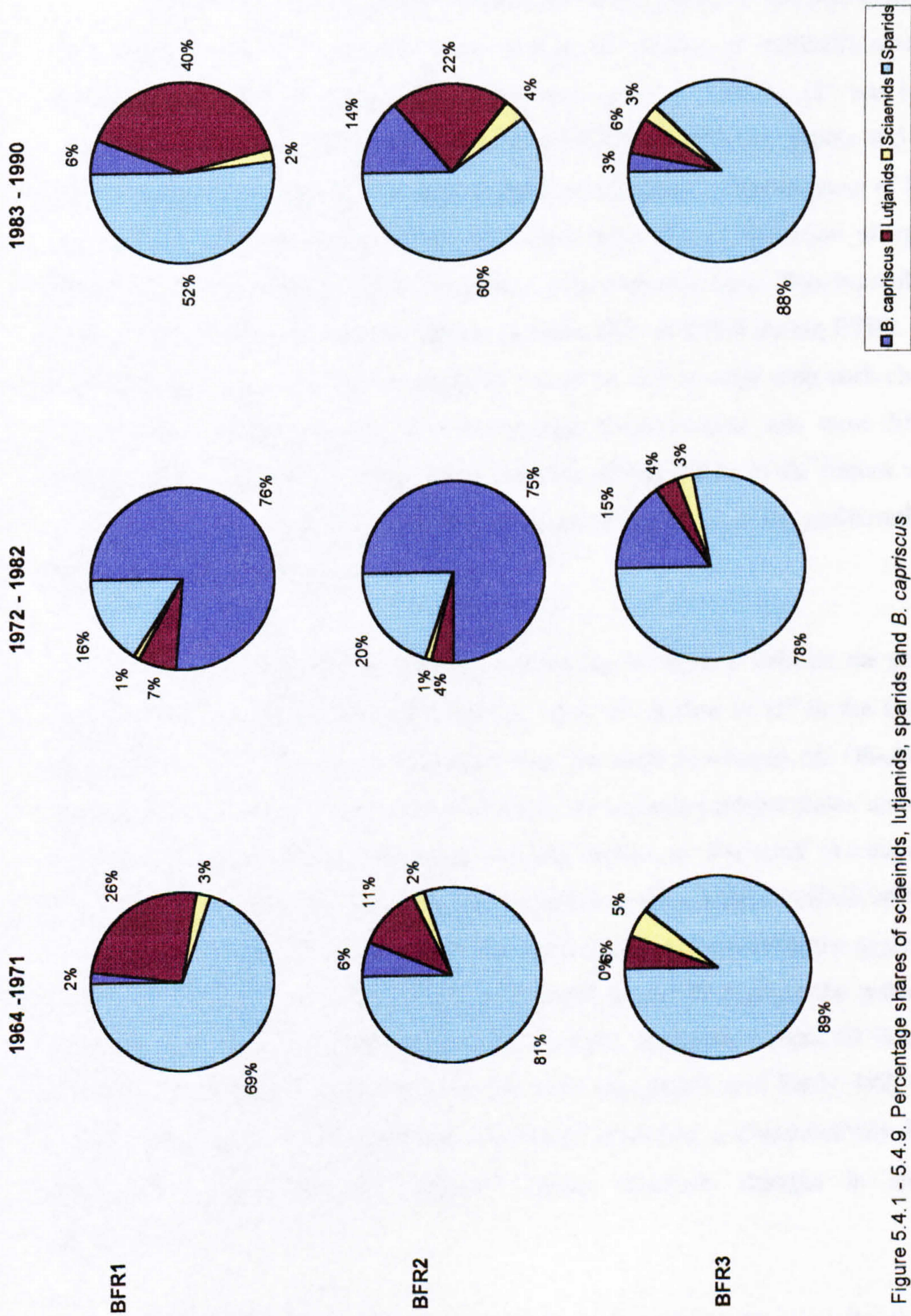


Figure 5.4.1 - 5.4.9. Percentage shares of sciaenids, lutjanids, sparids and *B. capriscus* in the three Bathymetric Frames and Environmental Time Blocks.



#### **5.4.2 Spatio-temporal variability of species diversity on Ghana's shelf**

The pattern of change of the Shannon Diversity Index,  $H''$  reflects changes in the ecosystem relating to environmental change, the decline of sardinella resources and the proliferation of triggerfish. In the first and second BFRs,  $H''$  was lowest during the second environmental time block (ETB2). In BFR3 (i.e. depths of 51-100 m)  $H''$  increased throughout the period under investigation. The increase of  $H''$  in this frame, especially during ETB2, may have been due to migration of species predominantly from BFR2 which has quite similar sediment type. This is confirmed by the corresponding increase in species richness ( $R_1$ ) in BFR3 during ETB2. Fish with preference for such type of sediment would be able to cope with such change. This situation further explains why assemblage discrimination was most difficult during ETB2. The drastic reduction of evenness during ETB2 in the frames where triggerfish initially occupied is a further evidence of the effect of the proliferation of the species on the ecosystem.

It has been argued that diversity indices can be used to indicate the general 'health' of an ecosystem (Magurran 1991); thus the decline in  $H''$  in the early to mid-1970s can be seen as an indication that the shelf ecosystem off Ghana was stressed at that time. The stress may be due to the declining temperatures, increased salinities, changes in other near-shore forcing factors as discussed in chapter 3, increased exploitation, the 'invasion' of triggerfish or the combined effects of these. The invasion of triggerfish is perhaps a more likely cause considering the aggressive behaviour of the species. The species proliferated almost throughout the waters off West Africa in mid-1970s, and was thought to have constituted about 50 % of the demersal fish biomass in the area at that time (Longhurst and Pauly 1987). A biomass change of such magnitude, especially involving a comparatively hardy species like triggerfish, can certainly induce structural changes in species assemblages.

Some factors that could influence the results of the analyses are the limited number of hauls, changes in sampling design and differences in the performance of

the various vessels used in the surveys (also see chapter 6). The use of weight in the Shannon Diversity Index potentially underestimates the effects of small-sized species. But as Wilhm (1968) points out, weight does not influence the results because the index is dimensionless but different values would be obtained. However, one would expect that differences in catchability of the various trawls used in the surveys could be an important source of variation (Fowler and McGlade 1987). As indicated in Table 6.2, all the trawl nets used in the surveys had a mesh size of 40 mm in the codend, except the Guinea 90 net which had a mesh of 45 mm. Thus the effect of differential catchability on the diversity values would be minimised. However, this factor could equally affect diversity indices calculated with numbers instead of weight.

#### **5.4.3 *Calculated densities in the Bathymetric Frames of Reference (BFR)***

During the Guinean Trawling Survey (GTS), the calculated total density of demersal fishes (including triggerfish) were 15.2, 12.3 and 17.0 kg ha<sup>-1</sup> in BFR1, BFR2 and BFR3 respectively (Figures 5.3.1). This means that the yield of demersal fish in each BFR was quite substantial. Between 1970 and 1975, an extremely low total density was observed in the shallowest frame (BFR1). In Figure 5.3.2 (which shows total demersal species excluding triggerfish), a similar picture is seen whereby catch rates in BFR1 are lowered drastically in the early to mid-1970s. The increased density in 1977 in all BFRs was due mainly to the increased abundance of triggerfish (Figure 5.3.3).

These figures show that the first two bathymetric frames are most vulnerable to changes: these could equally have been caused by fishing, environmental or other near-shore forcing factors. Longhurst and Pauly (1987) drew attention to the evidence that attributed major changes in the composition of demersal fish stocks off West Africa in the 1960s to heavy exploitation by fleets of small trawlers.

Figure 5.3.3 clearly portrays the advent and evolution of triggerfish in this ecosystem: the impact of this immigration becomes evident in the data set from 1975.

In this data set, *B. capriscus* dominates the second bathymetric frame, which hitherto was the approximate area occupied by the lutjanid assemblage. In the next six years, triggerfish extends to the other two BFRs, especially the 10-30 m zone. Longhurst and Pauly (1987) noted that in the whole area from Senegal to Nigeria, the species occupied “what used to be the biotope of the sciaenid community”.

The possible impacts of the explosion of triggerfish and environmental changes on the principal families and species of fish in the three assemblages are discussed below.

Sciaenidae: Figure 5.3.4 shows quite dramatic changes in the trend of density of sciaenids. Generally, the density of sciaenids was reduced in the 1970s (from a total of about 1 kg ha<sup>-1</sup> in all bathymetric frames during GTS to less than 0.01 kg ha<sup>-1</sup> in 1970). Gulland and Garcia (1984) showed that the decrease in temperature, river discharge and increase in salinity during the early 1970s, as have been described in chapter 3, may have reduced the carrying capacity of the area for warm water, low salinity sciaenid community. The virtual disappearance of sciaenids from GFR2 (and also from GRF 1 in 1977) appears to confirm the results of the AFR analysis where assemblage discrimination was extremely difficult during the second environmental time block (ETB2). An apparent recovery is seen in the early to mid-1980s.

The high density of the family in BFR3 (i.e. 51-100 m) is quite striking, given that sciaenids are thought to be mainly found in shallow waters. This is due to the fact that some genera and species in this family (e.g. *Argyrosomus* sp. and *Pentheroscion mbizi*) are deep water species which may be found in habitat as deep as 350 m (Schneider 1990). These tend to be large individuals, the weight of which could influence the results.

Lutjanidae: *Lutjanus* sp. and *Lethrinus atlanticus* make up this family. The species remained in BFR2 throughout the period under consideration, although the density reduced during the peak of the *Balistes* era, especially in the early 1980s. This confirms the observation in chapter 4 about the occurrences of *Lutjanus* spp. and *Balistes capriscus* in the derived assemblages. The substantial increase of the



density of the lutjanids in BFR1 and BFR2 in 1988 - 1989 may be seen as a 're-colonization' of these areas resulting from the sharp decline in abundance of triggerfish. In the GTS, lutjanids were recorded mainly in inshore waters (i.e. in BFR1 and BFR2).

Sparidae: As a group, the sparids are consistently present in all BFRs on the continental shelf off Ghana, especially in waters deeper than 50 m (Figure 5.3.6). The high density of the family in the mid 1970s (Figure 5.3.6) is a significant occurrence. Gulland and Garcia (1984) noted that the 'new' low temperature, increased salinity environment that prevailed in the Gulf of Guinea during ETB2, is suitable for the cool water, high salinity sparid community. *B. capriscus* belongs to this community (chapter 4; Longhurst 1969). However, the gradual reduction of the total density of Sparidae in all depth zones is observable between 1977 (peak period of density) and 1990; this may be attributable mainly to fishing but perhaps also to a reversal of the environmental conditions which also could have contributed to the decline of the triggerfish biomass.

Other Families: The Haemulidae (grunts), made up mainly of *Brachydeuterus auritus*, *Pomadasys incisus* and *Pomadasys jubelini* exhibit pulsation in total abundance (Figure 5.3.7). Obviously this behaviour is influenced by *B. auritus*, a semi-pelagic species which is occasionally caught in extremely large quantities, especially in coastal waters. With a total density of 10 kg ha<sup>-1</sup> in all three bathymetric frames (65 % of total weight in BFR1) during GTS, the yield stays lower than this for a decade and a half. In early to mid-1980s, high yields are obtained, first in BFR2, BFR3 and finally in BFR1. Low values were recorded during Guinea 90.

The density of serranids (groupers) exhibit a bimodal pattern of change in the period under consideration (Figure 5.3.8). The family is most abundant in waters deeper than 30 m. The other families, namely rays, cephalopods and soles, portray an underlying rising trend in density within the period under consideration (1964-1990). The significantly high density of these families in Guinea 90 is noteworthy; cephalopods in BFR1 and BFR3 and the other two in BFR2.

The analyses presented in these sections have treated each family as an entity and trends in overall density have been portrayed. However, the various species in each family could have acted differently from the group behaviour as a result of possible differences in response to environmental changes and other factors, and also to differential reaction to fishing gear. Consequently, the density of individual species could have undergone a pattern of change different from the family response pattern described here.

#### **5.4.4 Relative importance of selected families in the BFRs**

The pie charts (Figures 5.4.1 - 5.4.9) portray interesting changes in the assemblages over the 26 years of observations and within the three environmental time blocks (ETB). The situation in each BFR is elaborated below.

##### **BFR 1**

In the first Bathymetric frame (BFR1), Sparidae account for 69 % of the total density recorded for the three families and *Balistes capriscus* in the first environmental time block, ETB1 (i.e. before 1972). This is followed by Lutjanidae (26 %), Sciaenidae (3 %) and *B. capriscus* (2 %). In the second time block (1972 - 1982) when the population of *B. capriscus* increased in this ecosystem, the contribution of Sparidae in this frame reduced drastically to only 16 %; Lutjanidae account for 7 % and *B. capriscus* has 76 %. By ETB3 (1983 - 1990), when the balistes stock declined, sparids increase their share to 52 %, lutjanids to 40 %, *B. capriscus* to 4 % and sciaenids to 2 %.

##### **BFR 2**

In this depth range (31 - 50 m), the share of all three families is reduced considerably from the first ETB to the second (81 to 20 % for sparids; 11 to 4 % for lutjanids and 2 to 1 % for sciaenids). On the other hand *B. capriscus* increases its share from 6 to 75 %. By the third ETB (1982- 1990), the situation changes to become similar to that in ETB1, with the share of *B. capriscus* substantially reduced and that of the other families increased. Also in this frame, only sparidae correlate

significantly (and also positively) with *B. capriscus*. sciaenids correlate negatively, although this is not significant at the 5 % level.

### BFR 3

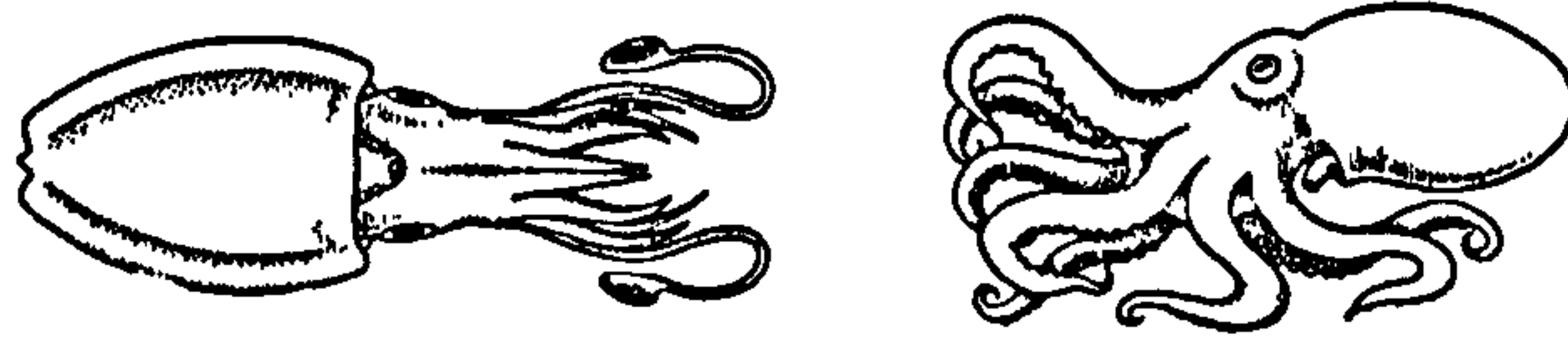
In this frame, the effect of *B. capriscus* is least shown. The species increases its share from 0 % in the first ETB to 15 % in the second. The contributions of the three families change only slightly to accommodate this modest rise and subsequent decline of triggerfish. *B. capriscus* also correlates positively and significantly ( $p < 0.05$ ) with Sparidae in this sector.

The information contained in the pie charts and as described above, support or confirm the results obtained in the analysis using the Assemblage Frame of Reference, including the theory that the proliferation of *B. capriscus* seriously disrupted the assemblage structure and behaviour. Towards the end of the observational period when the species had almost vanished from this ecosystem, the assemblages were looking similar to those in the pre-balistes era. However, it is uncertain whether the system was returning or had already returned to its original or 'natural' state.

Table 5.2 which gives the Kendall's coefficient of rank correlation ( $\tau$ ) between pairs of families and species considering the entire data sets (i.e. ignoring frames) also portrays other important relationships in the density data. The correlations between triggerfish and the other families are of special interest. This correlation is negative within all families except lutjanids, serranids and sparids and with rays this is significant at 5 % level. The latter relationship explains the substantial increase in the abundance of rays during ETB3 when the triggerfish had declined (Figure 5.3). There is also a significant negative correlation between Sparidae and Cephalopods which confirms the predator-prey relationship that exists between the two families (Pareiro and Bravo de Laguna 1980; Gulland and Garcia 1984). Sparidae are known to prey on the eggs of Cephalopods (especially *Sepia* sp.) (Pauly 1988), thus an increase in the biomass of Sparidae is likely to lead to a decrease in the biomass of Cephalopods and vice versa. Figures 5.3.6 and 5.3.11 are



consistent with this relationship. The significant positive correlation between serranids and sparids and between soles and cephalopods is also noteworthy.



## CHAPTER SIX:

# DEMERSAL FISHERY STOCKS IN SHELF WATERS OFF GHANA: THEIR ABUNDANCE AND EXPLOITATION

*"A population [of people] can be counted;  
but who knows how many fishes are in the sea?  
And yet it appears to me a project big with possibility.....".*

Hjort 1907



## Chapter Summary

Between 1963 and 1990, the abundance of demersal fishery stocks in Ghana's shelf waters underwent significant change whereby relative importance of major species altered in every trawl survey conducted in the area.

The assessed density of total demersal biomass (excluding triggerfish) decreased from 50 kg ha<sup>-1</sup> in 1963-64 to 32.4 kg ha<sup>-1</sup> in 1990. The lowest density of 22.5 kg ha<sup>-1</sup> occurred between 1973 and 1977. The potential yield of the demersal stock is estimated to be within 36,000 - 55,000 mt per annum and except in a few years, landed catches were either too close to the upper limit of the potential yield or exceeded it. Consequently, catch per unit effort declined, especially in the period after 1977.

*Balistes capriscus* dominated this ecosystem for nearly twenty years (from early 1970s to late 1980s) displacing *Brachydeuterus auritus* as the most abundant species. The abundance of the species was high between 1973 and 1982, reaching a value of 28 kg ha<sup>-1</sup> in the area between 30 and 50 m deep. The abundance declined and by 1990, the species had virtually disappeared from the study area. In the period of decline of *B. capriscus*, the abundance of rays, soles and cuttlefish increased.

The maximum sustainable yield of the present industrial shrimp fishery is estimated at about 350 mt annually. Although annual landed catch of the shrimping fleet is less than this figure, the low shrimp-to-fin-fish catch ratio, the high volume of discards (made up mainly of juvenile demersal fish) and the general destruction of the inshore habitat by shrimp vessels, call for stringent management measures in respect of this fishery.

## 6.1 INTRODUCTION

The stock assessment surveys that have been conducted on demersal fishery resources on the continental shelf and upper slope off Ghana have been reviewed in chapter 1. The objectives of these surveys included the following:

- i. exploration of the continental shelf for potential development of a trawl fishery (Salzen 1957),
- ii. estimation of total biomass and catch rates (Rijavec 1980; Koranteng 1981, 1984),

- iii. monitoring the biomass of fish stocks (Koranteng 1981, 1984),
- iv. collection of biological data on species of scientific and/or commercial importance (Williams 1968; Rijavec 1980), and
- v. collection of data on the marine environment (Williams 1968; Rijavec 1980; Koranteng 1981, 1984).

In spite of these laudable objectives, these surveys (Appendix 6.1 and van der Knaap 1985) have not resulted in any pragmatic policies for the management of the demersal fisheries in Ghana's shelf waters (Koranteng 1996). One reason for this situation is that only a few of the surveys have been exhaustively analysed and the reports readily available. As a result, knowledge of the resources, especially the potential yield, is still incomplete.

The fishing gear used in these surveys was unable to sample shrimps resources as well as desirable. Thus, even though a specialised fishery for shrimps has developed in Ghana in the last decade, the status of the exploited resource is also not well known. The last quantitative assessment of shrimp resources in Ghanaian waters was in 1969-70 (Jones 1970) which was before the collapse of an earlier shrimp fishery in the study area.

In fulfilment of the responsibility of Ghana as a fishing nation, the Fisheries Department collects records on all activities of Ghanaian fishing vessels fishing both at home and in foreign waters. There is a scheme in place for assessing fish catches that are made in Ghana's exclusive economic zone by canoes, inshore and registered industrial fishing vessels. Most of the fish landed in the nation's ports and harbours and at fishing villages is enumerated. Unauthorised catches (e.g. by poachers) are not accounted for in this scheme. In addition to providing the required statistics for the purposes of planning and investment, it is intended that the collected statistics be used to assess the rate of exploitation of the fish resources in order to ensure that they are exploited sustainably. Nevertheless, there appears to be a mismatch between total landings and the potential that demersal fish resources in Ghana's shelf waters can provide. The result is an apparent over-exploitation of the resources due to



overcapitalisation and inappropriate fishing practices

### **6.1.1 Objectives**

As a result of the observed changes in the structure and dynamics of the principal species assemblages on the continental shelf and upper slope off Ghana (chapters 4 and 5), the following questions can be asked:

- i. What is the effect of the upwelling and other forms of environmental forcing on demersal fish stocks?
- ii. Have the distribution and abundance of species changed since the Guinean Trawling survey 35 years ago?
- iii. If there is a change, is it reflected in the quantity and species composition of catches made by the commercial fishery?
- iv. What is the level of exploitation of the demersal fishery resources?
- v. What is the current status of these resources?

These questions are dealt with in this chapter. A detailed quantitative analysis of the bottom trawl surveys that have been conducted in Ghana's coastal waters, is undertaken. Also examined are data on landings and effort of the commercial fishery associated with the exploitation of these resources. The specific objectives of the analyses are:

- a. to assess the present state of the demersal fishery resources (including shrimps) on Ghana's continental shelf and upper slope,
- b. to establish the factors that may be responsible for changes in the distribution and abundance of the fish over the period of investigation,
- c. to assess the effects of the upwelling and other forms of environmental forcing, and long-term exploitation on the abundance and species composition of demersal fish stocks in Ghana's coastal waters, and
- d. to assess the level of exploitation.

Stock is used here to mean an exploited fish population (also see section

4.1.2) and the unit stock considered here follows the definition of Hilborn and Walters (1992), that is “.. a homogeneous collection of fish that are subjected to the same opportunities for growth and reproduction and the same risk of natural and fishing mortality”. It is further assumed that the fish populations in Ghana’s shelf waters could be considered as a unit for management purposes.

All available data collected during stock assessment surveys conducted in the study area between 1963 and 1992 are re-analysed using the same methods. This will help to discern trends and variability in abundance of demersal species within the period under study (1963 - 1992). The surveys include those conducted by the Marine Fisheries Research Division and also by international agencies (e.g. the Guinean Trawling Survey and the Guinea 90 survey).

In addition the available statistics of demersal fish catches from this ecosystem are examined with a view to assessing the level of exploitation and comparing this with the potential that the resource is capable of providing sustainably.

In this chapter ‘demersal’ refers to all true demersal (i.e. bottom-dwelling) species of fin-fish, molluscs and crustaceans, and semi-pelagic species such as *Balistes capriscus* and *Brachydeuterus auritus* that are caught mainly in bottom trawls (also see chapter 4, section 4.1.3).



## **6.2 STOCK ASSESSMENT BY TRAWL SURVEYS - THEORY AND PRACTICE WITH EMPHASIS ON SURVEYS IN GHANAIAN WATERS**

### ***6.2.1 Survey designs, sampling procedures and data collection***

The stock assessment surveys considered in this work are described in Table 6.1. These are the surveys for which the data were available for re-analysis. The table also includes explanation of the sampling design and methods used in the surveys.

The sampling procedures were almost identical in all the surveys. When the vessel arrives at a sampling station, the net is shot at a pre-determined depth (in the case of the systematic surveys) or the depth and trawling direction are chosen at random (in the case of the stratified random surveys). Depth of tow is determined by an echo sounder, and the average between the depth at start and end of the haul is taken as the depth of the station sampled.

The duration of a survey haul is the elapsed time between engagement of the brakes on the trawl winch drum when the net and bridles have been paid out, and subsequent release of the brakes to commence hauling in of the net. The planned duration was one hour in the GTS and MFRD surveys of 1969-1980, and thirty minutes in the later MFRD surveys and in the Guinea 90 survey. Sometimes towing is discontinued because the net gets stuck to the bottom or a trawl door hits a rock. If trawling has been done for at least 50 % of the planned time (i.e. 30 min in the GTS and 1969-70 MFRD surveys or 15 min in the 1979-92 MFRD and Guinea-90 surveys) and the net is not damaged to the extent that its performance would be affected, then the haul is taken. Otherwise, the haul is ignored and most often repeated. All such hauls that were not repeated are excluded from this work.

Table 6.1: Description of the trawl surveys used in this thesis, their design and methodology used.

| Survey            | Description  |
|-------------------|--|
| GTS<br>1963-1964  | <p>In the design of the Guinean Trawling Survey there were 63 transects spaced 40 miles (64.4 km) apart. Seven of the transects (numbers 27 - 33) were located in Ghanaian waters (Appendix 6.2). There were eight sampling stations on each transect located at depths of 15-20, 30, 40, 50, 70-75, 100, 200 and 400-600 m. Thus the survey followed a systematic design with hauls taken at pre-determined depths.</p> <p>GTS was in two phases, GUINEAN I (conducted between September and December 1963) and GUINEAN II (conducted in February to May 1964). Two vessels were used concurrently and four transects off Ghana (numbers 29 - 32) were fished simultaneously by both vessels for the purpose of comparing their performance. In the data presented in the reports (Williams 1968) the catches made by the two vessels during the simultaneous fishing in Ghanaian waters have been accounted for.</p>   |
| MFRD 1<br>1969-70 | <p>A systematic sampling design (Figure 6.3) was used in the MFRD surveys conducted between 1969 and 1980 and using the survey vessel <i>R/V 1</i>. In this design, there were five inshore-offshore transects placed at uneven intervals from one another and covering the shelf area of Ghana between 18 and 100 m deep. There were 21 stations on 5 transects.</p> <p>Seven survey cruises were undertaken in 1969 - 1970 (Rijavec 1980). Additional monthly cruises were made to sample stations on the Tema transect. All 184 hauls used here were made during daylight hours and each lasted for 1 hour. The net was always towed from west to east (i.e. against the Guinea Under Current (Figure 2.2) and trawling at about 3 knots (5.6 km hr<sup>-1</sup>).</p> <p>The original log sheets for this survey could not be located, hence the relevant data were extracted from the survey report (Rijavec 1980) in which catch data were presented as percentages.</p> |



Table 6.1 continued

|                    |  |
|--------------------|--|
| MFRD 1B<br>1973-77 | A number of survey cruises were undertaken with <i>R/V 1</i> during 1973 - 77. The survey design was basically that of the 1969 - 70 survey but with some modification in the station location and numbering. A total of 152 hauls were included in the data base for these years.   |
| MFRD 2<br>1979-80  | These were the first cruises made with the then newly-acquired fisheries research vessel " <i>R/V Kakadiamaa</i> " (or <i>R/V 5</i> ). The methodology and survey design followed those of the 1973-77 survey. A total of 149 trawl hauls were included in the analysis.   |
| MFRD A<br>1980     | <p>From August 1980, a new sampling design was introduced for the MFRD surveys (Appendix 6.4). In this design, the survey area is bounded by the 1° 10' E and 3° W longitudes and the 15 and 75 m depth contours. The area is divided into 3 zones (E, C and W), 9 strata (I - IX), 10 sectors (Keta, Add, Tema, Accra, Winneba, Saltpond, Cape Coast, Takoradi, Axim and Half Assini) and 40 stations. The survey area embodies most of the trawlable grounds of the Ghanaian shelf (Longhurst 1963; Rijavec 1980; Koranteng 1984) and forms about 78 % of the total shelf area of Ghana (Everett <i>et al.</i> 1982; Williams 1968). The upper depth limit was 'moved' to 100 m in later surveys. Other design considerations (e.g. criteria for stratification) are given in Koranteng (1980).</p> <p>In the survey plan, a cruise covering the entire survey area was to be undertaken once every three months during which all stations were to be worked. The survey periods were to coincide with the main hydrographic seasons in Ghanaian coastal waters. In addition, 6 stations off Saltpond (designated as the reference sector for the new trawl survey programme) were to be worked each month. All hauls were to be made during daylight hours (i.e. 0600 - 1800 hours GMT) and a trawling speed of about 3 knots (5.56 km hr<sup>-1</sup>) was to be used.</p> <p>In August 1980, the new survey programme was started, but it had to be discontinued because of breakdown of vital equipment on the vessel after the first cruise. 35 hauls, each of 30 minutes duration had been made.</p> |

Table 6.1 continued

|                   |   |
|-------------------|---|
| MFRD 3<br>1981-82 | This survey was carried out between April 1981 and April 1982 and followed the design of the previous survey. Seven monthly sampling cruises were taken in the Saltpond sector in addition to the 4 cruises made in all 10 sectors. 178 hauls from this survey have been used in this thesis.   |
| MFRD B<br>1983-84 | In 1983-84, only occasional monthly surveys off Saltpond could be conducted. This is because the MFRD trawl survey programme was beset with technical and operational problems at the time. Planned surveys could not be conducted and only 4-6 hauls were made each month between August, 1983 and December, 1984. A total of 31 hauls were made during this period.   |
| MFRD 4<br>1987-88 | From the same design, 4 quarterly surveys in all ten sectors were conducted between July, 1987 and November, 1988. These were interspersed with monthly surveys in the Saltpond sector. A total of 181 hauls from these years are included in the database.   |
| MFRD 5<br>1989    | 152 hauls were made between February and December 1989. 3 complete cruises were undertaken together with some monthly ones off Saltpond. The 4th cruise of the programme was abandoned following a breakdown of some equipment on the vessel and after 13 stations in the Keta to Accra sectors had been worked.  |
| MFRD 6<br>1990    | Three complete cruises and 3 monthly ones off Saltpond were undertaken in this programme which covered the period June-November, 1990. The programme could not be completed as planned.   |
| MFRD 7<br>1991-92 | As <i>R/V 5</i> was getting old and was beset with numerous technical problems the trawl survey programme was seriously affected. Between February 1991 and November 1992, 41 trawl hauls were made off Accra, which for operational reasons had been designated the reference sector instead of Saltpond. The data from this survey have not been used in this thesis. |



Table 6.1 continued

|                  |  |
|------------------|--|
| GUNEA-90<br>1990 | The Guinea-90 survey followed a systematic sampling design with variable distances between the transects. There were 27 transects between Sierra Leone and Ghana and 6 of these (Transects 21-26) were in Ghanaian waters (Appendix 6.5). The transects off Ghana were 50 nautical miles apart. The others were 22, 33 and 55 nautical miles apart for Sierra Leone west, Sierra Leone east-Liberia and Côte d'Ivoire sectors respectively. The depth ranges sampled off Ghana were 20-50 m, 50-100 m and 100 or more (Ramos <i>et al.</i> 1990). Trawl hauls were of 30 minutes duration and taken only during the day. <i>R/V Lagoapesca</i> made 29 successful hauls in Ghanaian waters in April 1990). |
|------------------|--|

After the net has been hauled in, the catch is sorted according to species. Each species is weighed separately. When the catch is too large, sub-samples are taken and weighed and the total catch extrapolated from the weighed samples. Catches from hauls that were discontinued are raised to catch per standard haul. In all cases, no adjustments were made to the data to account for differences in catchability among species.

In the MFRD surveys, the species are identified according to Blache *et al.* (1970), Fischer *et al.* (1981) and Schneider (1990). Species names used in the GTS survey conform to entries in Blach *et al.* (1970) but other older taxonomic reference books may also have been used.

### **6.2.2 Description of the vessels and fishing gears used in the surveys in Ghana**

The surveys considered in this work were conducted between 1963 and 1990 using five vessels. These are *R/V Thierry* and *R/V La Rafale* (for the GTS), *R/V Research* (or *R/V I*) and *R/V Kakadiamaa* (or *R/V 5*) (used in the MFRD surveys)

and *R/V Lagoapesca* (used in the Guinea 90 survey). *R/V 1* (used between 1969 and 1977) and *R/V 5* (in use since 1979) are dedicated fishery research vessels whereas the others were commercial vessels chartered for the surveys. *R/V Thierry*, *R/V La Rafale* and *R/V Research* were side trawlers, *R/V Kakadiamaa* is a multipurpose vessel that trawls from the stern and *R/V Lagoapesca* is a stern trawler. The principal characteristics of the vessels and the survey gear are given in Table 6.2. It is essential to note that as the vessels are of different designs, sizes, horsepower, they can be expected to have different fishing efficiencies. The two GTS vessels have almost the same specifications.

Similarly, the trawl nets used in the surveys were of different types, designs and sizes. The trawl net used in the GTS was the 'North Sea type' with 'Vigneron-Dahl' gear designed to give high opening (Williams 1968). It was made of manila netting except the codend which was nylon. In the MFRD surveys of 1969-70, high opening 'Larsen' and 'Engel' trawls constructed with synthetic netting were used. The Larsen net was used in 1969 and the Engel net was used thereafter (Rijavec 1980). The Engel net was sometimes fitted with a pseudo footrope of bobbins. Since 1979, an Engel high-opening net with bobbins is used in the MFRD surveys. Appendix 6.6 shows the design of this net. In the Guinea 90 survey, two types of nets, also constructed from synthetic netting material, were used. Off Ghana, the type I net, which is a 'T-shaped' trawl designed for hard bottoms, was utilized (Ramos *et al.* 1990). The principal specifications of the survey nets are also presented in Table 6.2.



Table 6.2: Specifications of research vessels and fishing gears used in the surveys

| Survey            | Vessel            | Total length (m) | Main Engine (hp) | GRT | Gear          | Codend mesh (mm) | Wing spread (m) | Trawling speed (km hr <sup>-1</sup> ) |
|-------------------|-------------------|------------------|------------------|-----|---------------|------------------|-----------------|---------------------------------------|
| GTS               | <i>Thierry</i>    | 35.0             | 600              | 200 | Vigneron-Dahl | 40               | 16.4            | 6.5                                   |
|                   | <i>La Rafale</i>  | 35.0             | 600              | 230 |               |                  |                 |                                       |
| MFRD<br>1969 - 77 | <i>Research</i>   | 22.4             | 280              | 50  | Larsen        | 40               | 14.4            | 5.6                                   |
|                   |                   |                  |                  |     | Engel 1       | 40               | 16.3            | 5.2                                   |
|                   |                   |                  |                  |     | Engel 2       | 40               | 14.2            | 4.8                                   |
| MFRD<br>1979 - 92 | <i>Kakadiamaa</i> | 29.3             | 700              | 173 | Engel         | 40               | 16.4            | 5.6                                   |
| Guinea 90         | <i>Lagoapesca</i> | 39.4             | 1260             | 475 | Type I        | 45               | 17.16           | 5.6                                   |

### **6.2.3 Estimation of fish abundance index and biomass by the swept area method**

In bottom trawl surveys, the stock biomass is usually estimated by the ‘swept area method’ with catch per haul as the index of abundance. The general formula for calculating fish biomass  $B$  estimated in a trawl survey, using this method is:

$$B = \frac{A}{a} \cdot \frac{\bar{X}}{q} \quad \dots 6.1$$

where  $A$  is the total area surveyed,  $a$  is the swept area of the net per haul (section 6.2.4),  $\bar{X}$  is the average catch per haul (the index of abundance) and  $q$  is the proportion of fish in the path of the net that are actually caught, referred to as the catchability coefficient (section 6.2.5). The density of the resource is calculated as estimated biomass per unit area.

The swept area method makes the following assumptions:

- i. speed of the vessel through the water is the same as that of the net on the seabed and that both vessel and net cover the same distance within the duration of the tow,
- ii. the speed is constant for the duration of the tow,
- iii. the vessel’s movement through the water is not impeded by currents,
- iv. the catch is proportional to area trawled.

The estimation procedures and general properties of the estimator, follow the normal sampling theory with the use of randomization to enable estimation of sampling variance and stratification to minimize this variance hence increase accuracy of the estimate (Cochran 1977; Pennington and Grosslein 1978).  $\bar{X}$  is estimated from

$$\bar{X} = \frac{\sum_{j=1}^n x_j}{n} \quad \dots 6.2$$



where  $x_j$  are the observed catches in each of  $n$  hauls (for each species or the total). In a stratified survey of  $k$  non-overlapping strata, if the mean catch per haul in stratum  $i$  and its variance are denoted by  $\bar{X}_i$  and  $\sigma_i^2$  respectively, then an unbiased estimate of the population mean  $\bar{X}$  is the stratified mean  $\bar{X}_{st}$  which is given by

$$\bar{X}_{st} = \frac{1}{N} \sum_{i=1}^k N_i \bar{X}_i = \sum_{i=1}^k W_i \bar{X}_i \quad \dots 6.3$$

where  $W_i = \frac{N_i}{N}$  is the relative size of the  $i^{\text{th}}$  stratum.  $N_i$  and  $N$  are the size of the stratum and survey area respectively.  $W_i$  could be  $\frac{A_i}{A}$  where  $A_i$  is the area of the  $i^{\text{th}}$  stratum and  $A$  is the total area surveyed ( $A = \sum_{i=1}^k A_i$ ). The variance of the stratified mean is given by

$$\text{var}(\bar{X}_{st}) = \sum_{i=1}^k W_i^2 \text{var} \bar{X}_i \quad \dots 6.4$$

The variance of the simple random sample mean in  $i^{\text{th}}$  stratum is given by

$$\text{var}(\bar{X}_i) = (1 - f_i) \frac{s_i^2}{n_i} \quad \dots 6.5$$

where  $s_i^2$  is an unbiased estimator of  $\sigma_i^2$ ,  $f_i$  is the sampling fraction and  $n_i$  is the number of samples in the  $i^{\text{th}}$  stratum (Barnett 1982). In trawl surveys,  $f_i$  is negligible (Smith and O'Boyle 1985) and equation 6.5 reduces to

$$\text{var}(\bar{X}_i) = \frac{s_i^2}{n_i} \quad \dots 6.6$$

and the variance of the stratified mean becomes

$$\text{var}(\bar{X}_{st}) = \sum_{i=1}^k W_i^2 \frac{s_i^2}{n_i} \quad \dots 6.7$$

The standard error of the estimated stratified mean is given by

$$\text{SE}(\bar{X}_{st}) = \sqrt{\text{var}(\bar{X}_{st})} \quad \dots 6.8$$

(Smith and O'Boyle 1985).

When the survey is post-stratified, then the unbiased estimate of the mean and variance are given by

$$\bar{X}_{\text{pst}} = \sum_{i=1}^k \frac{N_i}{N} \bar{X}_i \quad \dots 6.9$$

$$\text{var}(\bar{X}_{\text{pst}}) = \frac{1}{n} \sum_{i=1}^k \frac{N_i}{N} S_i^2 + \frac{1}{n^2} \sum_{i=1}^k (1 - \frac{N_i}{N}) S_i^2 \quad \dots 6.10$$

where  $n$  is the actual number of total samples taken (Cochran 1977; Fogarty 1985).

The swept area method of fish stock size estimation has been examined by many authors including Gulland (1975); Saville (1977); Clark (1979); Pauly (1980a); Troadec (1980). The method has also been reviewed by Doubleday and Rivard (1981); Stromme (1992) and Sparre and Venema (1992). Statistical aspects of the method have been covered by Grosslein (1971); Gulland (1975) and Fogarty (1985), among others. The choice and accuracy of the estimator of the index of abundance has also been the subject of many studies including that by Pennington and Grosslein (1978) and Somerton and Munro (1996 manuscript).

The distribution of the abundance estimator has been examined by



Pennington (1983, 1986) and others. It has been suggested that since the distribution of catches in a trawl survey tend to be skewed, it may best be described by the delta-distribution (Pennington and Grosslein 1983) or the negative binomial distribution (Taylor 1953; Pielou 1969). If a gaussian (or normal) distribution is assumed, then some variance stabilizing transformations must be applied to the data which usually, also contain many zero data values. The most popular of these is the logarithmic transformation of the form

$$y = \ln (x+c) \quad \dots 6.11$$

where  $x$  is the observed variable (Fogarty 1985; Smith and O'Boyle 1981) and  $c$  is a constant normally set at 1. The mean and standard deviation of the abundance estimator are then calculated in logarithmic units. The results may then be back transformed to original units using the expression

$$E(\bar{x}) = \exp(\bar{x}' + \frac{s^2}{2}) - 1 \quad \dots 6.12$$

where  $E(\bar{x})$  represents the estimated (back transformed) mean catch per haul,  $\bar{x}'$  and  $s^2$  are the mean and variance respectively in logarithmic units (Clarke and Brown 1977) or

$$E(\bar{x}) = \exp(\bar{x}') - 1 \quad \dots 6.13$$

(Campana and Simon 1984; McPherson 1990). The subtraction of 1 is the correction for adding 1 to the observations before taking the logarithm. Confidence intervals for the back transformed mean are also calculated in the logarithmic scale and back transformed. This interval is not symmetrical about the back transformed mean.

#### **6.2.4 The swept area per haul of the survey net**

The area swept by the net during one trawl haul is the product of the effective width (**b**) of the net and the distance (**d**) traversed by the gear during the haul (as illustrated in Appendix 6.7). **d** is approximated from the distance covered by the vessel which is calculated as the product of the velocity of the vessel and the duration of the haul, based on the assumption that the distance that the net covers on the seabed is the same as the distance covered by the vessel. The effective width of the net is usually taken to be a proportion ( $X_2$ ) of the length of the headline (**h**) of the net, i.e.

$$b = X_2 \cdot h \quad \text{....6.14}$$

(Pauly 1980a; Sparre and Venema 1992). In surveys in the southeast Asian region (SCSP 1978)  $X_2$  was taken to be 0.4 - 0.66 and in the Caribbean a value of 0.6 was used (Klima 1976). Pauly (1980a) suggests a value of 0.5.

On the other hand, Rijavec (1980) and Koranteng (1981, 1984) estimated **b** from Dinglassan's (1973) method. In this method the distance between the two trawl boards (**B**) is first determined from

$$B = A \cdot L + D \quad \text{....6.15}$$

and the wing spread (**b**) is then calculated from

$$b = \frac{B \cdot N}{N + T} \quad \text{....6.16}$$

where (using Dinglassan's notation)

**A** = outward shear per metre of the towing wire

**L** = length of warp from the towing block to the boards

**D** = distance between towing blocks

**N** = length of the net from the tip of the wing to the front part of the codend and



$T$  = length of lines from the boards to the wing tips.

These are illustrated in Appendix 6.8.

In this method,  $b$  is estimated from a series of measurements of  $A$  for various values of  $L$  (which depends on the depth trawled). The method assumes accurate geometry of the trawling gear (i.e. no curvature in towing warps between the vessel and the net).

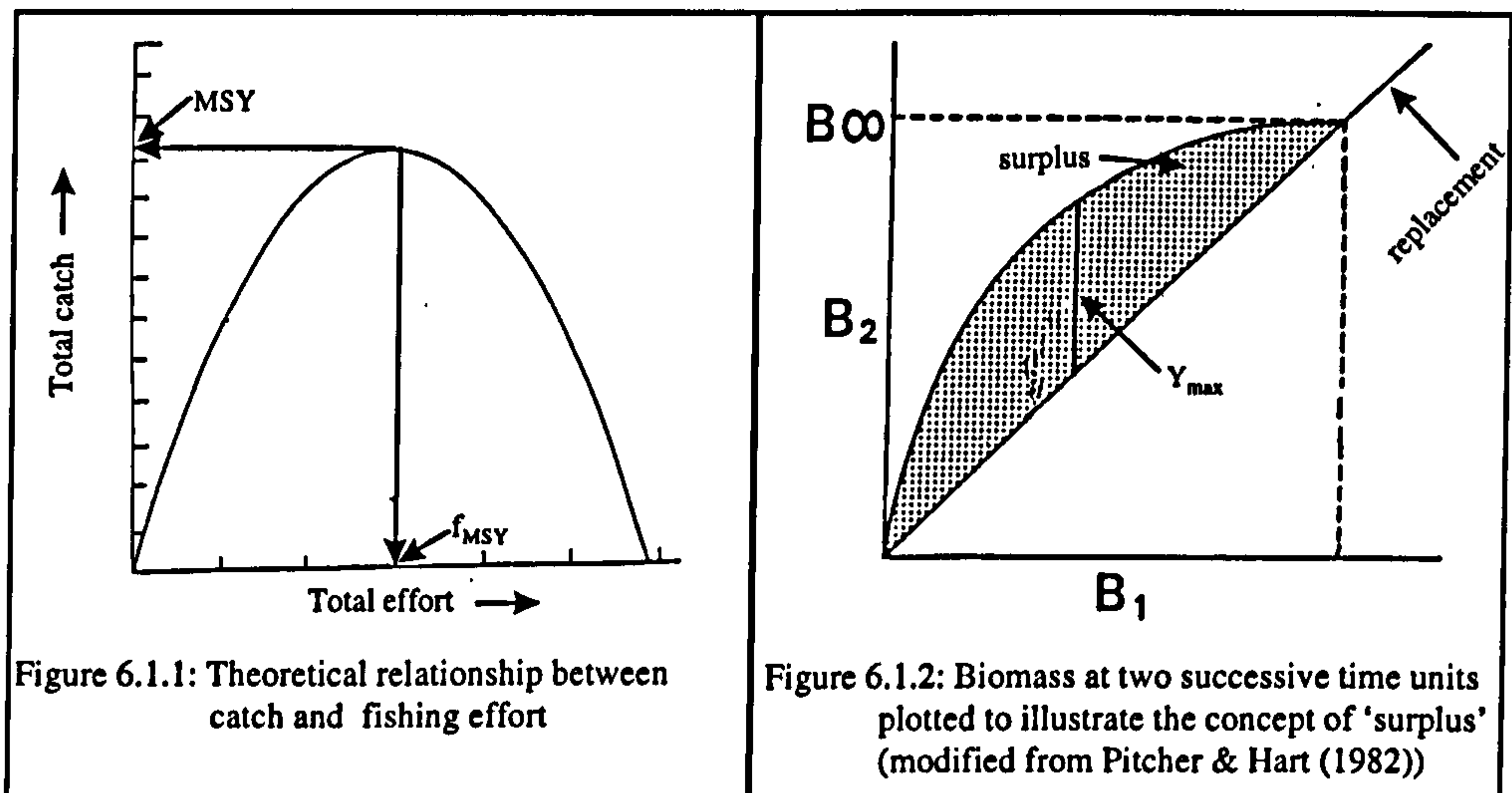
### **6.2.5 The catchability coefficient**

The proportion of fish in front of the net that are actually caught ( $q$ ) is difficult to estimate.  $q$  values of between 0.5 (Isarankura 1971; Saeger *et al.* 1976) and 1.0 (Gulland 1971; Rijavec 1980; Koranteng 1981, 1984; Stromme 1992) are usually used. If  $q$  is set to 1.0, then it is assumed that all fish in the path of the net are caught. A value of 0.5 doubles the estimate of biomass that would have been obtained from  $q = 1$ . According to Stromme (1992), "... the value of  $q$  to use is subject to discussion". Blaber *et al.* (1990) suggest using different values of  $q$  for different sizes of fish starting with 0.3 for fish of size less than 225 mm, 0.47 for those over 225 mm long and 1 for large (>1000 mm long) slow-swimming fish. Pauly (1980a) suggests a value 0.6 as a good compromise. In the NAN-SIS program the default value of  $q$  is 1.0.

### **6.2.6 Potential yield of a demersal fishery resource**

A classical understanding in fishery science is that as fishing effort exerted on a resource increases, the yield from the resource will also increase correspondingly until at some level of effort there is a maximum and beyond which yield declines. This is illustrated in Figure 6.1.1. The following questions then follow naturally: "what is the optimum effort" and "what is the maximum yield". These are the

questions that Hilborn and Walters (1992) consider as the wrong type of questions to ask about a fishery. The authors argue that since you cannot find the top of the yield curve without actually going beyond it, this approach (and research questions) have spelt the doom of many fisheries. However, finding answers to these questions continue to be important objectives in the management of many fisheries.



The traditional approaches to answering these questions through the use of the Surplus Production (or Yield) Model (also known as the Schaefer model) and the Dynamic Pool (or Beverton & Holt) Model, have been reviewed in chapter 1 and also in Allen and McGlade (1986). In accordance with Russell's (1931) axiom, the SYM begins on a premise that the biomass of a resource at two time periods (denoted as  $B_1$  and  $B_2$ ) are related by:

$$B_2 = B_1 + \text{recruitment} + \text{growth} - \text{natural mortality} - \text{catch} \quad \dots 6.17$$

Considering the sum of somatic growth and recruitment as production (Hilborn and Walters 1992), and in the absence of fishing, equation 6.17 becomes

$$B_2 = B_1 + \text{production} - \text{natural mortality} \quad \dots 6.18$$



and the difference between production and natural mortality is regarded as ‘surplus’ production of the stock (Figure 6.1.2). This surplus is what the fishery is expected to harvest and the maximum sustainable yield (MSY) is defined as ‘the largest annual catch that may be taken from a stock continuously without affecting the catch of future years’ (King 1995).

Several authors have discussed the usefulness of the MSY concept in fisheries management (e.g. Larkin 1977; Pitcher and Hart 1982; Gulland 1984; Patterson 1991; Hilborn and Walters 1992). Nevertheless, because of its simplicity and the fact that it can be easily explained to politicians and industrialists (Patterson 1991), MSY has been used to manage many fisheries around the world.

Hilborn and Walters (1992) consider the SYM (which they refer to as ‘biomass dynamic models’) as the most commonly used stock assessment model in tropical fisheries. Pauly (1994) also notes that ‘.. despite the adaptability of yield-per-recruit and other analytical models, it is on the surplus production model ..... and its various derivatives ..... that most management advice in the tropics will continue to be based’. In addition, the necessary equilibrium assumption in the surplus production model is more easily met in stocks of tropical species than in temperate species (Pauly 1994). The reason given by Pauly is that the relatively short-lived tropical species respond quicker to changes in effort than the long-lived temperate species. Patterson (1991) gives one important constraint of MSY when applied to multispecies fisheries as “.... occurring at such high levels of effort and relatively low catch per unit effort (cpue) that the fisheries tend to be unprofitable”.

To use the SYM in a tropical multispecies fishery, one would assume that all the species constitute one multispecies biomass (as if of one species). This is referred to as Total Biomass Schaefer Model, TBSM (Pauly 1979) or aggregated production model (Hilborn and Walters 1992).

Mathematically, the rate of change of biomass with time is defined as

$$\frac{dB}{dt} = G(B) - H(f) \quad \dots 6.19$$

where  $G(B)$  is the biomass regeneration function and  $H(f)$  is the fishing function. In the original Schaefer model (Schaefer 1954),  $G(B)$  follows a logistic relationship and Equation 6.19 becomes

$$\frac{dB}{dt} = rB\left(1 - \frac{B}{B_{\infty}}\right) - H(f) \quad \dots 6.20$$

where  $B$  is stock size (biomass),  $B_{\infty}$  is maximum stock size,  $r$  is instantaneous rate of increase of the stock and  $t$  is time (usually years). At equilibrium,

$\frac{dB}{dt} = 0$ ,  $H(f) = G(B)$ , and the equilibrium yield,  $Y_E$  is obtained from

$$Y_E = r B_E \left( \frac{B_{\infty} - B_E}{B_{\infty}} \right) \quad \dots 6.21$$

where  $B_E$  is the equilibrium stock size.

In this model, inter-specific linkages are not accounted for, environmental factors are ignored and the species are treated as independent management units (Sugihara *et al.* 1984). Variations of the model assume different forms of the biomass regeneration function (e.g. Pella and Tomlinson (1969); Fox (1970); Walter (1973)). Hilborn and Walters (1992) give alternative formulation of the biomass regeneration function for multispecies fisheries from which equation 6.20 becomes:

$$\frac{dB}{dt} = r B_t \left( 1 - \frac{B_t}{B_{\infty}} - c X_t \right) - H(f) \quad \dots 6.21b$$

where  $X_t$  is the biomass of a competitor or predator species and  $c$  is a parameter that



reflects the interaction or competition between the two biomasses  $B$  and  $X_i$ . For more than two species, the situation becomes complex.

Hilborn and Walters (1992) suggest that even though interactions between species exist in multispecies fisheries, the fact that they cannot be estimated is one reason that should make investigators concentrate on the aggregated biomass. The aggregated biomass approach has been used by Pauly (1979); Pope (1979); Ralston and Polovina (1982).

In later “improvements” of the surplus yield model, other factors like recruitment variability and environmental randomness have been accounted for (e.g. Beddington and May 1977; Schnute 1977; Walter 1978; Freon 1988).

Doubleday (1981); Doubleday and Rivard (1981) and Shepherd (1988) show that data from research vessel surveys may be likened to commercial catch and effort data from a fleet consisting of only one vessel and using a standardized fishing gear. Thus from such a survey, the biomass and potential yield of the resource may be obtained using the surplus yield model.

Gulland (1971) proposed that from biomass estimated through research vessel surveys (using the swept area method), the potential yield of an unexploited stock may be calculated from

$$P_y \approx 0.5 M \cdot B_0 \quad \dots 6.22$$

where  $B_0$  is the size of the unexploited biomass and  $M$  is the instantaneous rate of natural mortality experienced by the fish stock in question. The rationale behind the method is that from the Schaefer model, the biomass at MSY is equal to half the virgin biomass (i.e.  $B_{MSY} = \frac{1}{2} B_0$ ). It is further assumed in the model that fishing mortality at MSY is equal to  $M$ .

For a stock under exploitation, Cadima (*In* Troadec 1977) proposed the

following formula for calculating the potential yield:

$$P_y \approx 0.5 (MB' + Y') \quad \dots 6.23$$

where  $B'$  and  $Y'$  are the estimated biomass and catch (by the commercial fishery) respectively, at the time of the survey.

Both methods have been criticized in the literature just as the concept of MSY itself. For example, Gulland's (1971) method has been criticized by Francis (1974) and Beddington and Cooke (1983) on the grounds that  $F_{MSY}$  is often lower than  $M$ . This leads to overestimation of the potential yield. It has been shown that Cadima's (1977) method also overestimates the potential yield (Beddington and Cook 1983) and is not consistent (Garcia *et al.* 1989). Garcia *et al.* (1989) concluded that Equation 6.23 gives unbiased estimates only when (i) the stock is virgin, and (ii) when the stock happens to be fished at MSY at the time that it was being assessed. They propose the following alternative model for calculating the maximum sustainable yield:

$$MSY = \frac{(F_{msy} B_c)^2}{2 F_{msy} B_c - Y_c} \quad \dots 6.24$$

$$\text{or} \quad MSY = \frac{(M B_c)^2}{2 M B_c - Y_c} \quad \dots 6.25$$

for the Schaefer model, and

$$MSY = MB_c \exp\left(\frac{Y_c}{M B_c} - 1\right) \quad \dots 6.25b$$

for the Fox model, all with  $M = F_{msy}$ .



An important constraint in using the Gulland or any of the other methods to estimate the potential yield of a multispecies fishery (in which the whole resource is considered as one 'stock'), is the difficulty in obtaining a representative value of  $M$ .

In the more usual method of fitting this model to commercial catch data, if the equilibrium catch per unit effort  $U_E = \frac{Y_E}{f}$ , then it can be shown that in the case of the Schaefer model,

$$Y_E = af - bf^2 \quad \dots 6.26$$

where  $a = qB_\infty$  and  $b = \frac{q^2 B_\infty}{r}$ . From these,

$$f_{MSY} = -\frac{a}{2b} \quad \dots 6.27$$

$$\text{and } MSY = -\frac{a^2}{4b} \quad \dots 6.28$$

where  $f$  is fishing effort, and  $a$  and  $b$  are constants that may be obtained by fitting a polynomial regression of  $Y_E$  (equilibrium catch) on  $f$  and  $f^2$ .

### **6.3 CATCH ASSESSMENT SURVEYS IN GHANA**

The methods for collecting and processing fish catch data in Ghana differ from fleet to fleet. These are briefly described here; details are given in Koranteng (1989).

In the artisanal fisheries sector, a three-stage sample survey system (Banerji 1974) is used in which about forty enumerators take catch, effort and price data at 53 fish landing centres in the four maritime regions of Ghana. About 43 % of the total number of canoes in Ghana operate from these sampling centres and nationally, about 500 canoes are examined every day. The sampling centres are selected with probability proportional to the size of the centre (in terms of canoe population). Sampling at every centre is carried out on at least four days in the week. The field enumerators are provided with a chart that guides them to select canoes for observation as they arrive from fishing. All recorded data are sent to the MFRD in Tema for processing. This system has been in use in Ghana since 1972.

In the inshore sector, catch, effort and price data are collected by enumerators based at 8 landing centres from which these vessels operate. Each enumerator takes records on at least four days in the week either by complete enumeration or through sampling, depending on the number of vessels that land at the centre and the volume of landings. The information obtained from the inshore vessels is similar to that obtained from sampling the canoes and the same criterion is used to select vessels for examination if a sample is to be taken

All fishing companies that operate industrial trawlers, shrimpers and tuna fishing vessels in Ghana are required to submit accurate records of all their operations (trip by trip) to the Fisheries Department. The required information which is submitted on prescribed forms, includes fishing method, area fished, number of days at sea, number of days fished, quantity of fish (and shrimps in the case of shrimpers) caught and quantity exported. This information is also processed at the MFRD, Tema.



## **6.4 MATERIALS AND METHODS**

### **6.4.1 *The trawl survey data***

Data collected during the trawl surveys described in Table 6.1 were used in the estimation of stock sizes, investigations on seasonal variability and long-term trends in biomass and studies on spatial and temporal changes in species abundance. The GTS and Guinea 90 data sets are particularly useful as they contain hauls made in waters much deeper than the limit of the Ghanaian surveys.

To increase the precision of the estimate, the sampling stations in the systematic surveys were post-allocated to sampling strata used in the Ghanaian stratified surveys (Koranteng 1980). Four depth strata were used, namely less than 30 m, 31 - 50 m, 51-100 m and over 100 m.

All data sets were inputted into the NAN-SIS computer program for survey data logging and analysis (Stromme 1992). The species codes and names used have been described in chapter 4. The following families of (pelagic) fish were excluded from the analyses: Carangidae, Engraulidae, Clupeidae and Scombridae.

In the MFRD surveys carried out before August 1979, weights of fish were recorded to 0.2 kg accuracy and the data were entered as such. In later surveys, weights were recorded to 0.5 kg accuracy. Where the total catch of any species weighed less than 0.5 kg (or 0.2 kg in the 1969-70 surveys), a '+' was entered on the trawl log sheets for the species. To enter these into NAN-SIS, the '+' sign was replaced with 0.1 as the software could only handle numeric values in the catch field.

The horizontal opening of the survey net *b* was obtained from the reports on the respective surveys. In the GTS, the wing spread was assumed to be 16.4 m (Williams 1968) and that of the Larsen net used in the first year of the 1969-70 MFRD survey was calculated to be 14.4 m (Dinglassan 1973). As it was not possible

to determine when the pseudo-footrope (which affects the horizontal opening of the net and the trawling speed of the vessel) was used, the wing spread and towing speed used in analysing the data from the second year of the 1969 - 70 survey are average values for the two types of rigging. Thus  $b$  was taken to be 15.3 m for an average towing speed of  $5.0 \text{ km hr}^{-1}$  (Dinglassan 1973; Rijavec 1980; Table 6.2).

In experiments conducted during the 1981-82 survey (Koranteng unpublished data),  $b$  was estimated to be 11.9 m for the Engel net used (Appendix 6.6). This value is rather low and given all the uncertainties surrounding the estimate, the theoretical minimum horizontal spread corresponding to 40% of the headline length (SCSP 1978) was used in this thesis. This gives  $b$  as 16.4 m for the net used in the MFRD surveys of 1979 - 1992. For net type I used off Ghana during Guinea 90,  $b$  was given as 17.16 m (Ramos *et al.* 1990); 17.2 was used for the calculations in this work.

To obtain a rather conservative estimate of biomass, a  $q$  value of 0.75, being half way between 0.5 and 1.0 was used. This is because a value of 0.5 would probably give a 'false hope' for the industry and 1.0 used in previous work (Rijavec 1980; Koranteng 1981, 1984) is probably unrealistic. This does not allow any fish in the path of the net to escape.

#### **6.4.2 Catch and effort statistics from the commercial fishery**

The commercial catch data used in this thesis consists of landings made by the artisanal, semi-industrial and industrial fleets between 1960 and 1994. These were compiled from MFRD records and the FAO (Food and Agriculture Organization) FISHSTAT PC database (FAO 1996). Data on Ghana in FISHSTAT PC are furnished by MFRD of the Fisheries Department of Ghana. Only landings of demersal fish species are included in the data sets used here. Initially, catch data for all marine fin-fish, molluscs and crustaceans were extracted from FISHSTAT PC, and then data on Clupeidae, Engraulidae, Carangidae and Scombridae were removed as done with the trawl survey data. As there are no registered foreign fishing vessels



operating in Ghanaian waters, the information contained in FISHSTAT PC for Ghana represents the total landed catch from Ghanaian waters.

Appendix 6.9 gives annual catch of demersal fishes by all three fishing fleets. The FISHSTAT PC manual cautions that due to lack of data, the statistics for the years before 1970 may not be very accurate. This is exemplified by large figures appearing in the table as marine NEI (i.e. marine species Not Elsewhere Included). Certainly, some of the species under this category may not be demersal but since there is no way by which the data could be split the figures appearing under NEI were excluded from the analysis.

Annual catch and effort data for the small-sized inshore trawlers (i.e. vessels measuring 8 - 12 m long) for 1972 -1991 are presented in Appendix 6.10. This data set was compiled from records available at MFRD and the fishing effort is in 'number of fishing trips'. For these vessels, a fishing trip lasts for one day. Corresponding monthly catch and effort statistics were also compiled for this category of vessels and for the same period. Appendix 6.10 also gives catch and effort data for industrial trawlers. In this case, the fishing effort is in 'days fishing'.

Because of the importance of the shrimp fishery in this ecosystem, catch and effort data for the industrial shrimping fleet were also compiled from the records of MFRD, Tema and analysed separately.

### **6.4.3 Data analysis**

Preliminary data analyses were carried out using the facilities available in NAN-SIS. Additional analyses were done by exporting the data to other computer programs, mainly SPSS and Excel.

#### 6.4.3.1 Annual, seasonal and spatial changes in abundance of demersal fish stocks

Using the routines in NAN-SIS the density of selected fish species and families and also the total stock, were calculated for each survey. In this thesis, the emphasis is on the total demersal biomass, however some families and species have also been followed because of their commercial or scientific importance. The families are grunts (Haemulidae), seabreams (Sparidae), snappers (Lutjanidae including *Lethrinus atlanticus*), groupers (Serranidae), croakers (Sciaenidae), rays (mainly Dasyatidae, Myliobatidae, Rhinobatidae, Torpedinidae), sharks (mainly Carcharhinidae, Squatinidae and Triakidae), cephalopods (mainly Sepiidae, Octopodidae and *Loligo* sp.) and soles (Soleidae, Citharidae and Bothidae). These families are extremely important in the demersal fishery both in total quantity landed and in value. Red mullet (*Pseudupeneus prayensis*) and the bigeye grunt (also known as burrito) *Brachydeuterus auritus* were included for their commercial importance in the Ghanaian demersal fishery. Also included in the examination are Triggerfish (*Balistes capriscus*) for its scientific importance, as seen in previous chapters, and Atlantic bigeye (*Priacanthus arenatus*) as a representative low grade but important fish in the fishery. The use of density is to facilitate comparison of results from the various surveys that have been conducted with different vessels and gears as described above.

The data were then grouped according to the four quarters of the year (i.e. January - March, April - June, July - September and October - December); these correspond approximately to the seasons described in chapter 3. Only periods with at least one cruise that covered almost all the transects (or sectors) were included in this analysis. Consequently, only 13 years between 1963 and 1992 were considered. For these analyses, the three bathymetric frames of reference (i.e. depths of 10-30 m, 31-50 m, and 51-100 m) used in the examination of assemblage dynamics (chapter 5) were also used here.

A subset of years with surveys in both thermocline (April - June) and upwelling (July - September) seasons was selected and the calculated densities from



these surveys were compared. For this comparison, the two GTS years were considered as one. To investigate seasonal and long-term changes in the density of the stocks, species and families, 'analysis of variance' (ANOVA) techniques were employed using the models

$$d_{ijk} = \mu + b_i + s_j + y_k + \varepsilon_{ijk} \quad \dots 6.30$$

$$d_{ijk} = \mu + b_i + s_j + t_k + \varepsilon_{ijk} \quad \dots 6.31$$

where  $\mu$  is the overall mean density,  $b_i$  represents the bathymetric frame,  $s_j$  is season,  $y_k$  is the year,  $t_k$  is environmental time block and  $\varepsilon_{ijk}$  are random variation. A model including first order interactions was fitted but the interactions were later omitted as none was found significant.

The residual plots obtained from test runs of the models showed that the underlying distribution of the data is far from normal, as required for the analysis of variance. Rather, the distribution of density is skewed, just like the distribution of the catch per haul (cph; Figure 6.2). Consequently, a log transformation (Equation 6.11) was applied to the density values and the model was re-fitted using the transformed values.

The results of the GTS (beginning of the study period) and the Guinea 90 (end of the study period) surveys were compared. As Guinea 90 was in April, only data from GTS II (conducted in March) were utilized. For this comparison, four depth ranges, namely 10 - 30, 31 - 50, 51 - 100 and over 100 m were used.

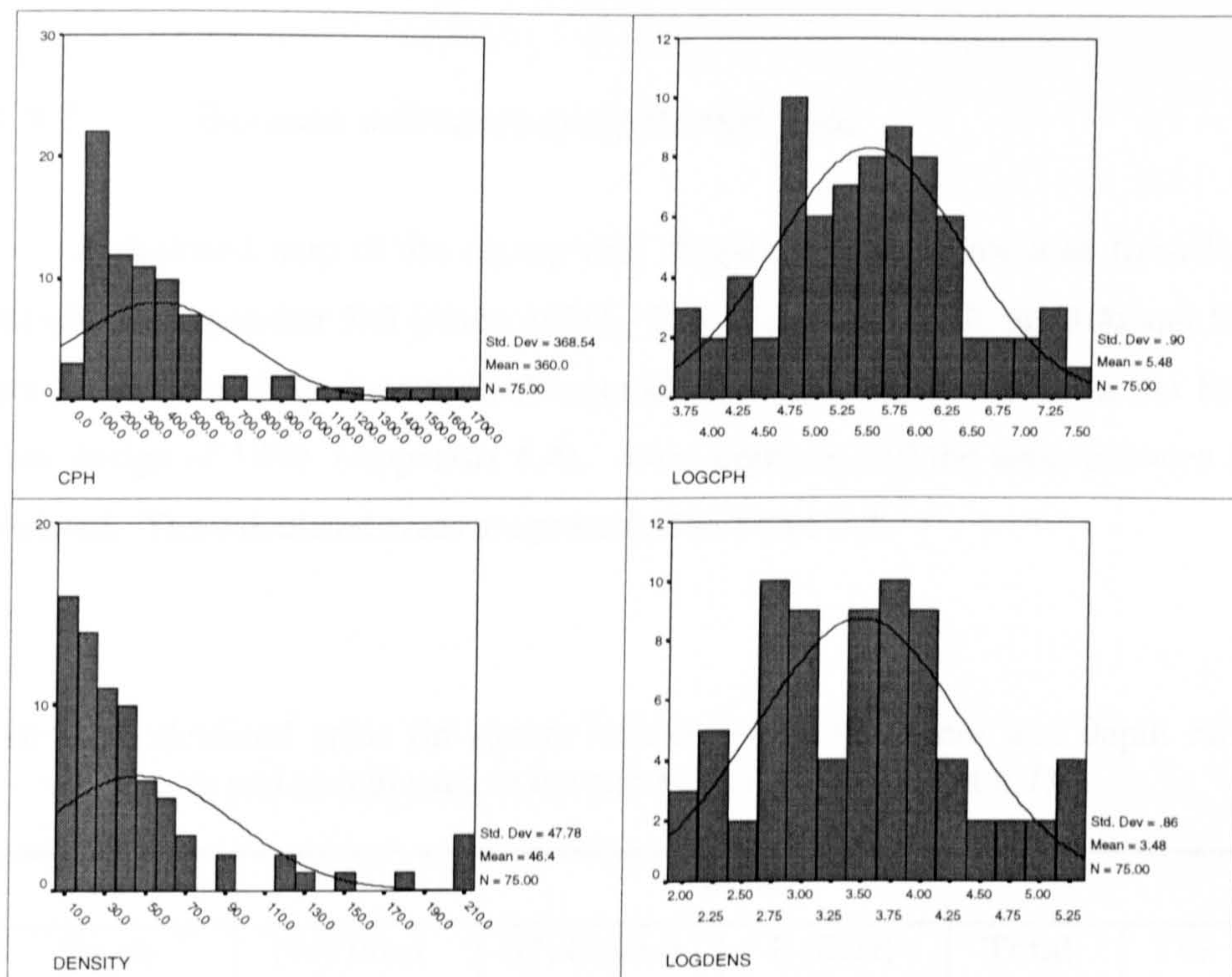


Figure 6.2: Figures illustrating the distribution of catch per haul (CPH), density and their logarithmic transformations (e.g.  $\text{LOGCPH} = \text{Ln}(\text{CPH} + 1)$ )

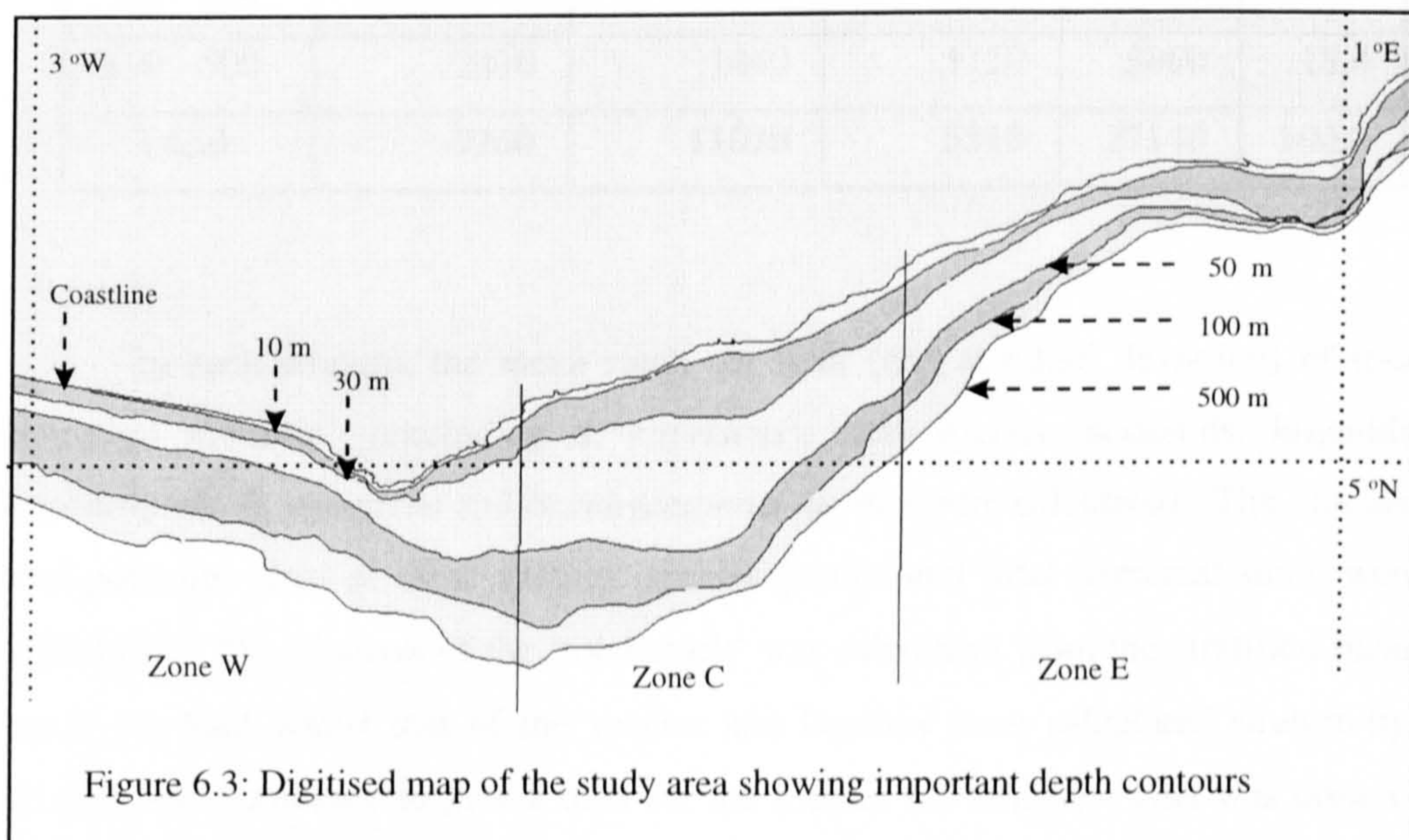


Figure 6.3: Digitised map of the study area showing important depth contours



6.4.3.2      Biomass estimates and potential yield

A digitised map of the survey area (Figure 6.3) was produced from British admiralty chart number 595 (Anon 1996). The coastline, 10, 30, 50, 100 and 500 m depth contours and the longitudinal boundaries separating the zones in the MFRD survey design of 1980 (Appendix 6.4), were digitised and the areas between them calculated. The calculated areas are presented in Table 6.3.

