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Modelling a Multispecies Schooling Fishery in an Upwelling Environment, Mauritania, West Africa.

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MODELLING A MULTISPECIES SCHOOLING FISHERY IN AN UPWELLING ENVIRONMENT, MAURITANIA, WEST AFRICA

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PREFACE

The Mauritanian Exclusive Economic Zone (EEZ) is the site of complex hydrographic and meteorologic processes. Mixing between the cold Sahara Current waters and the warm Mauritania Current surface waters, as well as the wind-induced coastal upwelling process, creates a unique environment favorable for the spawning and survival of many temperate and tropical species on the Mauritanian shelf and in adjacent coastal areas (Banc d'Arguin). As a result, a number of commercially-important neritic species and demersal species are found in this area. The objective of this study is to explore developing a general fisheries modelling framework that takes into consideration species-specific, environmental, regional, fleet behavioral, and economic factors to better represent the Mauritanian pelagic fishery.

The first chapter presents a description of the general geologic, physical, chemical and biological characteristics of the Mauritanian upwelling zone as it is presently understood. It also highlights differences between this system and other major upwelling centers in the world (e.g., off Peru and California).

The second chapter explores the structure and timing of the seasonal cycles of water temperature and wind in order to describe the hydrographic conditions that prevail in the Mauritanian EEZ. The main focus is to identify any recent changes in the upwelling regime and their potential impact on fish populations. In addition this chapter investigates the applicability of using

oceanographic data from coastal stations to adequately represent offshore conditions.

Chapter three gives a quantitative description of the fishery. It main focus is to identify catch composition, to characterize seasonal (hydrographic) and zonal patterns, and to explore potential differences between fishing vessel types in the yields of the small pelagic fishery.

The fourth chapter investigates how these seasonal patterns influence abundance estimates of the individual species. Specifically, it looks at various methods of adequately allocating the nominal fishing effort among species and species groupings. In this regard, various methods of computing catch per unit of effort (CPUE) are compared.

Chapter five presents a predictive model for the fishery and discusses the management implications of using raw unpartitioned versus proportionally allocated fishing effort in the model. It also derives a formula that can be used to compute confidence intervals around the Maximum Sustainable Yield of the species in the fishery. Finally, the summary section brings together all the pertinent results, findings and limits of the study.

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ABSTRACT

Off Mauritania, Northwest Africa, small pelagic fish have long been a valuable target of a large and diverse international fleet. In the early 1990's, average annual catch was about 400,000 metric tons in which three to four families were frequently represented: carangidae (*Trachurus trachurus*, *T. trecae* and *Decapterus rhonchus*); clupeidae (*Sardina pilchardus*, *Sardinella aurita* and *S. maderensis*); scombridae (*Scomber japonicus*); and lately, trichiuridae (*Trichiurus lepturus*).

Using empirical orthogonal function analysis, it was shown that the study area is a transition zone between permanent upwelling in the north (20-25°N) and regions with seasonal upwelling in the south (10-16°N). Also, from 1985 to 1993, a warming in the southern EEZ was identified as a part of a long-term successive cooling and warming trends of sea surface temperature (1946-1988). These trends were also reflected in coastal station data and suggest strong associations between physical processes at local stations and the large-scale processes in the Northwest African coast.

Univariate and multivariate time series analyses performed on catch per effort (CPUE), hydrographic seasons, north and south fishing zones, and fishing vessel types indicated considerable temporal and spatial patterns in species yields. These variations are shown to be closely associated with hydrological conditions. For instance, carangidae dominated catch composition particularly

during transitional water seasons while, *Sardina* was most abundant during the cold water season and in the northern fishing zone. Further investigations of the CPUE computation suggested that proportional allocation of the fishing effort among the individual species groups was a better alternative to computing CPUE based upon the whole catch which is presently the case. This method used a nonequilibrium Schnute's version of the Schaefer model, for which a new formula was derived that allows computing confidence intervals around the maximum sustainable yields. The results indicate that proportional allocation of the effort and the multivariate regression model considerably enhanced the fit of the model.

Given the complexity of the fishery and species interdependence in species catch, the techniques and procedures presented are highly recommended tools to model the fishery.

Key words: Multispecies Fisheries Modeling, Upwelling, Schooling Species, Mauritania, Northwest Africa.

CHAPTER 1
Overview on the Physical, Chemical and Biological Characteristics of the Study Area

INTRODUCTION

The Northwest African upwelling system is considered among the most productive ecosystems in the world (Letaconnoux and Went, 1970; Minas and Peres, 1974; Richards, 1980; Longhurst, 1981; Hempel, 1982). The Mauritanian region, particularly off Cape Blanc, is an area where the conjunction of different water masses creates a highly diverse biomass of temperate and tropical species (Hempel, 1982; Wolff et al., 1993). Extremely high catches of pelagic and demersal fishes as well as shellfish are recorded from this area (Josse and Garcia, 1986; Josse, 1989; Chavance and Girardin, 1991). Although the Northwest African upwelling has been extensively studied, most of the research has been directed toward developing a broad picture of the system's physical and biological processes. Some studies, however, are specific to the Mauritanian shelf and have a mesoscale framework (Brink, 1985; Wolff et al., 1993). Because the data used in these studies are usually of short duration and irregularly configured in time and space, many knowledge gaps still exist. Some general features, however, can be distinguished. It is the goal of this chapter to synthesize a description of the general geologic, physical, chemical and biological characteristics of the Mauritanian upwelling, which are important in understanding the diversity and richness of the ecosystem.

THE STUDY AREA

The Mauritanian coast is about 720 km long and lays between 16°04'N and 20°36'N. The continental shelf can be divided into two parts with the division area around Cape Timiris (19°20'N-16°35'W). In the northern part around Cape Blanc (20°48'N-17°04'W) the inner shelf is relatively wide (60-90 km). The coast is arcuate, concave to the west, and the Baie du Levrier and Banc d'Arguin are very important morphological features (Figure 1.1). The shelf width decreases gradually as one moves toward Cape Timiris where the 200 m isobath is only about 15 km from the coast. Numerous trenches and steep submarine canyons, often quite deep, are in this area and it is common to observe the 300-400 m contours very close to the coast. These canyons often have rocky and coralline faces (Maigret and Ly, 1986). In the southern part, the shelf width does not exceed 50 km and its borders are more regular. Few canyons are observed between 18°40' and 18°50'N and between 16° 30' and 16° 50'N. Finally, the axis of the coastline changes from a north-south to north-northeast-south-southwest trend off Nouakchott (18°N16°W).

GEOLOGICAL ASPECTS: THE SEDIMENTARY REGIME

The texture and composition of the Mauritanian shelf sediments is, to a great extent, influenced by the arid climate and upwelling (Chester et al., 1972; Milliman, 1977; Diester-Haass, 1978; Szekielda, 1978).

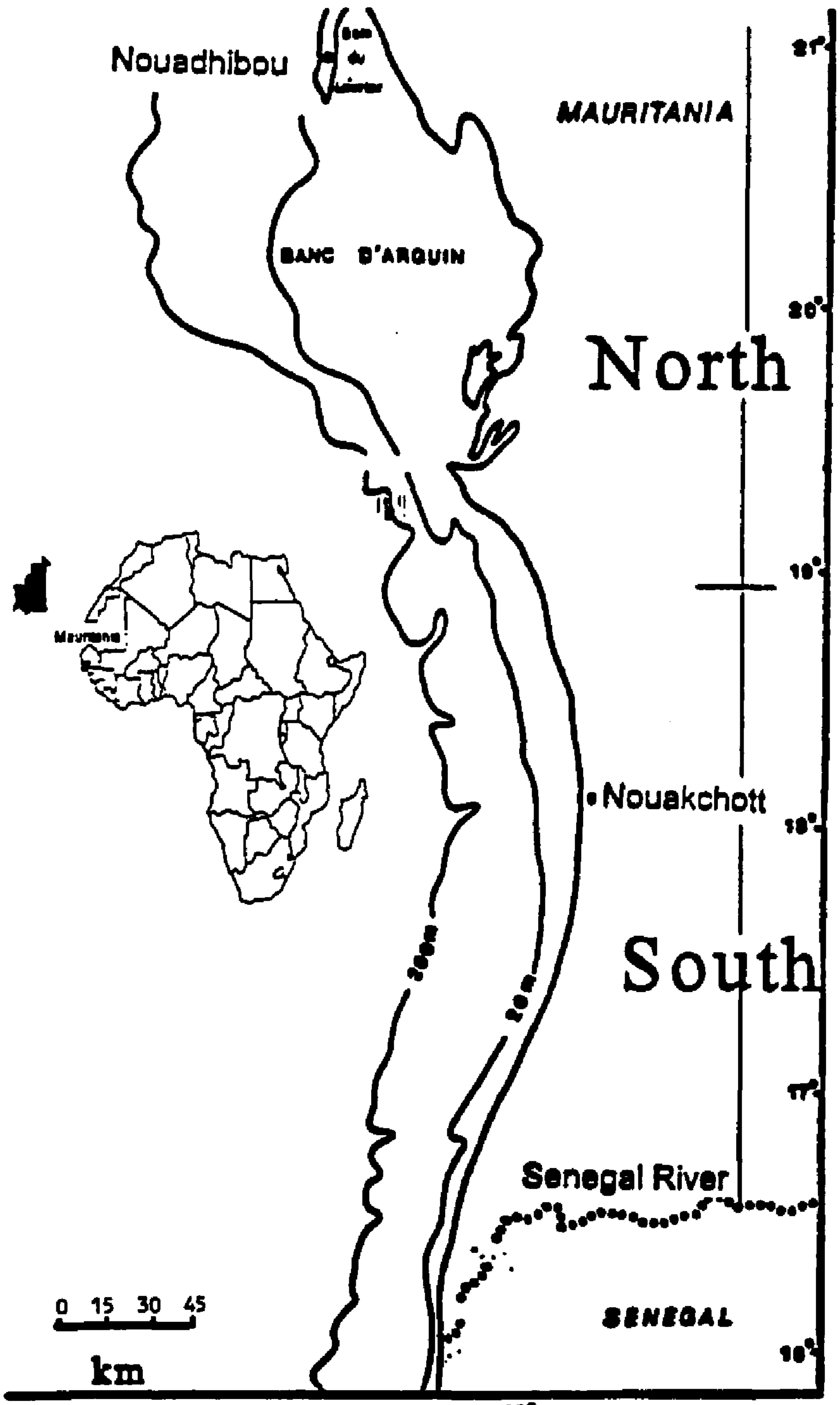


Figure 1.1. The study area (modified after Maigret and Ly, 1986).

Because the river runoff is limited to the southern extreme of the Exclusive Economic Zone (EEZ), i.e., Senegal River, the major source of terrestrial sediments appears to be airborne dust (Milliman, 1977; Szekielda, 1978). Atmospheric dust concentrations reach up to 1036 μg/m^3 and the yearly offshore transport of eolian dust is estimated to be between 15*10^6 and 65*10^6 mt/km of coastline (Lepple, 1975). These relatively high concentrations are mainly due to the presence of the Sahara Desert, which acts as a large reservoir for atmospheric dust. Clay mineralogy analysis of the < 2 μm fraction, which makes up more than 60% of the total dust material (Chester at al., 1972) indicates a composition dominated by illite (52%) and kaolinite (25%) with smaller amounts of chlorite and montmorillonite. Quartz, however, appears to be a major constituent (16%) of the bulk samples. These eolian dust concentrations are largely reflected in the marine sediments' composition, where concentrations of lutites average 50% (Domain, 1980). High organic content, a characteristic of upwelling regions, can be observed off Cape Blanc and surrounding Cape Timiris where concentrations reach up to 5% and 7%, respectively (Diester-Haass, 1978). Low concentrations of organic carbon are found near the coast and increase seaward. In this regard, Domain (1980) described the sediment cover from shore to offshore as being composed of sand (from 0 to 30-35 m depth), sandy silt (from 40 to 100-150 m) and silty sand (from 150 to 200 m and deeper). Coarse sands are usually associated with rocky outcrops on the shelf and appear at various latitudes. Generally, sands are

carbonate-rich. On the middle and outer shelves, relatively fresh bivalve shells and shell fragments are the dominant carbon components, while glauconite is the dominant component of the non-carbonate grains. In contrast, the inner shelf carbonate fraction is composed of echinoid spines and benthic foraminifera, while quartz and feldspar are dominant constituents of the non-carbonates (Milliman, 1977). As mentioned earlier, there is strong evidence that the terrigenous grains are derived from windblown solid material. In fact, their sizes are similar to those transported by winds and their location seems to coincide with high concentrations of atmospheric dust and suspended matter (Milliman, 1977). The input of sand and dust from winds can contribute significantly to the concentration of inorganic suspended matter in the water column (Chester et al., 1972; Milliman, 1977). Most of the organic material derived from eolian transport is resuspended within the water column by currents (see next section) and much of the remainder is reworked by benthic organisms. Thus, little of this organic material accumulates in the sediment (Milliman, 1977; Barber and Smith, 1981). A peculiarity is the Baie du Levrier where high concentrations of marine opal skeletons are observed in the bay sediments (Diester-Haass, 1978). The allochtonous or autochtonous nature of these particles, however, remains unanswered. In the southern limit of the Mauritanian shelf, there are appreciable amounts of mud, particularly between the 20 and 70 m isobaths, due to Senegal River runoff. Lutite concentrations in these fine-grained sediments reach up to 95 % (Domain, 1980).

METEOROLOGICAL ASPECTS

Mauritania is largely under the influence of strong northeast trade winds. There are three main factors that affect the climate off the Mauritanian coast: 1) the northeast high-pressure anticyclone called the Azores High, which drives equatorward winds over the Canary Islands region; 2) the Inter-Tropical Convergence Zone (ITCZ), the result of austral and boreal air mass convergence; and, 3) the nontropical, eastward-moving cyclones to the north of the trade winds region. These trade winds include continental trades known as Harmattan, which are distinct from the maritime trades. For a detailed analysis of the tropical atmospheric circulation, see Cool et al. (1974), Nieuwolt (1977), Wanthy (1983), and Hayward and Oguntoyinbo (1987). On a yearly scale, wind is mostly from the NNE and averages between 6 and 10 m/s in the northern part of the EEZ (Dubrovin et al., 1991). Seasonal variations in wind speed and direction are affected by seasonal meridional (south-north) shifts in the position of the Azores High and equatorial low pressure systems. During winter, the trade wind belt is located around 25-30°N, while the ITCZ moves northward to 2 °N. At this time pressure gradients are weak and, hence, so is the wind speed. In April-May, the Azores High moves southward and the size of the equatorial low pressure increases considerably because of spring/summer heating. As a result, pressure gradients increase as does wind strength. In August-September, the Azores High moves to its northernmost position and the trade winds weaken considerably.

Intra-monthly variations are mostly due to nontropical, eastward moving cyclones. Their interactions with high pressure modulate wind cycles from 2 to 6 days in length, depending on season (Cool et al., 1974; Romanov and Bishev, 1974). Winds are key factors driving physical processes in the Mauritanian EEZ and influencing seasonal upwelling variations.

PHYSICAL ASPECTS

Water masses

Numerous studies (Allain, 1970; Wozniak, 1970; Fraga, 1974; Peters, 1976; Tomczak, 1977 and 1982; Manriquez and Fraga, 1982; Barton et al., 1982;Tomczak, 1982; Fraga et al., 1985; Hagen and Shemainda, 1987; Dubrovin et al., 1991) have observed the following water masses on the Mauritanian shelf (Figure 1.2):

- Upwelling Water (UW) is cold water coming from great depths through the upwelling phenomenon.

- South Surface Water (SSW also known as Guinean Water) is warm (>26 °C) and moderately saline (35.3-35.7) surface water and forms a 30-40m thick layer. The northern edge of this water mass delimits the thermal front that is prominent around Cape Blanc in August-September. The SSW is separated from the SACW (see below) by a strong pycnocline.

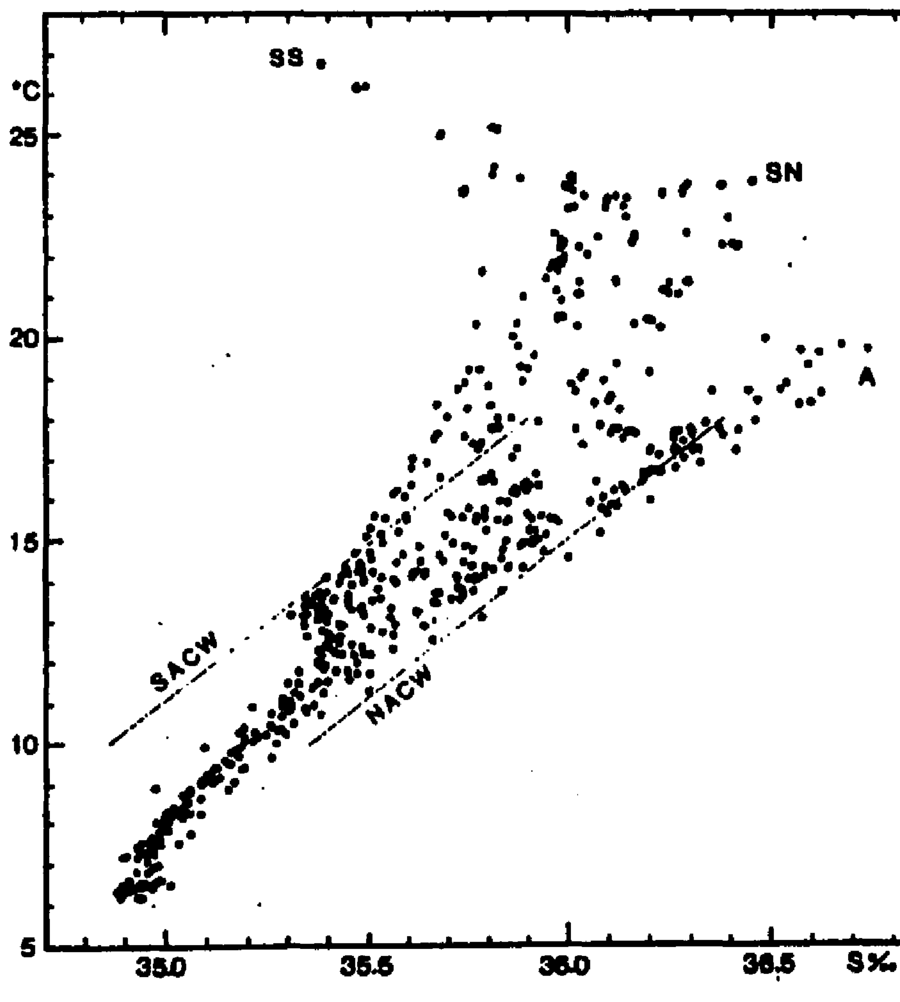


Figure 1.2. Sample temperature-salinity (T-S) diagrams (0-1000 m) in November 1975. NACW, North Atlantic Central Water; SACW, South Atlantic Central Water; SN, North Surface Water; SS, South Surface Water; A, Water with sinking properties (after Manriquez and Fraga, 1982).

- North Surface Water (NSW also known as Canarian Water) is formed by the southward flow of the Canary Current and is more saline (>36), colder and forms a much thicker (about 60 m) layer than SSW.

- North Atlantic Central Water (NACW) is located between 100 and 900 m depth, originates in the northern subtropical convergence, and flows southward.

- South Atlantic Central Water (SACW) is located between 100 and 600 m depth, originates in the southern subtropical convergence, and flows northward.

- Banc d'Arguin Water (BAW) is very warm, saline and is originally formed on the Banc d'Arguin area where it sinks off the shelf and is found at depths between 200 and 300 m. The extent of its distribution is, however, very limited.

- Water mass "A" is probably formed by the mixing of Canary Current water and the outer edge of the upwelling waters. Waters mass "A" then sinks and has properties similar to those of the upper layer of NACW.

The seasonal variation in these water masses indicates the following important shelf features (Figure 1.3, Dubrovin et al., 1991):

- In the northern part of the continental shelf (>19°30'N) during the warm season, there is an interaction of the NSW and SSW in the upper surface layer (50-70m). Below 100 m, the SACW and NACW mix. The SACW dominates down to a depth of approximately 300-400m, below which the NACW dominates. During the cold season, the NSW, SSW and NACW are present as distinct water masses

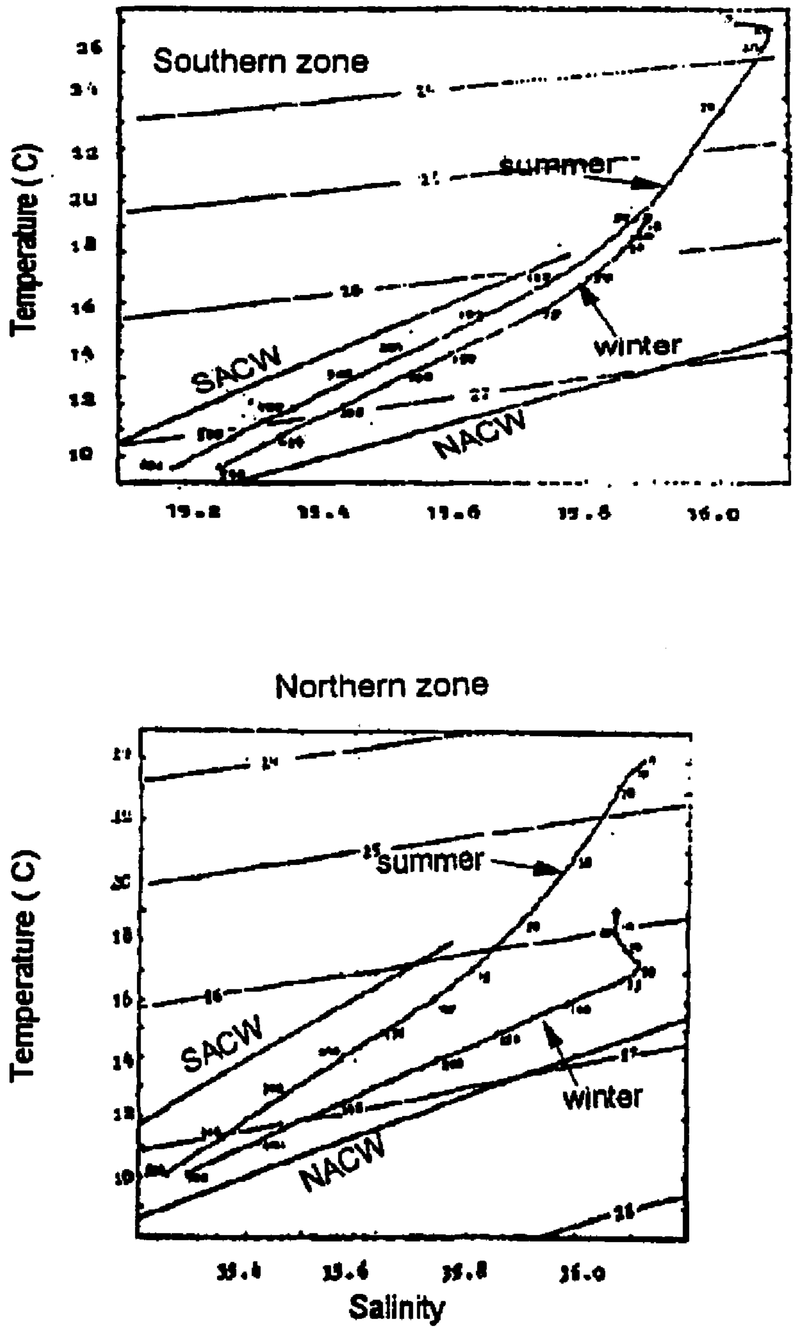


Figure 1.3. Sample T-S diagrams for the Mauritanian waters by hydrographic season and fishing zone; southern zone is shown at top and northern zone at the bottom (modified after Dubrovin et al., 1991).

with some mixing at the interfaces. At greater depths (>100m) the NACW largely dominates the SACW.

- In the southern part of the continental shelf (<19°30'N) during the warm season, there is an interaction of the NSW and SSW in the upper surface layer (20-30m). Below, there is mixing of SACW and NACW with SACW dominating the depths between 200 and 250 m. During the cold season, the NSW and SACW are observed in the surface layers, while in deeper layers there is an interaction between NACW and SACW with SACW dominating depths greater than 200 m.

Flow patterns: surface and sub-surface circulation

Offshore and along the outer northwest African shelf, a northern flow prevails. The flow is further enhanced by the meridional (latitudinal) large-scale pressure gradient in the eastern Atlantic (Fedoseev, 1970; Mittelstaedt, 1982 and 1983). This gradient, which is a persistent feature, is composed of a near-surface baroclinic component and a barotropic component (Mittelstaedt, 1983). The density gradient is due to latitudinal temperatures differences, the large amount of river discharge into the Gulf of Guinea, and high precipitation in coastal areas north of the Gulf. The barotropic component is associated with the compensatory flow due to the deflection of the Canary Current away from the coast around 20°N and the water mass excess created by the eastward transport of the Atlantic's Equatorial Countercurrent and Equatorial Undercurrent (Figure 1.4). Cape Blanc appears to represent the boundary for this northern flowing current.

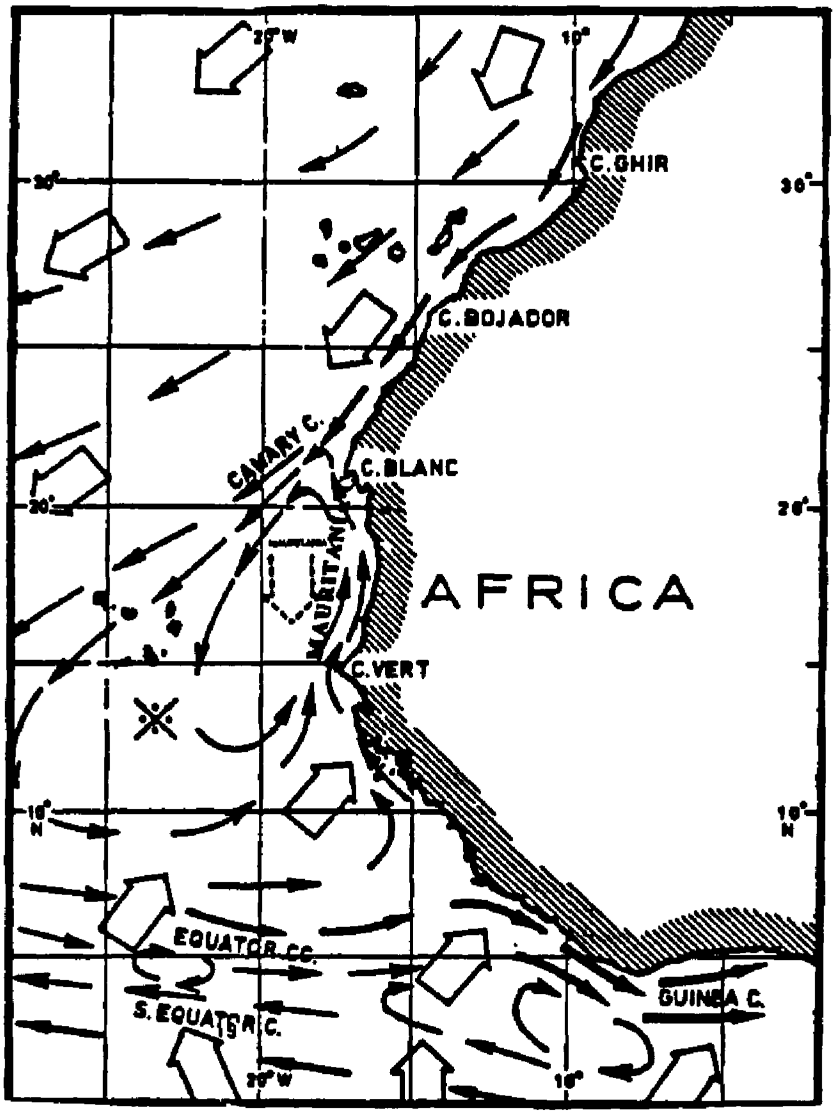


Figure 1.4. Idealized surface circulation during summer on the Northwest African shelf. Small black arrows indicate the directions of the major current systems within the area. Large open arrows denote the prevailing wind directions with moderate to strong wind speeds. Large broken arrow denotes intermittent changes in wind direction. Cross with 4 points denotes an area with weak and variable wind (modified after Mittelstaedt, 1983).

On the inner shelf, however, circulation generally favors the movement of surface waters southward towards the equator, i.e., in the direction of wind forcing, as long as the trade winds out of the N-NE (Figure 1.5) are well developed (Mittelstaedt, 1983). When the trades weaken, the southward flow turns into a northward flow at low latitudes (5-20°N). A very interesting feature of the interaction between the shelf and offshelf circulation is the number of quasi-permanent cyclonic gyres that are observed on the eastern border of the Canary Current. A cyclonic gyre is a permanent feature around Cape Blanc (Fedoseev, 1970; Mittelstaedt 1976 and 1983).

In the subsurface layers, an undercurrent also flows northward along the continental slope. This poleward current is characteristic of upwelling regions and was noticed in the Peruvian and Californian upwelling system (Smith, 1978; Neshyba et al., 1989). During the upwelling season, when the trade winds are strong, the subsurface undercurrent is absent from the continental shelf; and some evidence suggests that this undercurrent is the same as the subsurface countercurrent opposite to the southerly (equatorward) flow on the shelf driven by the trade winds (Mittelstaedt 1976 and 1983).

Although large-scale circulation along the Northwest African coast is well studied, the circulation over the Mauritanian shelf remains poorly understood. I present a generalized overview much of which is based upon Dubrovin et al. (1991).There is need to stress a strong northward flow, the Mauritania Current

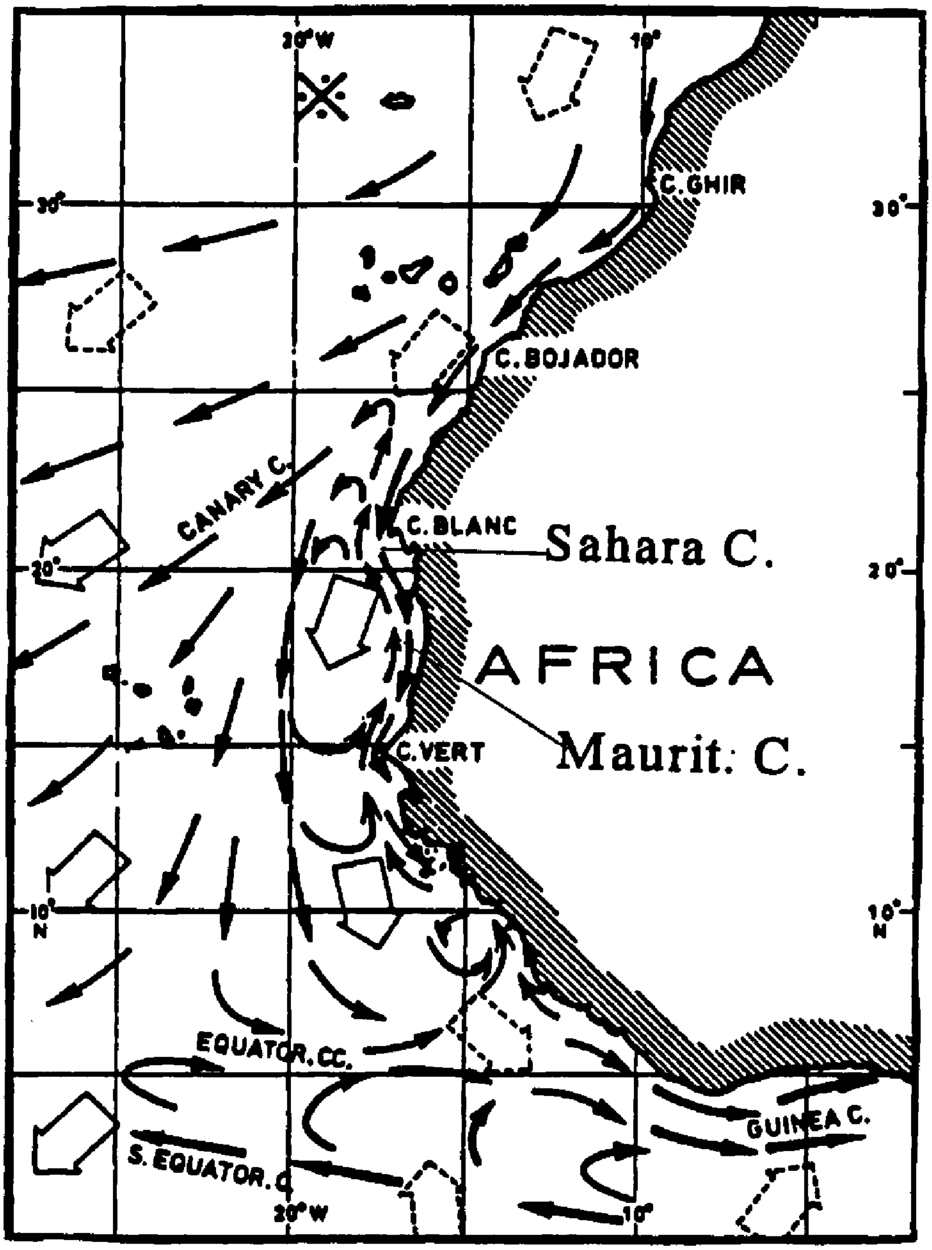


Figure 1.5. Idealized surface circulation during winter on the Northwest African shelf. Small black arrows indicate the directions of the major current systems. Large open arrows denote the prevailing wind directions with moderate to strong winds. Large broken arrows denote intermittent changes in wind direction and weak wind speeds. Cross with 4 points indicates an area with weak and variable winds (modified after Mittelstaedt, 1983).

(Figure1.5; Kirichek, 1971; Burkov et al., 1973; Bulatov, 1986). The origin of the Mauritania Current has been attributed in part to the northern branch of the eastward flowing Equatorial Countercurrent and the year-round northward flow produced by the meridional, large-scale pressure gradient in the eastern North Atlantic described above. During the warm water season (when the trade winds weaken), the Mauritania Current is very strong and extends over the whole area, including the continental shelf. On the shelf, two anticyclonic gyres are present between 17 and 19°N. Further north and offshore, another gyre, which probably delimits the boundary of the northward flow and the Canary Current, is observed. During the cold water season, the Mauritania Current is felt in the surface layers only south of 19°N. The shelf circulation is dominated by the trade-wind-induced, southward flow, the Sahara Current (Figure 1.5). At the boundary of the Mauritania and Sahara Currents, an anticyclonic gyre on the shelf occurs between 17 and 19°N. This circulation pattern is in agreement with geostrophic calculations and data measurements in the area (Fedoseev, 1970; Mittelstaedt et al., 1975; Mittelstaedt, 1983).

It should be emphasized, however, that this idealized scheme described above represents only average conditions; deviations and complexities are likely to occur at any specific time period.

Mesoscale circulation: the coastal upwelling

Upwelling is a process in which deep, usually nutrient-rich waters are brought to the surface. Hay and Brock (1992) define ten modes of upwelling: 1)

wind-driven coastal upwelling; 2) equatorial upwelling; 3) upwelling at oceanic divergences; 4) Kelvin-wave driven coastal upwelling; 5) upwelling from Ekman pumping; 6) bathymetry-driven upwelling; 7) upwelling through mesoscale and submesoscale cyclonic vortices; 8) upwelling from thermal domes; 9) current-induced upwelling; and, 10) upwelling from divergences within ocean currents. Although many of these modes can be found off the Mauritanian coast, our discussion will emphasize number one, the wind-driven coastal upwelling phenomenon. Longshore winds blowing equatorward along the eastern sides of northern hemisphere continents provoke a net offshore transport that is directed 90° to the right of the wind direction (Ekman, 1905). The offshore transport is directly proportional to the wind stress and inversely proportional to the Coriolis parameter (Sverdrup et al., 1942; Smith, 1968; Bishop, 1984). Because of continuity, offshore loss must be compensated by upwelled deeper water that is continually advected away from the area of upwelling by horizontal wind-driven flow. Studies of the Mauritanian upwelling have shown large dissimilarities within the EEZ that clearly demonstrate the mesoscale character of upwelling. For instance, observations indicate that near Cape Blanc, the upwelling occurs year-round, while south of Cape Timiris its duration is only 9 months (Schemainda et al., 1975). The hydrographic conditions in both areas seem to differ considerably as mentioned above.

North of Cape Blanc, direct current measurements on the shelf (21°40'N) indicate that the flow is essentially wind-driven and additionally enhanced by the

southward jet of the Canary Current or one of its branches (Mittelstaedt et al., 1975; Huyer, 1976; Barton et al., 1977; Halpern, 1977; Tomczak and Hughes, 1980). The depth of the upwelling water mass seems to be between 100 and 200 m (Barber and Smith, 1981) and the surface mixed layer often reaches the bottom of the inner shelf. The thickness of the offshore flow is about 10-35 m and the compensatory flow (onshore flow) seems to occur in a bottom Ekman layer. In fact, observations show the presence of strong bottom onshore and alongshore currents near Cape Blanc. These currents, while preventing an anoxic environment, are responsible for high sediment resuspension in the area. Sediments off Cape Blanc are mostly coarse and the water well-oxygenated (Rowe et al., 1977). A peculiarity of this ecosystem is that the classical poleward flow, mentioned earlier and noticed in other upwelling systems (e.g., off California and Peru), does not exist on the inner shelf.

Southward of Cape Blanc, the picture is likely to be more complicated by morphologic and bathymetric considerations. There are many prominent capes on the Mauritanian coast (e.g., Cape Blanc and Cape Timiris). In the lee of such capes, upwelling is generally greater than elsewhere in the neighboring areas (Mittelstaedt, 1983). Also, the deep canyons, which may act as channels for onshore flow, contribute considerably to upwelling water not only on the shelf but also nearshore, especially in the Banc d'Arguin area (Gostan and Guibout, 1974). On this flat, semi-enclosed bank, shallow depths and excessive heating cause the formation of warm and saline waters, the Banc d'Arguin water (BAW) mass. This

very dense water sinks below the much cooler upwelled water at its frontal zone, forming temperature inversions (Tomczak, 1973; Mittelstaedt, 1976, 1983 and 1991). At shallow depths, the BAW seems to flow southward; at greater depths (100-200 m), the water flows northward carried by the undercurrent along the continental slope (Peters, 1976; Mittelstaedt, 1983). Besides the presence of many canyons near Cape Timiris (Herbland, 1978), the southern part of the EEZ (south of 19°N) seems to have characteristics similar to those off the Peruvian coast (Barber and Smith, 1981; Gostan and Guibout, 1974). As in the north, the upwelling system may be confined to the shelf or extend as far as 50 km offshore (twice the shelf width) depending on the strength of the local winds. Poleward flow, however, appears to occur on this part of the shelf (Gostan and Guibout, 1974).

Sea surface temperatures (SST)

By analyzing monthly averages of sea surface temperature for one-degree squares along the eastern shore of the Atlantic between 7° and 44°N, Wooster et al. (1976) showed remarkable seasonality in the region's upwelling regime with a year-round cool water band near Cape Blanc. Upwelling appears to be present year round between 18°N and 30°N with maximum strength between 20 and 25°N (Buglakov et al., 1985). In a recent study, Dubrovin et al. (1991) calculated long-term, monthly mean SST for the Mauritanian shelf using a large grid of 20x20 minutes boxes, which is more representative of the mesoscale features of upwelling. Based on an objective analysis approach that took into account such criteria as zonal (onshore-offshore) and meridional (south-north) thermal gradients,

they found four distinct hydrographic seasons: a cold water season (January-May); a transitional cold-warm water season (June-July); a warm water season (August-October); and a transitional warm-cold water season (November-December).

The annual average SST of the continental shelf is 21°C while monthly means vary between 19 and 26 °C. During the cold water season, the whole shelf is invaded by cold water masses and the average SST is 18.4°C. In contrast, during the warm water season, the shelf is occupied by warm tropical waters (24-27°C) and the average SST is about 25°C. Seasonal amplitude of SST can vary up to 5 °C in the northern and up to 10 °C in the southern parts of the shelf. Continuous conductivity, temperature and depth measurements have demonstrated the patchy nature of the system, especially near Cape Blanc, where very complicated thermal, nutrient and chlorophyll concentration structures were observed (Tomczak, 1973, 1982; Weichart, 1974). Recent advances in satellite imagery have confirmed that rapid changes and strong water temperature gradients are permanent features of the Mauritanian EEZ (Szekielda, 1976; Van Camp et al., 1991; Cuq, 1993).

BIOLOGICAL AND CHEMICAL ASPECTS

Nutrient distributions

The Mauritanian shelf is characterized by interactions of water masses of different chemical and physical properties. The boundary limit between the NACW and SACW is located around Cape Blanc (Fraga, 1974; Manriquez and Fraga, 1982; Ilinas, Fraga and Barton, 1985). As such there are generally meridional and

zonal gradients in nutrient concentrations. The meridional gradient may be a reflection of differences in the proportions of NACW and SACW, the latter having higher nutrient concentrations. The zonal gradient most likely reflects coastal upwelling. Nutrients not only increase as one approaches the coast but also from north to south; and there appear to be wave-like shapes to the nutrient isopleths that have been attributed to upwelling, downwelling and internal waves (Weichart, 1974). Waters are usually much richer in nutrients south of Cape Timiris (19 °N) than north. Minas et al. (1982) indicate that phosphate and nitrate reach concentrations of about 1.5 and 20 μg-at/l, respectively. Extremely high phosphate concentrations have been observed in the waters near Nouakchott (known as the "Mauritanian dome"; Weichart, 1970, 1974). In addition to the advection of new nutrients into the area, many studies have emphasized the role played by zooplankton, phytoplankton, nekton and bacteria in regenerating nutrients (Leborgne, 1973 and 1978; Herbland and Voituriez, 1974; Smith et al., 1977; Whitledge, 1978; Blackburn, 1979; Coste and Minas, 1982; Smith and Whitledge, 1982). High concentrations of silicic acid, a limiting nutrient for diatoms which usually dominate upwelling areas (Strickland et al., 1969), are found in the Mauritanian upwelling (Nelson and Goering, 1978). The presence of diatom frustules in suspended particles and their absence from bottom sediments suggest regeneration within the water column (Milliman, 1977). Likewise, water column ammonium concentrations are high both before and after phytoplankton blooms (Herbland and Voituriez, 1974; Leborgne, 1978). In the Mauritanian dome, nutrient

concentrations remain high at the surface up to 120 miles offshore (Minas et al., 1982).

Plankton abundance and distribution

As noted earlier, the physical processes in the Mauritanian EEZ create strong meridional and zonal thermal gradients, especially in the Cape Blanc area. Despite the high levels of nutrients, chlorophyll concentrations and primary production levels are generally low. This low production mostly noticed north of Cape Blanc may be attributed to mixing and light penetration (Kullenburg, 1978; Morel, 1978, 1982). Packard (1979) showed that the ratio of compensation depth to mixed layer depth is around 0.7 over the northern Mauritanian shelf. Also, high concentrations of suspended matter may limit light penetration, especially inshore (Huntsman and Barber, 1977). Other authors report grazing as a potential cause for the observed low phytoplankton biomass (Packard and Blasco, 1974; Smith et al., 1977). Interestingly enough, some studies report very high chlorophyll concentrations near Cape Blanc (Gillbricht, 1977) and around the latitude of Nouakchott (Herbland et al., 1973; Walsh, 1976). A potential reason for these high concentration values may be the circulation pattern (advection cells) which may create favorable conditions for the aggregation of phytoplankton.

The interaction of the Mauritania and Sahara Currents results in the simultaneous presence of both cold and warm water species of phytoplankton and zooplankton. The phytoplankton community consists mostly of diatoms and flagellates (Reyssac, 1976, 1977; Bak and Nieuwland, 1993). The zooplankton

community seems to consist predominantly of copepods on the shelf and euphausiceans and thaliaceans on the slope (Blackburn, 1979; Kuipers et al., 1993).

CONCLUDING REMARKS

The Mauritanian EEZ is the site of very complex hydrographic and meteorologic processes. The area north of Cape Timiris seems to be much less unstable than the area south of it. Full understanding of the Mauritanian upwelling is still lacking despite the considerable number of scientific expeditions to the area of Cape Blanc and Cape Timiris in the 1970's. Because upwelling is inherently a mesoscale phenomenon, it is important to bear in mind that the results of such studies characterize the conditions only within the limited temporal and spatial scales of a particular study. Unfortunately, a simplified two-dimensional scheme (i.e., neglecting the alongshore component) is often used to describe the upwelling (Huyer, 1976; Halpern, 1977; Smith, 1981). This implies that the depth-integrated onshore-offshore flow must be zero (Brink, 1985). When one considers heat (Bryden et al., 1980; Richman and Badan-Dangon, 1983) and momentum (Allen and Smith, 1981) balances, however, the two-dimensionality of the system becomes highly questionable (Hagen and Gurina, 1985). In fact, the three-dimensionality of the flow fields and their highly time-dependant nature, as indicated by Eulerian and Langragian current measurements (Hagen and Gurina, 1985) directly contributes to the highly irregular paths followed by individual parcels of upwelled water, i.e., patchiness (Brink, 1985). In addition, bathymetry

plays an important role in the production of mesoscale upwelling structures because the potential vorticity is not locally conserved (Brink, 1985). Nonetheless, I have synthesized a macroscale picture for the area which might represent a qualitative description of the system as it is presently understood.

Mixing between the cold Sahara Current waters and the warm Mauritania Current surface waters, as well as the wind-induced coastal upwelling process, creates a unique environment favorable for the spawning and survival of many temperate and tropical species on the Mauritanian shelf and in adjacent coastal areas (Banc d'Arguin). As a result, a number of commercially-important neritic species and demersal species are found in this area. Knowledge of the oceanographic conditions is crucial to better management of these resources. In this regard, the next chapter explores the hydrographic conditions that have prevailed in the Mauritanian EEZ during the recent decades which are of interest to the fisheries in the area.

CHAPTER 2
Spatial and Temporal Trends of Sea-surface Temperature and Wind Patterns

INTRODUCTION

The richness of the Mauritanian ecosystem is due to the interaction of a number of bathymetric and hydrometeorologic factors, in particular upwelling (Boje and Tomczak, 1978; Richards, 1980; Longhurst, 1981). Pelagic fish in general, and clupeoids in particular, are known to closely respond to variations in their environment (Csirke and Sharp, 1984). As such, a clearer understanding of the pelagic fishery can be reached by studying the hydrographic conditions in the area.

The objective of this chapter is to explore the structure and timing of the seasonal cycles of temperature and wind in order to describe the hydrographic conditions that prevail in the Mauritanian EEZ. Other aspects of the seasonal cycle which are relevant to the pelagic fishery, are also analyzed, i.e., annual variability in the seasonal cycle and long term fluctuations in wind and sea surface temperature (SST) patterns. The main focus is to identify any recent changes in the upwelling regime which could potentially impact fish populations. The SST on the continental shelf and wind data from coastal stations are examined to characterize spatial and temporal variabilities and trends.

MATERIAL AND METHODS

Water temperature data were mainly extracted from the database of the National Center for Fisheries and Oceanography ("Centre National de Recherches Océanographiques et des Pêches" or CNROP), Nouadhibou, Mauritania. Additional data were obtained from the National Oceanographic Data Center (NODC), Washington, D.C., USA. These data contain measurements made by scientific research vessels (national and international) and by vessels engaged in regional industrial fishing. Because of the many gaps in these data, I restricted the period of the first portion of the study from 1985 to 1993. For SST 31,828 observations were used (Table 2.1). At first, data were analyzed separately according to their origin, i.e., research or fishing vessel, because of the respective qualities of the data. Data were checked for grossly erroneous values and duplicate observations. Based on mean squared error, I determined that collapsing these data does not increase the margin of error considerably. I then divided the continental shelf into 20 minutes of longitude and latitude grids or squares (Figure 2.1). Monthly and annual SST values were calculated for each square and used for all further calculations. I then partitioned the shelf into two areas, north and south of the 19° meridian, and the year into four hydrographic seasons according to Dubrovin et al. (1990,1991): cold water season (January-May); transitional cold-warm water season (June-July); warm water season (August-October) and; transitional warm-cold water season (November-December).

Table 2.1. Number of observations for SST data on the Mauritanian shelf by the 20' x 20' squares and month (1985-1993). Location of the squares is shown in Figure 2.1.

Square	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
11	7	13	9	23	13	18	5	0	0	0	0	0	88
12	44	89	152	356	219	154	0	0	5	17	0	6	1042
21	32	35	55	125	76	39	0	0	6	14	0	19	401
22	48	73	67	190	157	130	0	0	0	0	0	24	689
30	0	6	9	0	0	0	0	0	7	0	0	0	22
31	94	126	234	215	255	124	6	0	14	0	8	39	1115
32	17	29	25	68	57	59	0	0	0	0	0	21	276
40	11	31	12	20	19	6	0	0	7	0	5	0	111
41	80	185	169	280	391	327	5	0	7	5	9	95	1553
42	0	10	0	0	21	8	0	0	0	0	0	0	39
50	38	58	86	79	54	20	0	0	16	23	20	18	412
51	135	167	208	278	470	423	0	0	9	0	9	90	1789
60	88	99	96	74	30	39	7	0	74	69	60	57	693
61	138	169	237	233	295	397	24	0	34	12	26	139	1704
70	5	28	23	5	0	0	6	0	15	15	18	8	123
71	176	183	173	176	248	298	48	5	89	59	113	167	1735
72	0	8	14	27	46	13	0	0	0	0	0	0	108
80	7	6	8	0	0	0	0	0	0	0	0	0	21
81	411	214	300	211	97	128	81	8	87	61	171	151	1920
82	74	40	69	155	156	126	44	0	8	5	19	22	718
91	157	49	96	92	49	17	12	0	36	16	22	15	561
92	213	188	311	292	211	253	126	50	78	72	110	82	1986
102	93	113	198	104	104	79	90	158	251	103	49	43	1385
103	20	41	60	163	125	120	133	37	25	46	31	27	828
112	5	5	11	0	5	10	0	0	21	5	0	0	62
113	45	72	133	156	107	80	155	282	167	105	110	34	1446
114	33	34	95	79	46	54	194	183	85	65	49	35	952
123	38	50	40	27	16	19	14	97	36	40	32	5	414
124	287	393	346	328	95	52	665	925	428	310	220	170	4219
133	156	144	135	53	23	36	95	122	74	188	192	126	1344
134	300	463	386	165	83	31	461	485	490	423	283	181	3751
143	16	16	39	31	31	24	32	25	19	17	20	20	290
144	0	7	0	0	0	0	0	0	0	6	12	6	31
ALL	2768	3144	3796	4005	3499	3084	2203	2377	2088	1676	1588	1600	31828

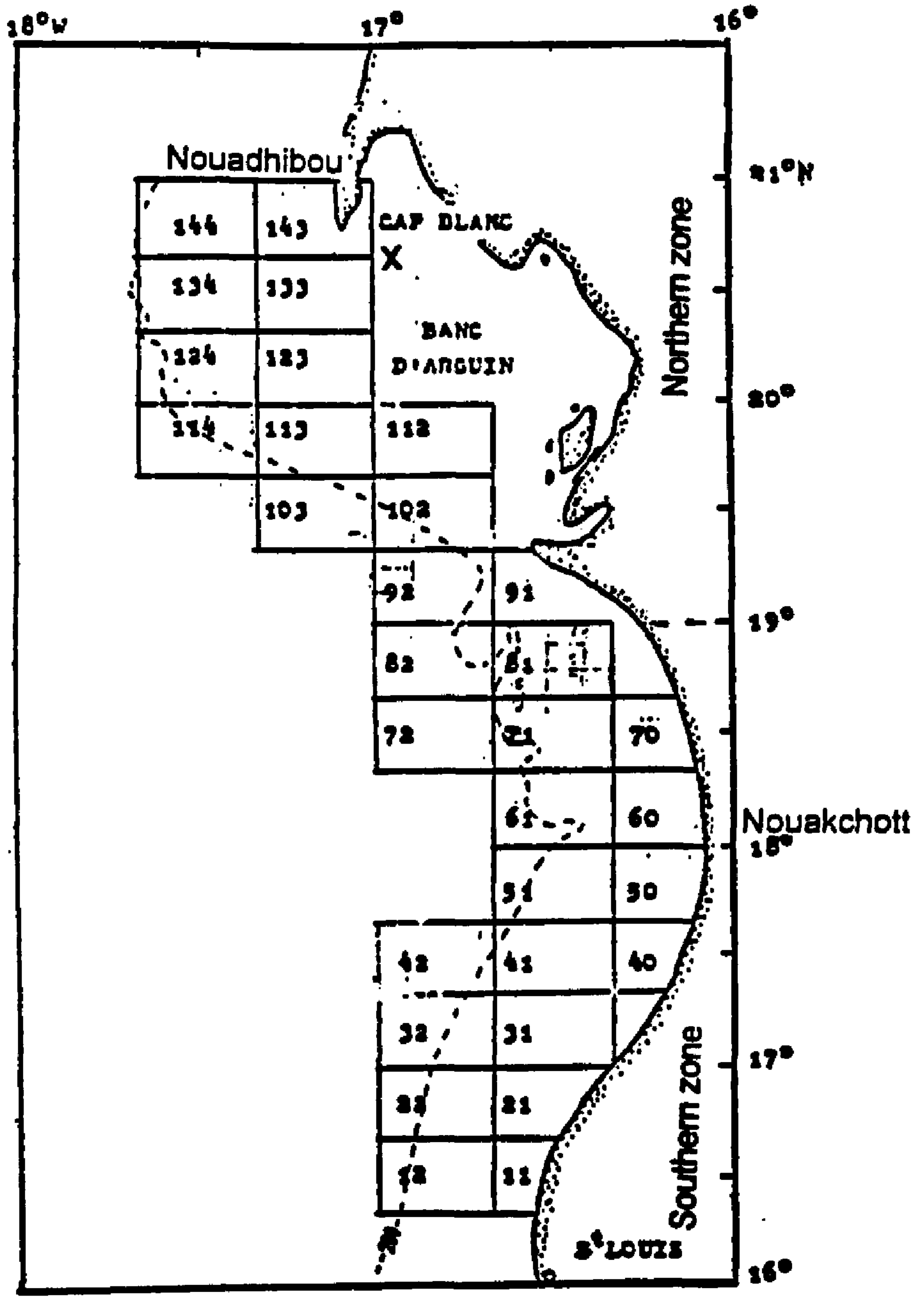


Figure 2.1. Geographic location of the 20' X 20' squares. The X represents the Bayadere coastal station. Also noted are the northern and southern zones on either side of the 19°N meridian.