Table 6.3 Calculated areas (in square kilometres) of the zones and depth ranges shown and as indicated in the survey design (Appendix 6.7).

|             | Zones    |             |          |       |       |
|-------------|----------|-------------|----------|-------|-------|
| Depth range | (W) West | (C) Central | E (East) | Total | %     |
| 0 - 10      | 1550     |             |          | 1550  | 5.7   |
| 10 - 30     | 960      | 2060        | 1720     | 4740  | 17.5  |
| 30 - 50     | 2320     | 5100        | 1500     | 8920  | 32.9  |
| 50 - 100    | 3570     | 2420        | 940      | 6930  | 25.5  |
| 100 - 500   | 2410     | 1440        | 1150     | 5000  | 18.4  |
| Total       | 9260     | 11020       | 5310     | 27140 | 100.0 |

In each stratum, the mean catch per hour (and standard deviation) of total demersal biomass (excluding *B. capriscus*), total sparids, sciaenids, lutjanids, cephalopods, *B. capriscus* and *Brachydeuterus auritus* were calculated. The biomass and potential yield of these species, species groups and total demersal stock were calculated. The biomass of the 'total stock' was calculated from the stratified mean catch per haul whilst that of the species and families were calculated stratum-by-stratum and combined to give a total for the species (or family). This was done to minimise the effect of sector preferences of species (and families) which are associated with depth and bottom type (chapters 4 and 5). It was found that this

depth preference is quite influential on the stratified mean.

The potential yield from the total demersal biomass was calculated using Cadima's (1977) method and also that of Garcia *et al.* (1989). The value of  $M$  (instantaneous rate of natural mortality) for a number of fish species was estimated from Pauly's (1980b) empirical equation, i.e.

$$M = \frac{0.985 \cdot K^{0.654} \cdot T^{0.463}}{L_{\infty}^{0.279}} \quad \dots 6.32$$

where  $L_{\infty}$  (using total length in cm) and  $K$  (annual value) are parameters of the von Bertalanffy growth function (VBGF) and  $T$  is the mean annual temperature (in °C) of the water body inhabited by the stock.  $T$  was taken to be 20 °C (chapter 3). Various estimates of  $K$  and  $L_{\infty}$  for fish species in the eastern central Atlantic area, particularly from the Gulf of Guinea, were obtained from the literature.  $M$  was calculated for each set of VBGF parameters and mean and standard deviation obtained from these.

#### 6.4.3.3 Analysis of commercial catch data

##### Fitting the surplus yield model

From the catch ( $c$ ) and effort ( $f$ ) data of the small-sized inshore vessels (for the years 1972 - 1991), a theoretical effort (total expected effort, TEF1) was calculated for the demersal catch (from all fleets) using the ratio:

$$TEF1 = \frac{C}{c} \cdot f \quad \dots 6.33$$

where  $C$  is the total catch of all fleets. TEF1 is the effort that the small-sized vessels would expend to catch the total quantity of demersal fish landed by all fleets. A Schaefer model was fitted to the time series of catch and expected effort data with a primary objective of comparing the resultant MSY with the potential yield calculated



from the trawl survey data.  $F_{msy}$  was not calculated as it could not be meaningfully interpreted in this case. Besides, Pauly (1988) argues that when the SYM is applied to total demersal biomass, there is no unique level of effort corresponding to MSY and the health of the fishery cannot be measured in terms of how much actual effort differs from  $f_{MSY}$ . Only the series of total demersal catch (excluding *B. capriscus* and unidentified marine fish) was used in this investigation. Equation 6.29 was solved to obtain the MSY. The analysis was repeated with expected effort (TEF2) obtained from the industrial trawl fishery catch and effort data (Appendix 6.10). A separate model was fitted to the industrial shrimping data.

#### Time series analysis of cpue

From the MFRD database, monthly values of catch per unit effort (cpue) for the small-sized inshore trawlers were calculated for

- i. the total demersal catch excluding *Balistes capriscus*, and
- ii. the total excluding *B. capriscus* and *Brachydeuterus auritus*.

These two species were excluded from the series because they are occasionally caught in large quantities and these would seriously affect the cpue series. Each time series was decomposed into trend, seasonal variation and remainder as done with the environmental parameters in chapter 3 and with the same objectives.

## 6.5 RESULTS

Appendix 6.11 is a set of outputs from the swept area analysis done in NAN-SIS. For the results of each survey, the species are arranged in order of importance (highest to lowest density in  $t\ nm^{-2}$ ). Only fish of density  $0.01\ t\ nm^{-2}$  or more are listed; all others are lumped in 'Other fish'. The outputs also give the distribution of samples in which various catch rates of each species were obtained and the calculated density in the indicated depth ranges. The percentage incidence gives an indication of the number of hauls in the surveys in which each of the listed species was found.

The version of the NAN-SIS software used in this work always uses the default value of  $q$  ( $=1$ ) in the calculations. Even though the user is given the option to change the parameters of the swept area equation as necessary, the value of  $q$  supplied is not accepted by the program. The writers of the software have identified this problem but could not have it corrected in the course of this work. Consequently, each density value given in this appendix has to be multiplied by 1.33 (i.e.  $\frac{1}{0.75}$ ) to arrive at the expected value. However, because of the following reasons this adjustment was not done as in other cases. Firstly this particular output from NAN-SIS is not exportable to other software packages for the necessary adjustments to be made outside the NAN-SIS environment and secondly the figures presented here are for the purposes of comparison only and since each one of them would be adjusted by the same value, this adjustment would not change the order of importance of the species.

Table 6.4 shows how the relative importance of species changed in the course of the study period. Unlike the relative index of importance used in chapter 4, only the density figures (from Appendix 6.11) were used to produce the ranking in this table. During the GTS and the MFRD1 surveys, the most abundant species was *B. auritus*. Its density in the total assessed, was 14.2 % and 13.9 % respectively in the two surveys (Appendices 6.11.1 and 6.11.2). Table 6.4 clearly shows how from virtually nowhere in the GTS ranking *B. capriscus* moved into the ninth position in 1969-70 and then dominated this ecosystem for nearly twenty years.

Species like *Brachydeuterus auritus*, *Pagellus bellottii*, *Sparus caeruleostictus* and *Pseudupeneus prayensis* maintained their relative importance throughout the period of investigation. Except during 1973-1977 when it moved down to the 18<sup>th</sup> position, *B. auritus* maintained its position at the top giving way only to *B. capriscus* in the years that the latter species dominated this ecosystem. *Pseudotolithus brachygnathus* and *Loligo* sp. which were important during GTS became completely unimportant for the rest of the time. The other *Pseudotolithus* species in the GTS top twenty (*Pseudotolithus senegalensis*) also showed up again



only once. This occurrence could be an indication of over-exploitation of these shallow-water species as discussed below (and also in chapter 5). Other specific changes are presented below in more details.

Table 6.4: Top 20 species (or genus)( by weight) in the Guinean Trawling Survey (stations of depth  $\leq 100$  m only) and their ranks in subsequent surveys. (M6 90 means MFRD survey 6 of 1990; i.e. MFRD 6 in Table 6.1)

|                                     | GTS<br>63/64 | M1<br>69/70 | M1B<br>73-77 | M2<br>79/80 | M3<br>81/82 | M4<br>87/88 | M5<br>89 | M6<br>90 |
|-------------------------------------|--------------|-------------|--------------|-------------|-------------|-------------|----------|----------|
| <i>Brachydeuterus auritus</i>       | 1            | 1           | 18           | 2           | 2           | 2           | 1        | 1        |
| <i>Pagellus bellottii</i>           | 2            | 3           | 2            | 3           | 3           | 3           | 2        | 2        |
| <i>Dentex congoensis</i>            | 3            | 23          | 3            | 11          | 11          | 14          | 11       | -        |
| <i>Priacanthus arenatus</i>         | 4            | 16          | 21           | 9           | 9           | 5           | 10       | 4        |
| <i>Sparus caeruleostictus</i>       | 5            | 6           | 4            | 4           | 5           | 6           | 3        | 6        |
| <i>Epinephelus aeneus</i>           | 6            | 10          | 11           | 7           | 7           | 11          | 4        | 11       |
| <i>Pseudupeneus prayensis</i>       | 7            | 8           | 7            | 5           | 4           | 4           | 4        | 3        |
| <i>Dentex angolensis</i>            | 8            | -           | 19           | 10          | 19          | 18          | 27       | -        |
| <i>Galeoides decadactylus</i>       | 9            | 11          | -            | 13          | 30          | 26          | -        | 26       |
| <i>Pseudotolithus senegalensis</i>  | 10           | -           | -            | 18          | -           | -           | -        | -        |
| <i>Loligo</i> sp.                   | 11           | -           | -            | -           | -           | -           | -        | -        |
| <i>Paracubiceps ledanoisi</i>       | 12           | 29          | -            | -           | 22          | 25          | -        | -        |
| <i>Dentex canariensis</i>           | 13           | 4           | 6            | 6           | 6           | 7           | 6        | 8        |
| <i>Boops boops</i>                  | 14           | 13          | 23           | 22          | 14          | 31          | 19       | 20       |
| <i>Raja miraletus</i>               | 15           | -           | -            | -           | 29          | 21          | 24       | 17       |
| <i>Sphyræna</i> sp.                 | 16           | 12          | -            | 21          | 28          | 32          | 22       | -        |
| <i>Dactylopterus volitans</i>       | 17           | 7           | 8            | -           | 26          | 8           | 9        | 13       |
| <i>Drepane africana</i>             | 18           | -           | -            | -           | -           | -           | -        | 33       |
| <i>Dentex gibbosus</i>              | 19           | 26          | 15           | 16          | 13          | 23          | -        | 33       |
| <i>Pseudotolithus brachygnathus</i> | 20           | -           | -            | -           | -           | -           | -        | -        |
| <i>Balistes capriscus</i>           | -            | 9           | 1            | 1           | 1           | 1           | 17       | -        |

### **6.5.1 Annual, seasonal and spatial changes in density of demersal fish stocks**

Calculated mean density of the selected families and species of fish for the years that meet the criteria listed in section 6.4.3.1 are summarised in Table 6.5. A summary of density values within sectors and seasons for the three environmental time blocks, and also sector means in each season, are given in Tables 6.6.1 - 6.6.4. Sectoral differences between ETBs are quite clear and conform to results in chapter 5. Seasonal differences in density are also consistent over the three ETBs. In each ETB highest densities were obtained during the upwelling season. The large standard errors indicate high variability in catches within years. This is particularly true for triggerfish.

The mean density for each season - upwelling and thermocline- are depicted in Figures 6.4.1 - 6.4.13. The density of the total demersal biomass is higher in the upwelling season than in the thermocline season (Figure 6.4.13).

Probability values from the analysis of variance to examine the significance of the fitted models are presented in Table 6.7. The results for both untransformed and transformed density values are shown; these are quite similar in most cases. The untransformed values are given here only for the purpose of comparing estimates obtained here with those from earlier analyses of the same data. For factors that are significant (i.e.  $p < 0.05$ ), mean density values for all levels (of the factor) are also given in the table. These are back-transformed means; Table 6.6 gives corresponding means of the untransformed values.



Table 6.5: Annual mean density (and standard error) of selected species, families and total demersal biomass evaluated in trawl surveys

| Year  |      | Total | Balistes | Croakers | Snappers | Seabreams | Grunts | Cephalopods | Soles | Groupers | Rays |
|-------|------|-------|----------|----------|----------|-----------|--------|-------------|-------|----------|------|
| 1963  | Mean | 17.08 | 0.00     | 1.03     | 0.42     | 5.37      | 3.30   | 0.69        | 0.04  | 0.76     | 0.36 |
|       | s.e. | 3.70  |          | 0.96     | 0.13     | 1.24      | 2.57   | 0.55        | 0.03  | 0.32     | 0.17 |
| 1964  | Mean | 14.95 | 0.00     | 0.32     | 0.41     | 4.25      | 3.35   | 0.08        | 0.02  | 0.55     | 0.27 |
|       | s.e. | 1.44  |          | 0.18     | 0.23     | 0.83      | 1.89   | 0.04        | 0.00  | 0.15     | 0.01 |
| 1969  | Mean | 16.59 | 0.49     | 0.33     | 0.93     | 2.90      | 5.70   | 0.99        | 0.10  | 0.28     | 0.09 |
|       | s.e. | 4.78  | 0.38     | 0.18     | 0.58     | 0.69      | 3.37   | 0.38        | 0.02  | 0.09     | 0.01 |
| 1970  | Mean | 10.54 | 0.35     | 0.23     | 0.46     | 2.96      | 0.87   | 0.76        | 0.05  | 0.47     | 0.04 |
|       | s.e. | 1.91  | 0.12     | 0.10     | 0.11     | 0.66      | 0.24   | 0.21        | 0.02  | 0.18     | 0.01 |
| 1975  | Mean | 7.73  | 4.64     | 0.10     | 0.32     | 3.14      | 0.36   | 0.20        | 0.05  | 0.35     | 0.34 |
|       | s.e. | 2.42  | 2.03     | 0.06     | 0.11     | 1.01      | 0.13   | 0.06        | 0.03  | 0.14     | 0.28 |
| 1977  | Mean | 11.61 | 8.33     | 0.06     | 0.74     | 7.23      | 0.08   | 0.24        | 0.02  | 0.42     | 0.13 |
|       | s.e. | 6.19  | 3.88     | 0.06     | 0.26     | 5.56      | 0.02   | 0.12        | 0.01  | 0.26     | 0.08 |
| 1979  | Mean | 14.28 | 20.19    | 0.74     | 0.58     | 5.07      | 2.84   | 0.22        | 0.01  | 0.69     | 0.06 |
|       | s.e. | 3.06  | 12.26    | 0.23     | 0.19     | 1.55      | 1.07   | 0.05        | 0.00  | 0.36     | 0.02 |
| 1980  | Mean | 10.31 | 4.99     | 0.20     | 0.48     | 3.86      | 1.71   | 0.19        | 0.02  | 0.96     | 0.07 |
|       | s.e. | 1.77  | 2.05     | 0.08     | 0.16     | 0.75      | 0.66   | 0.04        | 0.01  | 0.37     | 0.02 |
| 1981  | Mean | 13.27 | 8.07     | 1.19     | 0.47     | 4.80      | 2.31   | 0.50        | 0.05  | 0.77     | 0.10 |
|       | s.e. | 2.41  | 4.25     | 0.99     | 0.13     | 1.05      | 0.84   | 0.16        | 0.02  | 0.27     | 0.03 |
| 1982  | Mean | 18.88 | 13.97    | 0.06     | 0.27     | 5.07      | 6.57   | 0.65        | 0.04  | 0.71     | 0.10 |
|       | s.e. | 5.06  | 7.88     | 0.04     | 0.11     | 0.95      | 4.00   | 0.11        | 0.03  | 0.29     | 0.04 |
| 1988  | Mean | 11.73 | 0.89     | 0.16     | 0.52     | 2.76      | 1.63   | 0.85        | 0.04  | 0.43     | 0.24 |
|       | s.e. | 1.52  | 0.22     | 0.07     | 0.16     | 0.69      | 0.54   | 0.22        | 0.01  | 0.15     | 0.07 |
| 1989  | Mean | 10.15 | 0.17     | 0.10     | 0.65     | 2.77      | 1.91   | 0.52        | 0.05  | 0.39     | 0.18 |
|       | s.e. | 1.20  | 0.05     | 0.05     | 0.18     | 0.41      | 0.77   | 0.14        | 0.01  | 0.08     | 0.03 |
| 1990  | Mean | 11.12 | 0.07     | 0.22     | 0.50     | 2.44      | 1.24   | 0.91        | 0.11  | 0.40     | 0.33 |
|       | s.e. | 1.63  | 0.05     | 0.08     | 0.14     | 0.32      | 0.50   | 0.18        | 0.03  | 0.09     | 0.10 |
| Total | Mean | 12.23 | 4.00     | 0.33     | 0.52     | 3.61      | 2.19   | 0.59        | 0.05  | 0.54     | 0.17 |
|       | s.e. | 0.71  | 1.08     | 0.10     | 0.05     | 0.28      | 0.38   | 0.06        | 0.01  | 0.06     | 0.03 |

Table 6.6.1: Calculated mean density (by environmental time block, ETB and bathymetric frame, BFR) of indicated species and families (density in kg ha<sup>-1</sup>)

| ETB | BFR | Demersal | Balistes | Croakers | Snappers | Seabreams |
|-----|-----|----------|----------|----------|----------|-----------|
| 1   | 1   | 11.40    | 0.39     | 0.46     | 0.24     | 1.42      |
|     | 2   | 11.24    | 0.48     | 0.28     | 0.69     | 3.59      |
|     | 3   | 17.62    | 0.02     | 0.37     | 0.78     | 5.22      |
|     | All | 13.42    | 0.30     | 0.37     | 0.57     | 3.41      |
| 2   | 1   | 7.05     | 10.41    | 0.18     | 0.37     | 2.08      |
|     | 2   | 12.21    | 17.23    | 0.28     | 0.51     | 3.87      |
|     | 3   | 18.62    | 1.23     | 0.94     | 0.49     | 7.84      |
|     | All | 12.63    | 9.62     | 0.47     | 0.45     | 4.60      |
| 3   | 1   | 6.97     | 0.28     | 0.19     | 0.51     | 1.32      |
|     | 2   | 10.30    | 0.56     | 0.08     | 0.56     | 2.32      |
|     | 3   | 15.74    | 0.28     | 0.21     | 0.60     | 4.33      |
|     | All | 11.00    | 0.38     | 0.16     | 0.56     | 2.66      |
| All | 1   | 8.07     | 4.30     | 0.25     | 0.39     | 1.65      |
|     | 2   | 11.28    | 7.11     | 0.21     | 0.57     | 3.24      |
|     | 3   | 17.33    | 0.59     | 0.53     | 0.60     | 5.93      |
|     | All | 12.23    | 4.00     | 0.33     | 0.52     | 3.61      |

Table 6.6.2: Calculated mean density (by environmental time block, ETB and season) of indicated species and families (density in kg ha<sup>-1</sup>)

| ETB | Season | Demersal | Balistes | Croakers | Snappers | Seabreams |
|-----|--------|----------|----------|----------|----------|-----------|
| 1   | 1      | 11.39    | 0.22     | 0.41     | 0.41     | 3.10      |
|     | 2      | 10.15    | 0.24     | 0.02     | 0.58     | 3.37      |
|     | 3      | 16.11    | 0.17     | 0.41     | 0.77     | 3.77      |
|     | 4      | 13.06    | 0.61     | 0.43     | 0.42     | 3.19      |
|     | All    | 13.42    | 0.30     | 0.37     | 0.57     | 3.41      |
| 2   | 1      | 8.77     | 7.31     | 0.06     | 0.45     | 3.73      |
|     | 2      | 12.91    | 8.13     | 0.16     | 0.41     | 4.72      |
|     | 3      | 17.97    | 1.21     | 1.47     | 0.67     | 5.89      |
|     | 4      | 9.69     | 29.43    | 0.35     | 0.25     | 3.68      |
|     | All    | 12.63    | 9.62     | 0.47     | 0.45     | 4.60      |
| 3   | 1      | 11.59    | 0.91     | 0.07     | 0.50     | 3.07      |
|     | 2      | 10.48    | 0.20     | 0.09     | 0.66     | 2.81      |
|     | 3      | 12.39    | 0.32     | 0.36     | 0.51     | 2.59      |
|     | 4      | 9.91     | 0.30     | 0.12     | 0.51     | 2.25      |
|     | All    | 11.00    | 0.38     | 0.16     | 0.56     | 2.66      |
| All | 1      | 10.32    | 3.45     | 0.16     | 0.45     | 3.36      |
|     | 2      | 11.66    | 4.17     | 0.12     | 0.53     | 3.82      |
|     | 3      | 15.49    | 0.57     | 0.74     | 0.65     | 4.08      |
|     | 4      | 10.75    | 8.72     | 0.27     | 0.41     | 2.93      |
|     | All    | 12.23    | 4.00     | 0.33     | 0.52     | 3.61      |



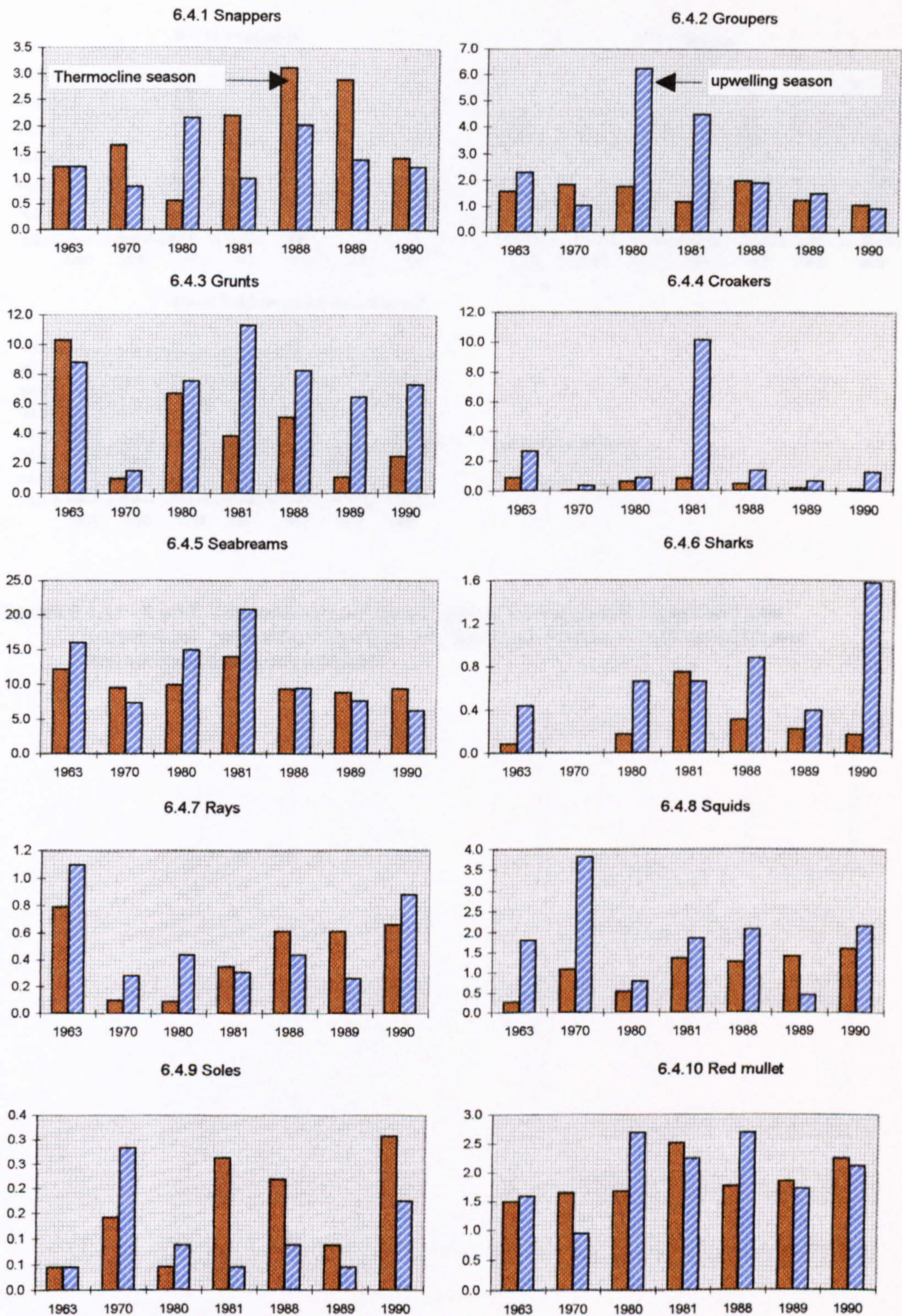
Table 6.6.3: Calculated mean density in each environmental time block, ETB of species and indicated families (density in kg ha<sup>-1</sup>)

| Species/family | ETB 1 | ETB 2 | ETB 3 | All   |
|----------------|-------|-------|-------|-------|
| Demersal       | 13.42 | 12.63 | 11.00 | 12.23 |
| Balistes       | 0.30  | 9.62  | 0.38  | 4.00  |
| Croakers       | 0.37  | 0.47  | 0.16  | 0.33  |
| Snappers       | 0.57  | 0.45  | 0.56  | 0.52  |
| Seabreams      | 3.41  | 4.60  | 2.66  | 3.61  |
| Grunts         | 2.69  | 2.44  | 1.59  | 2.19  |
| Rays           | 0.12  | 0.13  | 0.25  | 0.17  |
| Groupers       | 0.47  | 0.70  | 0.41  | 0.54  |
| Soles          | 0.06  | 0.03  | 0.07  | 0.05  |
| Cephalopods    | 0.73  | 0.34  | 0.76  | 0.59  |

Table 6.6.4: Calculated mean density of species and indicated families by season in each Bathymetric Frame of Reference (density in kg ha<sup>-1</sup>)

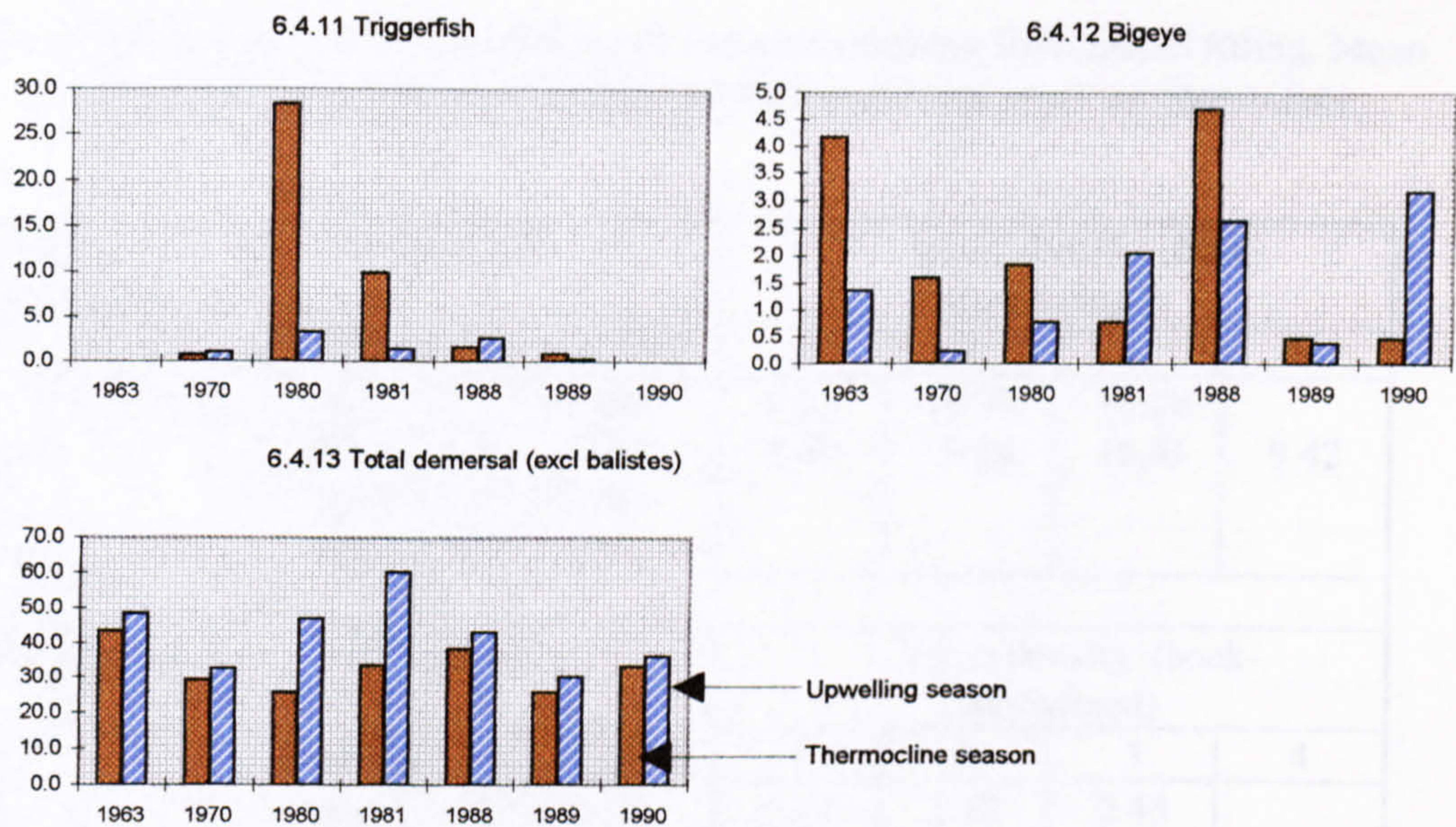
| Season | BFR | Demersal | Balistes | Croakers | Snappers | Seabreams |
|--------|-----|----------|----------|----------|----------|-----------|
| 1      | 1   | 6.79     | 6.23     | 0.04     | 0.44     | 1.54      |
|        | 2   | 9.90     | 3.47     | 0.25     | 0.52     | 3.26      |
|        | 3   | 14.28    | 0.66     | 0.20     | 0.40     | 5.28      |
|        | All | 10.32    | 3.45     | 0.16     | 0.45     | 3.36      |
| 2      | 1   | 5.33     | 2.21     | 0.05     | 0.58     | 1.57      |
|        | 2   | 10.29    | 9.27     | 0.10     | 0.54     | 2.55      |
|        | 3   | 19.36    | 1.03     | 0.21     | 0.46     | 7.33      |
|        | All | 11.66    | 4.17     | 0.12     | 0.53     | 3.82      |
| 3      | 1   | 14.38    | 0.32     | 0.79     | 0.32     | 2.14      |
|        | 2   | 13.90    | 1.24     | 0.28     | 0.70     | 4.32      |
|        | 3   | 18.19    | 0.14     | 1.17     | 0.93     | 5.79      |
|        | All | 15.49    | 0.57     | 0.74     | 0.65     | 4.08      |
| 4      | 1   | 5.17     | 10.48    | 0.07     | 0.17     | 1.23      |
|        | 2   | 10.70    | 15.21    | 0.23     | 0.50     | 2.81      |
|        | 3   | 16.37    | 0.47     | 0.52     | 0.57     | 4.75      |
|        | All | 10.75    | 8.72     | 0.27     | 0.41     | 2.93      |
| All    | 1   | 8.07     | 4.30     | 0.25     | 0.39     | 1.65      |
|        | 2   | 11.28    | 7.11     | 0.21     | 0.57     | 3.24      |
|        | 3   | 17.33    | 0.59     | 0.53     | 0.60     | 5.93      |
|        | All | 12.23    | 4.00     | 0.33     | 0.52     | 3.61      |





Figures 6.4.1 - 6.4.13: Calculated annual density (kg ha<sup>-1</sup>) of principal species and families from surveys conducted during upwelling and thermocline seasons (only years with surveys in both seasons are included)





Figures 6.4.11 - 6.4.13: Calculated annual density (kg ha<sup>-1</sup>) of triggerfish, bigeye and total demersal fish (excluding triggerfish; only years with surveys in both upwelling and thermocline seasons are included)



Table 6.7 Probability values for analysis of variance resulting from model fitting. Mean density values ( $t\text{ nm}^{-2}$ ) for significant factors (except year) are shown (see text).

| 1. Total demersal | Probability   |             | Mean density (back-transformed) |       |       |      |
|-------------------|---------------|-------------|---------------------------------|-------|-------|------|
|                   | untransformed | transformed | 1                               | 2     | 3     | 4    |
| BFR               | <0.01         | <0.01       | 6.57                            | 10.70 | 16.26 | 9.42 |
| Season            | <0.01         | <0.01       | 9.19                            | 9.24  | 14.41 |      |
| Year              | 0.02          | 0.02        |                                 |       |       |      |
| ETB               | 0.29          | 0.93        |                                 |       |       |      |
|                   |               |             |                                 |       |       |      |
| 2. Triggerfish    | Probability   |             | Mean density (back-transformed) |       |       |      |
|                   | untransformed | transformed | 1                               | 2     | 3     | 4    |
| BFR               | 0.02          | <0.01       | 1.35                            | 2.18  | 0.43  | 1.67 |
| Season            | 0.01          | 0.01        | 1.57                            | 1.66  | 0.39  |      |
| Year              | <0.01         | <0.01       |                                 |       |       |      |
| ETB               | <0.01         | <0.01       | 0.28                            | 4.04  | 0.31  |      |
|                   |               |             |                                 |       |       |      |
| 3. Snappers       | Probability   |             | Mean density (back-transformed) |       |       |      |
|                   | untransformed | transformed | 1                               | 2     | 3     | 4    |
| BFR               | 0.26          | 0.11        |                                 |       |       |      |
| Season            | 0.37          | 0.42        |                                 |       |       |      |
| Year              | 0.82          | 0.91        |                                 |       |       |      |
| ETB               | 0.64          | 0.69        |                                 |       |       |      |
|                   |               |             |                                 |       |       |      |
| 4. Seabreams      | Probability   |             | Mean density (back-transformed) |       |       |      |
|                   | untransformed | transformed | 1                               | 2     | 3     | 4    |
| BFR               | <0.01         | <0.01       | 1.38                            | 2.94  | 5.26  |      |
| Season            | 0.27          | 0.12        |                                 |       |       |      |
| Year              | <0.01         | <0.01       |                                 |       |       |      |
| ETB               | <0.01         | <0.01       | 2.78                            | 3.66  | 2.33  |      |
|                   |               |             |                                 |       |       |      |
| 5. Croakers       | Probability   |             | Mean density (back-transformed) |       |       |      |
|                   | untransformed | transformed | 1                               | 2     | 3     | 4    |
| BFR               | 0.82          | 0.72        |                                 |       |       |      |
| Season            | 0.79          | 0.64        |                                 |       |       |      |
| Year              | 0.11          | 0.28        |                                 |       |       |      |
| ETB               | 0.29          | 0.36        |                                 |       |       |      |
|                   |               |             |                                 |       |       |      |

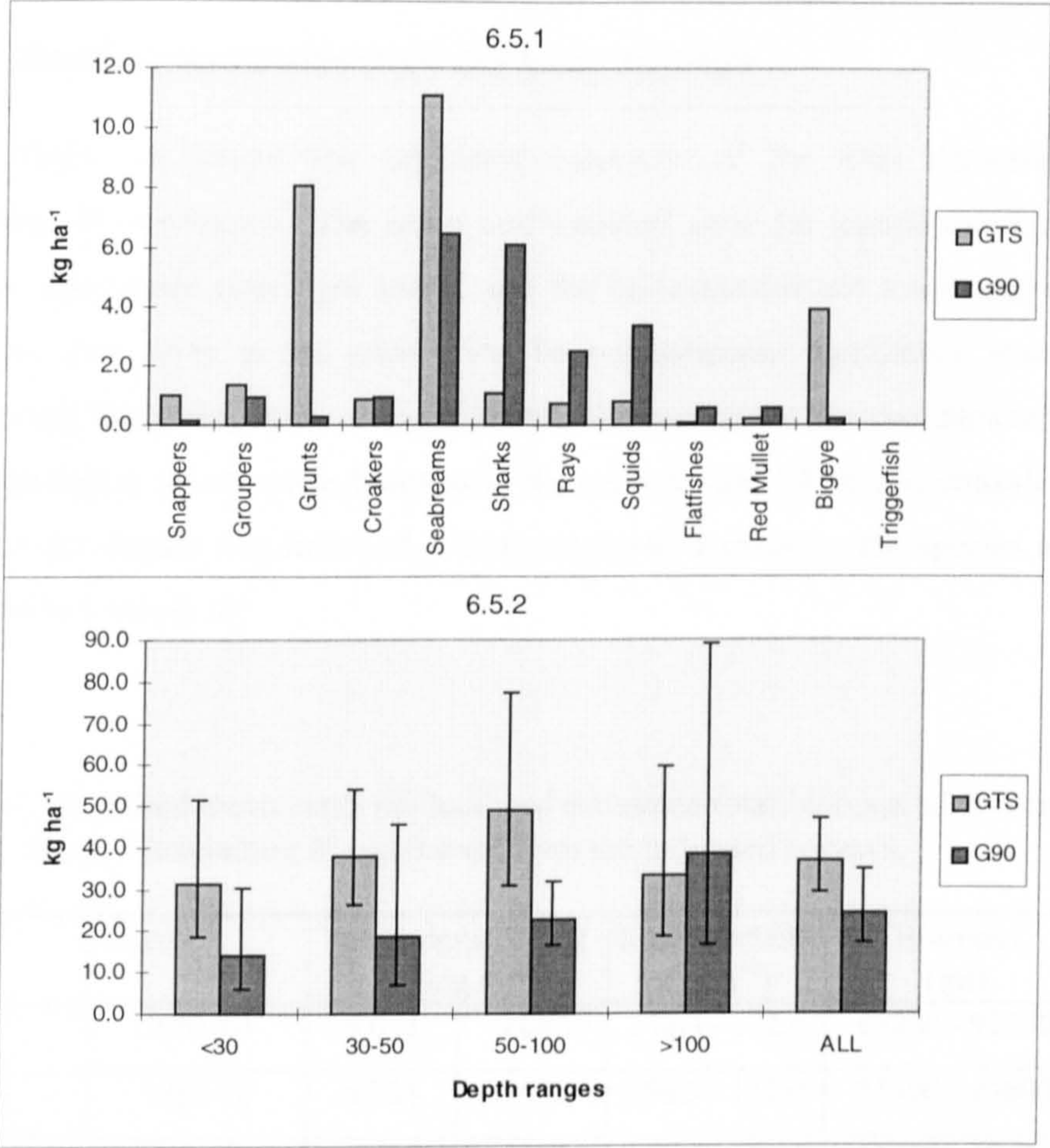


Table 6.7 continued

| 6. Soles       | Probability   |             | Mean density (back-transformed) |      |      |      |
|----------------|---------------|-------------|---------------------------------|------|------|------|
|                | untransformed | transformed | 1                               | 2    | 3    | 4    |
| BFR            | 0.22          | 0.22        |                                 |      |      |      |
| Season         | 0.37          | 0.39        |                                 |      |      |      |
| Year           | 0.03          | 0.02        |                                 |      |      |      |
| ETB            | 0.02          | 0.01        | 0.06                            | 0.03 | 0.07 |      |
|                |               |             |                                 |      |      |      |
| 7. Cephalopods | Probability   |             | Mean density (back-transformed) |      |      |      |
|                | untransformed | transformed | 1                               | 2    | 3    | 4    |
| BFR            | <0.01         | <0.01       | 0.76                            | 0.45 | 0.36 |      |
| Season         | 0.76          | 0.75        |                                 |      |      |      |
| Year           | 0.03          | <0.01       |                                 |      |      |      |
| ETB            | <0.01         | <0.01       | 0.58                            | 0.33 | 0.66 |      |
|                |               |             |                                 |      |      |      |
| 8. Rays        | Probability   |             | Mean density (back-transformed) |      |      |      |
|                | untransformed | transformed | 1                               | 2    | 3    | 4    |
| BFR            | 0.94          | 0.99        |                                 |      |      |      |
| Season         | 0.08          | 0.04        | 0.17                            | 0.21 | 0.15 | 0.06 |
| Year           | 0.11          | 0.02        |                                 |      |      |      |
| ETB            | 0.04          | 0.01        | 0.12                            | 0.09 | 0.23 |      |

### 6.5.2 Differences between GTS and Guinea 90 survey results

Mean density calculated from the results of the GTS and Guinea 90 surveys are depicted in Figure 6.5.1 for selected species and families, and in Figure 6.5.2 for the total demersal biomass. Very clear differences in status of the selected fish species and families are portrayed in the first figure. In the second figure, the difference in density within the sectors (depth zones) are shown. Table 6.8 gives the results of the analysis of variance of testing the difference between the calculated density from the two surveys. The ANOVA results (and Figure 6.5.2) show a significant decline in density of the total demersal stock between GTS II (March, 1964) and Guinea 90 (April 1990).



Figures 6.5.1 and 6.5.2: Estimated total demersal density - GTS II (March 1964) and Guinea 90 (April 1990) (back-transformed means).

Table 6.8: Analysis of variance table for comparing the results of the GTS and Guinea 90 surveys.

| Source of variation | degrees of freedom | Sum of Squares | Mean square | F     | Significance |
|---------------------|--------------------|----------------|-------------|-------|--------------|
| Depth               | 3                  | 1.992          | 0.664       | 0.945 | 0.424        |
| Survey              | 1                  | 3.893          | 3.893       | 5.538 | 0.021        |
| Residual            | 70                 | 49.212         | 0.730       |       |              |



### 6.5.3 Biomass estimates from the trawl surveys

Table 6.9 shows the calculated estimates of the total demersal biomass (excluding *B. capriscus*). The mean and standard error (in logarithmic units) of the index of abundance (catch per hour), and the back-transformed mean and confidence limits are also given in the table. The back-transformed confidence interval is not symmetrical about the mean. The estimated biomass values are also depicted in Figure 6.6. This figure shows a low biomass in the early-to-mid 1970s and considerably high values in the decade that followed. Total estimated biomass for the species and groups are given in Table 6.10.

Table 6.9. Stratified mean catch per haul and estimated total biomass of demersal species (excluding *B. capriscus*) from the indicated surveys.

| Survey    | Years   | mean density and<br>s.e. (log units) |       | Mean density<br>(kg h <sup>-1</sup> ) | Biomass<br>(mt) |
|-----------|---------|--------------------------------------|-------|---------------------------------------|-----------------|
| GTS       | 1963-64 | 5.653                                | 0.080 | 242.8 - 332.6                         | 67200 - 92100   |
| MFRD1     | 1969-70 | 4.724                                | 0.085 | 94.3 - 132.0                          | 35400 - 49600   |
| MFRD1B    | 1973-77 | 4.487                                | 0.132 | 67.6 - 114.1                          | 25400 - 42800   |
| MFRD2     | 1979-80 | 5.462                                | 0.108 | 189.6 - 290.1                         | 61000 - 93300   |
| MFRD3     | 1981-82 | 5.552                                | 0.092 | 214.2 - 307.7                         | 68900 - 98900   |
| MFRD4     | 1987-88 | 5.325                                | 0.066 | 179.5 - 232.8                         | 57700 - 74900   |
| MFRD5     | 1989    | 5.015                                | 0.061 | 132.7 - 168.8                         | 42700 - 54300   |
| MFRD6     | 1990    | 5.164                                | 0.070 | 151.4 - 199.6                         | 48700 - 64200   |
| GUINEA 90 | 1990    | 4.888                                | 0.221 | 85.0 - 203.6                          | 26100 - 62400   |

Table 6.10. Estimated total biomass of selected families and species. Estimates were made stratum by stratum and combined. The mean, lower (LL) and upper (UL) confidence limits are given.

| Species/Family      |      | GTS    | MFRD1 | MFRD1A | MFRD 2 | MFRD 3 | MFRD4 | MFRD5 | MFRD6 | GUINEA 90 |
|---------------------|------|--------|-------|--------|--------|--------|-------|-------|-------|-----------|
| Total<br>—          | LL   | 60000  | 36400 | 23100  | 54800  | 62000  | 59400 | 40600 | 46200 | 22300     |
|                     | Mean | 78800  | 48000 | 36000  | 76700  | 83700  | 72100 | 50200 | 58500 | 41200     |
|                     | UL   | 103700 | 63600 | 56100  | 108600 | 113300 | 87700 | 61900 | 74200 | 81400     |
| <i>B. capriscus</i> | LL   | 70     | 740   | 7800   | 20300  | 11280  | 3490  | 620   | 180   | -         |
|                     | Mean | 330    | 1370  | 14220  | 40080  | 20180  | 5950  | 1130  | 440   | 80        |
|                     | UL   | 670    | 2230  | 24760  | 79300  | 35580  | 9800  | 1800  | 750   | 200       |
| Lutjanids           | LL   | 190    | 520   | 490    | 330    | 280    | 430   | 390   | 380   | -         |
|                     | Mean | 560    | 920   | 890    | 610    | 540    | 770   | 740   | 770   | 300       |
|                     | UL   | 1230   | 1520  | 1500   | 1010   | 910    | 1270  | 1270  | 1380  | 2290      |
| Sciaenids           | LL   | 120    | 50    | 20     | 90     | 50     | 70    | 40    | 100   | -         |
|                     | Mean | 480    | 170   | 140    | 270    | 160    | 200   | 140   | 280   | 200       |
|                     | UL   | 1180   | 350   | 300    | 540    | 300    | 360   | 270   | 530   | 1190      |
| Sparids             | LL   | 16100  | 7500  | 4600   | 9400   | 11700  | 12700 | 8800  | 8300  | 2600      |
|                     | Mean | 24200  | 10700 | 7700   | 14200  | 16600  | 15800 | 11600 | 11200 | 5700      |
|                     | UL   | 36900  | 15300 | 12800  | 21500  | 23400  | 19700 | 15300 | 15100 | 14900     |



Table 6.10 continued

|                    |      |       |      |      |       |      |      |      |      |       |
|--------------------|------|-------|------|------|-------|------|------|------|------|-------|
| Cephalopods        | LL   | 16100 | 1300 | 400  | 11200 | 700  | 1800 | 700  | 1900 | 1100  |
|                    | Mean | 24200 | 1800 | 700  | 13400 | 1200 | 2500 | 1100 | 2800 | 3400  |
|                    | UL   | 36900 | 2700 | 1000 | 24100 | 1800 | 3500 | 1800 | 4100 | 10700 |
| <i>B. auritus</i>  | LL   | 1880  | 550  | 170  | 800   | 700  | 500  | 590  | 870  | -     |
|                    | Mean | 5500  | 1400 | 500  | 2000  | 1800 | 1300 | 1490 | 2010 | 850   |
|                    | UL   | 14700 | 2700 | 900  | 4000  | 3500 | 2600 | 2900 | 4000 | 4280  |
| <i>D. volitans</i> | LL   | 500   | 1750 | 760  | 250   | 340  | 2770 | 1260 | 1720 | 620   |
|                    | Mean | 1250  | 2930 | 1550 | 470   | 630  | 4340 | 2100 | 2780 | 4050  |
|                    | UL   | 2450  | 4610 | 2700 | 740   | 970  | 6580 | 3280 | 4270 | 18500 |

It is essential to note here that perhaps due to the small number of samples (hauls) taken during Guinea 90, the standard error of the calculated means are quite high. These resulted in wide confidence limits and some of which, after subtracting 1 according to equation 6.12, yielded negative figures for biomass. Such negative values have been replaced with a dash (-) in Table 6.10. The biomass estimates were converted to density and summarised by depth range as presented in Table 6.11.

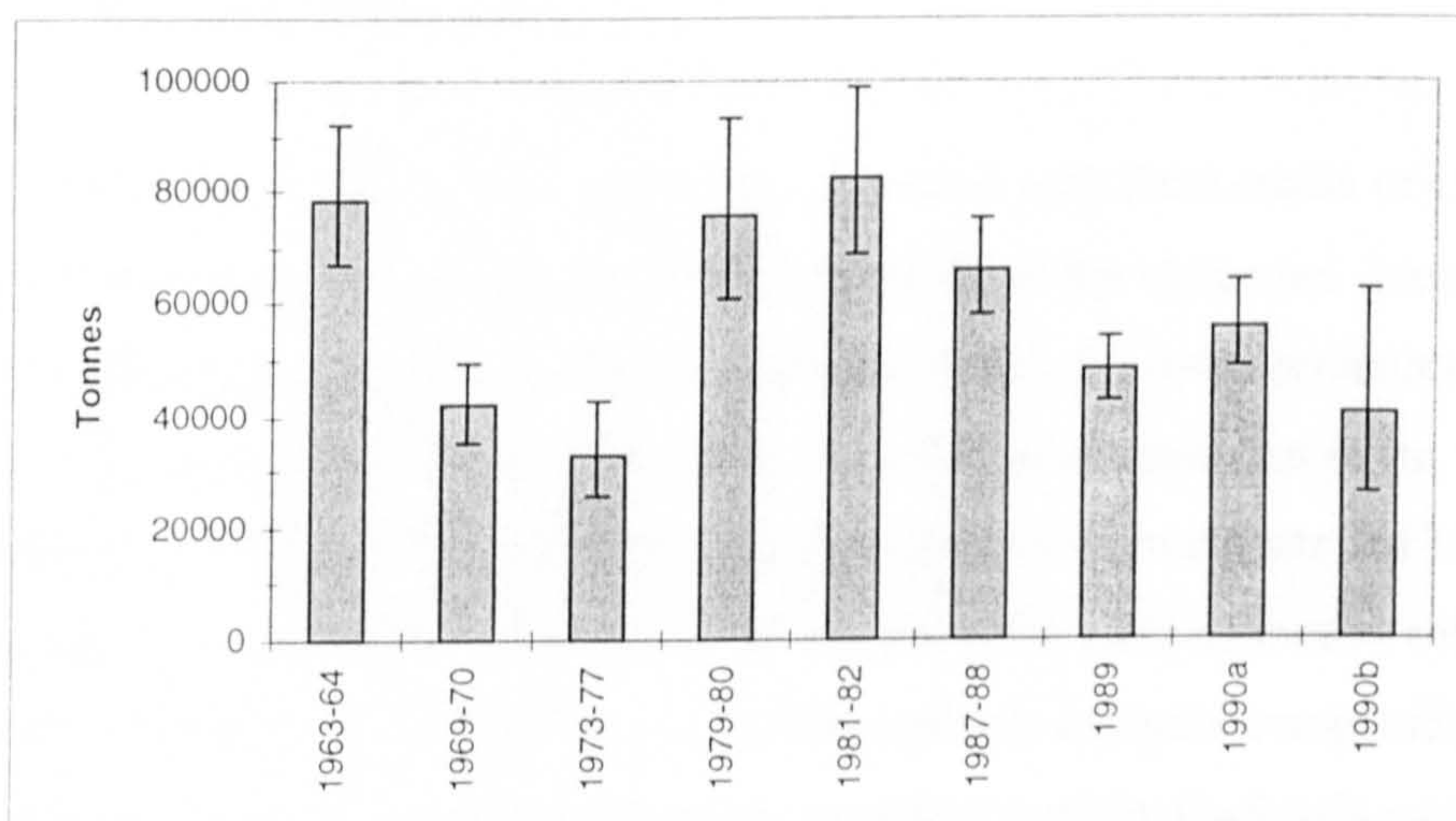


Figure 6.6: Estimated total demersal biomass, 1963 - 1990

Table 6.11 Summary (by depth range) of calculated density of the total demersal resource (excluding *B. capriscus*) ( $\text{kg ha}^{-1}$ )

| Survey   | Year    | 10-30 | 31-50 | 51-100 | 10-100 |
|----------|---------|-------|-------|--------|--------|
| GTS      | 1963-64 | 46.1  | 33.9  | 38.6   | 38.2   |
| MFRD 1   | 1969-70 | 10.3  | 23.3  | 32.3   | 20.4   |
| MFRD 2   | 1973-77 | 9.8   | 17.9  | 22.3   | 16.0   |
| MFRD 2   | 1979-80 | 36.2  | 41.9  | 31.9   | 36.6   |
| MFRD 3   | 1981-82 | 37.9  | 42.9  | 39.6   | 40.1   |
| MFRD 4   | 1987-88 | 20.1  | 32.7  | 48.2   | 31.9   |
| MFRD 5   | 1989    | 19.8  | 21.2  | 31.6   | 23.4   |
| MFRD 6   | 1990    | 20.7  | 28.0  | 34.3   | 27.2   |
| GUINEA90 | 1990    | 18.4  | 18.4  | 23.1   | 19.6   |



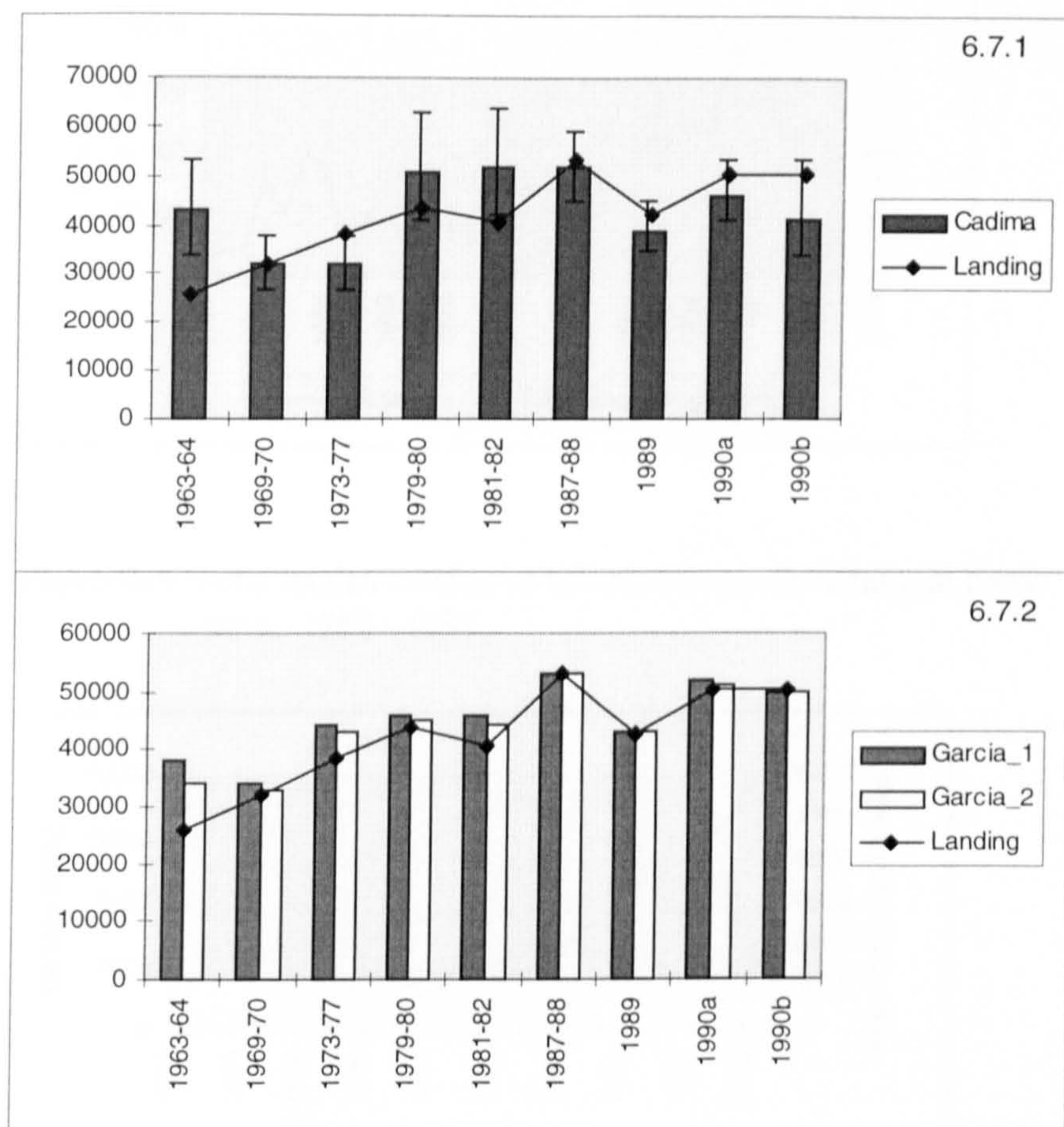
**6.5.4 Potential yield, maximum sustainable yield and landed catches**

Estimates of potential yield of the total demersal biomass calculated from the methods of Cadima (1977) and Garcia *et al.* (1989) are given in Table 6.12. The estimates are also shown in Figures 6.7.1 and 6.7.2, together with total annual landed catches at the time of the surveys. In the method of Garcia *et al.* (1989), estimates for both Schaefer and Fox models were calculated. The value of M (instantaneous rate of natural mortality) used in the calculations of potential yield was estimated to be  $0.76 \pm 0.12$  (Appendix 6.12).

Some of the figures for  $P_y$  that were calculated with the formula of Garcia *et al.* (1989) were quite inconsistent with the magnitude of the estimated biomass. It appears that there are problems with the estimators when the total commercial catch is close to the estimated biomass. Garcia *et al.* (1989) also noted that when  $F > M$ , the estimators diverge greatly and either underestimate or overestimate the MSY. It is important to note, however, that some of the potential yield estimates calculated from the Cadima (1977) and Garcia *et al.* (1989) methods are quite comparable. This means that, the issue of overestimation of the potential yield by Cadima's method (as discussed in section 6.2.6 above) may not be too critical in this work.

Table 6.12: Biomass, potential yield and landed catches, 1963 - 1990

| Year    | Landing | Biomass       | Cadima (1977)   | Garcia <i>et al.</i> (1989)<br>(Schaefer's model) | Garcia <i>et al.</i> (1989)<br>(Fox's model) |
|---------|---------|---------------|-----------------|---|--|
| 1963-64 | 25800   | 67200 - 92100 | 34,000 - 53,000 | 31,000 - 48,000                                   | 29,000 - 41,000                              |
| 1969-70 | 31900   | 35400 - 49600 | 27,000 - 38,000 | ~ 32,000  | ~ 32,000                                     |
| 1973-77 | 38400   | 25400 - 42800 | 27,000 - 38,000 | ~ 38,000  | ~ 38,000                                     |
| 1979-80 | 43800   | 61000 - 93300 | 41,000 - 63,000 | 44,000 - 56,000                                   | 44,000 - 51,000                              |
| 1981-82 | 40700   | 68900 - 98900 | 42,000 - 64,000 | 41,000 - 57,000                                   | 41,000 - 51,000                              |
| 1987-88 | 53100   | 57700 - 74900 | 45,000 - 59,000 | ~ 53,000  | ~ 53,000                                     |
| 1989    | 42400   | 42700 - 54300 | 35,000 - 45,000 | ~ 43,000  | ~ 43,000                                     |
| 1990a   | 50400   | 48700 - 64200 | 41,000 - 53,000 | ~ 52,000  | ~ 51,000                                     |
| 1990b   | 50400   | 26100 - 62400 | 34,000 - 53,000 | ~ 51,000  | ~ 51,000                                     |



Figures 6.7.1 and 6.7.2: Landed catches and potential yield calculated from Cadima's method (6.11.1) and Garcia *et al.*'s method (6.11.2)

Figure 6.8 shows evolution of total annual landed catches of demersal fish species from this ecosystem. Landed catches of triggerfish are also shown. Evolution of the effort of the small-sized inshore trawlers and industrial trawlers is presented in Figure 6.9. This figure portrays a consistent rise in industrial trawl effort and a decline in that of inshore trawlers.

Figure 6.10 is a plot of cpue versus expected effort (TEF 1). From this figure, it appears that the 1991 cpue value is a little out of place, all the same this value was retained in the analysis. Figures 6.11.1 and 6.11.2 are catch versus TEF1 and TEF2 respectively.



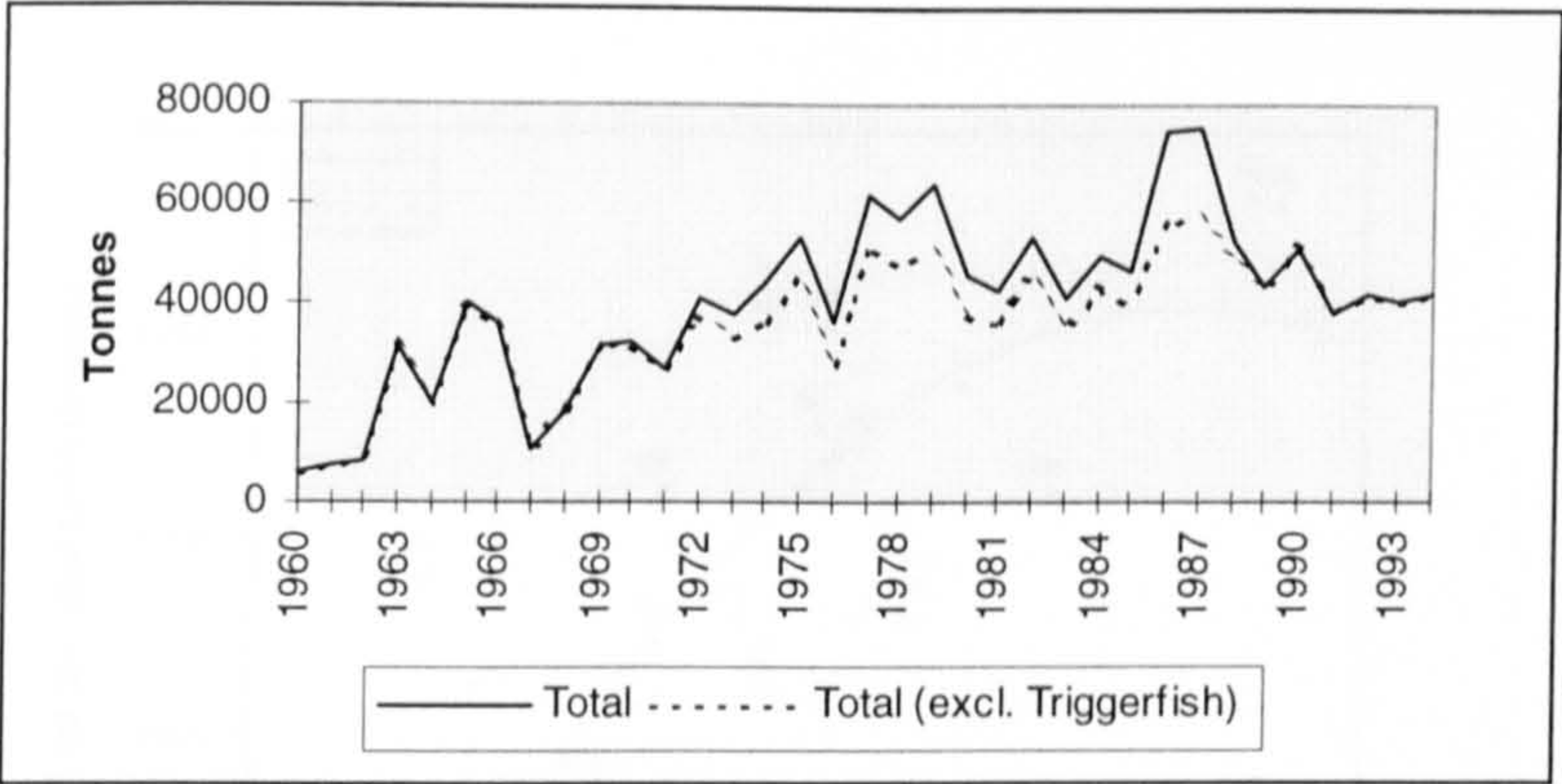


Figure 6.8: Total landed catches of Ghanaian vessels fishing in home waters, 1960 - 1994

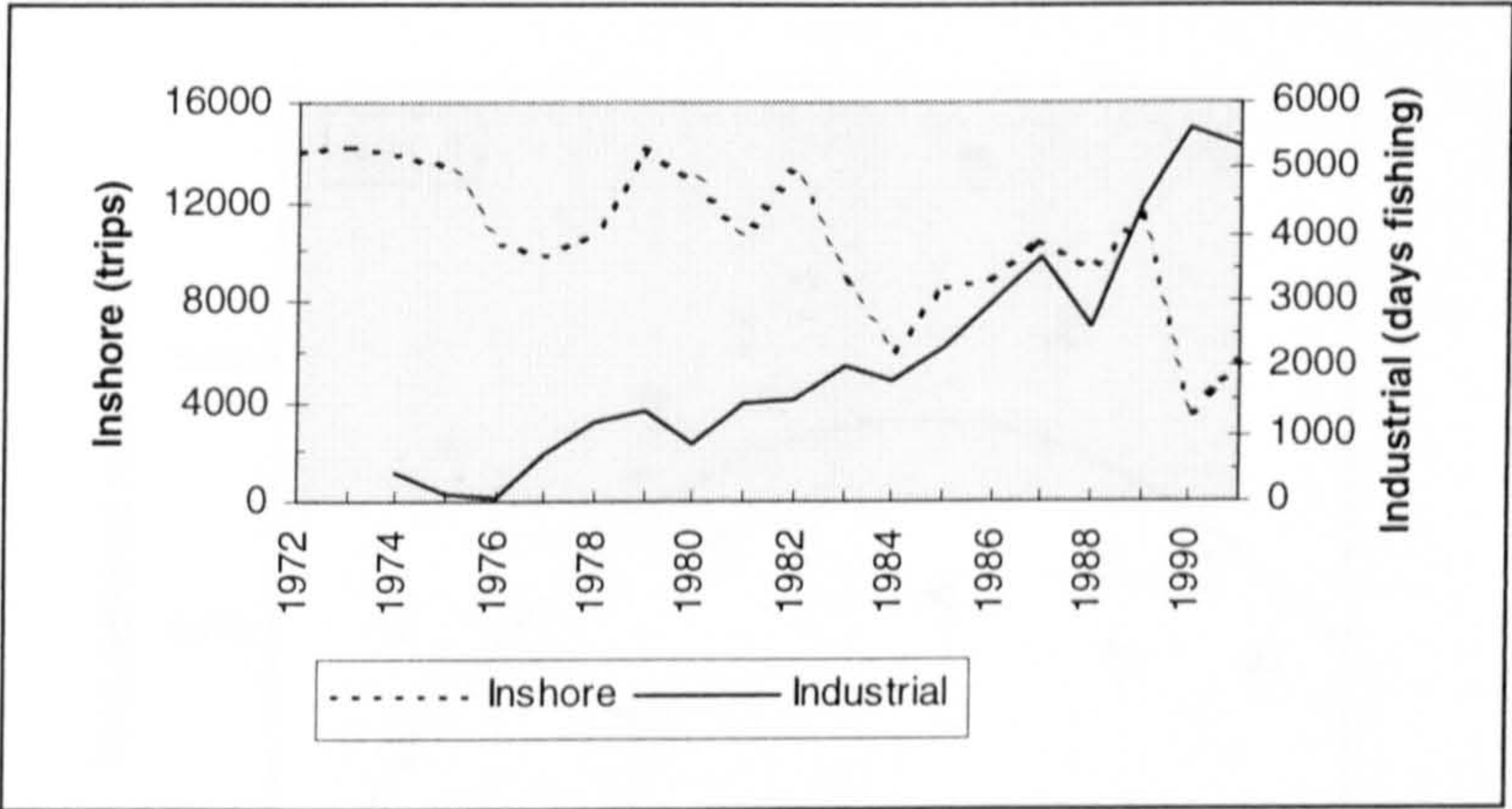


Figure 6.9: Evolution of trawling effort in the Ghanaian demersal fishery, 1972 - 1990

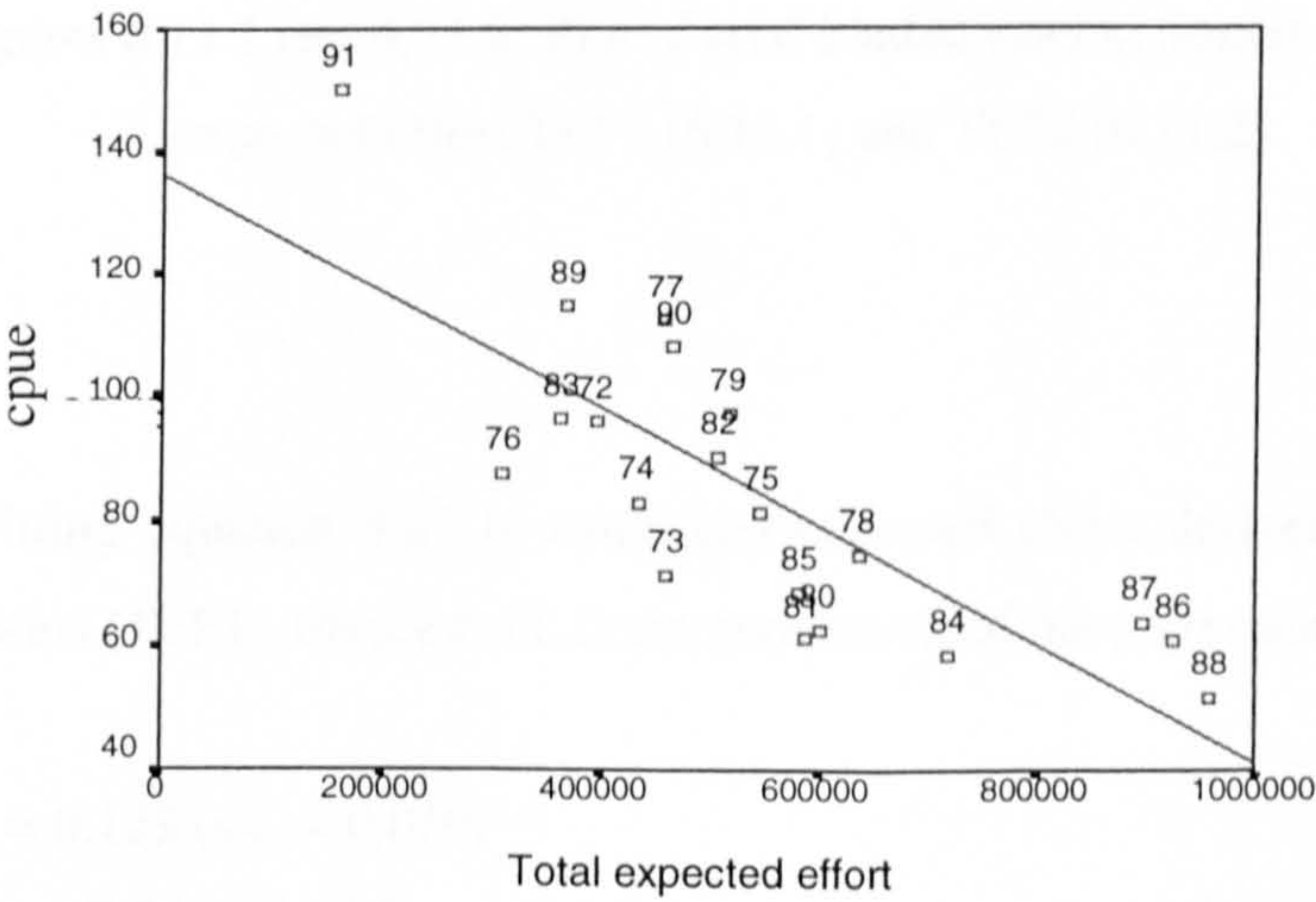
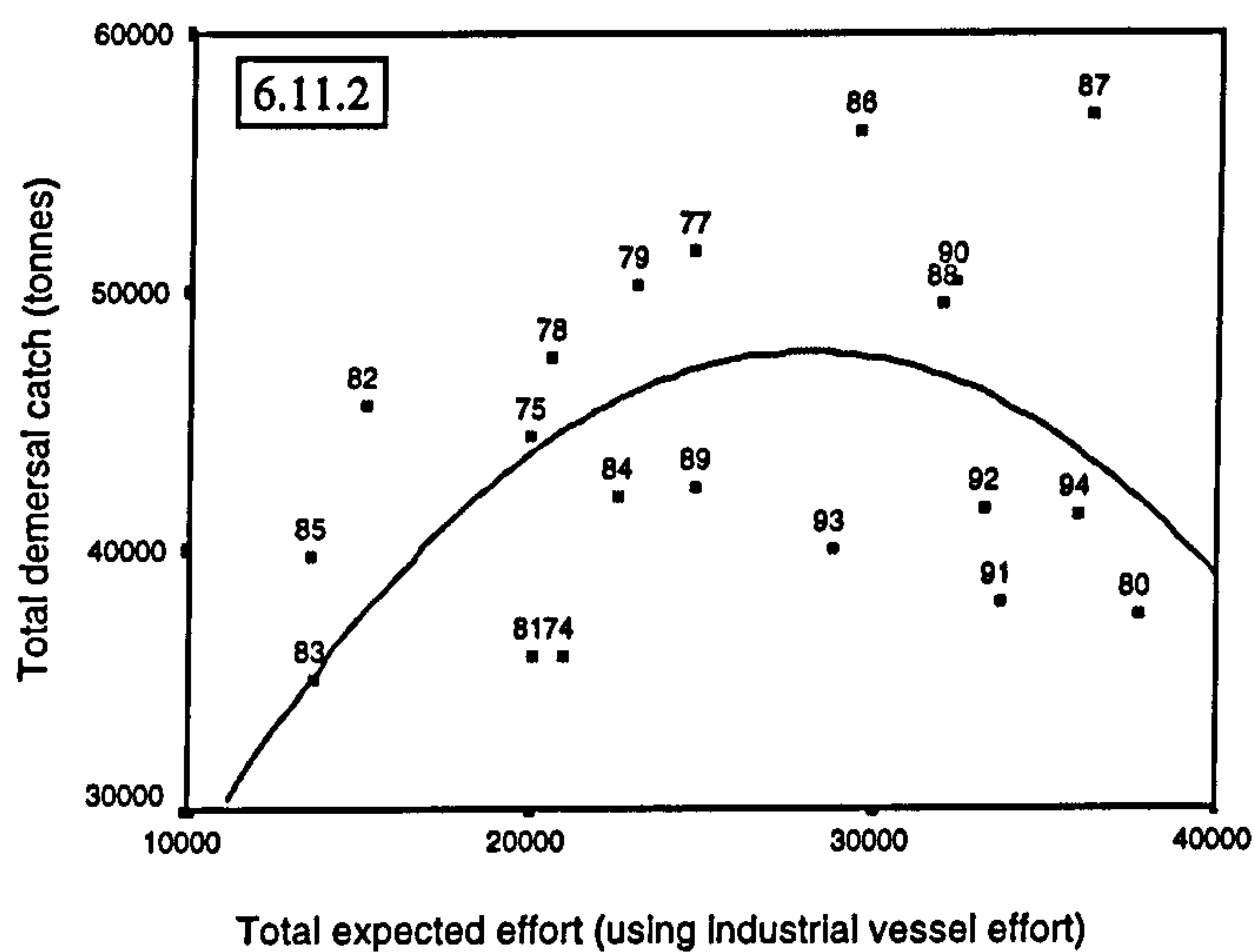
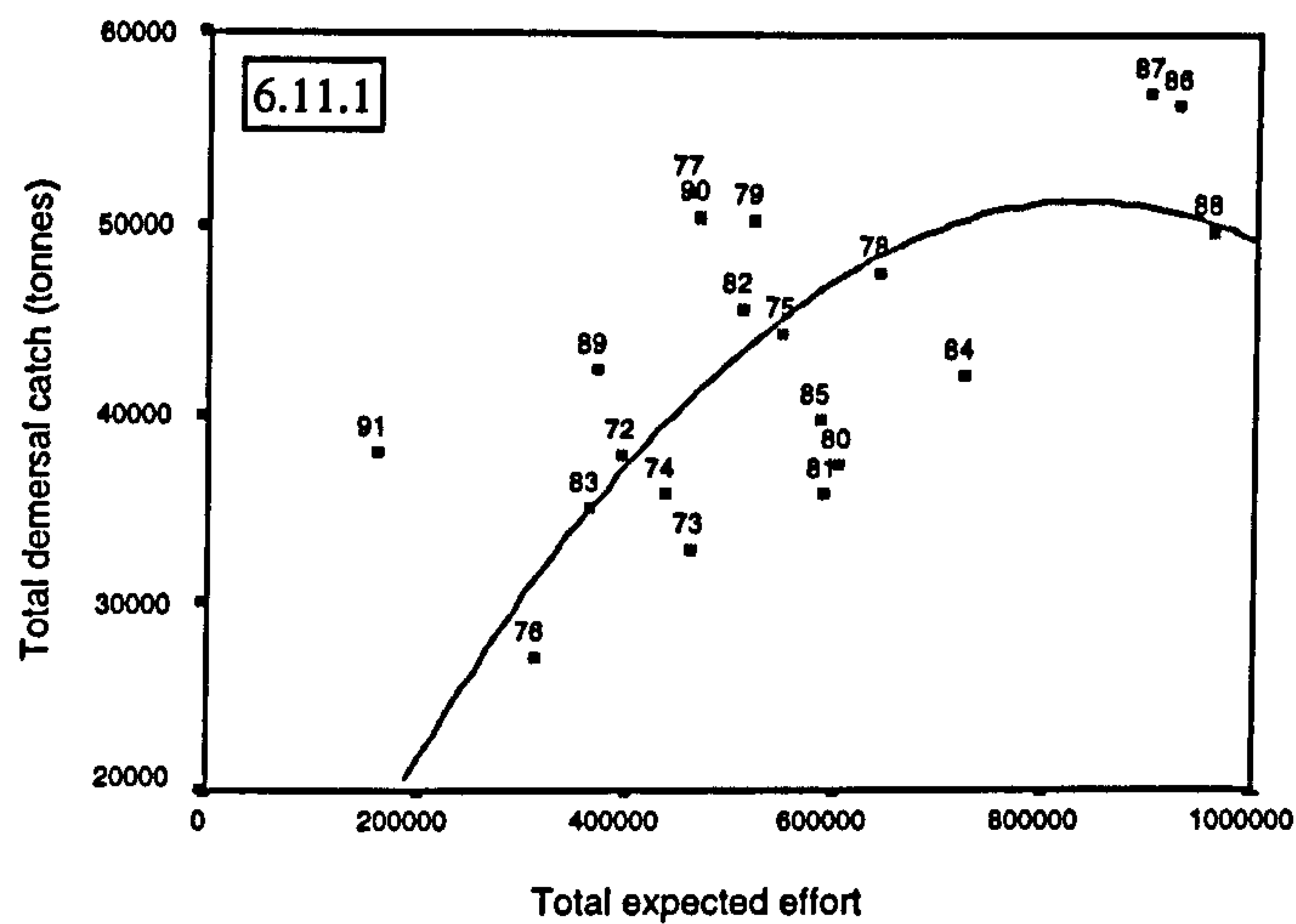


Figure 6.10: Plot of cpue (kg per trip) versus expected effort (TEF1).



Figures 6.11.1 and 6.11.2: Plot of total landed catches versus expected effort TEF1 (6.11.1) and TEF2 (6.11.2)

Fitting equation 6.27 to catch and expected effort derived from the small-sized vessels (TEF1; Figure 6.11.1) the parameters of the regression are:

$$a = 0.123 \text{ (s.e.} = 0.010\text{)}$$

$$b = -7.387 \times 10^{-8} \text{ (s.e.} < 0.0001\text{)}$$



From these estimates, and using equation 6.29, the maximum sustainable yield (MSY) is calculated to be about 51,200 mt per annum for the total demersal resource. When TEF2 (derived from industrial trawlers) is used (Figure 6.11.2), the regression estimates are as follows:

$$a = 3.405 \text{ (s.e.} = 0.252\text{)}$$

$$b = - 6.079 \times 10^{-5} \text{ (s.e.} < 0.001\text{), and}$$

$$\text{MSY} = 47,700 \text{ mt per annum, and}$$

The mean of the two MSY estimates is about 49,500 mt per annum.

Table 6.13 gives landed catches, effort and other statistics for the industrial shrimp fishery. A plot of landed catches of shrimps versus effort is shown in Figure 6.12 and parameter estimates from fitting the surplus yield model are:

$$a = 0.172 \text{ (s.e.} = 0.027\text{)}$$

$$b = - 2.113 \times 10^{-5} \text{ (s.e.} < 0.001\text{)}$$

$$\text{MSY} = 350 \text{ mt per annum}$$

$$f_{\text{msy}} = 4077 \text{ boat days}$$

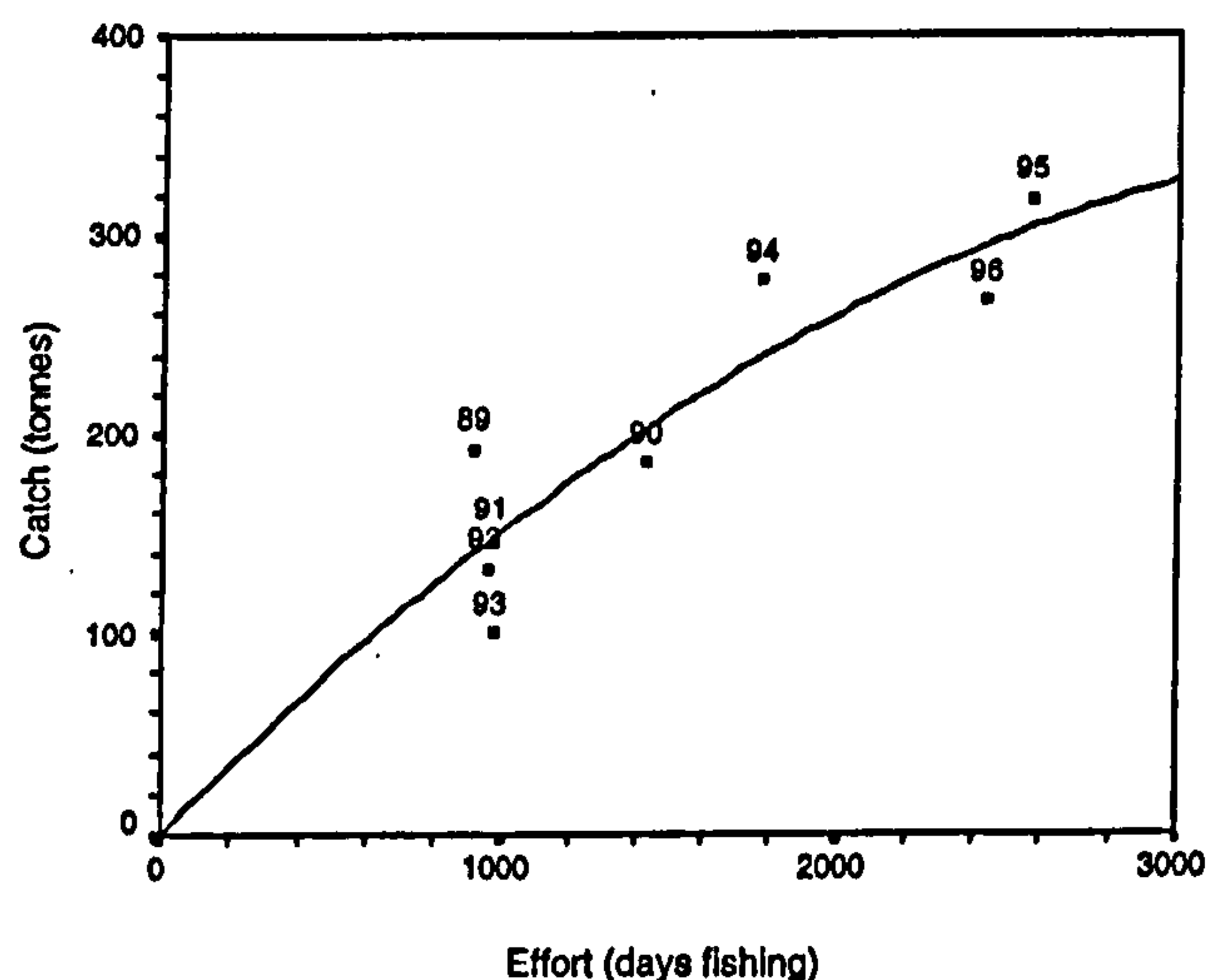


Figure 6.12: Yield curve for the industrial shrimp fishery, 1989-96

Table 6.13. Catch, effort and number of vessel in the industrial shrimp fishery in Ghana (The shrimp vessels were only seriously monitored from 1989).

| YEAR | Number of vessels | Effort (days fishing) | Fin-fish landed (mt) | Shrimps landed (mt) | Total landing (mt) | Shrimp-to-fin-fish ratio | cpue of shrimps (kg/day) | cpue of fin-fish (kg/day) |
|------|-------------------|-----------------------|----------------------|---------------------|--------------------|--------------------------|--------------------------|---------------------------|
| 1986 | 2                 |                       |                      | 5.4                 |                    |                          |                          |                           |
| 1987 | 2                 |                       |                      | 26.6                |                    |                          |                          |                           |
| 1988 | 4                 |                       |                      | 72.7                |                    |                          |                          |                           |
| 1989 | 5                 | 919                   | 187.2                | 193.0               | 380.2              | 1.03                     | 210                      | 204                       |
| 1990 | 8                 | 1431                  | 539.7                | 186.0               | 725.7              | 0.34                     | 130                      | 377                       |
| 1991 | 11                | 976                   | 637.3                | 147.6               | 784.9              | 0.23                     | 151                      | 653                       |
| 1992 | 5                 | 961                   | 253.6                | 132.5               | 386.1              | 0.52                     | 138                      | 264                       |
| 1993 | 8                 | 977                   | 1447.8               | 100.0               | 1547.8             | 0.07                     | 102                      | 1482                      |
| 1994 | 14                | 1772                  | 2165.2               | 277.1               | 2442.3             | 0.13                     | 156                      | 1222                      |
| 1995 | 17                | 2573                  | 2371.5               | 317.3               | 2688.8             | 0.13                     | 123                      | 922                       |
| 1996 | 16                | 2435                  | 2323.3               | 266.8               | 2590.1             | 0.11                     | 110                      | 954                       |

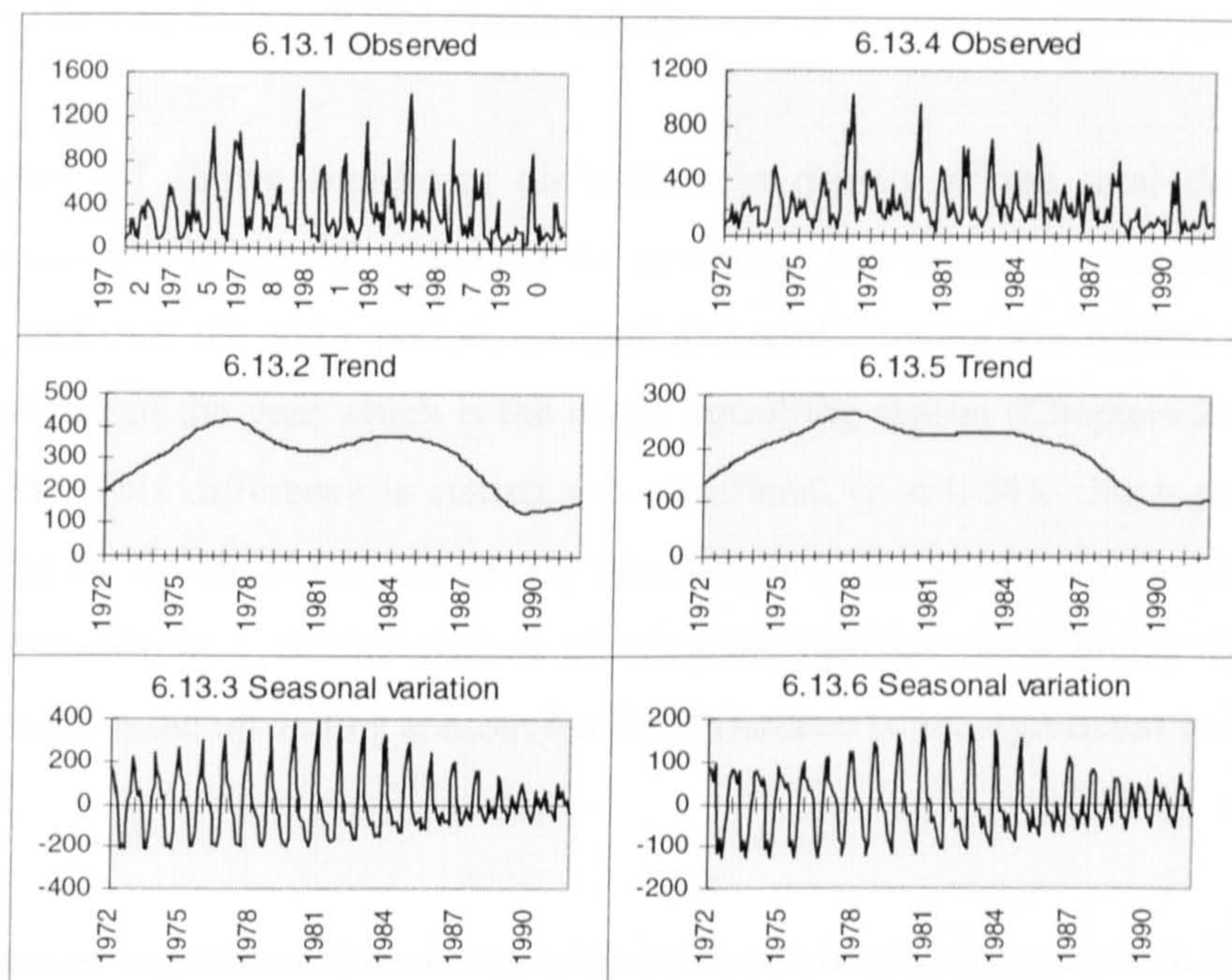
#### 6.5.5 Time series analysis of catch per unit effort

Figure 6.13 shows the calculated values, trend and seasonal variation of the time series of cpues. From the figures, it appears that there is little difference between the series with and without *B. auritus*. From the plots of seasonal variation, it seems that the high variability that characterised landings in the 1970s and early 1980s reduced towards the end of the series.



A: Excluding *B. capriscus*

B: Excluding *B. capriscus* and *B. auritus*



Figures 6.13.1 - 6.13.6: Observed, trend and seasonal variation of cpue; 8 - 12 m long inshore trawlers.

## 6.6 DISCUSSION

Important changes in the total demersal biomass and the biomass of other species and families are discussed below.

### 6.6.1 Annual, seasonal and spatial changes in fish density

The density of the total demersal biomass underwent major change over the 28-year period of investigation; starting at  $17.1 \text{ t nm}^{-2}$  (i.e. nearly  $50 \text{ kg ha}^{-1}$ ) in 1963, through  $7.7 \text{ t nm}^{-2}$  ( $22.5 \text{ kg ha}^{-1}$ ) in 1975 to  $11.1 \text{ t nm}^{-2}$  ( $32.4 \text{ kg ha}^{-1}$ ) in 1990 (Table 6.5). The average density over this period is  $12.2 \text{ t nm}^{-2}$  ( $35.6 \text{ kg ha}^{-1}$ ). The difference between years is statistically significant ( $p = 0.02$ ; Table 6.7). Between environmental time blocks (ETBs) the difference in density is not significant



although the mean density went down from  $13.4 \text{ t nm}^{-2}$  ( $38.5 \text{ kg ha}^{-1}$ ) in ETB1 to  $11.0 \text{ t nm}^{-2}$  ( $32.1 \text{ kg ha}^{-1}$ ) in ETB3 (Table 6.6.3).

Table 6.7 shows significant differences in density of the total demersal biomass (excluding triggerfish) between the upwelling and thermocline seasons. In each ETB, and over the entire period, the total demersal biomass was highest during the third quarter of the year which is the major upwelling season (Chapters 2 and 3, Table 6.6.2). This difference is statistically significant ( $p < 0.01$ ). Such result is important for the timing of future surveys. The density of Sciaenidae, Lutjanidae and Sparidae also exhibit a similar pattern of seasonal variation with higher catches (hence density) in the upwelling season; but the difference is not significant in any of these cases.

There are significant differences in overall mean density in space with density increasing from the first bathymetric frame, BFR1 (10 - 30 m) to BFR3 (51-100 m) in each ETB and in the overall (Table 6.6.1). These differences were discussed at length in chapter 5. The point to note in this table, and in Figure 6.5, is the widening gap between the density in inshore and offshore areas between GTS II in 1964 and Guinea 90 in 1990. This shows differential rates of exploitation between the bathymetric frames over time and resulting in the depletion of the shallow areas. Such differential exploitation is common in fisheries. It is important to note also that on the Ghanaian continental shelf it is not easy to trawl in the area deeper than 70 m (Salzen 1957; Williams 1968; Rijavec 1980; Koranteng 1980, 1984), thus limiting trawling mostly to relatively shallower areas. The exception is on the extreme west of the shelf where the area beyond 70 m is trawlable.

Spatial and temporal changes in the density of the major families of fish, as have been discussed in Chapter 5 for the thermocline season, are confirmed by the results presented in Tables 6.6.1 - 6.6.4. In the case of sparids, there is a significant increase in density from shallow to deep waters and significant changes between the three environmental time blocks with the highest density recorded during ETB2 and lowest in ETB3. The results obtained for cephalopods, rays and soles are rather



similar. For each of these, the highest density was recorded during ETB3 and the minimum was during ETB2. Rays also showed a significant seasonal difference with highest density recorded during the short warm season (April to June).

### **6.6.2 Differences between GTS and Guinea 90 survey results**

The Guinean Trawling Survey and the Guinea 90 survey were conducted at the beginning and end respectively of the period under investigation; thus the results show the situations at both ends of the 28 year period. As the two surveys were conducted approximately during the warm season (GTS II was in March and Guinea 90 was in April) comparisons could only be made for differences between the two surveys and also between depths.

The difference in density of the total demersal biomass estimated in the two surveys is statistically significant ( $p = 0.02$ ; Table 6.8) with higher density recorded during the GTS than during Guinea 90. The reduction in density is seen at all depth ranges except at depths of 100 m and over (Figure 6.5.2) where the density in Guinea 90 is higher than in the GTS. The higher density is due mainly to increased biomass of *Sepia officinalis* at these depths, especially on the eastern part of the shelf (Ramos *et al.* 1990).

On individual species and family basis (Figure 6.5.1), one can see a reduction in density of snappers, groupers, seabreams and even bigeye (*Priacanthus arenatus* which is not a high grade fish). The biggest change is with the grunts (which is mainly *Brachdeuterus auritus*). However, considering its semi-pelagic nature, and thus a possible higher influence of the environment on its abundance, it may be inadequate to measure change in *Brachdeuterus auritus* with information from just two surveys. The reduction in density of high value fishes like sparids, snappers and groupers, is an indication of change induced by fishing (Gulland 1972). This is because fishers would normally target these species. On the other hand, the density of sharks, rays, cephalopods and soles increased.

### 6.6.3 Long-term changes in stock biomass

The total demersal biomass (excluding triggerfish) in waters of 100 m deep or less, reduced from 67,000 - 92,000 mt evaluated during GTS to less than half this quantity in the years between 1973 and 1977 (25,000 - 43,000 mt, Table 6.9 and Figure 6.6). In the survey conducted in 1979-80, a higher average biomass of 75,000 mt was obtained. In successive surveys, the biomass increased further to a peak of about 83,000 mt in 1981-82 but declined thereafter.

The low value of the estimated biomass between 1969 and 1977 is rather significant. Several factors may have contributed to this situation and these may be broken down into (i) assessment factors and (ii) biology. All surveys conducted during the period in question were done with *R/V I*. It is possible that the vessel's performance and the catchability of the survey gear resulted in low catch rates. Such vessel effect includes even subtle differences like rigging of the net, mode of shooting and hauling in the survey net, and vessel noise (Somerton 1996, mimeograph). Vessel noise affects the behaviour of fish schools as the vessel approaches.

What looks even more plausible is an overestimation of the swept area of the survey net using Dinglassan's method. The results obtained from such experiments on wing spread are highly variable and quite inconsistent (personal observation). The wing spread depends very much on water depth, sea state (Koranteng unpublished information) towing direction and strength and direction of water currents (Dinglassan 1973). The assumption of accurate geometry of the trawling gear (i.e. no curvature in towing warps between the vessel and the net) may not be achievable. The vertical opening of the survey net also affects the catch rate in terms of how much of semi-pelagic species the gear can reach. From equation 6.1, and considering the size of the survey area and the swept area of the net, overestimating the latter would lead to significant underestimation of the biomass.

Another factor is the paucity of cruises between 1970 and 1977 and the



limitation in coverage of those cruises. For example, only 152 hauls were made between 1973 and 1977. But for the findings on the behaviour of the marine environment around this period, the surveys between 1973 and 1977 would have been conveniently ignored. This leads to the possible biological effect on the biomass. The period was characterised by dramatic changes in the biological and physical components of this ecosystem including drastic decline of the biomass of *Sardinella aurita* and proliferation of *Balistes capriscus* (chapter 2), drop in temperatures and increase in salinity of shelf waters (chapter 3).

Also, there was an increase in fishing activities of large industrial fishing vessels around this period in these waters (Mensah and Koranteng 1988).

#### **6.6.4 Potential yield, maximum sustainable yield and landed catches**

The potential yield calculated from the 1963-64 GTS survey, using both methods of Cadima (1977) and Garcia *et al.*(1989) varied between 29,000 and 53,000 mt per annum. The average is about 38,000 mt. The catch in that year was about 26,000 mt, which is less than the potential yield. The fishery was in a healthy state. As the biomass declined resulting in low potential yield (average of 32,000 mt per annum in 1973-77), landings stayed a little higher than the average potential yield (Figure 6.7.1) indicating over-exploitation of the resource. As the biomass 'recovered', potential yield also increased to 35,000 - 64,000 mt with an average of 47,000 mt per annum between 1979 and 1990. Between 1979 and 1988, landings were within the range of the potential yield but were too close to the upper limit (Figure 6.7.1). After 1988, landings exceeded the potential yield. Landed catches were always within the limits of the potential yield estimated by Garcia *et al.*'s (1989) method, although they were mainly at the upper end.

From these results, it appears that the potential yield of the total demersal biomass on Ghana's continental shelf is somewhere between 36,000 - 55,000 mt per annum with an average of about 43,000 mt. In the period that stocks were assessed through trawl surveys, landings from the fishery averaged between 11,000 and

56,000 mt per annum.

It is essential to note here that whereas the biomass has been assessed with survey nets with minimum mesh of 40 mm in their codends, several nets in use in the industry only have 25 mm codend mesh (see chapter 7). This means that the biomass available to the fishery is much more than estimated in these surveys although much of it would be juvenile fish. For example, a large proportion of landings is made by beach seines, the landings of which are mainly juvenile fish. This is one of the primary reasons why landed catches are so high compared to the estimated biomass.

The estimated value of the maximum sustainable yield (MSY) from the catch and effort data (49,500 mt per annum) is rather comparable to the potential yield estimated from the trawl surveys (i.e. about 43,000 mt). It is indeed an impressive result considering the kind of fishing effort used in the analysis.

The maximum sustainable yield of shrimps obtained in this analysis is much lower than the 650 mt estimated in 1970 for *P. notialis* alone. One reason is that the data used here do not include catches made by artisanal and semi-industrial fleets which also amount to about 600 mt per annum (Anon 1990). Generally, this is made up of small-sized shrimps of lower commercial value. From these analyses, it would appear that the shrimp fishery is in good shape. However, considering the possible impact of industrial shrimping on the ecosystem, in terms of habitat destruction and discards of juvenile fish, then stringent management measures must be taken to regulate the fishery.

#### **6.6.5 Time series analysis of catch per unit effort of trawlers**

The decomposition of the time series of cpue shows an underlying increasing trend of catch per unit effort between 1972 and 1977 and a decrease since then (Figures 6.13.2 and 6.13.5). This is further evidence of a fishery that has reached its limit of exploitation and in fact showing signs of over-exploitation. The decline in cpue, especially in the last ten years is rather worrying and seems to suggest that the



effort on the fishery needs to be reduced.

#### **6.6.6 Possible causes of falling catch rates in the demersal fishery of Ghana**

In fisheries, declining catch rates are usually attributed to over-fishing. Some of the causes of the declining catch rates in the Ghanaian demersal fishery are examined here.

##### **6.6.6.1 Destructive fishing methods and the use of undersized meshes**

Studies conducted by the Marine Fisheries Research Division (MFRD unpublished data) show that the mesh size in codends of trawls in use in the Ghanaian demersal fishery range between 25 and 70 mm (stretched diagonal). Many nets have a mesh size less than the 60 mm permitted under Ghana's fisheries laws (PNDCL 256) and recommended by the FAO Fishery Committee for the Eastern Central Atlantic (FAO 1980). The use of under-sized mesh is widespread, especially in the inshore fishery where the codends of the trawl nets used by many of these vessels are lined with small-meshed netting (J-L. Lauzière<sup>4</sup> *pers. comm.*).

It is common practice for fishers operating in an over-exploited and usually unmanaged or poorly managed fishery to use smaller-sized meshes as a means to increase their catch. Pauly *et al.* (1989) and Pauly (1994) describe such a situation as *Malthusian overfishing*, which “occurs when poor fishers, faced with declining catches and lacking any other alternative, initiate wholesale resource destruction in their effort to maintain their incomes”. Pauly *et al.* (1989) give the symptoms of *Malthusian overfishing* (in order of seriousness) as:

1. use of gears and mesh sizes that are not sanctioned by government,
2. use of gears not sanctioned within the fisherfolk communities,
3. use of gears that destroy the resource base, and

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<sup>4</sup> Mr. J.L. Lauzière is an MCS (Monitoring, Control and Surveillance) expert and was consultant to the Ghana Fisheries Sub-sector Capacity Building Project in 1997.

4. use of 'gears' such as dynamite or sodium cyanide that do all of the above and even endanger the fisherfolks themselves.

Artisanal fishers in Ghana use beach seine, hook-and-line and bottom-set gill nets to exploit demersal fishes. A large part of the beach seine net is made up of 10 mm mesh netting (Doyi 1984) and this results in the gear catching substantial quantities of young fish of all species. This situation is aggravated by the fact that there is market for all sizes of fish in Ghana; therefore, there appears to be some benefit, even if marginal, in catching juvenile fish.

Although not a widespread practice, some artisanal fishers also use dynamite in fishing. This non-selective method of fishing is extremely destructive to fish habitats and fish stocks.

#### 6.6.6.2 The impact of industrial shrimping on the demersal ecosystem of Ghana

In Ghana, shrimps are caught by all fleets (except tuna fishing vessels), mainly from shallow waters and close to estuaries. The industrial shrimp vessels are required to use shrimp trawls of 40 mm mesh in the codend. In practice smaller mesh sizes are used and the semi-industrial vessels use even much smaller mesh sizes. Artisanal operators catch shrimps mainly in beach seines.

The upsurge of commercial shrimping in Ghana in the last decade has been a source of worry to fisheries administrators. This is because, it was not based on any scientific evaluation of the resources. Unable to stop the fishery, the Fisheries administrators reacted to the situation by granting shrimping licences which limit the vessels to specific areas only. These are the areas where the fishery normally operates and which coincide with the areas identified in the shrimp assessment surveys in 1970 (Jones 1970). Unfortunately, there is no information to say whether this regulation is complied with, but it is widely believed that it isn't. Industrial shrimpers are to operate mainly in the vicinity of the Volta estuary and Cape St. Paul



(on the east) and around the Pra estuary and westward towards Cape Three Points (on the west; Figure 2.4.1).

In the earlier fishery (1969 - 1975), an average of 720 mt of shrimps (mainly *Penaeus notialis* and *Parapeneopsis atlantica*) was caught annually. The potential yield of *Penaeus notialis*, the most important shrimp species in the area, was estimated to be between 650 and 670 mt per annum (Jones 1970; Garcia and Lhomme 1980). In the present fishery, landed catch of shrimps (mainly *P. notialis*) increased from just about 5.4 mt in 1986 to a maximum of 317 mt in 1995 (Table 6.13). The proportion of fin-fish in the landed catch is quite high and the ratio of shrimp-to-fin-fish catch varied between 1.03 during the early stages of the fishery to 0.07 in 1993.

During 1989 and 1990, Fisheries Department's observers on shrimp vessels estimated that as much as 20 % of the catches of shrimp vessels are discarded at sea (these are mainly juvenile fin-fish). It was also estimated that on the average, for every kilogram of shrimp landed, another kilogram of fin-fish are discarded (Anon 1990). These statistics raise serious concern about the shrimp fishery in Ghana's shelf waters and the potential impact of such fishery on the demersal fish resources generally.

In many parts of the world, it is believed that coastal shrimp fisheries contribute significantly to the destruction of juvenile demersal fishes. In Sierra Leone, the shrimp fishery contributed significantly to the reduction in catch rates of principal demersal species (Coutin 1989). In Nigeria, the high composition of juvenile croakers (*Pseudotolithus* sp.), grunts (*Pomadasys* sp.) and soles (*Cynoglossus* sp.) in the catches of shrimp vessels poses a serious problem in the fishing industry (Ajayi and Anyanwu 1997). In Southeast Asia, where catch of shrimps decreases with distance from the coast and therefore shrimpers operate close inshore (Pauly 1988), this fishery is considered very destructive to demersal fin-fish resources.

#### 6.6.6.3 Effects of nearshore processes and environmental degradation

Coastal ecosystems like estuaries, lagoons, mangroves and wetlands contribute significantly to the health of marine fish stocks providing breeding, nursery and feeding grounds for marine fish species. In Ghana, juveniles of a number of commercially important marine fish species like Lutjanidae, Serranidae and Penaeidae are found in coastal lagoons (Pauly 1976; Koranteng 1995). Worldwide, it is estimated that about 95 percent of marine production originate from coastal ecosystems (Naeve 1996). This means that activities in the coastal zone can have a significant impact on marine fish resources.

Encroachment of wetlands is a serious problem world wide (e.g. see Price 1996); in Ghana, wetlands are now increasingly threatened from human activities. Urbanisation, pollution of lagoons, and over-exploitation of lagoon fish resources have put severe environmental stress on coastal wetlands and estuaries (Koranteng 1995). A number of coastal wetlands have lost their mangrove cover due mainly to the use of mangroves as fuel wood (Koranteng 1995). The possible effect of these is a reduction in the contribution of the wetlands to the recruitment of demersal fish and shrimp stocks.

#### 6.6.7 Comparisons with demersal fish stocks elsewhere

In the GTS, the density of total demersal biomass in neighbouring areas were as follows: western Côte d'Ivoire - 28.9 kg ha<sup>-1</sup>, eastern Côte d'Ivoire (including part of western Ghana) - 41.9 kg ha<sup>-1</sup>, Ghana - 36.5 kg ha<sup>-1</sup>, Dahomey (comprising of Togo, Benin and part of Nigeria) - 33.6 kg ha<sup>-1</sup> and Nigeria - 29.3 kg ha<sup>-1</sup>. These are rather similar results although the density in the central upwelling zone off Côte d'Ivoire and Ghana is relatively higher than the other areas. But during the Guinea 90 survey twenty-eight years later, the density was 37.3 and 36.1 kg ha<sup>-1</sup> in Ivorian and Ghanaian waters respectively (Ramos *et al.* 1990). Density in shallow areas was much higher in Côte d'Ivoire than in Ghana. The density in the Ivorian and Ghanaian areas was also higher than in the Liberian and Sierra Leonean sectors.



The observed increase in density of total demersal biomass on the continental shelf of Ghana between 1969-70 (20.4 kg ha<sup>-1</sup>) and 1979-80 (36.6 kg ha<sup>-1</sup>) was also seen in neighbouring Ivorian waters, although to a lesser extent. There the density assessed through the CHALCI bottom trawl surveys increased from 1.1 t km<sup>-2</sup> in 1966-67 to 1.3 t km<sup>-2</sup> in 1978-80 (Caverivière 1982).

It was noted earlier in this thesis that the changes in demersal fish biomass and assemblage properties may be due to a combination of factors including fishing, climate and environmental changes. In Sierra Leone, Coutin (1989) concluded that fishing has had a relatively small impact on the stocks. Further afield, changes in the Gulf of Thailand demersal fishery (including community structure) were also attributed entirely to the tremendous increase in fishing effort (Tiews *et al.* 1967). However Gulland (1972) does not think that this is entirely right, arguing that fishing will reduce fish that are expensive and attractive to fishers but in the Gulf of Thailand there was an increase in the biomass of *Lutjanus* sp. along side with increase in squid and Heterosomata. Therefore, it appears that it is not easy to isolate the cause of changes in fish populations.

#### **6.6.8 Peculiar case of *Balistes capriscus* in the shelf ecosystem off Ghana**

The proliferation of *Balistes capriscus* in the coastal waters of Ghana and Côte d'Ivoire is the biggest occurrence in the demersal resource since the Guinean Trawling Survey. It is interesting to note that in the survey conducted with *R/V Birkut* between Guinea and Ghana in 1961 (Chrzan 1961), *B. capriscus* was ranked 13<sup>th</sup> among the 80 species caught off Ghana and Côte d'Ivoire. This was equivalent to 2.02 % of the total catch in this area which was surveyed in May. This means that the species was actually present in this ecosystem before its period of proliferation thus confirming the views of old fishers on this issue. Thus, it is difficult to understand why its share of the biomass was negligible in 1963-64 at the time of the Guinean Trawling Survey. In the same *Birkut* survey, *B. capriscus* was recorded off Guinea where it was the 17<sup>th</sup> most abundant species and accounted for 0.69 % of the total catch. The areas off Guinea and Ghana to Côte d'Ivoire, later became the two

epicentres from which the species spread almost throughout the Gulf of Guinea.

The dramatic change in the stock biomass of *B. capriscus* over the study period has been confirmed in this analysis. The results presented here corroborate observations in the field and events in the industry. The density of the species (back-transformed means) increased from 0.30 t nm<sup>-2</sup> (0.9 kg ha<sup>-1</sup>) in ETB1 to 9.62 t nm<sup>-2</sup> (28.1 kg ha<sup>-1</sup>) in ETB2, declining thereafter to 0.38 t nm<sup>-2</sup> (1.1 kg ha<sup>-1</sup>) in ETB3 (Tables 6.6.1 and 6.6.2). The density reached as high as 17.2 t nm<sup>-2</sup> (50.2 kg ha<sup>-1</sup>) in BFR2 during ETB2. Thus, the biggest biomass of the demersal component of *B. capriscus* recorded during the study period was about 40,000 mt in 1979-80. The average annual landing in those two years was 10,800 mt giving it a potential yield of 13,000 - 34,000 mt per annum (from Cadima's formula). Thus the landed catches were much less than the potential yield (also see Koranteng 1984). In the same period, the average demersal biomass of all other species was about 77,000 mt. Between 1979-80 and 1981-82, the demersal biomass of *B. capriscus* reduced by 50 percent.

*B. capriscus* is more abundant in the warm season (especially in the last quarter of the year) than in the upwelling season. In ETB2, for example, the mean density in the thermocline season was over twenty times higher than in the major upwelling season (Table 6.6.2). Generally, the highest density was in the second (30 - 50 m) depth range followed by the 10 - 30 m range.

#### **6.6.9 General limitation of the analyses**

In section 6.6.3 above, some of the factors that could affect biomass estimation by swept area method have been stated. In addition to these factors which are mainly related to accuracy of estimation parameters and behaviour of the survey gear, deliberate avoidance of rocky grounds during the survey would also seriously affect the results. It is unwise and certainly expensive to trawl on bad ground where the gear is likely to get damaged or lost. The biomass of fish with preference for



such grounds is thus under-estimated.

Comparing results of surveys conducted with different vessels can be problematic given the problem of vessel effect which cannot easily be detected or eliminated. Many factors come into play in these comparisons. Even where the same gear is deployed on the same vessel, repairs to the gear (e.g. mending of damaged net) can result in significantly different catch rates before and after the mending (Somerton 1996 mimeograph).

A general observation on the biomass estimates is the choice of 0.75 for the catchability coefficient,  $q$ . Fish of different sizes may be caught with varying efficiency (Ricker 1975). As there was no basis to guide the choice of  $q$ , it was not possible to adopt the approach of Blaber *et al.* (1990) where different catchability coefficients are used for different sizes of fish. Besides, catchability can vary within a year (Ricker 1975).

The choice of  $X_2$  (Equation 6.14) for the estimation of  $b$  (wing spread of the survey net) is quite arbitrary. Blaber *et al.* (1994), recorded a wing spread of 60 % of headrope length. Obviously, this ratio will also depend on the design of the net.

Timing of the survey can also affect the results. To avoid the effect of time of day on the results presented here, all hauls used in the analysis were made during daylight hours (i.e. 6.00 a.m. to 6.00 p.m.). Nevertheless, the effect of time of day may still be present in the data as certain species perform diurnal vertical movements. For example, Rijavec (1980) found that the average catch of flatfishes during the night is over 27 times more than during the day. The implication of this difference is that with all surveys in this work limited to daylight hours, the biomass of flatfishes and species that behave like them, will probably be underestimated. Similar day-night differences were observed during the GTS (Williams 1968).

From equation 6.23, it is obvious that the potential yield is proportional to the assessed biomass, the catches made during the survey period and  $M$ , the

instantaneous rate of natural mortality. Thus the choice of  $M$  in this method is quite crucial. The question is, are the samples from which  $M$  was estimated representative enough and is the assumption of 20 °C temperature valid for all the areas from where samples were taken for the estimation of  $L_{\infty}$  and  $K$ ?

The catch and effort data on the small-sized inshore vessels have some limitations that could affect the results from fitting the SYM. These are: (i) species targeting, and (ii) range of operation of the vessels. In the first case, these vessels, especially those based in Elmina in the Central Region, were targeting triggerfish in much of their operations until the species disappeared from the area. Consequently, the decline of this fishery brought serious disruption in the operation of these vessels and severe financial difficulties to the vessel owners (Koranteng *et al.* 1994). In the second case, the range of operation of these vessels, measuring not more than 12 m, is rather limited to shallow waters. This means that they may not have access to the complete distribution of the total demersal biomass and this could affect the 'expected' effort used in the modelling. Since the two MSY estimates are quite similar, the effects of these limitations may perhaps be minimal and one could place some confidence in the estimates.

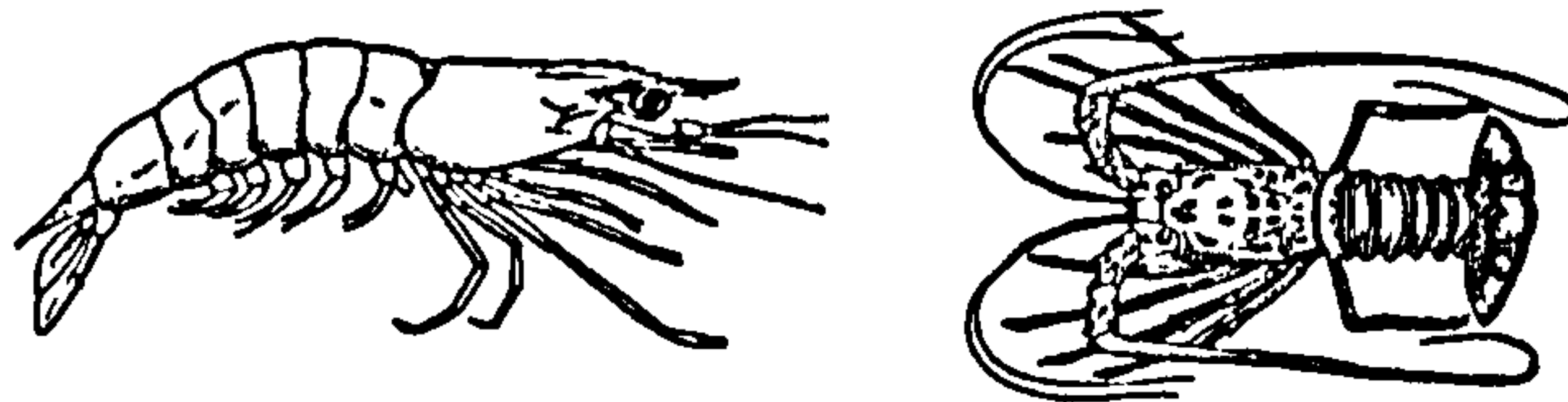
Another source of error in this work is the reliability of the statistics used. For example, it is believed that the catch data in respect of inshore vessels in Ghana is perhaps underestimated. This is because the undisclosed quantity of fish taken by crew members as 'sea allowance' is only estimated and this is thought to be quite substantial. On the other hand, on the basis of scarcity of fish at the landing centres in recent years, there are speculation that artisanal catches are overestimated (J.-L. Lauzière *pers. comm.*). In the case of the industrial fishing vessels, the fisheries administration does not appear to have suitable means to check the authenticity of the data supplied.

The accuracy of FAO's statistics has often been questioned mainly because of irregularities in reporting by member countries, especially in situations where foreign flag vessels are involved in the fishery. Great care has been taken in this thesis to



extract from FISHSTAT PC as realistic subset of data as possible. However, the large quantity of fish recorded as 'Marine fishes nei' is rather worrying. In Ghana this is made up of unidentified landings from mainly industrial trawlers and shrimpers. The implication is that even if 50 % of this quantity is added to the catch data used in this analysis, then the resources are certainly grossly overexploited.

Also not accounted for in the landings data used here are fish caught by poachers. For example, there has always been speculation about Ivorian trawlers fishing off the western part of Ghana but no one has been able to quantify the volume of fish caught by poachers. Fish discarded at sea, especially by industrial trawlers and shrimpers, is also not accounted for. However, the problem of discards may be smaller than it appears. This is because in Ghana, it is known that canoe fishers collect undesired fish (mainly undersized) from the trawlers at sea in exchange for fresh supplies of food. This is fish that the trawlers would normally discard. The statistics on landed catches of triggerfish is also rather inaccurate as large quantities of triggerfish were discarded at sea, especially in the early years of its proliferation. Thus much more triggerfish had been caught than indicated in the landing statistics.



## **CHAPTER SEVEN:**

### **MANAGING THE DEMERSAL FISHERY RESOURCES OF GHANA**

*".... As the fishing power increases the stock falls,  
but the yield at first rises.  
Later ... it ceases to rise,  
and that creates the main problem of fishing".*

**Graham's Great Law of Fishing**



## **Chapter Summary**

The total allowable catch of 40,000 mt per annum is allocated to the three principal fleets in the demersal fishery. If a legal mesh is used in beach seines, the artisanal fleet is expected to catch about 25,000 mt per annum, the semi-industrial and industrial fleets are allocated 2,000 and 13,000 mt per annum respectively. It is proposed that the number of industrial vessels be initially fixed at 33, made up of 25 trawlers and 8 shrimpers. More vessels may be allowed in the fishery if smaller vessels are used and mesh sizes increased.

Other suggested management options for the demersal fishery include limiting the capacity of industrial trawlers to 300 GRT and shrimpers to 200 GRT and increasing codend mesh size for industrial fishing from 60 to 70 mm (for fin-fish) and from 40 to 50 mm (for shrimps). In addition, size of shrimp trawls must be limited by length of headline rope.

Also any subsidies that will make the artisanal fleet grow must be avoided. The beach seine net must have meshes of at least 25 mm and a seasonal closure of the fishery after the major upwelling season will be beneficial for the resources. In addition, operation of beach seines close to estuaries and lagoons must be banned.

Potential labour in the fishing communities must be re-directed through education and introduction of alternative trades.

## **7.1 INTRODUCTION**

The fishery resources on Ghana's continental shelf exemplify the inherent variability that characterise marine fish populations. Variability in distribution and abundance of fishery resources results from the effects of fishing and changes in the marine environment which can be highly dynamic in an upwelling ecosystem. The contribution of near-shore forcing and other environmental factors on the dynamics of fishery resources are clearly apparent, and it has been shown in this thesis that all such factors contribute to stock perturbations in terms of variation in species assemblages (Chapter 5), species composition and biomass (Chapter 6). However, because it is difficult to predict or quantify the amplitude and pace of global environmental change it is equally difficult to account for such change in assessment of fishery resources. This ultimately results in uncertainty in the real status of the resources.

In view of this uncertainty and also the variable nature of the environment, management of fish resources should to be done with caution, and be adaptive in nature. In adaptive management, potential yields could be varied each year by using information on the fishery from previous years (Tyler *et al.* 1982), or stochastic effects on recruitment could be introduced to generate a clearer picture of the risks of over-exploitation (Allen and McGlade 1986).

As shown in chapter 3, the marine environment off Ghana is highly variable from year to year and also within the year and that these in turn affect the status of the resources. However, management of the fishery resources has not kept pace with the changing environment and resources. In the last decade or so, and especially since the Ghana government initiated an economic recovery programme (ERP), there have been consistent attempts by a number of investors (both Ghanaians and foreigners) to import foreign-built industrial fishing vessels for use in Ghanaian waters. Every month, the Ministry of Food and Agriculture (MOFA) receives a number of applications for permission to import fishing vessels. Although many of such applications are rejected by the Ministry, on the advice of the Fisheries Department, the fishing effort of industrial trawlers has increased considerably since the mid 1970s (Figure 6.9). In this decade, the effort of trawlers and shrimpers increased from 5595 boat-days in 1990 to 8433 in 1996 (Table 6.13 and Appendix 6.10).

At the same time, fisheries operators and administrators have expressed concern about reduction in the modal size of landed trawl fishes, especially of seabreams, and the general decline in catch rates (Mensah and Koranteng 1988; Koranteng 1994). These have usually been blamed on the following:

- i. excessive fishing effort resulting from over-capitalisation in the industry,
- ii. the use of small-sized meshes for trawling,
- iii. the use of destructive fishing methods (e.g. dynamite), and
- iv. large industrial trawlers and shrimpers fishing in shallow inshore areas.



In this chapter, possible approaches to the management of the resources are suggested in the light of environmental and stock variation (e.g. of declining catch rates) in the Ghanaian demersal fishery and also in line with international initiatives in management of renewable resources. Inputs for the formulation of a management plan for the demersal fishery, including levels of fishing effort, vessel and mesh size for trawling, are proposed.

## **7.2 SOME ASPECTS OF FISHERIES MANAGEMENT IN GHANA**

In the past, management of fisheries in Ghana was linked to traditional beliefs and practices. In spite of the changing nature of marine fisheries and the society as a whole, some of these practices are still adhered to in the fishing communities (Koranteng 1996). For example, in every fishing community in Ghana, one day in the week (usually Tuesday, Thursday or Sunday) is set aside as a non-fishing day. This day is like the 'Sabbath' reserved for the appeasement of the sea god. Social functions in the fishing community, including public meetings, marriages and funerals are held on this day and fishers also use the day to repair their nets and canoes or service their outboard motors (Koranteng and Nmashie 1987). In actual fact, this traditional practice has a conservation value as the mandatory rest helps to control fishing effort. Unfortunately, this traditional rule does not strictly apply to the other sectors of the industry, especially the industrial fleet.

Presently, formal management of fisheries in Ghana is the responsibility of the Fisheries Department (of the Ministry of Food and Agriculture) in accordance with the Fisheries Law of 1991 (i.e. PNDCL 256). PNDCL 256 will soon be replaced with the Fisheries Management and Development Act (hereafter referred to as FMDA) which is yet to receive parliamentary approval. Management is mainly directed towards limiting fishing effort of industrial vessels (especially trawlers and shrimpers). No TACs (total allowable catch) are set and no quotas issued.

As described in Chapter 1, the fishing industry in Ghana is made up of three sectors: artisanal, semi-industrial and industrial (including shrimp fisheries). The artisanal sector is an indigenous rural industry, virtually open-access and without any institutionalised means of limiting entry into the fishery. Generally speaking, 'sons follow fathers'. Also, many artisanal gears have small-sized meshes and sometimes the fishers use dynamite to 'fish'. Artisanal fishers neither require a licence nor pay any fee to fish. The sector is self-financing although there is government assistance usually in the form of subsidies (e.g. on fuel and fishing gear). Recognising the important contributions of artisanal fisheries to employment and food security, governments world wide try not to interfere in their activities.

In Ghana, an inshore or industrial fishing vessel requires a licence before it goes fishing. All such vessels are registered and issued with a fishing licence by the Fisheries Department. In accordance with PNDCL 256, industrial fishing vessels are first registered by the Shipping Commissioner (Ministry of Transport).

Some provisions of PNDCL 256 which deal with management of demersal fisheries are as follows:

i. Mesh size regulations

- a. the mesh size in the codend of bottom trawls (for catching fin-fish) must not be less than 60 mm (stretched diagonal),
- b. the corresponding mesh for shrimp trawls must not be less than 40 mm,
- c. mesh size for gillnets must not be less than 50 mm (for multifilament netting) or 75 mm (for monofilament netting), and in general
- d. no net of mesh less than 25 mm may be manufactured, imported or used for fishing in Ghana.

ii. Fishing zones

No towing gear shall be used in coastal waters the depth of which is less 30 m. In addition, no motor fishing vessel of 50 GRT or more is permitted to use a bottom trawl in coastal waters shallower than 30 m (area referred to as Inshore



Exclusion Zone, IEZ). Shrimp vessels are required to operate at designated areas only; these areas are indicated on the shrimping licence.

iii Unauthorised fishing methods

The use of dynamite and chemicals for fishing is prohibited.

Generally, these laws are not obeyed, consequently the use of undersized meshes is the rule rather than the exception in all sectors of the fishing industry and large vessels are often seen ostensibly fishing in shallow waters to the annoyance and detriment of artisanal fishers (Mensah and Koranteng 1993; Koranteng 1994; Koranteng *et al.* 1994; Lauzière 1997).

The industrial fleet of large, relatively well-equipped, foreign-built vessels using heavier and bigger fishing gear, are often seen to cause more harm to the resources than the other two fleets. The operation of these vessels, especially in shallow waters, arguably to exploit shallow water cephalopods and shrimps for export, is clearly detrimental to fish stocks. This practice destroys nursery grounds of most fishes; substantial quantities of juvenile fish are caught incidentally and subsequently discarded at sea. These activities also conflict with those of the other fleets, especially the canoes, as the large vessels quite often destroy nets that have been set by the canoes (Mensah and Koranteng 1993). One reason for this state of affairs is that there is practically no enforcement mechanism in place as the Monitoring, Control, Surveillance and Enforcement Unit described in PNDCL 256 was never set up.

It is essential to note that PNDCL 256 is silent on the number and size of fishing gear and vessels that could or should be used for fishing in Ghana's waters. Consequently, the question that has concerned MOFA and fisheries administrators in Ghana for sometime now is 'how many industrial fishing vessels should be permitted to fish in Ghana's shelf waters?'.

In the proposed Fisheries Management and Development Act (FMDA), the Director of Fisheries is required to prepare, keep and review a fisheries management

and development plan for each fishery in Ghana. Each fishery plan is to include, among other things, the state of the exploited resources, potential yield and level of exploitation. No such management plan is in place yet for managing fisheries in Ghana, although preparations are being made to put one together and the recommendations made in this chapter are intended to provide input for this plan.

### **7.3 INTERNATIONAL INITIATIVES IN FISHERIES MANAGEMENT APPLICABLE TO GHANA**

Globally, fisheries management is changing in nature, approach and objectives especially since coastal States claimed 200 miles of exclusive economic zone (EEZ) in the 1970s in accordance with the UN Convention on the Law of the Sea (UNCLOS III). Since UNCLOS III, other international initiatives have emerged with a view to ensuring sustainable exploitation of fishery resources. Relevant among these are:

- i. Agenda 21 of the UN Conference on Environment and Development (UNCED, Rio de Janeiro, June 1992),
- ii. FAO International Code of Conduct for Responsible Fisheries (1995), and
- iii. UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (New York, 1992-1995).

With these initiatives, it has become necessary to take a holistic view of renewable resources and manage them accordingly. It is customary in fisheries management today for countries to prepare a fisheries management plan which is a complete embodiment of the vision of the fisheries - management objectives (e.g. greatest yield, greatest value, etc.), harvesting (or exploitation) levels, contribution to food security, socio-economic considerations, provision of employment and income and conservation of biodiversity. In this regard some rather basic but important concepts have been adopted in fisheries management. Some of these that are applicable to the Ghanaian situation are presented below.



### **7.3.1 *Precautionary approach to fisheries management***

In view of uncertainties associated with stock evaluation as mentioned above and with many elements of the fishery system, it has become necessary to take a precautionary approach in the management of fisheries (FAO 1995). Principle 15 of the Rio Declaration of the UN Conference on Environment and Development, the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks and the FAO International Code of Conduct for Responsible Fisheries all prescribe a precautionary approach to all fisheries management issues.

A precautionary approach involves “..the application of prudent foresight to avoid unacceptable or undesirable situations taking into account that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to change in the environment and human values..” (FAO 1995). It requires, *inter alia*, that all fishing activities are authorised (e.g. all boats are licensed), prior identification of undesirable outcomes (e.g. over-exploitation of resources and over-development of harvesting capacity) and that measures have been identified that will avoid or correct them promptly.

### **7.3.2 *Development of sustainability indicators***

Chapter 40 of Agenda 21 calls for development of Sustainability Indicators so as to serve as a basis for:

- i. establishing cost-effective data collection systems,
- ii. monitoring conditions and trends in the fishery sector,
- iii. informed decision-making, and
- iv. for early warning systems.

At the Ninety-fourth Session of the FAO Council (1988), sustainable development was defined as “...the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations...”

The following are listed as some of the possible indicators of sustainability in fisheries (S. M. Garcia<sup>5</sup> *pers. comm.*):

i. Fishery-related indicators made up of

- a. yield-related indicators (e.g. Maximum Sustainable Yield (MSY), Maximum Constant Yield (MCY) and Long - Term Average Yield (LTAY)),
- b. capacity-related indicators (effort to achieve the yield-related indicators, e.g.  $F_{MSY}$ ,  $F_{MCY}$  and  $F_{LTAY}$ ),
- c. economic indicators (e.g. economic self-sustainability, maximum rent),
- d. technological indicators (e.g. environmentally-friendly fishing gears, lowest possible discard rate),
- e. social indicators (e.g. food security, maximum sustainable employment, minimum social unrest),
- f. institutional indicators (e.g. effective monitoring control and surveillance, effective peoples' participation),

ii. Ecosystems-related indicators made up of

- a. resource biomass (e.g. virgin biomass, biomass at MSY)
- b. resource demographic structure (e.g. length and age composition, sex ratio, ratio of average length to length at first maturity), and
- c. biological diversity (e.g. minimum possible species loss, minimum loss of genetic diversity).

### **7.3.3 Co-management and participatory approach to fisheries management**

In many parts of the world, particularly in countries where conservation awareness has not caught on well with the people, fisheries management is often seen

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<sup>5</sup> Dr. S.M. Garcia is Director, Fishery Resources Division, FAO, Rome.



as a governmental responsibility. But, it is obvious that effective capacity of government agencies to manage a fishery such as Ghana's where the artisanal sector is the largest, is rather limited. Co-management is defined by Pomeroy (1995) as "... the sharing of responsibility and/or authority between the government and the local resource users/community to manage the fishery or resource ". Participatory approach to management has objectives similar to these, however, in this case government is still the final authority in matters relating to resource use.

These concepts have emerged from the realisation that a fishery cannot be managed effectively without the co-operation of fishers (e.g. see Maguire 1997). In Ghana where every fishing community has a "chief fisherman" who, with the help and advice of a council of elders, oversees all aspects of artisanal fisheries in the community, participatory approach can be a workable and an important tenet of fisheries management.

The FAO IDAF (Integrated Development of Artisanal Fisheries in West Africa) Programme has organised round table consultations on applicability of this management approach in the West African region (Satia and Horemans 1995). The participatory approach is also being used in other parts of the world, notably in Southeast Asia, Japan and Europe. In Europe, a meeting was convened at Groningen, Holland in February 1997 to discuss this subject (Earll 1997).

#### ***7.3.4 Ecosystem approach to management of marine resources***

In recent years, the concept of an ecosystem approach to the management of resources has gained importance. The UN Convention on the Law of the Sea (UNCLOS III) mandates Nation States to incorporate an ecosystem approach of management in their domestic laws. Article 6.2 of the FAO Code of Conduct for Responsible Fisheries suggests that management should ensure the conservation of both target and non-target species belonging to the same ecosystem.

The definition and objectives of the ecosystem management approach are varied (Larkin 1996). This approach involves integrated use of ecology, fisheries

biology, fisheries management, oceanography, sociology and economics in the management of resources (McGlade 1989; Larkin 1996). McGlade (1995) sees it as a more effective means of integrating social and economic factors into resource conservation and governance. McGlade and Price (1993) give issues relating to food supply, production and impacts of man-induced activities on fisheries as examples of biological and fishery-related questions that can be answered by the ecosystem approach.

Following on from this, UNCLOS III also enjoins Nation States to act co-operatively to minimise and control pollution in shared jurisdiction zones and high seas and to ensure the avoidance of over-exploitation of resources. This leads to the concept of management by large marine ecosystems (LMEs). Sherman (1993) lists the five operational modules in the LME concept as (1) productivity, (2) fish and fisheries, (3) pollution and health, (4) socio-economic conditions and (5) governance.

### ***7.3.5 Total allowable catch and property rights-based management***

In many fisheries in the world, especially those that are managed, there is a system of allocating an estimated total allowable catch (TAC) to fishing sectors, companies or vessels. Although the TAC management approach is a biological measure which aims primarily at protecting fish resources, it is also an attempt to eliminate the common property problem in which every harvester seeks to maximise his benefit as long as the resource remains (Hardin 1968; Berkes 1989; Arnason 1993). Persons or parties participating in a fishery are given property rights either through access licences or by individual catch quotas. In the former, a fishing licence holder is given the right to participate in the fishery and in the latter, the quota holder is given a property right in the fish stocks and his catch is secured by his quota (Arnason 1993). When the quota is transferable, it is referred to as individual transferable quota (ITQ).

When it is adhered to, TAC restrictions help to conserve fish stocks (Arnason 1993). However, such a system of management relies on accurate catch statistics, effective monitoring, control and surveillance network and honesty of the operators



and even in the most sophisticated management set-up, this system of management can have problems. A classic example is the demersal fishery (especially of cod) on Canada's east coast where, according to Maguire (1997) “..many of the ingredients to establish a successful fishery management process were in place...” and yet the fishery collapsed. The author notes that the following could have contributed to the collapse:

- i. over-reliance on established TACs and other scientifically-based fishery management methods,
- ii. the failure of fisheries administrators to recognise the important role that harvesters and processors could play in the management of the resources, and
- iii. mis-reporting of catches leading to the use of inaccurate statistics in assessment of the stocks.

#### ***7.3.6 Mesh size regulations and zonation of fishing grounds***

At its Sixth Session at Agadir, Morocco (11 - 14 December 1979), CECAF (FAO's Fishery Committee for the Eastern Central Atlantic) recommended to its member countries to “...adopt as a first stage, a single mesh with an opening size of at least 60 mm for exploring all demersal species....” (FAO 1980). The primary objective of mesh size regulations is to control the size at which fish are first exploited by the fishery. In a multispecies fishery, setting a single optimum mesh size is an over-simplification of a complex problem. This is because the optimum mesh for every species depends on its size and shape, among other factors. Nevertheless, this recommendation was adopted by many member States, but its enforcement is far from desirable.

Several coastal States in West Africa also have areas reserved for artisanal fishing and within which industrial fishing is not permitted. Examples of such exclusion zones are:

- i. a 3-mile inshore zone in Cameroon,
- ii. a 7-mile artisanal fishing zone and a 12 miles zone for vessels of 250 GRT or less in The Gambia,
- iii. a variable prohibition zone in Morocco (3, 6, 12 or 15 miles from the coast) depending on conditions in the various fisheries concerned.

This regulation is usually put in place to protect nursery grounds (e.g. in line with the International Code of Conduct for Responsible Fisheries) as well as the livelihood of artisanal fishers. Horemans (1996) noted that even where there is no clear management plan for the fisheries, these two provisions are usually found in the legislation of many States in West Africa. In Ghana, the Inshore Exclusion Zone is defined by depth, being 30 m or less within which no towing gear must be used (also see section 7.2).

#### **7.4 RESOURCE ALLOCATION AND 'OPTIMUM' INDUSTRIAL TRAWLING EFFORT IN GHANA'S DEMERSAL FIN-FISH AND SHRIMP FISHERIES**

In chapter 6, the potential yield of the demersal resource of Ghana was estimated to be between 36,000 and 55,000 (average 46,000) mt per annum. The results of fitting the surplus production model to the commercial landed catch data also gave a maximum sustainable yield of 49,500 mt per annum. As the last trawl survey was in 1990, and considering the increased industrial fishing effort since then (see Figure 6.9 and section 7.2) and as a precautionary measure, the total allowable catch (TAC) is taken to be about 40,000 mt per annum. This potential is apportioned to the various fleets and from it the optimum number of industrial vessels to allow in the fishery is determined.

To divide the TAC among the fishing fleets, it is necessary to determine priorities in the fishery. In Ghana, Part III (9) of the Fisheries Development and Management Act (FDMA) authorises the Director of Fisheries to give priority to artisanal and semi-industrial fisheries in the allocation of fishing licenses or quotas. Similarly, by Article 6.18 of the FAO International Code of Conduct for Responsible



Fisheries coastal States accept to offer small-scale fishers, preferential access to resources. Consequently, the artisanal and semi-industrial fleets are allocated a percentage of this TAC and the rest left for the industrial fleet. The sizes and average performance of the existing industrial vessels will determine how many can be allowed in the industry. In practice, things are not so simple but for the purposes of this work, the above arrangement will be the basis for determining the optimum size of the industrial fleet.

#### **7.4.1 Fleet allocated quotas (FAQ)**

Between 1972 and 1994, the canoe fleet which did not change much in strength (numbers of canoes and gears) produced between 12,000 and 40,000 mt of demersal fish (the long-term average is  $28,900 \pm 3,800$ ) annually. Since 1990 the annual average landed catch has been about 31,000 mt. As discussed later (section 7.5), this is made up of large quantities of small-sized fish caught with the beach seines. If the regulation on minimum mesh size is enforced, then the catch of this fleet is expected to reduce. Consequently, if 25,000 mt per annum is allocated to the artisanal fleet, then the other two fleets have between them 15,000 mt of demersal fish to catch in a year.

The inshore fleet landed between 800 and 5,500 mt of fish in 1972 - 1994 with an average of 3,800 ( $\pm 400$ ) mt. The average landed catch in this decade is about 1,400 mt per annum as the fleet has declined (see section 1.4.2.2). Allocating 2,000 mt of the TAC to the inshore fleet leaves the industrial fleet (trawlers and shrimpers) with a total of 13,000 mt of demersal fish to catch annually. The shrimpers also exploit shrimps with an annual potential of around 350 mt (see section 6.5.4).

#### **7.4.2 Number and sizes of vessels in the industrial fishing sector**

Table 7.1 gives the number of industrial vessels (by size category) that were licensed to operate in Ghana in 1995. It also gives the mean annual landed weight of each category of vessels as ranging from 60 mt for vessels of less than 100 gross

registered tonnage (GRT) to 1287.5 mt for those of 351- 400 GRT. The overall (weighted) average landed catch is 560 mt per vessel for the year. From this average, then only 23 vessels will be required to catch the industrial fleet's quota of 13,000 mt. Of the 57 industrial vessels registered to operate in 1995, only 51 (34 trawlers and 17 shrimpers) actually operated and landed about 9,700 mt of demersal fish in that year. This gives an average landing of less than 200 mt per vessel for the year (i.e. less than 1.0 mt per vessel per day).

Table 7.1: Size (GRT) distribution and average production of industrial vessels registered to operate in Ghana in 1995.  
Source: MFRD, Tema.

| GRT       | Number of vessels | Percentage (number) | Annual mean landed weight (mt) |
|-----------|-------------------|---------------------|--------------------------------|
| < 100     | 4                 | 7.0                 | 60.0                           |
| 100 - 150 | 6                 | 10.5                | 80.6                           |
| 151 - 200 | 8                 | 14.0                | 363.7                          |
| 201 - 250 | 5                 | 8.8                 | 264.2                          |
| 251 - 300 | 16                | 28.1                | 523.2                          |
| 301 - 350 | 5                 | 8.8                 | 1052.5                         |
| 351 - 400 | 3                 | 5.3                 | 1287.5                         |
| 401 - 450 | 2                 | 3.5                 | 202.0                          |
| >1000     | 8                 | 14.0                | 1129.5                         |
| Total     | 57                | 100.0               |                                |

Between 1980 and 1994, average landed weight of industrial trawlers was 1.8 mt per vessel per day (Appendix 6.10) and corresponding weight for shrimpers was 1.0 mt per vessel per day (Table 6.13). If each vessel operates for 250 days per annum (Afful 1993) then 29 trawlers (or about 7,220 trawling-days) will be required to land the 13,000 mt allocated to the industrial sector. On the other hand, if a daily



catch rate of 1.4 mt (for shrimpers and trawlers) is used in a second scenario, then the fleet size will be 37 vessels. Therefore, it appears that the optimum number of industrial vessels is between 29 and 37 (or an average of 33 vessels).

From Table 6.13, the average catch rate of shrimpers is 140 kg of shrimps per vessel per day. This means that 2500 shrimping-days (i.e. 10 shrimpers) will be required to harvest the estimated MSY of 350 mt per annum. From these analyses, it is recommended that the industrial fleet be made up of 25 trawlers and 8 shrimpers as a precautionary measure.

In practice, fisheries management objectives go far beyond the MSY concept and factors like greatest value of the catch and maximum employment in the fishing industry must be considered although, according to McGlade (1989), these are usually deeply entwined. This means that unless a firm management stand is taken, one can expect that the numbers of trawlers and shrimpers in the Ghanaian fishery would be more than have been suggested here. It is possible that the demersal resource in Ghana's shelf waters can support more than 33 vessels if the sizes of these vessels can be limited and the appropriate mesh sizes used in the trawls. This is because the quantity of discards will be reduced and higher yields can be expected.

Some of the vessels operating presently in Ghanaian waters are too large given the narrow continental shelf (maximum width of 80 km, Koranteng 1980). Some vessels included in Table 7.1 were acquired principally for fishing in distant waters where the fishery resources are richer (chapter 1) and these vessels are not suitable for fishing profitably in Ghanaian waters. It would be desirable to have smaller-sized industrial vessels in this fishery.

In neighbouring Côte d'Ivoire, most demersal trawlers are less than 100 GRT and no vessels exceed 250 GRT and in Nigeria, most trawlers are between 100 and 150 GRT (FAO 1994). In the latter country trawlers are limited to 25.3 m in length and 150 GRT and corresponding figures for shrimp vessels are 23.2 m and 130 GRT (Ajayi and Anyanwu 1997). Off Northwest Africa where the fishery resources are richer and the continental shelf is relatively wider, trawlers are usually between 200

and 400 GRT and shrimpers are up to 350 GRT (J.-L. Lauzière *pers. comm.*). Further afield, for example in the North Atlantic cod fishery, many of the trawlers are about 140 GRT (Hannesson 1996).

Therefore, looking at the size distribution of vessels presently in the industrial fishery, it is recommended that only vessels of 300 GRT or less should be allowed in the industrial trawl fishery in Ghana; shrimpers should not exceed 200 GRT. The maximum length of vessel may also be limited to 30 m or less. Vessels within this size range and GRT appear most suitable for fishing in Ghana's shelf waters.

## **7.5 MANAGEMENT OPTIONS FOR DEMERSAL FISHERIES IN GHANA**

Through a consistent and objective analysis of the stock situation vis-à-vis landed catches from this ecosystem, it has been shown in this thesis that since 1963, the total biomass of demersal fish stocks of Ghana has fluctuated with an underlying decreasing trend. It has also been shown that landed catches of commercial fishing vessels also fluctuated and that catch per unit effort declined since 1977, particularly in the last decade. Although some of these issues are not new to fisheries administrators in Ghana, in the past they were not presented as vividly or coherently as done here. Consequently, the question of falling catch rates, for example, was rather speculative in the past.

To ensure continuity of the demersal fishery, sustenance of livelihood of fishing communities and maintenance of biodiversity and also in line with relevant international initiatives in fisheries management, it is essential that sustained effort is made to manage the demersal fish resources of Ghana. The right to fish carries with it the obligation to conserve and manage the resources effectively (UNCLOS III and International Code of Conduct for Responsible Fisheries). Under these international initiatives and in line with the precautionary approach it behoves on Ghana to take all the necessary measures to arrest and reverse the situation of over-exploitation of resources by eliminating excess fishing capacity and ensuring environmentally-



friendly fishing activities in its EEZ. Considering the multi-faceted nature of the fisheries, effective management of demersal fish resources of Ghana will require a holistic approach with some specifics applicable to each of the main fleets. The following options are applicable to all fleets:

- a. all fishing crafts must be registered and operators must pay licence fees; licences must be renewed annually or quarterly (in the case of industrial vessels); this will streamline fishing effort and improve fishery statistic,
  - b. mesh size regulations (minimum mesh of 25 mm in all gears, 50 mm for shrimping and 60 mm for trawling must be enforced),
  - c. the inshore exclusion zone must be enforced.
- 
- a. Specific recommendations for the various fleets are presented below. It may be essential to carry out studies to evaluate the possible impact of some of the measures on the resources. For example in depth studies must be conducted on the shrimp fishery, specifically on the biology and population dynamics of the principal shrimp species, links with coastal wetland ecosystems and socio-economic aspects of the industry.