Furthermore, long-term average SST have been derived and were used to determine water temperature temporal and spatial anomalies. Also, bottom water temperature data from a coastal station, Bayadere (20°40'N-17°04'W; Figure 2.1), were extracted from the CNROP database. This coastal station is known to represent typical upwelling variations in the northern part of the Mauritanian EEZ (Arfi, 1985, 1987; Loktionov, 1989).

Wind data have been obtained from the meteorological stations of Nouadhibou (21°N17°W) and Nouakchott (18°N16°W; Figure 2.1) for the period 1960-1993 (Agence pour la Sécurite de la Navigation Aérienne en Afrique - ASECNA). These wind data consist of 8 daily observations sampled at 3 hours intervals. For these two stations, which we assume represent the conditions in the northern (Nouadhibou) and southern (Nouakchott) parts of the EEZ, daily, monthly and yearly Ekman transports are estimated (see Bakun, 1973; Bakun et al., 1976; Wooster et al., 1976). First, the tangential wind stress (τ_y; metric tons/ second per 100 m of coastline) is calculated:

$$\tau_y=\rho_a\, C_D\, v(u^2+v^2)^{1/2} \qquad (1)$$

where ρ_a is air density ($1.22*10^{-3}$ g/cm^3);
C_D is an empirical drag coefficient ($1.05*10^{-3}$);
v is the component of tangential (alongshore) observed wind speed (ms^{-1}); and
u is the component of perpendicular (cross-shore) observed wind speed (ms^{-1}).

Then the surface Ekman transport also denoted as the Coastal Upwelling Index (CUI; m^3.s^{-1} per 100 m of coastline) was estimated by using:

$$CUI = \tau_y/f \qquad (2)$$

in which τ_y is the tangential wind stress;
f (the Coriolis parameter) $=2\Omega \sin\varphi$;
φ is latitude of the given station; and
Ω is the Earth rotation constant ($0.729 \cdot 10^{-4}$ s^{-1}).

Trend analysis was conducted on yearly CUI and water temperature values using the Seasonal Kendall Test (SKT) for trend (Hirsh et al., 1982). This nonparametric procedure is suitable because it is believed to be robust against outliers, collinearity and seasonality (Hirsh et al., 1982). Long term trends as well as large scales feature in SST were also investigated using the Comprehensive Ocean Atmosphere Data Set (COADS). These data consist of monthly SST measurements made around the shipping lanes in the Atlantic and averaged in 2° x 2° squares. More than one million observations were collected in the study area selected here which covers from 10 °N to 30 °N for about 43 years (1946-1988). Empirical Orthogonal Function (EOF) analysis of the data set was conducted using PRINCOMP (SAS, 1989). The EOF is a multivariate technique useful for data and trend reduction which enables highly correlated variables to be reduced to a small number of orthogonal functions (Preisendorfer and Mobley, 1988; Johnson and Wichern, 1992). This reduction technique is frequently applied to oceanographic and meteorologic data (Craddock, 1965; Kundu and Allen, 1976; Wang and Walsh, 1976; Weare, 1977; Servain and Legler, 1986). Whether the phenomena observed at local coastal stations were reflected at larger scale (the above defined squares) was investigated using Kendall Rank correlation coefficient (Conover, 1980) as well as regression techniques (Myers, 1986).

Finally, a Fourier analysis (Stuart, 1961; Chatfield, 1980) was performed on monthly SST means to investigate possible periodicities in the data.

RESULTS AND DISCUSSION

Wind pattern

At Nouadhibou, monthly wind speed varies from 6 to 9 m/s. The highest wind speeds are observed in May-June and the lowest in November-December (Table 2.2). During most of the year, wind direction is northerly (90 % from NNW-N-NNE (Table 2.3). From December to February, winds from the northeast or north prevail. In spring, wind direction shifts to northerly and dominates April to June. From July to September, a northwesterly component becomes visible. By October winds from the northeast direction start to develop again. At Nouakchott, average monthly wind speed is much less than at Nouadhibou and ranges from 3 to about 6 m/s (Table 2.4). Also, wind direction is much more variable with only 55% coming from a northerly direction (NNW-N-NNE). The WSW component contributes 10% to the wind spectrum during the year (Table 2.5).

The CUI closely follows the wind patterns. In the northern part of the EEZ, the mean wind stress has a component from the north favorable for the development of year-round coastal upwelling, with maximal intensity from March to July (Tables 2.2 and 2.4; Figures 2.2 and 2.3). In the southern part of the EEZ, the CUI is much lower than in the north because of the reduction in wind speed

Table 2.2. Monthly mean wind speed (V;m/s), its standard deviation (STD) and alongshore component (UY;m/s) and Coastal Upwelling Index (CUI; $m^3.s^{-1}$ per 100m of coastline) at Nouadhibou.

MONTH	V	STD	UY	CUI
1	6.14	1.73	-4.98	97
2	6.9	1.02	-6.40	149
3	8.28	1.24	-7.67	199
4	8.39	0.82	-8.07	205
5	9.04	0.82	-8.77	237
6	9.22	0.58	-9.05	252
7	8.23	0.38	-7.72	201
8	7.54	0.56	-6.69	163
9	7.64	0.69	-7.06	173
10	7.46	0.94	-7.00	161
11	6.39	0.83	-5.77	115
12	6.17	1.09	-4.79	94

Table 2.3. Percent frequency of observed wind direction at Nouadhibou*.

	Month												
Wind direction	1	2	3	4	5	6	7	8	9	10	11	12	year
ENE	18	6	5	0	1	0	0	0	0	0	12	19	5
NNE	64	59	45	27	19	25	8	2	14	16	42	57	32
NNW	13	29	46	69	80	74	83	85	79	80	44	15	58
WNW	1	3	2	4	1	1	6	9	2	2	2	1	3
WSW	4	2	1	0	0	0	1	2	2	1	1	5	1
SSW	1	1	2	0	0	0	2	2	2	2	0	2	1
SSE*	-	-	-	-	-	-	-	-	-	-	-	-	0
ESE*	-	-	-	-	-	-	-	-	-	-	-	-	0

* The SSE and NNE acounted for less than 1% and were rounded to zero.

Table 2.4. Monthly mean wind speed (V;m/s), its standard deviation (STD) and alongshore component (UY;m/s) and Coastal Upwelling Index (CUI; $m^3.s^{-1}$ per 100m of coastline) at Nouakchott.

MONTH	V	STD	UY	CUI
1	4.91	1.04777	-2.16548	23
2	4.12	0.47631	-2.55131	30
3	4.82	0.46101	-3.20527	44
4	5.21	0.26208	-4.36578	67
5	5.31	0.29884	-4.65011	73
6	4.9	0.84060	-3.49244	55
7	4.41	0.58758	-2.38177	27
8	3.95	0.45576	-1.33258	20
9	3.08	0.29482	-1.12878	17
10	3.73	0.47625	-3.01677	35
11	3.92	0.53717	-2.34711	25
12	5.01	0.36313	-1.23570	12

Table 2.5. Percent frequency of observed wind direction at Nouakchott*.

	Month												
Wind direction	1	2	3	4	5	6	7	8	9	10	11	12	year
ENE	51	30	26	12	0	0	2	1	1	15	36	58	20
NNE	30	39	39	26	22	10	3	3	10	31	42	14	23
NNW	12	17	26	58	68	56	37	20	27	43	16	5	32
WNW	0	5	0	1	9	24	48	52	36	6	0	0	14
WSW	8	8	10	3	2	10	10	18	21	2	6	23	10
SSW	0	1	0	0	0	0	0	5	6	2	1	0	1
SSE*	-	-	-	-	-	-	-	-	-	-	-	-	0
ESE*	-	-	-	-	-	-	-	-	-	-	-	-	0

* The SSE and NNE acounted for less than 1% and were rounded to zero.

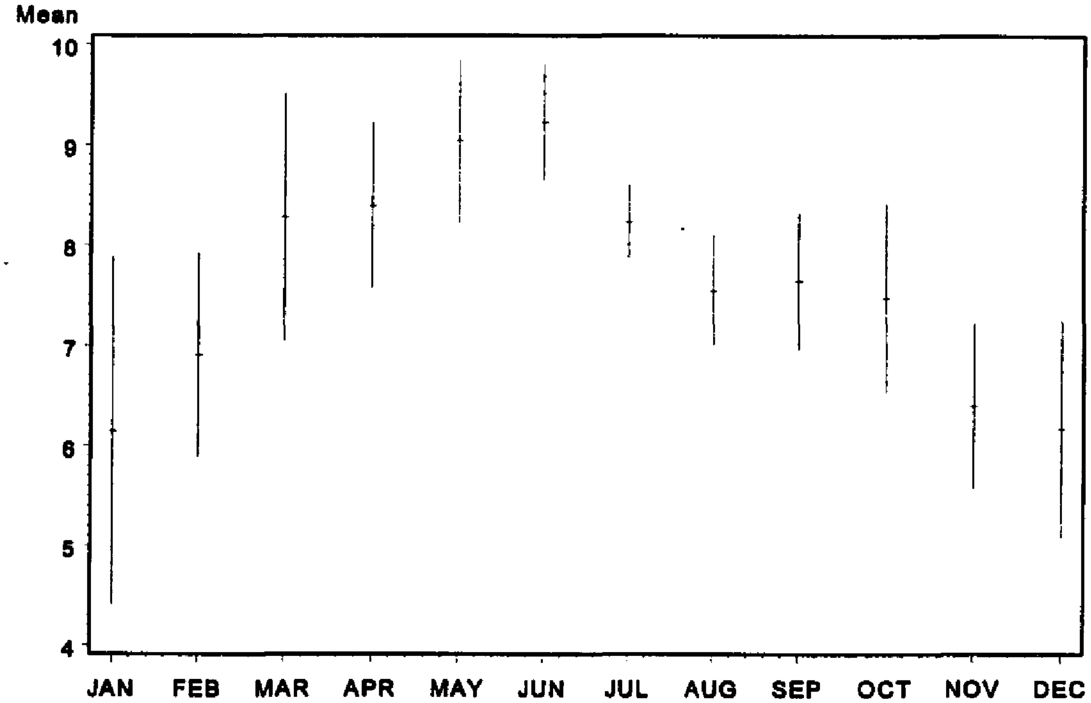


Figure 2.2. Average monthly wind speed (m/s) at Nouadhibou. Also shown are standard deviations bars.

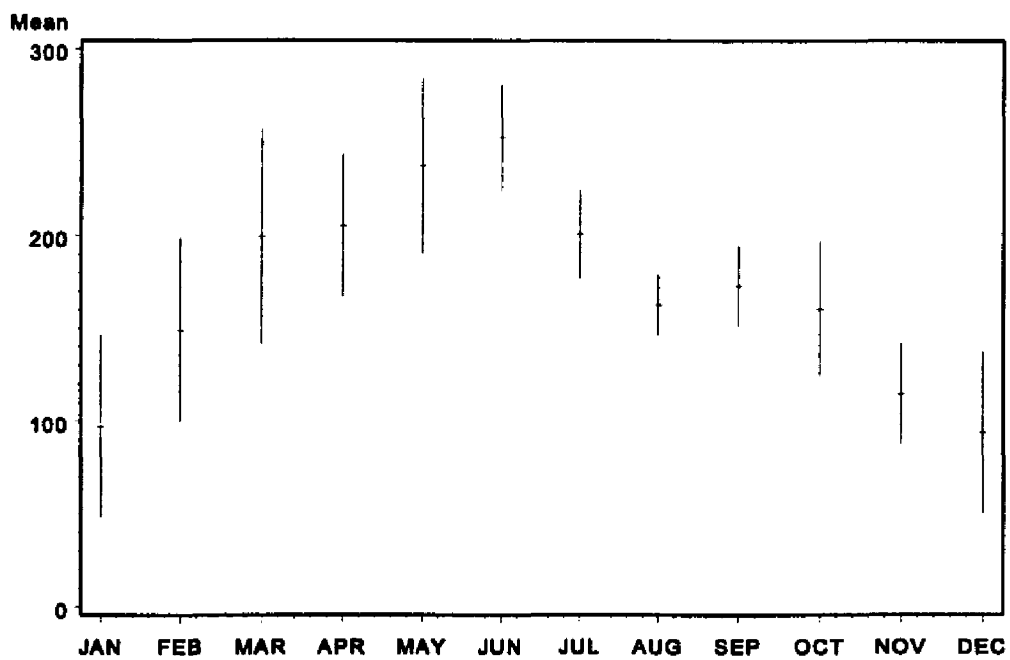


Figure 2.3. Average monthly Coastal Upwelling Index (m^3/s per 100 m of coast) at Nouadhibou. Also shown are standard deviations bars.

and increased directional variability (Tables 2.3 and 2.5; Figures 2.4 and 2.5). In fact, the trade winds favorable for the development of upwelling are more consistent in the northern part of the EEZ year round. In the southern part, they weaken considerably, especially around July. Variability in wind speed and direction is mostly affected by the position of the Azores High pressure anticyclone system and the Inter-Tropical Convergence Zone (ITCZ; see previous chapter). During December and January, the trade wind belt is located around 25-30°N, while the ITCZ moves northward to 2-5°N. At this time, atmospheric pressure gradients are weak and, hence, the wind speed is also. From February to June, the ITCZ continues to move northward, while its size increases considerably because of spring/summer heating, and the Azores High Pressure anticyclone moves southward. As a result, pressure gradients increase as does wind strength. Beginning in July, and especially in August-September, the Azores High Pressure System moves to its northernmost position and the trade winds weaken considerably. During this period, which corresponds to the rainy season, we observe the apparition of a wind coming from the south and associated with the monsoons (Nieuwolt, 1977; Wanthy, 1983).

Intra-monthly variations were not investigated here but are mostly due to nontropical, eastward moving cyclones (sometimes called easterly waves). Their interactions with the ambient high pressure modulate wind cycles from 2 to 6 days, depending on season (Cool et al., 1974; Romanov and Bishev, 1974). Previous

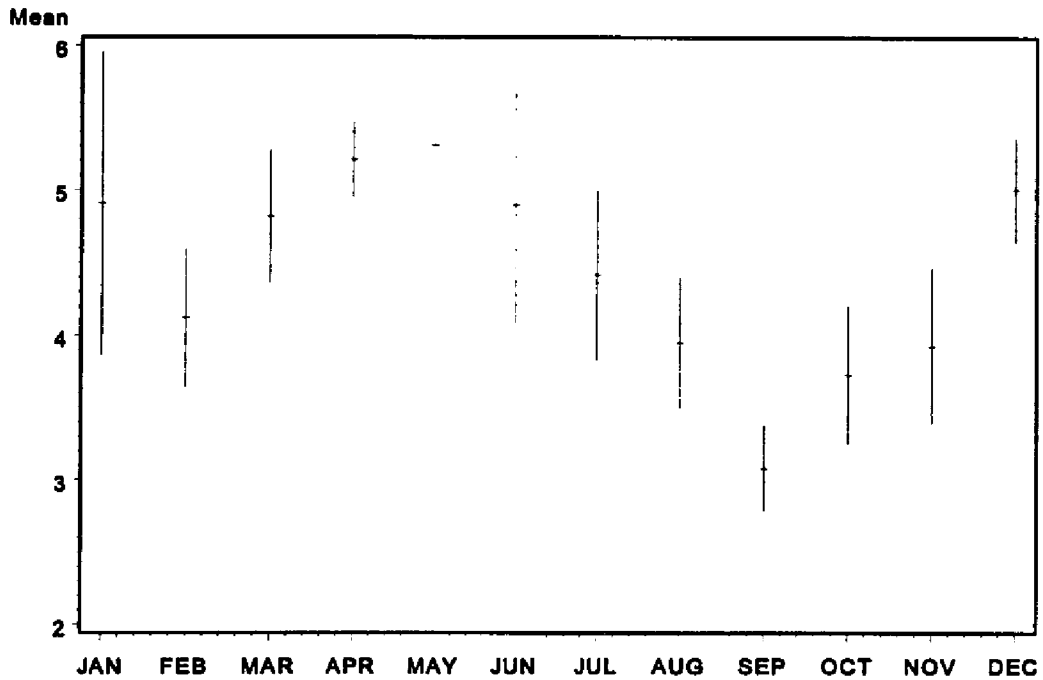


Figure 2.4. Average monthly wind speed (m/s) at Nouakchott. Also shown are standard deviations bars.

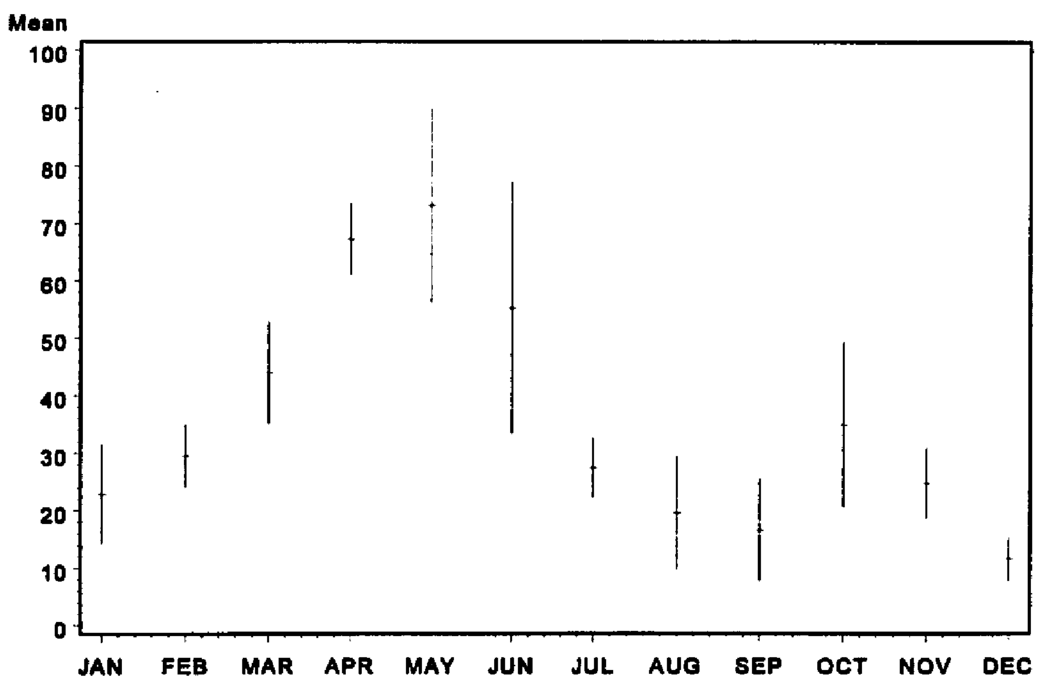


Figure 2.5. Average monthly Coastal Upwelling Index (m^3/s per 100 m of coast) at Nouakchott. Also shown are standard deviations bars.

studies of wind stability indicate that during most of the year winds stronger than 8 m.s^{-1} last only for 3-5 days on average (Ould-Dedah, 1993). From April to June, however, they last for 14 days on average. During this period weaker winds ($\leq$8 m.s^{-1}) are of short duration (Ould-Dedah, 1993).

Upwelling yearly mean intensity in the northern EEZ did not show a statistically significant trend during the period 1960-1993 (Figure 2.6). Bottom water temperatures at the Bayadere coastal station (1963-1988) show similarities with the upwelling intensity. Bottom water temperatures appear to be colder at times of high CUI values and warmer at times of lower CUI values. However, when analyzing monthly CUI values over the period of the study (Figure 2.7), a downward trend is observed; the SKT yielded the statistic S'=-536 and var(S')=46122, (Z'=2.7; P$\leq$0.004; see Hirsh et al., 1982). In a similar study, Arfi (1985, 1987) indicated that the upwelling intensity showed important fluctuations over the period 1950-1982. He identified a first phase (1955-1960) where strong upwelling intensity occurred and a second phase (1960-1969) with minimal intensity which was followed by a period of irregularities that showed a return to initial conditions.

During the last decade (1983-1993) which is of particular interest to the present study, it seemed that, on first examination, the northern station did not show any trend. A closer investigation, however, revealed that the upwelling intensity increased from 1983 to 1988 (S'=36; Z'=1.89) and then decreased after 1990 (S'=-26; Z'=-2.7). A downward trend in the upwelling intensity occured at the

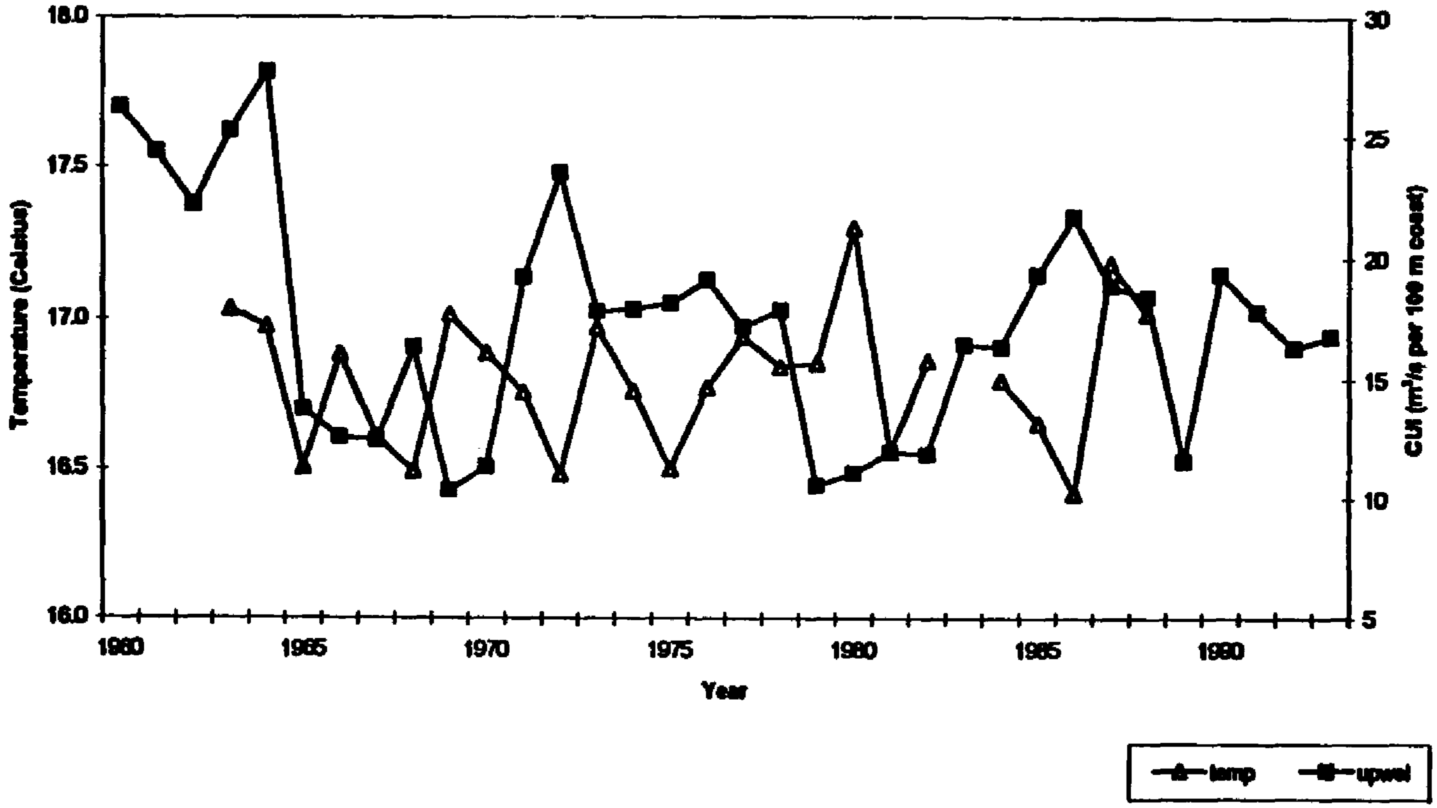


Figure 2.6. Yearly average bottom water temperature (°C) at Bayadere (1963-1988) and coastal upwelling index (m^3/s per 100 m of coastline) at Nouadhibou (1960-1993).

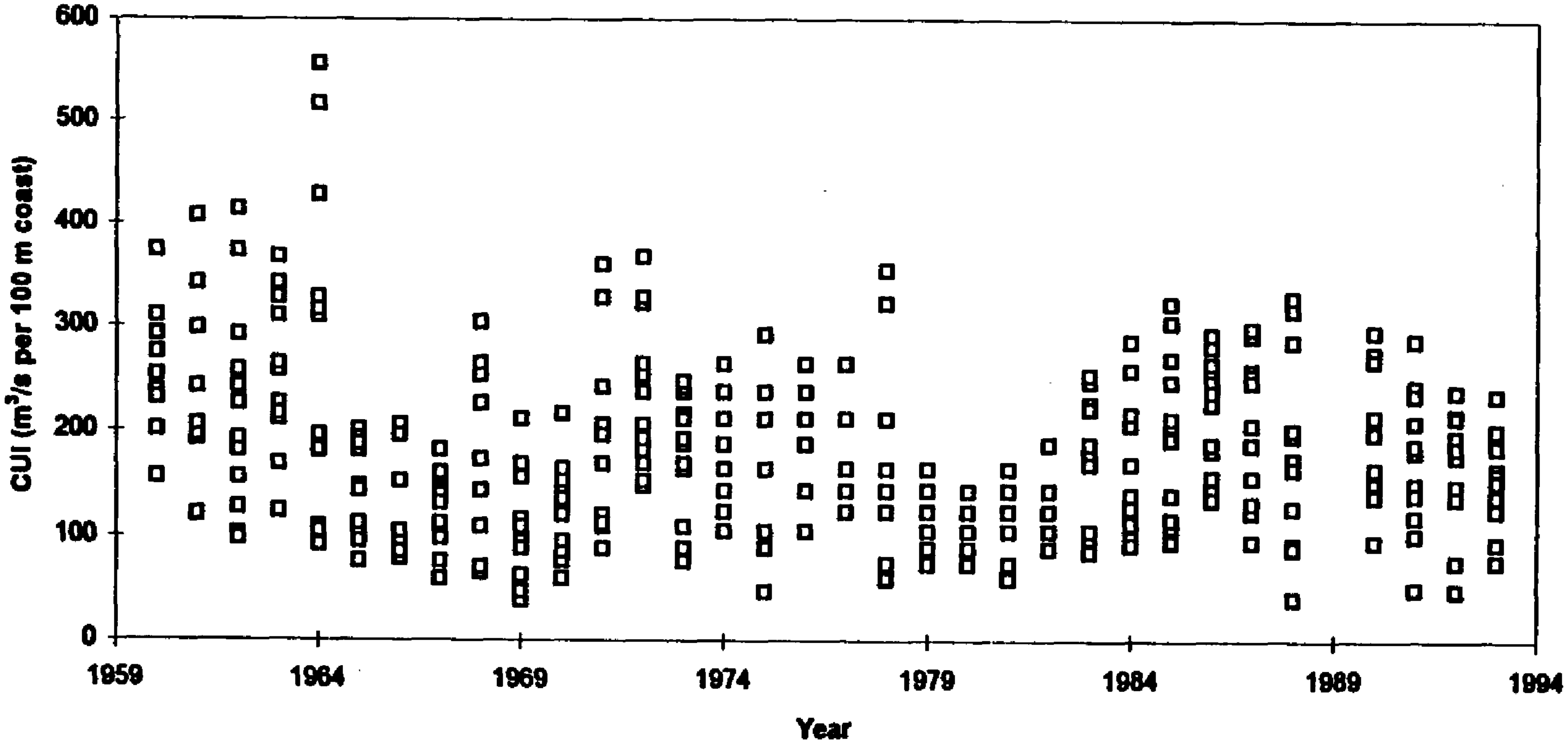


Figure 2.7. Average monthly Coastal Upwelling Index values at Nouadhibou (1960-1993).

southern station (Nouakchott) from 1985 to 1991 (S'=-54; Z'=-3.27). Previous studies using the same data set have indeed suggested an increase of upwelling intensity between 1983 and 1986 (Tchernikov and Chavance, 1988; Loktionov, 1989).

Sea surface temperature

Average monthly SST exhibit a strong seasonal pattern in both the northern and southern zones (Figure 2.8). From January to May cold waters are observed over the whole continental shelf. Later in the year, SST increases to a maximum around August-September (warm season) and then drops quickly toward the end of the year. On average, the northern zone has much colder SST than the south (Figure 2.8). The seasonal warming-cooling cycle and north-south (meridional) gradient are consistent with the physical processes active in the area. At the beginning of the year, upwelling is very intense and the southward-flowing, cold Sahara Current invades the shelf. This period is generally characterized by relatively weak SST variability (Loktionov, 1989; Dubrovin et al., 1991). Average SST is 18.4°C for the whole shelf (standard deviation ± 0.94 °C; Table 2.6). Beginning in June, SST rises due to increased solar radiation and a change in the upwelling intensity, especially in the southern part of the EEZ, where the strongest thermal gradients are observed (Dubrovin et al., 1991; Loktionov, 1989; Loktionov et al., 1989). During the warm season (July-October) the trade winds favorable to the development of upwelling weaken and the inner and outer shelves are occupied by a warm, northward-flowing current, the Mauritania Current. Average

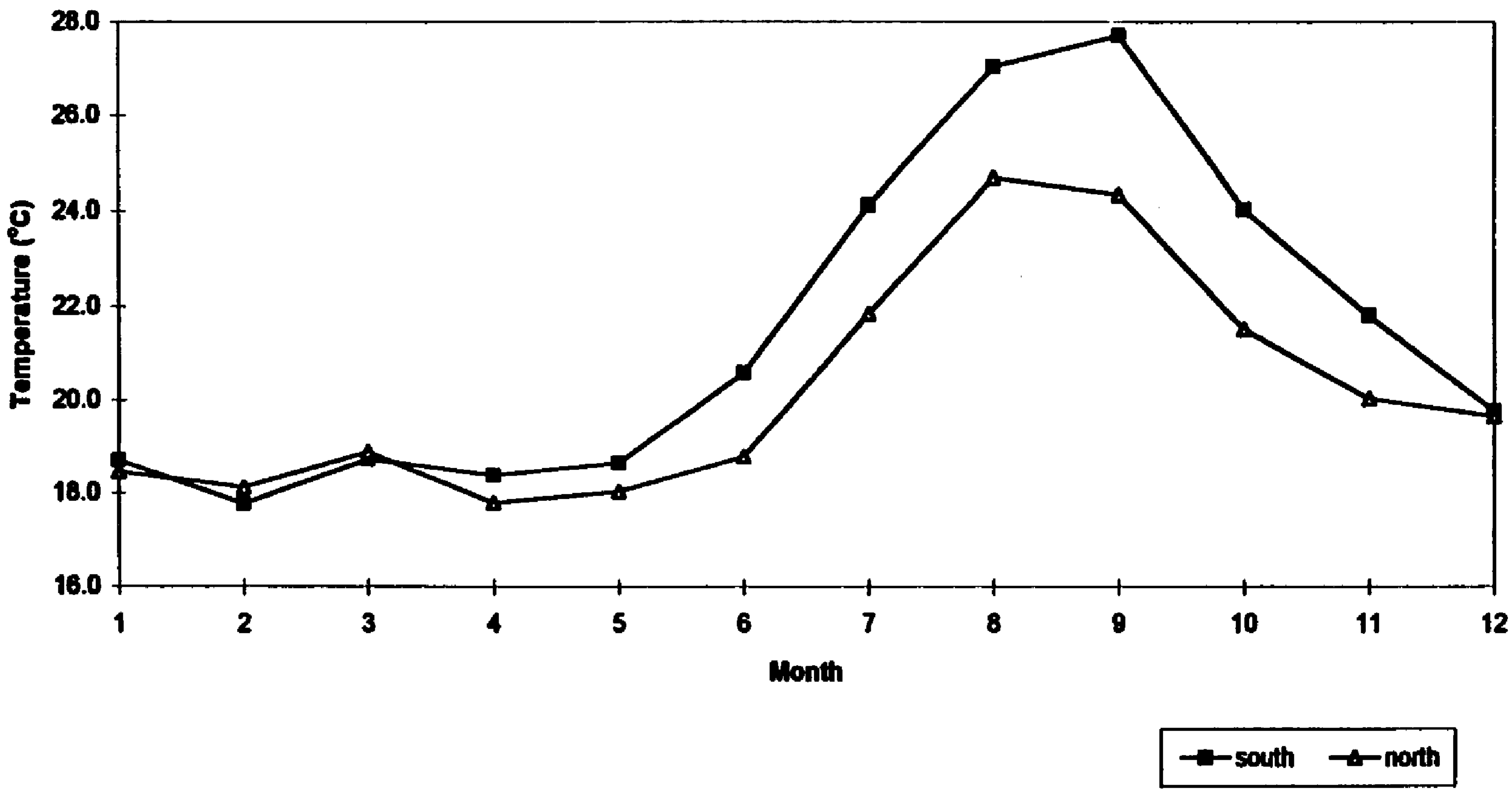


Figure 2.8. Average monthly sea surface temperature (°C) on the Mauritanian shelf for the northern and southern zones (1985-1993).

Table 2.6. Mean sea surface temperatures (°C) and their standard deviations (std) for the Mauritanian shelf during the different hydrographic seasons.

Season	Southern zone	std	Northern zone	std	Whole shelf	std
cold	18.52	0.95	18.21	0.97	18.43	0.97
cold-warm	21.45	1.99	20.31	1.80	21.01	1.99
warm	25.60	2.57	23.47	2.13	24.58	2.59
warm-cold	20.71	1.61	20.05	1.00	20.49	1.46

SST is 24.5°C for the whole shelf (standard deviation ± 2.59 °C, Table 2.6). From November to December, there is a cooling of shelf SST and a rather quick return to the initial conditions, where isotherms are distributed parallel to the isobaths (Dubrovin et al., 1991).

No long term warming or cooling of the SST on the shelf was easily identifiable. It is possible that the interannual variability is so high that the SKT could not detect any trend for the annual mean SST. However, when working with monthly SST values for each year, there seems to be an upward trend in SST (warming) in the southern zone (S'=47; var(S')=700; Z'=1.74). Plots of yearly seasonal SST anomalies (seasonal SST value for the year minus the long-term seasonal SST value) showed positive values in the southern zone which may be an indication of such warming. Contours of average SST over the years (1985-1993; Figure 2.9) show similar patterns to the classical cooling-warming described above.

Large-scale sea surface temperature patterns

The eigenvalues of the EOF analysis indicate that three components provide a good summary of these data (i.e., account for 97% of the total variability). Subsequent components account for less than 1 % each (Table 2.7).

The first component (PRIN1) reflects the seasonal signal, since the first eigenvector shows approximately equal loadings on all stations (Figure 2.10). This component accounts for 88.5 % of the total variability, a percentage which

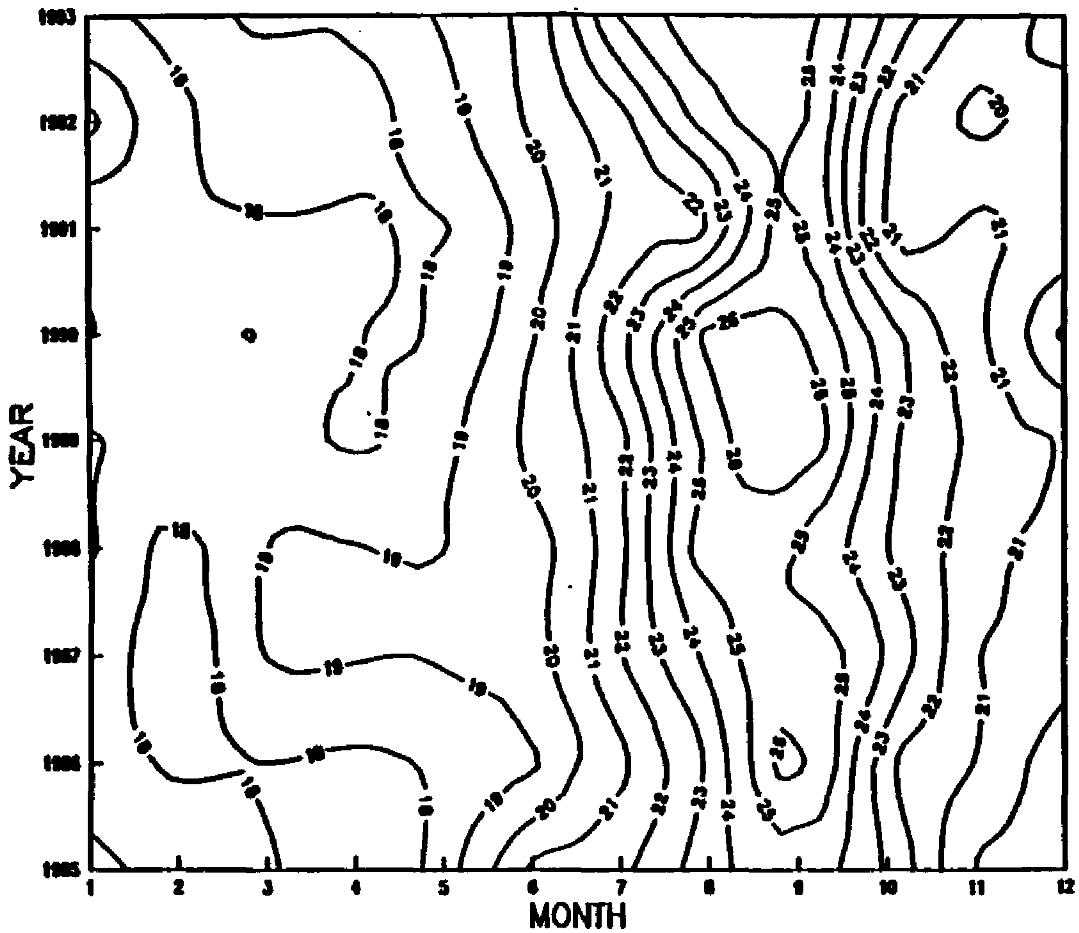


Figure 2.9. Mean sea surface temperature (^{o}C) over the whole Mauritanian shelf (1985-1993).

Table 2.7. Eigenvalues and eigenvectors of the empirical orthogonal function analysis of sea surface temperature (°C) along the Northwest African coast. PRIN1, PRIN2, PRIN3 denote the first three orthogonal functions.

LATITUDE	ORTHOGONAL FUNCTIONS			TEMPERATURE	
	PRIN1	PRIN2	PRIN3	MEAN	STD
28-30N	0.33	-0.05	0.07	20.24	1.66
26-30N	0.33	-0.06	0.24	20.27	1.49
24-26N	0.30	-0.23	0.69	19.66	1.41
22-24N	0.31	-0.32	0.19	19.64	1.28
20-22N	0.30	-0.43	-0.37	19.64	1.82
18-20N	0.32	-0.18	-0.39	21.79	2.93
16-18N	0.33	0.01	-0.27	23.13	3.25
14-16N	0.33	0.23	-0.21	23.93	3.40
12-14N	0.32	0.43	-0.05	24.72	3.25
10-12N	0.29	0.63	0.13	25.86	2.34
% variance explained	88.50	6.10	2.70	-	-
Cumulative %	88.50	94.60	97.30	-	-

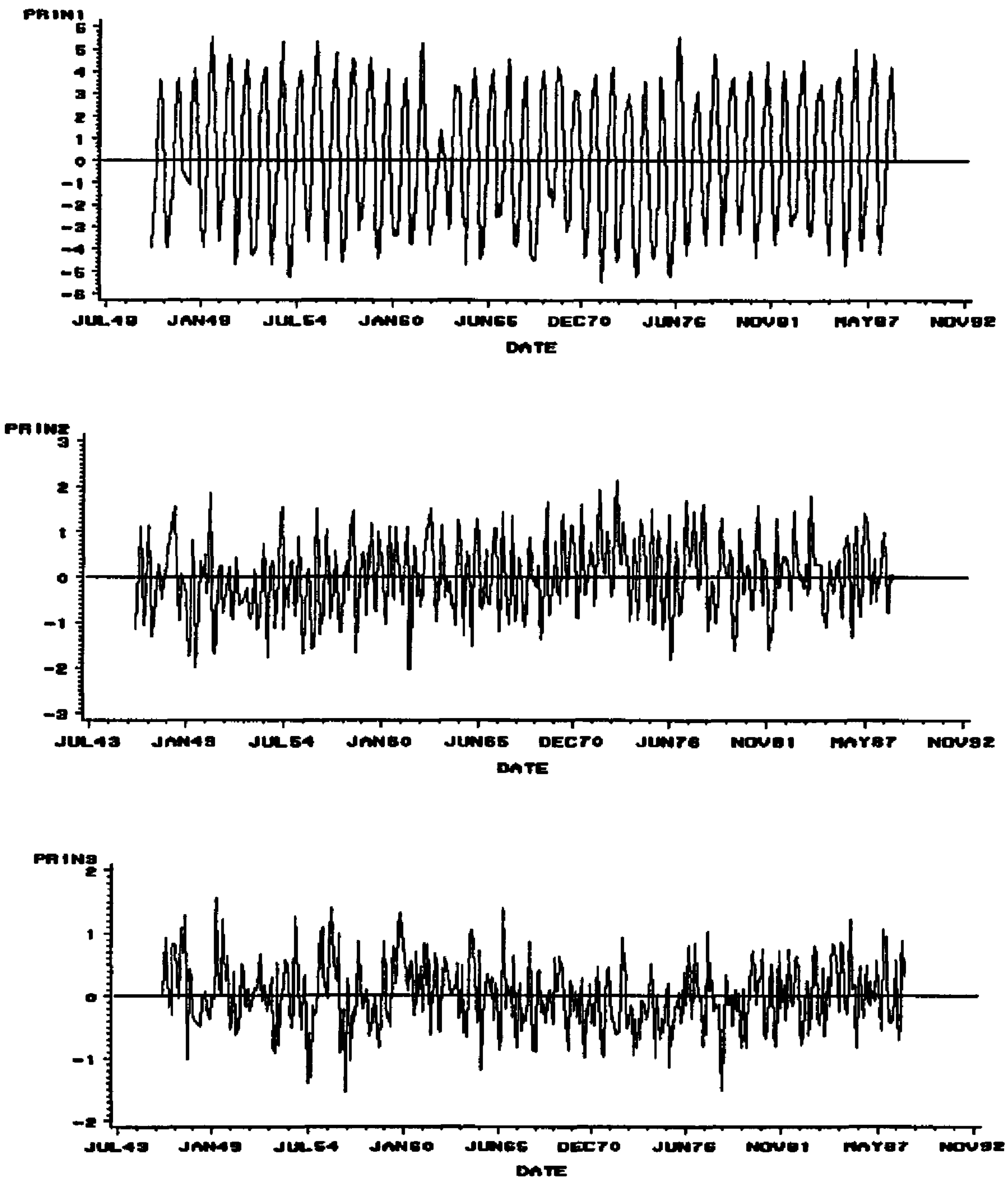
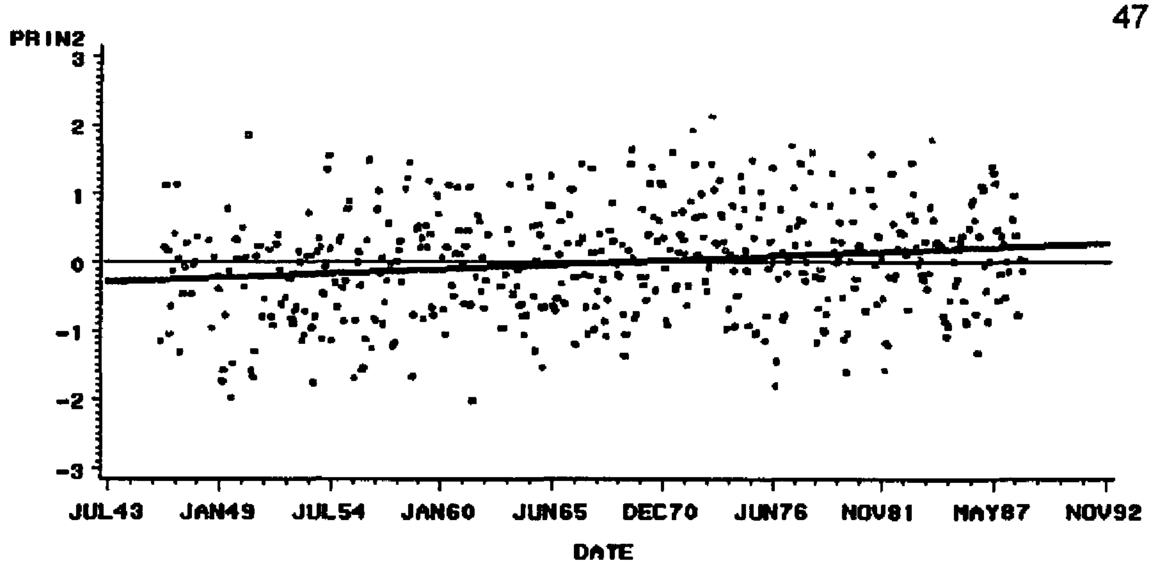


Figure 2.10. Plots of time coefficients for the first three orthogonal functions (i.e., PRIN1, PRIN2 and PRIN3) for sea surface temperature along the Northwest African coast (10-30°N).

actually shows the dominance of the seasonal signal in the Atlantic (Picaut, 1985). Similar studies but on larger scales in the Atlantic reported values for the first eigenvector between 80 and 84% of the total variance (Weare, 1977; Servain and Legler, 1986).

The second eigenvector (PRIN2), which contributes 6.1% of the total variance, has negative loadings on northern latitudes and positive loadings on southern stations. This can be interpreted as a measure of spatial separation reflecting the influence of upwelling. In this regard, it is interesting to note that the latitudes between 18 and 26 °N have the highest negative loadings and are known to be regions of permanent upwelling (Wooster et al., 1976; Speth and Detlefsen, 1979, 1982). Time series plots of PRIN2 appear to indicate an increase in the amplitude of the separation between regions of permanent upwelling and regions with sesonal upwelling (slope of regression significantly different from zero, $P<0.001$; Figure 2.11). A closer look revealed an increasing trend in the upwelling intensity and, hence, a long-term cooling trend for the regions between 20 and 26 ^{0}N. The reverse is observed for the southern regions, where consdierable heating occured. This can explain why SST averaged over all square grids did not show any trend.

What then is happening in the transitional waters between these two regions? This question was addressed by plotting SST anomalies for months of maximum upwelling intensity, i.e., January to May or the cold water season, at



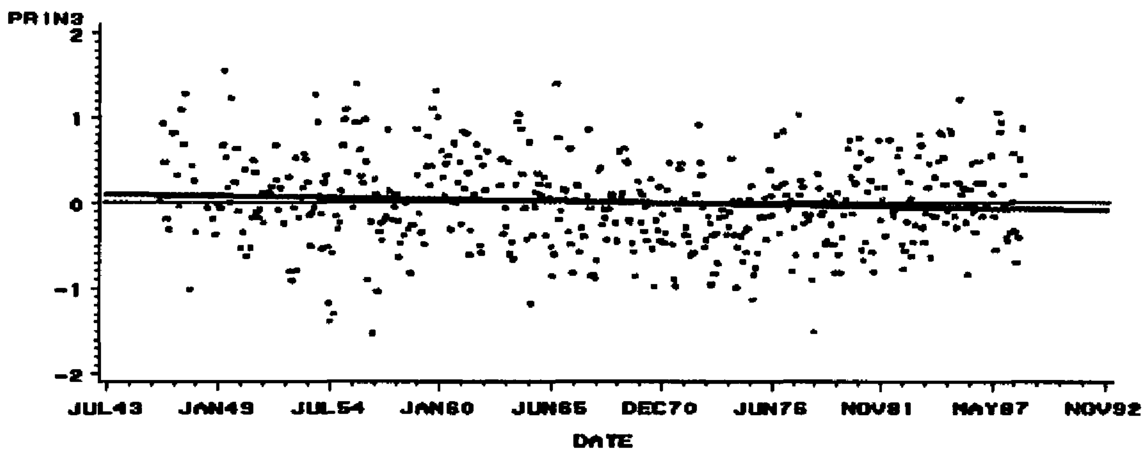


Figure 2.11. Plots showing linear trend (thick line) for the second (top) and third principal component time coefficients (bottom) for sea surface temperature along the Northwest African coast (10-30°N).

latitude 18-20 °N (Figure 2.12). Interestingly, when plotting SST anomalies for the warmest months (August-September) at the above latitude, a downward (cooling) trend can be easily identified (Figure 2.12), while south of 14 °N and north of 22 °N no such trend was observed. As such, I hypothesize that a southward extension of the upwelling limit may be taking place. In other words, during the last decades the front delimiting the ITCZ movement did not go further north as it used to. Therefore, upwelling intensity in the warmest months (Agust-September) increased in the northern regions and so did heating in the southern zones. This may be seen by correlating the second principal component, which was interpreted as being a measure of the spatial (latitudinal) separation, with the upwelling intensity. It was expected that the correlation would be maximum for the cold water, maximum upwelling season between January and May. It appeared, however, that the correlation is much stronger during the warm water season (August-September; Kandall Tau=-0.73, P=0.0001) than during the cold water season (Kendall Tau=-0.21).