#### ***7.5.1 Management options applicable to the artisanal sector***

In Ghana, many artisanal fishers see fishery resources as common to all and owned by no one and that as long as one can acquire fishing gear nothing should stop him from going fishing. Consequently, artisanal fishery is virtually open access. The chief fisherman (see section 7.3.3) only sees to the observance of traditional fishing practices, settling of disputes and performs other community-related duties. He does not prevent people from entering the fishery. Therefore, management options for this fleet must aim at addressing the free access problem and ensuring the use of acceptable fishing methods and gears. Arnason (1993) is of the opinion that the traditional free access is not compatible with sensible utilization of fish stocks. The involvement of traditional authority to the benefit of managing the resources must be

exploited. This is in line with the precautionary and participatory approaches to resource management mentioned above.

The following management measures are proposed:

- a. participatory approach to management envisaged in the FMDA must be formalised whereby traditional authorities in the fishing communities and District Assemblies will play a definite role in managing the resources,
- b. all forms of subsidies that will encourage new entrants or the build up of additional effort of present operators must be avoided,
- c. the open-access nature of the artisanal sector must end through the registration of canoes and operators and introduction of fishing licence fee (even if nominal); canoe registration is already contained in the FMDA,
- d. further expansion of the fleet must be discouraged (e.g. by placing 5-year ban on carving of new canoes),
- e. formal education of children in the rural fishing communities must be encouraged,
- f. fishers must be educated on the effects of fishing, especially with un-approved methods,
- g. the problem of poverty in the fishing communities must be addressed; alternative trades that will take potential and excess labour away from the fishery must be introduced in the fishing communities.

Because of its destructive nature, the beach seine has been abolished in some West African countries (e.g. in The Gambia, Guinea and Guinea Bissau) (CECAF 1997; Lauzière 1997). For socio-economic reasons, it may be extremely difficult if not impossible, to take such a measure in Ghana. However, efforts must be made to minimise the destruction caused by this gear. In this regard, the following additional management measures are also suggested:

- a. operation of the beach seine gear close to estuaries and lagoons must be banned as these areas tend to be important nursery grounds for many fish species,



- b. a short period of closure of the fishery every year should be considered; the period of ban must immediately follow the major upwelling season during which most species spawn.

### ***7.5.2 Management options applicable to the inshore sector***

The incidence of trawling with illegal meshes is most prevalent in this sector. In addition, these vessels tend to trawl in shallow waters. Thus, options to manage this fleet must include:

- a. mesh size regulations (the 60 mm minimum mesh size regulation is applicable to this fleet),
- b. enforcement of regulations on the Inshore Exclusion Zone
- c. logbooks must be introduced on this fleet; this should help in assessment of fishing effort exerted by the fleet, and
- d. further expansion of this fleet must be discouraged except as replacement for large industrial vessels.

### ***7.5.3 Management options applicable to industrial trawlers***

The major problems that need to be addressed with this fleet are over-capacity, compliance of regulation on zonation of fishing grounds, and mis-reporting of catches. As deduced above (section 7.4.2) it is obvious that presently there are too many vessels in the industrial trawl and shrimp fisheries. Article 7.6.3 of the International Code of Conduct for Responsible Fisheries states “ where excess fishing capacity exists, mechanisms should be established to reduce capacity to levels commensurate with the sustainable use of fisheries resources so as to ensure that fishers operate under economic conditions that promote responsible fisheries...”. In addition, Ghana is obliged under the international initiatives mentioned above to exercise effective control over vessels that fly Ghana flag to ensure that their activities are responsible in terms of management and conservation of resources.

The following options are proposed:

- a. there should be a total ban on granting of permits to import industrial vessels and issuance of fishing licences until further notice,
- b. the number of vessels in the industrial fishery must be reduced immediately; as a first step, only vessels of GRT not exceeding 300 must remain in the trawl fishery; vessels larger than this and that are presently in the fishery must be:
  1. removed,
  2. only be permitted to fish in waters deeper than 60 m, but for a limited period after which they have to be withdrawn or
  3. their licenses changed to operate as distant-water vessels fishing in more productive EEZs outside of Ghana's,
- c. the minimum codend mesh size for industrial trawl nets must be raised to at least 70 mm as obtains in many countries in the West African region (see Table 7.2),
- d. cost of fishing licence must be based on the tonnage of the vessel; using rates in other West African countries, Lauzière (1997) proposes a fee of US\$10 per GRT (this is equivalent to a half of the rate charged in Senegal and a tenth of the Mauritanian rate),
- e. it is further proposed here that licence fee for each GRT in excess of 300 must be much more than US\$10,
- f. fishing licences must be issued quarterly (or at least half yearly) and conditions for renewals must include submission of accurate statistics of all operations in previous quarter (or half year),
- g. Fisheries observers and inspectors must be on board industrial vessels (both trawlers and shrimpers) as often as possible,
- h. all logbooks must be accessible to the Fisheries Department (vessels in this fleet carry logbooks),
- i. any form of benefit enjoyed by the industrial fleet (including subsidy on fuel) must be abolished.



Table 7.2: Examples of mesh size requirements in coastal countries in West Africa. (countries are listed from north to south).  
Source: CECAF (1997)

| Country                | Bottom trawl for        | Mesh size (mm) |
|------------------------|-------------------------|----------------|
| Morocco and Mauritania | fish and cephalopod     | 70             |
| Senegal and The Gambia | fish and cephalopod     | 70             |
|                        | coastal shrimps         | 50             |
|                        | deep sea shrimps        | 40             |
| Guinea Bissau          | fin-fish and cephalopod | 70             |
|                        | shrimps                 | 40             |
| Liberia                | fin-fish                | 90             |
|                        | shrimps                 | 50             |
| Ghana                  | fin-fish                | 60             |
|                        | shrimps                 | 40             |
| Benin                  | fin-fish                | 70             |
|                        | shrimps                 | 50             |
| Nigeria                | fin-fish                | 77             |
|                        | shrimps                 | 44             |

#### **7.5.4 Management of the industrial shrimp fishery in Ghana**

The first obvious recommendation to make about management of the shrimp fishery is to place a freeze on its expansion. From the production curve (Figure 6.12), the shrimp fishery itself appears to be in good shape, however, because of its detrimental effect on demersal resources generally, stringent measures must be adopted to regulate this fishery. The consistently low shrimp-to-fin-fish catch ratio and the high percentage of discards destroy demersal fin-fish resources. The following management options are recommended:

- a. the number of shrimpers must be reduced to 8 each of which must not exceed 200 GRT,
- b. the areas of operation of shrimpers must be clearly defined and strictly enforced in order to reduce the proportion of fin-fishes caught and discards,
- c. the minimum mesh allowed in shrimp trawls must be raised from 40 mm to 50 mm as obtains in other countries in the sub-region (Table 7.2),
- d. size of shrimp net must be limited (by headline rope length), and
- e. bycatch excluder device must be introduced into the fishery.

The management options suggested in this thesis are summarised in Figure 7.1 and in Table 7.3.



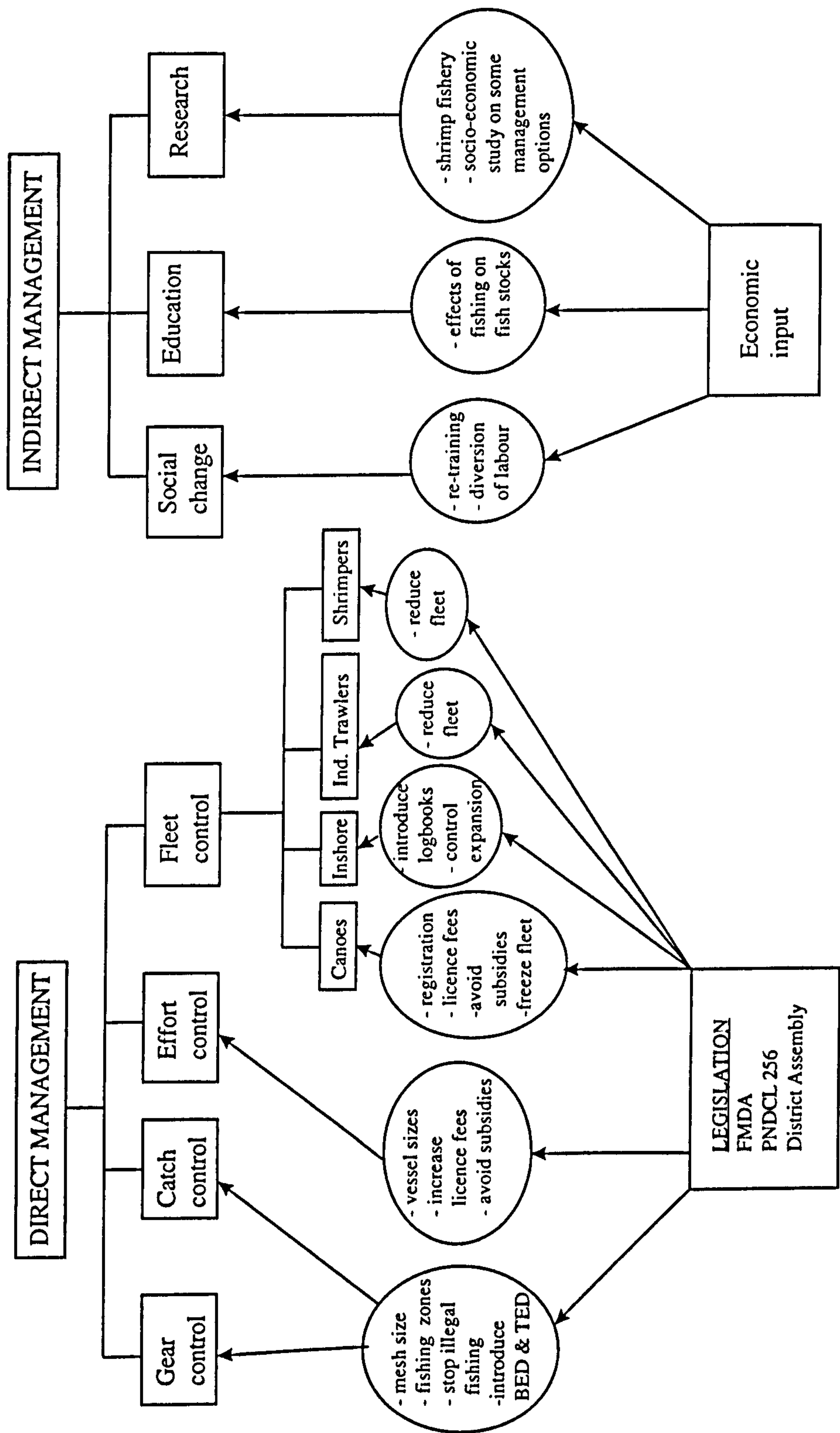


Figure 7.1. Model of relationships between management options for the demersal fishery of Ghana

Table 7.3: Summary of expected fishing activities in the proposed fishing zones

| Area                                | Vessel control   | Gear control   | Other measures  |
|-------------------------------------|--|--|---|
| Inshore Exclusion Zone, < 30 m deep | <ul style="list-style-type: none"> <li>- artisanal crafts</li> <li>- inshore vessels may only fish with pelagic and passive gears</li> <li>- industrial vessels completely excluded from fishing in this zone</li> </ul> | <ul style="list-style-type: none"> <li>- no trawling</li> <li>- no shrimping</li> <li>- mesh size <math>\geq 25</math> mm</li> </ul>   | <ul style="list-style-type: none"> <li>- closed seasons for beach seines</li> <li>- ban on beach seines operating close to estuaries and lagoons</li> <li>- no dynamite</li> <li>- no chemicals</li> <li>- logbooks on all semi-industrial vessels</li> </ul> |
| 30 - 60 m deep                      | <ul style="list-style-type: none"> <li>- artisanal crafts</li> <li>- semi-industrial vessels</li> <li>- industrial trawlers <math>\leq 300</math> GRT</li> <li>- shrimpers <math>\leq 200</math> GRT</li> </ul>          | <ul style="list-style-type: none"> <li>- mesh size <math>\geq 60</math> mm in semi-industrial trawl nets</li> <li>- mesh size <math>\geq 70</math> mm in industrial trawl nets</li> <li>- mesh size <math>\geq 50</math> mm for shrimping</li> <li>- encourage use of bycatch and turtle excluder devices</li> <li>- observers and inspectors on board industrial vessels</li> </ul> | <ul style="list-style-type: none"> <li>- no dynamite</li> <li>- no chemicals</li> <li>- logbooks on all semi-industrial and industrial vessels</li> </ul>   |
| > 60 m deep                         | <ul style="list-style-type: none"> <li>- artisanal crafts</li> <li>- inshore vessels</li> <li>- industrial trawlers &gt; 300 GRT</li> <li>- shrimpers &gt; 200 GRT</li> </ul>  | <ul style="list-style-type: none"> <li>- mesh size <math>\geq 60</math> mm in semi-industrial trawl nets</li> <li>- mesh size <math>\geq 70</math> mm in industrial trawl nets</li> <li>- mesh size <math>\geq 50</math> mm for shrimping</li> <li>- observers and inspectors on board industrial vessels</li> </ul>   | <ul style="list-style-type: none"> <li>- no dynamite</li> <li>- no chemicals</li> <li>- logbooks on all semi-industrial and industrial vessels</li> </ul>   |



### 7.5.5 Overview of some of the suggested options

Over-capacity is a difficult problem to deal with and owners of industrial vessels must be encouraged to shed excess capacity by replacing large vessels with smaller ones. A period of say 2-3 years must be allowed within which trawlers of over 300 GRT (and shrimpers of over 200 GRT) should be removed. When this is achieved, the number of industrial vessels of less than 301 GRT may be increased after careful re-assessment of the situation.

On the mesh size, a study of the *Pagellus bellottii* fishery of Ghana (Koranteng and Pitcher 1987) showed that raising the minimum mesh size from 60 mm to 75 mm would minimise the risks of collapse of this fishery. *P. bellottii* is an important component of the demersal fishery of Ghana and a relatively small fish, hence this recommendation should be even more beneficial for the larger species in this multi-species fishery.

The minimum mesh size for shrimp fishing in neighbouring Côte d'Ivoire is 50 mm; the types and sizes of shrimps there are similar to those in Ghanaian waters (Garcia and Lhomme 1980).

A bycatch excluder device (BED) mounted in the shrimp net reduces bycatch of fin-fish (Watson and Seidel 1980) and is thus useful for the management of the fish resources. In addition to conserving fin-fish resources, BED also reduces time required to sort catches on the vessel and consequently improves efficiency at no cost to the resource. In some shrimp fisheries in the sub-region (e.g. in Nigeria) the use of turtle excluder device (TED) is also being considered (Mr. P. Amiengheme<sup>6</sup> *pers. comm.*). This device allows turtles to escape from the shrimp net if caught. For conservation purposes, the use of TED is gradually becoming mandatory for shrimp fisheries where the products are exported to the United States. Three species of marine turtles: olive ridley (*Lepidochelys olivacea*), green turtle (*Chelonia mydas*)

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<sup>6</sup> Mr. P. Amiengheme is Assistant Director, Federal Department of Fisheries, Lagos, Nigeria.

and leatherback (*Dermochelys coriacea coriacea*) are known to nest along the shores of Ghana<sup>7</sup>. Therefore, it is useful to introduce TEDs in order to avoid catching these endangered reptiles as they proceed to or from shore to lay eggs.

Generally, fisheries management measures are grouped under biological and economic headings (Arnason 1993). In this grouping, biological management involves imposition of catch limits (e.g. as with TACs), closed seasons and protection of spawning grounds and economic management deals with issues like taxes and access. No such distinction has been made in this thesis and the model of relationships between the proposed management options (Figure 7.1) breaks the options into two: direct and indirect. Direct options are those that apply directly to sectors of the industry, especially factors of production - gears, vessels, etc. and the indirect ones impact on the industry via secondary actions and are mainly socio-political. Also, whereas direct management options require legislation, enforcement and participation of local authorities, indirect methods require mainly economic inputs. For example to effect social change through re-training requires financial commitments from government and partners (e.g. District Assemblies).

The proposed differential licence fees on excess GRT is not a new concept in Ghana. This kind of differential rates is already applied to electricity tariffs and to import duties on cars. To avoid cheating, all applications for fishing licence must be accompanied, *inter alia*, by international certificate of tonnage issued by a competent ship surveyor and as produced for registration of the vessel at the Ministry of Transport.

The register of vessels kept by the Fisheries Department of Ghana has serious inconsistencies as regards vessel sizes and GRTs. For example, according to Lauzière (1997) a vessel measuring 65 m and equipped with an engine of 2,200 HP has a declared tonnage of 449 in this register. The GRT of such a vessel is more likely to be about 800 - 900. Therefore, the size limitation and cost of licences must

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<sup>7</sup> According to an article in "NKO", the magazine of the Wildlife Clubs of Ghana, 1996.

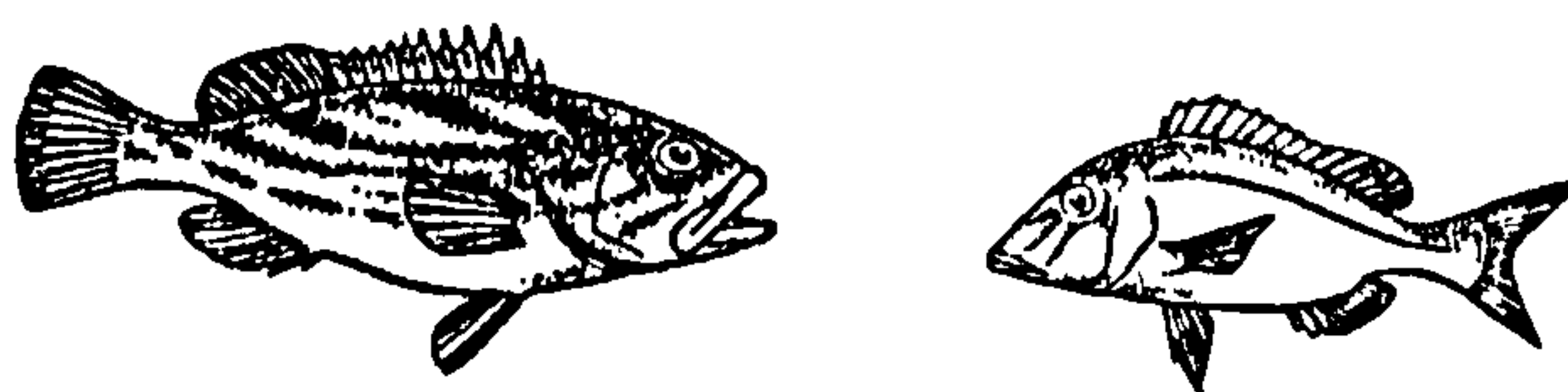


eventually be based on length of vessel as this can be most easily measured than tonnage.

In this thesis the emphasis on control of TAC is by limiting access and ensuring acceptable fishing methods rather than catch quotas. This is because of the higher level of enforcement required when ITQs are used and also to minimize incidence of mis-reporting as there is no real benefit to under-report catches under access control.

On the question of subsidy, especially to the artisanal fishers, it needs to be said that subsidy can be a tool in the developing process and may actually be beneficial for the fishery (Mabawonko 1990). It is for this reason that a clear distinction has been made in this thesis (see section 7.5.1b). Thus government may still offer subsidy for example, towards the promotion of a new, more resource and environmentally-friendly fishing gear in place of beach seines.

Closure of a fishery is not a new concept in Ghana. It is a common practice in lagoon fisheries (e.g. see Koranteng 1994). As this is not done in the marine fisheries sector, it would be difficult initially, to implement the suggestion to close the beach seine fishery. Needless to say, if the mesh size regulation is strictly complied with, and operation of the beach seine gear is moved away from estuaries and entrances to lagoons, then it may not be necessary to close the fishery. This is because the destructive nature of the gear would be greatly minimised by these other measures.



**CHAPTER EIGHT:**

**GENERAL CONCLUSIONS  
AND SUGGESTIONS FOR FUTURE RESEARCH**



## 8.1 CONCLUSIONS

The upwelling zone off Ghana and Côte d'Ivoire is unique in the Guinea Current large marine ecosystem and is different from other upwelling areas. The seasonal coastal upwelling that occurs in this ecosystem is not of the classical Ekman type. In this ecosystem, cooling of surface waters occurs when there are no winds strong enough to blow surface waters offshore as happens in wind-induced upwelling. It is thought that the upwelling is caused by a combination of factors including evaporation, currents, wind and remote forcing.

In this thesis, some light has been shed on the nature and types of changes that have occurred in the physical parameters of Ghana's shelf waters and in associated atmospheric and near-shore forcing factors. It has also been shown that the period between 1963 and 1992 had within it sub-periods with distinct environmental characteristics; these are referred to as Environmental Time Blocks (ETBs). In the first ETB (i.e. the time period before 1972) sea surface and bottom temperatures were relatively high and salinity was low. The second ETB was characterised by low temperatures (both surface and bottom) and high but stable salinity. In the third ETB, a rising trend in sea surface and bottom temperature was observed with a drop in salinity.

Within these broad environmental time blocks, some shorter periods could also be identified. For example, the period between 1980 and 1986 was quite similar to the one before 1975. These two periods were characterised by close to average atmosphere-ocean climate with occasional short-lasting perturbations in some of the environmental parameters. Such infrequent perturbations can destroy the internal dynamics of a system and are therefore important in determining biological production (Margalef 1986; McGlade 1990; Baird *et al.* 1991).

The well-documented 1983-84 unusually warm event in the tropical Atlantic was not very prominent in the coastal waters off Ghana. In fact its presence was only felt because it followed the cold year of 1982. 1975-1979 and 1987-1992 were quite unique within the period under study, with the former an unusually cold period

and the latter a relatively warm one. Whilst the literature is quite clear on the warm climatic events that occurred in the Atlantic over the last three decades, attempting to draw a parallel with ENSO (El Niño Southern Oscillation) events in the Pacific, the cold period of 1975-79, identified in this work, has not been seriously discussed before in the literature.

1975-79 was a period of global change in the shelf waters off Ghana, as well as in climatic and near-shore factors contributing to the status of continental shelf waters. The period was characterized by sustained cold temperatures in the atmosphere, coastal surface waters and in deep shelf waters. The mixed layer was shallow, due to the persistence of the thermocline at depths shallower than the long-term mean. Coastal (surface) and deep-water (sub-surface) salinities were relatively high, but quite stable in terms of seasonal variation.

Total rainfall was severely reduced during this period and consequently the amount of freshwater input into the sea was also reduced. Sea level pressure was lower than the long-term average and although wind speed generally increased between 1963 and 1992, its seasonal variability decreased during 1975-79. The peak events occurred from 1975-76 during which most of the factors mentioned attained either their highest or lowest values. The period following 1975-79 saw rapid increase of both sea surface and sea bottom temperature and large variability in some of the environmental parameters (e.g. salinity).

Environmental changes such as those listed above affect the distribution and abundance of fishery resources as well as the biology of some species of fish. The trends and environmental time blocks established in this study have arisen from analyses of a number of atmospheric and ocean climatic parameters instead of a single factor, thereby increasing the level of confidence attached to them.

The analyses of community structure generated species assemblages comparable to those described by Fager and Longhurst (1968) and Longhurst (1969) for the whole Gulf of Guinea. Six fish species assemblages have been identified from the GTS data. The first two, namely the sciaenid and lutjanid assemblages, are



predominantly supra-thermocline whilst the two sparid assemblages begin at the thermocline depth of about 40 m and extend offshore. The last two (deep shelf and upper slope) assemblages occur well below the thermocline.

The continental shelf off Ghana is characterised by a belt of soft, muddy substrate in shallow waters down to about 30 m deep, followed by a wide area of mixed to hard bottom type. Associated with the soft substrate is the sciaenid community made up mainly of species of the *Pseudotolithus* and *Galeoides* genera. On the western part of the shelf, the soft muddy bottom types extend into deep waters (over 50 m off Cape Three Points) thus extending the distribution of the sciaenid assemblage. The soft bottom is also found in deep waters in the immediate environs of the Volta estuary and around Cape St. Paul indicating that this type of substrate is associated with large river outlets where large quantities of sediments enter the sea from the rivers. Associated with the hard-to-mixed substrate are the lutjanid and the sparid assemblages (shallow and deep parts).

There are clear faunal discontinuities around 30 m, 100 m and 200 m deep with the first ecotone closely related with depth and the thermocline, the second to a steep shelf drop, and the third to significant division between shelf and slope assemblages.

There are also community differences in the longitudinal space which are related to the type of sediment. Main assemblages contain sub-assemblages the locations of which are determined mainly by their association with different sediment types. The structure of the assemblages is determined primarily by depth and sediment type the latter of which is more important when considering a restricted depth gradient as in the MFRD surveys. The dynamics of the assemblages, including seasonal movements of component species, are influenced by physico-chemical properties of the water masses, mainly temperature, salinity and dissolved oxygen. Therefore, upwelling which changes the characteristics of these water masses on the continental shelf, also has an effect on the dynamics of demersal species assemblages.

Examination of the properties of the three shallow to mid-shelf assemblages identified from the data for each of the surveys examined in this work, does not show conclusively, evidence of change over the time period considered. However, a number of observations can be made that support the conclusions presented in this work. These include:

- i. a number of species remain faithful to their assemblages over the period of investigation,
- ii. the lutjanid assemblage appears to be more stable than expected,
- iii. seasonal movement of demersal fishes is towards shallow waters in the cold season and deep waters in the warm season,
- iv. the importance of *Lutjanus* sp. within the lutjanid assemblage declined over the period under consideration; it was shown that the changes are linked, *inter alia*, with the abundance of triggerfish, *Balistes capriscus* and potentially the effect of exploitation.

Between 1964 and 1990, the structure of demersal species assemblages on the continental shelf off Ghana underwent significant changes. At the beginning of the period (i.e. during ETB1), it was relatively easy to identify the three main assemblages, namely sciaenid, lutjanid and sparid (consisting of both shallow and deep parts), using TWINSpan. In ETB2, during which the triggerfish (*Balistes capriscus*) proliferated in this ecosystem, it was not easy to identify the three assemblages. The lutjanid and sparid assemblages were most difficult to discriminate between as they were destabilised by the advent of the triggerfish. With the decline of the triggerfish, the two assemblages re-established themselves but it cannot be said whether the system was returning or had already returned to its original state.

Generally, species diversity (measured by the Shannon Diversity Index) declined between 1970 and 1977 (i.e. within ETB2). Thereafter, there was a gradual rise and subsequent stabilization of the index. This change in species diversity was similar in the three depth zones (Bathymetric frames of reference), namely 10-30 m,



31-50 m and 51-100 m (i.e. BFR1, BFR2 and BFR3), although it was more pronounced in BFR1. In addition, species diversity was generally highest in BFR2, except during ETB2 when triggerfish occupied this frame. Species richness and evenness also underwent changes during the observational period. For example the Margalef Richness Index which was very high in BFR1 and BFR2 during ETB1, reduced drastically in both frames during ETB2. The Pielou Evenness Index also decreased between ETB1 and ETB2 but increased in ETB3.

The total density of demersal fish species generally declined between 1964 and 1990. The change was different in the three BFRs with BFR1 experiencing the largest variation. *B. capriscus* was encountered in large quantities in the study area from about 1970 and its peak in density occurred in 1977-80. The species occupied the biotopes of the sciaenid and lutjanid assemblages (i.e. BFR1 and BFR2) expanding to BFR3 only from 1981 when its density in this ecosystem had started to decline. It appears that the low temperature, high salinity environment was more conducive for the sparid assemblage to which *B. capriscus* belongs. This may have contributed to the sudden increase in the abundance of this species. The abundance of other members of the assemblage (e.g. Sparidae and *Cephalacanthus volitans*) also increased during ETB2.

During the period when triggerfish dominated in the study area, the total density of sciaenids declined. Also during the observational period (1964-1990), there were shifts in the distribution of lutjanids. It appears that the lutjanids were displaced by the colonizing triggerfish into either BFR1 or BFR3. Sparidae were consistently present in all three BFRs (especially in BFR2 and BFR3) and throughout the period of investigation. The density of sparids was low in BFR1, especially during ETB2. In BFR2, there was a consistent reduction in the density of sparids between 1964 and 1990 whereas in BFR3, where the density was generally highest, a decline was observed between 1977 and 1990.

The relative importance of Scianidae, Lutjanidae and Sparidae in the three BFRs changed in response to alterations in the ecosystem resulting from the invasion of *B. capriscus*. Among the three families and triggerfish, Sparidae dominated in all

three BFRs during ETB1. This position was assumed by triggerfish during ETB2 (especially in BFR1 and BFR2) but as the species declined during ETB3, Sparidae re-established their dominance.

There were appreciable increases in the density of rays, cephalopods and soles, especially in BFR2 following the disappearance of triggerfish.

It is obvious, therefore, that the proliferation of *B. capriscus* in this ecosystem de-stabilized the assemblages of constituent demersal species. The sciaenid and lutjanid assemblages were most affected by the sudden change in the abundance of triggerfish.

The relative importance of species within the demersal fish stock of Ghana, as measured by the percentage of the weight in the total catch during trawl surveys, underwent considerable changes between the Guinean Trawling Survey in 1963 and the Guinea 90 survey in 1990. At the beginning of the period, the most abundant species was *Brachydeuterus auritus* (the bigeye grunt). When the abundance of *Balistes capriscus* increased in this ecosystem, it displaced *B. auritus* as the most abundant species and dominated the ecosystem for nearly 20 years. However, some sparid species, notably *Pagellus bellottii* and *Sparus caeruleostictus* and also the west African goatfish *Pseudupeneus prayensis* maintained their relative importance in the stocks over the 28 year period.

There is also a significant difference between the density of fish in shallow waters and those in deep waters. In the period under investigation, the density in shallow waters declined considerably compared to areas deeper than 50 m. The total biomass of demersal fish (excluding *B. capriscus*) in waters of 10-100 m decreased from about 79,000 mt (or 50 kg ha<sup>-1</sup>) in 1963-64 to about 58,000 mt (32.4 kg ha<sup>-1</sup>) in 1990. The biomass reached its lowest value of about 36,000 mt (22.5 kg ha<sup>-1</sup>) in the period between 1973 and 1977. However, the paucity of surveys during this period may have contributed to this apparent decline of biomass. There is also a significant difference between density of fish in the thermocline and upwelling seasons; density during upwelling is higher than density in the thermocline season.



The density of triggerfish increased dramatically at the beginning of the 1970s reaching a high value of over 28 kg ha<sup>-1</sup> in the 30-50 m depth zone at the peak of its abundance in the late 1970s. The decline in abundance of this species was noticed in the 1981-82 survey and by 1990, the species had almost completely disappeared from the ecosystem. In the period of investigation, other species like rays, soles and cephalopods (notably *Sepia* sp.) increased in biomass and in importance.

From the results of the surveys and fitting a surplus production model to commercial catch and effort data from this fishery (covering the period 1972-1994), it appears that the potential yield of the demersal fish stocks in Ghana's continental shelf waters lies within 36,000 - 55,000 mt per annum. Between 1960 and 1994, landings of demersal fish caught from the area ranged between 5,800 and 57,000 mt. If one includes unidentified marine fish, some of which are demersal, then the catch exceeded 70,000 mt in some years. The situation is aggravated by the fact that a large proportion of the catch is made by artisanal fishers using beach seines, which target mainly juvenile fish of all types and species.

A time series analysis of catch per unit effort showed that the fishery underwent two phases, namely a period of increasing cpue between 1972 and 1977 followed by a decline. This is a further indication of an over-exploited fishery. At the time of the Guinean Trawling Survey, the density of demersal fish in the Ghanaian sector was higher than in the Ivorian sector. During the Guinea 90 survey the recorded density in the Ghanaian sector was lower than in the Ivorian sector.

The causes of these changes in the state of demersal fisheries are difficult to isolate but clearly include fishing and the effect of marine environmental changes. However, given that the Ghanaian and Ivorian shelves experience similar environmental conditions, it can be concluded that the changes on the Ghanaian side may be due primarily to increased fishing effort.

The demersal fishery of Ghana is over-exploited and overcapitalised and subsequently the biomass and catch rates varied over the past three decades. A

number of factors have contributed to falling catch rates. Principal among there are the use of under-sized meshes, the use of un-approved fishing methods and over-exploitation resulting from over-capacity. Assessment of the resources is inadequate and so management must adopt a precautionary approach if sustainability of the fishery is to be ensured.

Unfortunately, there does not appear to be any sustained management strategy for fisheries. Because of the multiplicity of gears used, management of these resources is complex - a factor which any management plan should take into account. The following recommendations are made towards the management of the resources; they have been made on the premise that the newly-established Monitoring Control and Surveillance Division of the Fisheries Department will be given the means to operate and the necessary administrative backing to enforce fisheries regulations.

1. The complexity of the fishery requires that an ecosystem approach be followed in monitoring the fishery and in formulating a management plan.
2. Because of inaccurate reporting of catches, especially in the industrial fishery, and possible overestimation of catches in the artisanal fisheries, the TACs estimated in this work should only be seen as one tool for the management of fishery resources and that management must be adaptive in nature and guided by the precautionary approach.
3. Participatory management must be adopted as some form of traditional management already exists in the artisanal sector which is the biggest harvester of marine fish resources in Ghana. This approach would be particularly useful in formulating regulatory measures for the operation of beach seines.
4. Mesh size is a big problem in all sectors of the industry and special effort must be made to enforce mesh size and other regulations on the use of illegal fishing methods.
5. Industrial fishing effort must be reduced by removing trawlers of over 300 GRT and shrimpers over 200 GRT from the coastal fisheries.
6. Full benefit of the fish resources would be realised by removing open access, avoiding subsidies that will increase fishing effort and charging economic fishing licence fees.



## **8.2 SUGGESTIONS FOR FUTURE WORK**

This thesis has touched on a number of issues, processes and problems in the fisheries of Ghana; lack of time, data or relevant information has meant that many were not treated in as much detail as might be needed. These issues range from the biology and population dynamics of the fishes to fisheries management. The thesis itself covers a wide range of diverse but related subjects that together give a clear understanding of the functioning of the coastal ecosystem of Ghana, especially regarding the demersal fish component. In a way, this thesis may be regarded as providing the basis for further research on several issues opened up here for discussion. Changes in both physical and biological components of this ecosystem have been examined. Possible areas for further research are presented below.

### ***8.2.1 Physical components of the Ghanaian shelf ecosystem***

Regarding the physical components of the system, general patterns of change in the marine climate have been examined. Some relationships have been observed between local and global changes in upwelling ecosystems. Sometimes the scale of relationships and comparisons are not as detailed as would be desirable. Therefore, what would be of scientific interest and beneficial for the understanding of dynamics of fish population in the eastern Atlantic would be a comparison of the patterns of change found in this work to events in the adjacent Canary and Benguela Current upwelling systems. For example, how did these other systems lying to the immediate north and south of the Guinea Current respond to the observed cooling between 1972 and 1982? Some investigation in this direction is currently being conducted at the Ecosystems Analysis and Management Group, University of Warwick with assistance from the EU-sponsored INCO-DC (International Co-operation with Developing Countries) Gulf of Guinea Project (under the leadership of Professor Jacqueline McGlade).

It would also be interesting to follow up on the links that were seen between sea surface temperature patterns in the Gulf of Guinea and off Brazil on the western

Atlantic and further to the south. Such investigation would probably throw some light on ENSO events and the remote forcing theory discussed in chapter 2.

### **8.2.3 Biological components of the Ghanaian shelf ecosystem**

This study has concentrated on changes at the community and population levels and very little was done at species level. An interesting study would be to examine the biological reaction of demersal species to changes in the environment. For example, it has been shown that *Sardinella aurita* reacted to the intensification of the minor upwelling off Ghana and Côte d'Ivoire by changing its reproductive strategy to take advantage of the improved and prolonged favourable conditions in the ecosystem (Pezennec and Bard 1992, Pezennec 1995; Pezennec and Koranteng 1997). The growth and population dynamics of the fish also changed. Did any demersal species experience such changes in their biology and population dynamics?

### **8.2.4 Assemblage analysis on a scale finer than used in this thesis**

The analyses in this study concentrated on the main assemblages. In some instances, it was difficult to explain some of the results. It would therefore be interesting to examine the assemblages in more detail and track sub-assemblages in time and space. For example, it is clear that the sciaenid assemblage has clear east and west components. How did these geographic sub-assemblages behave over time? Information at such higher resolution is essential for the management of the shrimp fishery and zonation of fishing grounds for management purposes.

### **8.2.5 Primary productivity and trophic level linkages**

In the course of this thesis, a preliminary steady-state model of the coastal fisheries ecosystem of Ghana was derived using ECOPATH 3.0 (Dogbey 1997). A large amount of data for the study was taken from this thesis and also from the literature. The model was able to assess the levels of fishing intensity for pelagic and demersal resources in the Ghanaian shelf ecosystem. It is essential that this work be



continued, as it could provide clues to understanding the biological consequences of the observed changes in the physical components of the environment in terms of trophic level dynamics.

#### **8.2.6 Stock assessment**

The most recent survey data used in this work were collected in 1990. The results of the analysis have shown how variable stocks can be; therefore, it is essential that these surveys be continued. The importance of current data for stock assessment is demonstrated in the Canadian groundfish fishery where according to Walters and Maguire (1996) the use of inaccurate data in stock assessment contributed to the collapse of an important marine resource.

The observed changes in species composition of the stock appear to indicate that in addition to drawing relationships with the environment, it would be beneficial also to assess the effect of exploitation (trawling) on the stocks. It is essential to note that in most fisheries where a potential yield has been calculated, this potential has always been exceeded and new assessments result in new potential. Pauly (1995) discusses this problem which he calls the “.. shifting baseline syndrome” and calls for models that incorporate indigenous, but unwritten, knowledge (anecdotes) about the fish resources under study.

Direct methods of stock assessment have been used in this work and the use of length frequency data for assessment has yet to be explored. During all the surveys the data of which have been analysed in this thesis, a large amount of length frequency data were also collected, which could be used in an independent assessment to corroborate the findings in this work. For example Koranteng and Pitcher (1987) used only length frequency data to assess the status of the *Pagellus bellottii* fishery of Ghana. Substantial amount of work has been done by scientists at ICLARM on development of methodologies to utilise length data for such purpose.

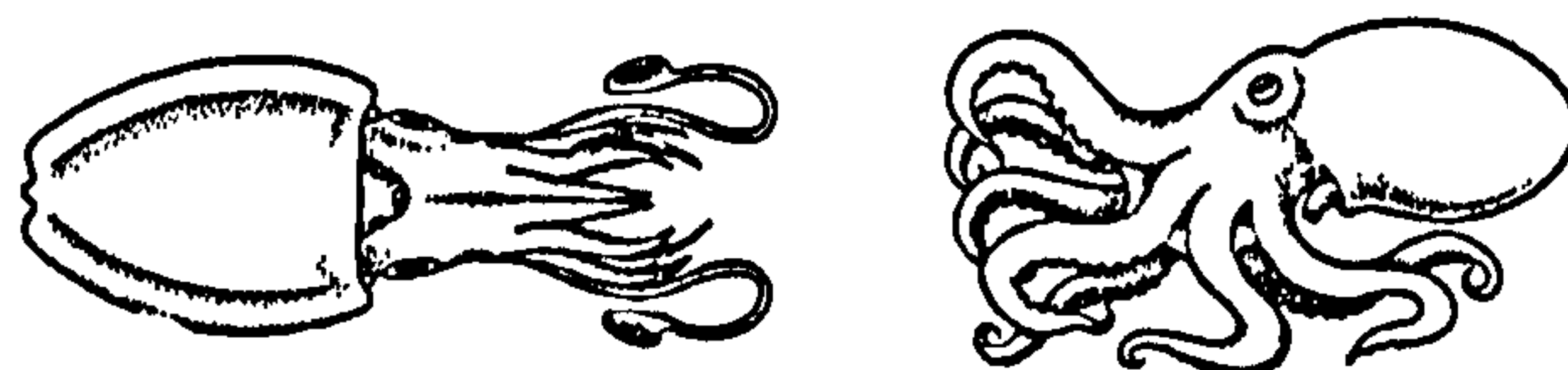
### **8.2.7 Analysis of catch and effort data**

The Schaefer model fitted in this work (for the total demersal biomass) gave interesting results that were very comparable to the results obtained from the direct assessment using swept area methods and potential yield calculations. This analysis could be improved by using more refined effort data. The data used in this work could be supplemented with information obtained from independent enquiries in the fishing industry. Such an analysis is critical in determining the appropriate size of the industrial fleet (trawlers and shrimpers). In this regard, the analysis undertaken for the demersal catch also needs to be re-run with the addition of recent data.

For the purposes of predicting future catches, it would also be desirable to model the relationships between marine environmental and near-shore parameters and catches.

### **8.2.8 Socio-economic studies**

The management recommendations made in this thesis include some socio-economic aspects like removal of subsidies, shedding excess capacity and ways of cutting down effort exerted by artisanal fishers. The socio-economic impact of these actions need to be assessed as well as the economic consequences of increased mesh sizes. These would help to determine government actions that might help to mitigate the social cost of these fisheries management measures.





## APPENDICES

Appendix 3.1. Inventory of coastal sea surface temperature and salinity data assembled for this work

| Station           | Position<br>Latitude longitude | SST                        | Salinity    |
|-------------------|--------------------------------|----------------------------|-------------|
| Keta              | 05°55' N 00°59' E              | 1969 - 1992                | 1970 - 1992 |
| Tema              | 05°35' N 00°04' E              | 1963 - 1992                |             |
| Winneba           | 05°20' N 00°20' W              | 1970 - 1992                |             |
| Takoradi          | 04°53' N 01°46' W              | 1969 - 1992                |             |
| Cape Three Points | 04°47' N 02°07' W              | 1970 - 1992                |             |
| Axim              | 04°52' N 02°14' W              | 1969 - 1992                |             |
| Half Assini       | 05°06' N 02°53' W              | 1969 - 1981<br>1990 - 1992 |             |

Appendix 3.2. Properties of sampling stations on the Tema hydrographic transect

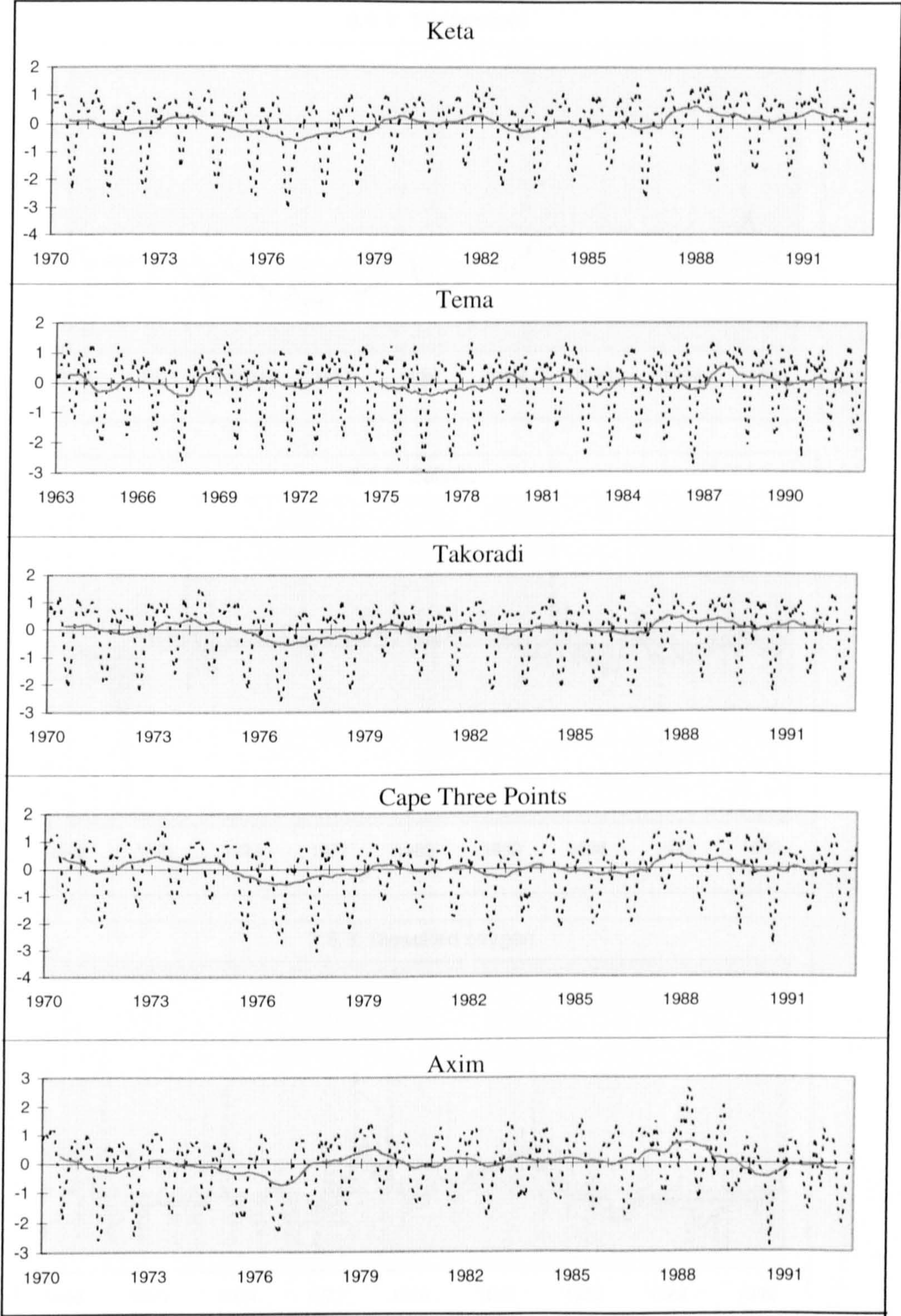
| Station | Position<br>Latitude Longitude | Depth<br>(m) | Distance<br>from shore<br>(km) | Depths sampled (m)   |
|---------|--------------------------------|--------------|--------------------------------|----------------------|
| A1      | 05°33.5' N 00°01' E            | 33           | 10                             | 0 10 20 30           |
| A2      | 05°26.2' N 00°01' E            | 52           | 24                             | 0 10 20 30 50        |
| B       | 05°23.0' N 00°03' E            | 108          | 30                             | 0 10 20 30 40 75 100 |
| C       | 05°21.3' N 00°03' E            | off shelf    | 32                             | 0 10 20 30 40 75 100 |

Appendix 3.3. Inventory of atmospheric data obtained from MSD, Accra.

| Station     | Air temperature | Rainfall* |
|-------------|-----------------|-----------|
| Ada         | 1961-1993       | 1963-1993 |
| Tema        | 1961-1993       | 1961-1993 |
| Saltpond    | 1961-1993       | 1963-1993 |
| Takoradi    | 1961-1993       | 1963-1993 |
| Axim        | 1961-1993       | 1963-1993 |
| Half Assini |                 | 1963-1993 |

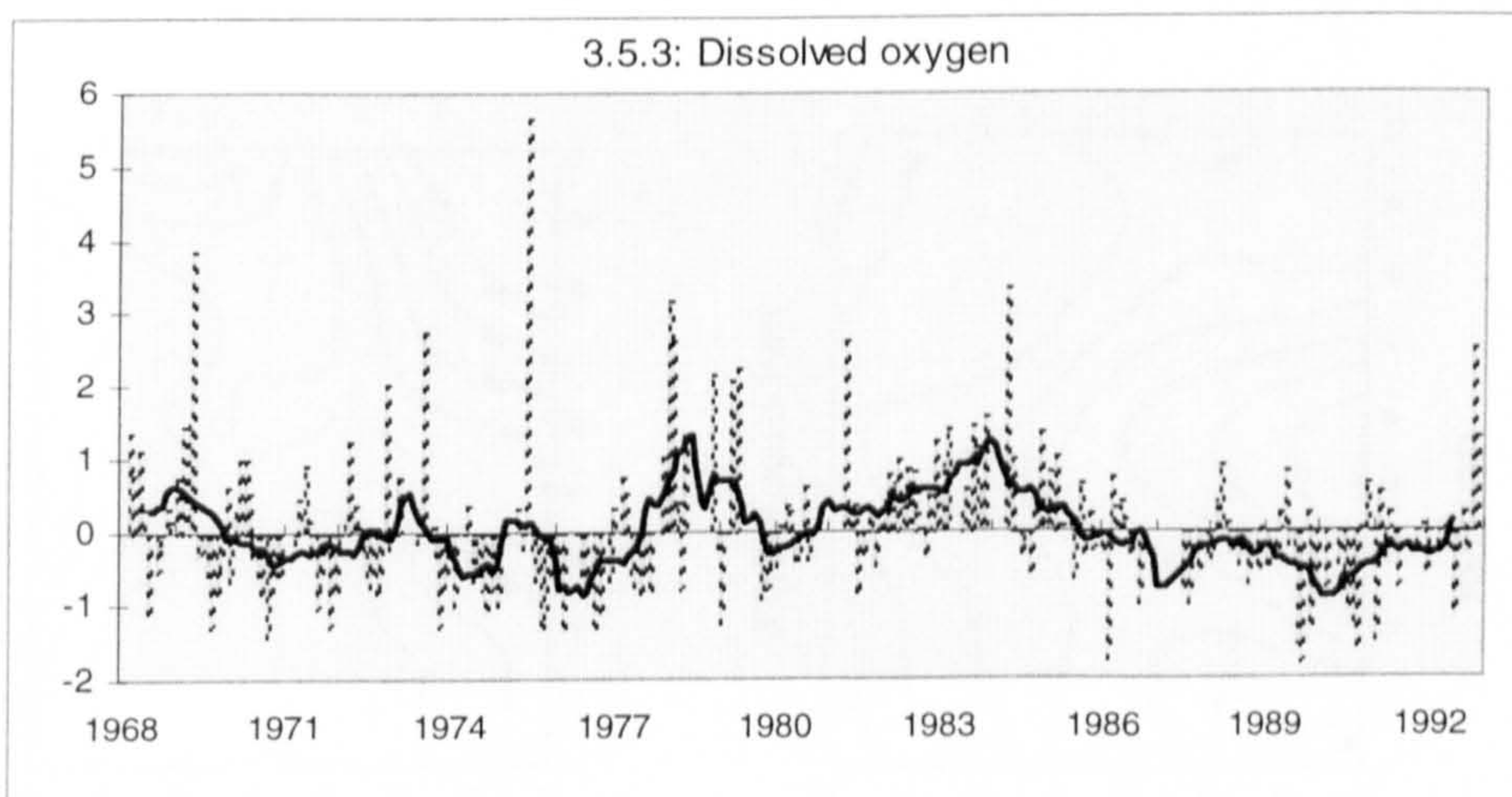
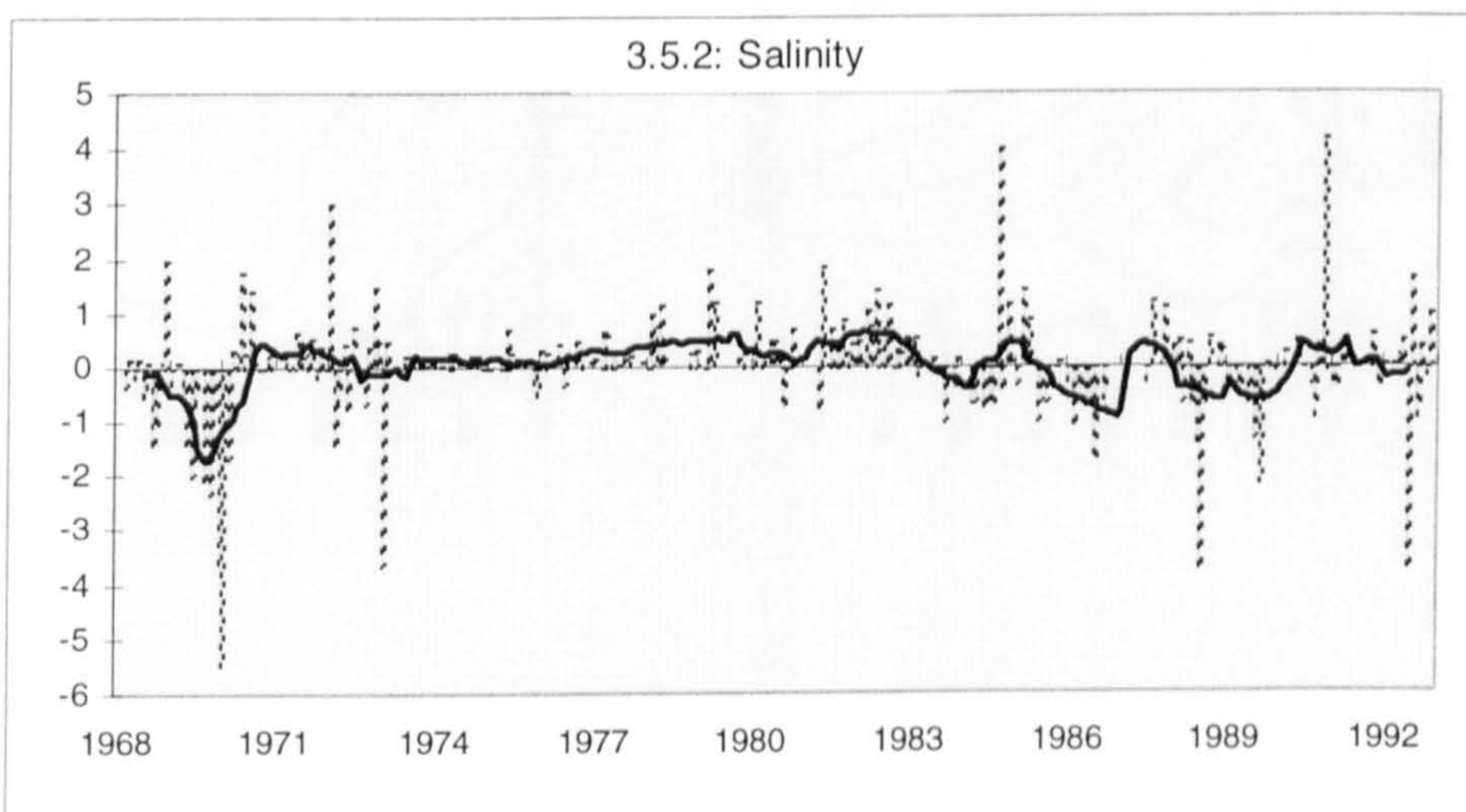
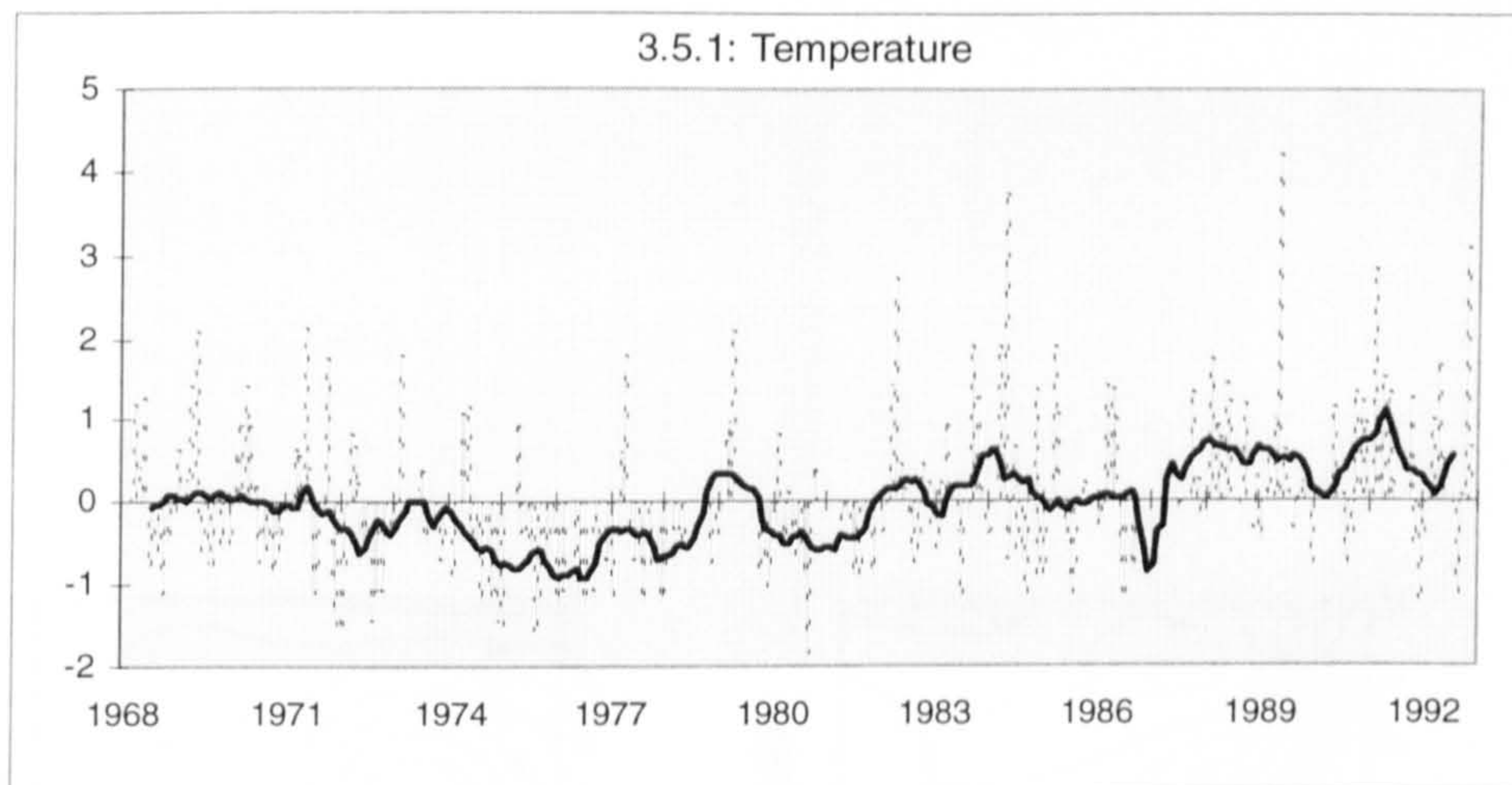
\* There are some missing values, especially in the Half Assini data.





Appendix 3.4. SST anomalies for the indicated coastal stations in Ghana

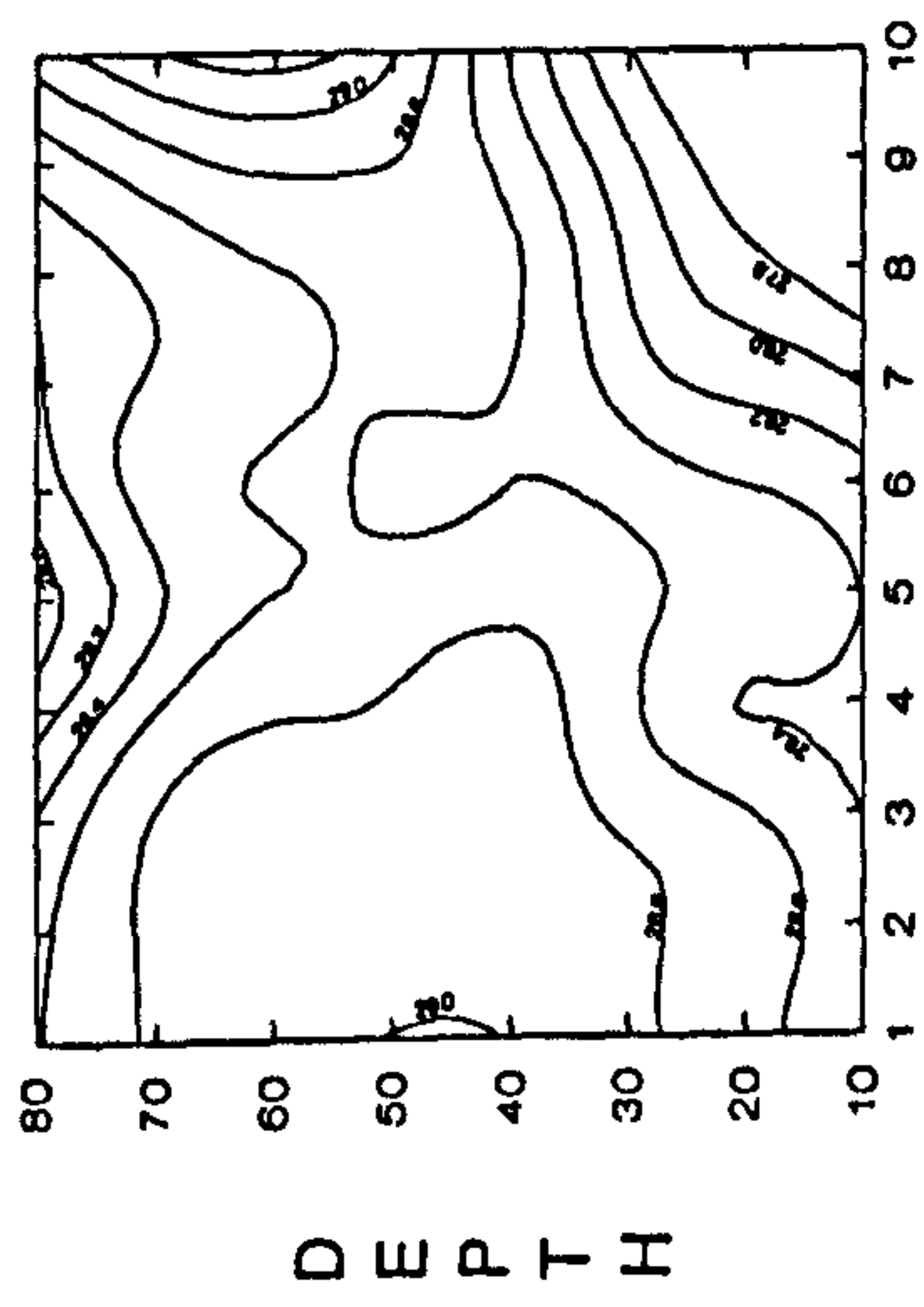




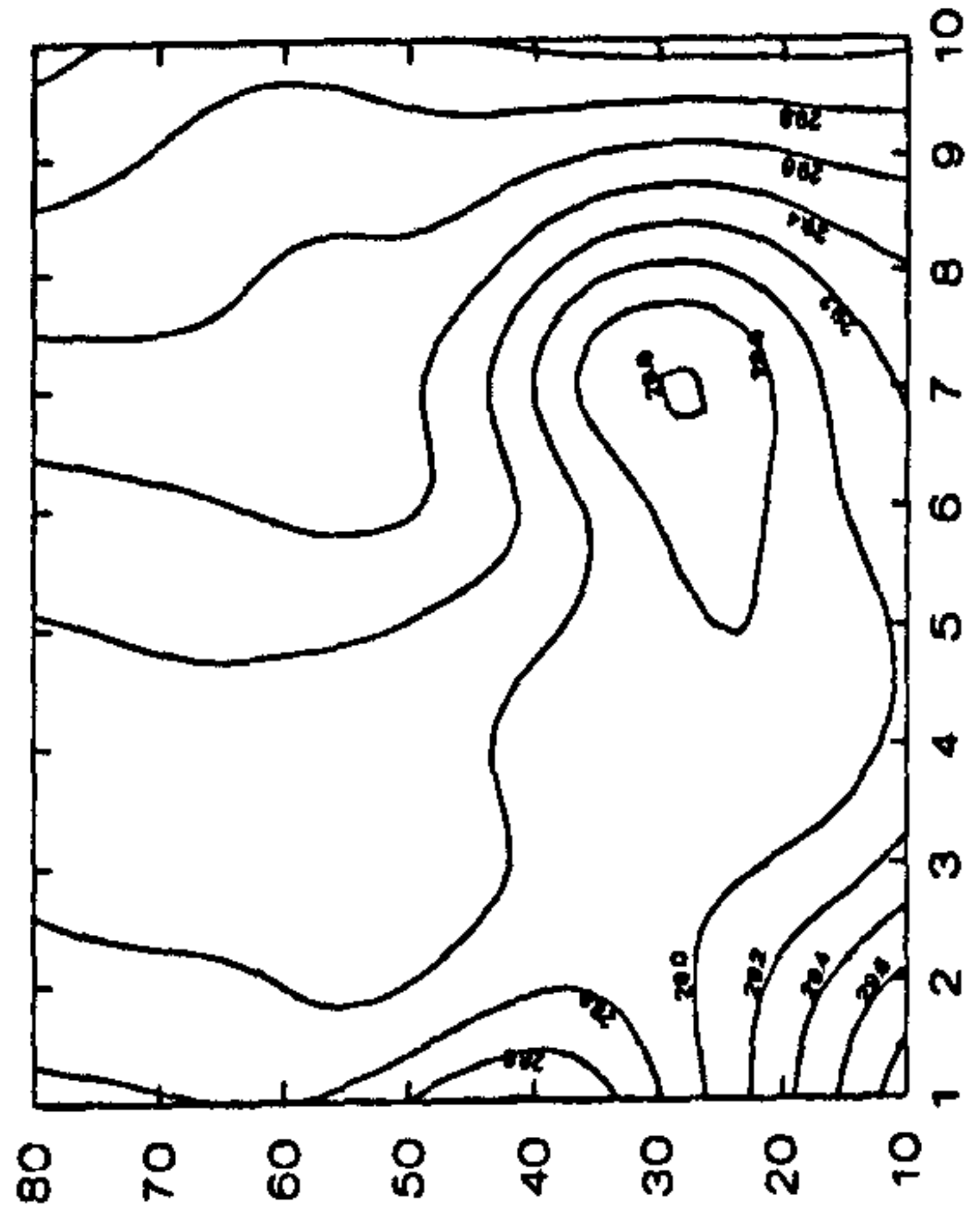
Appendix 3.5: Anomalies of temperature, salinity and dissolved oxygen measured Tema hydrographic station B (100 m deep)