The third eigenvector (PRIN3) is more difficult to interpret but seems to represent some spatial features of SST seasonal variability. The corresponding time coefficients reveal a possible downward trend in SST (Figure 2.11).

The fourth and subsequent components have much more complex spatial and temporal features. Their relative contribution (less than 1% each) is much smaller than the previously discussed components and might be simply considered as noise (see Craddock, 1965 and 1973; Weare, 1977).

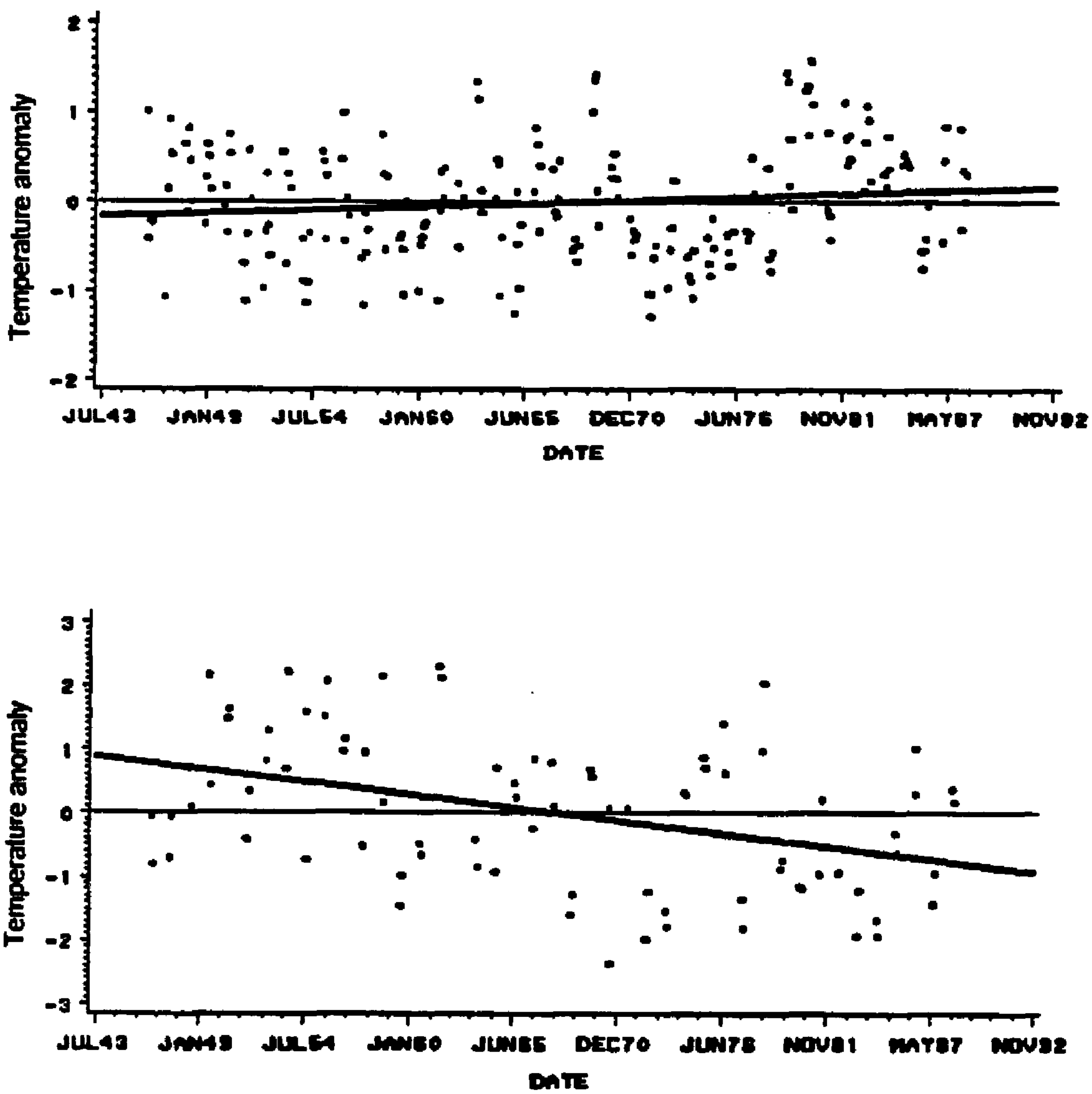


Figure 2.12. Plots of sea surface temperature anomalies showing linear trend (thick line)during the cold water or maximum upwelling intensity season (January-May; top) and warm water season (August-September; bottom) for a selected 2° x 2° square (18-20°N) along the Northwest African coast. Temperature anomalies are calculated by substracting the mean monthly SST in a given year from the long-term monthly average SST.

Interannual variability

Fourier analysis of monthly SST revealed significant characteristic periods at about one, 2 and 5 to 6 years (Figure 2.13). The one year period obviously reflects the annual (seasonal) cycle. The quasi-biannual signal has been identified in many analyses as a characteristic of the tropical Atlantic (Chu, 1984; Servain, 1991). Such a signal was somehow linked to the stratospheric zonal gradient (Yasunari, 1989). Previous analysis of pressure fields specific to the study area have also reported peaks of spectral density at frequencies of about 24 months (Michelchen, 1980). The peak in spectral density at the 5-6 year interval may reflect a cycle in cooling and warming trends. The study area went through some successive cooling and warming events. Generally, the middle years of the last decade (1982-1988) show relatively negative anomalies (cooling) in the northern part of the Mauritanian EEZ (Figure 2.14). The SST anomaly was computed as being equal to the mean monthly SST in a given year minus the long-term average. Again this is in agreement with the high upwelling index values reported earlier for the same time period. This cooling period was then followed by a warming trend (1989-1993). This cooling and warming pattern may be a part of long term processes affecting the Northwest African coast.

Link to coastal stations

There appears to be strong agreement between SST and CUI plotted for selected months (January-May; Figure 2.15). The Kendall Rank Correlation Coefficient indicates a negative association between SST and CUI computed at

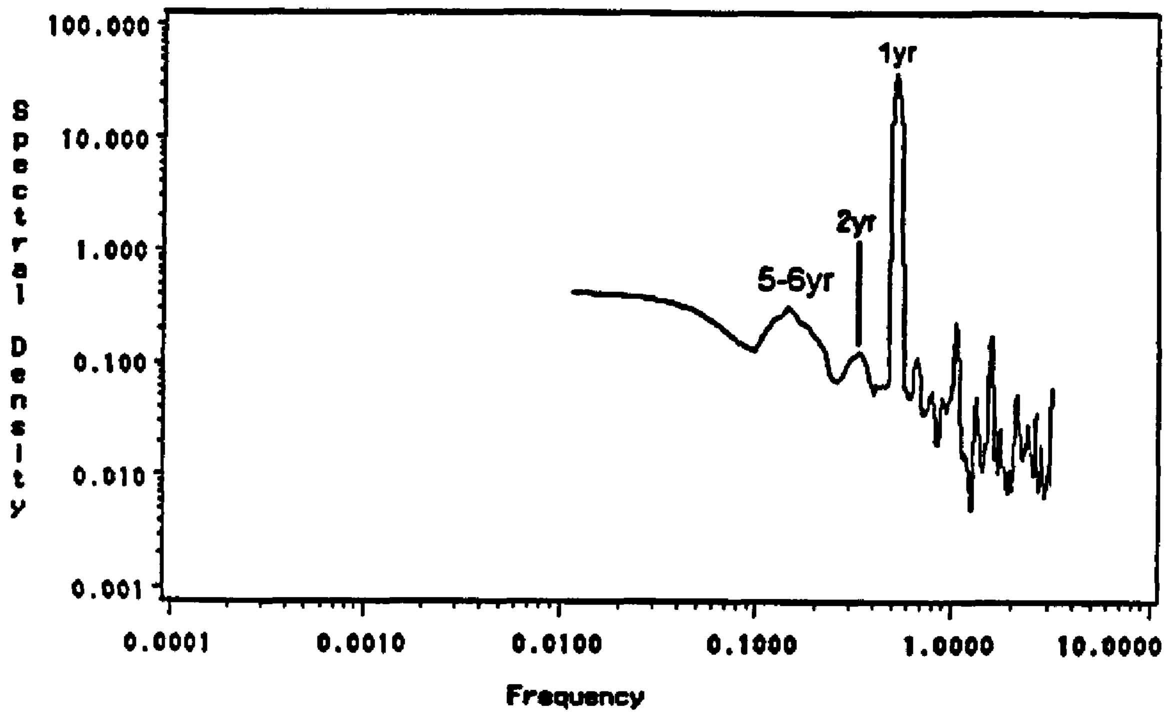
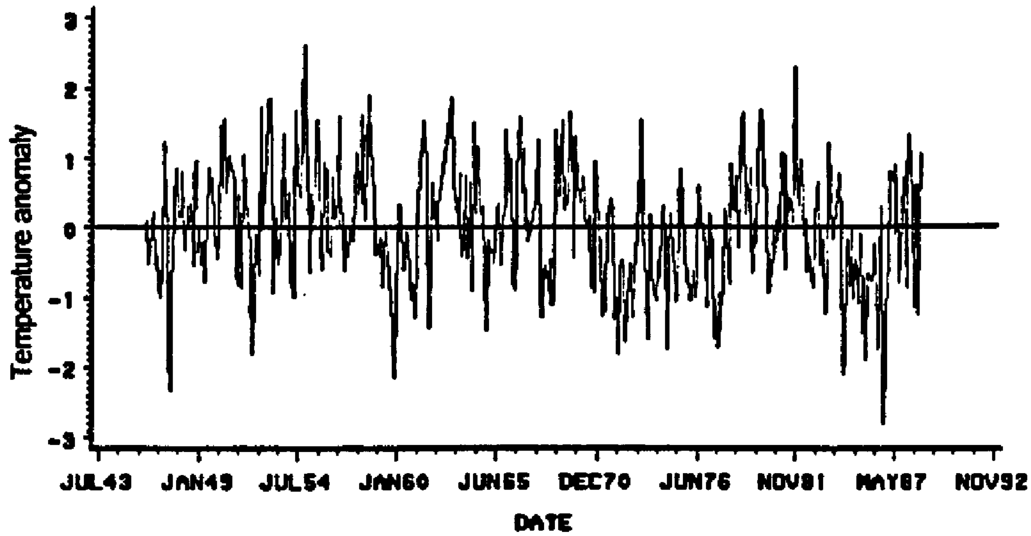


Figure 2.13. Plot of the $\log_{10}$ spectral energy vs. $\log_{10}$ frequency (10 months) for sea surface temperature along the Northwest African coast. Note that the maximum energy corresponds to the annual signal (one year period).



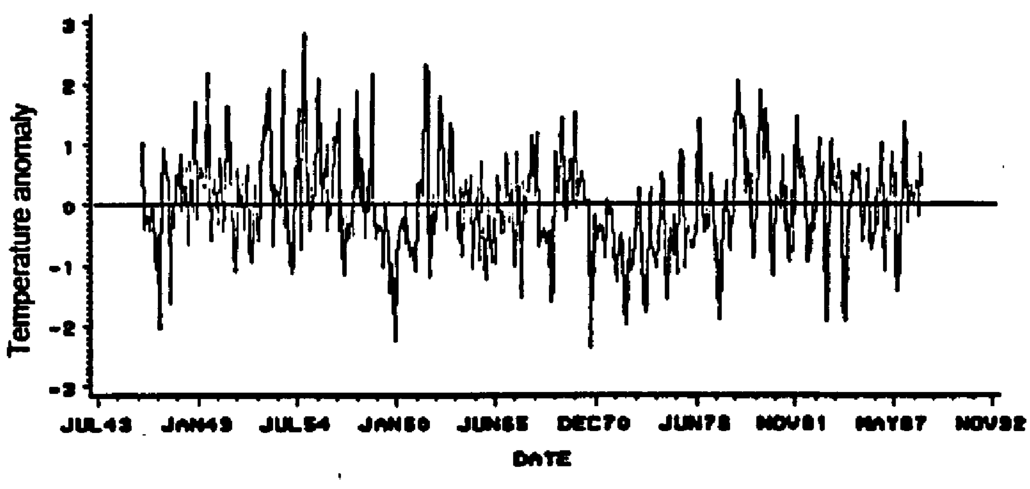


Figure 2.14. Plots of sea surface temperature anomalies at latitutdes of 18-20°N (top) and 16-18° N (bottom) on the Northwest African coast from 1946 to 1988. Temperature anomalies are calculated by substracting the mean monthly SST in a given year from the long-term monthly average SST. Negative values, therefore, indicate short-term cooling.

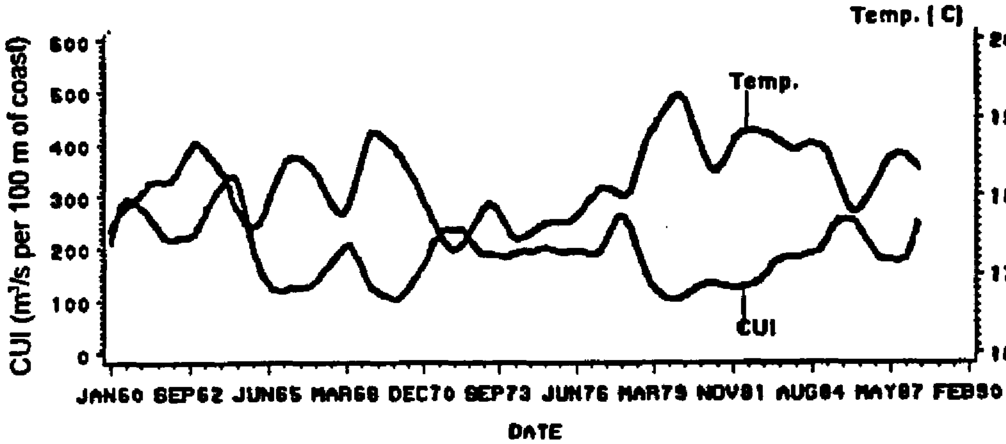


Figure 2.15. Temporal plot of sea surface temperature (°C) at latitude 18-20°N and Coastal Upwelling Index (m³/s per 100 m of coastline) at Nouadhibou during the cold water season, January-May (1960-1988).

the station Nouadhibou (Kendall Tau b=-0.29, $P<0.0001$). This coastal station, therefore, gives an adequate representation of the oceanographic processes in the Mauritanian shelf waters. The representativeness of coastal stations is furthermore supported by a previous study that found strong correlations between ship-recorded pressures and sea-level coastal stations along the tropical Atlantic coast of Africa (Bigg, 1993).

CONCLUSION

Investigations of the timing and structure of SST and bottom water temperature and wind reveal seasonal patterns as well as complex spatial patterns. The Mauritanian shelf is a confluence of the mixture between colder waters in the north and warmer waters in the south as well as upwelling waters. Hence, given the complexity of the area, a larger scale study was needed to investigate the oceanographic processes. Coastal stations can give an adequate representation of the seasonal cycle.

In the last decade, the shelf area went through a cooling trend (1982-1988) and then a warming trend (1989-1993). This seems to be part of a long-term process affecting the Northwest African coast. It was interesting to note the discrepancies between northern regions with permanent upwelling and southern regions where the upwelling is seasonal. It was hypothesized that a southern extension of the upwelling limit is taking place. Also, although the seasonal (annual) signal was dominant, periodicities at lower frequency (2 and 5-6 years) were also present. The peak in spectral density at 2 years is believed to

represent atmospheric processes in the tropical Atlantic, while the 5-6 year peak may represent the above mentioned cooling and warming trends. This latter speculation, however, warrants further investigation. In addition, there was a strong relationship between SST at 18-20°N and CUI computed at the coastal station of Nouadhibou. This may allow for adequate predictions of oceanographic processes over the Mauritanian shelf from coastal stations.

CHAPTER 3
The Small Pelagic Fishery

INTRODUCTION

Due to the combination of a number of hydro-climatic factors (as seen in the previous chapter), the Mauritanian waters have a very high and diverse fish biomass (Letaconnoux and Went, 1970; Hempel, 1982; Wolff et al., 1993). Small pelagic fish have long been a valuable target of a large and diverse international fleet. In the 1980's, annual catch has averaged about 400,000 metric tons (Chavance and Girardin, 1991). Three major families are frequently represented in the catch: Carangidae, composed of Atlantic horse mackerel (*Trachurus trachurus*), cunene horse mackerel (*T. trecae)* and false scad (*Decapterus rhonchus*); Clupeidae, represented by three species, European pilchard (*Sardina pilchardus*), round (*Sardinella aurita)* and Madeiran (*S. maderensis*) sardinella; and Scombridae consisting of a single species, chub mackerel (*Scomber japonicus*). Lately, considerable catches of Trichiuridae have been made, in particular largehead hairtail (*Trichiurus lepturus*). Bioprofiles of these species and their fisheries have been reviewed (Garcia, 1982; Josse and Garcia, 1986; Josse, 1989; Chavance and Girardin, 1991). A succinct description of the biology and fisheries of these species is presented because of their importance in interpreting the evolution and variability of their catch statistics.

SPECIES BIOLOGY

Clupeidae

Sardina pilchardus (Walbum, 1792) the European pilchard or sardine, was originally distributed from the English Channel to 26 °N off Morocco (Freon and Stequert, 1979). In the early sixties, the species range began to extend southward to Cape Timiris (19 °N) off Mauritania (Boely, 1982) and today reaches as far south as Senegal, 16 °N (Marchal, 1991a). This vast range, however, is occupied by a number of distinct stocks. Off Africa, three populations have been identified, although a limited degree of mixing is possible. The southern stock, shared by Morocco and Mauritania, 21 °N-26 °N, is the subject of this study. In the Mauritanian Exclusive Economic Zone (EEZ), sardine migration has a distinct pattern. Sardines are taken in continental shelf waters during September-October and disappear around June (warm season). Spawning occurs from October through April with an apparent maximum in December-January (Chavance et *al.*, 1991a). The sardine is usually encountered in shallow waters (< 100 m) where it forms schools and feeds mostly on phytoplankton. It can, however, colonize the entire continental shelf (Chavance et *al.*, 1991a; Marchal, 1991a).

Sardinella aurita (Valenciennes, 1847) round sardinella, is found along the African coast from as far north as the Mediterranean Sea south to Angola (26 °S), but is most abundant south of 24 °N (Boely et al., 1982; Boely, 1982; Marchal, 1991a and b). The northern population, which is targeted by fleets operating in Mauritanian waters, has latitudinal boundaries lying between 12 °N and 24° N

(Chavance et *al.*, 1991a). Several authors hypothesize that this population constitutes two separate stocks: a Saharan and a Mauritanian stock. Both stocks, however, share the northern part of the Mauritanian EEZ as their reproductive site (Chavance et *al.*, 1991a). The round sardinella performs seasonal migrations (perpendicular to the coast) and daily vertical migrations depending on age, sex, and hydrographic conditions (Ansa-Emmin, 1982). During the warm water season (August-October), adults migrate along the coast following cold water masses (Marchal, 1991a and 1991b) while younger fish remain concentrated in shallower waters (Boely et al., 1982). During the upwelling or cold water season (January-May), both adults and young migrate toward the coast. Some fraction of the young and adult stock stays in the northern part of the Mauritanian shelf and does not migrate at all. Therefore, round sardinella can be encountered off Mauritania year around (Chavance at *al.*, 1991a). Two spawning seasons have been identified for this species, December-January and July-August. Round sardinella filter-feed on plankton as well as small detritus particles (Marchal, 1991b; Nieland, 1982).

Sardinella maderensis (Lowe, 1839) also known as *Sardinella eba* (Valenciennes, 1847) Madeiran sardinella, extends from Cape Barbas (22 °N) southward to at least Angola (26 °S) and perhaps further south (Fischer et al., 1981). It is a coastal species inhabiting rather shallow depths (<50 m) with fairly high salinity and warm temperatures (>24 °C; Boely, 1982; Marchal, 1991b). This species does not appear to undergo large seasonal migrations. The major part of

the spawning season occurs between May and September with a secondary peak in early winter, December-January (Chavance et *al.*, 1991a). In Mauritania, an important nursery for this species is located in the Baie du Levrier and Banc d'Arguin areas (Maigret, 1972). The Madeiran sardinella is an active filter-feeder, whose stomach contents have contained zooplankton, detritus and anchovy larvae (Nieland, 1982).

Carangidae

Trachurus trachurus (Linnaeus, 1758) the Atlantic horse mackerel, is encountered off the African coasts from the Strait of Gibraltar to Senegal (14°N). Its geographic distribution extends northward into the Mediterranean Sea and along the European Atlantic coasts up to Norway (Chavance et al., 1991a; Fischer et *al.*, 1981). In Mauritania, this species is taken on the continental shelf during the cold water season and moves southward, reproducing along the coast (Garcia, 1982). Spawning occurs in water temperatures between 15 and 18 °C. During the transitional cold-warm water season, they start reversing their migration, moving back toward the north and exiting the Mauritanian waters by July (Garcia, 1982; Chavance et *al.*, 1991a). Acoustic surveys have detected important concentrations between 18° 05'N and 19° 47'N (Josse and Chavance, 1988a,b). Atlantic horse mackerel feeds on fish, squid and zooplankton, especially copepods and euphausiads (Fischer et al., 1981; Boely and Freon, 1980). Frequently, this species inhabits waters 100 to 200 m deep over sandy bottoms, but may be found at greater depths (Fischer et al., 1981; Chavance et al., 1991a).

Trachurus trecae (Cadenat, 1949) the Cunene horse mackerel, is distributed from Mauritania to southern Angola (Fischer et al., 1981). This species is present year round on the continental shelf. Its migration is closely related to the displacement of the ITCZ front (Chavance et al., 1991a). During the cold water season, Cunene is abundant in the southern part of the continental shelf. It starts migrating northward with the arrival of warm waters from the south and, hence, occupies the whole shelf region during the warm season (Chavance et al., 1991a). Two regions have been delimited as the spawning ground for this species: the area between 14° 45'N and 19° 20'N (Boely and Freon, 1980); and the area surrounding Cape Blanc (20 °N) during the cold season (Overko, 1971). Cunene horse mackerel has the same feeding habits as the Atlantic horse mackerel, but occupies more coastal waters, 20-100 m depth (Chavance et al., 1991a; Fischer et al., 1981).

Decapterus rhonchus (Geoffroy Saint-Hilaire, 1817) also known as *Caranx rhonchus* or false scad, has a distribution range similar to the Cunene horse mackerel (Chavance et al., 1991a). It extends from the Angolan coasts up to Morocco and even Spain, but is most abundant off Morocco and Senegal (Fischer et al., 1981). This species is present off Mauritania year round being most abundant in the southern part of the continental shelf (Chavance et al., 1991a). False scad appears to migrate along the African coast in response to hydrological conditions, i.e., ITCZ movement (Garcia, 1982). Like the carangid species, listed above, false scad feeds on fish, squid and crustaceans (Fischer et al., 1981). It is

found most frequently in depths of 30 to 50 m but can be taken at greater depths (≥ 150 m, Fischer et al., 1981; Chavance et al., 1991a).

All three species form schools during the day and break into individuals or smaller shoals at night (Chavance et al., 1991a; Fischer et al., 1981).

Scombridae

Scomber japonicus (Houttuyn, 1780) chub mackerel, is a cosmopolitan species inhabiting temperate, subtropical and tropical waters of the Atlantic, Pacific and Indian Oceans (Fischer et al., 1981; Krivospitchenko, 1979). It is distributed over the entire Mauritanian continental shelf at depths ranging from 15 to 400 m (Krivospitchenko and Domanevski, 1984). Its migration scheme is closely connected to hydrologic conditions, such as the displacement of the 19 to 20 °C isotherm (Schemainda and Nehring, 1975; Krivospitchenko and Dubrovin, In press). Chub mackerel shoals start to concentrate in the southern part of the Mauritanian continental shelf around April and move northward, where their abundance is highest from June to September. They start migrating southward and exit the Mauritanian EEZ by December (Chavance et al., 1991a). Chub mackerel is a schooling fish found mostly in coastal waters and feeds on small pelagic fishes, especially clupeids and pelagic invertebrates (Fischer et al., 1981; Krivospitchenko and Domanevski, 1984).

Trichiuridae

Although many species of this family are taken in the fishery, only one is abundant, *Trichiurus lepturus* (Linnaeus, 1758) the largehead hairtail. It is found

throughout the African coasts (Fischer et al., 1981). Off Mauritania, no studies have been conducted on this species. Largehead hairtail is a benthopelagic fish found mostly in coastal waters where it feeds on various kinds of fish, and sometimes cephalopods and crustaceans (Fischer et al., 1981).

THE FISHERIES

In Mauritanian waters, small pelagic fish have long been targets for large international fleets from Cuba, France, Germany, Ghana, Iraq, Rumania, the old Soviet Union, Poland and Spain. During the last decade, Rumanian, Russian, and, to some degree until 1986, German vessels have made up most of the effort. By Russia I mean the old Soviet Union which now consists of such countries as Estonia, Lithuania, Russia and Ukraine. For simplicity these latter countries will be referred to as Russia throughout the remainder of the text. Rumania has been exploiting pelagic species off Mauritania since the 1970's with a diverse fleet consisting of purse-seiners and trawlers of different sizes. Since 1978, however, the Rumanian fleet has been comprised of a single size category of vessel, namely "RTMS". The Russian fishery, however, started operating in the fifties with some interruptions. After 1985 Russian vessels were present every year and accounted for at least 60% of the total effort in the pelagic fishery. Rumania was responsible for mading up virtually the rest of the pelagic fishing effort until 1991 when they left the fishery leaving the Russian trawlers responsible for virtually all of the fishery effort in the study area. The other minor either had effort that was

consistent for only a few years (Germany) or was episodic (Bulgaria, Ghana, etc). The fleets of interest operate in the EEZ under agreements from the Mauritanian government and the ship's country. These joint ventures are then managed by local Mauritanian companies. The Mauritanian government and local companies receive a portion of the ship's profits. For example, some of the foreign fleets are required to have a crew of about 35% Mauritanians and generally turn over about 30% of the total gross profits (Ould Soueilem, 1992). Vessel landings, which consist of frozen fish and at-sea processed products such as fish meal and oil, are not landed in Mauritania itself, but rather are carried by cargo-ships to Eastern Europe and Sub-saharan Africa. This study focuses primarily on the Rumanian and Russian fleets during 1987-1993 when they dominated the fishery. These fleets are composed of highly mobile, mid-water trawlers whose average characteristics fit into four categories or vessel types (Table 3.1).

Most of the studies off Northwest Africa have indicated that the small shoaling fish stocks are not yet overexpoited (Josse and Garcia, 1986; Josse, 1989) although these species have always been characterized by large catch fluctuations (Saville, 1980; Csirke and Sharp, 1984, May, 1984; Csirke, 1988; Roy, 1990; Cury and Roy, 1991). For example sardine landings (Mauritania and Sahara combined) were extremely high in the 1970's increasing from 80,000 metric tons in 1969 to 650,000 metric tons in 1976 (Freon and Stequert, 1979), dropping to zero in the early 1980's, and increasing again with little variability by

Table 3.1. Physical characteristics of the different vessels operating in the Mauritanian EEZ in 1989 (after Chavance, 1991).

Vessel type	*Name*	*Width (m)*	*Length (m)*	*Nation*	*Displacement (Metric tons)*	*Crew*	*Horse-Power*
1	"Super Atlantik" (RTMS)	15.2	102	Rumania	3163	88	3880
2	"Super Atlantik" (RTMS)	15.2	102	Russia	3019	87-92	3880
3	"Atlantik" (RTMA)	14	82	Russia	2177	80-96	2320
4	"Medium Trawlers" (BMRT)	14	85	Russia	2400	77-93	2000

the late 1980's (Josse, 1989; Chavance et *al.*, 1991a). The catch variability may be partially explained by the spatial and seasonal distribution patterns of the species involved. Moreover, environmental variables, manifested in the four hydrographic seasons, and fleet fishing capabilities (strategies) play key roles in describing these patterns (see below).

This chapter analyzes commercial catch data for small pelagic fishes off Mauritania during the period 1987-1993. I am primarily interested in investigating and characterizing spatial and short-term temporal variations in species' catch per unit effort (CPUE). Also, I will focus on potential similarities and differences between Rumanian and Russian fleets as well as differences within Russian vessels.

MATERIAL AND METHODS

Data description

Commercial fisheries statistics from 1987-1993 were compiled from official landings provided by the ships operating in the EEZ and were kindly made available through the Centre National de Recherches Océanographiques et des Pêches (CNROP) Nouadhibou, Mauritania. Some supplementary data were extracted for the year 1989 from the CNROP archives (Chavance, 1990). Reported catches are expressed in metric tons by country, fishing vessel type, month, year and species or species group. Nominal fishing effort is expressed in days. Since some ships report only combined catch, the following species or species groupings had to be used: *Sardina pilchardus*, *Sardinella* (*Sardinella aurita*

and *S. maderensis* combined), *Scomber japonicus*, *Trichiurus lepturus*, and Carangid (*Trachurus trachurus*, *T. trecae* and *Decapterus rhonchus* combined). All other species, if any, were grouped within the "OTHER" category, which generally includes pelagic fishes such as anchovy and tuna and, demersal fishery species such as hake and octopus. Monthly data were summed by hydrographic season, according to Dubrovin et al. (1991). The continental shelf was divided into two fishing zones: a northern zone, located north of the 19 °N parallel, and a southern zone (16°N to 19°N). Vessels types were defined after Table 3.1.

Statistical analyses

I used the general linear model (GLM) procedure in SAS (SAS®, 1989) to perform univariate (ANOVA) and multivariate (MANOVA) data analyses. Multivariate analyses (Anderson, 1984; Johnson and Wichern, 1992) were deemed appropriate because 1) interdependence likely exists between the response variables (i.e., CPUE of different species); 2) they test for simultaneous main effects (i.e., fishing zone, fishing vessel type, hydrographic season) on the response variables; and, 3) they offer overall control of experimentwise error rate (Type I error). Also, I used contrasts tests for specific *a priori* comparisons. Post hoc comparisons were carried out using Tukey's studentized multiple comparison test at the 5% significance level. The MANOVA used CPUE of the different species or species groups as dependent variables and fishing vessel type (TYPE), fishing zone (ZONE) and hydrographic season of the year (SEASON) as independent variables. The treatment YEAR was considered as a block, i.e., any

year-to-year variations have been removed. Possible linear trends associated with the block, however, were tested using contrasts. The CPUE distribution was found to be lognormal; therefore, all means presented were geometric means. Descriptive statistics were generated and various plots of catch, effort and CPUE were produced to investigate seasonal and spatial patterns as well as fishing vessel differences. Also, a considerable amount of the analysis was directed to assessing the magnitude of the possible interactions. If interactions are not statistically significant, then the treatment effects (i.e., zone, type and season) are independent; hence, direct interpretation of the main effects would be adequate. When interactions do exist, however, determining the nature of the interaction is important because one should not make direct inferences on the main effects. In such cases, there is a joint or combined effect of treatments on the dependent variables.

RESULTS

General considerations on effort and catch

From 1987 to 1993 total effort dropped from about 9661 to 7092 fishing days (Figure 3.1). Most of the decrease in effort resulted from the loss of the Rumanian fleet (Vessel type 1; Table 3.2). After 1990, the Rumanian vessels stopped operating in the EEZ. The majority of the remaining total effort was due to the Russian vessel type 2. Vessel type 4 had the lowest contribution, while types 1 and 3 were somewhat comparable. Although the fleet effort was almost constant from month to month (Figure 3.2), it exhibited large seasonal and spatial

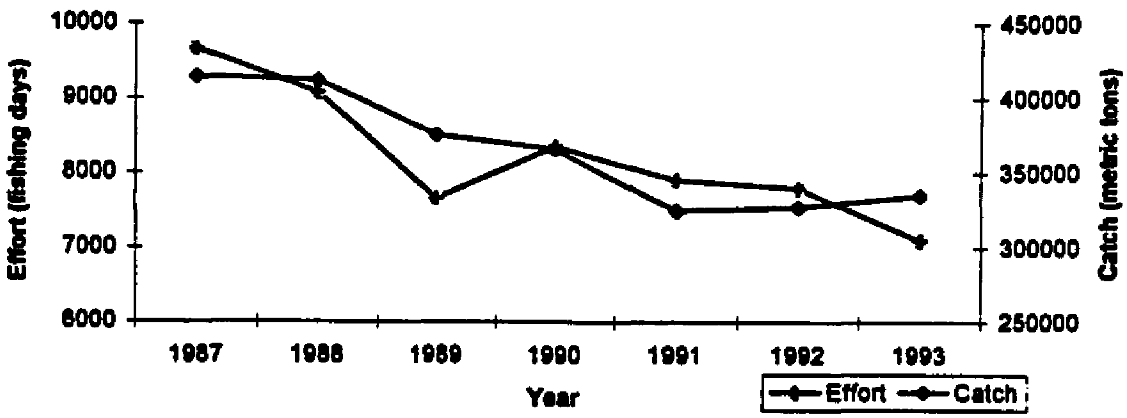


Figure 3.1. Yearly total catch (metric tons) and effort (fishing days) for all taxa, hydrographic seasons, fishing vessel types and fishing zones (1987-1993).

Table 3.2. Total effort (fishing days) and percentage of effort by vessel type (%typtot) for all taxa each year (1987-1993).

YEAR		Fishing days by vessel type 1	2	3	4	GRAND TOTAL BY YEAR
1987	total	2772	2170	2937	1782	9661
	%type	28.7	22.5	30.4	18.4	100.0
1988	total	3042	2213	2924	895	9074
	%type	33.5	24.4	32.2	9.9	100.0
1989	total	2126	2060	2619	854	7659
	%type	27.8	26.9	34.2	11.2	100.0
1990	total	1642	3072	2546	1097	8357
	%type	19.6	36.8	30.5	13.1	100.0
1991	total	0.00	5338	2213	350	7901
	%type	0.00	67.6	28.0	4.4	100.0
1992	total	0.00	6307	1451	31	7789
	%type	0.00	81.0	18.6	0.4	100.0
1993	sum	0.00	6634	306	152	7092
	%type	0.00	93.5	4.3	2.1	100.0
GRAND TOTAL BY TYPE	sum	9582	27794	14996	5161	57533
	%typtot	16.7	48.3	26.1	9.0	100.0

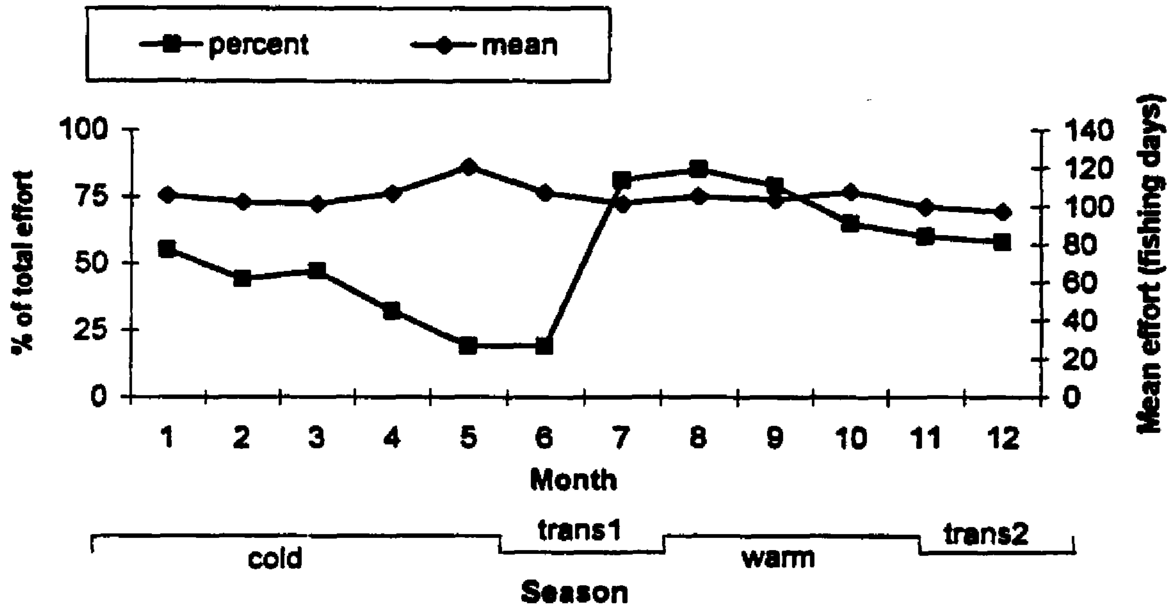


Figure 3.2. Percentage of effort (fishing days) spent in the northern fishing zone and average monthly effort values for all vessel types combined (1987-1993). Also presented are the hydrographic seasons: cold, cold to warm, warm, and warm to cold.

variations (Tables 3.3 and 3.4). During the beginning of the year (January-July) 51-61% of the effort occurred in the southern zone. During the remainder of the year, the reverse was true, 59-76% of the effort occurred in the northern continental shelf waters (Table 3.3). The distribution of effort across the northern and southern fishing zones was about the same. On average, most fleets spent more time fishing in the northern zone (53%) than in the south (47%; Table 3.3). The Russian vessel type 2 seemed to be the only vessel category that had fished considerably more in the south (58%) than in the north (Table 3.4).

Total catch decreased from 426,000 metric tons in 1987 to 328,000 metric tons in 1993 (Table 3.5; Figure 3.1). The year 1990 was of particular interest because it was the only year where *Sardinella* catch, 107,400 metric tons, exceeded the carangid catch (89,950 metric tons; Figure 3.3, Table 3.5). Overall catch composition indicated the dominance of Carangidae (40%) and Clupeidae (*Sardina pilchardus* and *Sardinella* spp. combined=28%). Scombridae and Trichiuridae accounted for only 5% and 19%, respectively (Table 3.5). When looking at species seasonal differences, 74% of the total *Sardina* (*Sardina pilchardus*) catch was made during the cold season and 40 % of the *Sardinella* (*Sardinella* spp.) catch occurred during the warm season; similarly, *Sardina* represent 20% of the total catch during the cold season and *Sardinella* 27 % during the warm season. On average, 39% of the Carangidae catch was taken during the cold season. The proportion of Carangid catch to the total combined catch (i.e., all taxa combined), however, was more or less constant over the year

Table 3.3. Total, mean, range and percentage of fishing effort (days) by hydrographic season and fishing zone (N=northern; S=southern) for all vessel types combined (1987-1993).

HYDROGRAPHIC SEASON	Number of fishing days by fishing zone							
	N				S			
	total	mean	range	%	total	mean	range	%
cold	9462	84	254	39	14666	130	640	61
trans1	4675	104	407	49	4852	105	518	51
warm	11211	160	465	76	3599	51	421	24
trans2	5358	119	357	59	3710	77	373	41
TOTAL	30706	112	465	53	26827	97	640	47

Table 3.4. Total, mean, range and percentage of fishing effort (days) by vessel type and fishing zone (N=northern; S=southern) for all hydrographic seasons combined (1987-1993).

VESSEL TYPE	Number of fishing days by fishing zone							
	N				S			
	total	mean	range	%	total	mean	range	%
1 (Rumanian)	6346	132	273	66	3236	67	236	34
2	11766	140	463	42	16028	191	640	58
3	9826	126	290	66	5170	65	231	34
4	2768	44	139	54	2393	36	192	46

Table 3.5. Yearly total effort (fishing days) and catch (metric tons) by taxa.

YEAR	*Effort*	*Sardina*	*Sardinella*	*Scomber*	*Trichiurus*	*Carangid*	*Other*	*Total catch*
1987	9661	30654	56613	24301	60644	204750	49845	414385
1988	9074	39628	59600	30545	64208	187828	36712	411798
1989	7659	47016	57061	17149	55194	165617	33904	375168
1990	8357	32902	107408	20077	57458	89956	66328	365829
1991	7901	51735	57582	8223	77785	112259	8477	324713
1992	7789	29380	47554	16723	76374	131552	8579	327027
1993	7092	46792	45371	16186	88636	125157	6292	334922
Mean	8219	39730	61599	19029	68614	145303	30020	364835
Percentage of total catch		11	17	5	19	40	8	100

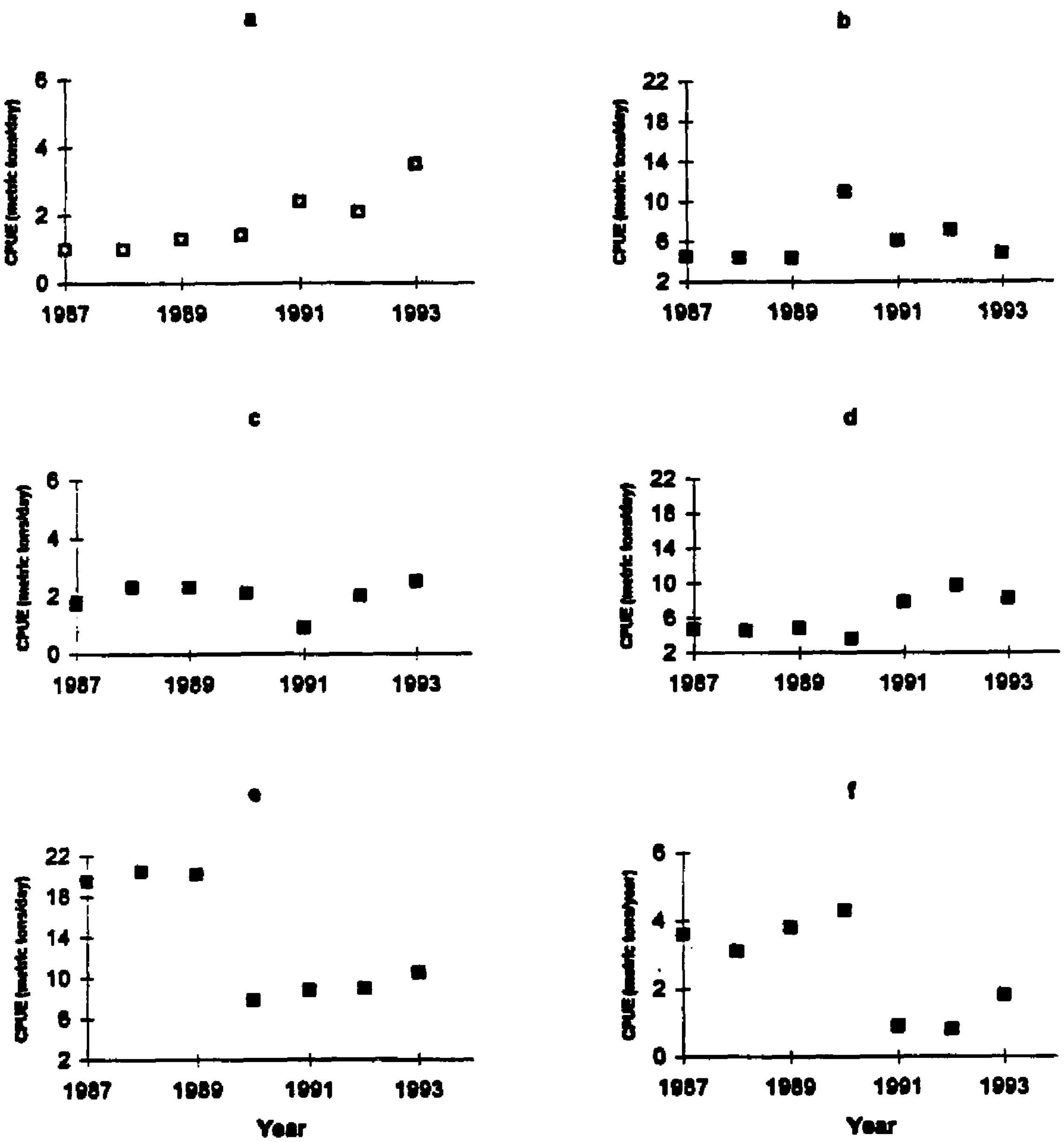


Figure 3.3. Yearly geometric mean CPUE (metric tons/day) values by taxa: a) Sardina; b) Sardinella spp. c) Scomber; d) Trichiurus; e) Carangid; and f) Other.

(37-54%) with two peaks occurring during the transitional seasons (43-54%; Table 3.6). Zonal differences indicated that *Sardina, Sardinella* and OTHER catch were primarily taken in the northern zone (88, 62 and 70% of total catch, respectively) while Carangid catch was higher in the southern region (60% of total catch). *Scomber* (*Scomber japonicus*) and *Trichiurus* (*Trichiurus lepturus*) did not exhibit zonal differences (Table 3.7).

Single species analysis

Sardina pilchardus

On average, *Sardina* catch accounted for 11% of the total combined catch (Table 3.5). Catch was highest, 20% of the total combined catch, during the cold season (January-May) when 74% of the *Sardina* catch was taken (Table 3.6). During the cold-warm transitional and warm seasons, *Sardina*'s percentage of the total catch decreased to 2-4% and finally increased again during the warm-cold transitional season when 20 % of the *Sardina* catch was taken (14% of the total combined catch;Table 3.6). *Sardina* catch was considerably higher in the northern zone (88% of all *Sardina* catch; 18% of the total combined catch) than in the southern zone (3 % of the total combined catch; Table 3.7). Also, in the northern zone, *Sardina* represented up to 36% of the total catch for the Rumanian fleet (vessel type 1; Table 3.8). For the Russian vessels (types 2-4), this proportion ranged between 11 and 14% (Table 3.8). By contrast, the proportion of *Sardina* in the southern zone was low (2-4%) for all types of vessels. Likewise, *Sardina* catch made up to 44% of the total combined catch in the northern zone, but never

Table 3.6. Seasonal mean catch (metric tons) and percentage of total combined catch for species or species groupings (%species) and percentage of that taxa's total catch by hydrographic season (%season) for all vessel types and fishing zones combined (1987-1993).

		Sardina	*Sardinella*	*Scomber*	*Trichiurus*	Carangid	Other	Grand Total
cold	mean	915	597	176	868	1770	312	4576
	%species	20	13	4	19	38	7	100
	%season	74	30	29	39	39	33	40
trans1	mean	74	1029	462	978	2316	445	5206
	%species	1	19	9	18	45	8	100
	%season	2	20	31	19	21	19	19
warm	mean	95	1210	229	909	1656	455	4476
	%species	2	27	5	20	37	10	100
	%season	4	40	23	26	22	29	25
trans2	mean	680	444	247	885	1914	441	4462
	%species	14	10	5	19	43	9	100
	%season	20	10	17	16	18	19	16

Table 3.7. Mean catch (metric tons)and percentage of total combined catch for species or species groupings (%species) and percentage of that taxa's total catch by fishing zone (%zone) for all vessel types and hydrographic seasons combined (1987-1993).

		Sardina	*Sardinella*	*Scomber*	*Trichiurus*	Carangid	Other	Grand Total
north. fishing zone	mean	983	1011	267	897	1534	498	865
	%species	18	20	5	17	30	10	100
	%zone	88	62	53	50	40	70	54
south. fishing zone	mean	137	595	232	902	2243	212	736
	%species	3	14	5	20	53	5	100
	%zone	12	38	47	50	60	30	46

Table 3.8. Mean catch (metric tons) and percentage of total combined catch for taxa by vessel type and fishing zone (N=northern; S=southern) for all hydrographic seasons combined (1987-1993).

TYPE	ZONE		*Sardina*	*Sardinella*	*Scomber*	*Trichiurus*	Carangid	Other	Grand Total
1	N	mean	1956	978	465	59	1623	313	-
		%	36	18	9	1	30	6	100
	S	mean	102	554	246	66	1341	396	-
		%	4	20	9	2	50	15	100
2	N	mean	1000	1291	310	1830	2507	543	-
		%	13	17	4	25	34	7	100
	S	mean	226	1068	369	2169	4919	311	-
		%	2	12	4	24	54	3	100
3	N	mean	875	1318	254	864	1223	804	-
		%	15	25	5	16	24	15	100
	S	mean	130	376	195	546	1114	190	-
		%	4	15	8	21	45	8	100
4	N	mean	197	230	63	301	434	298	-
		%	11	15	4	20	30	20	100
	S	mean	43	267	76	237	627	168	-
		%	3	19	5	16	46	11	100

exceeded 4% in the southern zone (Table 3.9). These spatial and temporal variations in *Sardina* catch were clearly seen in the fishing zone effect and hydrographic season effect ($P \leq 0.0001$;Table 3.10) and in the significant interactions of zone*type and zone*season ($P \leq 0.000$). After examination of the sum of squares (Table 3.10) and the interaction plots (Figure 3.4), careful interpretation of the main effects is possible. In general, CPUE was always greater in the northern part of the EEZ for the cold season, and for the Rumanian vessels (Tables 3.11-3.13). For example, the highest *Sardina* CPUE was found in the northern zone during the cold season (11.9 metric tons/day) while negligible yield was recorded in the southern zone during the transitional cold-warm and warm seasons (0.1-0.2 metric tons/days; Table 3.14). Vessel type 1 (Rumanian) appeared to catch more *Sardina* particularly in the northern zone (6.6 metric tons/day) than did their Russian counterparts (Tables 3.13 and 3.15).

Sardinella aurita and *S. mederensis* (combined)

Over the study period, *Sardinella spp* catch accounted for 17% of the total combined catch (Table 3.5). Catch was particularly high (27% of the total combined catch) during the warm season (August-October) when about 40% of the *Sardinella* catch was taken (Table 3.6). More *Sardinella* were caught in the northern zone (62% of the total catch; Table 3.7) than in the southern zone (38 %). Russian vessels type 3 took the highest proportion of *Sardinella* in both the southern and northern zones, 15 and 25% , respectively (Table 3.8). These spatial

Table 3.9. Mean catch (metric tons) and percentage of total combined catch for taxa by hydrographic season and fishing zone (N=northern; S=southern) for all vessel types combined (1987-1993).

SEASON	ZONE		*Sardina*	*Sardinella*	*Scomber*	*Trichiurus*	Carangid	Other	Total
cold	N	mean	1578	557	74	584	515	317	-
		%	44	15	2	16	14	9	100
	S	mean	240	636	278	1156	3025	307	-
		%	4	11	5	20	54	5	100
trans1	N	mean	136	1322	534	885	1987	602	-
		%	2	23	10	16	37	11	100
	S	mean	14	749	394	1069	2639	287	-
		%	0	14	8	21	52	5	100
warm	N	mean	176	1844	368	1340	2524	763	-
		%	2	27	5	19	36	11	100
	S	mean	9	585	82	472	788	137	-
		%	0	29	4	22	38	6	100
trans2	N	mean	1223	521	315	1001	1932	587	-
		%	21	9	6	18	35	11	100
	S	mean	137	373	181	768	1898	299	-
		%	3	11	5	20	53	8	100

Table 3.10. Analysis of variance test results with interactions for differences in CPUE (metric tons/day) for Sardina due to year, vessel types, fishing zones and hydrographic seasons.