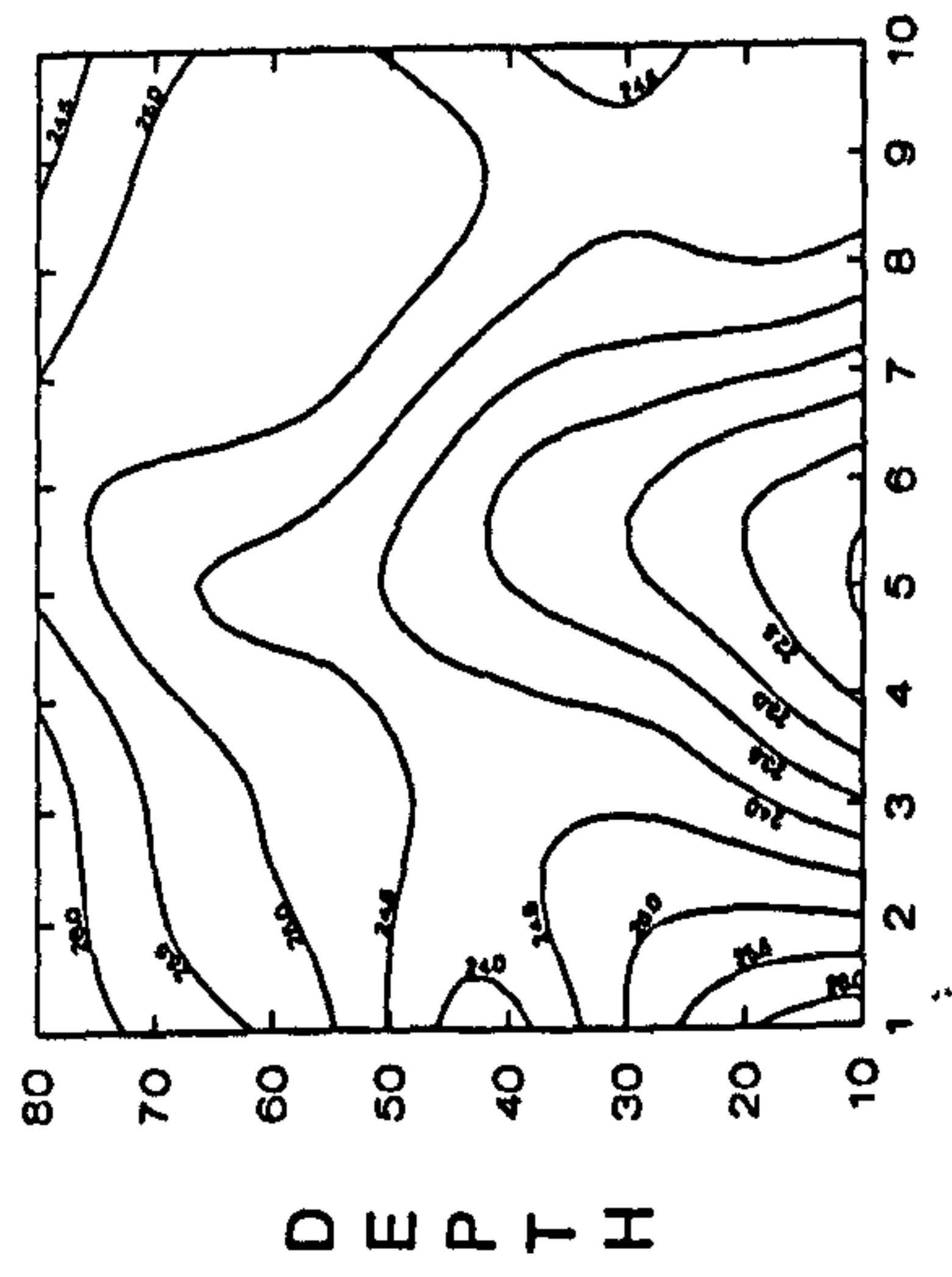
3.6.1: May 1981



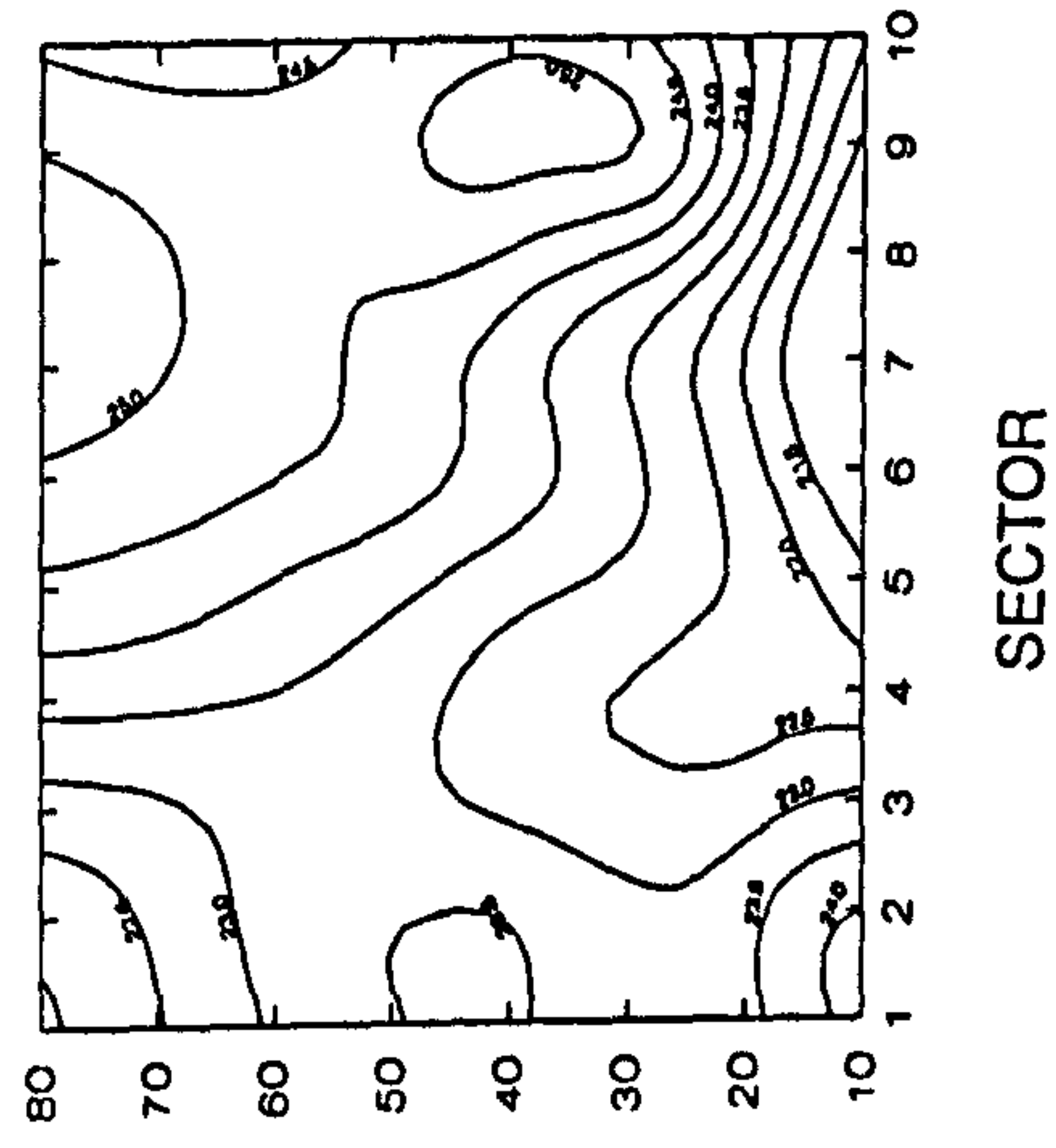
3.6.2: May 1989



3.6.3: August 1981

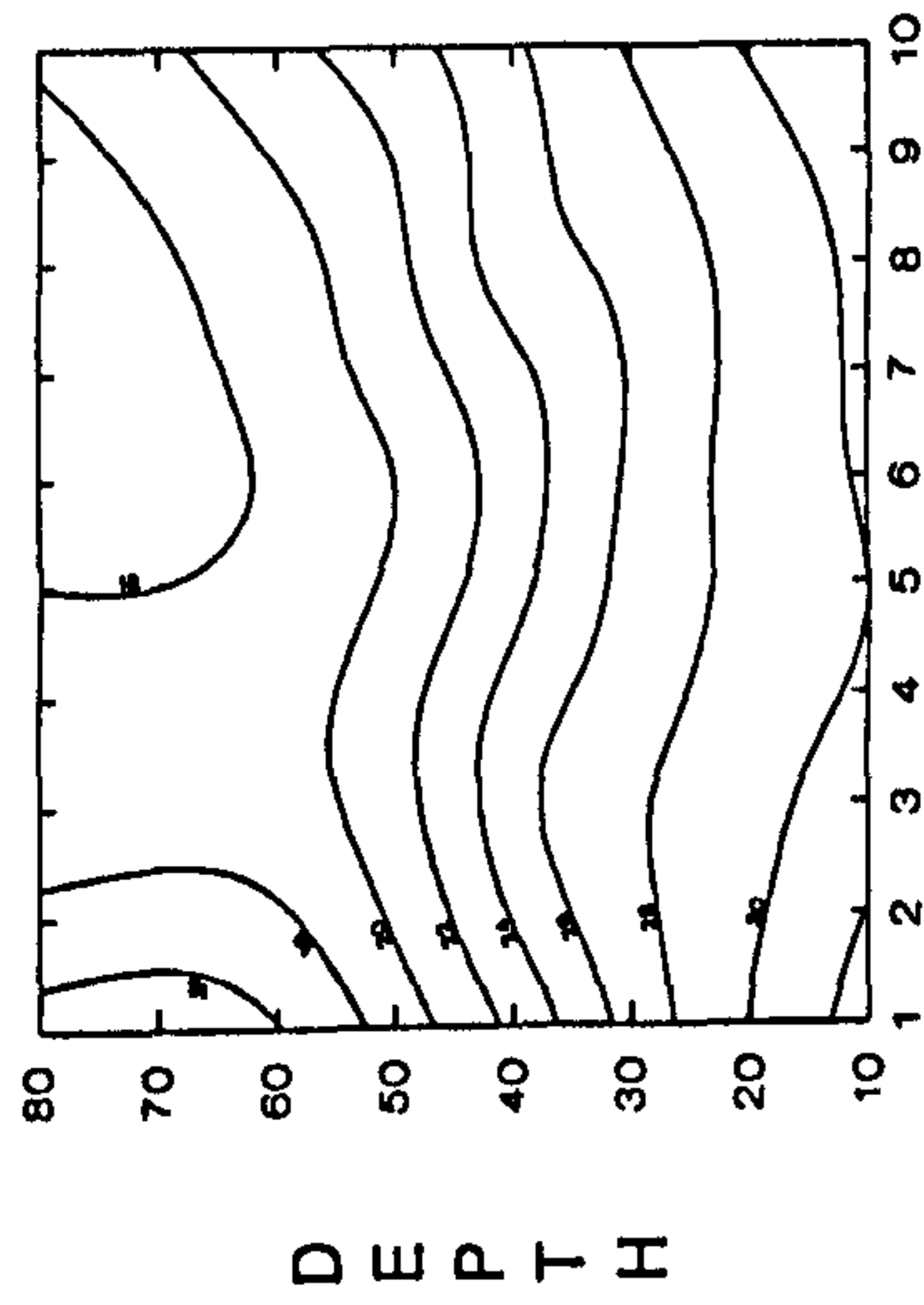


3.6.4: August 1989

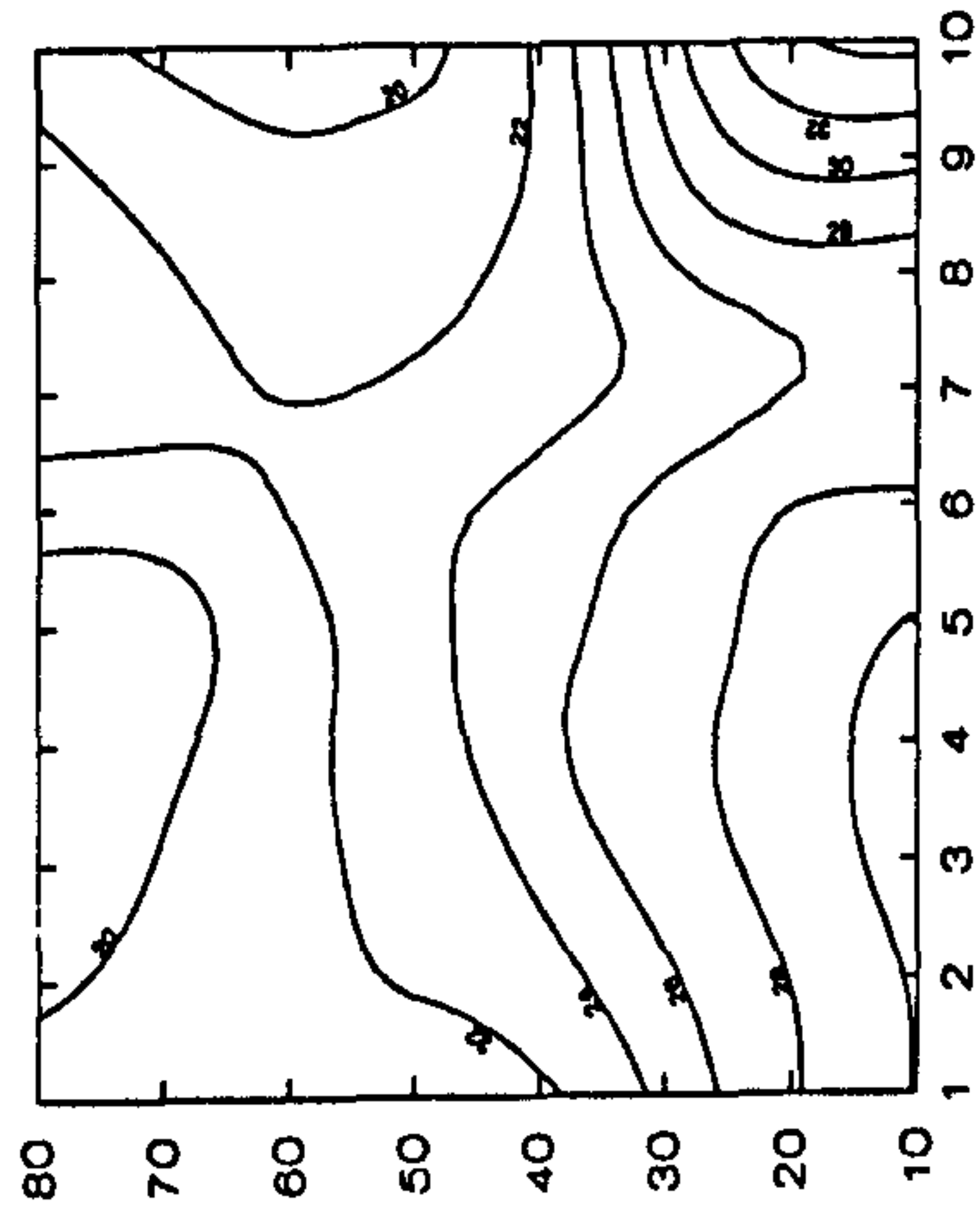


Appendices 3.6.1 - 3.6.4: Spatial distribution of sea surface temperature recorded during trawl surveys

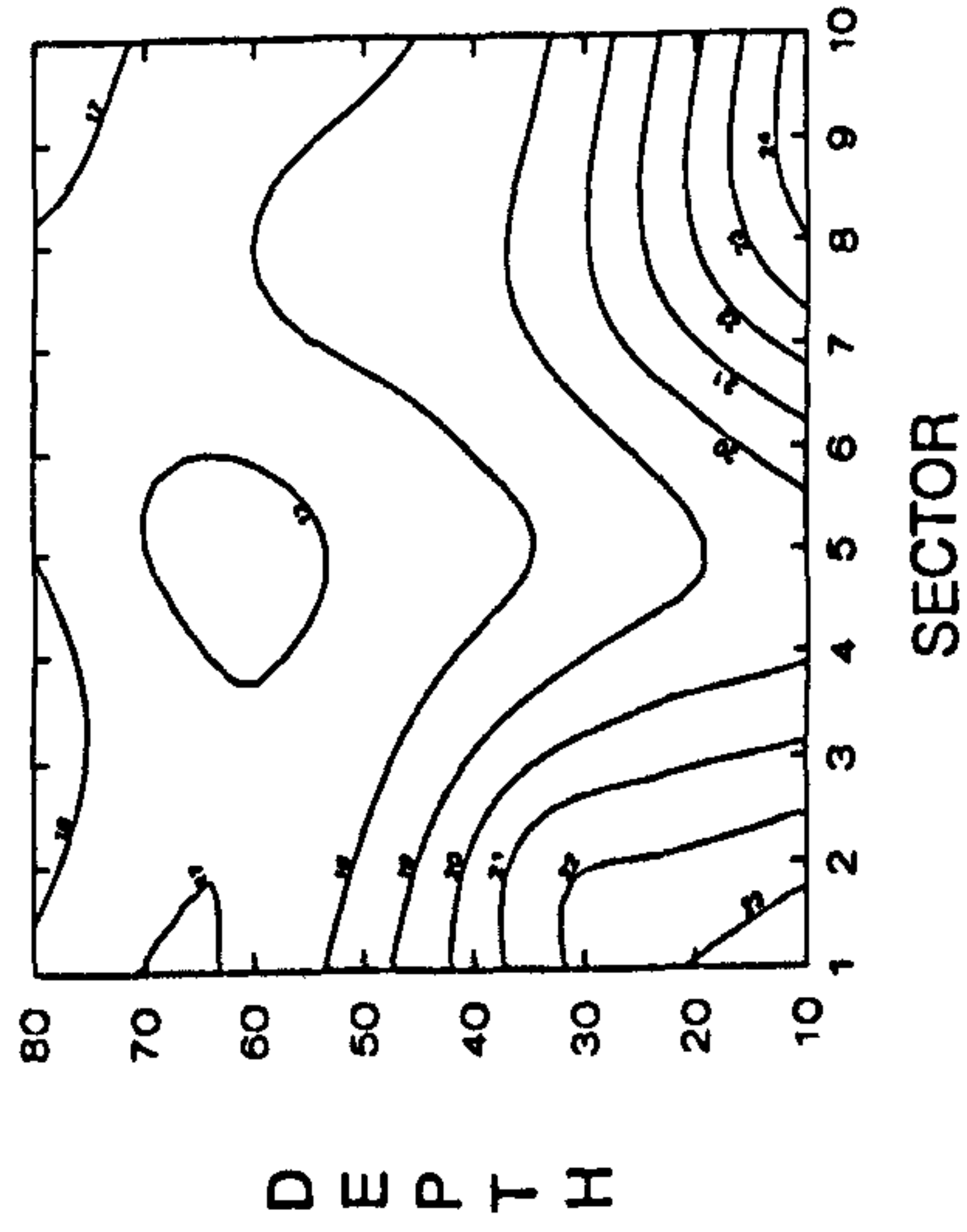
3.6.5: May 1981



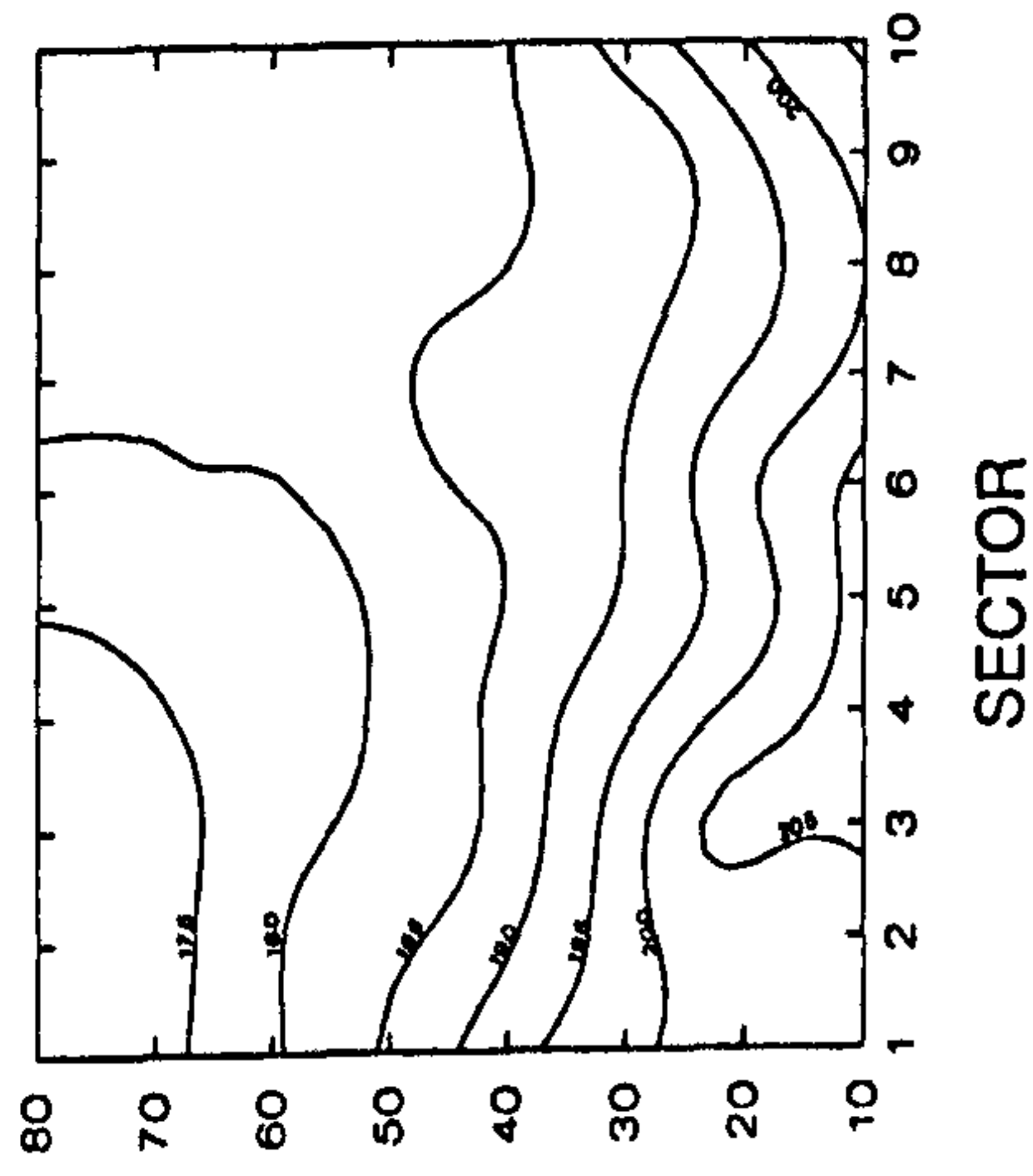
3.6.6: May 1989



3.6.7: August 1981

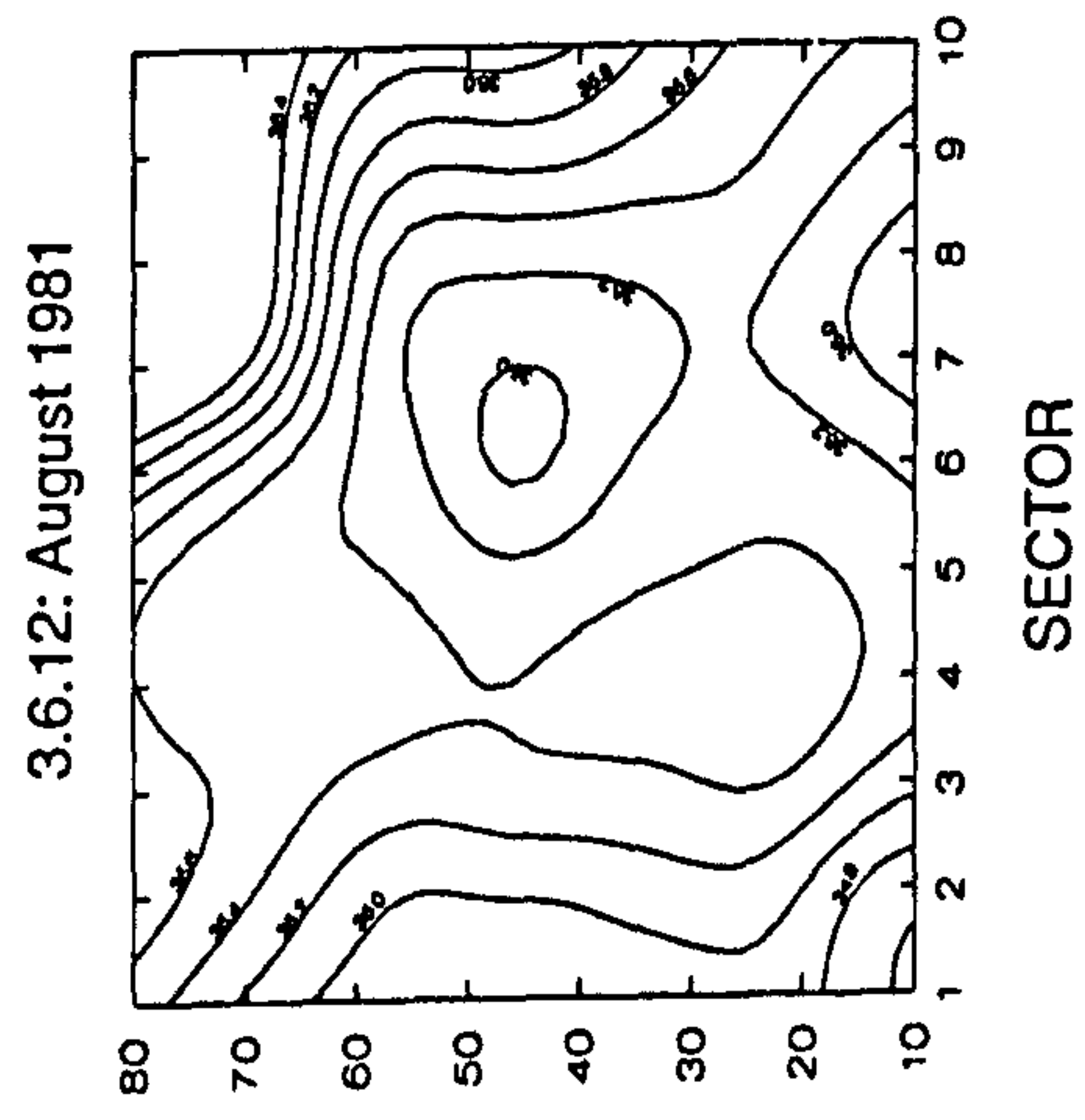
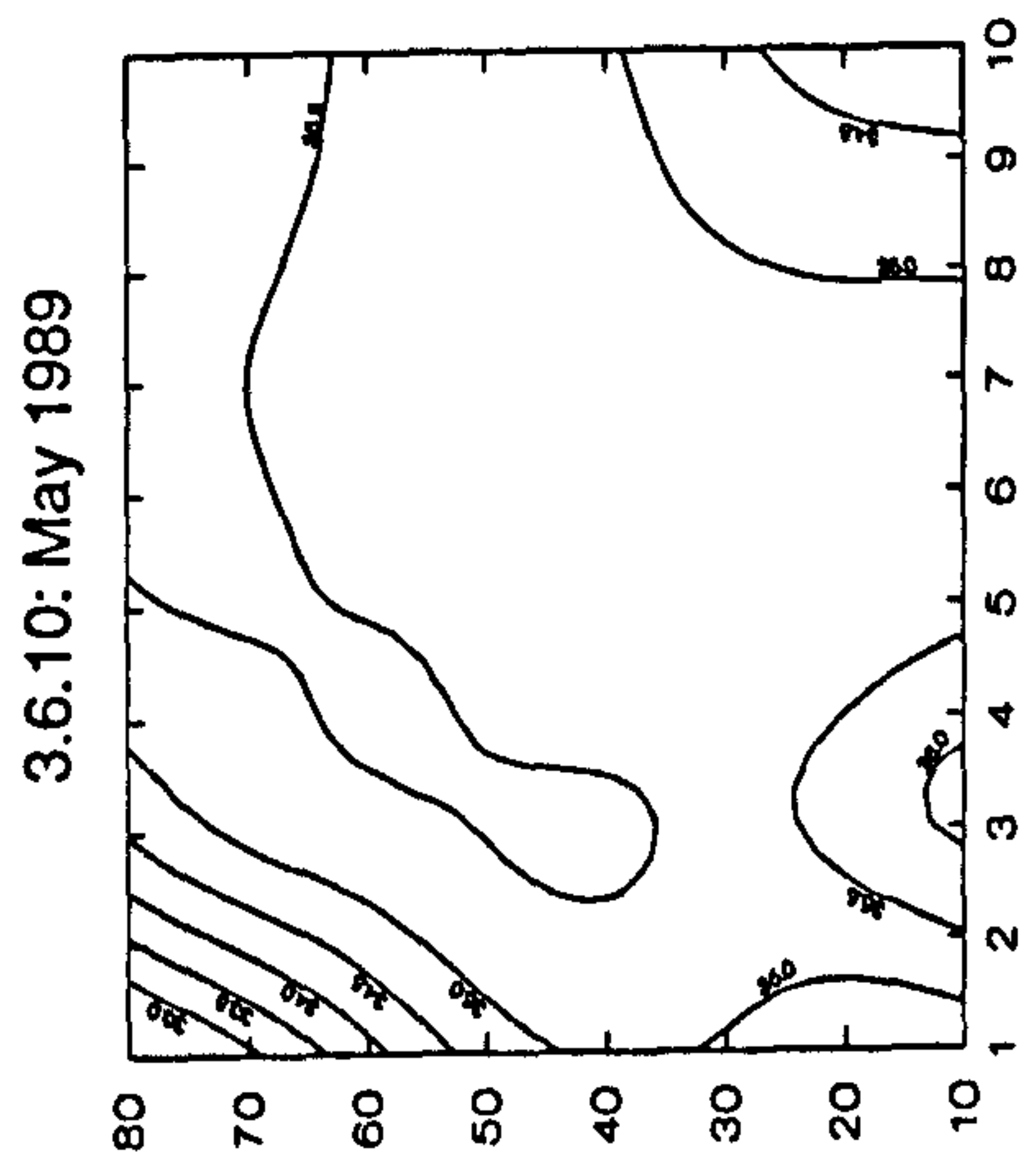
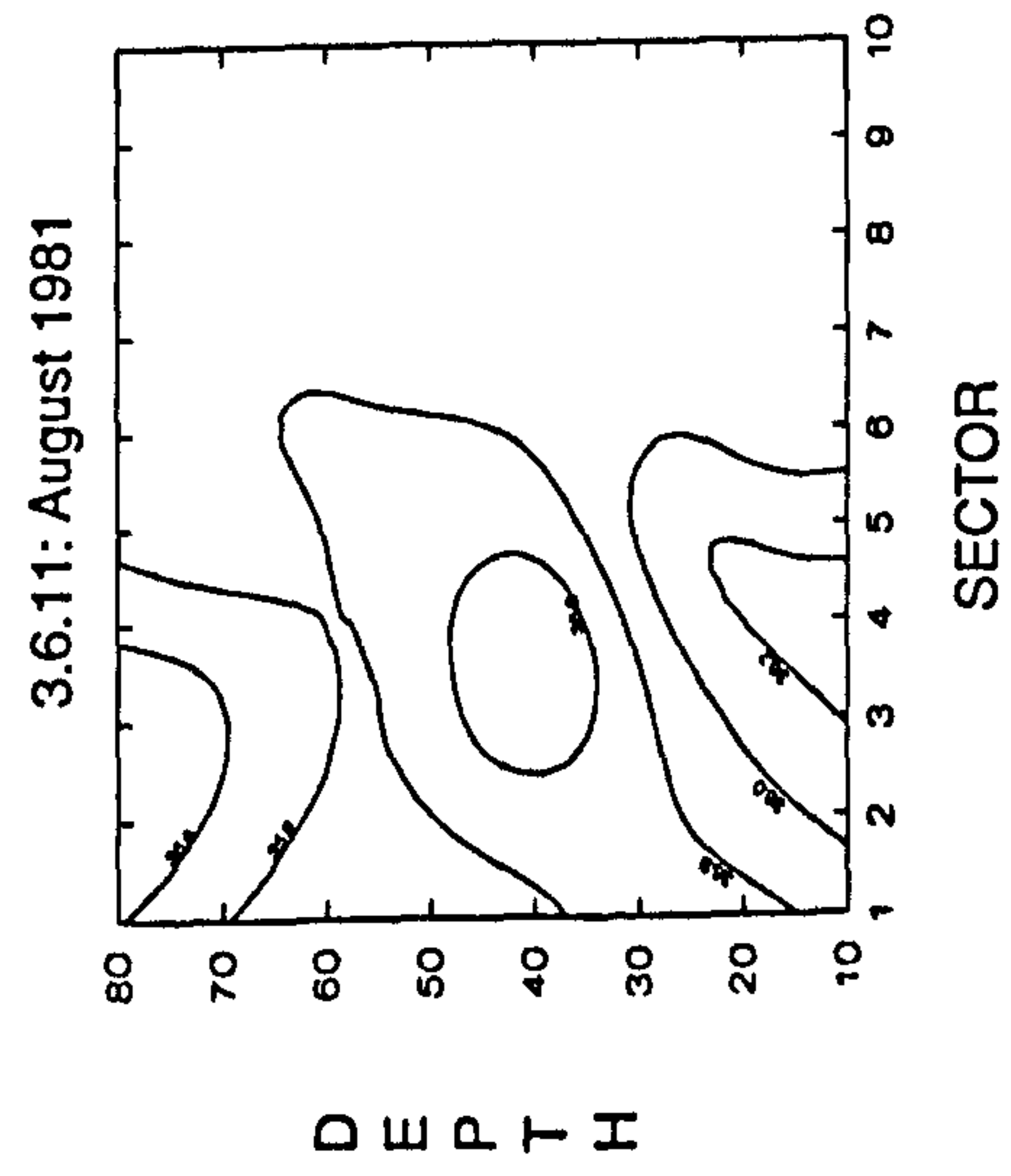
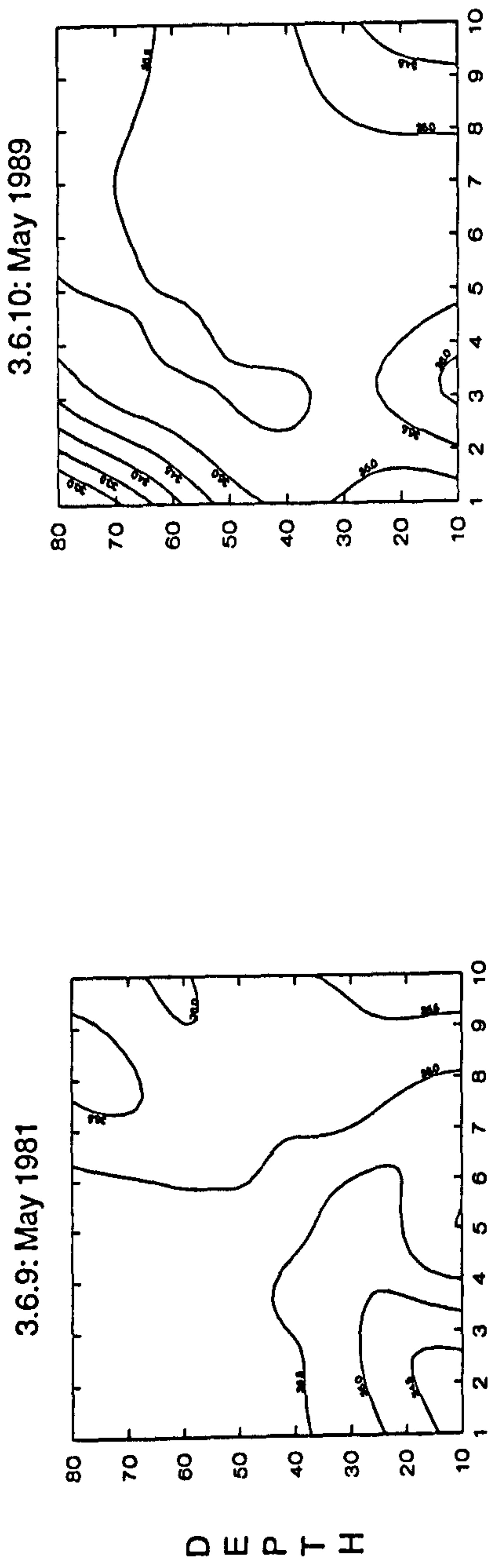


3.6.8: August 1989

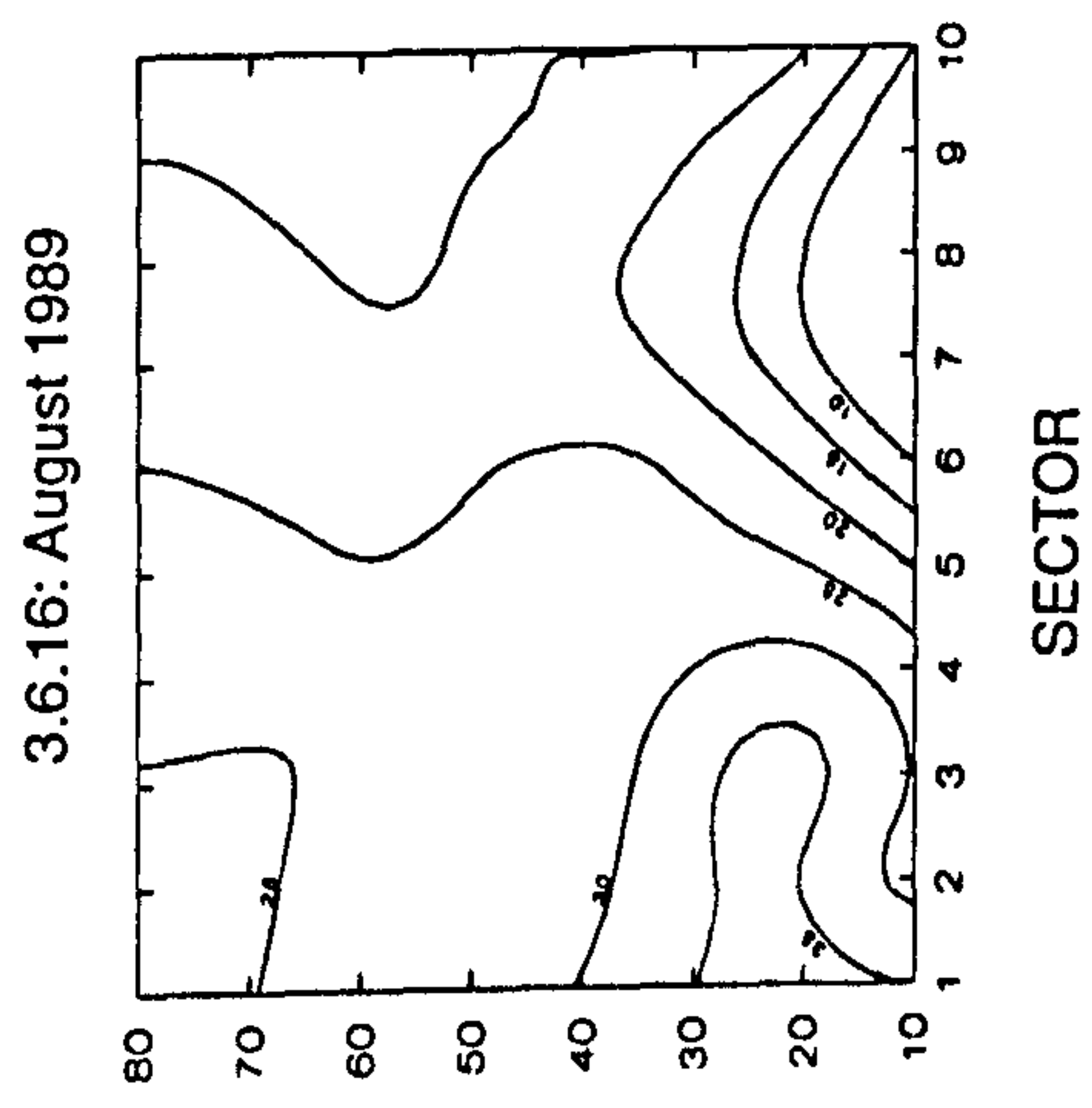
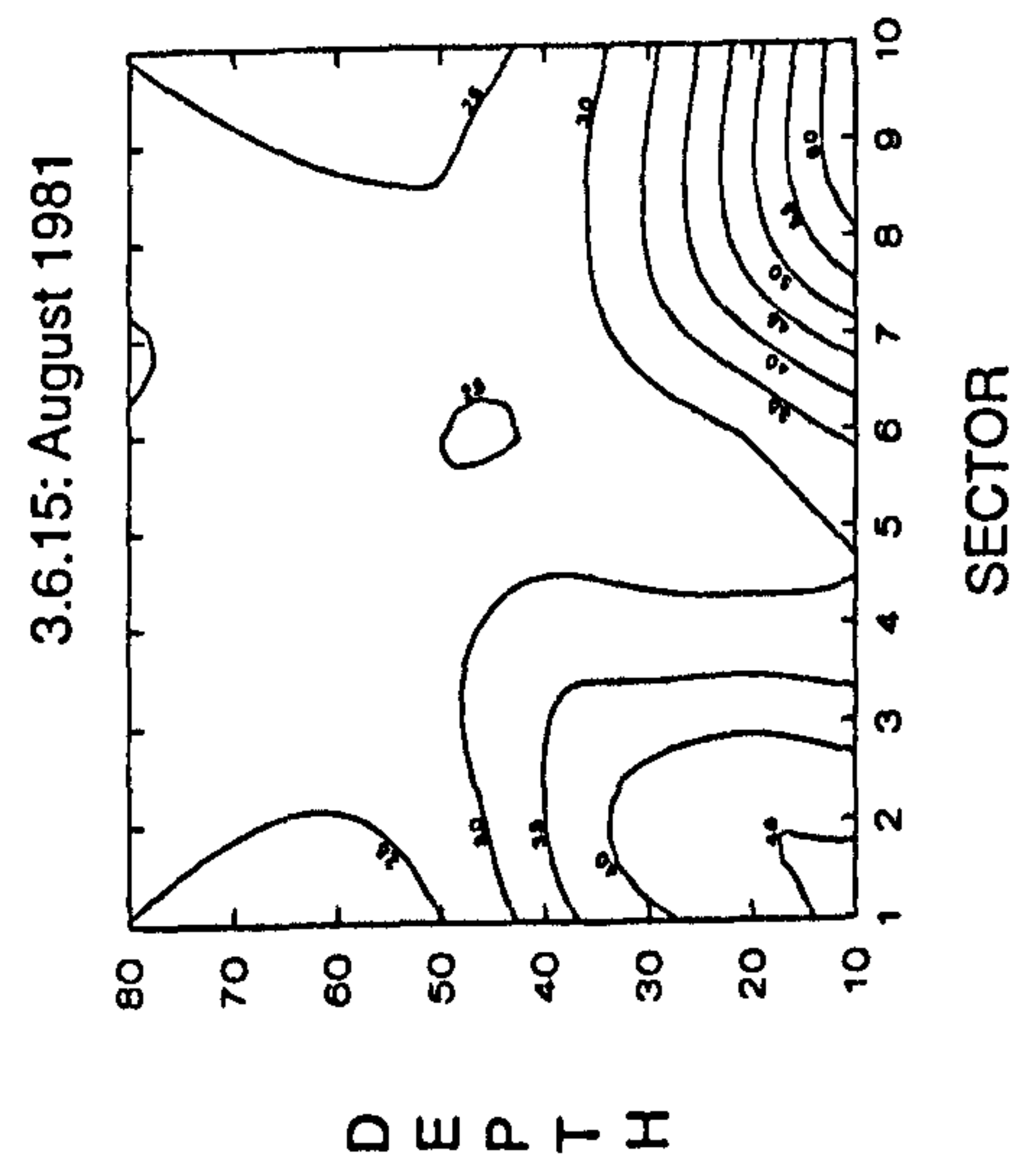
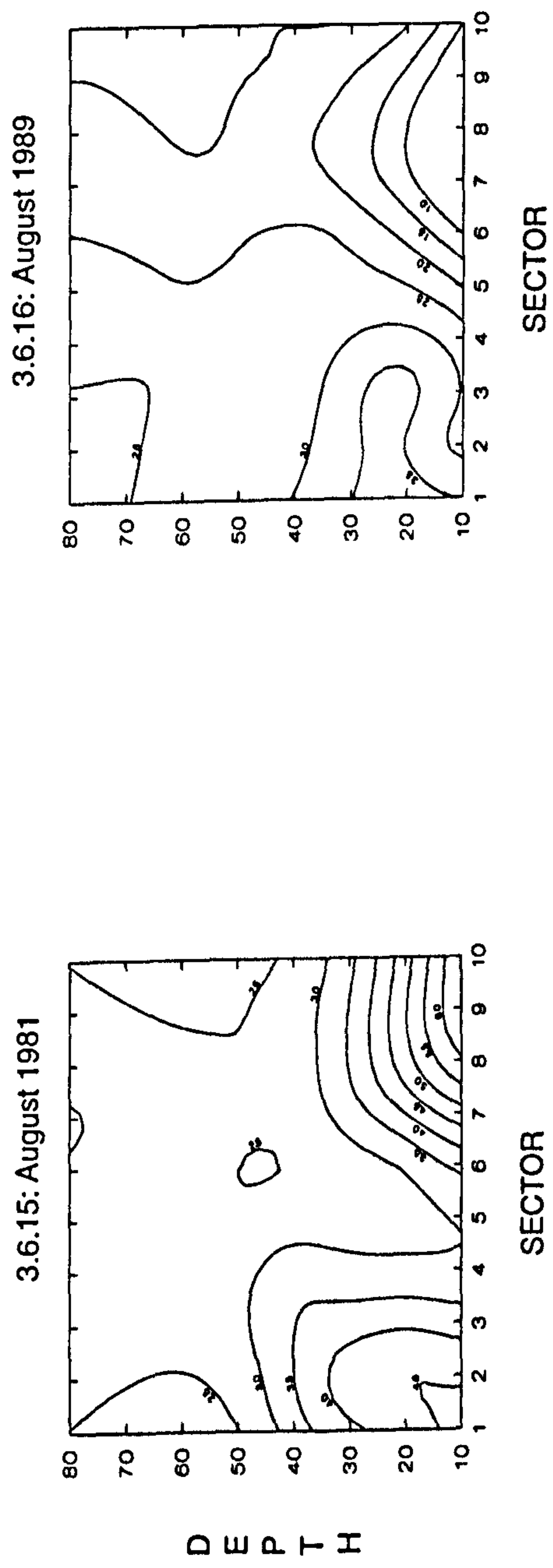
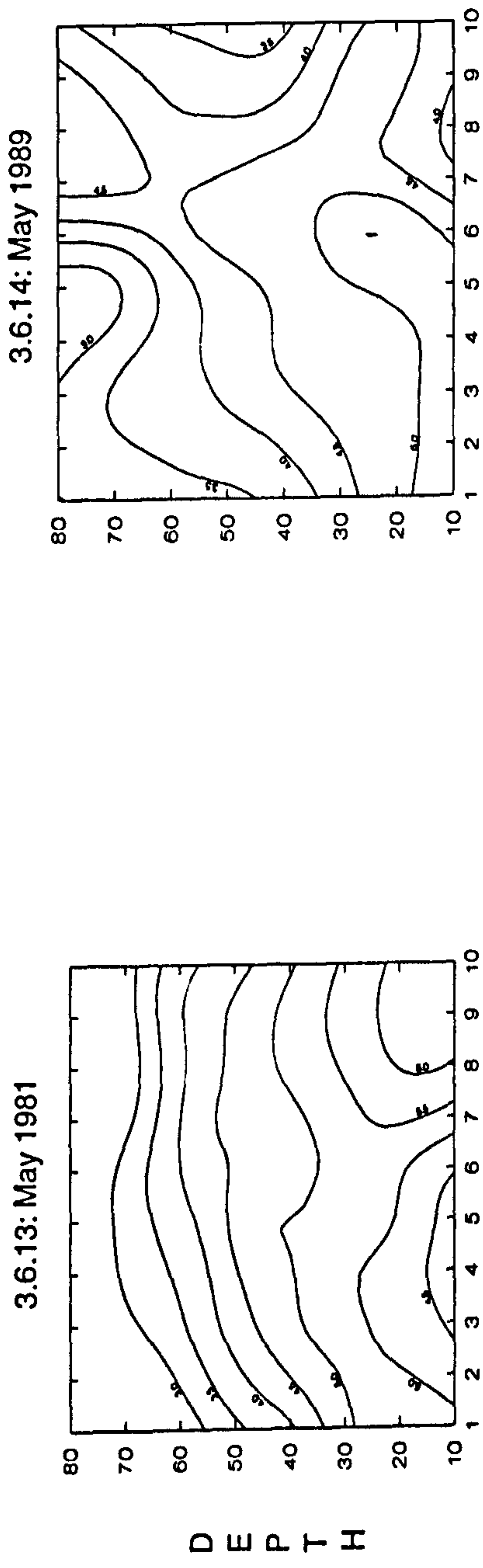


Appendices 3.6.5 - 3.6.8: Spatial distribution of bottom temperature recorded during trawl surveys





Appendices 3.6.9 - 3.6.12: Spatial distribution of bottom salinity recorded during trawl surveys



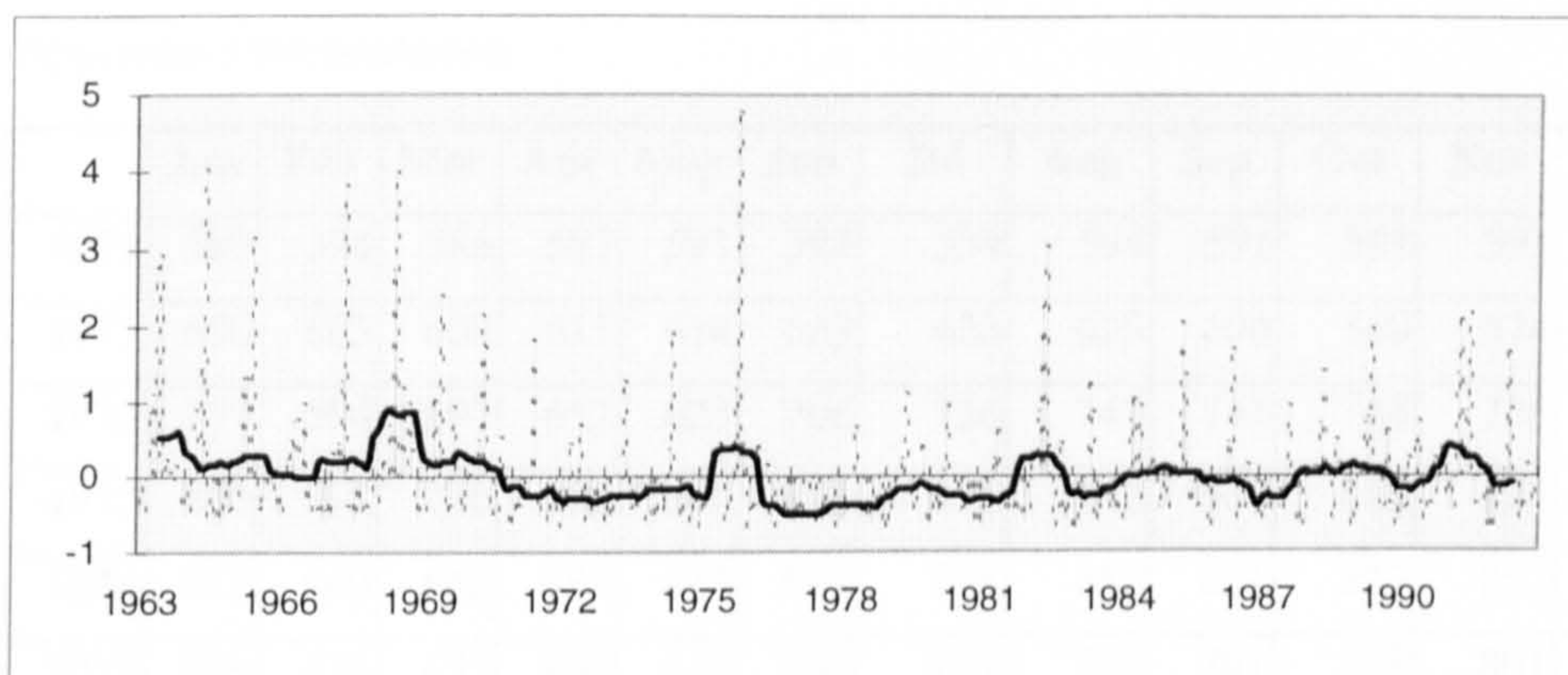
Appendices 3.6.13 - 3.6.16: Spatial distribution of bottom dissolved oxygen recorded during trawl surveys



Appendix 3.7: Total annual rainfall (mm) at five meteorological stations, 1963-1992

| YEAR | ADA    | TEMA   | SALTPOND | TAKORADI | AXIM   |
|------|--------|--------|----------|----------|--------|
| 1963 | 991.4  | 884.3  | 1389.4   | 1967     | 3238.2 |
| 1964 | 597.2  | 525.7  | 1243.1   | 1536.4   | 1697.4 |
| 1965 | 827.3  | 847.1  | 1075.3   | 1292.3   | 2929.3 |
| 1966 | 818    | 495.9  | 882.9    | 924.3    | 1522.8 |
| 1967 | 1056.3 | 673.7  | 1101     | 1319.3   | 1727.2 |
| 1968 | 1694.3 | 1720.5 | 1492.9   | 2066.3   | 3031.5 |
| 1969 | 618.9  | 649.8  | 1074.2   | 1249.4   | 2332.3 |
| 1970 | 963.7  | 690.3  | 897.4    | 1376.2   | 1867.9 |
| 1971 | 298.2  | 902.2  | 350.3    | 475      | 596.4  |
| 1972 | 312.2  | 822.7  | 297.1    | 325.7    | 658.8  |
| 1973 | 370.8  | 851    | 414.8    | 404.9    | 619.8  |
| 1974 | 439.9  | 799.6  | 497.2    | 563.9    | 920.6  |
| 1975 | 796.1  | 700.8  | 1438.5   | 1601     | 2966.5 |
| 1976 | 186.3  | 560.7  | 243.6    | 364.7    | 727.1  |
| 1977 | 132.1  | 329.4  | 206      | 228.9    | 435.7  |
| 1978 | 197.7  | 378.8  | 292.6    | 368.5    | 908.3  |
| 1979 | 297.4  | 878.1  | 539.1    | 572.6    | 1072.7 |
| 1980 | 225.7  | 901.3  | 384.7    | 487      | 709.7  |
| 1981 | 279.8  | 721.2  | 369.3    | 299.7    | 580.8  |
| 1982 | 1247.5 | 673    | 1270.9   | 1132.6   | 2276.9 |
| 1983 | 513.5  | 330.4  | 442.7    | 470.8    | 1260.8 |
| 1984 | 726.9  | 461.3  | 705.1    | 1027.7   | 1943.6 |
| 1985 | 665.7  | 537.6  | 1166.9   | 889      | 1832.8 |
| 1986 | 495.8  | 368    | 907.2    | 742.4    | 2057.1 |
| 1987 | 196.1  | 693.3  | 333.2    | 435.7    | 869.1  |
| 1988 | 848.2  | 730    | 910      | 970.1    | 1787.9 |
| 1989 | 949.4  | 642.8  | 898.5    | 947.1    | 1533.8 |
| 1990 | 669.7  | 542.9  | 594.1    | 732.2    | 1385.1 |
| 1991 | 1313.9 | 758.1  | 1133.5   | 1199     | 1664.8 |
| 1992 | 359.2  | 457.9  | 601      | 1053.5   | 1849.3 |





Appendix 3.8: The rainfall index smoothed with a 13-point moving average.

Appendix 3.9.1: Monthly mean discharge rate ( $\text{m}^3 \text{s}^{-1}$ ) of the Volta River

|             | Jan | Feb | Mar | Apr | May | Jun  | Jul  | Aug  | Sep   | Oct   | Nov  | Dec |
|-------------|-----|-----|-----|-----|-----|------|------|------|-------|-------|------|-----|
| <b>1950</b> | 36  | 23  | 11  | 27  | 36  | 62   | 339  | 962  | 2355  | 2484  | 432  | 51  |
| <b>1951</b> | 25  | 26  | 26  | 17  | 86  | 80   | 498  | 1253 | 5039  | 8101  | 5880 | 435 |
| <b>1952</b> | 203 | 101 | 29  | 56  | 85  | 162  | 781  | 1360 | 4668  | 9338  | 2022 | 307 |
| <b>1953</b> | 203 | 130 | 105 | 66  | 138 | 1222 | 1977 | 3026 | 4923  | 5340  | 778  | 248 |
| <b>1954</b> | 145 | 94  | 65  | 37  | 132 | 409  | 546  | 678  | 3506  | 4508  | 1159 | 425 |
| <b>1955</b> | 201 | 126 | 84  | 61  | 119 | 297  | 1776 | 4239 | 7109  | 7790  | 1997 | 365 |
| <b>1956</b> | 193 | 119 | 85  | 76  | 110 | 214  | 311  | 623  | 2772  | 3711  | 445  | 242 |
| <b>1957</b> | 108 | 62  | 41  | 79  | 72  | 1397 | 2195 | 2693 | 6747  | 8613  | 2798 | 638 |
| <b>1958</b> | 189 | 101 | 88  | 107 | 65  | 193  | 205  | 456  | 1711  | 1401  | 281  | 189 |
| <b>1959</b> | 148 | 51  | 29  | 34  | 87  | 138  | 866  | 1010 | 4044  | 4532  | 588  | 102 |
| <b>1960</b> | 36  | 18  | 14  | 30  | 91  | 277  | 736  | 1953 | 4885  | 6719  | 878  | 198 |
| <b>1961</b> | 79  | 35  | 17  | 23  | 72  | 236  | 1097 | 1694 | 2492  | 2923  | 279  | 166 |
| <b>1962</b> | 76  | 28  | 22  | 52  | 118 | 635  | 1848 | 2641 | 6472  | 6976  | 1512 | 355 |
| <b>1963</b> | 129 | 34  | 42  | 39  | 189 | 195  | 2603 | 5819 | 12494 | 10706 | 3819 | 366 |
| <b>1964</b> | 154 | 97  | 27  | 38  | 33  | 32   | 30   | 35   | 33    | 36    | 24   | 22  |
| <b>1965</b> | 22  | 24  | 24  | 24  | 24  | 24   | 25   | 20   | 68    | 102   | 127  | 136 |
| <b>1966</b> | 156 | 150 | 173 | 153 | 150 | 164  | 161  | 161  | 158   | 158   | 161  | 167 |
| <b>1967</b> | 173 | 195 | 226 | 269 | 303 | 371  | 396  | 419  | 405   | 436   | 504  | 512 |
| <b>1968</b> | 589 | 524 | 524 | 526 | 529 | 524  | 524  | 538  | 543   | 541   | 535  | 535 |
| <b>1969</b> | 543 | 552 | 560 | 566 | 569 | 569  | 572  | 566  | 589   | 572   | 580  | 574 |



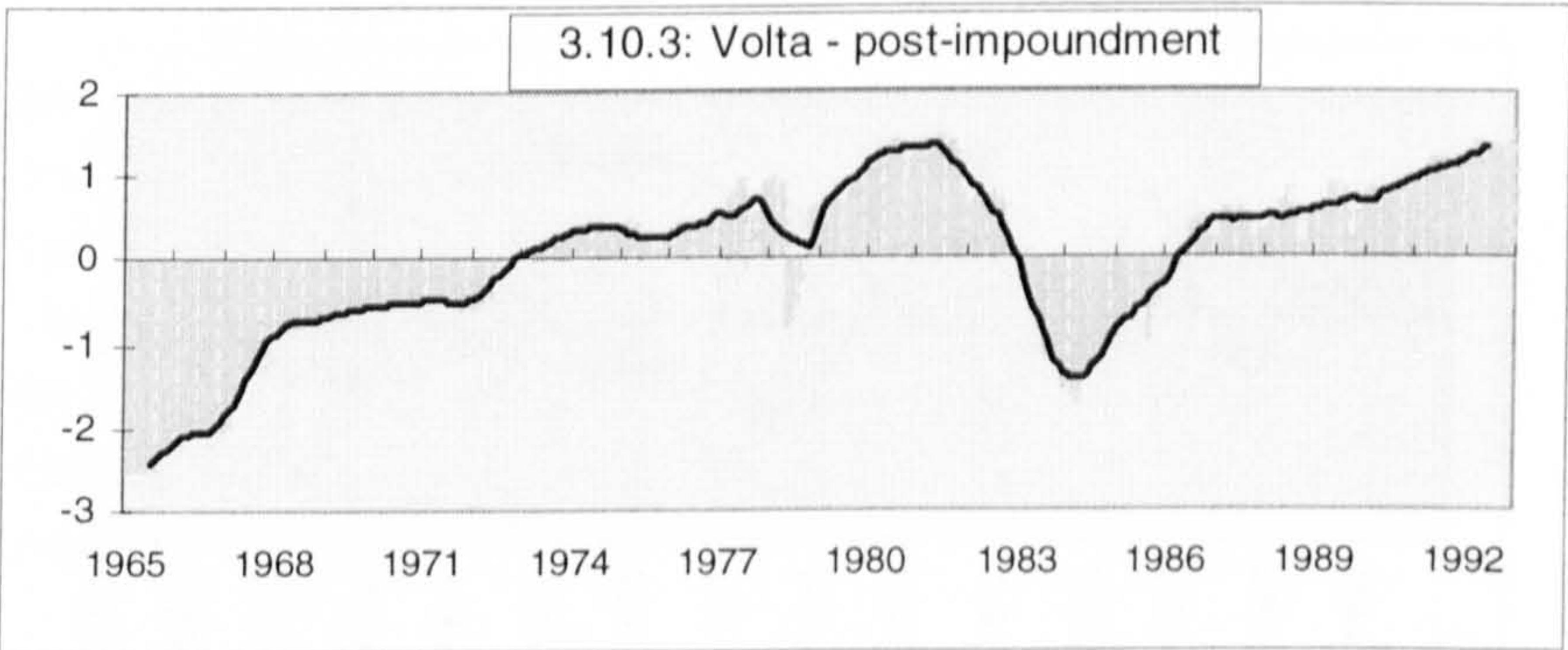
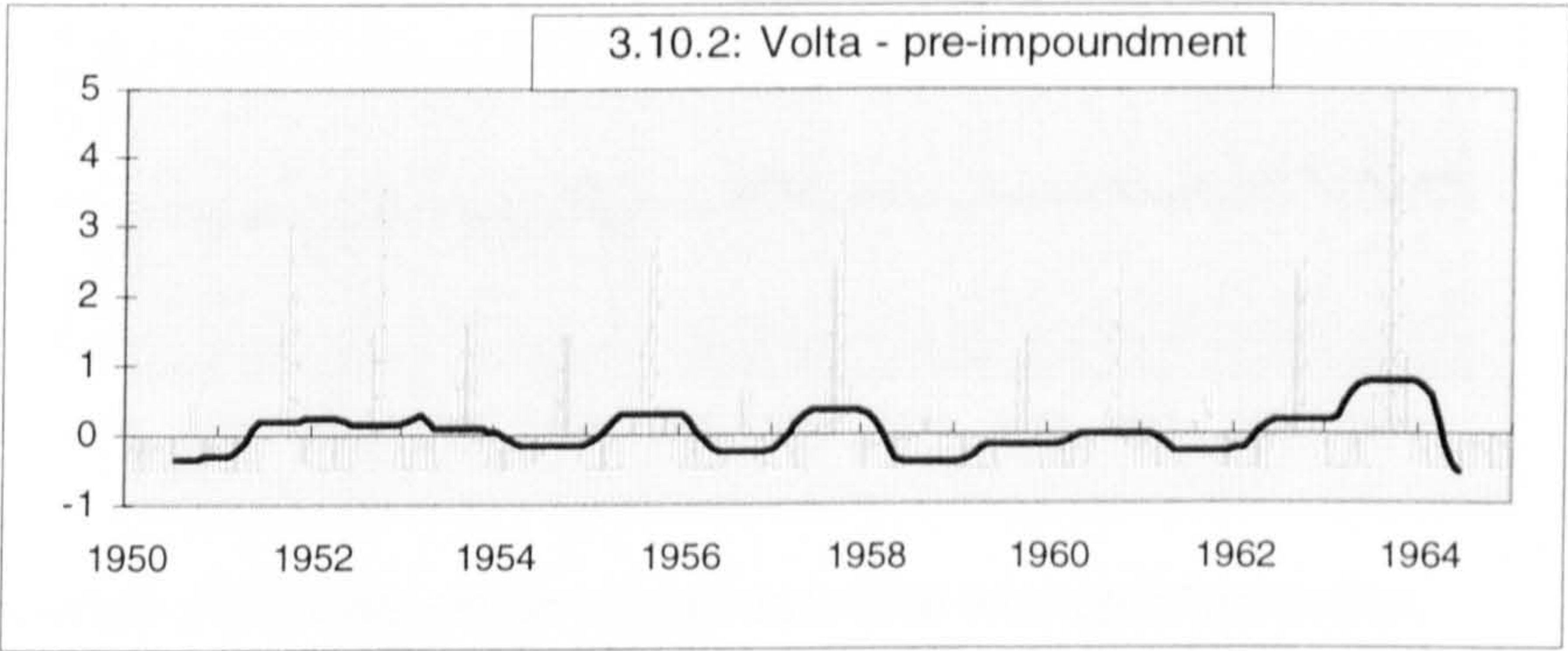
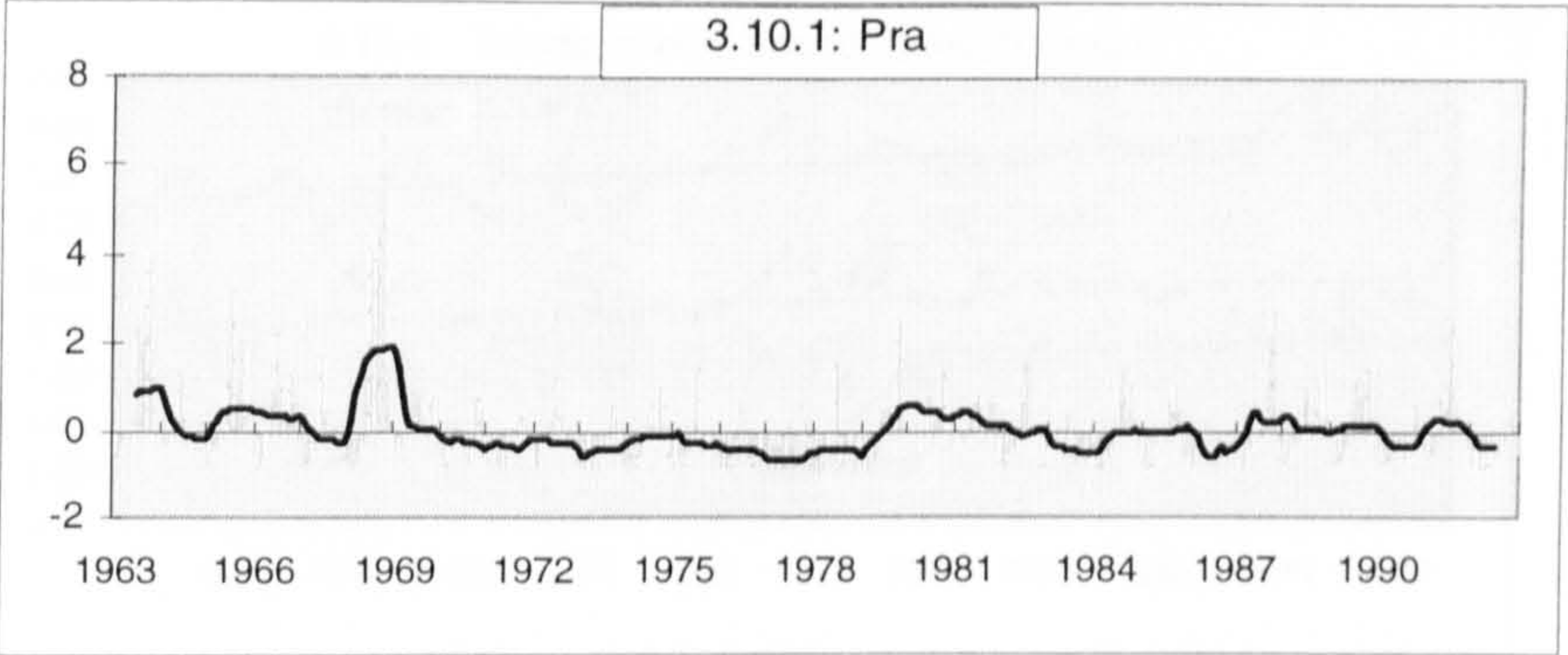
## Appendix 3.9.1 continued

|      | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1970 | 583  | 594  | 586  | 597  | 591  | 597  | 594  | 594  | 591  | 591  | 591  | 591  |
| 1971 | 600  | 603  | 608  | 611  | 614  | 623  | 620  | 625  | 608  | 560  | 574  | 577  |
| 1972 | 577  | 594  | 597  | 617  | 623  | 708  | 736  | 741  | 741  | 744  | 756  | 750  |
| 1973 | 770  | 758  | 736  | 790  | 809  | 812  | 815  | 812  | 801  | 812  | 824  | 821  |
| 1974 | 841  | 860  | 860  | 855  | 872  | 863  | 874  | 863  | 821  | 835  | 857  | 835  |
| 1975 | 849  | 874  | 852  | 860  | 826  | 807  | 792  | 787  | 781  | 775  | 801  | 832  |
| 1976 | 852  | 863  | 872  | 863  | 835  | 863  | 855  | 863  | 869  | 872  | 852  | 852  |
| 1977 | 874  | 894  | 951  | 974  | 1022 | 1013 | 699  | 807  | 894  | 940  | 1002 | 1005 |
| 1978 | 1024 | 1030 | 996  | 1005 | 498  | 512  | 572  | 662  | 750  | 804  | 917  | 920  |
| 1979 | 948  | 934  | 942  | 971  | 999  | 982  | 945  | 1005 | 999  | 1016 | 1047 | 1056 |
| 1980 | 1081 | 1101 | 1118 | 1124 | 1126 | 1152 | 1155 | 1152 | 1132 | 1024 | 1084 | 1104 |
| 1981 | 1109 | 1143 | 1143 | 1143 | 1149 | 1172 | 1163 | 1149 | 1152 | 1118 | 1033 | 976  |
| 1982 | 930  | 947  | 958  | 941  | 949  | 947  | 973  | 951  | 938  | 926  | 741  | 743  |
| 1983 | 740  | 672  | 643  | 629  | 630  | 510  | 420  | 409  | 412  | 423  | 404  | 293  |
| 1984 | 289  | 277  | 258  | 280  | 356  | 358  | 363  | 364  | 402  | 435  | 467  | 479  |
| 1985 | 477  | 525  | 540  | 542  | 610  | 685  | 602  | 580  | 467  | 566  | 669  | 650  |
| 1986 | 687  | 700  | 702  | 704  | 742  | 792  | 868  | 879  | 894  | 878  | 855  | 810  |
| 1987 | 816  | 893  | 919  | 898  | 906  | 911  | 898  | 877  | 864  | 810  | 845  | 847  |
| 1988 | 830  | 882  | 896  | 937  | 952  | 985  | 917  | 879  | 790  | 796  | 875  | 893  |
| 1989 | 889  | 924  | 947  | 993  | 999  | 1002 | 987  | 946  | 818  | 809  | 896  | 947  |
| 1990 | 977  | 978  | 986  | 960  | 970  | 973  | 944  | 967  | 977  | 1003 | 976  | 1022 |
| 1991 | 1025 | 1033 | 1067 | 1090 | 1075 | 1006 | 1088 | 1034 | 1022 | 1021 | 1075 | 1072 |
| 1992 | 1077 | 1114 | 1143 | 1151 | 1123 | 1139 | 1141 | 1108 | 1130 | 1123 | 1151 | 1181 |

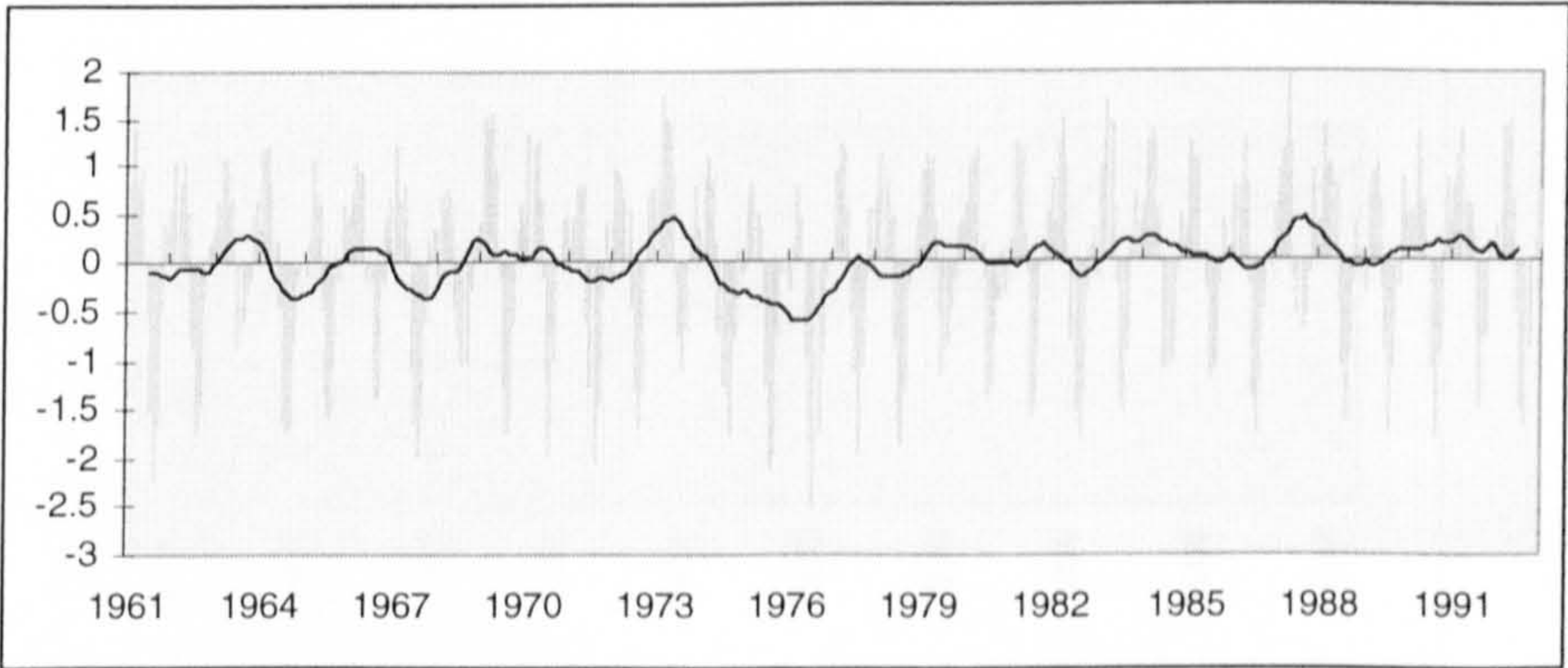
Appendix 3.9.2: Monthly mean discharge rate (m<sup>3</sup> s<sup>-1</sup>) of the Pra River

|      | Jan | Feb | Mar | Apr | May | Jun | Jul  | Aug  | Sep  | Oct  | Nov | Dec |
|------|-----|-----|-----|-----|-----|-----|------|------|------|------|-----|-----|
| 1963 | 97  | 84  | 114 | 124 | 157 | 311 | 694  | 631  | 779  | 1039 | 459 | 183 |
| 1964 | 170 | 123 | 182 | 173 | 225 | 475 | 276  | 137  | 193  | 185  | 179 | 141 |
| 1965 | 65  | 72  | 111 | 138 | 171 | 451 | 865  | 343  | 465  | 638  | 290 | 170 |
| 1966 | 100 | 51  | 82  | 190 | 183 | 400 | 684  | 424  | 314  | 475  | 355 | 164 |
| 1967 | 84  | 58  | 62  | 118 | 179 | 556 | 306  | 113  | 193  | 222  | 141 | 82  |
| 1968 | 50  | 31  | 62  | 99  | 163 | 569 | 1049 | 1139 | 1703 | 1297 | 455 | 279 |
| 1969 | 157 | 113 | 136 | 177 | 295 | 409 | 391  | 221  | 185  | 198  | 383 | 128 |
| 1970 | 86  | 58  | 152 | 152 | 220 | 233 | 145  | 71   | 172  | 366  | 308 | 92  |
| 1971 | 64  | 38  | 69  | 49  | 45  | 230 | 235  | 233  | 204  | 286  | 131 | 110 |
| 1972 | 36  | 18  | 51  | 191 | 221 | 472 | 288  | 192  | 121  | 193  | 126 | 66  |
| 1973 | 42  | 18  | 18  | 66  | 56  | 162 | 138  | 177  | 346  | 280  | 189 | 64  |
| 1974 | 27  | 9   | 36  | 85  | 217 | 293 | 331  | 250  | 417  | 336  | 229 | 80  |
| 1975 | 43  | 68  | 53  | 93  | 152 | 259 | 520  | 140  | 92   | 233  | 135 | 100 |
| 1976 | 31  | 28  | 53  | 85  | 156 | 415 | 192  | 86   | 58   | 127  | 212 | 63  |
| 1977 | 29  | 13  | 12  | 18  | 42  | 277 | 64   | 22   | 45   | 282  | 81  | 54  |
| 1978 | 12  | 5   | 24  | 119 | 219 | 525 | 102  | 57   | 134  | 210  | 152 | 57  |
| 1979 | 31  | 14  | 16  | 49  | 83  | 261 | 310  | 298  | 298  | 721  | 330 | 240 |
| 1980 |     |     |     |     | 218 | 362 | 246  | 317  | 275  | 487  |     |     |
| 1981 |     |     | 131 | 165 | 270 | 336 | 391  | 323  | 349  | 379  | 333 | 183 |
| 1982 | 59  | 52  | 103 | 117 | 198 | 334 | 525  | 214  | 206  | 204  | 140 | 53  |
| 1983 |     |     |     |     | 106 | 294 | 189  | 68   | 107  | 168  | 88  | 77  |
| 1984 | 28  | 21  | 48  | 93  | 114 | 282 | 338  | 505  | 262  | 439  | 259 | 122 |
| 1985 | 74  | 40  | 56  | 134 | 139 | 211 | 341  | 358  | 432  | 307  | 250 | 104 |
| 1986 | 77  | 57  |     |     |     |     |      |      |      |      |     |     |
| 1987 | 0   | 0   | 63  | 138 | 130 | 172 | 223  | 362  | 662  | 763  | 297 | 136 |
| 1988 | 71  | 63  | 127 | 130 | 175 | 420 | 386  | 179  | 378  | 424  | 272 | 158 |
| 1989 | 74  | 60  | 65  | 79  | 134 | 248 | 467  | 367  | 463  | 501  | 276 | 182 |
| 1990 | 89  | 68  | 72  | 83  | 114 | 162 | 207  | 83   | 170  | 330  | 185 | 205 |
| 1991 | 95  | 78  | 103 | 154 | 377 | 413 | 688  | 351  | 292  | 257  | 203 | 130 |
| 1992 | 69  | 38  | 35  | 49  | 183 | 231 | 212  | 102  | 167  | 307  | 239 | 110 |