Source	*df*	*Sum of squares*	*F*	*Pr>F*
YEAR	6	5.52	2.33	**0.0349**
TYPE	3	14.78	12.50	**0.0001**
ZONE	1	34.63	87.84	**0.0001**
ZONE*TYPE	3	4.35	3.68	**0.0136**
SEASON	3	70.54	59.64	**0.0001**
TYPE*SEASON	9	4.67	1.32	0.2323
ZONE*SEASON	3	18.40	15.56	**0.0001**
ZONE*TYPE*SEASON	9	2.32	0.66	0.7482

Note: Bold values are significant at $\alpha \leq 0.05$

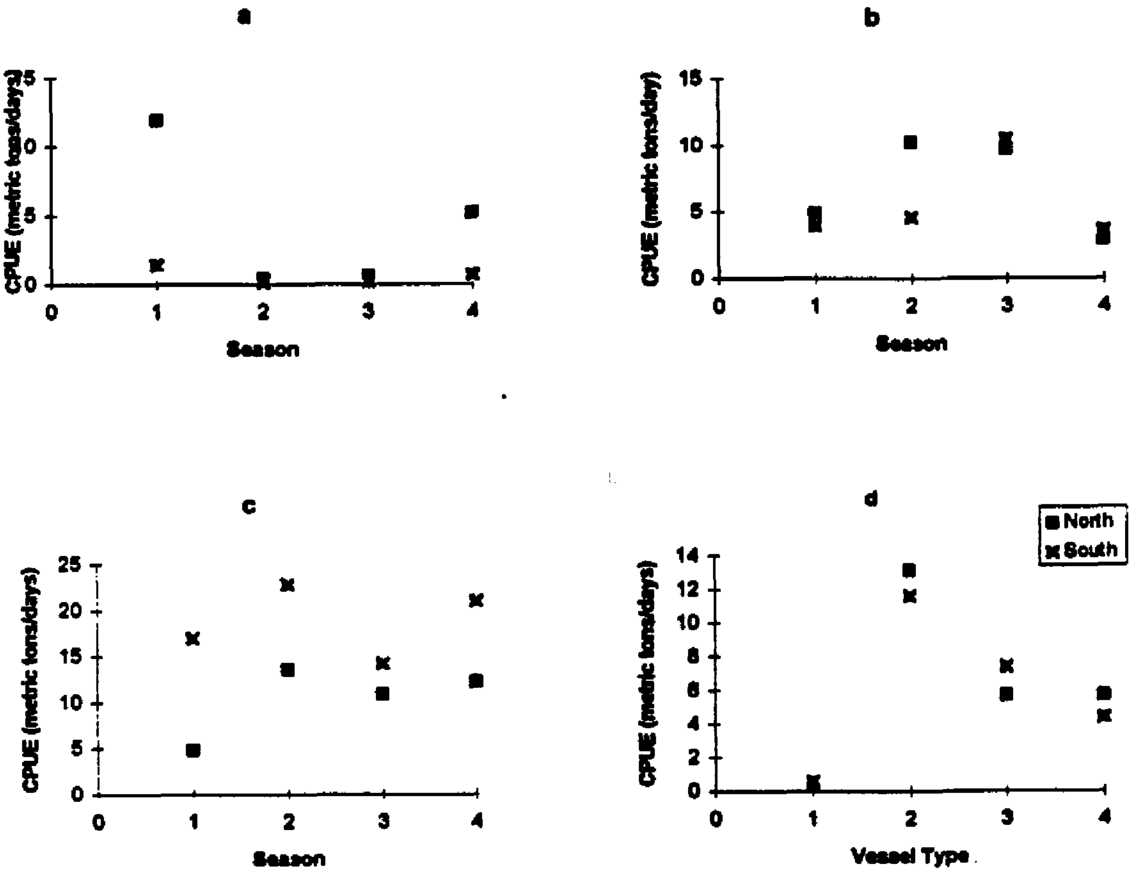


Figure 3.4. Plots of the interaction hydrographic season*fishing zone and vessel type*fishing zone for a) *Sardina*; b) *Sardinella* spp.; c) Carangid; and d) *Trichiurus* catch per unit effort data.

Table 3.11. CPUE (metric tons/day) geometric mean values for each species grouping by fishing zone (N=northern; S=southern) for all vessel types and hydrographic seasons combined.

Zone	*Sardina*	*Sardinella*	*Scomber*	*Trichiurus*	*Carangid*	*Other*
N	2.9	6.3	1.9	5.3	9.8	3.1
S	0.5	5.2	2	5.4	18.4	2.3

Table 3.12. CPUE (metric tons/day) geometric mean values for each species grouping by hydrographic season for all vessel types and fishing zones combined. Also presented are Tukey's studentized multiple comparison tests by taxa. Treatments with nonoverlapping letters are siginficantly different at $\alpha \leq 0.05$

Season	*Sardina*		*Sardinella*		*Scomber*		*Trichiurus*		*Carangid*		*Other*	
cold	4.5	(A)	4.4	(B)	1.3	(B)	5.4	(A)	9.3	(B)	2.4	(A)
trans.1	0.2	(C)	7	(B)	3.5	(A)	6.1	(A)	17.7	(A)	2.4	(A)
warm	0.4	(C)	10.1	(A)	1.5	(B)	5.1	(A)	12.5	(B)	2.7	(A)
trans.2	2.3	(B)	3.2	(B)	2	(B)	4.8	(A)	16.1	(A)	3.3	(A)

Table 3.13. CPUE (metric tons/day) geometric mean values for each species grouping by vessel type for all hydrographic seasons and fishing zones combined. Also presented are Tukey's studentized multiple comparison tests by taxa. Treatments with nonoverlapping letters are siginficantly different at an $\alpha \leq 0.05$.

Vessel type	*Sardina*		*Sardinella*		*Scomber*		*Trichiurus*		*Carangid*		*Other*	
1	2.8	(A)	6.3	(AB)	2.9	(A)	0.4	(C)	13.7	(B)	1.5	(B)
2	1	(B)	5.9	(AB)	1.8	(B)	12.3	(A)	22	(A)	2.9	(A)
3	1.5	(B)	6.5	(A)	2.1	(AB)	6.5	(B)	8.8	(C)	2.8	(A)
4	1.2	(B)	4.3	(B)	1.5	(B)	5	(B)	11.9	(B)	3.5	(A)

Table 3.14. CPUE (metric tons/day) geometric mean values for each species grouping by fishing zone (N=northern; S=southern) and hydrographic season for all vessel types combined.

Season	*Zone*	*Sardina*	*Sardinella*	*Scomber*	*Trichiurus*	*Carangid*	*Other*
cold	N	11.9	4.9	0.7	5	4.8	3
trans.1	N	0.4	10.2	3.9	5.7	13.6	3
warm	N	0.6	9.7	1.7	5.6	10.9	3.1
trans.2	N	5.2	2.9	2.2	4.9	12.2	3.4
cold	S	1.4	4	1.9	5.9	17	2
trans.1	S	0.1	4.6	3.2	6.5	22.8	1.8
warm	S	0.2	10.5	1.3	4.6	14.2	2.3
trans.2	S	0.7	3.6	1.9	4.7	21	3.2

Table 3.15. CPUE (metric tons/day) geometric mean values for each species grouping by fishing zone (N=northern; S=southern) and vessel type for all hydrographic seasons combined.

Vessel type	*Zone*	*Sardina*	*Sardinella*	*Scomber*	*Trichiurus*	*Carangid*	*Other*
1	N	6.6	6.5	2.4	0.3	9.8	1.2
2	N	2.1	7	2	13.1	17.4	3.5
3	N	3.1	7.4	2.1	5.7	5.3	3.5
4	N	1.7	4.2	1.3	5.7	9.5	4.3
1	S	0.9	6.1	3.5	0.6	19.1	1.9
2	S	0.3	5	1.7	11.6	27.9	2.3
3	S	0.5	5.7	2	7.4	14.1	2.2
4	S	0.7	4.4	1.6	4.4	14.8	2.7

and temporal variations in *Sardinella* catch were seen within the significant hydrographic season and vessel type effects and fishing zone*hydrographic season interaction (Table 3.16). Based on sum of squares, the seasonal effect accounted for most of *Sardinella* CPUE variability ($F=15.95$; $P \leq 0.0001$; Table 3.16). The hydrographic season*fishing zone interaction plot indicated that *Sardinella* CPUE was higher in the northern zone from January to July, but lower during the remainder of the year (Figure 3.4). Highest CPUE's were observed in the southern zone during the warm season (10.5 metric tons/day) and in the northern zone during the cold-warm transitional and warm seasons (10.2 and 9.7 metric tons/day, respectively; Table 3.14). Post hoc comparisons of vessel types indicated that Russian type 3 vessels had significantly higher *Sardinella* yields (6.5 metric tons/day) than type 4 (4.3 metric tons/day; Table 3.13).

Scomber japonicus

On average, chub mackerel catch accounted for about 5% of the total combined catch (Table 3.5). Catch was highest (9% of the total combined catch) during the transitional cold-warm season (June-July) and lowest from January to May (Table 3.6). The overall distribution of chub mackerel catch between the northern and southern zones was about the same, accounting for 53 and 47%, respectively (Table 3.7). Chub mackerel represented up to 9% of the total combined catch for the Rumanian fleet (vessel type 1) in both fishing zones (Table 3.8). For the Russian vessels, this proportion ranged between 4 and 8% (Table 3.8), depending on the fishing zone. It appeared that CPUE varied mostly with

Table 3.16. Analysis of variance test results with interactions for differences in CPUE (metric tons/day) for Sardinella due to year, vessel types, fishing zones and hydrographic seasons.

Source	*df*	*Sum of squares*	*F*	*Pr>F*
YEAR	6	16.64	5.46	**0.0001**
TYPE	3	5.33	3.50	**0.0171**
ZONE	1	0.83	1.64	0.2026
ZONE*TYPE	3	0.91	0.59	0.6195
SEASON	3	24.30	15.95	**0.0001**
TYPE*SEASON	9	2.60	0.57	0.8206
ZONE*SEASON	3	4.39	2.88	**0.0379**
ZONE*TYPE*SEASON	9	1.12	0.25	0.9869

Note: Bold values are significant at $\alpha \leq 0.05$

hydrographic season and vessel type (Table 3.17). Vessel type*hydrographic season and fishing zone*hydrographic season interactions were significant ($P \leq 0.016$ and 0.001, respectively; Table 3.17). The CPUE's were statistically higher during the transitional cold-warm season (3.5 metric tons/day) and low the rest of the year (1.3-2.0 metric tons/day; Table 3.12). The northern zone had the highest yield except during the cold season (Table 3.14). The Rumanian vessels have the highest yield in both the southern (3.5 metric tons/day) and northern (2.4 metric tons/day) zones, while type 4 vessels had the smallest average CPUE in the southern (1.3 metric tons/day) and northern zones (1.6 metric tons/day; Table 3.15).

Trichiurus lepturus

Trichiurus landings accounted for 19% of the total combined catch and this contribution to the total catch was almost constant over the four hydrographic seasons (Tables 3.5 and 3.6). Catch was also equally distributed between the northern and southern zones (Table 3.7). More *Trichiurus* were caught in the cold and warm seasons (39 and 26%, respectively) than in the transitional seasons (16-19%). The Russian fleet caught the vast majority of largehead hairtail in both zones (e.g., 16-25% of the total combined catch) while Rumanian vessels took very few, 1- 2%, from either fishing zone (Table 3.8). Only vessel type and hydrographic season were significant in the analysis of variance (Table 3.18). Enough evidence was present, however, to examine the possible fishing zone*vessel type interaction ($P \leq 0.097$; Table 3.18). Vessel types 1 and 3 had

Table 3.17. Analysis of variance test results with interactions for differences in CPUE (metric tons /day) for Scomber due to year, vessel types, fishing zones and hydrographic seasons.

Source	*df*	*Sum of squares*	*F*	*Pr>F*
YEAR	6	5.43	4.14	**0.0007**
TYPE	3	4.23	6.45	**0.0004**
ZONE	1	0.18	0.82	0.3669
ZONE*TYPE	3	0.85	1.30	0.2774
SEASON	3	12.91	19.67	**0.0001**
TYPE*SEASON	9	4.67	2.37	**0.0155**
ZONE*SEASON	3	3.58	5.46	**0.0014**
ZONE*TYPE*SEASON	9	1.17	0.59	0.8001

Note: Bold values are significant at $\alpha \leq 0.05$

Table 3.18. Analysis of variance test results with interactions for differences in CPUE (metric tons/day) for Trichiurus due to year, vessel types, fishing zones and hydrographic seasons.

Source	*df*	*Sum of squares*	*F*	*Pr>F*
YEAR	6	3.32	1.60	0.1523
TYPE	3	97.40	93.72	**0.0001**
ZONE	1	0.00	0.00	0.9465
ZONE*TYPE	3	2.23	2.15	0.0969
SEASON	3	2.93	2.82	**0.0410**
TYPE*SEASON	9	1.17	0.38	0.9449
ZONE*SEASON	3	1.47	1.41	0.2409
ZONE*TYPE*SEASON	9	1.67	0.53	0.8480

Note: Bold values are significant at $\alpha \leq 0.05$

higher largehead hairtail CPUE's in the southern than the northern zone; the reverse is true for vessel types 2 and 4 (Figure 3.3; Table 3.15). Russian vessel type 2 had a significantly higher CPUE (12.3 metric tons/day) while Rumanian vessels harvested the least (0.4 metric tons/day; Table 3.13). The seasonal variation appeared to be weak, since catch comparisons did not show any significant seasonal yield differences (Table 3.12). On average the highest CPUE was observed during the cold-warm transitional period (6.1 vs. 4.8-5.4 metric tons/day; Table 3.12).

Carangidae

Carangid catch dominated the fisheries landings accounting for 40% of the total combined catch (Table 3.5). The carangid proportion of the total combined catch by hydrographic season was always high (37-45%), being highest during both transitional seasons (Table 3.6). It also appeared that carangid catch was higher in the southern zone (60% of the category catch or 53% of the total combined catch) than in the northern zone (40% of the category catch or 30 % of the total catch; Table 3.7). In the southern zone, carangids represented 50% of the total combined catch for the Rumanian fleet and ranged between 45 and 54% for the Russian vessels (Table 3.8). In the northern zone the carangid proportion was lower for all vessel types (24-34%; Table 3.8). All treatment main effects, i.e., fishing zone, vessel type and hydrographic season, were significant as was the zone*season interaction (Table 3.19 and Tables 3.11-3.13). The fishing zone*vessel type interaction was almost significant ($P \leq 0.06$; Table 3.19). Exami-

Table 3.19. Analysis of variance test results with interactions for differences in CPUE (metric tons/day) for Carangids due to year, vessel types, fishing zones and hydrographic seasons.

Source	*df*	*Sum of squares*	*F*	*Pr>F*
YEAR	6	34.198	22.82	**0.0001**
TYPE	3	26.766	35.72	**0.0001**
ZONE	1	12.984	51.98	**0.0001**
ZONE*TYPE	3	1.860	2.48	0.0631
SEASON	3	6.483	8.65	**0.0001**
TYPE*SEASON	9	2.408	1.07	0.3874
ZONE*SEASON	3	5.556	7.41	**0.0001**
ZONE*TYPE*SEASON	9	1.468	0.65	0.7500

Note: Bold values are significant at $\alpha \leq 0.05$

nation of the interaction plots and sum of squares values (Table 3.19; Figure 3.4) indicated that the near significance of the fishing zone*vessel type interaction indeed warranted consideration. Carangid yields were higher in the southern (18.4 metric tons/day) than in the northern fishing zone (9.8 metric tons/day). Also, seasonal differences indicated that CPUE was higher during both transitional seasons (cold-warm and warm-cold) with average values of 17.7 and 16.1 metric tons/day, respectively. Significantly lower CPUE's were recorded during the cold (9.3 metric tons/day) and warm water seasons (12.5 metric tons/day; Table 3.12). The CPUE for Russian vessel type 2 was statistically highest (22.0 metric tons/day) while type 3 yields were the lowest (8.8 metric tons/day; Table 3.13). Vessel types 1 and 4 had similar yields (Tables 3.13 and 3.15).

OTHER species

On average, species group OTHER accounted for about 8% of the total combined catch and varied little throughout the year (Tables 3.5 and 3.6). OTHER catch was considerably higher in the northern zone (70% of species group catch or 10% of the total combined catch) than in the southern zone (5 % of the total catch; Table 3.7). Also, OTHER represented 7-20% of the total combined catch for the Russian fleet in the northern but only 3-11% in the southern zone (Table 3.8). The reverse was observed for the Rumanian vessels (Type 1) for which the proportion was higher in the southern (15% of the total combined catch) than in the northern zone (6%, Table 3.8).

The variability in CPUE for the OTHER category was characterized by significant differences in vessel types, fishing zones, and the combined effect of type and zone (Table 3.20). Type 1 vessels had the lowest CPUE values, 1.2 and 1.9 metric tons/day in the northern and southern fishing zones, respectively. Yields for Russian vessels were always higher in the northern than in the southern zone (Table 3.15).

Multispecies analysis

As stated earlier, univariate analysis allowed us to test for differences among vessel types, hydrographic seasons and fishing zones for each species or species grouping. These results, however, would not guarantee an overall error protection, since catch of one species influences the catch of other species. Also, some significant results might be spurious because serial univariate analyses inflate the overall experimentwise error rate. As such, in order to validate the univariate analyses, these variations at the joint or combined taxa level need investigation (Table 3.21).

First, it should be noted that year (treated within the multivariate analysis as a blocking factor) had a significant (Table 3.21) effect as it did in all univariate (individual taxa) analyses except for *Trichiurus* ($P \leq 0.153$; Table 3.18). Moreover, total fishery CPUE tended to show an overall statistically significant linear and quadratic trend over the years (Table 3.22). In the previous sections, the various species or species groupings exhibited spatial and temporal variabilities as was the case for the multivariate analysis of total fishery CPUE. Univariate analyses

Table 3.20. Analysis of variance test results with interactions for differences in CPUE (metric tons/day) for OTHER species due to year, vessel types, fishing zones and hydrographic seasons.

Source	*df*	*Sum of squares*	*F*	*Pr>F*
YEAR	6	42.54	20.33	**0.0001**
TYPE	3	16.82	16.08	**0.0001**
ZONE	1	1.93	5.54	**0.0199**
ZONE*TYPE	3	3.10	2.96	**0.0341**
SEASON	3	1.95	1.87	0.1379
TYPE*SEASON	9	2.58	0.82	0.5978
ZONE*SEASON	3	0.81	0.77	0.5115
ZONE*TYPE*SEASON	9	1.07	0.34	0.9599

Note: Bold values are significant at $\alpha \leq 0.05$

Table 3.21. Multivariate analysis of variance test results with interactions for differences in CPUE (metric tons/day) for the joint or multispecies model by year, vessel types, fishing zones and hydrographic seasons. Numdf=numerator degrees of freedom; Dendf=denominator degrees of freedom.

Source	*Wilks' Lambda*	*F*	*Numdf*	*Dendf*	*Pr > F*
YEAR	0.17	8.73	36	635	**0.0001**
TYPE	0.10	27.73	18	408	**0.0001**
ZONE	0.54	20.50	6	144	**0.0001**
ZONE*TYPE	0.74	2.51	18	408	**0.0006**
SEASON	0.25	14.47	18	408	**0.0001**
TYPE*SEASON	0.72	0.98	54	739	0.5092
ZONE*SEASON	0.62	4.11	18	408	**0.0001**
ZONE*TYPE*SEASON	0.82	0.54	54	739	0.9974

Note: Bold values are significant at $\alpha \leq 0.05$

Table 3.22. Multivariate analysis of variance test criteria and F statistics for the hypothesis of no overall linear or quadratic effect and no differrences between cold and warm hydrographic seasons, and no differences between fishing vessel type 1 and 2. Numdf=numerator degrees of freedom; Dendf=denominator degrees of freedom.

Contrast	*Wilks' Lambda*	*F*	*Numdf*	*Dendf*	*Pr > F*
Linear year	0.369	41.10	6	144	0.0001
Quadratic year	0.845	4.41	6	144	0.0004
Vessel type 1 vs. 2	0.201	95.26	6	144	0.0001
Cold vs. Warm season	0.542	20.24	6	144	0.0001

showed that some taxa yields were higher in one fishing zone during specific hydrographic seasons and that some fishing vessel types tended to have high taxa yields in a particular fishing zone. For example, *Sardina* yields were highest during the cold season, fishing vessel type 3 tended to catch more *Sardinella* in the north. As such, and given the nature of interdependence between species, all taxa jointlyexhibited an overall combined fishing zone and hydrographic season as well as fishing zone and vessel type effects ($P \leq 0.001$; Table 3.21). Most of the variability in the response variable (total fishery CPUE) can be explained by differences in vessel type ($P \leq 0.001$), fishing zone ($P \leq 0.001$) and hydrographic season ($P \leq 0.001$; Table 3.21). Rumanian fishing vessels also differ considerably from the Russian ones; and yields in the warm water season are much different from those taken in the cold water season (Table 3.22).

DISCUSSION

Total effort consistently decreased from 9661 to 7092 fishing days during 1987-1993. This is only an apparent decrease, however, because the Rumanian fleet stopped operating after 1990. Since 1991, the nominal fishing effort remained about the same. More importantly, on a monthly basis, the total effort did not show any variability (Figure 3.2) implying that the various vessel types tended to fish at the same level throughout the year. In fact, the distribution of total effort between the two fishing zones is almost identical (Table 3.3) Seasonal variations within zone, however, indicate a high degree of fleet mobility over the continental shelf. Vessels tend to move gradually toward the southern zone at the beginning of the

year and by May more than 80% of the effort is distributed within the southern zone. At the beginning of the transitional cold-warm water season (June-July), fleets start to move toward the northern zone, where 85% of the total effort is concentrated by August (warm water season). Southward fleet movement starts again around the transitional warm-cold water season (November-December). This pattern has been described by Chavance (1988, 1990) although his observations were limited to a single year. It should also be noted that Russian vessel type 2 tended to stay longer in the southern zone (Table 3.4).

Multivariate and univariate analyses indicate combined effects of fishing zone and vessel type and zone and hydrographic season (Tables 3.10 and 3.15-3.21). Jointly all taxa yields clearly show spatial and temporal variability in fishing zone, hydrographic season and fishing vessel types. Each species or group of species, however, has distinct characteristics depending on the hydrographic season, fishing zone, and whether or not it is a primary fishery target. For carangids, the highest catches are observed during both transitional water seasons (Table 3.12). These seasons appear to match the migration period of *Trachurus trachurus* and *T. trecae* over the Mauritanian continental shelf (Chavance et al., 1991a and b; Josse, 1991). Carangid yields also appear to be lower in the north than in the south, and are lower during the cold water season. This latitudinal difference is probably due to the presence of colder water masses over the whole continental shelf and particularly within the northern zone. In fact, acoustic evaluations conducted on the Mauritanian continental shelf indicate that

carangids dominate the pelagic biomass in the southern zone, especially during the cold water season (Josse and Chavance, 1988a and b). During the cold water season, carangid catch is principally composed of *Trachurus trachurus* in both the northern and southern fishing zones, with *Decapterus rhonchus* being absent from the north during the cold season (Chavance et al., 1991a) while *T. trecae* is predominant only in the south. During the remainder of the year, however, *T. trecae*, is the dominant species for both fishing zones. In fact, Chavance et al. (1991a) found the following mean carangid composition based on the Russian vessels catch (1986-1989) for both fishing zones combined: *T. trecae* 64.5%, *D. rhonchus* 25.2 %, and *T. trachurus* 10.3 %.

Seventy-four percent of the *Sardina* catch is taken during the cold season with an additional 20% taken during the transitional warm-cold water season (November-December; Table 3.6). *Sardina* migrate onto the Mauritanian continental shelf in September-October and disappear around June (Chavance et al., 1991a). The species appears to prefer the cold waters that invade the continental shelf during the cold water season and, therefore, yields are much higher in the northern fishing zone. When the water is cold, *Sardina* catch can represent up to 20% of the total combined catch. The actual fishery catch may be lower than availability would suggest given that acoustic surveys indicate that *Sardina* represents up to 45% of the pelagic fish biomass in the northern part of the continental shelf during the cold season (Josse and Chavance, 1988a and b).

Sardinella spp. catch is the reverse of that for *Sardina* being particularly high during the warm water and transitional cold-to-warm seasons. The catch for *Sardinella* spp. during the warmer seasons probably reflects their spawning seasons. Round sardinella spawns between July and August and a major part of the Madeiran sardinella spawning season occurs between May and September (Chavance, 1991). It is difficult to distinguish the catch of one *Sardinella* species from the other. Both species are present year round, although acoustical surveys show that round sardinella disappear from the northern part of the continental shelf in May (Josse and Chavance, 1988a). As such, I expect that the catch of the transitional cold-warm water season to probably be composed of Madeiran sardinella.

Chub mackerel catch is low during the cold water season (January-May) especially in the northern zone. It abundance increases during the remaining months of the year. This seasonality reflects their migrational pattern, i.e., chub mackerel schools appear to follow certain environmental conditions like the displacement of the 19 to 20^{0}C isotherm (Schemainda and Nehring, 1975; Krivospitchenko and Dubrovin, In press). Shoals start to concentrate over the southern continental shelf around April and move northward, where their abundance is maximal from June to September. Afterwards they start migrating southward and exit the Mauritanian EEZ by December (Chavance et al., 1991a).

There are several strong indications that all fishing vessel types tend to primarily target carangid species. First, the composition of the total combined

catch is largely dominated by this group (40%, Table 3.5). Second, throughout the year, this species group is consistently present making up at least 30% of the total combined catch. Third, fleet displacement tends to follow their migration scheme.

Clupeids constitute the second primary target for the pelagic fleet. They account for about 38% of the total combined catch. Fishing vessels concentrate heavily on *Sardina* during the cold water season, when abundance is maximal (74% of the *Sardina* catch is taken during this period). Also the carangid catch is not very high during the cold season, especially in the northern zone. *Sardinella* spp., on the other hand, are caught throughout the year, but their maximum yield is taken during the warm season, when *Sardina* have disappeared from the continental shelf. As mentioned earlier, this season corresponds to the spawning period of the two *Sardinella* spp. (round and Madeiran sardinella; Chavance et al., 1991a).

The final group targeted includes largehead hairtail, chub mackerel and the OTHER category consisting of unidentified species. Although these species or species groups exhibit large seasonal and spatial variations, their catch is primarily determined by the availability of the primarily and secondarily targeted groups (i.e., Carangids and Clupeids) and by the type of fishing vessel rather than by species availability. For example, *Trichiurus lepturus* catch comprises between 16 and 25 % of the total catch of the Russian fleet (vessel type 2-4), whereas, it comprises only about 1% to 2% of the total combined catch of the Rumanian fleet (vessel type 1). Likewise, catch for the OTHER category is low for the Rumanian vessels

and higher for the Russian vessels. There appears to be no indication of any considerable effort being specifically directed toward catching chub mackerel and all vessel types have comparable yields.