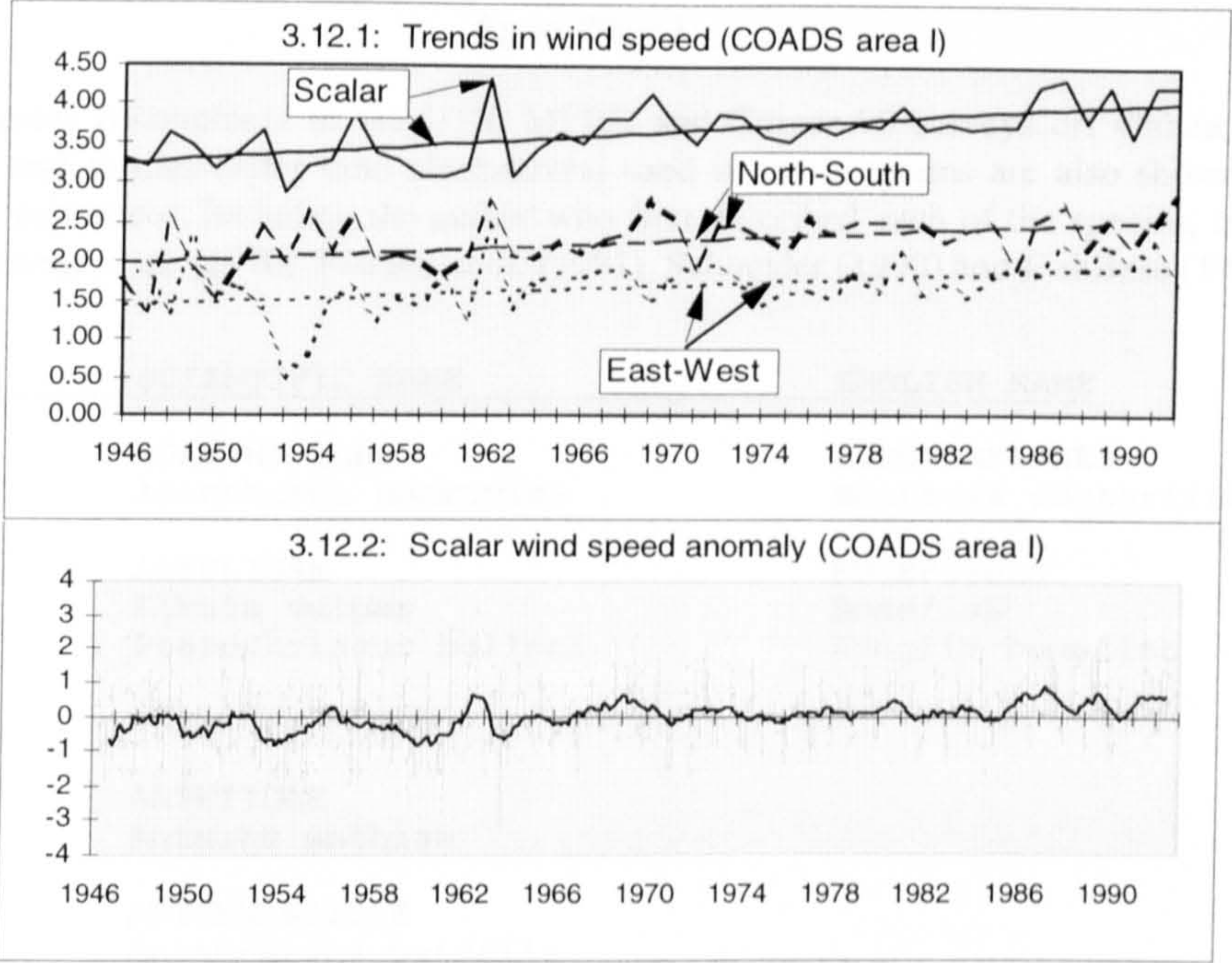


Appendix 3.10: Discharge rate anomalies, Pra and Volta Rivers

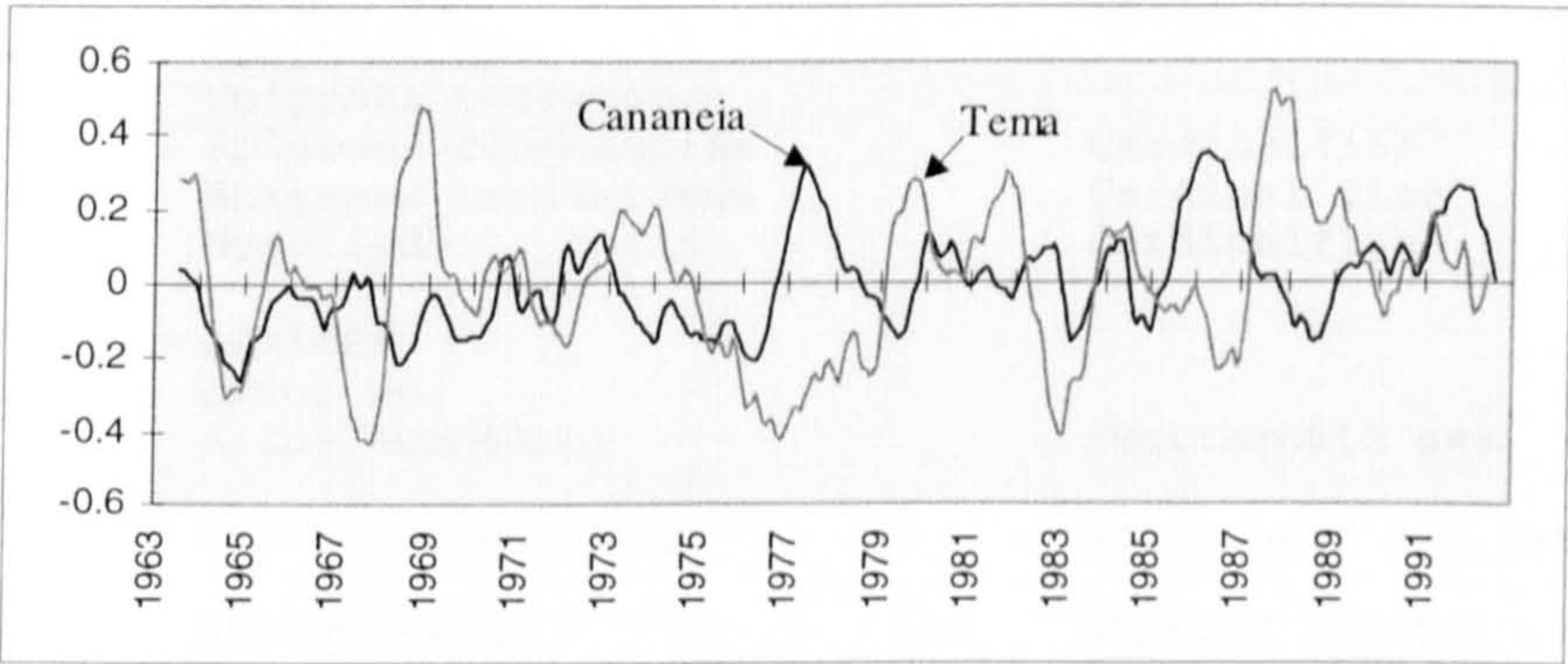


Appendix 3.11: Air temperature anomalies, coastal meteorological stations

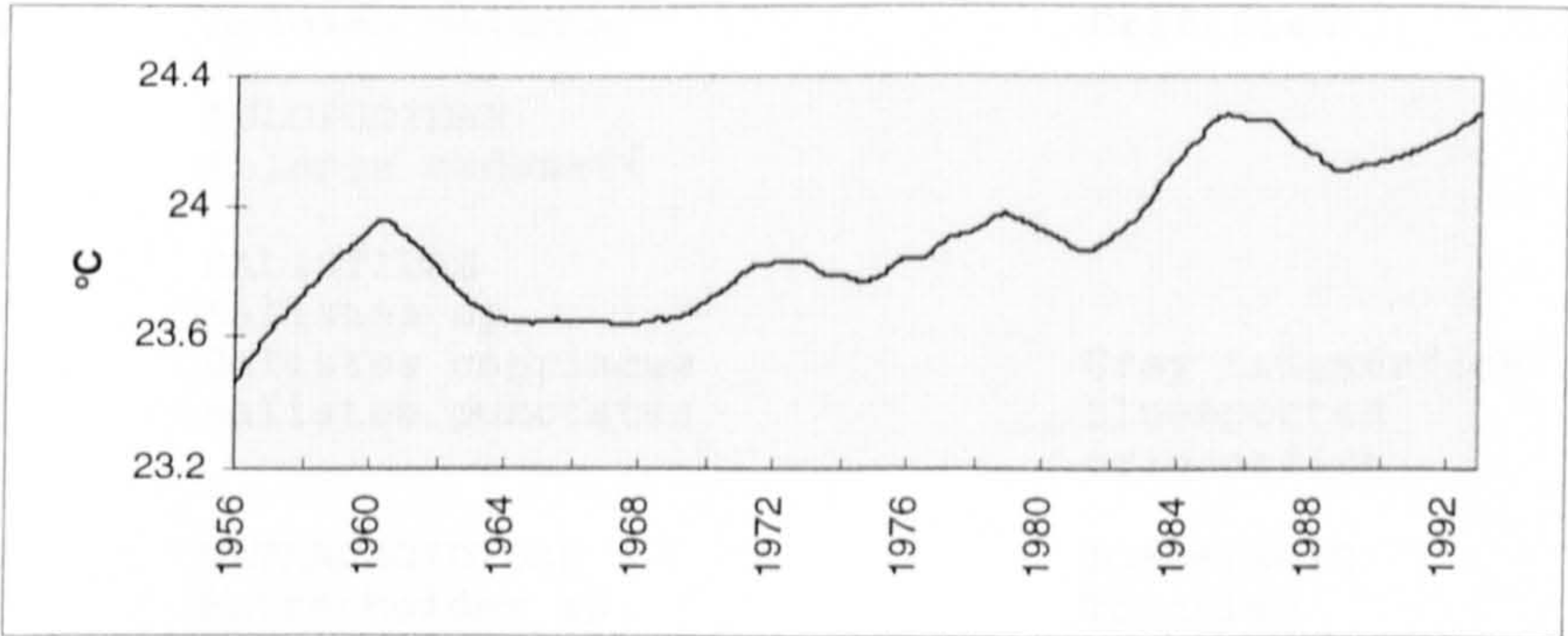




Appendix 3.12: Components of wind and scalar wind speed anomalies, COADS Area I



Appendix 3.13: SST anomalies at Tema (Ghana) and Cananeia (Brazil)



Appendix 3.14: Trends and anomalies of SST recorded off Cananeia, Brazil



# Appendix 4.1:

List of species encountered in the GTS, MFRD and Guinea-90 surveys off Ghana; some synonyms and species codes (and alternatives) used in the programs are also shown. Full taxonomic references, including the author who first described each of the species, may be found in Blache *et al.* (1970), Fischer *et al.* (1981), Schneider (1990) and FishBase (1996).

| CODE    | SCIENTIFIC NAME              | ENGLISH NAME            |
|---------|------------------------------|-------------------------|
| ACAAA00 | ACANTHURIDAE                 | SURGEONFISHES           |
| ACAAC01 | Acanthurus monroviae         | Monrovia doctorfish     |
| ALBAA00 | ALBULIDAE                    | BONEFISHES              |
| ALBAL01 | Albula vulpes                | Bonefish                |
| ALBPT01 | Pterothrissus belloci        | Longfin bonefish        |
| ANGAA00 | ANGUILLIFORMES               |                         |
| ANTAA00 | ANTHIIDAE                    |                         |
| ANTAN02 | Anthias anthias              |                         |
| ANTEN00 | ANTENNARIIDAE                |                         |
| ANTEN01 | Antennarius pardalis         |                         |
| ANTEN05 | Antenarius hispidus (histro) |                         |
| ANTEN10 | Antennarius sp.              | Frogfishes              |
| APOAA00 | APOGONIDAE                   | Cardinalfishes          |
| APOAP00 | Apogon sp.                   | Cardinalfish            |
| APOEP00 | Epigonus sp.                 |                         |
| APOEP01 | Epigonus telescopus          |                         |
| APOEP02 | Epigonus constanciae         | Cardinalfish            |
| APOEP09 | Epigonus treulavasae         | Cardinal fish           |
| APOHY01 | Hypoclydonia bella           | Cardinalfish            |
| ARDAA00 | ARIIDAE                      |                         |
| ARDAR00 | Arius sp.                    |                         |
| ARDAR01 | Arius heudeloti              | Smoothmouth sea         |
| catfish |                              |                         |
| ARDAR02 | Arius latiscutatus           | Rough-head sea catfish  |
| ARGAA00 | ARGENTINIDAE                 | HERRING SMELTS          |
| ARGAR01 | Argentina sphyraena          | Argentine               |
| ARMAA00 | ARIOMMIDAE                   |                         |
| ARMAR00 | Ariomma sp.                  |                         |
| ARMAR01 | Arioma bondi                 | Silver rag driftfish    |
| ARMAR04 | Ariomma melanum              | Driftfish               |
| AULAA00 | AULOPODIDAE                  |                         |
| AULAU01 | Aulopus cadenati             |                         |
| BALAA00 | BALISTIDAE                   |                         |
| BALBA00 | Balistes sp.                 |                         |
| BALBA01 | Balistes capriscus           | Grey triggerfish        |
| BALBA02 | Balistes punctatus           | Bluespotted triggerfish |
| BATAA00 | BATRACHOIDIDAE               | TOADFISHES              |
| BATBA00 | Batrachoides sp.             | Toadfish                |
| BATBA01 | Batrachoides liberiensis     | Hairy toadfish          |
| BATBA02 | Batrachoides didactylus      |                         |
| BATBA03 | Batrachoides rosignali       | Toadfish                |

| CODE    | SCIENTIFIC NAME              | ENGLISH NAME               |
|---------|------------------------------|----------------------------|
| BELAA00 | BELONIDAE                    | NEEDLEFISHES               |
| BELAB01 | Ablennes hians               | Flat needlefish            |
| BLEAA00 | BLENNIIDAE                   | COMBTOOTH, SABERTOOTH      |
| BLEBL00 | Blennius sp.                 | BLENNIES<br>Blennie        |
| BOTAA00 | BOTHIDAE                     |                            |
| BOTAR02 | Arnoglossus imperialis       |                            |
| BOTBO00 | Bothus sp.                   |                            |
| BOTBO01 | Bothus podas africanus       |                            |
| BOTCH01 | Chascanopsetta lugubris      | Pelican flounder           |
| BOTCI02 | Citharichthys stampflii      | Smooth flounder            |
| BOTMO00 | Monolene spp.                | Small mouth flounder       |
| BOTMO01 | Monolene microstoma          | Smallmouth<br>moonflounder |
| BOTSC01 | Scyacium micrurum            | Channel flounder           |
| BRAAA00 | BRAMIDAE                     |                            |
| BRABR01 | Brama brama                  | Atlantic pomfret           |
| BRCBR01 | Branchiostegus semifasciatus | Zebra tilefish             |
| CALAA00 | CALLIONYMIDAE                | DRAGONETS                  |
| CALSY05 | Synchiropus phaeton          |                            |
| CAPAA00 | CAPROIDAE                    | Boarfishes                 |
| CAPAN01 | Antigonia capros             | Boarfish                   |
| CARAA00 | CARANGIDAE                   |                            |
| CARAL01 | Alectis alexandrinus         | Alexandrina pompano        |
| CARAL03 | Alectis ciliaris             | African pompano            |
| CARAL05 | Blepharis crinitus           |                            |
| CARCA00 | Caranx sp.                   | Horse mackerel             |
| CARCA01 | Caranx carangus              |                            |
| CARCA02 | Caranx crysos                | Blue runner                |
| CARCA03 | Caranx senegallus            | Senegal jack               |
| CARCA14 | Caranx hippos                |                            |
| CARCH01 | Chloroscombrus chrysurus     | Atlantic bumper            |
| CARDE00 | Decapterus sp.               | Scad                       |
| CARDE01 | Decapterus punctatus         | Round scad                 |
| CARDE02 | Decapterus rhonchus          | False scad                 |
| CARDE04 | Decapterus macarellus        | Mackerel scad              |
| CAREL01 | Elagatis bipinnulata         |                            |
| CARHE01 | Hemicaranx bicolor           | Two colour jack            |
| CARLI01 | Lichia amia                  | Leerfish                   |
| CARLI02 | Lichia glauca                | Leerfish                   |
| CARSA01 | Selar crumenophthalmus       | Bigeye scad                |
| CARSE00 | Seriola sp.                  |                            |
| CARSE04 | Seriola lalandi              | Yellowtail amberjack       |
| CARSE05 | Seriola dumerili             |                            |
| CARSL01 | Selene dorsalis              | African lookdown           |
| CARTC00 | Trachinotus sp.              | Pampano                    |
| CARTC02 | Trachinotus goreensis        | Longfin pompano            |
| CARTR00 | Trachurus sp.                |                            |
| CARTR01 | Trachurus trachurus          | Atlantic horse<br>mackerel |
| CARTR02 | Trachurus trecae             | Cunene horse mackerel      |
| CARUR00 | Uraspis sp.                  |                            |
| CARUR01 | Uraspis secunda              | Cottonmouth jack           |
| CARUR02 | Uraspis heidi                | Jack (mackerel)            |
| CELAA00 | CENTROLOPHIDAE               | MEDUSAFISHES               |
| CELCE01 | Centrolophus niger           | Blackfish; Black ruff      |
| CELHY01 | Hyperoglyphe moselii         | African barrelfish         |



| CODE    | SCIENTIFIC NAME            | ENGLISH NAME          |
|---------|----------------------------|-----------------------|
| CELSC01 | Schedophilus pamarco       | Pamarco blackfish     |
| CENAA00 | CENTRACHANTIDAE            | PICARELS              |
| CENSM01 | Smaris macrolepidotus      |                       |
| CENSP01 | Spicara alta               | Bigeye picarel        |
| CHAAA00 | CHAETODONTIDAE             |                       |
| CHACH00 | Chaetodon sp.              |                       |
| CHACH01 | Chaetodon hoeferi          |                       |
| CHACH02 | Chaetodon marcellae        |                       |
| CHACH09 | Chaetodon luciae           |                       |
| CHACH10 | Chaetodon altipinnis       | Butterfly fish        |
| CHAH001 | Holacanthus africanus      |                       |
| CHIAA00 | CHILODIPTERIDAE            | CHILODIPTERIDAE       |
| CHLAA00 | CHLOROPHTHALMIDAE          |                       |
| CHLCH00 | Chlorophthalmus sp.        | Greeneye              |
| CHLCH01 | Chlorophthalmus atlanticus | Atlantic greeneye     |
| CHLCH02 | Chlorophthalmus fraser     | Greeneye              |
| CITAA00 | CITHARIDAE                 |                       |
| CITCI00 | Citharus sp                |                       |
| CITCI02 | Citharus macrolepidothus   | Spotted flounder      |
| CLUAA00 | CLUPEIDAE                  |                       |
| CLUEM01 | Ethmalosa fimbriata        |                       |
| CLUHA01 | Harengula rouxi            |                       |
| CLUIL01 | Ilisha africana            | West African ilisha   |
| CLUSL01 | Sardinella aurita          | Round sardinella      |
| CLUSL02 | Sardinella maderensis      | Madeiran sardinella   |
| CMBAA00 | Cymbium spp                | Snails                |
| CONAA00 | CONGRIDAE                  | CONGER EELS           |
| CONBA01 | Bathycongrus africanus     |                       |
| CONCO01 | Conger conger              |                       |
| CONPA01 | Paraconger notialis        |                       |
| CONUR02 | Uroconger vicinus          | Conger                |
| COTAA00 | COTTIDAE                   |                       |
| COTCO01 | Cottunculoides spinosus    |                       |
| CRAAA00 | C R A B S                  |                       |
| CRACA01 | Calappa pelli              | Box crab              |
| CRACA11 | Calappa rubroguttata       | Spotted box crab      |
| CRAPO31 | Portunus validus           | Smooth swimcrab       |
| CRAPO60 | Callinectes sp             |                       |
| CRNAA00 | CRANGONIDAE                | Hardshell shrimp      |
| CRNPO00 | Pontophilus sp.            | Hardshell shrimp      |
| CRUAA00 | C R U S T A C E A N S      |                       |
| CYGAA00 | CYNOGLOSSIDAE              |                       |
| CYGCY00 | Cynoglossus sp             | Tonguesoles           |
| CYGCY01 | Cynoglossus canariensis    | Canary tonguesole     |
| CYGCY02 | Cynoglossus monodi         | Guinean tonguesole    |
| CYGCY05 | Cynoglossus goreensis      |                       |
| CYGCY08 | Cynoglossus senegalensis   | Senegalese tonguesole |
| CYGCY09 | Cynoglossus browni         | Nigerian tonguesole   |
| CYMAA00 | S N A I L                  |                       |

| CODE    | SCIENTIFIC NAME                | ENGLISH NAME          |
|---------|--------------------------------|-----------------------|
| DACAA00 | DACTYLOPTERIDAE                |                       |
| DACDA01 | Dactylopterus volitans         | Flying gurnard        |
| DIAPH00 | Diaphus sp.                    |                       |
| DIOAA00 | DIODONTIDAE                    |                       |
| DIOCH00 | Chilomycterus sp.              | Porcupinefish         |
| DIOCH01 | Chilomycterus spinosus mauret. |                       |
| DIOCH03 | Chilomycterus orbicularis      | Birdbeak burrfish     |
| DIOCH07 | Chilomycterus antennatus       | Burrfish              |
| DIOCH08 | Chilomycterus reticulatus      | Spotfin burrfish      |
| DIODI00 | Diodon sp.                     | Porcupine fish        |
| DIODI01 | Diodon hystrix                 | Porcupine fish        |
| DIODI03 | Diodon maculatus               | Porcupine fish        |
| DREAA00 | DREPANIDAE                     | SICKLEFISHES          |
| DREDR01 | Drepane africana/punctata      | African sicklefish    |
| ECHAA00 | ECHINODERMATA                  |                       |
| ECNAA00 | ECHENEIDIDAE                   |                       |
| ECNEC01 | Echeneis naucrates             | Sharksucker           |
| ELOAA00 | ELOPIDAE                       | TENPOUNDERS           |
| ELOEL00 | Elops sp.                      |                       |
| ELOEL01 | Elops senegalensis             |                       |
| ELOEL03 | Elops lacerta                  | West African ladyfish |
| EMMAA00 | EMMELICHTHYIDAE                |                       |
| EMMER01 | Erythrocles monodi             | Atlantic rubyfish     |
| ENGAA00 | ENGRAULIDIDAE                  |                       |
| ENGEN01 | Engraulis encrasicolus         | European anchovy      |
| EPHAA00 | EPHIPPIDAE                     |                       |
| EPHCH01 | Chaetodipterus goreensis       | African spadefish     |
| EPHCH02 | Chaetodipterus lippei          |                       |
| EXOAA00 | EXOCOETIDAE                    | FLYING FISHES         |
| EXOFO01 | Fodiator acutus                | Sharpchin flyingfish  |
| FISAA00 | FISTULARIIDAE                  | CORNETFISHES          |
| FISFI00 | Fistularia sp                  |                       |
| FISFI01 | Fistularia petimba             |                       |
| FISFI02 | Fistularia villosa             | Cornetfish            |
| FISFI04 | Fistularia tabacaria           |                       |
| GEMPR01 | Promethichthys prometheus      | Promethean escolar    |
| GERAA00 | GERREIDAE                      |                       |
| GEREU01 | Eucinostomus melanopterus      | Flagfin mojarra       |
| GOBAA00 | GOBIIDAE                       | GOBIES                |
| GOBGO00 | Gobius spp.                    |                       |
| GOBGO10 | Gobiodes sp.                   | Gobies                |
| GONAA00 | GONOSTOMATIDAE                 | Bristlemouths         |
| GONYA02 | Yarrela blackfordi             | Bristtlemouth         |
| GRAAA00 | GRAMISTIDAE                    |                       |
| GRARY01 | Rypticus saponaceus            |                       |
| GYMAA00 | GYMNURIDAE                     | Butterfly Rays        |
| HAEAA00 | HAEMULIDAE/POMADASYIDAE        | GRUNTS                |
| HAEBR01 | Brachydeuterus auritus         | Bigeye grunt          |



| CODE    | SCIENTIFIC NAME              | ENGLISH NAME                |
|---------|------------------------------|-----------------------------|
| HAEDI00 | Diagramma sp.                | Grunts                      |
| HAEDI01 | Diagramma mediterraneus      |                             |
| HAEDI02 | Diagramma macrolepis         | Biglip grunt                |
| HAEDI03 | Diagrama canariensis         | Grunt                       |
| HAEPL01 | Plectorhynchus mediterraneus | Rubberlip grunt             |
| HAEPL02 | Plectorhynchus macrolepis    |                             |
| HAEPO00 | Pomadasys sp.                |                             |
| HAEPO01 | Pomadasys jubelini           | Sompat grunt                |
| HAEPO02 | Pomadasys incisus            | Bastard grunt               |
| HAEPO03 | Pomadasys peroteti           | Burro                       |
| HAEPO04 | Pomadasys rogeri             | Pigsnout grunt              |
| HALAA00 | HALOSAURIDAE                 | Halosaurs                   |
| HALHA01 | Halosaurus ovenii            | Halosaur                    |
| HETER00 | HETEROSOMATA                 |                             |
| HOLAA00 | HOLOCENTRIDAE                | SOLDIERFISHES               |
| HOLAD01 | Adyorix hastatus             | Red squirreelfish           |
| JELLY00 | JELLYFISH                    |                             |
| KUHAA00 | KUHLIIDAE                    | Daras                       |
| KUHPA01 | Parakuhlia macrophthalmus    | Dara                        |
| LABAA00 | LABRIDAE                     |                             |
| LABAC01 | Acantholabrus palloni        |                             |
| LABBO01 | Bodianus speciosus           | Blackbar hogfish            |
| LABBO07 | Bodianus iagonensis          |                             |
| LABCR01 | Coris julis                  |                             |
| LABDI01 | Diastodon speciosus          |                             |
| LABPS02 | Pseudolepidaplois scrofa     |                             |
| LABTH01 | Thalassoma pavo              |                             |
| LABXY01 | Xyrichthys novacula          | Pearly razorfish            |
| LATAA00 | LATILIDAE                    |                             |
| LATLA01 | Latilus semifasciatus        |                             |
| LETAA00 | LETHRINIDAE                  |                             |
| LETLE01 | Lethrinus atlanticus         | Atlantic emperor            |
| LOBAA00 | PALINURIDAE                  |                             |
| LOBPA20 | Panulirus sp                 |                             |
| LOBPA23 | Panulirus regius             | Royal spiny lobster         |
| LOBPA28 | Panulirus vulgaris           | Spiny lobster               |
| LOPAA00 | LOPHIIDAE                    | ANGLERS                     |
| LOPLO02 | Lophiodes kempfi             |                             |
| LOPLP00 | Lophius sp                   | Angler                      |
| LOPLP01 | Lophius piscatorius          |                             |
| LOPLP07 | Lophius atlanticus           | Angler fish                 |
| LUTAA00 | LUTJANIDAE                   |                             |
| LUTAS01 | Apsilus fuscus               | African forktail<br>snapper |
| LUTLU00 | Lutjanus sp                  |                             |
| LUTLU01 | Lutjanus goreensis           | Goreean snapper             |
| LUTLU02 | Lutjanus agennes             | African red snapper         |
| LUTLU03 | Lutjanus fulgens             |                             |
| LUTLU07 | Lutjanus dentatus            | African brown snapper       |
| MARAA00 | MACROURIDAE                  | Grenadier                   |
| MACCO01 | Coelorinchus coelorhynchus   | Hollowsnout grenadier       |
| MARHM01 | Hymenocephalus italicus      |                             |
| MARMA01 | Malacocephalus laevis        | Softhead grenadier          |

| CODE    | SCIENTIFIC NAME              | ENGLISH NAME                |
|---------|------------------------------|-----------------------------|
| MARMA02 | Malacocephalus occidentalis  | Western softhead grenadier  |
| MARNE03 | Nezumia aequalis             | Smooth grenadier            |
| MERAA00 | MERLUCCIIDAE                 | HAKES                       |
| MERME00 | Merluccius sp                |                             |
| MERME03 | Merluccius polli             | Benguela hake               |
| MISCE00 | MISCELLANEOUS                | MISCELLANEOUS               |
| MONAA00 | MONACANTHIDAE                | FILEFISHES                  |
| MONAL00 | Alutera sp                   |                             |
| MONAL01 | Alutera punctata             |                             |
| MONAL02 | Aluterus blankerti           |                             |
| MONST01 | Stephanolepis hispidus       |                             |
| MORGA01 | Gadella maraldi              | Codling                     |
| MORLA00 | Leamonema sp.                | Guinea codling              |
| MORLA01 | Laemonema laureysi           | Guinea codling              |
| MUGAA00 | MUGILIDAE                    | MULLETS                     |
| MUGMU00 | Mugil sp                     |                             |
| MULAA00 | MULLIDAE                     | GOATFISHES                  |
| MULPS01 | Pseudupeneus prayensis       | West African goatfish       |
| MURAA00 | MURAENIDAE                   |                             |
| MURLY00 | Lycodontis sp                | Moray                       |
| MURLY05 | Lycodontis mareei            | Spotjaw moray               |
| MURMU01 | Muraena helena               | Mediterranean moray         |
| MUXAA00 | MURAENESOCIDAE               | PIKE CONGERS                |
| MUXCY01 | Cynoponticus ferox           | Guinean pike conger         |
| NOMAA00 | NOMEIDAE                     | DRIFTFISHES                 |
| NOMPA00 | Paracubiceps sp              |                             |
| NOMPA01 | Paracubiceps ledanosi        | Silver-rag driftfish        |
| NOMPA02 | Paracubiceps multisquamis    | Brown driftfish             |
| OGCAA00 | OGCOCEPHALIDAE               | BAT FISHES,<br>RATTLEFISHES |
| OGCDI01 | Dibranchus atlanticus        |                             |
| OMMAA00 | OMMASTREPHIDAE               | Squid                       |
| OMMIL01 | Illex coindetii              | Shortfin squid              |
| OPDAA00 | OPHIDIIDAE                   | CUSC EELS                   |
| OPDBR01 | Brotula barbata              | Bearded brotula             |
| OPDLU01 | Luciobrotula corethromycter  |                             |
| OPHAA00 | OPHICHTHIDAE                 |                             |
| OPHMY01 | Mystriophus rostellatus      | African spoon-nose eel      |
| OPHPI02 | Pisodonophis semicintus      |                             |
| OPOAA00 | OPLOPHORIDAE                 |                             |
| OPOSY01 | Systellaspis pellucida       |                             |
| OSTAA00 | OSTRACIIDAE                  | BOXFISHES                   |
| OSTAC01 | Acanthostracion guineensis   |                             |
| OSTAC02 | Acanthostracion notacanthus  |                             |
| OSTAC03 | Acanthostracion quadricornis | Scrawled cowfish            |
| OSTAC04 | Ostracion exicornis          |                             |
| OSTOS00 | Ostracion sp.                |                             |
| OSTOS05 | Ostracion tricornis          |                             |



| CODE    | SCIENTIFIC NAME             | ENGLISH NAME             |
|---------|-----------------------------|--------------------------|
| OXYAA00 | OXYNOTIDAE                  | Centrines (Shark)        |
| OXYOX01 | Oxinotus centrina           | Centrines (shark)        |
| PANAA00 | PANDALIDAE                  | Nylon shrimp             |
| PANHE01 | Heterocarpus ensifer        | Armed nylon shrimp       |
| PANPL00 | Plesionika sp.              | Golden shrimp            |
| PANPL01 | Plesionika ensis            | Golden shrimp            |
| PANPL02 | Plesionika martia           | Golden shrimp            |
| PECAA00 | PERCOPHIDIDAE               |                          |
| PECBE00 | Bembrops sp.                | Duckbill                 |
| PECBE02 | Bembrops greyi              |                          |
| PECBE03 | Bembrops heterurus          | Squaretail duckbill      |
| PERAA00 | PERISTEDIIDAE               | Armoured searobins       |
| PERPE01 | Peristedion cataphractum    | Armoured searobins       |
| PLAAA00 | PLATYCEPHALIDAE             |                          |
| PLAGR01 | Grammoplites gruveli        | African spiny flathead   |
| PLIAA00 | PLATIRHINIDAE               |                          |
| PLIZA01 | Zanobatus schoenleinii      |                          |
| PLNAA00 | POLYNEMIDAE                 | THREADFINS               |
| PLNGA01 | Galeoides decadactylus      | Lesser African threadfin |
| PLNPE01 | Pentanemus quinquarius      | Royal threadfin          |
| PLNPO00 | Polynemus sp.               |                          |
| PLNPO01 | Polydactylus quadrifilis    | Threadfin                |
| POCAA00 | POMACENTRIDAE               |                          |
| POCCH00 | Chromis sp                  |                          |
| POCCH01 | Chromis cadenati            | Striped chromis          |
| POCCH02 | Chromis lineatus            |                          |
| POCCH03 | Chromis chromis             | Chromis                  |
| POCCH04 | Chromis limbatus            |                          |
| POCCH05 | Chromis cautus              |                          |
| POTAA00 | POMATOMIDAE                 | BLUEFISHES               |
| POTPO01 | Pomatomus saltatrix         | Bluefish                 |
| PRIAA00 | PRIACANTHIDAE               |                          |
| PRIPR01 | Priacanthus arenatus        | Atlantic bigeye          |
| PSEAA00 | PSETTODIDAE                 | SPINY TURBOTS            |
| PSEPS00 | Psettodes sp                |                          |
| PSEPS01 | Psettodes belcheri          | Spottail spiny turbot    |
| PSEPS04 | Psettodes cadenati          | Turbot                   |
| RACAA00 | RACHYCENTRIDAE              |                          |
| RACRA01 | Rachycentron canadum        | Cobia                    |
| RAYAA00 | R A Y S                     |                          |
| RAYDA00 | DASYATIDAE                  | STINGRAYS                |
| RAYDA10 | Dasyatis sp                 | Stingrays                |
| RAYDA11 | Dasyatis margarita          |                          |
| RAYDA12 | Dasyatis hastata (D.aspera) | Roughtail stingray       |
| RAYDA13 | Dasyatis marmorata          | Stigray                  |
| RAYDI11 | Zanobathus atlanticus       |                          |
| RAYMO00 | MOBULIDAE                   | DEVIL RAYS, MANTAS       |
| RAYMO10 | Mobula sp.                  | Manta                    |

| CODE     | SCIENTIFIC NAME              | ENGLISH NAME         |
|----------|------------------------------|----------------------|
| RAYMY00  | MYLIOBATIDAE                 |                      |
| RAYMY11  | Myliobatis aquila            |                      |
| RAYMY21  | Pteromylaeus bovinus         | Duckbill ray         |
| RAYRA00  | RAJIDAE                      |                      |
| RAYRA10  | Raja sp.                     |                      |
| RAYRA11  | Raja miraletus               |                      |
| RAYRA14  | Raja punctatus               |                      |
| RAYRA15  | Raja straeleni               | Spotted skate        |
| RAYRA16  | Raja undulata/picta          | Undulate ray         |
| RAYRA17  | Raja barnadi                 |                      |
| RAYRB00  | RHINOBATIDAE                 |                      |
| RAYRB10  | Rhinobatos sp.               |                      |
| RAYRB12  | Rhinobatus albomaculatus     | Guitarfish           |
| RAYRB17  | Rhinobatos cemiculus         | Blackchin guitarfish |
| RAYRB20  | Rhinobatos percellens        |                      |
| RAYRB21  | Rhinobatos rhinobatos        | Common guitarfish    |
| RAYRB22  | Rhinobatos irvinei           |                      |
| RAYTO00  | TORPEDINIDAE                 | ELECTRIC RAYS        |
| RAYTO01  | Torpedo sp.                  | Torpedo              |
| RAYTO11  | Torpedo torpedo              |                      |
| RAYTO12  | Torpedo marmorata            |                      |
| RAYTO13  | Torpedo nobiliana            | Electric ray         |
| SCAAA00  | SCARIDAE                     | PARROTFISHES         |
| SCARU01  | Scarus hoefleri              |                      |
| SCASP00  | Sparisoma sp.                |                      |
| SCASP01  | Sparisoma radians            |                      |
| SCASP02  | Sparisoma rubripinnis        |                      |
| SCASP04  | Euscarius cretensis          | >> Sparisoma cretens |
| SCIAA00  | SCIAENIDAE                   | CROAKERS             |
| SCIAR00  | Argyrosomus sp               |                      |
| SCIAR01  | Argyrosomus regius           | Meagre               |
| SCIMI01  | Miracorvina angolensis       | Angola croaker       |
| SCIPN01  | Pentheroscion mbizi          |                      |
| SCIPS00  | Pseudotolithus sp            |                      |
| SCIPS01  | Pseudotolithus elongatus     | Bobo croaker         |
| SCIPS02  | Pseudotolithus senegalensis  | Cassava croaker      |
| SCIPS03  | Pseudotolithus typus         | Longneck croaker     |
| SCIPS04  | Pseudotolithus epipercus     | Guinea croaker       |
| SCIPS05  | Pseudotolithus brachygnathus | Law croaker          |
| SCRIPT00 | Pteroscion sp                |                      |
| SCRIPT01 | Pteroscion peli              | Boe drum             |
| SCISC01  | Sciaena umbra                |                      |
| SCIUM00  | Umbrina spp.                 | Drum                 |
| SCIUM01  | Umbrina canariensis          | Canary drum          |
| SCIUM02  | Umbrina steindachneri        |                      |
| SCIUM09  | Umbrina cirrosa              | Shi drum             |
| SCMAA00  | SCOMBRIDAE                   |                      |
| SCMAC01  | Acanthocybium solandri       | Wahoo                |
| SCMAU01  | Auxis thazard                | Frigate tuna         |
| SCMCY01  | Cybum tritor                 |                      |
| SCMEU01  | Euthynnus alletteratus       | Little tunny         |
| SCMKA01  | Katsuwonus pelamis           | Skipjack tuna        |
| SCMOR01  | Orcynopsis unicolor          | Plain bonito         |
| SCMSA01  | Sarda sarda                  | Belted bonito        |
| SCMSC01  | Scomber japonicus            | Chub mackrel         |
| SCMSC02  | Scomber scombrus             |                      |
| SCMSM01  | Scomberomorus tritor         | Spanish mackerel     |
| SCMSM11  | Scomberomorus maculatus      | Spanish mackerel     |
| SCMTH02  | Thunnus albacares            | Yellowfin tuna       |



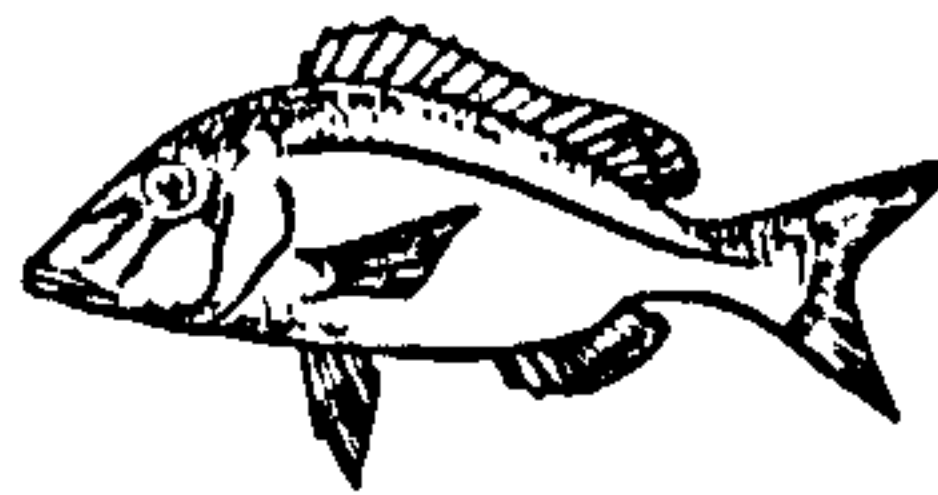
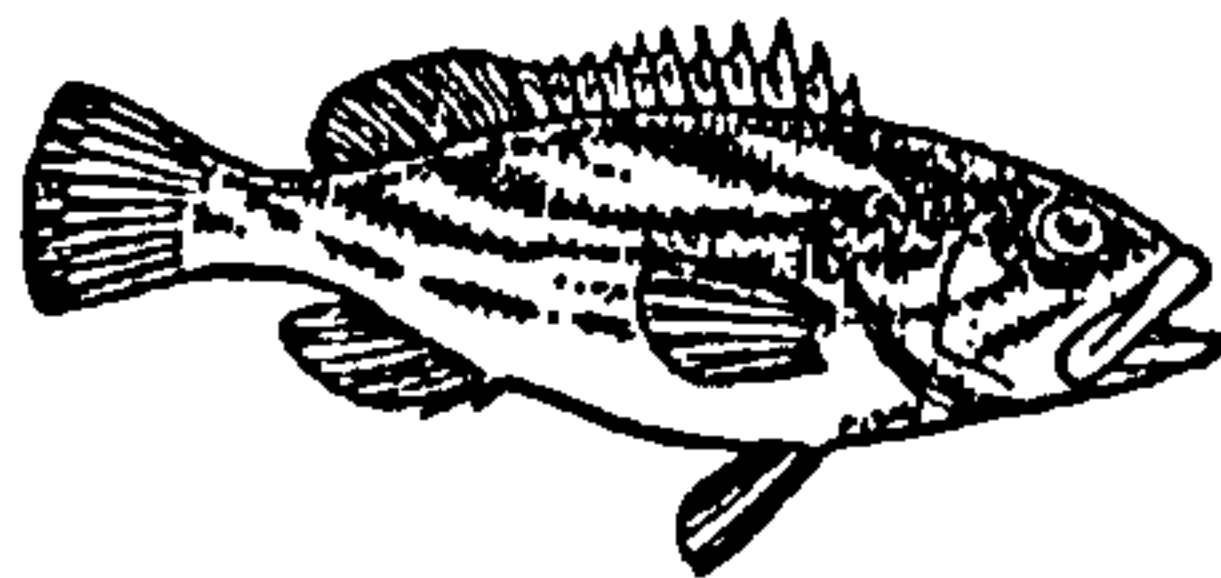
| CODE    | SCIENTIFIC NAME          | ENGLISH NAME           |
|---------|--------------------------|------------------------|
| SCRAA00 | SCORPAENIDAE             | SCORPIONFISHES         |
| SCRPO01 | Pontinus kuhlii          | Offshore rockfish      |
| SCRSC00 | Scorpaena sp             |                        |
| SCRSC02 | Scorpaena angolensis     | Angola rockfish        |
| SCRSC04 | Scorpaena stephanica     | Spotted-fin rockfish   |
| SCRSC05 | Scorpaena scrofa         | Red scorpionfish       |
| SCRSC07 | Scorpaena senegalensis   | Scorpionfish           |
| SCRSE03 | Setarches guentheri      | Deepwater scorpionfish |
| SCYAA00 | SCYLLARIDAE              | SLIPPER LOBSTER        |
| SCYSC01 | Scyllarides herklotsii   | Red slipper/Rock       |
| lobster |                          |                        |
| SCYSC02 | Scyllarides latus        | Slipper lobster        |
| SERAA00 | SERRANIDAE               | GROUPERS               |
| SERCE02 | Cephalopholis taeniops   | Bluespotted seabass    |
| SERCE13 | Cephalopholis aurantia   | Golden hind            |
| SEREP00 | Epinephelus sp           |                        |
| SEREP01 | Epinephelus aeneus       | White grouper          |
| SEREP02 | Epinephelus guaza        | Dusky grouper          |
| SEREP03 | Epinephelus fasciatus    | Dungat grouper         |
| SEREP04 | Epinephelus alexandrinus | Golden grouper         |
| SEREP05 | Epinephelus caninus      | Dogtooth grouper       |
| SEREP26 | Epinephelus goreensis    |                        |
| SEREP28 | Epinephelus rivulatus    | Halfmoon grouper       |
| SEREP35 | Epinephelus itajara      | Jewfish                |
| SERSE02 | Serranus accraensis      |                        |
| SERSE03 | Serranus cabrilla        | Comber                 |
| SERSE04 | Serranus sanctaehelenae  | Helena comber          |
| SERSE13 | Serranus africana        |                        |
| SHAAA00 | S H A R K S              |                        |
| SHACA00 | CARHARHINIDAE            |                        |
| SHACA10 | Carcharhinus sp          |                        |
| SHACA25 | Carcharhinus signatus    | Night shark            |
| SHACA61 | Rhizoprionodon acutus    | Milk shark             |
| SHAET01 | Etmopterus spinax        | Dogfish shark          |
| SHAHM21 | Paragaleus pectoralis    | Shark                  |
| SHALE00 | LEPTOCHARIIDAE           | BARBELED HOUNDSHARKS   |
| SHALE11 | Leptocharias smithii     | Barbeled houndshark    |
| SHASC00 | SCYLIORHINIDAE           |                        |
| SHASC21 | Scyliorhinus canicula    | Smallspotted catshark  |
| SHASC24 | Scyliorhinus stellaris   | Nursehound             |
| SHASQ00 | SQUALIDAE                |                        |
| SHASQ13 | Centrophorus uyato       | Little gulper shark    |
| SHASQ42 | Etmopterus pusillus      | Smooth lanternshark    |
| SHASQ81 | Squalus blainvillei      | Longnose spurdog       |
| SHASQ84 | Squalus fernandinus      |                        |
| SHAST00 | SQUATINIDAE              | ANGEL SHARKS           |
| SHAST01 | Squatina sp.             | Angel shark            |
| SHAST11 | Squatina oculata         | Smoothback angelshark  |
| SHAST12 | Squatina africana        | African angelshark     |
| SHAST13 | Squatina aculeata        | Sawback angelshark     |
| SHAST14 | Squatina squatina        | Angel shark            |
| SHAST15 | Centroscyllium fabricii  | Black dogfish          |
| SHATR00 | TRIAKIDAE                |                        |
| SHATR21 | Mustelus mustelus        | Smoothhound            |
| SHATR51 | Galeorhinus galeus       | Tope/Soupfin shark     |

| CODE    | SCIENTIFIC NAME             | ENGLISH NAME             |
|---------|-----------------------------|--------------------------|
| SHRAA00 | S H R I M P S               |                          |
| SHRAA01 | Shrimps. small. non comm.   |                          |
| SHRPE00 | PENAEIDAE                   | PENAEID SHRIMPS          |
| SHRPE21 | Parapenaeopsis atlantica    | Guinea shrimp            |
| SHRPE31 | Parapenaeus longirostris    |                          |
| SHRPE60 | Penaeus sp                  |                          |
| SHRPE61 | Penaeus notialis            | Pink shrimp              |
| SHRPE62 | Penaeus kerathurus          | Caramote prawn           |
| SHRPL00 | Pleslonika sp.              |                          |
| SHRSI14 | Sicyonia galeata            | Tufted rock shrimp       |
| SOLAA00 | SOLEIDAE                    |                          |
| SOLBA00 | Bathysolea sp               | (Deepwater) Rock soles   |
| SOLBA01 | Bathysolea polli            | Rock sole                |
| SOLDI02 | Dicologoglossa hexophthalma | Ocellated wedge sole     |
| SOLMI01 | Microchirus frechkopi       | Frenchkop's sole         |
| SOLMI03 | Microchirus ocellatus       | Four-eyed sole           |
| SOLMO01 | Monochirus hispidus         | Whiskered sole           |
| SOLPE01 | Pegusa lascaris             | Sand sole                |
| SOLPE02 | Pegusa cadenati             | Sand sole                |
| SOLSO00 | Solea sp.                   |                          |
| SOLSO01 | Solea hexophthalma          |                          |
| SOLSO02 | Solea solea                 | Common sole              |
| SOLSY04 | Synaptura cadenati          | Guinean sole             |
| SOLVA01 | Vanstraelenia chirophtalma  |                          |
| SPAAA00 | SPARIDAE                    |                          |
| SPABO01 | Boops boops                 | Bogue                    |
| SPADE00 | Dentex sp                   | Dentex                   |
| SPADE01 | Dentex angolensis           | Angola dentex            |
| SPADE02 | Dentex canariensis          | Canary dentex            |
| SPADE03 | Dentex macrophthalmus       | Large eye dentex         |
| SPADE04 | Dentex congoensis           | Congo dentex             |
| SPADE05 | Dentex gibbosus             | Pink dentex              |
| SPADI00 | Diplodus sp                 | Seabream                 |
| SPAPA02 | Pagellus bellottii          | Red panadora             |
| SPAPA06 | Pagrus gibbiceps            | Golden-headed seabream   |
| SPAPA07 | Pagellus bogaraveo          | Blackspot seabream       |
| SPAPR03 | Pagrus auriga               |                          |
| SPASA01 | Sparus caeruleostictus      | Bluespotted seabream     |
| SPASA02 | Sparus pagrus africanus     | Southern common seabream |
| SPASA03 | Sparus auriga               | Redbanded seabream       |
| SPASA04 | Sparus pagrus pagrus        |                          |
| SPASL01 | Sarpa salpa                 |                          |
| SPHAA00 | SPHYRAENIDAE                |                          |
| SPHSP00 | Sphyraena sp                |                          |
| SPHSP01 | Sphyraena guachancho        |                          |
| SPHSP02 | Sphyraena sphyraena         |                          |
| SPHSP03 | Sphyraena afra              |                          |
| SPHSP04 | Sphyraena barracuda         | Great barracuda          |
| SQUAA00 | C E P H A L O P O D A       |                          |
| SQULO11 | Alloteuthis africana        | African squid            |
| SQULO20 | Loligo sp                   |                          |
| SQUOC00 | OCTOPODIDAE                 |                          |
| SQUOC10 | Octopus sp.                 | Octopus                  |
| SQUOC11 | Octopus vulgaris            | Common octopus           |



| CODE    | SCIENTIFIC NAME             | ENGLISH NAME               |
|---------|-----------------------------|----------------------------|
| SQUSE00 | SEPIIDAE                    |                            |
| SQUSE10 | Sepia sp                    | Cuttlefish                 |
| SQUSE11 | Sepia officinalis hierredda | Common cuttlefish          |
| SQUSE21 | Sepiella ornata             |                            |
| STOAB00 | STOMATOPODS                 |                            |
| STOSQ00 | Squilla sp                  | Mantis shrimps             |
| STRAA00 | STROMATEIDAE                | BUTTERFISH                 |
| STRST01 | Stromateus fiatola          | Butterfish                 |
| SYBAA00 | SYNBRANCHIDAE               |                            |
| SYBSY01 | Synbranchus afer            |                            |
| SYGAA00 | SYNGNATHIDAE                |                            |
| SYGHI06 | Hippocampus punctatus       | Seahorse                   |
| SYNAA00 | SYNODONTIDAE                |                            |
| SYNSA01 | Saurida brasiliensis        | Brazilian lizardfish       |
| SYNSY00 | Synodus sp.                 | Lizardfish                 |
| SYNSY02 | Synodus synodus             | Diamond lizardfish         |
| SYNTR01 | Trachinocephalus myops      | Bluntnose lizardfish       |
| TETAA00 | TETRAODONTIDAE              | PUFFERS                    |
| TETEP01 | Ephippion guttifer          | Pricky puffer              |
| TETLA00 | Lagocephalus sp.            | Puffer                     |
| TETLA01 | Lagocephalus laevigatus     | Sooth puffer               |
| TETLA06 | Lagocephalus lagocephalus   | Oceanic puffer             |
| TETLI01 | Liosaccus cutaneus          |                            |
| TETSP02 | Sphoeroides spengleri       | Guinean puffer             |
| TETSP03 | Sphoeroides cutaneus        |                            |
| TETTE00 | Tetraodon spp.              | Puffer                     |
| TETTE01 | Tetraodon pustulatus        | Puffer                     |
| TRAAA00 | TRACHINIDAE                 | WEEVERFISHES               |
| TRATR00 | Trachinus sp                | Weever                     |
| TRATR01 | Trachinus armatus           | Greater weever             |
| TRATR06 | Trachinus radiatus          | Starry weever              |
| TRGAA00 | TRIGLIDAE                   |                            |
| TRGLE00 | Lepidotrigla sp             |                            |
| TRGLE01 | Lepidotrigla carolae        | Carol burnard              |
| TRGLE02 | Lepidotrigla cadmani        | Scalebreast gurnard        |
| TRGPE01 | Preristedion cataphractum   |                            |
| TRGTR00 | Trigla sp                   |                            |
| TRGTR01 | Trigla capensis             |                            |
| TRGTR02 | Trigla lyra                 | Piper gurnard              |
| TRGTR03 | Trigla gabonensis           |                            |
| TRGTR04 | Trigla lineata              | Gurnard                    |
| TRHAA00 | TRACHICHTHYIDAE             | SLIMEHEADS                 |
| TRHGE02 | Gephyroberyx darwini        | Darwin's slimehead         |
| TRHHO00 | Hoplostethus sp.            | Slimehead                  |
| TRHHO01 | Hoplostethus cadenati       | Black slimehead            |
| TRHHO02 | Hoplostethus mediterraneus  | Mediterranean<br>slimehead |
| TRHHO03 | Hoplostethus atlanticus     | Orange roughy              |
| TRIAA00 | TRICHIURIDAE                |                            |
| TRIBE01 | Benthodesmus tenuis         | Slender frostfish          |
| TRILE00 | Lepidopus sp.               |                            |
| TRILE01 | Lepidopus caudatus          | Silver scabbardfish        |
| TRITR01 | Trichiurus lepturus         | Largehead hairtail         |

| CODE    | SCIENTIFIC NAME      | ENGLISH NAME           |
|---------|----------------------|------------------------|
| TURAA00 | T U R T L E S        | TURTLES                |
| URAAA00 | URANOSCOPIDAE        | STARGAZERS             |
| URAU00  | Uranoscopus sp       |                        |
| URAU01  | Uranoscopus polli    | Whitespotted stargazer |
| URAU02  | Uranoscopus cadenati | West African stargazer |
| URAU03  | Uranoscopus albesca  | Longspine stargazer    |
| URAU05  | Uranoscopus scaber   |                        |
| XIPAA00 | XIPHIIDAE            | SWORDFISHES            |
| XIPXI01 | Xiphias gladius      | Swordfish              |
| ZEIAA00 | ZEIDAE               |                        |
| ZEICT02 | Cyttus hololepis     |                        |
| ZEICY01 | Cyttopsis roseus     | Rosy dory              |
| ZEIZE01 | Zeus faber           | John dory              |
| ZEIZN01 | Zenopsis conchifer   | Silvery John dory      |
| ZENZI00 | Cyttus sp.           |                        |
| ZENZI01 | Zenion hololepis     | Zeniontid              |





#### **Appendices 4.2 - 4.4:**

Two-way table output from the analysis of the trawl survey data using TWINSpan. Stations (with their numbers typed vertically) are in columns and species (represented by their codes and sequential number in file) are in rows. Only 60 - 80 most abundant species are shown (depending on total number of species encountered in the survey). Values in the main body of the table indicate species abundance and are as follows:

1:  $w < 0.5$ ; 2:  $0.5 < w < 5$ ; 3:  $5 < w < 50$ ; 4:  $50 < w < 500$ ; 5:  $w > 500$   
where  $w$  is weight in kg. Derived communities are separated and labelled. Hierarchy is shown in binary notation along the bottom and right margins for stations and species respectively.

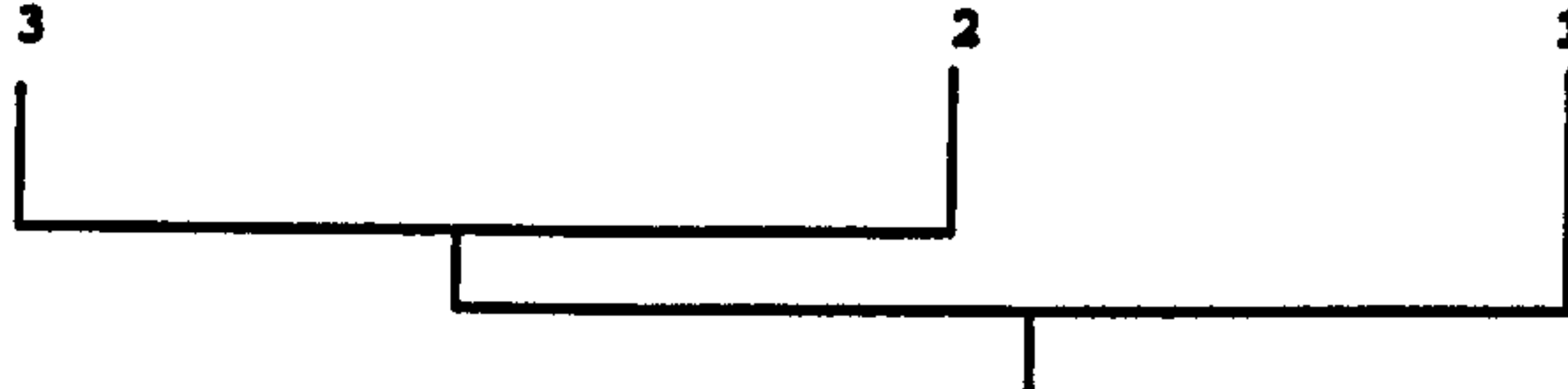
Appendix 4.2.1: TWINSpan two-way table output for the GTS data (both cruises combined).

|     |          | 1                | 2                          | 3                       | 4                            | 5               | 6           |
|-----|----------|------------------|----------------------------|-------------------------|------------------------------|-----------------|-------------|
|     |          | 244 11 25 556448 | 4231122333488677866667776  | 888958 11               | 123334677 12234458456779     | 135567231       | 2558        |
|     |          | 9127568321340349 | 6477856018712734723890561  | 348055901               | 23972398417420840966575281   | 56360869154     | 2190        |
| 6   | RAY RA11 | 2233-231-33-33-3 | -112322223-13122122222222  | 3232-443-               | --1232212221222221122-222-   | -----2-21-      | ---- 0000   |
| 58  | TRI TR01 | -24333--3--1112- | -----1-1-----              | -----                   | -----1-----                  | -----           | --22 00010  |
| 50  | HAE BR01 | 325433345-444331 | 5-133--433--2-11-231-3133  | 44--4124-               | -----1-----                  | -----           | ---- 000110 |
| 56  | SHR PE61 | -111122-----2222 | -----1-2-1-----            | 2112-333-               | --11-----                    | -----           | ---- 000110 |
| 62  | CYG CY01 | -3--1-1-1-1-2    | --1--122-1-----1-1-        | 11-1-33-                | -----11-----                 | -----           | ---- 000110 |
| 97  | TET EP01 | -33--2-1--31213  | -----1-2--322-3121--2      | 1-3-----                | -----                        | -----           | ---- 000110 |
| 2   | CAR SL01 | 1241-232-33-1332 | -----3-----1-----          | 11-----                 | -----                        | -----           | ---- 000111 |
| 45  | CLU IL01 | -34433-----32--  | -----                      | -----                   | -----                        | -----           | ---- 000111 |
| 48  | DRE DR01 | 42411231-----2-- | --2-----4-----             | -----                   | -----                        | -----           | ---- 000111 |
| 51  | HAE PO01 | 33243322-----2-- | --2-----4-----             | -----                   | -----                        | -----           | ---- 000111 |
| 52  | PLN GA01 | 434322333--33--  | --33--1-----               | -----                   | -----                        | -----           | ---- 000111 |
| 54  | SCI PS02 | 224433233--1--   | --2--13-----               | -----                   | -----                        | -----           | ---- 000111 |
| 80  | RAY DA11 | 2--12-21--3--3-  | -21-----1--1-----          | -----1--2-----          | -----2--                     | -----           | ---- 000111 |
| 18  | SCM SC01 | -----            | -----2344333--1-33213212   | 12-----3-               | 35434343221-34-4-3234434-    | --3--2-----     | ---- 001000 |
| 122 | SPA BO01 | -----            | -1-1122222-----2-22211     | -1--1--                 | --233343423--222432113334-   | -----1--        | ---- 001001 |
| 123 | SPA SA04 | -----            | --22-----21-21--           | -2-----                 | -----1--2--2-----12--        | -----           | ---- 001001 |
| 135 | POC CH00 | -----            | -----12-----1312-          | -----                   | --23-2--13-----              | -----           | ---- 001001 |
| 13  | CAR DE00 | -----2-----      | -3-2343-432-----3-31--     | 1-----3-3-3-----22-3-   | -----2--                     | -----           | ---- 001010 |
| 59  | PLA GR01 | -1--2-1-11-1-    | -----11-111-11-----1-1-11  | 1-----1111-1-----1--1-- | -----1--                     | -----           | ---- 001010 |
| 95  | RAY TO11 | -23--1-----2-3   | --12--11--112211212221-    | 2221-----               | --1-11--222--1--23-323-      | -----21--       | ---- 001010 |
| 96  | SPA DE00 | -----2-1-----    | -----1-----3--22-3         | -----                   | -----3-2-----                | -----1--        | ---- 001010 |
| 102 | BOT SC01 | -21-----11-      | --1122--1--1-22111111211   | 211-----                | -----1-----1--1--            | -----1--        | ---- 001010 |
| 128 | RAY TO12 | -----3--1--      | -12-11--12-2-----2-        | -----                   | --12-2-----2-----23-         | -----1--        | ---- 001010 |
| 3   | DAC DA01 | -----1-3-3-----  | -323333-31123223132332332  | 1-1--3-2                | 2-2232--212--1-1-----        | -----           | ---- 001011 |
| 5   | MUL PS01 | 22--2-2-3-1-1-   | 4-33344333322132-33343333  | 22--3-4-2               | 33333323233--1-11-1--        | -----           | ---- 001011 |
| 8   | SER EP01 | -23--2--2-333-   | 2233333323--2-323-23333-2  | 333-33--                | 4333333333-3333-33-4--2-     | -----           | ---- 001011 |
| 10  | SPA PA02 | -33--333-333-3-3 | 443444444442433434343344   | 433333344               | 44334344434--3--333333433    | -----1--        | ---- 001011 |
| 12  | TET LA01 | -----1-2-3-11--  | -1--11-111-2132-1-11-21-2  | 1-----                  | -----1-----                  | -----           | ---- 001011 |
| 15  | CLU SL01 | -----131-----    | --114-1342-----2-44234221  | 32--33-                 | 534-2--3-22-----312--        | -----           | ---- 001011 |
| 20  | SPA DE02 | 3--1--1--1-2--   | 124333333-33--33-3-333333  | 13-----                 | 3-23-22-222--223--31-22--    | -----2--        | ---- 001011 |
| 22  | SPA SA01 | 3441-3-2-----333 | -334434342322133342333333  | 2233-1--                | 3-33332-222--1-----3-11--    | -----           | ---- 001011 |
| 231 | SPH SP00 | -----3-322--     | 4-----3-1232-21321232      | 23--31--                | -----1-----                  | -----           | ---- 001011 |
| 83  | BAL BA02 | 3--1-----        | -332213331-11233-2-331313  | -----                   | -----3-----                  | -----2--        | ---- 001100 |
| 124 | SYN TR01 | -----            | -1-411-----21--1-2221--1   | -----                   | -----                        | -----2--        | ---- 001100 |
| 149 | DIO CH01 | -----1--         | -----11-11-22-----2121-    | 11-----                 | -----1-1-----                | -----1--        | ---- 001100 |
| 84  | CAR DE02 | -1--1-----       | 4122-22-241-1-----         | 13-----                 | -----31-----2--1--           | -----           | ---- 001101 |
| 90  | HAE DI01 | 2--1-----        | --11-222-----12-----221-11 | -----                   | -----23334322-----33333333   | -----           | ---- 001101 |
| 92  | PSE PS01 | -12--1-----1     | --2212-221--1-22--1-1-2    | -----                   | -----                        | -----           | ---- 001101 |
| 103 | CHA CH09 | 2-----           | -11112211-1--131-1-121222  | -----                   | -----11-1--1-----            | -----           | ---- 001101 |
| 106 | HAE PO02 | 2-----1-1-----   | -222-3-23-3-----           | -----                   | -----1--1--1-----            | -----           | ---- 001101 |
| 109 | LET LE01 | 312-----         | -22212222--22333-2-31-3-3  | -----                   | -----                        | -----           | ---- 001101 |
| 183 | LUT LU01 | 3-----           | -3--22-----3-3--21-2-      | -----                   | -----                        | -----           | ---- 001101 |
| 28  | FIS FI02 | -----11          | -321131121-112211-1221212  | 1111-----               | --1-211-2-11-----            | -----           | ---- 001110 |
| 98  | ACA AC01 | -----            | -331-3223-12-133-3-3313-2  | -----                   | -----                        | -----           | ---- 001110 |
| 110 | LUT LU02 | -----            | -232-3223-3--43-2-231333   | -----                   | -----2-----                  | -----           | ---- 001110 |
| 111 | LUT LU03 | 2-1-----         | -222-3333-23--2-32-233333  | -----                   | -----32-----                 | -----           | ---- 001110 |
| 113 | MON AL01 | -1-----          | -322222--1112211-212212    | -----                   | -----                        | -----           | ---- 001110 |
| 125 | BAL BA01 | -----            | 12--21212-1--2323-33323--  | -----                   | -----2-----                  | -----           | ---- 001110 |
| 127 | LAB BO07 | 1-----           | -2-111--12--32-1--21-12    | -----                   | -----1-----                  | -----           | ---- 001110 |
| 177 | RAY DA13 | -----            | -2--121-----2--221221      | -----                   | -----2-1--2-----             | -----           | ---- 001110 |
| 180 | FIS FI04 | -----            | -2--1-22--2--11--2-112-    | -1-----                 | -----334--2-----             | -----           | ---- 001110 |
| 185 | RAY RB12 | -----1--         | -----212--22--2--221122    | -----                   | -----                        | -----           | ---- 001110 |
| 260 | CAR DE01 | -----            | -----1--323-1222           | -----                   | -----13-----32-              | -----           | ---- 001110 |
| 17  | SCI UM01 | -----            | --2-22-3-3-----32-         | -----                   | 4--2--1-11--1-----1-231      | -----1--        | ---- 001111 |
| 133 | CHA CH02 | -----            | -----11-----21-1--1211     | -----                   | --11-11111--1-----           | -----           | ---- 001111 |
| 16  | PRI PR01 | ---1-----2-221   | 313244132311133-234343333  | 3-331-323               | -333322333312222-33233344-   | 4-----1211-     | ---- 010    |
| 34  | ZEI ZE01 | -----1-----      | -----111--1-----           | -----                   | --112-2-----1-1221-          | -----1-----     | ---- 010    |
| 191 | CIT CI02 | -----1-----      | -----1-----1--1--2--       | 11-----                 | --1-----111-----221--        | -----1--        | ---- 010    |
| 14  | CAR TR00 | --1--22-----     | -2-2323345--2--2-13134211  | 21-23-343               | 35334334433-433434333444-    | 5-4--21--       | ---- 01100  |
| 21  | SPA DE05 | -----1-----      | --1-23--2-232-21-23133     | 1-----3                 | 3-33-3312232-3323312--31-    | 3-4-----        | ---- 01100  |
| 41  | TRG LE02 | -----1-----      | -1-11--1-----1-21111221    | 11-1--4                 | --1-11--221-31-22-21112211   | -----12-2-      | ---- 01100  |
| 120 | SHA TR21 | -----1-----      | --2212-2-1-----112-        | -----1--                | --21-----3-2-----            | -----2--        | ---- 01100  |
| 32  | SPA DE01 | -----2-----      | --221222--2-----           | 23-3-1--                | --11-23213442342322441333    | 4--2--2-2-      | ---- 01101  |
| 33  | SPA DE04 | -----3-----      | -----2-----1-----1         | 24-2-----               | --3333343334434444444443     | --3--3332-      | ---- 01101  |
| 119 | SHA LE11 | -----            | -22222-2-----              | 1-----                  | -----2-----1--3--            | -----           | ---- 0111   |
| 136 | SHA ST11 | -----            | -----2-----                | -----                   | --12212-221--121--33-2221    | -----33231-     | ---- 10011  |
| 158 | TET LI01 | -----            | -----                      | -----                   | -----11-----1--1-222-        | -----2211-      | ---- 10011  |
| 37  | EMM ER01 | -----            | -----                      | -----                   | -----2-1-----33-             | 1-3--132-       | ---- 10100  |
| 38  | NOM PA01 | -----            | -----                      | -1-13--                 | --11-3-----33344-333432-     | 5444344414-     | --3 10100   |
| 24  | TRG TR02 | -----            | -----                      | 33-----23               | -----23-----2-               | 3-3--121--1-3   | 101010      |
| 26  | CEN SM01 | -----1-----      | -----                      | -----                   | -----1--32-2-21-233-         | 4-3--33233-     | 101010      |
| 35  | CAP AN01 | -----            | -----                      | -----                   | -----213-----344-            | 3-4-224434-     | 101011      |
| 39  | SCI PN01 | -----11-----     | -----                      | -----33-----            | -----2-----1--4-214          | 4--331214-      | --2 101011  |
| 36  | CHL CH01 | -----            | -----                      | -----                   | -----                        | 131--432-2--34  | 101100      |
| 67  | NOM PA02 | -----            | -----                      | -----                   | -----3-----1-----            | --4--3221--32-3 | 101100      |
| 69  | CHL CH00 | -----            | -----                      | -----                   | -----                        | -----3-331 33-- | 101100      |
| 19  | SHA HM21 | -----22-----122- | -----2-----                | 2--2-----2-----         | 4-33-----                    | 1100            |             |
| 11  | SQU LO20 | -3--3-4-4-21--   | -34221-332--132212111-113  | 12113--33               | --23-----3-23--1-11314       | --4-3423-3--23- | 1101        |
|     |          | 0000000000000000 | 00000000000000000000000000 | 0000000000              | 00000000000000000000000000   | 1111111111 1111 |             |
|     |          | 0000000000000000 | 111111111111111111111111   | 1111111111              | 1111111111111111111111111111 | 0000000000 1111 |             |
|     |          | 0000000001111111 | 00000000000000000000000000 | 1111111111              | 1111111111111111111111111111 | 00000000001     |             |
|     |          | 0111111011111111 | 000000000001111111111111   | 0000000000              | 1111111111111111111111111111 | 0000111111      |             |
|     |          | 0011111 0000111  | 011111111100000011111111   | 0000111111              | 00000000000111111111111111   | 000011          |             |
|     |          | 00011            | 0011111111001111100000001  | 00111                   | 00111111111000000000111111   |                 |             |
|     |          | 1                | 2                          | 3                       | 4                            | 5               | 6           |



Appendix 4.2.2: TWINSpan two-way table output for the GTS data (both cruises combined).

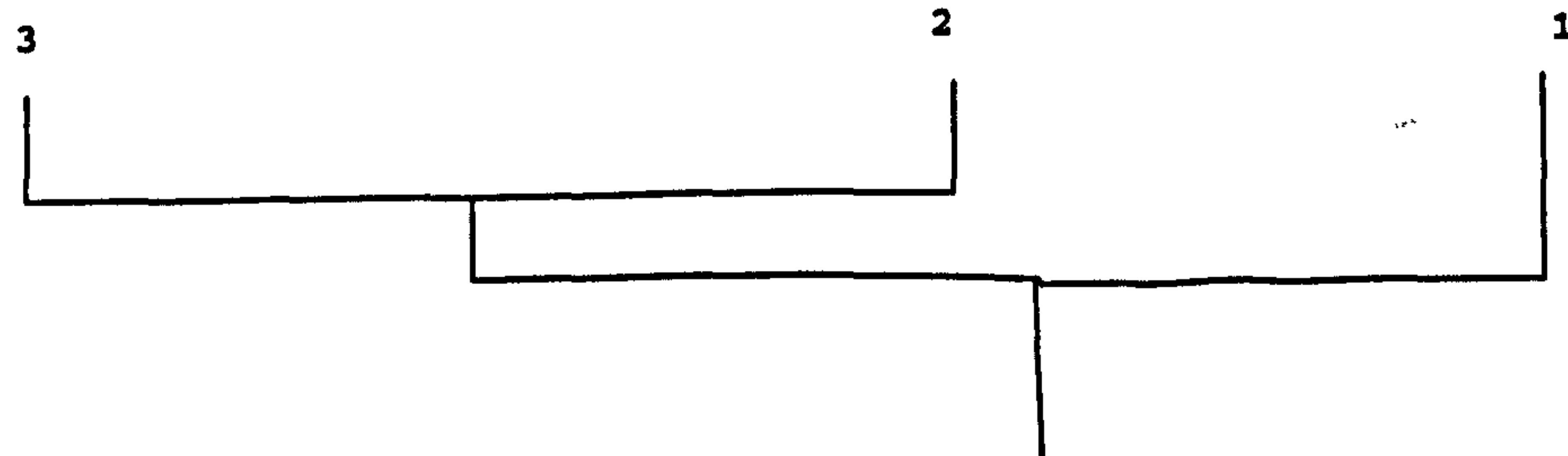
|     |          | 3                              | 2                        | 1              |        |
|-----|----------|--------------------------------|--------------------------|----------------|--------|
|     |          | 94558 1138868123334456779      | 1132672423366677767888   | 21244 156 5448 |        |
|     |          | 1645519018383497239586417023   | 7816205740718945673712   | 96312752083349 |        |
| 58  | TRI TR01 | 1-1-----1-----1-----           | -----1-----              | -3-243331--12- | 111101 |
| 54  | SCI PS02 | -----                          | 2-3-----1-----           | 2332443312---- | 111101 |
| 52  | PLN GA01 | -----                          | 33-----1-1-----          | 4233432333-3-- | 111101 |
| 51  | HAE PO01 | -----1-----                    | 2-----2-2-----           | 3323243--2---- | 111101 |
| 48  | DRE DR01 | -----                          | -----42-----             | 4212411--3-2-- | 111101 |
| 45  | CLU IL01 | -----                          | -----                    | -3-3443-3--2-- | 111101 |
| 2   | CAR SL01 | -----3-----1--1-----           | -----3-----1             | 122241--133332 | 111101 |
| 80  | RAY DA11 | --31-----2-----                | -----2-1-----1-1-        | 222---11----3- | 11011  |
| 50  | HAE BR01 | -5441-24-34-34-----            | 333-23---4131-113-1-23   | -3425435434331 | 11011  |
| 97  | TET EP01 | --3-----2132-----              | ---11-----21----223-3    | -2133---1--213 | 11010  |
| 62  | CYG CY01 | --1---33-21-11--11-----1--     | 1-2-----1-----1-----1    | -1--3--1--1-2  | 10110  |
| 56  | SHR PE61 | -----333221-111-----2--        | -----1-----1-----1       | -2-1111-22-222 | 10110  |
| 59  | PLA GR01 | 1-1-----11-1--11111--1----     | -11--11--1-1----1--11    | ---1---1-211-- | 10100  |
| 29  | MIS CE00 | --2-4-332---3-3232-----3----   | -3-3-3---33-----3-       | 333--23-33---- | 10100  |
| 6   | RAY RA11 | -----344333322123222112222--   | 2322222-12122222212113   | 221233--3333-3 | 10100  |
| 4   | HET ER00 | -----33--21111-211-2--11-1--   | 2222212-12221222112112   | -222332-33-112 | 100    |
| 128 | RAY TO12 | -----2-----12--2-----          | -11---1-1-2-----2--2-    | -----31-----   | 01111  |
| 95  | RAY TO11 | -----22221-11-3--2221--        | 121-12---1--12221121-1   | -1-23-----2-3  | 01111  |
| 22  | SPA SA01 | -----1-----2232233322--22233-  | 444443333333333333322    | 332441-----333 | 01111  |
| 10  | SPA PA02 | 343313344433334343434344       | 444443444434444343324    | -3333---333-3  | 011101 |
| 8   | SER EP01 | -----233-223-333333413333343   | 33333333232-233332-2--   | -2-23---3--333 | 011101 |
| 28  | FIS FI02 | -----111111-2112--2-11--       | 1121-13-31222212122111   | -----11        | 011011 |
| 20  | SPA DE02 | -1-----1--323-22--3222-3-      | 33333333234333333-3-3-   | 31-----12--    | 011011 |
| 5   | MUL PS01 | -413-3-4232-3233332-31233-33   | 33343343-3333423313-22   | 2222-----1-    | 011011 |
| 3   | DAC DA01 | -----33-21112-2232---212-2-    | 333332313-22333322123    | -13-----       | 011011 |
| 16  | PRI PR01 | -1231--3223-3333322333333333   | 3234244331134333313-11   | -----1-----22  | 01100  |
| 84  | CAR DE02 | -4-----41--3-31-----           | 2-22--211-2-----1        | -1--1-----     | 010110 |
| 15  | CLU SL01 | -----33-43-424-2---3--22-53    | 113-4442-1-123222-----   | -11-----3----  | 010110 |
| 14  | CAR TR00 | ---3--34352-3133433343433235   | 2343142-23-113221----2   | -2--1----2---- | 010110 |
| 33  | SPA DE04 | 3-----2--4333334443332--       | --2-----1-----1----      | -----3-        | 01010  |
| 32  | SPA DE01 | 3---1-----2--3-11-24322133--   | -----2-                  | -----2-        | 01010  |
| 122 | SPA BO01 | -----1-----2--212334132423--   | 1122-22-12-1-2-21-----   | -----          | 010011 |
| 18  | SCM SC01 | -----3-31-3243434333322-35     | 2334334--3-221121-----   | -----          | 010011 |
| 135 | POC CH00 | -----23-2-----13--             | --2-31-----1-12-----     | -----          | 010010 |
| 41  | TRG LE02 | 1-1-----4-1-111-11-1--2211--   | 111-21--1--111122-----   | -----          | 010010 |
| 21  | SPA DE05 | -----3-1-1-33-33-11223-3-      | 1--3232---3-221323-2-    | --1-----       | 010010 |
| 13  | CAR DE00 | -----31---3--3-----3-          | 234331423---3-----       | -2-----        | 001111 |
| 17  | SCI UM01 | 1-----2---1--11-4-             | 2-32--23-----32-----     | -----          | 001110 |
| 149 | DIO CH01 | -----11--1--1-11-----          | --1--1-----2221-2-11     | -----1--       | 001101 |
| 260 | CAR DE01 | -----2-----13--                | ---31-----23--221----    | -----          | 001100 |
| 180 | FIS FI04 | -----1-----1---2--             | --2--11--22-2-112-1-2-   | -----          | 001011 |
| 177 | RAY DA13 | -----2-1--                     | --2-11-21-122-22-2--     | -----          | 001011 |
| 125 | BAL BA01 | -1-----3---2-----              | -222-21121--3323-233--   | -----          | 001011 |
| 113 | MON AL01 | -----                          | 22-2122-3-222122112111   | ---1-----      | 001010 |
| 110 | LUT LU02 | -----                          | 2-32213-223323333-4-3-   | -----          | 001010 |
| 98  | ACA AC01 | -----                          | 1-32313132323333-13-2-   | -----          | 001010 |
| 185 | RAY RB12 | -----                          | ---1-12--2-22212--22     | -----1-----    | 001001 |
| 127 | LAB BO07 | -----1-----                    | -1-11111--22-22-1-3-2-   | 1-----         | 001001 |
| 111 | LUT LU03 | -----32-----                   | 2-332332232323-33-233-   | 2---1-----     | 001001 |
| 103 | CHA CH09 | -----11-1-----1--              | 1112112111121212213--    | 2-----         | 001000 |
| 83  | BAL BA02 | -----1-----3-----              | 2233211-33333333123-11   | 31-----        | 001000 |
| 183 | LUT LU01 | -----                          | ---2312---32-2---3---    | 3-----         | 000111 |
| 109 | LET LE01 | -----                          | 21222-2-22233133-33-22   | 3--12-----     | 000111 |
| 90  | HAE DI01 | -----                          | 1--2-12--21122--112---   | 21-----        | 000111 |
| 106 | HAE PO02 | -----1-----1-----1--           | 2-3---33222-----         | 2-1-----1--    | 000100 |
| 92  | PSE PS01 | -----1-----                    | 212---2--222-121--2-1-   | -1-12-----1-   | 000100 |
| 231 | SPH SP00 | -4231-----2-13-----1-----      | ---21-3---23222323-1-    | -----32-3---   | 0000   |
| 102 | BOT SC01 | -----12111-----1--1----        | 11-2112---111221-21-1    | --21-----11-   | 0000   |
| 12  | TET LA01 | --1--3---11-1-----1-----       | -11--21-11-21--1-32121   | -12-----1----- | 0000   |
| 11  | SQU LO20 | 1-23-4--321112-23-----1--      | 223-2-1-334311211321-1   | -343---1-----  | 0000   |
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|     |          | 000000000000000000000000000000 | 111111111111111111111111 | 00000000000111 |        |
|     |          | 000001111111111111111111111111 | 0000000000011111111111   | 000001111111   |        |
|     |          | 011110000000111111111111111111 | 0000000011100000000011   | 01111000011    |        |





| 3              |        |                                 |            |                 |                              |      |                  |        |  | 2   |                          |     |   |          |    |   |  |  |  | 1 |  |  |  |  |  |  |  |  |  |
|----------------|--------|---------------------------------|------------|-----------------|------------------------------|------|------------------|--------|--|---|--------------------------|-----|---|----------|----|---|--|--|--|---|--|--|--|--|--|--|--|--|--|
| 1111           | 1      | 1                               | 1          | 1               | 11                           | 11   | 11               | 1      | 1111   | 11111   | 1                        | 111 | 1 | 11111111 | 11 | 1 |  |  |  |   |  |  |  |  |  |  |  |  |  |
| 77012366346013 | 334333 | 3566778014562901112345556789922 | 2234481293 | 550113129901112 | 3115784342122778888199002445 | 1378 | 2990112223670263 | 561233 | 9637700390550038998422114747028196680146867238118495691255675733 | 679064350284593687120392730834081345517674484459522 | 156123089695422117587923 |     |   |          |    |   |  |  |  |   |  |  |  |  |  |  |  |  |  |

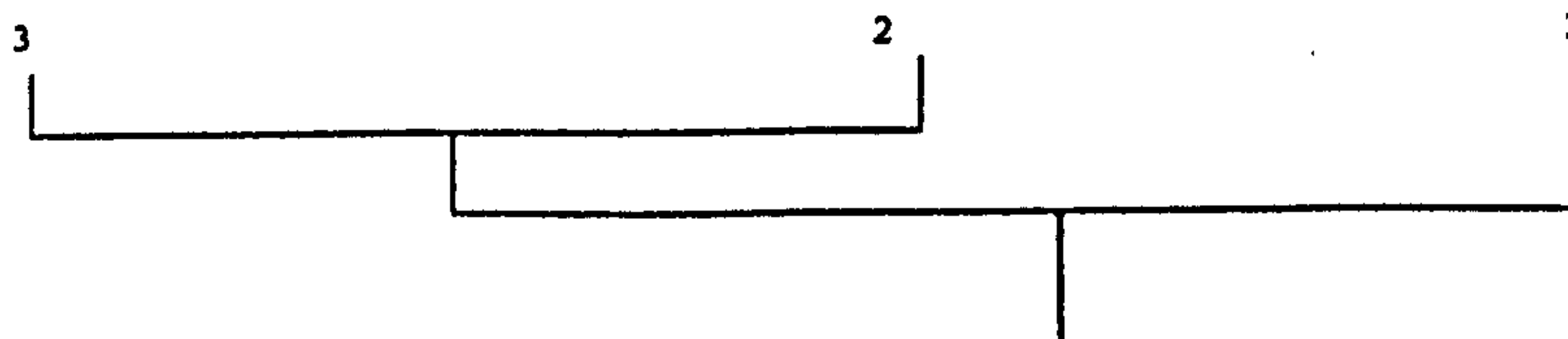
|     |          |   |   |        |
|-----|----------|---|---|--------|
| 34  | MON ST01 | -----1-----   | -----1-21-----1-1-1-----  | 000000 |
| 35  | OST AC01 | -----2-----   | -2-----1-2-1-31321231-----1-2-31-3-----                                       | 000000 |
| 68  | LET LE01 | -----3-21-33-23322223-42-----22-2-----3-----                      | 22-----33-21-33-23322223-42-----22-2-----3-----                               | 000000 |
| 29  | BAL BA02 | -----5-----1-----2-----   | -2-123332223-32223323322-2-----1-1-12-4-13-----                               | 000001 |
| 31  | DIO CH01 | -----1-----1-----1-----   | -1-----11-12-1-11-3-----1-3-----1-----1-1-----                                | 000001 |
| 40  | ACA AC01 | -----1-----1-----1-----   | -3-3-342-34-33-33133-3-3-----3-----3-----1-----1-----                         | 000001 |
| 44  | LAB DI01 | -----22-----2-----1-----  | -2-2-133-2-3-23332-----1-----1-----   | 000001 |
| 70  | LUT LU01 | -----3-----3-----3-----   | -3-2-3-2-2-----3-43-----2-----2-----1-----1-----                              | 000001 |
| 42  | CHA CH00 | -----2-----11-----1122-1-----2-2-----                             | -22-1-1-21222-----2-1-----1-----1-----  | 000010 |
| 45  | LUT AS01 | -----3-1-----133-----   | -332-1-123-22-----1-----1-----  | 000010 |
| 46  | LUT LU02 | -----3-----3-----3-----   | -----233-3-3-----1-----1-----   | 000010 |
| 47  | LUT LU03 | -----2-----2-2-2-2-3-----3333333323                               | -33323333232-134-2333312342-----1-1-23-----                                   | 000010 |
| 48  | MON AL02 | -----1-----2-----12-----3-----                                    | -----2-122-1-2113-----23-----   | 000010 |
| 57  | SCR SC00 | -----1-----1-----1-----   | -----1-----2-2-----1-----1-----   | 000010 |
| 43  | HAE DI01 | -----2-----1-2-----3-2-----2-----                                 | -2-----4-2-3-----2-----2-----   | 000100 |
| 91  | SER EP26 | -----2-3-----22-3-----  | -3-33-----43-1-----1-----2-----2-----   | 000100 |
| 93  | POC CH00 | -----4-----3-----23-----  | -43-1-----1-----2-----2-----  | 000100 |
| 24  | PRI PR01 | 11-13124422231-3334-1-321-2-3-212133-32-322223-434-122-213        | -3333332-32-2-33233-----333-2-----2133-3-343434111-1                          | 000101 |
| 107 | CHA CH09 | -----2-----1-----2-----   | -2-----2-----2-----   | 000101 |
| 17  | SPA DE02 | -3-3212321-323-3312-31-1134433333343443333123433334333334         | 343333333332234333333333-323-213-2-343333233-33-----2-221-21-----2-3          | 00011  |
| 41  | CAR SE05 | -----2-----1-----1-----2-----3-3-----23                           | -211-2-----2-3-----1-----1-----   | 00011  |
| 49  | POC CH02 | -----4-1-----1-32-13-23421-2241-                                  | -----1-----1-----1-----   | 001000 |
| 51  | TRG TR00 | 1-1-3-2-32-2-2-1-1-----1-----23311322-22-3222-1-22123211          | -----1-----1-----11-----1-----1-----  | 001000 |
| 61  | SCI UM01 | -----3-----123-----54-2-----2-22-3-3-----                         | -----2-----2-----   | 001000 |
| 50  | SPA DE05 | -32-331-----23-----2-1-343-243233332-223-23333332-33223           | 2333321-----21-----3-3-----   | 001001 |
| 52  | ZEI ZE01 | 1-11-323-2-23-----1-322-12-122-2-11-2-2312222-2223                | 2-321-----3-----2-22-----3-2-----   | 001001 |
| 108 | DIO DI00 | -----1-----2-----2-----2-----                                     | -----2-----2-----   | 001001 |
| 114 | CAR DE04 | -----1-----3-----1-----2-----1-2-----                             | -----2-1-----   | 001001 |
| 25  | SPA DE01 | 332433444-21223-2-3-1-----1-3-3-43-----3-----                     | -----3-----3-----   | 001010 |
| 64  | SPA DE04 | 41233444344231-----2-----3-4-----1-3-2-3-----                     | -----3-----3-----   | 001010 |
| 66  | NOM PA01 | 3-332324212-3-1-----1-24-1-----2-3-----1-1-----                   | -----1-----1-----   | 001011 |
| 94  | CAR TR00 | -----1-332-----1-3-----2-----1-----2-----                         | -----1-----1-----   | 0011   |
| 20  | DAC DA01 | -----1-3-22-121-2-----2-22-23-----132132223-321-----22-21-21      | -2-3-----2-2-2-----2-211-11-----111-2332231-----2211-----                     | 0011   |
| 39  | TRG LE00 | 1-21-2-22-233-2-----2-1-13-2-2-13-12-----1-211-----1-----         | -2-----1-----1-----11-----  | 0100   |
| 13  | FIS FI02 | 333233233-321-123-233133331-223-33-1-32233122321-322-1312-----1-  | -333133-12311233222112-2-----1-12111-31-12-222123-----1-----2-1-----2-----    | 01010  |
| 53  | CAR SA01 | -----21-----3-----  | -----1-----2-4-----1-----2-----   | 01010  |
| 88  | LAB XY01 | -----11-----  | -----2-21-2-----1-----11-----   | 01010  |
| 2   | BOT SC01 | -----12-21111-----111-2-----2-1-2-11-----1-111-11-2-11            | -222-1-----1-22213-1-1-2-----2-----1-----222322-1-----1-----2-1-1-22-11-----  | 010110 |
| 9   | SER EP01 | -2-3-33-3-44-33223234333432-4-44-----23-34333-3434323333-3-2----- | 44333333333234233-3-3-----3-----3-----1-3-----                                | 010110 |
| 10  | SPA SA01 | -123222-22-2333233321333212333333333433323433333343-33333         | 33333433333342333443343-3333323-3-343333343343-----2-3341-----                | 010110 |
| 11  | SQU SE10 | 323323-3-23-----2-----332-23-----323-33-23-----                   | -----31-233-2331-3-----3-----2-3341-----                                      | 010110 |
| 22  | MUL PS01 | 1-2332-133332333333-1232-1-1-343343-322-32222433333333433         | 444333443334314133333312442333-1334334342231123-----33121-122-32-----1-1----- | 010110 |
| 26  | SPA PA02 | 23332322-2-324434343-22332-222-3234343432344-3244434534124432     | 44443433333214123-2332-44-32231134343434331231-----3323223313222-131-2-----   | 010110 |
| 59  | HAE PO02 | -----4-1-33-3-231-----3-----2-----3-2-----4-----                  | -----3-----1-31-----1-4-----1-33-----   | 010111 |
| 75  | CAR DE02 | -----33-----33-----1-----1-----1-1-----3-32                       | -1-----11-1-1-2-----243-13-----2-1-1-----221-----11-----11-12-----1-----      | 010111 |
| 131 | SQU SE11 | 3-32-3-33-----4-----3231333-----323-----332                       |   |        |

[illegible]



Appendix 4.4. TWINSpan two-way table output for the MFRD5 data ('complete' cruises combined).

|     | 3  | 2   | 1  |
|-----|--|---|--|
|     | 111 1                                    | 1   | 1 111  |
|     | 337 2569979000670222334567 269167890378  | 47 880 58 1511011466 1246681234550124845779 3 14  | 44933578935602590009   |
|     | 2341270255493481814574829704021566890037 | 3773916322544231168549986136799712583400029831809 | 15367684055976872566   |
| 52  | DIO CH01                                 | -----2-----2-2-----1-----                         | -----1-----32--2-1-----1--2-----22-----33                              |
| 11  | MON ST01                                 | ---1-----1-----1-----                             | -----2-----2-----11-2-----1-----112- -1-----1-----                     |
| 30  | LET LE01                                 | -----1-----1-----                                 | -----2-----22-----3-43432222332 -3-----2-----1-----                    |
| 32  | OST AC01                                 | 1-----2-----1-----                                | -----1-----1-----313-----122-1322--2-333 -3-----2-----1-----           |
| 45  | RAY RB10                                 | -----2-----2-----                                 | -----3-22-----2-----22-32-21 2-----1-----                              |
| 67  | GRA RY01                                 | -----21-----                                      | -----1-1-----1--1-211 -1-----1-----                                    |
| 68  | LUT LU01                                 | -----   | -----3-----3-----4-----2-----  |
| 103 | LUT LU02                                 | -----   | -----4-3-3-----2-----  |
| 53  | HAE DI01                                 | -----32--1-3-2-----1-----                         | -----3-----2-23-2-23-2 -2-----2-----1-----                             |
| 71  | SCR SC00                                 | -----2-----1-3-----                               | -----1-11-----1-----22- -1-----1-----                                  |
| 74  | LAB XY01                                 | -----2-----1-----                                 | -----1-21--11-1-----11-----1-----                                      |
| 9   | LUT LU03                                 | -----2-3-----1-----1-----3                        | 4332-33323332223333-----323-33-3-23333323433 1-----3-----              |
| 31  | LUT AS01                                 | -----3-----1-----1-----3                          | 3--11-33-32332-12-12-----2-22-----3-12-----                            |
| 3   | CHA CH00                                 | -----1-1-----1-----1-----                         | 22211122-22-22213221--13--22-232--2--123211-2333 -1-----1-----         |
| 27  | ACA AC01                                 | -----2-----2-----                                 | -----22-----332-3-1-----3-----14-3432223--14-----                      |
| 28  | BAL BA02                                 | -----2-----2-----2-----2-----                     | -----1-----2-----2-231--333--22233-1233333323-2-231--1-----1-----      |
| 54  | LAB DI01                                 | -----2-----1-----                                 | 22-----1-2-----2-----22-12-2-312--31-----                              |
| 58  | POC CH00                                 | -----1-----                                       | -----4352-2-----2-3-----2-----2-----                                   |
| 62  | SPA SA04                                 | -----2-----2-----                                 | 3-33-2-----32-2-----2-22-----  |
| 35  | SPA DE05                                 | -----3-----2-----1-----132-2                      | 33333322132111--1-----   |
| 56  | CAR SE05                                 | -----2-----2-----1-----                           | -----22-----2-----2-----   |
| 61  | HOL AD01                                 | -----32-----                                      | 122111-----11-----2-----1-----13--                                     |
| 14  | POC CH02                                 | -----3-----33-----                                | 4-----3-----31-----  |
| 16  | SCI UM00                                 | -----2-23-----                                    | 2-----2-----2-----3-----   |
| 17  | SCM SC01                                 | 23-2-2-----1-----12-----2                         | -----324-----1-----1-----  |
| 26  | TRG TR00                                 | 4333223-1-----2-----13-3-----11-----33--132-      | 2-----22-213233-2233--2-2-----213-----2-----                           |
| 34  | SPA BO01                                 | 434-3-----4-----2-----333                         | -----2-2-3-----1-3-----  |
| 13  | NOM PA01                                 | 3-2-3-13-1-----                                   | -----2-----  |
| 21  | SPA DE04                                 | 343334444-----3-1-----                            | -----2-----3-----  |
| 60  | SPA DE01                                 | 432-332-2--12--3-----3-----                       | -----2-----1-----3-----  |
| 18  | SER SE02                                 | ---1123-----1321-11-1--212-2-----                 | -----1-----1-----  |
| 81  | SCI UM01                                 | -----11-1-11-----3-----                           | -----1-3-----  |
| 125 | CAR TR02                                 | -----42412-3-----3-----                           | -----2-----2-----1-----  |
| 19  | SHA CA61                                 | 3233--233--3-223-3-----33--3-3223-3               | -----3-3-----2-----33-----3-----22--                                   |
| 59  | SHA ST01                                 | 2---32-----3-2-----                               | -----3-----2-----1-----  |
| 63  | ZEI ZE01                                 | -11-----22-----2-----12-----                      | -----1-----12--2-----2-----1-----                                      |
| 101 | TRG LE00                                 | -----1-----332-----3--2-----2211--                | -1-112-----2-----1-----1-2-----1-----                                  |
| 2   | CAR DE00                                 | -----3-----23-----21-121-----343                  | -----333-32-----2-----11-1-2-2-----2-----                              |
| 5   | CLU SL01                                 | -----2-----1-1-----21-2--1-----1--22--            | -----234-2-----1-----31-----3-----12-----                              |
| 7   | FIS FI02                                 | 3332121--1-----12-2-----2-2-32--22-22211331       | -1312332132322-133212321-1123333333333322-213- 33311-----1-----        |
| 12  | MUL PS01                                 | 3333322-1322113311321231-121322323312333          | 44243334343-34444334-2232333233323131233333323332 1-1-2-3-2-----222--  |
| 20  | SPA DE02                                 | 2--32-3-1121-2-----32--2223-113-3322313323        | 4333343333333333333-31-22233333333334333333333 -222-32--1-21--         |
| 22  | SPA PA02                                 | -3-234433432234-3333-3433341223323333323          | 312123131333333343333334123333332333--3--3333323- -1-2-2-122--1--332-- |
| 29  | DAC DA01                                 | -1-----2--1-2-2-12222-2311-3333333223             | 3-2332332343333-3-3333-222331122-3-212322-1-1-2- -2-2-----122--1--     |
| 33  | PRI PR01                                 | 43-----212-3331231213-22-----2-331--1-221         | 1221--4--33332-13322--43-1--22-33-313-13-323332- -2-----1-----11-2--   |
| 69  | MON AL02                                 | -----2-----3-3-3--2-----                          | -----322--2-2-2-----2-1--233- -2-----2-----                            |
| 50  | BAL BA01                                 | -----1-----11-33-1--1-222-1111222312-2            | -----1-2--1--123333233323332433222-1--12--2- -3-122-----11--           |
| 76  | CAR CA02                                 | -----1-----1-----2-2-----                         | -----21--2-----2-----2-----12-----                                     |
| 1   | BOT SC01                                 | -----1-12-----1-----1-2-132--2-21--2-----         | -----2-1212-32-2--1-2111-----1-11332-- -2-121-1-----1                  |
| 23  | SPA SA01                                 | -2-333323331-----33312233123313233223-33          | 4333333333333333333-323  |

[illegible]



Appendix 4.5. Species lists of assemblages described by Fager and Longhurst (1968) and (Longhurst 1969); some older names have been replaced with new synonyms.

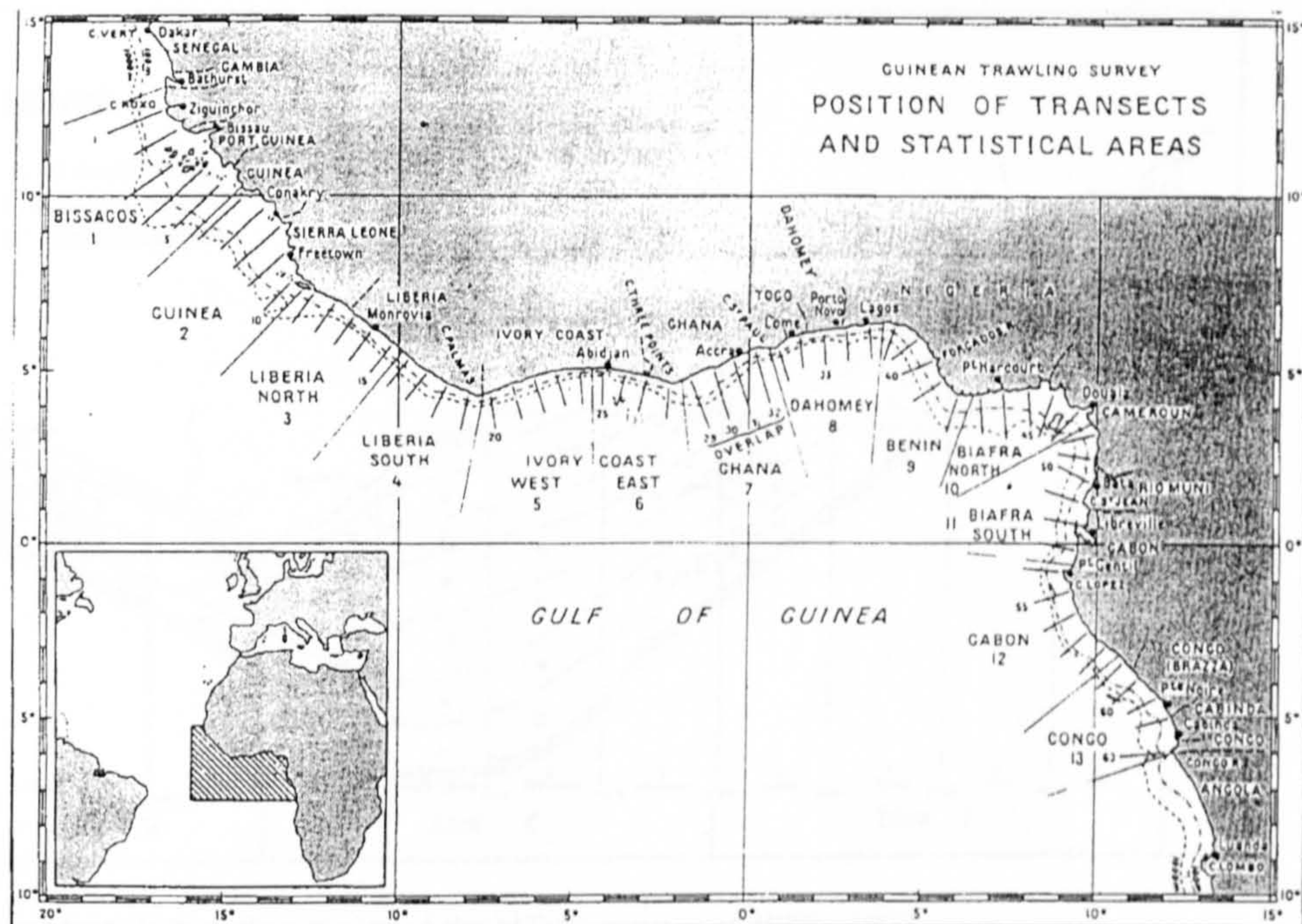
|   |  |  |
|---|--|--|
| <p><b>A</b><br/><u>Sciaenid community</u></p> <p><i>Brachydeuterus auritus</i><br/><i>Galeoides decadactylus</i><br/><i>Selene dorsalis</i><br/><i>Pseudotolithus senegalensis</i><br/><i>Pseudotolithus typus</i><br/><i>Arius</i> spp.<br/><i>Ilisha africana</i><br/><i>Pteroscion peli</i><br/><i>Drepane africana</i><br/><i>Pomadasya africana</i><br/><i>Dasyatis margarita</i><br/><i>Cynoglossus browni</i><br/><i>Pentanemus quinquarius</i><br/><i>Sphyræna</i> spp.<br/><i>Ephippium guttifer</i><br/><i>Chloroscombrus chrysurus</i><br/><i>Lagocephalus laevigatus</i><br/><i>Eucinostomus melanopterus</i></p> | <p><b>D</b><br/><u>Sparid community (shallow element)</u></p> <p><i>Cheilomycterus antennatus</i><br/><i>Sparus caeruleostictus</i><br/><i>Dentex canariensis</i><br/><i>Balistes forcipatus</i><br/><i>Dactylopterus volitans</i></p> <p><b>D</b><br/><u>Sparid community (deep element)</u></p> <p><i>Priacanthus arenatus</i><br/><i>Fistularia villosa</i><br/><i>Pseudupeneus prayensis</i><br/><i>Epinephelus aeneus</i><br/><i>Pagellus bellottii</i><br/><i>Raja miraletus</i><br/><i>Dactylopterus volitans</i><br/><i>Sardinella aurita</i><br/><i>Torpedo torpedo</i><br/><i>Mustelus mustelus</i><br/><i>Boops boops</i><br/><i>Scomber japonicus</i><br/><i>Trachurus</i> spp.<br/><i>Pentheroscion mbizi</i><br/><i>Brotula barbata</i><br/><i>Uranoscopus albescens</i><br/><i>Lepidotrigla cadmani</i><br/><i>Lepidotrigla laevispinis</i><br/><i>Dentex angolensis</i><br/><i>Dentex congoensis</i><br/><i>Squatina oculata</i><br/><i>Paracubiceps ledanoisi</i><br/><i>Smaris macrophthalmus</i><br/><i>Saurida parri</i><br/><i>Eucitharus linguatula</i><br/><i>Sphyræna</i> spp.<br/><i>Lagocephalus laevigatus</i><br/><i>Scyacium micrurum</i><br/><i>Neanthias accraensis</i></p> | <p><b>E</b><br/><u>Deep shelf community</u></p> <p><i>Peristedion cataphractum</i><br/><i>Antigonia capros</i><br/><i>Zenopsis</i> sp.<br/><i>Synagrops microlepis</i><br/><i>Bemprops heterurus</i><br/><i>Pterothrissus belloci</i><br/><i>Monolene microstoma</i><br/><i>Chlorophthalmus</i> spp.</p> <p><b>F</b><br/><u>Continental slope community</u></p> <p><i>Chaunas pictus</i><br/><i>Benthodesmus tenuis</i><br/><i>Setarches guentheri</i><br/><i>Epigonus telescopus</i><br/><i>Galeus polli</i><br/><i>Moridae</i><br/><i>Macrouridae</i><br/><i>Etmopterus pusillus</i><br/><i>Halosaurus oweni</i><br/><i>Cyttus roseus</i><br/><i>Merluccius</i> spp.<br/><i>Hoplostethus</i> spp.<br/><i>Trigla lyra</i><br/><i>Dibranchius atlanticus</i><br/><i>Gonostomatidae</i><br/><i>Hypoclydonia bella</i><br/><i>Chascanopsetta</i> sp.</p> |
| <p><b>B</b><br/><u>Eurybathic or thermocline species</u></p> <p><i>Trichiurus lepturus</i><br/><i>Cynoglossus canariensis</i><br/><i>Paragaleus gruveli</i><br/><i>Rhizoprionodon acutus</i><br/><i>Platycephalus gruveli</i><br/><i>Torpedo torpedo</i></p>  |  |  |
| <p><b>C</b><br/><u>Lutjanid community</u></p> <p><i>Lethrinus atlanticus</i><br/><i>Lutjanus goreensis</i><br/><i>Lutjanus agennes</i><br/><i>Balistes forcipatus</i><br/><i>Chaetodon hoefleri</i><br/><i>Acanthurus monroviae</i><br/><i>Ostracion tricornis</i></p>  |  |  |



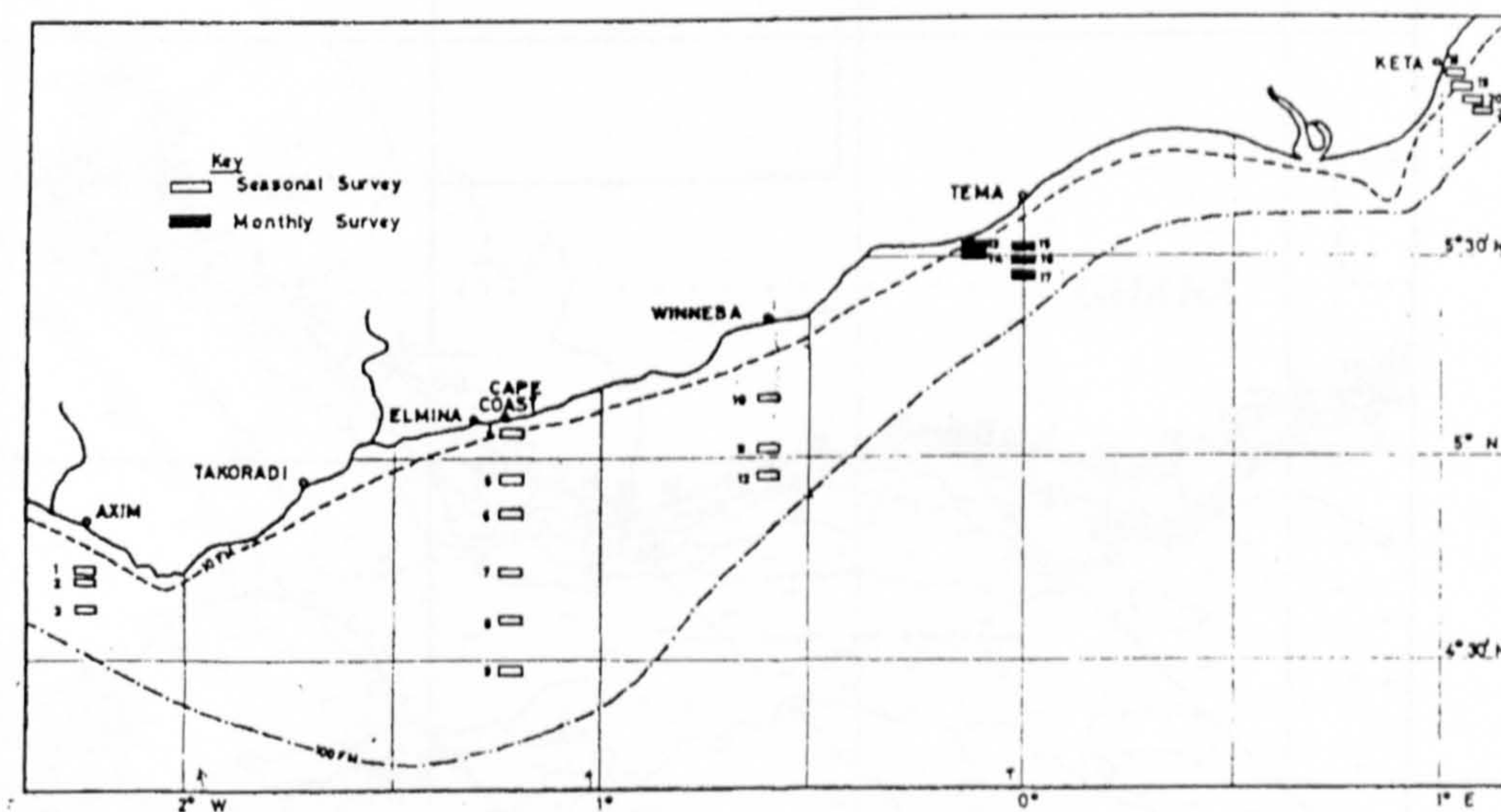
Appendix 6.1. Inventory of trawl surveys conducted in Ghana's marine waters between 1956 and 1992.

| Survey                   | Year    | Coverage           | Remarks                     |
|--------------------------|---------|--------------------|-----------------------------|
| <i>R/V Cape St. Mary</i> | 1956    | Ghana              | Limited area                |
| <i>Birkut</i>            | 1961    | Guinea - Ghana     | 14 hauls in Ghanaian waters |
| GTS                      | 1963-64 | West Africa        | 7 transects off Ghana       |
| MFRD 1                   | 1969-70 | Ghana              | Rijavec (1980)              |
| MFRD 1B                  | 1973-77 | Ghana              | Sporadic sampling           |
| MFRD 2                   | 1979-80 | Ghana              | Koranteng (1981)            |
| MFRD A                   | 1980    | Ghana              | Survey discontinued         |
| MFRD 3                   | 1981-82 | Ghana              | Koranteng (1984)            |
| MFRD B                   | 1983-84 | Ghana              | Survey discontinued         |
| MFRD 4                   | 1987-88 | Ghana              |                             |
| MFRD 5                   | 1989    | Ghana              |                             |
| MFRD 6                   | 1990    | Ghana              |                             |
| Guinea-90                | 1990    | Sierra Leone-Ghana | 6 transects off Ghana       |
| MFRD 7                   | 1991-92 | Ghana              | Limited to Accra sector     |



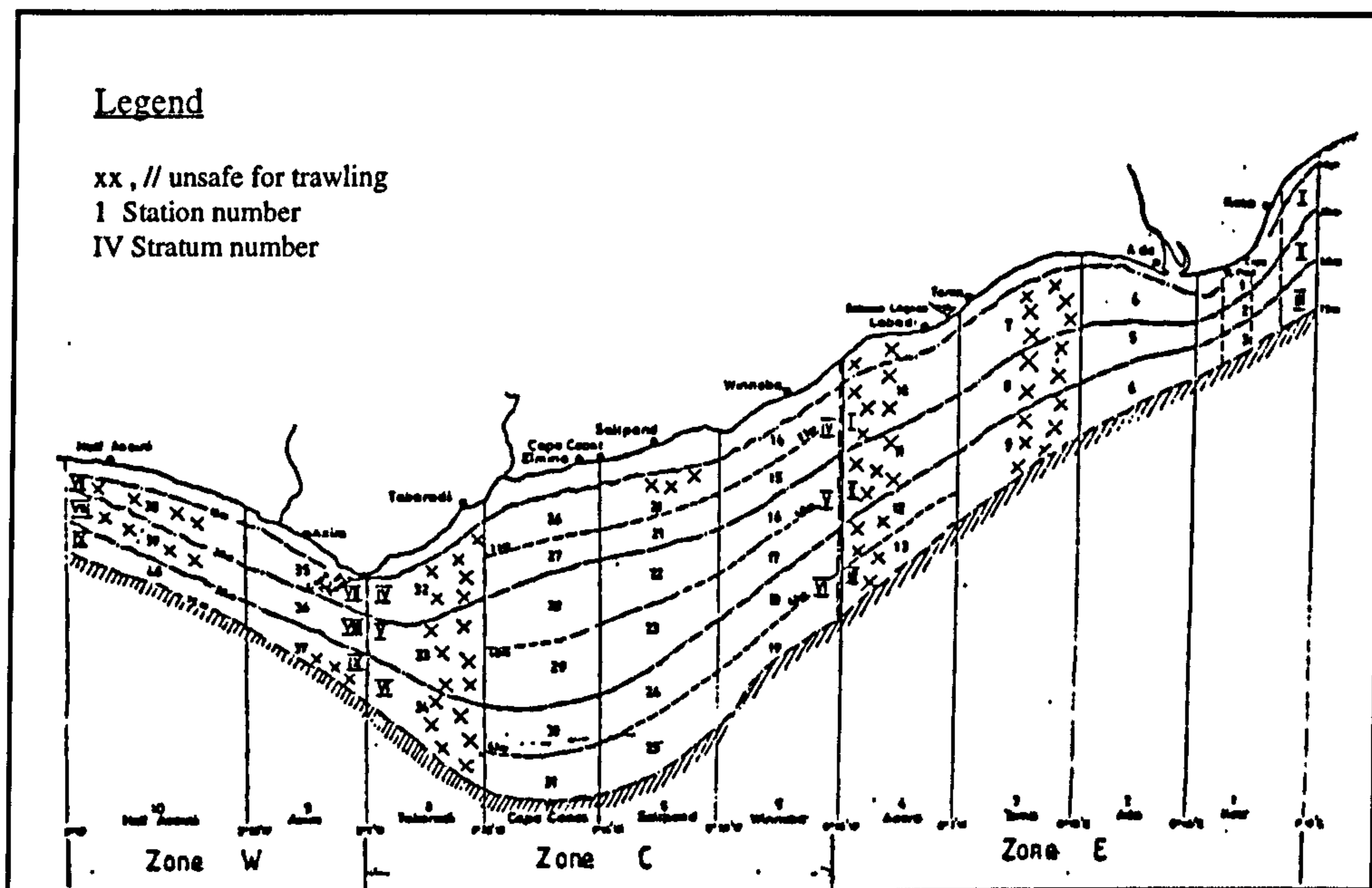


Appendix 6.2: GTS transects and statistical areas (from Williams 1968)

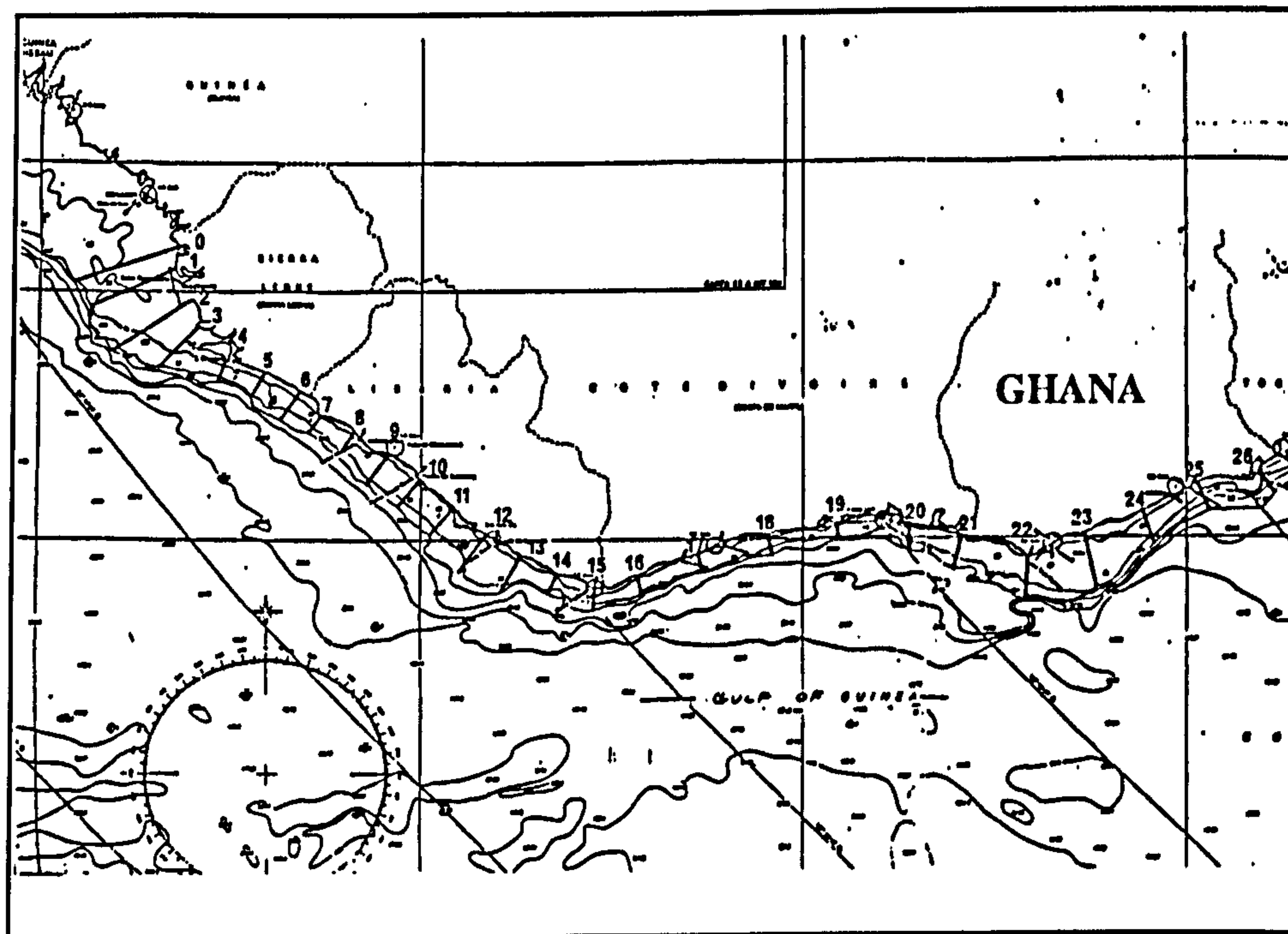


Appendix 6.3: Sampling design of the MFRD surveys of 1969 - 1980 (from Rijavec 1980)

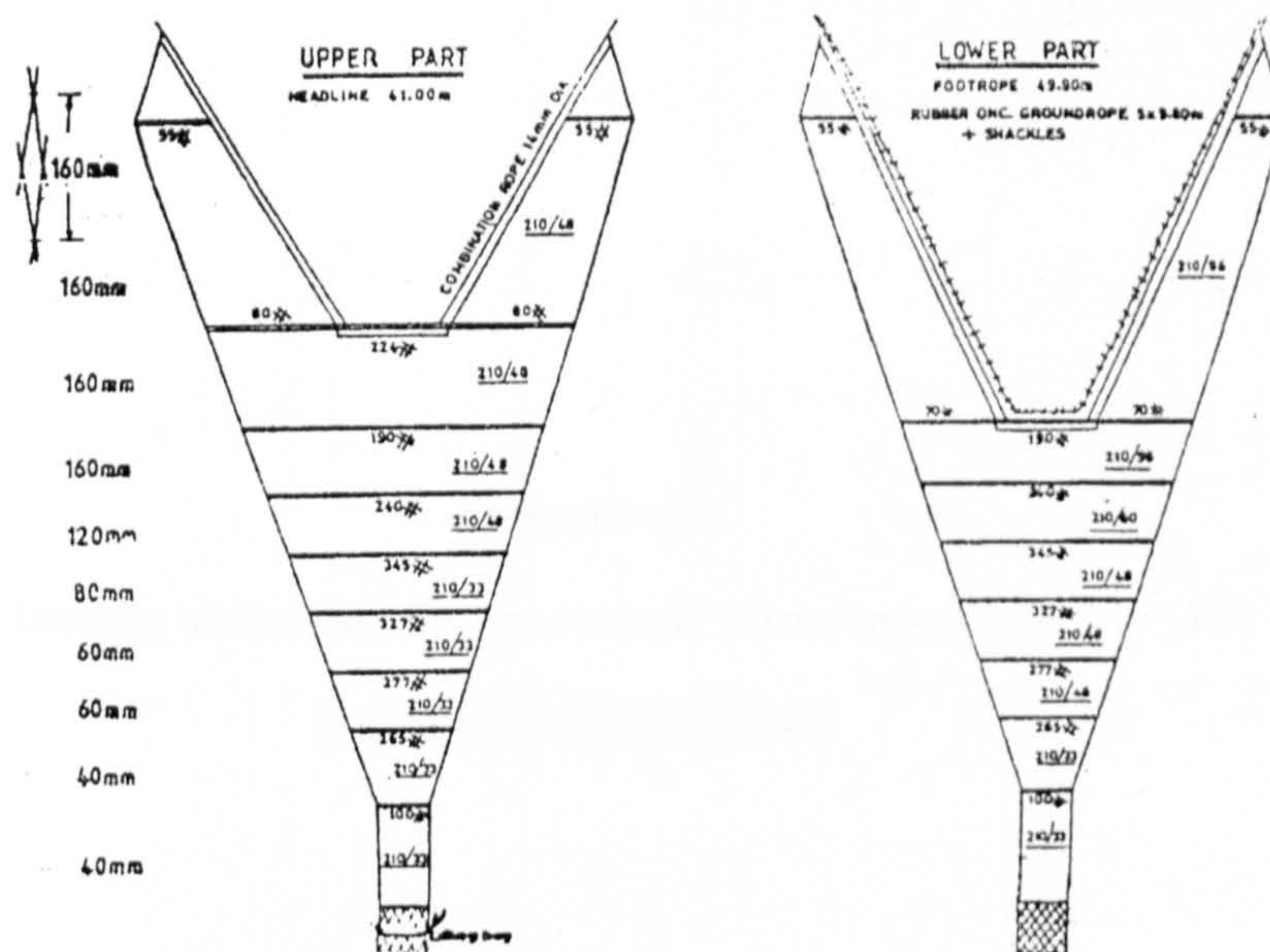




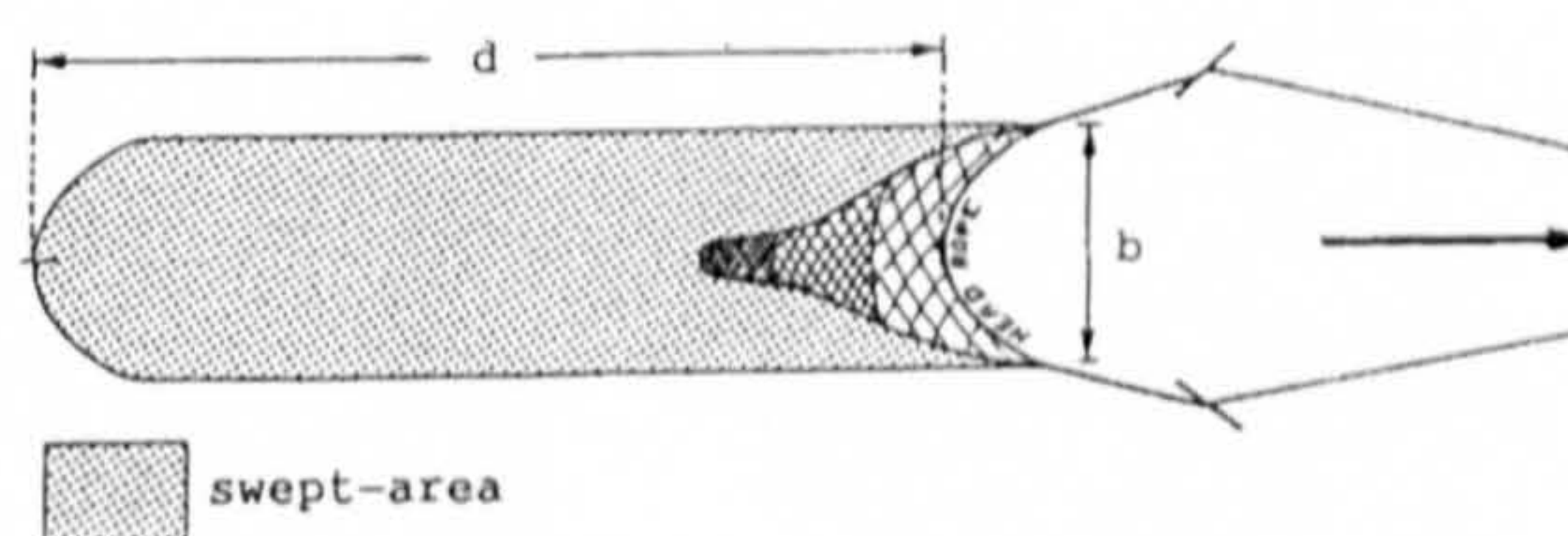
Appendix 6.4: Sampling design of the MFRD surveys of 1980 - 1992  
 (from Koranteng 1984)



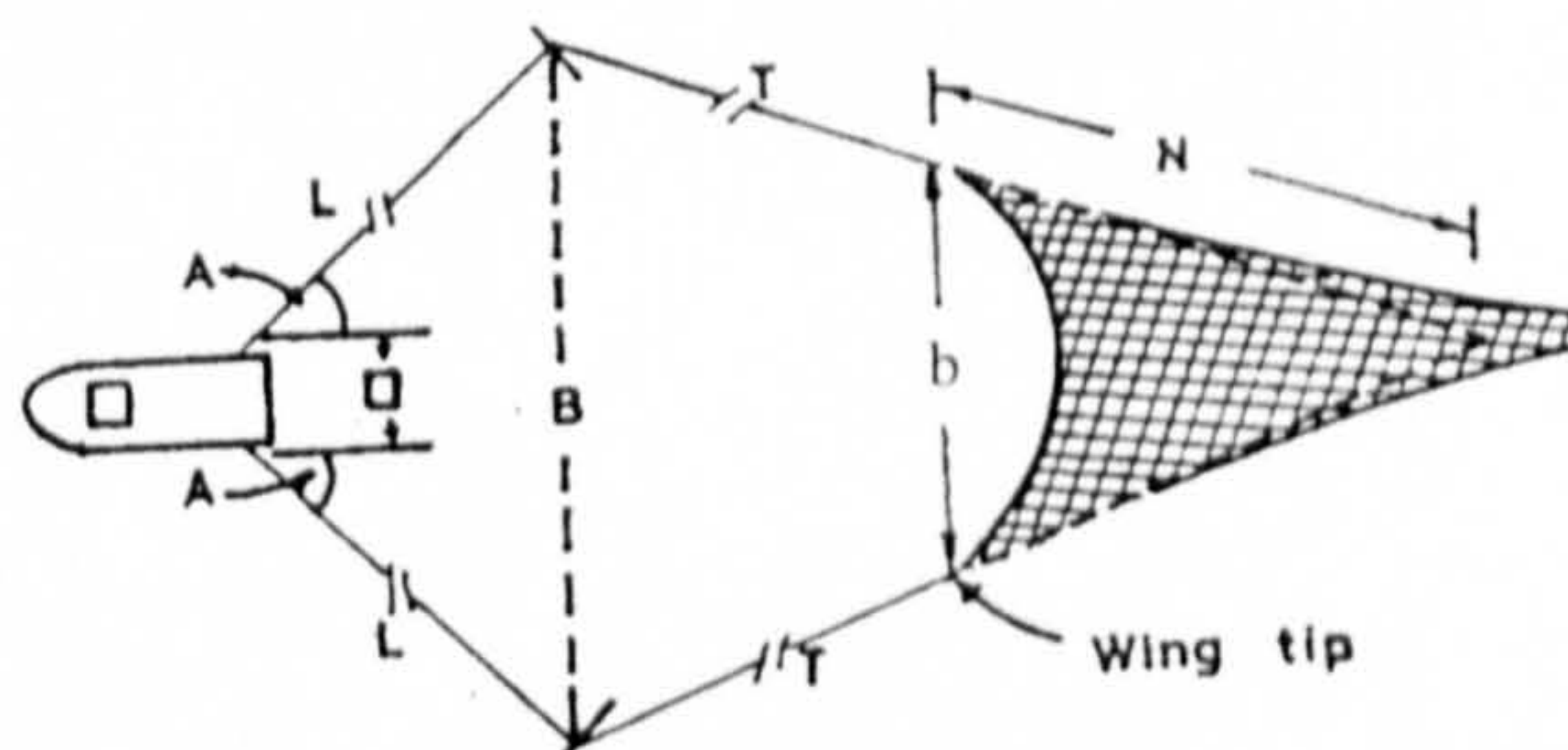
Appendix 6.5: Guinea 90 transects and areas; transects 21 - 26 are in Ghanaian waters  
 (from Ramos *et al.* 1990)



Appendix 6.6: Design of the Engel high-opening trawl net used in the MFRD surveys (from Koranteng 1984)



Appendix 6.7: Figure to illustrate swept area of trawl net (from Stromme 1992)



Appendix 6.8: Schematic illustration of Dinglassan's method of estimating wing spread of the survey net (from Dinglassan 1973)



**Appendix 6.9:**

**Total landings of demersal fish species from Ghanaian waters 1960 - 1994**

**Source: FAO FISHSTAT PC**

| SPECIES                             | Common English name            | 1960  | 1961  | 1962  | 1963  | 1964  | 1965  | 1966  | 1967  | 1968  | 1969  | 1970  | 1971  |
|-------------------------------------|--------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| <i>Ariidae</i>                      | Sea catfishes nei              | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Balistidae</i>                   | Triggerfishes, durgons         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Brachydeuterus auritus</i>       | Bigeye grunt                   | 600   | 600   | 700   | 2800  | 2200  | 8000  | 7500  | 400   | 4400  | 8200  | 5700  | 7800  |
| <i>Cynoglossidae</i>                | Tonguefishes nei               | 200   | 600   | 700   | 3400  | 0     | 1700  | 1500  | 300   | 600   | 900   | 400   | 600   |
| <i>Dentex angolensis</i>            | Angolan dentex                 | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Dentex congoensis</i>            | Congo dentex                   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Dentex spp</i>                   | Dentex nei                     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Drepane africana</i>             | African sicklefish             | 0     | 0     | 0     | 0     | 0     | 3400  | 3400  | 300   | 100   | 1100  | 600   | 500   |
| <i>Elasmobranchii</i>               | Sharks, rays, skates, etc      | 0     | 300   | 100   | 800   | 100   | 1100  | 900   | 200   | 800   | 1400  | 900   | 400   |
| <i>Epinephelus spp</i>              | Groupers nei                   | 1000  | 1300  | 600   | 1000  | 300   | 2100  | 0     | 100   | 100   | 700   | 1600  | 300   |
| <i>Haemulidae</i>                   | Grunts, sweetlips, nei         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Lutjanus spp</i>                 | Snappers nei                   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 100   | 900   | 1700  | 400   |
| <i>Merluccius senegalensis</i>      | Senegalese hake                | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Natantia</i>                     | Natantian decapods nei         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 200   | 300   | 600   | 300   | 500   |
| <i>Octopodidae</i>                  | Octopuses                      | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Pagellus bellottii bellottii</i> | Red pandora                    | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Panulirus spp</i>                | Tropical spiny lobsters nei    | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 100   | 700   | 500   | 300   |
| <i>Perciformes</i>                  | Demersal percomorphs nei       | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Polynemidae</i>                  | Threadfins, tasselfishes nei   | 500   | 700   | 700   | 5300  | 4500  | 6300  | 7700  | 800   | 1700  | 1700  | 2200  | 2600  |
| <i>Pseudopenaeus prayensis</i>      | West African goatfish          | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Pseudotolithus spp</i>           | West African croakers          | 800   | 800   | 900   | 6400  | 2300  | 9300  | 9000  | 2000  | 2100  | 2700  | 2300  | 2100  |
| <i>Rajiformes</i>                   | Skates and rays, nei           | 600   | 600   | 100   | 2900  | 2300  | 3700  | 4300  | 200   | 600   | 900   | 600   | 600   |
| <i>Reptantia</i>                    | Marine crabs nei               | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Selene dorsalis</i>              | African moonfish               | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Sepiidae, Sepiolidae</i>         | Cuttlefishes, bobtail squids   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Soleidae</i>                     | Soles nei                      | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Sparidae</i>                     | Porgies, seabreams, nei        | 1700  | 1900  | 3600  | 7700  | 7100  | 3500  | 1200  | 5100  | 2800  | 8000  | 11300 | 6500  |
| <i>Sparus(=Pagrus) spp.</i>         | Pargo breams, nei              | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| <i>Sphyræna spp</i>                 | Barracudas                     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 2900  | 1400  | 2100  | 1400  |
| <i>Trichiurus lepturus</i>          | Largehead hairtail             | 400   | 1000  | 1000  | 1500  | 1000  | 1000  | 1000  | 1000  | 2000  | 2100  | 2300  | 3000  |
| <i>Triglidae</i>                    | Gurnards, searobins nei        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
|                                     | Marine fishes nei              | 6800  | 5900  | 9500  | 9400  | 13500 | 3500  | 15600 | 15400 | 10700 | 11900 | 13700 | 8000  |
|                                     | TOTAL                          | 12600 | 13700 | 17900 | 41200 | 33300 | 48600 | 52100 | 26000 | 29300 | 43200 | 46200 | 35000 |
|                                     | Total (excl marine fishes nei) | 5800  | 7800  | 8400  | 31800 | 19800 | 40100 | 36500 | 10600 | 18600 | 31300 | 32500 | 27000 |
|                                     | Demersal (excl. Triggerfish)   | 5800  | 7800  | 8400  | 31800 | 19800 | 40100 | 36500 | 10600 | 18600 | 31300 | 32500 | 27000 |



| Common English name            | 1972  | 1973  | 1974  | 1975  | 1976  | 1977  | 1978  | 1979  | 1980  | 1981  | 1982  | 1983  | 1984  | 1985  | 1986  |
|--------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Sea catfishes nei              | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 22    | 30    | 2     | 68    |
| Triggerfishes, durgons         | 3000  | 4900  | 7688  | 8773  | 8940  | 9685  | 9389  | 13326 | 8225  | 6198  | 7121  | 5536  | 6992  | 6104  | 18610 |
| Bigeye grunt                   | 10700 | 11000 | 13621 | 11987 | 10513 | 9775  | 13451 | 15010 | 9323  | 5981  | 12524 | 10099 | 17370 | 13886 | 22032 |
| Tonguefishes nei               | 900   | 600   | 1345  | 1805  | 147   | 531   | 234   | 408   | 141   | 87    | 306   | 409   | 433   | 197   | 400   |
| Angolan dentex                 | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 494   |
| Congo dentex                   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 82    |
| Dentex nei                     | 0     | 0     | 0     | 780   | 190   | 3314  | 4518  | 4033  | 2180  | 2398  | 2241  | 588   | 1128  | 2039  | 1378  |
| African sicklefish             | 700   | 500   | 114   | 41    | 0     | 54    | 49    | 83    | 98    | 20    | 94    | 19    | 66    | 13    | 1023  |
| Sharks, rays, skates, etc      | 200   | 1000  | 2399  | 6473  | 689   | 628   | 206   | 1012  | 754   | 531   | 905   | 265   | 489   | 802   | 510   |
| Groupers nei                   | 200   | 100   | 116   | 17    | 1058  | 2176  | 700   | 1186  | 1516  | 1276  | 1312  | 367   | 463   | 1014  | 1002  |
| Grunts, sweetlips, nei         | 0     | 0     | 0     | 1432  | 1429  | 845   | 2415  | 595   | 809   | 943   | 661   | 665   | 722   | 360   | 932   |
| Snappers nei                   | 600   | 500   | 408   | 161   | 194   | 196   | 212   | 361   | 145   | 526   | 284   | 194   | 373   | 644   | 488   |
| Senegalese hake                | 200   | 0     | 434   | 516   | 16    | 0     | 0     | 0     | 42    | 2     | 0     | 0     | 2     | 5     | 0     |
| Natanian decapods nei          | 600   | 400   | 670   | 413   | 726   | 643   | 423   | 202   | 585   | 490   | 339   | 332   | 217   | 508   | 553   |
| Octopuses                      | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 8     | 0     | 0     | 0     | 0     | 0     | 0     |
| Red pandora                    | 0     | 0     | 0     | 4676  | 2722  | 5988  | 10297 | 10681 | 8391  | 12408 | 11475 | 3854  | 8228  | 4286  | 5190  |
| Tropical spiny lobsters nei    | 400   | 0     | 17    | 21    | 10    | 26    | 420   | 231   | 109   | 168   | 176   | 128   | 204   | 133   | 555   |
| Demersal percomorphs nei       | 0     | 0     | 0     | 0     | 0     | 0     | 130   | 720   | 129   | 145   | 442   | 135   | 128   | 114   | 424   |
| Threadfins, tasselfishes nei   | 3400  | 2200  | 1818  | 317   | 1136  | 3529  | 3524  | 4982  | 3161  | 1695  | 4093  | 1362  | 1761  | 2582  | 3779  |
| West African goatfish          | 500   | 600   | 365   | 285   | 188   | 408   | 1396  | 983   | 734   | 708   | 798   | 344   | 499   | 360   | 1152  |
| West African croakers          | 4200  | 3100  | 2195  | 2073  | 1621  | 2116  | 1684  | 2453  | 1688  | 1214  | 1956  | 1039  | 1072  | 1199  | 2370  |
| Skates and rays, nei           | 1200  | 1000  | 1483  | 5005  | 1736  | 373   | 787   | 645   | 455   | 365   | 581   | 772   | 632   | 333   | 219   |
| Marine crabs nei               | 0     | 0     | 0     | 10    | 6     | 1     | 0     | 18    | 0     | 5     | 9     | 31    | 10    | 22    | 5     |
| African moonfish               | 600   | 1000  | 1650  | 793   | 111   | 7112  | 2192  | 1950  | 828   | 1537  | 1329  | 4737  | 2514  | 2489  | 5352  |
| Cuttlefishes, bobtail squids   | 0     | 0     | 0     | 584   | 795   | 685   | 700   | 255   | 697   | 545   | 1355  | 1642  | 1844  | 2014  | 1355  |
| Soles nei                      | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| Porgies, seabreams, nei        | 9200  | 6700  | 4896  | 1249  | 590   | 0     | 0     | 0     | 0     | 0     | 0     | 3090  | 125   | 2661  | 2073  |
| Pargo breams, nei              | 0     | 0     | 0     | 1850  | 796   | 3002  | 824   | 754   | 799   | 1467  | 668   | 828   | 2106  | 827   | 722   |
| Barracudas                     | 2200  | 2900  | 2099  | 1713  | 199   | 3010  | 1564  | 1008  | 1396  | 1620  | 1140  | 1240  | 822   | 637   | 1803  |
| Largehead hairtail             | 2100  | 1200  | 2224  | 2187  | 2284  | 7221  | 1724  | 2646  | 3436  | 1682  | 2941  | 2828  | 830   | 2597  | 2255  |
| Gurnards, searobins nei        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| Marine fishes nei              | 5100  | 4800  | 7148  | 31987 | 6405  | 1494  | 2451  | 2566  | 7567  | 12511 | 3757  | 4840  | 4118  | 3946  | 3574  |
| TOTAL                          | 46000 | 42500 | 50690 | 85148 | 42501 | 62812 | 59290 | 66108 | 53216 | 54522 | 56507 | 45366 | 53178 | 49774 | 78400 |
| Total (excl marine fishes nei) | 40900 | 37700 | 43542 | 53161 | 36096 | 61318 | 56839 | 63542 | 45649 | 42011 | 52750 | 40526 | 49060 | 45828 | 74826 |
| Demersal (excl. Triggerfish    | 37900 | 32800 | 35854 | 44388 | 27156 | 51633 | 47450 | 50216 | 37424 | 35813 | 45629 | 34990 | 42068 | 39724 | 56216 |

| Common English name            | 1987  | 1988  | 1989  | 1990  | 1991  | 1992  | 1993  | 1994  |
|--------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Sea catfishes nei              | 10    | 10    | 2     | 1     | 2     | 0     | 2     | 0     |
| Triggerfishes, durgons         | 18283 | 3033  | 612   | 25    | 8     | 198   | 9     | 11    |
| Bigeye grunt                   | 16627 | 11114 | 9727  | 20278 | 11670 | 11024 | 11940 | 18216 |
| Tonguefishes nei               | 557   | 265   | 309   | 272   | 427   | 195   | 247   | 231   |
| Angolan dentex                 | 0     | 422   | 59    | 405   | 261   | 284   | 428   | 183   |
| Congo dentex                   | 0     | 111   | 36    | 180   | 98    | 151   | 364   | 112   |
| Dentex nei                     | 1757  | 4443  | 1652  | 1714  | 1010  | 840   | 1192  | 813   |
| African sicklefish             | 67    | 121   | 19    | 59    | 7     | 18    | 20    | 7     |
| Sharks, rays, skates, etc      | 1632  | 1893  | 1845  | 1347  | 951   | 914   | 1981  | 1171  |
| Groupers nei                   | 800   | 2030  | 1496  | 1035  | 470   | 225   | 385   | 169   |
| Grunts, sweetlips, nei         | 1285  | 995   | 581   | 526   | 543   | 449   | 659   | 575   |
| Snappers nei                   | 948   | 1507  | 1298  | 975   | 842   | 635   | 895   | 716   |
| Senegalese hake                | 2     | 2     | 1     | 2     | 1     | 0     | 0     | 0     |
| Natantian decapods nei         | 1602  | 1177  | 1509  | 2637  | 1204  | 2236  | 1148  | 1507  |
| Octopuses                      | 309   | 0     | 76    | 139   | 147   | 334   | 43    | 73    |
| Red pandora                    | 7789  | 8533  | 8777  | 5870  | 5315  | 8724  | 7915  | 5635  |
| Tropical spiny lobsters nei    | 754   | 173   | 173   | 130   | 71    | 218   | 369   | 510   |
| Demersal percormorphs nei      | 857   | 307   | 343   | 614   | 321   | 300   | 0     | 0     |
| Threadfins, tasselfishes nei   | 3313  | 1781  | 1817  | 1663  | 2433  | 1826  | 2120  | 3247  |
| West African goatfish          | 737   | 441   | 765   | 570   | 470   | 247   | 163   | 190   |
| West African croakers          | 2379  | 2369  | 1414  | 1602  | 1557  | 2340  | 1301  | 1104  |
| Skates and rays, nei           | 980   | 525   | 484   | 232   | 189   | 231   | 272   | 296   |
| Marine crabs nei               | 239   | 238   | 37    | 322   | 86    | 75    | 195   | 462   |
| African moonfish               | 4555  | 2594  | 2049  | 1357  | 946   | 1202  | 882   | 501   |
| Cuttlefishes, bobtail squids   | 1867  | 1726  | 2776  | 1981  | 3566  | 1541  | 1673  | 2396  |
| Soles nei                      | 0     | 0     | 0     | 0     | 0     | 28    | 0     | 0     |
| Porgies, seabreams, nei        | 1072  | 508   | 92    | 58    | 160   | 239   | 443   | 165   |
| Pargo breams, nei              | 718   | 1239  | 1887  | 2283  | 1214  | 1200  | 1862  | 834   |
| Barracudas                     | 3773  | 3552  | 1485  | 2633  | 2229  | 1753  | 1970  | 1095  |
| Largehead hairtail             | 2157  | 1480  | 1740  | 1519  | 1789  | 4341  | 1445  | 1140  |
| Gurnards, searobins nei        | 0     | 0     | 0     | 22    | 6     | 7     | 140   | 14    |
| Marine fishes nei              | 5523  | 3778  | 19575 | 20100 | 31441 | 18840 | 23855 | 19787 |
| TOTAL                          | 80592 | 56367 | 62636 | 70551 | 69434 | 60615 | 63918 | 61160 |
| Total (excl marine fishes nei) | 75069 | 52589 | 43061 | 50451 | 37993 | 41775 | 40063 | 41373 |
| Demersal (excl. Triggerfish    | 56786 | 49556 | 42449 | 50426 | 37985 | 41577 | 40054 | 41362 |



Appendix 6.10: Small-sized inshore and industrial trawler catch and effort data used for the estimation of 'expected effort' for fitting the Schaefer model

|      | Small-sized inshore trawlers |          |          |        | Industrial trawlers |          |          |        |
|------|------------------------------|----------|----------|--------|---------------------|----------|----------|--------|
| Year | TOTAL                        | Balistes | Demersal | Effort | TOTAL               | Balistes | Demersal | Effort |
| 1972 | 4199.0                       | 2846.6   | 1352.4   | 14144  | 5307.9              | 0.0      | 5307.9   |        |
| 1973 | 5623.3                       | 4603.5   | 1019.8   | 14350  | 2576.7              | 0.0      | 2576.7   |        |
| 1974 | 6736.9                       | 5572.0   | 1164.8   | 14130  | 720.9               | 11.9     | 709.0    | 413    |
| 1975 | 9260.5                       | 8169.5   | 1091.0   | 13456  | 436.0               | 211.5    | 224.5    | 101    |
| 1976 | 8642.3                       | 7747.3   | 895.0    | 10269  | 591.1               | 103.8    | 487.3    | 80     |
| 1977 | 7765.4                       | 6671.8   | 1093.6   | 9726   | 1440.8              | 0.0      | 1440.8   | 689    |
| 1978 | 6152.7                       | 5306.8   | 845.9    | 11376  | 3638.4              | 844.4    | 2794.0   | 1211   |
| 1979 | 11020.8                      | 9751.6   | 1269.2   | 13109  | 3317.9              | 299.2    | 3018.8   | 1379   |
| 1980 | 6071.8                       | 5272.9   | 798.8    | 12865  | 1038.1              | 185.7    | 852.4    | 859    |
| 1981 | 5540.8                       | 4891.5   | 649.2    | 10657  | 2922.0              | 317.0    | 2605.0   | 1454   |
| 1982 | 5540.8                       | 4891.5   | 649.2    | 7802   | 4816.8              | 230.2    | 4586.6   | 1515   |
| 1983 | 4194.4                       | 3354.5   | 839.9    | 8738   | 5148.9              | 19.5     | 5129.3   | 1998   |
| 1984 | 3693.1                       | 3401.5   | 291.7    | 5002   | 3500.2              | 96.5     | 3403.7   | 1823   |
| 1985 | 7117.6                       | 6853.4   | 264.2    | 7625   | 7012.1              | 284.7    | 6727.5   | 2300   |
| 1986 | 7117.6                       | 6853.4   | 264.2    | 8878   | 5723.8              | 28.0     | 5695.8   | 2988   |
| 1987 | 5832.6                       | 5166.6   | 666.0    | 10520  | 5932.2              | 213.2    | 5719.1   | 3656   |
| 1988 | 2713.5                       | 2229.4   | 484.1    | 9360   | 4120.7              | 36.3     | 4084.4   | 2633   |
| 1989 | 1140.8                       | 26.0     | 1114.8   | 9733   | 6104.4              | 4.9      | 6099.5   | 4481   |
| 1990 | 938.3                        | 0.6      | 937.7    | 8691   | 6494.0              | 0.0      | 6494.0   | 5593   |
| 1991 | 992.7                        | 0.4      | 992.3    | 4205   | 4782.9              | 0.0      | 4782.9   | 5326   |
| 1992 |                              |          |          |        | 5116.4              | 1.2      | 5115.2   | 4088   |
| 1993 |                              |          |          |        | 4917.1              | 1.4      | 4915.7   | 3532   |
| 1994 |                              |          |          |        | 5582.8              | 0.6      | 5582.2   | 4854   |

## **Appendices 6.11.1 - 6.11.9:**

**Output of swept area analysis from the NAN-SIS program**



## 6.11.1 GTS, 1963 - 64

| SPECIES NAME                 | SAMPLE DISTRIB. BY CATCH CLASSES |    |    |     |     |      | t inci-<br>dence | Mean<br>dens.<br>t/nm² | Mean densities by bottom depth strata t/nm² |         |         |          |
|------------------------------|----------------------------------|----|----|-----|-----|------|------------------|------------------------|---|---------|---------|----------|
|                              | Lower limits, Kg/nm              |    |    |     |     |      |                  |                        | 10- 30m                                     | 30- 50m | 50-100m | 100-600m |
|                              | >0                               | 10 | 30 | 100 | 300 | 1000 |                  |                        |   |         |         |          |
| Brachydeuterus auritus       | 24                               | 5  | 6  | 2   | 2   |      | 43               | 1.69                   | 5.06  | 1.34    | 0.18    |          |
| Pagellus bellottii           | 30                               | 22 | 13 | 1   |     |      | 73               | 1.38                   | 1.01  | 2.79    | 1.31    | 0.15     |
| Dentex congoensis            | 19                               | 10 | 6  | 1   |     |      | 40               | 0.84                   |   | 0.04    | 2.19    | 1.25     |
| Paracubiceps ledanosi        | 16                               | 6  | 5  | 2   |     |      | 32               | 0.78                   |   | 0.01    | 0.64    | 2.01     |
| Priacanthus arenatus         | 55                               | 6  | 2  | 1   |     |      | 70               | 0.65                   | 0.14  | 0.51    | 1.44    | 0.52     |
| MISCELLANEOUS                | 37                               | 1  |    | 2   |     |      | 42               | 0.63                   | 0.23  | 0.10    | 1.99    | 0.19     |
| Sparus caeruleostictus       | 35                               | 16 |    |     |     |      | 56               | 0.43                   | 0.57  | 0.88    | 0.17    |          |
| Epinephelus aeneus           | 41                               | 11 |    |     |     |      | 57               | 0.37                   | 0.12  | 0.63    | 0.60    | 0.09     |
| Loligo sp                    | 44                               | 4  | 3  |     |     |      | 56               | 0.35                   | 0.48  | 0.15    | 0.08    | 0.73     |
| Dentex angolensis            | 25                               | 5  | 2  |     |     |      | 35               | 0.34                   |   | 0.02    | 1.09    | 0.26     |
| Pseudupeneus prayensis       | 44                               | 6  |    |     |     |      | 55               | 0.29                   | 0.26  | 0.60    | 0.26    |          |
| Antigonia capros             | 8                                | 3  | 3  |     |     |      | 15               | 0.25                   |   |         | 0.11    | 1.03     |
| Galeoides decadactylus       | 10                               | 4  | 1  |     |     |      | 16               | 0.22                   | 0.78  | 0.07    |         |          |
| Pseudotolithus senegalensis  | 10                               | 1  | 2  |     |     |      | 14               | 0.21                   | 0.82  | 0.01    |         |          |
| Boops boops                  | 31                               | 7  |    |     |     |      | 42               | 0.19                   |   | 0.08    | 0.48    | 0.23     |
| Squalus fernandinus *        | 4                                |    | 1  | 1   |     |      | 7                | 0.18                   |   |         |         | 0.81     |
| Pentheroscion mbizi          | 14                               | 3  | 1  |     |     |      | 20               | 0.18                   |   | 0.02    | 0.23    | 0.54     |
| Dentex canariensis           | 39                               | 3  |    |     |     |      | 46               | 0.15                   | 0.19  | 0.28    | 0.10    | 0.01     |
| Raja miraletus               | 64                               | 3  |    |     |     |      | 74               | 0.15                   | 0.18  | 0.28    | 0.08    | 0.02     |
| Dentex gibbosus              | 37                               |    | 1  |     |     |      | 42               | 0.14                   | 0.03  | 0.06    | 0.17    | 0.35     |
| Smaris macrolepidotus        | 16                               |    | 1  |     |     |      | 19               | 0.13                   |   |         | 0.02    | 0.56     |
| Sphyræna sp                  | 22                               |    | 1  |     |     |      | 25               | 0.10                   | 0.33  | 0.06    | 0.01    |          |
| Paragaleus pectoralis        | 11                               |    | 1  |     |     |      | 13               | 0.10                   | 0.01  | 0.02    |         | 0.43     |
| Drepane africana/punctata    | 7                                | 4  |    |     |     |      | 12               | 0.10                   | 0.21  | 0.07    |         |          |
| Dactylopterus volitans       | 40                               |    |    |     |     |      | 44               | 0.10                   | 0.13  | 0.24    | 0.04    |          |
| Chlorophthalmus atlanticus   | 6                                | 3  |    |     |     |      | 10               | 0.08                   |   |         |         | 0.34     |
| Hypoclydonia bella           | 3                                | 2  |    |     |     |      | 5                | 0.08                   |   |         |         | 0.36     |
| Serranus africana            |                                  |    | 1  |     |     |      | 1                | 0.07                   |   |         |         | 0.30     |
| Pseudotolithus brachygnathus | 1                                |    | 1  |     |     |      | 2                | 0.07                   | 0.28  |         |         |          |
| Lutjanus fulgens             | 22                               |    |    |     |     |      | 24               | 0.07                   | 0.06  | 0.15    | 0.04    |          |
| Lutjanus agennes             | 16                               | 2  |    |     |     |      | 20               | 0.07                   | 0.19  | 0.09    |         |          |
| Trichiurus lepturus          | 15                               | 1  |    |     |     |      | 18               | 0.06                   | 0.21  |         |         | 0.01     |
| Umbrina canariensis          | 17                               |    | 1  |     |     |      | 20               | 0.06                   |   | 0.21    | 0.02    | 0.01     |
| Paracubiceps multiequamis *  | 6                                | 4  |    |     |     |      | 11               | 0.06                   |   |         | 0.05    | 0.23     |
| Balistes punctatus           | 24                               | 1  |    |     |     |      | 27               | 0.06                   | 0.15  | 0.07    | 0.01    |          |
| Acanthurus monroviae         | 18                               |    |    |     |     |      | 20               | 0.06                   | 0.08  | 0.13    |         |          |
| Centrophorus uyato           | 1                                |    | 1  |     |     |      | 2                | 0.05                   |   |         |         | 0.25     |
| Pteroscion peli              | 5                                |    | 1  |     |     |      | 7                | 0.05                   | 0.18  |         |         |          |
| Penaeus notialis             | 22                               |    |    |     |     |      | 24               | 0.01                   | 0.01  | 0.03    | 0.01    |          |
| Plesionika sp.               | 2                                |    |    |     |     |      | 2                |                        |   |         |         |          |
| Penaeus kerathurus           | 1                                |    |    |     |     |      | 1                |                        |   |         |         |          |
| Penaeus sp                   | 5                                |    |    |     |     |      | 5                |                        |   | 0.01    |         |          |
| Parapenaeopsis atlantica     | 4                                |    |    |     |     |      | 4                |                        |   |         |         |          |
| Other fish                   |                                  |    |    |     |     |      |                  | 1.13                   | 1.81  | 1.22    | 0.69    | 1.00     |
| Sum all species              |                                  |    |    |     |     |      |                  | 11.93                  | 13.61                                       | 10.17   | 12.01   | 12.48    |
| Sum Snappers                 |                                  |    |    |     |     |      |                  | 0.16                   | 0.32  | 0.28    | 0.04    |          |
| Sum Groupers                 |                                  |    |    |     |     |      |                  | 0.50                   | 0.21  | 0.64    | 0.69    | 0.41     |
| Sum Grunts                   |                                  |    |    |     |     |      |                  |                        |   |         |         |          |
| Sum Croakers                 |                                  |    |    |     |     |      |                  | 0.62                   | 1.43  | 0.25    | 0.25    | 0.57     |
| Sum Seabreams                |                                  |    |    |     |     |      |                  | 3.53                   | 1.81  | 4.27    | 5.56    | 2.25     |
| Sum Sharks                   |                                  |    |    |     |     |      |                  | 0.41                   | 0.04  | 0.06    | 0.10    | 1.67     |
| Sum Rays                     |                                  |    |    |     |     |      |                  | 0.23                   | 0.27  | 0.45    | 0.18    | 0.04     |
| Sum Squids                   |                                  |    |    |     |     |      |                  | 0.35                   | 0.48  | 0.15    | 0.08    | 0.73     |
| Sum                          |                                  |    |    |     |     |      |                  |                        |   |         |         |          |
| Sum commercial shrimps       |                                  |    |    |     |     |      |                  | 0.01                   | 0.01  | 0.04    | 0.01    |          |

Number of stations included in analysis, total and by depth strata

91

23

25

23

20

## 6.11.2 MFRD1, 1969 - 70

| SPECIES NAME               | SAMPLE DISTRIB. BY CATCH CLASSES |    |    |     |          | % inci-<br>dence | Mean<br>dens.<br>t/nm² | Mean densities by bottom depth strata t/nm² |         |         |          |
|----------------------------|----------------------------------|----|----|-----|----------|------------------|------------------------|---|---------|---------|----------|
|                            | Lower limits, Kg/nm              |    |    |     |          |                  |                        | 10- 30m                                     | 30- 50m | 50-100m | 100-200m |
|                            | >0                               | 10 | 30 | 100 | 300 1000 |                  |                        |   |         |         |          |
| Brachydeuterus auritus     | 43                               | 13 | 2  | 2   | 2        | 37               | 1.23                   | 1.80  | 0.35    | 1.80    |          |
| Chromis lineatus           | 27                               | 4  | 4  | 4   | 1        | 24               | 0.88                   |   | 0.22    | 2.91    |          |
| Pagellus bellottii         | 121                              | 25 | 6  |     |          | 90               | 0.72                   | 0.44  | 0.73    | 1.04    |          |
| Dentex canariensis         | 81                               | 28 | 4  |     |          | 66               | 0.64                   | 0.06  | 0.73    | 1.23    |          |
| Sepia sp                   | 127                              | 14 | 2  | 1   |          | 86               | 0.60                   | 1.12  | 0.42    | 0.22    |          |
| Sparus caeruleostictus     | 125                              | 20 |    |     |          | 86               | 0.50                   | 0.16  | 0.62    | 0.76    |          |
| Dactylopterus volitans     | 84                               | 11 | 4  | 1   |          | 60               | 0.46                   | 0.08  | 0.94    | 0.24    |          |
| Pseudupeneus prayensis     | 111                              | 8  | 1  |     |          | 71               | 0.32                   | 0.11  | 0.42    | 0.44    |          |
| Balistes capricornus       | 68                               | 3  | 5  |     |          | 44               | 0.31                   | 0.27  | 0.53    | 0.03    |          |
| Epinephelus aeneus         | 58                               | 13 | 1  |     |          | 43               | 0.28                   | 0.03  | 0.12    | 0.80    |          |
| MISCELLANEOUS              | 142                              | 3  | 1  |     |          | 87               | 0.28                   | 0.16  | 0.28    | 0.43    |          |
| Galeoides decadactylus     | 20                               | 1  | 1  | 1   |          | 14               | 0.19                   | 0.54  | 0.02    |         |          |
| Sphyræna guachancho        | 41                               | 4  | 2  |     |          | 28               | 0.15                   | 0.10  | 0.03    | 0.39    |          |
| Boops boops                | 21                               | 3  | 2  |     |          | 15               | 0.15                   | 0.01  |         | 0.51    |          |
| Diagramma mediterraneus    | 39                               | 2  | 2  |     |          | 26               | 0.14                   |   | 0.28    | 0.11    |          |
| Lutjanus fulgens           | 45                               | 6  |    |     |          | 30               | 0.13                   |   | 0.16    | 0.25    |          |
| Priacanthus arenatus       | 57                               | 1  | 1  |     |          | 35               | 0.12                   | 0.02  | 0.04    | 0.35    |          |
| Acanthurus monroviae       | 32                               | 5  | 1  |     |          | 21               | 0.12                   |   | 0.29    | 0.04    |          |
| Acanthostracion guineensis | 36                               | 6  |    |     |          | 25               | 0.11                   | 0.03  | 0.25    |         |          |
| Balistes punctatus         | 47                               | 2  |    |     |          | 29               | 0.11                   | 0.02  | 0.24    | 0.02    |          |
| Lutjanus goreensis         | 21                               |    | 1  |     |          | 13               | 0.10                   |   | 0.10    | 0.21    |          |
| Fistularia villosa         | 86                               | 2  |    |     |          | 51               | 0.10                   | 0.05  | 0.20    | 0.02    |          |
| Lethrinus atlanticus       | 55                               | 1  |    |     |          | 33               | 0.09                   | 0.08  | 0.15    | 0.01    |          |
| Dentex congolensis         | 18                               | 2  | 1  |     |          | 13               | 0.08                   |   | 0.01    | 0.27    |          |
| Pantheroescion mbizi       | 6                                | 5  |    |     |          | 7                | 0.08                   |   | 0.03    | 0.26    |          |
| Lutjanus agennes           | 18                               | 2  |    |     |          | 12               | 0.08                   |   | 0.13    | 0.11    |          |
| Dentex gibbosus            | 34                               | 3  |    |     |          | 22               | 0.07                   |   | 0.05    | 0.18    |          |
| Trichiurus lepturus        | 21                               | 3  |    |     |          | 14               | 0.06                   | 0.04  | 0.10    | 0.01    |          |
| Trigla gabonensis          | 63                               | 1  |    |     |          | 38               | 0.06                   | 0.01  | 0.08    | 0.08    |          |
| Paracubiceps ledanosii     | 5                                | 1  | 1  |     |          | 4                | 0.06                   |   |         | 0.21    |          |
| Pennaeus notialis          | 23                               |    |    |     |          | 14               | 0.02                   |   | 0.03    | 0.03    |          |
| Parapennaecopsis atlantica | 3                                |    |    |     |          | 2                |                        |   |         |         |          |
| Other fish                 |                                  |    |    |     |          |                  | 0.59                   | 0.49  | 0.88    | 0.47    |          |
| Sum all species            |                                  |    |    |     |          |                  | 8.83                   | 5.62  | 8.43    | 13.43   |          |
| Sum Snappers               |                                  |    |    |     |          |                  | 0.33                   |   | 0.44    | 0.58    |          |
| Sum Groupers               |                                  |    |    |     |          |                  | 0.28                   | 0.03  | 0.13    | 0.81    |          |
| Sum Grunts                 |                                  |    |    |     |          |                  |                        |   |         |         |          |
| Sum Croakers               |                                  |    |    |     |          |                  | 0.13                   | 0.07  | 0.08    | 0.20    |          |
| Sum Seabreams              |                                  |    |    |     |          |                  | 2.21                   | 0.67  | 2.20    | 4.07    |          |
| Sum Sharks                 |                                  |    |    |     |          |                  | 0.01                   | 0.01  | 0.04    |         |          |
| Sum Rays                   |                                  |    |    |     |          |                  | 0.03                   | 0.03  | 0.04    | 0.02    |          |
| Sum Squids                 |                                  |    |    |     |          |                  | 0.62                   | 1.12  | 0.45    | 0.23    |          |
| Sum                        |                                  |    |    |     |          |                  |                        |   |         |         |          |
| Sum commercial shrimps     |                                  |    |    |     |          |                  | 0.02                   |   | 0.03    | 0.03    |          |

Number of stations included in analysis, total and by depth strata

168 56 66 46



## 6.11.3 MFRD1B, 1973 - 77

| SPECIES NAME              | SAMPLE DISTRIB. BY CATCH CLASSES |    |    |     |     |      | t inci-<br>dence | Mean<br>dens.<br>t/nm <sup>2</sup> | Mean densities by bottom depth strata t/nm <sup>2</sup> |         |         |          |
|---------------------------|----------------------------------|----|----|-----|-----|------|------------------|------------------------------------|---|---------|---------|----------|
|                           | Lower limits, Kg/nm              |    |    |     |     |      |                  |                                    | 10- 20m   | 20- 50m | 50-100m | 100-200m |
|                           | >0                               | 10 | 30 | 100 | 300 | 1000 |                  |                                    |   |         |         |          |
| Balistes capricus         | 68                               | 25 | 14 | 12  | 2   |      | 78               | 3.48                               | 4.38  | 4.63    | 0.28    |          |
| Pagellus bellottii        | 77                               | 17 | 5  | 1   |     |      | 66               | 0.74                               | 0.34  | 0.59    | 1.58    |          |
| Dentex congensis          | 7                                | 1  |    | 2   | 1   |      | 7                | 0.57                               |   |         | 2.33    |          |
| Sparus caeruleostictus    | 103                              | 14 | 1  |     |     |      | 78               | 0.48                               | 0.25  | 0.57    | 0.67    |          |
| Argyrosomus sp            |                                  |    |    |     | 1   |      | 1                | 0.45                               |   |         | 1.85    |          |
| Dentex canariensis        | 89                               | 7  | 4  |     |     |      | 66               | 0.42                               | 0.15  | 0.39    | 0.87    |          |
| Pseudupeneus prayensis    | 92                               | 8  | 3  |     |     |      | 68               | 0.34                               | 0.11  | 0.47    | 0.48    |          |
| Dactylopterus volitans    | 64                               | 8  | 2  |     |     |      | 49               | 0.32                               | 0.02  | 0.70    | 0.14    |          |
| Lutjanus fulgens          | 53                               | 5  | 2  |     |     |      | 39               | 0.21                               | 0.01  | 0.29    | 0.26    |          |
| Stromateus fiatola        | 13                               |    |    | 1   |     |      | 9                | 0.19                               |   | 0.01    | 0.76    |          |
| Epinephelus aeneus        | 54                               | 6  |    |     |     |      | 39               | 0.19                               | 0.04  | 0.20    | 0.39    |          |
| Sepia sp                  | 91                               | 1  | 1  |     |     |      | 61               | 0.18                               | 0.28  | 0.11    | 0.14    |          |
| Acanthurus monroviae      | 25                               | 2  | 2  |     |     |      | 19               | 0.14                               | 0.06  | 0.15    | 0.26    |          |
| Lagocephalus laevigatus   | 64                               | 4  |    |     |     |      | 44               | 0.11                               | 0.19  | 0.10    | 0.02    |          |
| Dentex gibbosus           | 36                               | 2  | 1  |     |     |      | 26               | 0.11                               |   | 0.12    | 0.24    |          |
| Drepane africana/punctata | 16                               |    |    | 1   |     |      | 11               | 0.11                               | 0.26  | 0.04    |         |          |
| Chromis sp                | 12                               | 1  | 1  |     |     |      | 9                | 0.10                               |   |         | 0.40    |          |
| Brachydeuterus auritus    | 30                               | 3  |    |     |     |      | 22               | 0.10                               | 0.22  | 0.01    | 0.05    |          |
| Dentex angolensis         | 4                                |    | 3  |     |     |      | 5                | 0.09                               |   |         | 0.37    |          |
| Pomadourys incisus        | 15                               | 4  |    |     |     |      | 13               | 0.09                               | 0.06  | 0.12    | 0.07    |          |
| Priacanthus arenatus      | 53                               | 1  |    |     |     |      | 36               | 0.08                               | 0.01  | 0.13    | 0.09    |          |
| Fistularia sp             | 38                               | 1  | 1  |     |     |      | 26               | 0.08                               | 0.01  | 0.18    | 0.04    |          |
| Boops boops               | 14                               | 2  | 1  |     |     |      | 11               | 0.06                               | 0.01  | 0.05    | 0.15    |          |
| Apsilus fuscus            | 34                               | 2  |    |     |     |      | 24               | 0.06                               |   | 0.03    | 0.19    |          |
| Balistes punctatus        | 35                               | 2  |    |     |     |      | 24               | 0.06                               | 0.03  | 0.13    |         |          |
| Trichiurus lepturus       | 20                               |    | 1  |     |     |      | 14               | 0.05                               | 0.04  | 0.02    | 0.12    |          |
| Penaeus notialis          | 3                                |    |    |     |     |      | 2                |                                    |   |         |         |          |
| Parapanaeopsis atlantica  | 2                                |    |    |     |     |      | 1                |                                    |   |         |         |          |
| Shrimps, small, non comm. | 3                                |    |    |     |     |      | 2                |                                    |   |         |         |          |
| S H R I M P S             | 2                                |    |    |     |     |      | 1                |                                    |   |         |         |          |
| Other fish                |                                  |    |    |     |     |      |                  | 0.70                               | 0.63  | 0.64    | 0.88    |          |
| Sum all species           |                                  |    |    |     |     |      |                  | 9.51                               | 7.10  | 9.68    | 12.74   |          |
| Sum Snappers              |                                  |    |    |     |     |      |                  | 0.32                               | 0.03  | 0.39    | 0.60    |          |
| Sum Groupers              |                                  |    |    |     |     |      |                  | 0.20                               | 0.04  | 0.20    | 0.43    |          |
| Sum Grunts                |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum Croakers              |                                  |    |    |     |     |      |                  | 0.51                               | 0.05  | 0.05    | 1.89    |          |
| Sum Seabreams             |                                  |    |    |     |     |      |                  | 3.48                               | 0.76  | 1.72    | 6.23    |          |
| Sum Sharks                |                                  |    |    |     |     |      |                  | 0.03                               |   | 0.03    | 0.08    |          |
| Sum Rays                  |                                  |    |    |     |     |      |                  | 0.09                               | 0.17  | 0.03    | 0.05    |          |
| Sum Squids                |                                  |    |    |     |     |      |                  | 0.20                               | 0.28  | 0.15    | 0.16    |          |
| Sum                       |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum commercial shrimps    |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |

Number of stations included in analysis, total and by depth strata

182 55 60 37

## 6.11.4 MFRD2, 1979 - 80

| SPECIES NAME                       | SAMPLE DISTRIB. BY CATCH CLASSES |    |    |     |     |      | t inci-<br>dence | Mean<br>dens.<br>t/nm <sup>2</sup> | Mean densities by bottom depth strata t/nm <sup>2</sup> |         |         |          |  |
|------------------------------------|----------------------------------|----|----|-----|-----|------|------------------|------------------------------------|---|---------|---------|----------|--|
|                                    | Lower limits, Kg/nm              |    |    |     |     |      |                  |                                    | 10- 30m   | 30- 50m | 50-100m | 100-200m |  |
|                                    | >0                               | 10 | 30 | 100 | 300 | 1000 |                  |                                    |   |         |         |          |  |
| <i>Balistes capricus</i>           | 56                               | 28 | 26 | 9   | 8   | 8    | 89               | 15.22                              | 16.93   | 20.81   | 0.38    | 0.01     |  |
| <i>Brachydeuterus auritus</i>      | 41                               | 6  | 14 | 3   |     |      | 43               | 1.05                               | 0.94  | 1.38    | 0.68    |          |  |
| <i>Pagellus bellottii</i>          | 87                               | 41 | 9  |     |     |      | 91               | 1.01                               | 0.23  | 1.35    | 1.44    | 0.17     |  |
| <i>Sparus caeruleostictus</i>      | 103                              | 24 | 3  |     |     |      | 87               | 0.67                               | 0.44  | 0.83    | 0.61    |          |  |
| <i>Pseudupeneus prayensis</i>      | 97                               | 20 | 2  | 1   |     |      | 81               | 0.61                               | 0.08  | 0.97    | 0.42    |          |  |
| <i>Dentex canariensis</i>          | 101                              | 19 | 2  |     |     |      | 82               | 0.49                               | 0.08  | 0.50    | 1.02    |          |  |
| <i>Epinephelus aeneus</i>          | 74                               | 15 |    |     |     |      | 60               | 0.39                               | 0.06  | 0.41    | 0.79    |          |  |
| <i>Pomadasys incisus</i>           | 32                               | 8  | 2  | 1   |     |      | 28               | 0.35                               | 0.01  | 0.62    | 0.12    |          |  |
| <i>Priacanthus arenatus</i>        | 81                               | 8  | 1  |     |     |      | 60               | 0.26                               | 0.05  | 0.35    | 0.30    |          |  |
| <i>Dentex angolensis</i>           | 7                                | 2  | 4  |     |     |      | 9                | 0.25                               |   | 0.13    | 0.80    | 2.71     |  |
| <i>Dentex congoensis</i>           | 7                                | 3  | 4  |     |     |      | 9                | 0.20                               |   | 0.06    | 0.81    | 0.23     |  |
| <i>Chromis lineatus</i>            | 6                                | 1  | 1  | 1   |     |      | 6                | 0.19                               |   | 0.02    | 0.86    |          |  |
| <i>Galeoides decadactylus</i>      | 22                               | 1  | 3  |     |     |      | 17               | 0.16                               | 0.06  | 0.29    |         |          |  |
| <i>Pomadasys jubelini</i>          | 21                               | 6  | 1  |     |     |      | 18               | 0.15                               | 0.03  | 0.27    |         |          |  |
| <i>Lutjanus fulgens</i>            | 57                               | 4  |    |     |     |      | 41               | 0.12                               | 0.01  | 0.13    | 0.21    |          |  |
| <i>Dentex gibbosus</i>             | 42                               | 3  |    |     |     |      | 30               | 0.10                               |   | 0.06    | 0.33    |          |  |
| <i>Sepia officinalis hierredda</i> | 72                               |    |    |     |     |      | 48               | 0.09                               | 0.12  | 0.09    | 0.02    | 8.01     |  |
| <i>Pseudolithus senegalensis</i>   | 16                               | 2  | 1  |     |     |      | 13               | 0.08                               | 0.07  | 0.11    | 0.01    |          |  |
| <i>Umbrina</i> spp.                | 17                               |    | 2  |     |     |      | 13               | 0.07                               |   | 0.07    | 0.16    |          |  |
| <i>Lethrinus atlanticus</i>        | 50                               |    | 1  |     |     |      | 34               | 0.07                               | 0.08  | 0.10    |         |          |  |
| <i>Sphyræna</i> sp                 | 47                               | 2  |    |     |     |      | 33               | 0.06                               | 0.08  | 0.06    | 0.03    |          |  |
| <i>Boops boops</i>                 | 34                               | 1  | 1  |     |     |      | 24               | 0.06                               |   | 0.02    | 0.23    |          |  |
| <i>Chromis</i> sp                  | 5                                |    | 1  |     |     |      | 4                | 0.06                               |   | 0.01    | 0.28    |          |  |
| <i>Trichiurus lepturus</i>         | 23                               |    | 1  |     |     |      | 16               | 0.05                               |   | 0.09    | 0.01    |          |  |
| <i>Sepia</i> sp                    | 26                               | 1  |    |     |     |      | 18               | 0.05                               | 0.12  | 0.02    | 0.03    |          |  |
| <i>Pteroscion peli</i>             | 10                               |    | 1  |     |     |      | 7                | 0.05                               | 0.01  | 0.09    |         |          |  |
| <i>Apsilus fuscus</i>              | 22                               | 2  |    |     |     |      | 16               | 0.05                               |   | 0.04    | 0.13    |          |  |
| <i>Penaeus notialis</i>            | 13                               |    |    |     |     |      | 9                |                                    | 0.01  |         |         |          |  |
| <i>Parapenaeopsis atlantica</i>    | 2                                |    |    |     |     |      | 1                |                                    |   |         |         |          |  |
| Shrimps, small, non comm.          | 1                                |    |    |     |     |      | 1                |                                    |   |         |         |          |  |
| Other fish                         |                                  |    |    |     |     |      |                  | 0.65                               | 0.24  | 0.53    | 1.30    | 5.93     |  |
| Sum all species                    |                                  |    |    |     |     |      |                  | 22.56                              | 19.65   | 28.91   | 10.95   | 9.06     |  |
| Sum Snappers                       |                                  |    |    |     |     |      |                  | 0.19                               | 0.03  | 0.19    | 0.35    |          |  |
| Sum Groupers                       |                                  |    |    |     |     |      |                  | 0.41                               | 0.06  | 0.41    | 0.84    |          |  |
| Sum Grunts                         |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |  |
| Sum Croakers                       |                                  |    |    |     |     |      |                  | 0.26                               | 0.09  | 0.29    | 0.31    | 4.17     |  |
| Sum Seabreams                      |                                  |    |    |     |     |      |                  | 2.82                               | 0.76  | 2.89    | 5.32    | 3.11     |  |
| Sum Sharks                         |                                  |    |    |     |     |      |                  | 0.05                               | 0.02  | 0.04    | 0.10    | 1.13     |  |
| Sum Rays                           |                                  |    |    |     |     |      |                  | 0.03                               | 0.02  | 0.02    | 0.04    | 0.22     |  |
| Sum Squids                         |                                  |    |    |     |     |      |                  | 0.15                               | 0.24  | 0.11    | 0.09    | 0.07     |  |
| Sum                                |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |  |
| Sum commercial shrimps             |                                  |    |    |     |     |      |                  |                                    | 0.01  |         |         |          |  |

Number of stations included in analysis, total and by depth strata

149

40

77

31

1



## 6.11.5 MFRD3, 1981 - 82

| SPECIES NAME                       | SAMPLE DISTRIB. BY CATCH CLASSES |    |    |     |     |      | t inci-<br>dence | Mean<br>dens.<br>t/nm <sup>2</sup> | Mean densities by bottom depth strata t/nm <sup>2</sup> |         |         |          |
|------------------------------------|----------------------------------|----|----|-----|-----|------|------------------|------------------------------------|---|---------|---------|----------|
|                                    | Lower limits, Kg/nm              |    |    |     |     |      |                  |                                    | 10- 30m   | 30- 50m | 50-100m | 100-200m |
|                                    | >0                               | 10 | 30 | 100 | 300 | 1000 |                  |                                    |   |         |         |          |
| <i>Balistes capricus</i>           | 89                               | 21 | 16 | 8   | 12  | 1    | 83               | 6.89                               | 7.59  | 11.34   | 1.67    |          |
| <i>Brachydeuterus auritus</i>      | 32                               | 10 | 7  | 4   | 3   |      | 31               | 1.92                               | 1.11  | 2.85    | 1.59    |          |
| <i>Pagellus bellottii</i>          | 98                               | 41 | 21 | 3   |     |      | 91               | 1.62                               | 0.85  | 2.12    | 1.70    |          |
| <i>Pseudupeneus prayensis</i>      | 106                              | 31 | 11 |     |     |      | 83               | 0.91                               | 0.55  | 1.62    | 0.46    |          |
| <i>Sparus caeruleostictus</i>      | 130                              | 26 | 8  |     |     |      | 92               | 0.82                               | 0.99  | 0.82    | 0.67    |          |
| <i>Dentex canariensis</i>          | 102                              | 32 | 3  |     |     |      | 77               | 0.68                               | 0.42  | 0.39    | 0.36    |          |
| <i>Epinephelus aeneus</i>          | 63                               | 23 | 9  |     |     |      | 53               | 0.64                               | 0.09  | 0.73    | 0.36    |          |
| <i>Umbrina canariensis</i>         | 13                               | 2  |    |     | 1   |      | 9                | 0.52                               |   |         | 1.46    |          |
| <i>Priacanthus arenatus</i>        | 101                              | 9  | 5  |     |     |      | 65               | 0.42                               | 0.39  | 0.29    | 0.59    |          |
| <i>Balistes punctatus</i>          | 40                               | 1  |    |     | 1   |      | 24               | 0.36                               | 0.14  | 0.05    | 0.86    |          |
| <i>Dentex congolensis</i>          | 10                               | 6  | 4  | 1   |     |      | 12               | 0.27                               |   |         | 0.76    |          |
| <i>Sepia officinalis hierredda</i> | 69                               | 9  |    |     |     |      | 44               | 0.22                               | 0.22  | 0.24    | 0.20    |          |
| <i>Dentex gibbosus</i>             | 57                               | 5  | 2  |     |     |      | 36               | 0.21                               |   | 0.09    | 0.50    |          |
| <i>Boops boops</i>                 | 35                               |    | 1  | 1   |     |      | 21               | 0.18                               | 0.01  | 0.04    | 0.44    |          |
| <i>Chromis lineatus</i>            | 18                               | 3  | 3  |     |     |      | 13               | 0.17                               |   | 0.01    | 0.45    |          |
| <i>Lutjanus fulgens</i>            | 55                               | 4  | 1  |     |     |      | 34               | 0.16                               | 0.19  | 0.10    | 0.21    |          |
| <i>Chromis sp</i>                  | 9                                | 2  | 1  | 1   |     |      | 7                | 0.15                               |   | 0.01    | 0.41    |          |
| <i>Sepia sp</i>                    | 39                               | 4  | 1  |     |     |      | 25               | 0.14                               | 0.28  | 0.11    | 0.07    |          |
| <i>Dentex angolensis</i>           | 16                               | 8  | 1  |     |     |      | 14               | 0.14                               |   |         | 0.29    |          |
| <i>Pomadourys incisus</i>          | 32                               | 3  | 2  |     |     |      | 21               | 0.12                               | 0.12  | 0.08    | 0.18    |          |
| <i>Acanthurus monroviae</i>        | 19                               | 7  |    |     |     |      | 15               | 0.12                               | 0.13  | 0.20    | 0.01    |          |
| <i>Paracubiceps ledanosi</i>       | 22                               | 1  | 1  |     |     |      | 13               | 0.10                               |   | 0.01    | 0.27    |          |
| <i>Fistularia villosa</i>          | 115                              |    |    |     |     |      | 65               | 0.10                               | 0.01  | 0.14    | 0.12    |          |
| <i>Rhizoprionodon acutus</i>       | 35                               | 1  |    |     |     |      | 20               | 0.09                               |   | 0.08    | 0.16    |          |
| <i>Lethrinus atlanticus</i>        | 33                               | 2  |    |     |     |      | 20               | 0.07                               | 0.19  | 0.05    |         |          |
| <i>Dactylopterus volitans</i>      | 78                               | 2  |    |     |     |      | 45               | 0.07                               | 0.04  | 0.06    | 0.09    |          |
| <i>Lagocephalus laevigatus</i>     | 56                               | 1  |    |     |     |      | 32               | 0.06                               | 0.17  | 0.02    |         |          |
| <i>Sphyræna sphyraena</i>          | 47                               | 2  |    |     |     |      | 38               | 0.05                               | 0.09  | 0.05    | 0.01    |          |
| <i>Raja miraletus</i>              | 67                               |    |    |     |     |      | 38               | 0.05                               | 0.01  | 0.03    | 0.11    |          |
| <i>Galeoides decadactylus</i>      | 16                               | 3  |    |     |     |      | 11               | 0.05                               | 0.11  | 0.04    |         |          |
| <i>Pennaeus notialis</i>           | 6                                |    |    |     |     |      | 3                |                                    |   |         |         |          |
| <i>Pennaeus sp</i>                 | 3                                |    |    |     |     |      | 2                |                                    |   |         |         |          |
| <i>Parapennaeopsis atlantica</i>   | 1                                |    |    |     |     |      | 1                |                                    |   |         |         |          |
| Other fish                         |                                  |    |    |     |     |      |                  | 0.54                               | 0.60  | 0.44    | 0.71    |          |
| Sum all species                    |                                  |    |    |     |     |      |                  | 17.84                              | 14.30   | 22.21   | 16.01   |          |
| Sum Snappers                       |                                  |    |    |     |     |      |                  | 0.24                               | 0.25  | 0.17    | 0.30    |          |
| Sum Groupers                       |                                  |    |    |     |     |      |                  | 0.67                               | 0.09  | 0.75    | 1.02    |          |
| Sum Grunts                         |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum Croakers                       |                                  |    |    |     |     |      |                  | 0.58                               | 0.11  | 0.06    | 1.50    |          |
| Sum Seabreams                      |                                  |    |    |     |     |      |                  | 3.92                               | 2.27  | 3.66    | 5.43    |          |
| Sum Sharks                         |                                  |    |    |     |     |      |                  | 0.12                               |   | 0.08    | 0.27    |          |
| Sum Rays                           |                                  |    |    |     |     |      |                  | 0.06                               | 0.02  | 0.04    | 0.13    |          |
| Sum Squids                         |                                  |    |    |     |     |      |                  | 0.26                               | 0.50  | 0.36    | 0.30    |          |
| Sum                                |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum commercial shrimps             |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |

Number of stations included in analysis, total and by depth strata

178

49

66

63

| SPECIES NAME                       | SAMPLE DISTRIB. BY CATCH CLASSES |    |    |     |     |      | t inci-<br>dence | Mean<br>dens.<br>t/nm <sup>2</sup> | Mean densities by bottom depth strata t/nm <sup>2</sup> |         |         |          |
|------------------------------------|----------------------------------|----|----|-----|-----|------|------------------|------------------------------------|---|---------|---------|----------|
|                                    | Lower limits, Kg/nm              |    |    |     |     |      |                  |                                    | 10- 30m   | 30- 50m | 50-100m | 100-200m |
|                                    | >0                               | 10 | 30 | 100 | 300 | 1000 |                  |                                    |   |         |         |          |
| <i>Balistes capriscaus</i>         | 95                               | 19 | 11 | 2   | 1   | 1    | 71               | 2.04                               | 1.39  | 4.15    | 0.49    |          |
| <i>Brachydeuterus auritus</i>      | 30                               | 11 | 5  | 6   |     |      | 29               | 1.06                               | 1.53  | 1.27    | 0.42    |          |
| <i>Pagellus bellottii</i>          | 106                              | 35 | 11 | 1   |     |      | 85               | 0.98                               | 0.26  | 0.81    | 1.80    |          |
| <i>Pseudupeneus prayensis</i>      | 127                              | 25 | 4  |     |     |      | 86               | 0.61                               | 0.23  | 0.84    | 0.71    |          |
| <i>Priacanthus arenatus</i>        | 96                               | 13 | 3  | 2   |     |      | 63               | 0.58                               | 0.07  | 0.44    | 1.19    |          |
| <i>Sparus caeruleostictus</i>      | 128                              | 26 | 1  |     |     |      | 86               | 0.54                               | 0.38  | 0.62    | 0.61    |          |
| <i>Dentex canariensis</i>          | 117                              | 24 | 4  |     |     |      | 80               | 0.54                               | 0.26  | 0.36    | 0.99    |          |
| <i>Dactylopterus volitans</i>      | 108                              | 18 | 4  |     |     |      | 71               | 0.51                               | 0.14  | 0.65    | 0.70    |          |
| <i>Sepia officinalis hierredda</i> | 136                              | 18 |    |     |     |      | 85               | 0.80                               | 0.70  | 0.51    | 0.30    |          |
| <i>Chromis sp</i>                  | 13                               | 4  | 3  | 3   |     |      | 13               | 0.47                               |   | 0.03    | 1.35    |          |
| <i>Epinephelus aeneus</i>          | 73                               | 22 | 4  |     |     |      | 55               | 0.46                               | 0.08  | 0.55    | 0.73    |          |
| <i>Lutjanus fulgens</i>            | 58                               | 8  | 2  | 1   |     |      | 38               | 0.31                               | 0.16  | 0.41    | 0.33    |          |
| <i>Chromis lineatus</i>            | 14                               | 3  | 2  | 1   |     |      | 11               | 0.27                               |   | 0.02    | 0.77    |          |
| <i>Dentex congolensis</i>          | 11                               | 4  | 5  |     |     |      | 11               | 0.26                               |   |         | 0.75    |          |
| <i>Diagramma mediterraneus</i>     | 28                               | 1  |    | 1   |     |      | 17               | 0.22                               | 0.61  | 0.06    | 0.03    |          |
| <i>Pomadasys jubelini</i>          | 6                                |    | 1  | 1   |     |      | 4                | 0.16                               | 0.01  | 0.45    |         |          |
| <i>Acanthurus monroviae</i>        | 30                               | 9  | 1  |     |     |      | 22               | 0.16                               | 0.04  | 0.31    | 0.11    |          |
| <i>Dentex angolensis</i>           | 11                               | 6  | 2  |     |     |      | 11               | 0.13                               |   |         | 0.38    |          |
| <i>Rhizoprionodon acutus</i>       | 52                               | 4  |    |     |     |      | 31               | 0.12                               |   | 0.12    | 0.23    |          |
| <i>Lepidotrigla sp</i>             | 39                               | 3  | 1  |     |     |      | 24               | 0.11                               |   | 0.02    | 0.31    |          |
| <i>Raja miraletus</i>              | 99                               | 1  |    |     |     |      | 55               | 0.11                               | 0.01  | 0.10    | 0.21    |          |
| <i>Pistularia villosa</i>          | 99                               | 2  |    |     |     |      | 56               | 0.11                               | 0.02  | 0.06    | 0.25    |          |
| <i>Dentex gibbosus</i>             | 52                               | 3  |    |     |     |      | 30               | 0.10                               |   | 0.03    | 0.26    |          |
| <i>Umbrina spp.</i>                | 15                               | 2  | 1  |     |     |      | 10               | 0.10                               | 0.02  | 0.02    | 0.26    |          |
| <i>Paracubiceps ledanosi</i>       | 17                               |    | 2  |     |     |      | 11               | 0.10                               |   |         | 0.29    |          |
| <i>Galeoides decadactylus</i>      | 19                               | 3  | 1  |     |     |      | 13               | 0.09                               | 0.10  | 0.16    |         |          |
| <i>Pomadasys incisus</i>           | 34                               | 3  | 1  |     |     |      | 21               | 0.09                               | 0.06  | 0.07    | 0.14    |          |
| <i>Trigla sp</i>                   | 60                               |    |    |     |     |      | 33               | 0.08                               |   | 0.05    | 0.18    |          |
| <i>Lutjanus goreensis</i>          | 17                               | 1  | 1  |     |     |      | 10               | 0.08                               | 0.04  | 0.09    | 0.10    |          |
| <i>Balistes punctatus</i>          | 56                               | 3  |    |     |     |      | 33               | 0.08                               | 0.13  | 0.12    |         |          |
| <i>Boops boops</i>                 | 22                               | 4  |    |     |     |      | 14               | 0.07                               |   | 0.09    | 0.11    |          |
| <i>Sphyræna sphyraena</i>          | 46                               | 1  |    |     |     |      | 26               | 0.06                               | 0.05  | 0.08    | 0.04    |          |
| <i>Dasyatis hastata (D.aspera)</i> |                                  |    | 1  |     |     |      | 1                | 0.06                               | 0.18  |         |         |          |
| <i>Acanthoetracion guineensis</i>  | 31                               | 3  |    |     |     |      | 19               | 0.05                               | 0.12  | 0.02    |         |          |
| <i>Lethrinus atlanticus</i>        | 32                               | 1  |    |     |     |      | 18               | 0.05                               | 0.10  | 0.04    |         |          |
| <i>Penaeus notialis</i>            | 15                               |    |    |     |     |      | 8                | 0.01                               |   | 0.01    |         |          |
| <i>Penaeus sp</i>                  | 1                                |    |    |     |     |      |                  |                                    |   |         |         |          |
| <i>Parapenaeopsis atlantica</i>    | 11                               |    |    |     |     |      | 6                |                                    |   |         |         |          |
| Other fish                         |                                  |    |    |     |     |      |                  | 0.76                               | 0.68  | 0.61    | 0.82    |          |
| Sum all species                    |                                  |    |    |     |     |      |                  | 12.03                              | 7.38  | 13.17   | 14.86   |          |
| Sum Snappers                       |                                  |    |    |     |     |      |                  | 0.45                               | 0.26  | 0.54    | 0.80    |          |
| Sum Groupers                       |                                  |    |    |     |     |      |                  | 0.49                               | 0.08  | 0.58    | 0.79    |          |
| Sum Grunts                         |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum Croakers                       |                                  |    |    |     |     |      |                  | 0.16                               | 0.08  | 0.09    | 0.30    |          |
| Sum Seabreams                      |                                  |    |    |     |     |      |                  | 2.67                               | 0.90  | 1.92    | 5.02    |          |
| Sum Sharks                         |                                  |    |    |     |     |      |                  | 0.14                               |   | 0.12    | 0.28    |          |
| Sum Rays                           |                                  |    |    |     |     |      |                  | 0.22                               | 0.26  | 0.16    | 0.24    |          |
| Sum Squids                         |                                  |    |    |     |     |      |                  | 0.53                               | 0.73  | 0.52    | 0.31    |          |
| Sum                                |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum commercial shrimps             |                                  |    |    |     |     |      |                  | 0.01                               |   | 0.01    |         |          |

Number of stations included in analysis, total and by depth strata

181

56

63

62



## 6.11.7 MFRD5, 1989

| SPECIES NAME                | SAMPLE DISTRIB. BY CATCH CLASSES |    |    |     |     |      | t inci-<br>dence | Mean<br>dens.<br>t/nm <sup>2</sup> | Mean densities by bottom depth strata t/nm <sup>2</sup> |         |         |          |
|-----------------------------|----------------------------------|----|----|-----|-----|------|------------------|------------------------------------|---|---------|---------|----------|
|                             | Lower limits, Kg/nm              |    |    |     |     |      |                  |                                    | 10- 30m   | 30- 50m | 50-100m | 100-200m |
|                             | >0                               | 10 | 20 | 100 | 300 | 1000 |                  |                                    |   |         |         |          |
| Brachydeuterus auritus      | 40                               | 8  | 2  | 3   | 2   |      | 36               | 1.31                               | 0.32  | 1.36    | 2.17    |          |
| Pagellus bellottii          | 101                              | 25 | 3  |     |     |      | 85               | 0.67                               | 0.28  | 0.75    | 0.94    |          |
| Sparus caeruleostictus      | 119                              | 15 | 1  |     |     |      | 89               | 0.52                               | 0.47  | 0.58    | 0.50    |          |
| Pseudupeneus prayensis      | 106                              | 27 |    |     |     |      | 88               | 0.52                               | 0.21  | 0.53    | 0.81    |          |
| Chromis sp                  | 12                               | 1  | 1  | 1   | 1   |      | 11               | 0.43                               |   | 0.02    | 1.23    |          |
| Dentex canariensis          | 106                              | 11 | 3  |     |     |      | 79               | 0.42                               | 0.32  | 0.27    | 0.67    |          |
| Sepia officinalis hierredda | 108                              | 7  | 3  |     |     |      | 78               | 0.36                               | 0.52  | 0.22    | 0.36    |          |
| Epinephelus aeneus          | 59                               | 11 | 1  |     |     |      | 47               | 0.30                               | 0.12  | 0.25    | 0.51    |          |
| Dactylopterus volitans      | 99                               | 4  | 2  |     |     |      | 68               | 0.26                               | 0.06  | 0.24    | 0.47    |          |
| Priacanthus arenatus        | 86                               | 4  | 2  |     |     |      | 61               | 0.25                               | 0.16  | 0.17    | 0.40    |          |
| Dentex congolensis          | 6                                | 9  | 2  |     |     |      | 11               | 0.23                               |   |         | 0.68    |          |
| Lagocephalus laevigatus     | 79                               | 3  | 1  |     |     |      | 54               | 0.22                               | 0.27  | 0.34    | 0.04    |          |
| Lutjanus fulgens            | 52                               | 8  |    |     |     |      | 39               | 0.21                               | 0.18  | 0.17    | 0.27    |          |
| Lethrinus atlanticus        | 33                               | 1  | 1  | 1   |     |      | 24               | 0.18                               | 0.50  | 0.05    |         |          |
| Chromis lineatus            | 9                                | 1  | 2  |     |     |      | 8                | 0.14                               |   |         | 0.41    |          |
| Fistularia villosa          | 103                              | 1  |    |     |     |      | 68               | 0.14                               | 0.15  | 0.17    | 0.10    |          |
| Balistes capricus           | 79                               | 3  |    |     |     |      | 54               | 0.13                               | 0.06  | 0.24    | 0.07    |          |
| Acanthurus monroviae        | 25                               | 5  | 1  |     |     |      | 20               | 0.13                               | 0.12  | 0.25    | 0.02    |          |
| Boops boops                 | 17                               | 6  |    |     |     |      | 15               | 0.11                               | 0.04  | 0.12    | 0.16    |          |
| Trigla sp                   | 56                               | 1  |    |     |     |      | 38               | 0.08                               |   | 0.04    | 0.18    |          |
| Pomadourys incisus          | 27                               | 4  |    |     |     |      | 20               | 0.08                               | 0.10  | 0.10    | 0.04    |          |
| Sphyræna sphyraena          | 47                               |    | 1  |     |     |      | 32               | 0.07                               | 0.05  | 0.14    | 0.02    |          |
| Rhizoprionodon acutus       | 36                               | 1  |    |     |     |      | 24               | 0.07                               |   | 0.04    | 0.17    |          |
| Raja miraletus              | 72                               |    |    |     |     |      | 47               | 0.07                               | 0.02  | 0.06    | 0.14    |          |
| Pomadourys jubelini         | 12                               |    | 1  |     |     |      | 9                | 0.07                               | 0.22  | 0.02    |         |          |
| Balistes punctatus          | 44                               |    |    |     |     |      | 29               | 0.07                               | 0.13  | 0.08    |         |          |
| Dentex angolensis           | 17                               |    | 1  |     |     |      | 12               | 0.05                               |   | 0.01    | 0.14    |          |
| Apsilus fuscus              | 35                               | 1  |    |     |     |      | 24               | 0.05                               |   | 0.04    | 0.10    |          |
| Anthias anthias             | 6                                |    | 1  |     |     |      | 8                | 0.05                               |   |         | 0.15    |          |
| Penaeus notialis            | 18                               |    |    |     |     |      | 12               | 0.01                               | 0.02  |         |         |          |
| Parapenaeopsis atlantica    | 8                                |    |    |     |     |      | 5                |                                    |   |         |         |          |
| PENAEIDAE                   | 1                                |    |    |     |     |      | 1                |                                    | 0.01  |         |         |          |
| Other fish                  |                                  |    |    |     |     |      |                  | 0.68                               | 1.17  | 0.49    | 0.59    |          |
| Sum all species             |                                  |    |    |     |     |      |                  | 7.88                               | 5.50  | 6.78    | 11.34   |          |
| Sum Snappers                |                                  |    |    |     |     |      |                  | 0.32                               | 0.32  | 0.28    | 0.37    |          |
| Sum Groupers                |                                  |    |    |     |     |      |                  | 0.31                               | 0.12  | 0.26    | 0.55    |          |
| Sum Grunts                  |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum Croakers                |                                  |    |    |     |     |      |                  | 0.08                               | 0.20  | 0.01    | 0.05    |          |
| Sum Seabreams               |                                  |    |    |     |     |      |                  | 2.05                               | 1.11  | 1.75    | 3.24    |          |
| Sum Sharks                  |                                  |    |    |     |     |      |                  | 0.09                               |   | 0.05    | 0.23    |          |
| Sum Rays                    |                                  |    |    |     |     |      |                  | 0.13                               | 0.16  | 0.11    | 0.15    |          |
| Sum Squids                  |                                  |    |    |     |     |      |                  | 0.36                               | 0.52  | 0.22    | 0.37    |          |
| Sum                         |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum commercial shrimps      |                                  |    |    |     |     |      |                  | 0.01                               | 0.03  |         |         |          |

Number of stations included in analysis, total and by depth strata

182

48

52

52

## 6.11.8 MFRD6, 1990

| SPECIES NAME                | SAMPLE DISTRIB. BY CATCH CLASSES |    |    |     |     |      | t inci-<br>dence | Mean<br>dens.<br>t/nm <sup>2</sup> | Mean densities by bottom depth strata t/nm <sup>2</sup> |         |         |          |
|-----------------------------|----------------------------------|----|----|-----|-----|------|------------------|------------------------------------|---|---------|---------|----------|
|                             | Lower limits, Kg/nm              |    |    |     |     |      |                  |                                    | 10- 30m   | 30- 50m | 50-100m | 100-200m |
|                             | >0                               | 10 | 30 | 100 | 300 | 1000 |                  |                                    |   |         |         |          |
| Brachydeuterus auritus      | 47                               | 10 | 1  | 3   | 1   |      | 46               | 0.99                               | 0.34  | 2.59    | 0.06    |          |
| Pagellus bellottii          | 80                               | 28 | 6  |     |     |      | 84               | 0.89                               | 0.38  | 1.13    | 1.16    |          |
| Pseudupeneus prayensis      | 91                               | 20 | 3  |     |     |      | 84               | 0.59                               | 0.20  | 0.49    | 1.10    |          |
| Priacanthus arenatus        | 78                               | 4  | 1  | 2   |     |      | 63               | 0.57                               | 0.16  | 0.15    | 1.40    |          |
| Sepia officinalis hierredda | 103                              | 14 | 1  |     |     |      | 87               | 0.55                               | 0.40  | 0.92    | 0.44    |          |
| Sparus caeruleostictus      | 105                              | 16 |    |     |     |      | 90               | 0.50                               | 0.47  | 0.45    | 0.57    |          |
| Chromis sp                  | 10                               | 3  | 5  | 1   |     |      | 14               | 0.41                               |   |         | 1.21    |          |
| Dentex canariensis          | 102                              | 9  | 1  |     |     |      | 83               | 0.38                               | 0.34  | 0.28    | 0.51    |          |
| Chromis cadenati            | 1                                |    |    |     | 1   |      | 1                | 0.31                               |   |         | 0.93    |          |
| Lagocephalus laevigatus     | 58                               | 7  | 2  |     |     |      | 50               | 0.29                               | 0.34  | 0.33    | 0.21    |          |
| Epinephelus aeneus          | 43                               | 11 |    |     |     |      | 40               | 0.27                               | 0.06  | 0.16    | 0.58    |          |
| Chromis lineatus            | 4                                | 1  | 2  | 1   |     |      | 6                | 0.26                               |   | 0.01    | 0.79    |          |
| Dactylopterus volitans      | 88                               | 5  |    |     |     |      | 67               | 0.23                               | 0.07  | 0.26    | 0.35    |          |
| Lutjanus fulgens            | 48                               | 5  | 1  |     |     |      | 40               | 0.22                               | 0.06  | 0.28    | 0.30    |          |
| Pomadasye incisus           | 36                               | 2  | 1  |     |     |      | 28               | 0.17                               | 0.12  | 0.12    | 0.26    |          |
| Fistularia villosa          | 83                               | 3  |    |     |     |      | 64               | 0.15                               | 0.03  | 0.24    | 0.16    |          |
| Raja miraletus              | 85                               |    |    |     |     |      | 63               | 0.14                               | 0.04  | 0.14    | 0.24    |          |
| Apellus fuscus              | 21                               |    |    | 1   |     |      | 16               | 0.14                               | 0.01  | 0.01    | 0.39    |          |
| Rhizoprionodon acutus       | 23                               | 3  | 1  |     |     |      | 20               | 0.13                               | 0.02  | 0.08    | 0.28    |          |
| Boops boops                 | 14                               | 2  | 1  |     |     |      | 13               | 0.09                               |   | 0.05    | 0.20    |          |
| Balistes punctatus          | 39                               |    |    |     |     |      | 39               | 0.08                               | 0.13  | 0.11    |         |          |
| Trichiurus lepturus         | 20                               | 1  | 1  |     |     |      | 16               | 0.07                               | 0.11  | 0.07    | 0.01    |          |
| Trigla sp                   | 24                               | 2  |    |     |     |      | 19               | 0.07                               |   | 0.02    | 0.18    |          |
| Pteroscion peli             | 15                               | 2  |    |     |     |      | 13               | 0.07                               | 0.19  | 0.02    |         |          |
| Dasyatis sp                 | 23                               |    | 1  |     |     |      | 18               | 0.07                               | 0.07  | 0.11    | 0.01    |          |
| Galeoides decadactylus      | 25                               | 1  |    |     |     |      | 19               | 0.07                               | 0.18  | 0.02    |         |          |
| Scyacium micrurus           | 98                               |    |    |     |     |      | 73               | 0.07                               | 0.05  | 0.11    | 0.06    |          |
| Lepidotrigla sp             | 43                               | 1  |    |     |     |      | 33               | 0.06                               | 0.01  | 0.10    | 0.07    |          |
| Argyroscopus regius         | 1                                | 1  | 1  |     |     |      | 2                | 0.06                               | 0.03  |         | 0.14    |          |
| Lethrinus atlanticus        | 22                               | 1  |    |     |     |      | 24               | 0.06                               | 0.10  | 0.07    |         |          |
| Acanthurus monroviae        | 24                               | 1  | 1  |     |     |      | 19               | 0.06                               | 0.04  | 0.14    | 0.01    |          |
| Octopus sp.                 | 36                               |    |    |     |     |      | 27               | 0.05                               | 0.01  | 0.03    | 0.10    |          |
| Dentex gibbosus             | 34                               |    |    |     |     |      | 25               | 0.05                               |   | 0.01    | 0.13    |          |
| Acanthostracion guineensis  | 26                               | 3  |    |     |     |      | 21               | 0.05                               | 0.13  | 0.02    |         |          |
| Lutjanus goreensis          | 11                               | 2  |    |     |     |      | 10               | 0.05                               | 0.05  | 0.09    | 0.01    |          |
| Pomadasye jubelini          | 10                               | 2  |    |     |     |      | 9                | 0.05                               | 0.09  | 0.08    |         |          |
| Drepane africana/punctata   | 7                                | 2  |    |     |     |      | 7                | 0.05                               | 0.12  | 0.02    |         |          |
| Parapenaeopsis atlantica    | 20                               |    |    |     |     |      | 15               | 0.03                               | 0.08  |         |         |          |
| Penaeus notialis            | 20                               |    |    |     |     |      | 15               | 0.01                               | 0.01  | 0.01    |         |          |
| Other fish                  |                                  |    |    |     |     |      |                  | 0.77                               | 0.86  | 0.66    | 0.86    |          |
| Sum all species             |                                  |    |    |     |     |      |                  | 9.13                               | 8.30  | 9.28    | 12.72   |          |
| Sum Snappers                |                                  |    |    |     |     |      |                  | 0.44                               | 0.13  | 0.45    | 0.70    |          |
| Sum Groupers                |                                  |    |    |     |     |      |                  | 0.31                               | 0.10  | 0.18    | 0.67    |          |
| Sum Grunts                  |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum Croakers                |                                  |    |    |     |     |      |                  | 0.20                               | 0.34  | 0.03    | 0.21    |          |
| Sum Seabreams               |                                  |    |    |     |     |      |                  | 1.95                               | 1.19  | 1.92    | 2.69    |          |
| Sum Sharks                  |                                  |    |    |     |     |      |                  | 0.18                               | 0.03  | 0.08    | 0.40    |          |
| Sum Rays                    |                                  |    |    |     |     |      |                  | 0.24                               | 0.17  | 0.30    | 0.26    |          |
| Sum Squids                  |                                  |    |    |     |     |      |                  | 0.62                               | 0.43  | 0.88    | 0.54    |          |
| Sum                         |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum commercial shrimps      |                                  |    |    |     |     |      |                  | 0.04                               | 0.09  | 0.01    |         |          |

Number of stations included in analysis, total and by depth strata

138

48

48

48



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| SPECIES NAME                | SAMPLE DISTRIB. BY CATCH CLASSES |    |    |     |     |      | % inci-<br>dence | Mean<br>dens.<br>t/nm <sup>2</sup> | Mean densities by bottom depth strata t/nm <sup>2</sup> |         |         |          |
|-----------------------------|----------------------------------|----|----|-----|-----|------|------------------|------------------------------------|---|---------|---------|----------|
|                             | Lower limits, Kg/nm              |    |    |     |     |      |                  |                                    | 10- 30m   | 30- 50m | 50-100m | 100-600m |
|                             | >0                               | 10 | 30 | 100 | 300 | 1000 |                  |                                    |   |         |         |          |
| Hypoclydonia bella          | 2                                | 1  | 2  |     | 1   |      | 21               | 1.75                               |   |         |         | 5.64     |
| Squatina oculata            | 6                                |    |    | 1   |     |      | 24               | 0.92                               |   |         | 0.03    | 2.92     |
| Sepia officinalis hierredda | 17                               | 1  | 1  | 1   |     |      | 69               | 0.77                               | 1.47  | 0.19    | 1.40    |          |
| Dactylopterus volitans      | 14                               | 3  | 1  |     |     |      | 62               | 0.52                               | 0.08  | 1.50    | 0.65    |          |
| Mustelus mustelus           | 10                               | 1  | 1  |     |     |      | 41               | 0.40                               |   | 0.03    | 0.07    | 1.17     |
| Lepidotrigla carolae        | 6                                | 2  | 1  |     |     |      | 31               | 0.39                               |   |         | 0.73    | 0.35     |
| Sparus caeruleostictus      | 11                               |    | 2  |     |     |      | 45               | 0.35                               | 0.82  | 0.79    | 0.27    |          |
| Pagellus bellottii          | 14                               | 1  | 1  |     |     |      | 55               | 0.32                               | 0.01  | 0.24    | 0.73    |          |
| Dentex gibbosus             | 2                                |    | 1  |     |     |      | 10               | 0.28                               |   |         | 0.02    | 0.88     |
| Raja miraletus              | 14                               | 1  |    |     |     |      | 52               | 0.28                               |   | 0.34    | 0.48    | 0.13     |
| Dentex congoensis           | 6                                |    | 1  |     |     |      | 24               | 0.27                               |   |         | 0.11    | 0.73     |
| Chlorophthalmus atlanticus  | 5                                | 1  | 1  |     |     |      | 21               | 0.27                               |   |         |         | 0.87     |
| Umbrina canariensis         | 2                                | 1  | 1  |     |     |      | 14               | 0.22                               |   | 0.24    | 0.01    | 0.85     |
| Dentex canariensis          | 16                               | 1  |    |     |     |      | 59               | 0.21                               | 0.15  | 0.22    | 0.39    | 0.01     |
| Dentex angolensis           | 10                               | 1  |    |     |     |      | 38               | 0.21                               |   |         | 0.28    | 0.34     |
| Gephyroberyx darwini        | 4                                |    | 1  |     |     |      | 17               | 0.20                               |   |         |         | 0.66     |
| Sphoeroides cutaneus        | 4                                | 2  |    |     |     |      | 21               | 0.19                               |   |         | 0.08    | 0.55     |
| Torpedo sp.                 |                                  |    | 1  |     |     |      | 3                | 0.19                               |   |         |         | 0.61     |
| Epinephelus aeneus          | 8                                | 1  |    |     |     |      | 31               | 0.18                               | 0.08  | 0.09    | 0.40    |          |
| Zenopsis conchifer          | 3                                | 2  |    |     |     |      | 17               | 0.17                               |   |         |         | 0.56     |
| Squatina aculeata           | 1                                |    | 1  |     |     |      | 7                | 0.15                               |   |         |         | 0.48     |
| Pseudupeneus prayensis      | 13                               | 1  |    |     |     |      | 48               | 0.14                               | 0.12  | 0.28    | 0.20    |          |
| Trigla sp                   | 18                               |    |    |     |     |      | 62               | 0.12                               | 0.06  | 0.09    | 0.12    | 0.17     |
| Spicara alta                | 1                                | 1  |    |     |     |      | 7                | 0.12                               |   |         |         | 0.39     |
| Chlorophthalmus fraser      | 5                                | 1  |    |     |     |      | 21               | 0.10                               |   |         |         | 0.31     |
| Balistes punctatus          | 5                                | 1  |    |     |     |      | 21               | 0.10                               | 0.39  | 0.19    | 0.03    |          |
| Sepia sp                    | 22                               |    |    |     |     |      | 69               | 0.08                               |   | 0.04    | 0.12    | 0.09     |
| Rhinobatos rhinobatos       | 1                                | 1  |    |     |     |      | 7                | 0.08                               | 0.02  | 0.43    |         |          |
| Lethrinus atlanticus        | 1                                | 1  |    |     |     |      | 7                | 0.07                               | 0.29  | 0.15    |         |          |
| Zeus faber                  | 7                                |    |    |     |     |      | 24               | 0.06                               |   |         | 0.10    | 0.08     |
| SQUALIDAE                   | 1                                | 1  |    |     |     |      | 7                | 0.06                               |   |         |         | 0.19     |
| Priacanthus arenatus        | 9                                |    |    |     |     |      | 31               | 0.06                               | 0.01  | 0.18    | 0.06    |          |
| Lagocephalus laevigatus     | 8                                |    |    |     |     |      | 28               | 0.05                               | 0.07  | 0.01    | 0.09    |          |
| Bathysolea polli            | 6                                |    |    |     |     |      | 21               | 0.05                               |   |         |         | 0.14     |
| Brachydeuterus auritus      | 7                                |    |    |     |     |      | 17               | 0.05                               | 0.05  | 0.22    | 0.01    |          |
| Sicyonia galeata            | 1                                |    |    |     |     |      | 3                |                                    |   |         |         |          |
| Parapenaeus longirostris    | 3                                |    |    |     |     |      | 10               |                                    |   |         |         |          |
| Other fish                  |                                  |    |    |     |     |      |                  | 1.06                               | 0.91  | 1.83    | 0.44    | 1.64     |
| Sum all species             |                                  |    |    |     |     |      |                  | 10.44                              | 4.53  | 7.06    | 6.79    | 19.46    |
| Sum Snappers                |                                  |    |    |     |     |      |                  | 0.04                               | 0.04  | 0.15    | 0.02    |          |
| Sum Groupers                |                                  |    |    |     |     |      |                  | 0.23                               | 0.08  | 0.10    | 0.41    | 0.14     |
| Sum Grunts                  |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum Croakers                |                                  |    |    |     |     |      |                  | 0.23                               | 0.01  | 0.27    | 0.01    | 0.59     |
| Sum Seabreams               |                                  |    |    |     |     |      |                  | 1.66                               | 0.98  | 1.25    | 1.80    | 2.02     |
| Sum Sharks                  |                                  |    |    |     |     |      |                  | 1.57                               |   | 0.03    | 0.10    | 4.90     |
| Sum Rays                    |                                  |    |    |     |     |      |                  | 0.44                               | 0.13  | 0.99    | 0.50    | 0.86     |
| Sum Squids                  |                                  |    |    |     |     |      |                  | 0.86                               | 1.51  | 0.24    | 1.53    | 0.09     |
| Sum                         |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |
| Sum commercial shrimps      |                                  |    |    |     |     |      |                  |                                    |   |         |         |          |

Number of stations included in analysis, total and by depth strata

29

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Appendix 6.12 Parameters of the von Bertalanfy growth function obtained from literature and estimates of M.

| Family     | Species                        | $L_{\infty}$ | K    | M    | Source                       |
|------------|--------------------------------|--------------|------|------|------------------------------|
| Sparidae   | <i>S. caeruleostictus</i>      | 44.76        | 0.49 | 0.86 | Rijavec (1973)               |
|            | <i>P. bellottii</i>            | 30.76        | 0.44 | 0.89 | Rijavec (1973)               |
|            | <i>D. canariensis</i>          | 59.96        | 0.24 | 0.50 | Rijavec (1973)               |
|            | <i>P. bellottii</i>            | 28.8         | 0.38 | 0.82 | Koranteng (1985)             |
|            | <i>P. bellottii</i>            | 32.0         | 0.23 | 0.57 | Koranteng (1985)             |
|            | <i>Dentex angolensis</i>       | 29.6         | 0.43 | 0.88 | Konan (1977)*                |
| Sciaenidae | <i>Pseudotolithus typus</i>    | 89.7         | 0.18 | 0.37 | Poinsard (1973)*             |
|            | <i>P. senegalensis</i>         | 52.7         | 0.35 | 0.66 | Troadec (1971)*              |
|            | <i>P. senegalensis</i>         | 54.0         | 0.52 | 0.85 | Troadec (1971)*              |
|            | <i>P. senegalensis</i>         | 62.5         | 0.17 | 0.39 | Sun (1975)*                  |
|            | <i>Pteroscion peli</i>         | 25.0         | 0.71 | 1.29 | Fontana & Baron (1976)*      |
| Haemulidae | <i>Brachydeuterus auritus</i>  | 23.5         | 0.73 | 1.33 | Fontana & Bouchereau (1976)* |
|            | <i>Brachydeuterus auritus</i>  | 25.8         | 0.33 | 0.77 | Barro (1976)*                |
|            | <i>Pomadasys jubelini</i>      | 42.9         | 0.46 | 0.82 | Caverivière (1982)           |
| Others     | <i>Cynoglossus canariensis</i> | 52.0         | 0.48 | 0.81 | Thiam (1978)*                |
|            | <i>Cynoglossus canariensis</i> | 53.5         | 0.34 | 0.64 | Chauvet (1972)*              |
|            | <i>Galeoides decadactylus</i>  | 47.0         | 0.16 | 0.41 | Samba (1974)*                |
|            | <i>Pentanemus quinquarius</i>  | 26.4         | 0.48 | 0.98 | Fontana & Baron (1976)*      |
|            | <i>Balistes capriscus</i>      | 40.7         | 0.37 | 0.73 | Caverivière (1982)           |
|            | <i>Balistes capriscus</i>      | 40.7         | 0.43 | 0.81 | Ofori-Danson(1989)           |
|            | <i>Balistes capriscus</i>      | 37.5         | 0.54 | 0.96 | Caverivière (1982)           |
|            | <i>Balistes capriscus</i>      | 38.0         | 0.42 | 0.81 | Caverivière (1982)           |
|            | <i>Balistes capriscus</i>      | 41.0         | 0.14 | 0.39 | Caverivière (1982)           |
|            |                                |              |      |      |                              |

\* Cited in Caverivière (1982).  $L_{\infty}$  as total length.





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