Key differences were also noticed between the Rumanian and Russian Clupeidae catch (*Sardina* and *Sardinella* spp. combined). Although the proportion of *Sardinella* catch to the total combined catch is almost identical for the four vessel types, Rumanian ships have a much higher *Sardina* catch with an average proportion of 36% of the total catch in the northern zone, while the Russian fleet's average catch proportion does not exceed 15%. In the southern zone, all fleets have low *Sardina* catch (2-4% of the total catch). Finally, it appears that catch differences within the Russian fleet (vessel types 2-4) are mostly attributed to differences in the physical characteristics of the vessels. On average, type 2 has the highest yields, and taxa yields for type 3 vessels are generally higher than type 4 vessels, except for the Carangid group. This may be a reflection of type 3 vessels tending to stay more in the northern part of the continental shelf; on average 66% of their total effort is spent in the northern fishing zone (Table 3.4). As such they seem to catch more Clupeidae and fewer Carangidae (Tables 3.12 and 3.15).

A key point to notice is the complex interaction of fleet displacement and the seasonal availability of the species. All fleets during all four seasons tend to follow the maximum Carangid concentrations possible, whereas other species' abundances may be maximal elsewhere. For example, during the cold water

season, *Sardina pilchardus* yield is relatively high, especially in the north. Yet, the vast majority of the fleet stays in the south to harvest Carangids. During the warm season, *Sardinella* spp. contribute greatly to the total fleet catch because it is ubiquitous and Carangid abundances are generally low. *Trichiurus* yield is constant year round and is targeted only by Russian vessels. As mentioned above, no considerable effort is directed toward the chub mackerel.

I have limited this study to the identification of catch composition, to the characterization of seasonal and zonal patterns, and to the exploration of potential differences between fishing vessels types in the CPUE of the small pelagic fishery. Although we are not primarily interested in yearly differences, our analyses show that CPUE exhibits significant yearly trends. This yearly variability as well as species interdependence will be further investigated in the next chapters.

CHAPTER 4
Estimation of Catch Per Unit of Effort

INTRODUCTION

As indicated in the previous chapter, species catch varies seasonally. Therefore, assessing the impact such variations might have upon our abundance estimates is of interest. Although some biomass estimates are available from acoustic surveys, most of the abundance estimates have to rely upon fishery dependent data, i.e., catch and effort data from commercial fisheries. Catch per unit of effort or CPUE is the most commonly used index of fish abundance in fisheries science and plays a key role in many stock assessment models (Gulland, 1964). It is defined as the catch realized by a fishery per unit of fishing effort expended (Cook, 1984). The CPUE or catch rate is often computed as the ratio of total catch to total effort for a given year.

It is generally assumed that the average CPUE (U) is proportional to the average density (A) according to: U=q*A, where q is the catchability coefficient which is assumed to be constant (Gulland, 1964 and 1983; Clark, 1985) . This relationship is far from reality, for fishes are not uniformly distributed in the ocean. Even catches made by the same boat at about the same place and time tend to vary. This estimate also does not take into account such effects as seasonal or spatial variability. Gulland (1955, 1956) attempted to address the assumption of q being constant for the North Sea haddock (Melanogrammus aeglefinus) and

plaice (Pleuronectes platessa) fishery. First, he divided the data area into small space grids and time intervals, then, he compared the overall abundance or density index to the calculated subdensities at a given time period. If fish were uniformly distributed, the ratio of both density indices would be 1. Instead, he found that fishermen tended to concentrate their effort in subareas where fish concentrations were presumed to be high. Also, he noticed seasonal fluctuations in fish concentrations. The heterogeneity becomes even more pronounced in the case of schooling species which form aggregates. As a result, dividing the fishing area into the smallest grid possible, in which fish density is nearly uniform, became common practice of the International Tropical Tuna Commission (Clark, 1985). Clark (1985) proposed an alternative approach by considering fishing as a random process that follows a Poisson distribution (Paloheimo and Dickie, 1964).Therefore, CPUE, would be a random variable whose expectation is in part determined by fish density and updated using prior information from the fishermen's logbooks (average number of schools encountered, experience, etc). Regardless of the models used, determining the best CPUE estimate is still a crucial step.

The first section of this chapter concentrates on estimating CPUE given catch and effort data only. The objective is to assess the variability associated with the CPUE estimates by comparing regression and ratio estimators. Furthermore, the following questions will be addressed: 1) Should catch and effort be treated as a ratio of two random variables? What is the distribution of the data when the

variables are not independent? 2) Should we force the regression through the origin even when these data show the presence of a significant intercept? 3) How appropriate is the use of a regression model? Is a simple linear model adequate or is there a curvature that adjusts for variability at high effort levels?

The second section of this chapter deals with estimating CPUE for individual species or species groupings. At the present time, the pelagic fishery's effort data are reported as total effort for the combined catch rather than at an individual species level. The techniques mentioned above will be used in an attempt to adequately partition the effort among individual species or species groups.

MATERIAL AND METHODS

Data description

Fisheries statistics were provided by the Centre National de Recherches Océanographiques (CNROP), Nouadhibou, Mauritania. They consist of catch (metric tons) and effort (fishing days and number of trawling hours) data extracted from the logbooks of pelagic fishing vessels operating in the Mauritanian EEZ. The time period covers 1991 through 1993. Only vessels of similar physical characteristics were included in this study. As such I have considered only one vessel category, i.e., Super Atlantic Trawlers or vessel type 2. Each year was divided into four distinct hydrographic seasons as follows: season 1 (January-May); season 2 (June-July); season 3 (August-October); and, season 4 (November-December) following Dubrovin et al. (1990, 1991). The continental

shelf was divided into two fishing zones: a northern and a southern fishing area demarketed by the 19^0N parallel (see Chapters 2 and 3 for more details).

The statistical design, therefore, consisted of a 3*4*2 factorial design (3 years*4 seasons*2 zones). For each of the 24 cells, a CPUE index was computed using the ratio and regression methods outlined below. The techniques were evaluated on the basis of model adequacy and variance of the estimates.

It is important to note that the choice among the two techniques presented depends primarily on the objective of the study. The ratio method is based on simple random sampling and has very limited assumptions, while the regression method assumes an infinite population. If the researcher is primarily interested in modeling rather than population estimation, the regression method could be the better choice as will be shown later.

Ratio estimators

There are two main advantages in using ratio estimators (Cochran, 1977). First, the computations are easily compared to other statistical techniques such as maximum likelihood methods. Second, there are limited assumptions about the frequency distribution of the parameters. Usually, analyses focus on looking at the shape of the distribution (problems related to excessive skewness and asymmetry) while little attention is given to its functional form.

For a given cell, CPUE index was calculated as the ratio of total catch (metric tons) to total effort (fishing days) according to the following formula:

$$R_i = \frac{\sum_{j=1}^{n_i} Y_{ij}}{\sum_{j=1}^{n_i} X_{ij}} = \frac{\bar{Y}_i}{\bar{X}_i} \tag{1}$$

where Yij is total catch for all j^{th} vessels' catch values in the i^{th} cell;
Xij is total effort for all j^{th} vessels' effort values in the i^{th} cell;
R_i is CPUE index or catch rate for the i^{th} cell;
$\bar{X}_i$ is average effort in the i^{th} cell; and
$\bar{Y}_i$ is average catch in the i^{th} cell.

The distribution of ratio estimates is complex but tends to be normal as the sample sizes increase (Cochran, 1977). In general, ratio estimators are consistent but biased. The bias is of the order of n^{-1} and becomes negligible in large sample sizes (Konijn, 1973; Cochran, 1977). Exact bias formulae are given by Hartley and Ross (1954) who derived an exact formula for the bias of the ratio estimator by considering:

$$cov(\hat{R}, \bar{x}) = E(\frac{\bar{y}}{\bar{x}} * \bar{x}) - E(\hat{R})\, E(\bar{x}) = \bar{Y} - \bar{X} E(\hat{R})$$

where cov( ) denotes covariance of the given random variables, E( ) is the expected value, and $\hat{R}$, $\bar{x}$ and $\bar{y}$ are estimators for CPUE, average fishing effort and average catch, respectively, as in equation (1).

Henceforth, the bias is:

$$E(\hat{R}) - R = -\frac{1}{\bar{X}}\, cov(\hat{R}, \bar{x})$$

Using Schwartz's inequality (Casella and Berger, 1992), we have

$$|bias(\hat{R})| = \frac{|\rho\sigma_{\hat{R}}\ \sigma_{\bar{x}}|}{\bar{X}} \le \frac{\sigma_{\hat{R}}\ \sigma_{\bar{x}}}{\bar{X}}$$

where σ denotes standard error and ρ denotes the correlation coefficient between catch and effort. Then an upper bound on the bias is:

$$\frac{|bias(\hat{R})|}{\sigma_{\hat{R}}} \le \frac{\sigma_{\bar{x}}}{\bar{X}} = cv(\bar{x})$$

where cv( ) denotes the coefficient of variation.

Using Taylor series (Cochran, 1977; Casella and Berger, 1992), an approximation for the bias is given by:

$$Bias(\hat{R}) = \frac{1}{\bar{X}^2}(\hat{R}^2\sigma_x^2 - \sigma_{yx}) \qquad (2)$$

The variance of the ratio has been shown (Cochran , 1977; Sukhatme and Sukhatme, 1984) to be approximated by:

$$\sigma_{\hat{R}}^2 = \frac{1}{\bar{X}^2}(\sigma_y^2 + \hat{R}^2\sigma_x^2 - 2\hat{R}\sigma_{yx}) \qquad (3)$$

Values given in formulae (2) and (3) are valid provided that the sample sizes are large enough (n>30) so that the coefficients of variation for x and y do not exceed 10% (Cochran, 1977). Tin's modified and Beale's ratio estimators (Tin, 1965) were

also used for a comparative purpose. These two ratios are corrected for bias of order n^{-1}.

Regression estimators

Regression is an alternative method that can be used to determine CPUE indices. Under certain conditions (Bibby, 1977; Myer, 1986), least squares estimators (LSE) are known as Minimum Variance Unbiased Estimators (MVUE). Such conditions imply that the error terms are normally distributed, uncorrelated and have common variance (homoskedascity). This method, however, can be extremely lengthy (Smith, 1980).

Most of the work in this section has been directed toward coming up with the best model to describe the relationship between catch and effort. The general model used is:

$$Y_{ijkl} = \prod_{ijk} \alpha_{ijk} \, X_{ijk}^{\beta_{ijk}} \exp(\epsilon) \qquad (4)$$

where: Y_{ijkl}= catch (metric tons) for i^{th} year, j^{th} season, k^{th} zone and l^{th} replicate;
X_{ijk}= effort (fishing days) for i^{th} year, j^{th} season, and k^{th} zone;
α_{ijk}= slope for i^{th} year, j^{th} season and k^{th} zone;
β_{ijk}= power term for i^{th} year, j^{th} season and k^{th} zone;
$\epsilon \sim NID(0,\sigma^2)$, i.e., the error terms are independant and normally distributed;
and $i \neq j \neq k \neq l$; i=1,3; j=1,4; k=1,2 and l=1,n (replicates).

Note that the model assumes that the errors are multiplicative. Equation (4) was linearized using a natural log transformation:

$$\ln Y_{ijkl} = \sum_{ijk} \ln(\alpha_{ijk}) + \sum_{ijk} \beta_{ijk} * \ln(X_{ijk}) + \epsilon \qquad (5)$$

The previous model was also fitted by restricting the power term (β_{ijk}) to 1, so that the slope will yield a CPUE estimate. This restriction resulted in an ordinary linear regression model of the form:

$$\ln Y_{ijkl} = \sum_{ijk} \alpha_{ijk} \ln(X_{ijk}) + \varepsilon \qquad (6)$$

To assess the validity of the regression model, plots of the error variances against the dependant variable (effort) were generated. Depending upon whether the variance is constant, proportional to X^2, or proportional to X, adequate weight functions could be, respectively:

$$\frac{\sum \hat{x}_i \hat{y}_i}{\sum \hat{x}_i^2} \qquad (7)$$

$$\frac{\sum \frac{\hat{y}_i}{\hat{x}_i}}{n} \qquad (8)$$

$$\frac{\sum \hat{y}_i}{\sum \hat{x}_i} \qquad (9)$$

Equation (9) is not the same as the ratio estimator presented in equation (1) because, once again, the assumptions are different. It is interesting, however, to note that this estimate is a Best Linear Unbiased Estimator (BLUE) provided no significant intercept is detected and the variance of the error terms is constant (Cochran, 1977).

In equations (7-9) $x'_i=\ln(X_i)$ and $y'_i=\ln(Y_i)$ are normally distributed (μ,σ^2) while in equations (3-6), X_i and Y_i are log-normally distributed with

$$\mu_1=e^{\mu+\frac{\sigma^2}{2}} \tag{10}$$

$$\sigma_1^2=e^{2\mu+2\sigma^2} - e^{2\mu+\sigma^2} \tag{11}$$

Finally, the Mean Square Error (MSE) for an estimator was defined as:

$$\text{MSE} = \text{Variance} + (\text{Bias})^2 \tag{12}$$

Proc GLM and Proc REG (SAS, 1989) were used for model fitting and hypothesis testing. Also, INSIGHT (SAS, 1989) as well as a BEST FIT software were used to fit the distribution of the data.

RESULTS AND DISCUSSION

Ratio estimators

Individual ratio estimates performed on the raw CPUE data (total catch/total effort: metric tons/fishing days) range from 10.25 to 32.12 (Table 4.1). The corresponding standard errors were so high that many of the confidence intervals include zero values. This is a reflection of the high variance, since both the coefficients of variation for catch and effort exceed 10% in all cases (Table 4.1). As such, variance calculations based on equation (3) may not be adequate. Beale's ratio estimate and the Tin's modified ratio estimate performed well in reducing the bias (Tables 4.2). The standard errors, however, either remained about the same or increased slightly. None of the estimators is notably more efficient than the other with regard to total variability (variance and bias). It might be then more appropriate to use a less biased estimator (Tin or Beale's). Similar

Table 4.1. Individual standard ratio estimates (R) and associated standard errors and bias. Also presented are correlation coefficient and coefficients of variation for effort and catch data by year, hydrographic season and fishing zone (N=northern; S=southern).

Year	*Season*	*Zone*	*R*	*Error*	*Bias*	*Correlation Coefficient*	*Coeff. var. effort*	*Coeff. var. catch*
91	cold	N	10.25	5.74	-1.24	0.91	1.13	1.35
91	cold	S	19.68	6.42	-0.36	0.80	0.38	0.54
91	cold-warm	N	20.80	6.94	0.06	0.80	0.45	0.56
91	cold-warm	S	28.51	8.10	-0.52	0.84	0.39	0.52
91	warm	N	25.78	17.77	-0.78	0.72	0.68	1.00
91	warm	S	22.18	9.41	-2.95	0.92	0.72	0.98
91	warm-cold	N	24.93	8.36	0.08	0.92	0.79	0.86
91	warm-cold	S	29.17	8.84	0.20	0.88	0.57	0.64
92	cold	N	17.04	10.59	0.02	0.80	0.84	1.04
92	cold	S	27.27	7.22	0.56	0.91	0.62	0.65
92	cold-warm	N	26.22	13.50	0.04	0.75	0.58	0.77
92	cold-warm	S	32.12	12.25	0.26	0.80	0.52	0.63
92	warm	N	19.70	9.59	2.16	0.66	0.58	0.60
92	warm	S	16.25	7.65	-1.46	0.89	0.75	0.98
92	warm-cold	N	17.50	7.97	-2.85	0.94	0.95	1.20
92	warm-cold	S	26.91	12.46	-2.70	0.88	0.64	0.91
93	cold	N	16.57	10.36	-4.68	0.92	0.98	1.38
93	cold	S	26.30	9.56	-0.85	0.88	0.60	0.74
93	cold-warm	N	23.13	9.92	-1.61	0.86	0.58	0.81
93	cold-warm	S	30.97	6.75	0.84	0.90	0.50	0.49
93	warm	N	16.28	6.26	0.03	0.88	0.71	0.80
93	warm	S	15.38	7.73	-1.39	0.86	0.68	0.95
93	warm-cold	N	21.44	12.87	-5.80	0.92	1.01	1.39
93	warm-cold	S	20.41	8.10	-0.72	0.83	0.52	0.70

Table 4.2. Individual Beale's (Rb) and Tin's modified (Rm) ratio estimates and associated standard errors (Se) and bias by year, hydrographic season and fishing zone (N=northern; S=southern).

Year	*Season*	*Zone*	*Rb*	*Se(Rb)*	*Bias(Rb)*	*Rm*	*Se(Rm)*	*Bias(Rm)*
91	cold	N	10.80	5.65	-0.55	12.87	5.93	2.08
91	cold	S	20.00	6.40	-0.32	20.42	6.39	-0.25
91	cold-warm	N	20.75	6.94	0.05	20.69	6.94	0.04
91	cold-warm	S	28.97	8.07	-0.45	29.56	8.04	-0.36
91	warm	N	26.32	17.75	-0.54	27.37	17.73	-0.05
91	warm	S	24.13	8.88	-1.95	28.48	8.46	0.27
91	warm-cold	N	24.89	8.36	0.05	24.78	8.36	-0.02
91	warm-cold	S	29.02	8.84	0.15	28.77	8.84	0.07
92	cold	N	17.02	10.59	0.01	16.99	10.59	-0.01
92	cold	S	26.87	7.19	0.40	26.16	7.17	0.13
92	cold-warm	N	26.19	13.50	0.03	26.14	13.50	0.01
92	cold-warm	S	31.91	12.24	0.21	31.59	12.24	0.12
92	warm	N	18.09	9.27	1.61	15.61	8.95	0.77
92	warm	S	17.18	7.51	-0.93	19.29	7.41	0.26
92	warm-cold	N	19.00	7.55	-1.50	23.67	7.90	2.68
92	warm-cold	S	28.82	12.10	-1.91	32.57	11.74	-0.37
93	cold	N	18.96	9.51	-2.39	27.25	10.79	5.53
93	cold	S	26.93	9.51	-0.63	28.03	9.46	-0.23
93	cold-warm	N	24.33	9.75	-1.20	26.46	9.56	-0.48
93	cold-warm	S	30.30	6.68	0.67	29.32	6.60	0.43
93	warm	N	16.26	6.26	0.02	16.22	6.26	0.00
93	warm	S	16.33	7.59	-0.95	18.28	7.46	-0.04
93	warm-cold	N	24.30	11.87	-2.86	34.60	13.82	7.74
93	warm-cold	S	20.99	8.05	-0.57	21.89	8.00	-0.33

results were reported by Tin (1965) and Konijn (1973). In all cases the coefficient of correlation is more than ½ of the ratio of cv(x)/cv(y) which indicates the probable superiority of the ratio estimator over the simple mean estimator (Cochran, 1977; Scheaffer et al., 1990).

Similar calculations were then performed on Napierian (or natural) log-transformed values and the results were satisfactory. Unlike the previous case, the efficiency of various ratio estimators differ. Tin's (1965) modified estimator is the most efficient among the three (Table 4.3). In fact, the lognormal distribution seems to fit the distribution of catch and effort well (Andersen, 1964). As such, working under the assumption that the catch and effort are asymptotically bivariate lognormal yields apparently the best ratio estimates. It is important, however, to note that the values presented are geometric means. Equation (10) can be used to compute the arithmetic mean and equation (11) the corresponding variance.

These results were not expected given that CPUE ratios tend to have a normal distribution. Normality has been noticed by various authors who have stated that the sampling distribution approaches normality as sample size increases, a result of the Central Limit Theorem (Cochran, 1977). In this case, the $\log_e$-transformed values provide better estimates than the untransformed catch and effort values because of the skewness of the raw variables (Table 4.4).

Regression estimators

The first series of outputs are simple linear regressions on the raw CPUE data. The intercepts did not significantly differ from zero (P<0.0001). The regres-

Table 4.3. Relative efficiency of standard (R), Beale's (Rb) and Tin's (Rm) ratio estimators using mean squared error as the basis for comparison of $\log_e$- transformed catch (metric tons) and effort (days) by year, hydrographic season and fishing zone (N=northern; S=southern). Also presented is the average relative efficiency.

Year	*Season*	*Zone*	*R*	*Rb*	*Rm*	*Rb/R*	*Rm/R*
91	cold	N	0.94	0.58	0.26	0.62	0.28
91	cold	S	0.02	0.02	0.02	0.97	0.95
91	cold-warm	N	0.09	0.07	0.06	0.86	0.72
91	cold-warm	S	0.03	0.03	0.03	0.97	0.94
91	warm	N	0.16	0.13	0.10	0.81	0.62
91	warm	S	0.74	0.52	0.30	0.70	0.41
91	warm-cold	N	0.25	0.20	0.15	0.80	0.60
91	warm-cold	S	0.20	0.17	0.14	0.84	0.67
92	cold	N	1.61	0.99	0.43	0.61	0.27
92	cold	S	0.04	0.04	0.04	0.94	0.87
92	cold-warm	N	0.12	0.11	0.10	0.92	0.84
92	cold-warm	S	0.12	0.11	0.09	0.90	0.79
92	warm	N	0.10	0.10	0.09	0.94	0.87
92	warm	S	0.32	0.25	0.18	0.78	0.56
92	warm-cold	N	0.93	0.55	0.21	0.59	0.23
92	warm-cold	S	0.15	0.13	0.11	0.88	0.76
93	cold	N	5.22	1.98	0.23	0.38	0.04
93	cold	S	0.05	0.05	0.04	0.91	0.82
93	cold-warm	N	0.23	0.20	0.17	0.87	0.73
93	cold-warm	S	0.25	0.20	0.16	0.82	0.63
93	warm	N	0.18	0.16	0.13	0.86	0.72
93	warm	S	0.28	0.22	0.15	0.77	0.53
93	warm-cold	N	0.68	0.42	0.17	0.61	0.24
93	warm-cold	S	0.12	0.10	0.09	0.87	0.74
		average	0.53	0.30	0.14	0.80	0.62

Table 4.4. Some descriptive statistics and goodness of fit test results for catch per unit effort (metric tons/day) and the individual catch (metric tons) and effort (fishing days) variables.

		ratio	*catch*	*effort*
Statistic				
	Minimum	0.45	0.00	1.00
	Maximum	65.49	4060.00	114.00
	Mode	12.81	10.15	1.81
	Mean	21.36	469.56	20.11
	Std Deviation	11.04	537.53	18.83
	Variance	121.91	39.28	354.53
	Skewness	0.46	2.47	1.72
	Kurtosis	2.82	12.14	6.51
Goodness of fit	Chi-Square			
	Function			
	Lognormal	1.04	0.02	0.15
	Normal	0.20	4650.65	11.85
	Gamma	0.41	-	-
	K-S Test			
	Lognormal	0.09	0.10	0.09
	Normal	0.06	0.20	0.17
	Gamma	0.07	-	-

sion coefficient estimates are very close to the ones obtained by ratio estimation (Table 4.5). The standard errors are, however, much lower in the regression case. Also, residual plots indicate non-homogeneity of the error variances (Figures 4.1 and 4.2). As such these models, using untransformed values, were not deemed appropriate. The next model considered was the general model presented in equation (4). This model was the best candidate based on standard errors of the estimates and residual plots. Different versions of this model were fitted and their behavior evaluated based on resiual plots and standard errors of the estimates (Figure 4.3 and 4.4). The first hypothesis tested was that the power term (β) differs between hydrographic seasons and fishing zones within the same year. The GLM output of the covariance analysis shows no significant differences at the α=0.05 level (Table 4.6). The power terms were 1.17, 1.20 and 1.16 for the years 1991, 1992 and 1993, respectively.

The power term was tested against one (i.e., β_j=1) and the hypothesis was rejected. Catch and effort can not be described by a simple linear model. Surprisingly, catch seems to have high variability at low levels of effort (all β>1). This point needs further investigation. One might hypothesize that this curvature is related to high uncertainty at very low levels of effort. For practical reasons, we restrictively set the power term to be one. The fit results are given in Figure 4.4. This model is the best candidate for computing the CPUE values. Finally, we fitted a $\log_e$-$\log_e$ model with no slope. This model is just another variant of the above model and seems to fit the data well (Figure 4.5).

Table 4.5. Catch per unit effort values from Ordinary Least Square (OLS) and restricted power model and associated standard errors by year, hydrographic season and fishing zone (N=northern; S=southern).

			OLS		Power	
Year	*Season*	*Zone*	*Reg. coeff*	*Stand. error*	*Reg. coeff*	*Stand. error*
91	cold	N	10.79	3.61	2.13	0.11
91	cold	S	19.99	0.95	2.91	0.10
91	cold-warm	N	20.76	3.28	2.85	0.12
91	cold-warm	S	28.95	2.22	3.27	0.11
91	warm	N	26.30	1.32	2.98	0.10
91	warm	S	24.07	6.25	2.91	0.12
91	warm-cold	N	24.89	3.36	3.00	0.12
91	warm-cold	S	29.02	3.14	3.34	0.13
92	cold	N	17.02	3.59	2.64	0.12
92	cold	S	26.88	0.71	3.22	0.11
92	cold-warm	N	26.19	1.89	3.10	0.11
92	cold-warm	S	31.92	1.72	3.33	0.12
92	warm	N	18.11	0.96	2.89	0.09
92	warm	S	17.16	1.77	2.54	0.12
92	warm-cold	N	18.98	2.27	2.52	0.10
92	warm-cold	S	28.78	1.76	3.03	0.11
93	cold	N	18.93	4.82	2.59	0.09
93	cold	S	26.92	0.58	3.10	0.08
93	cold-warm	N	24.30	2.97	2.91	0.10
93	cold-warm	S	30.31	2.50	3.43	0.11
93	warm	N	16.26	2.12	2.55	0.10
93	warm	S	16.30	2.68	2.50	0.12
93	warm-cold	N	24.24	3.02	2.70	0.12
93	warm-cold	S	20.97	1.79	2.91	0.12

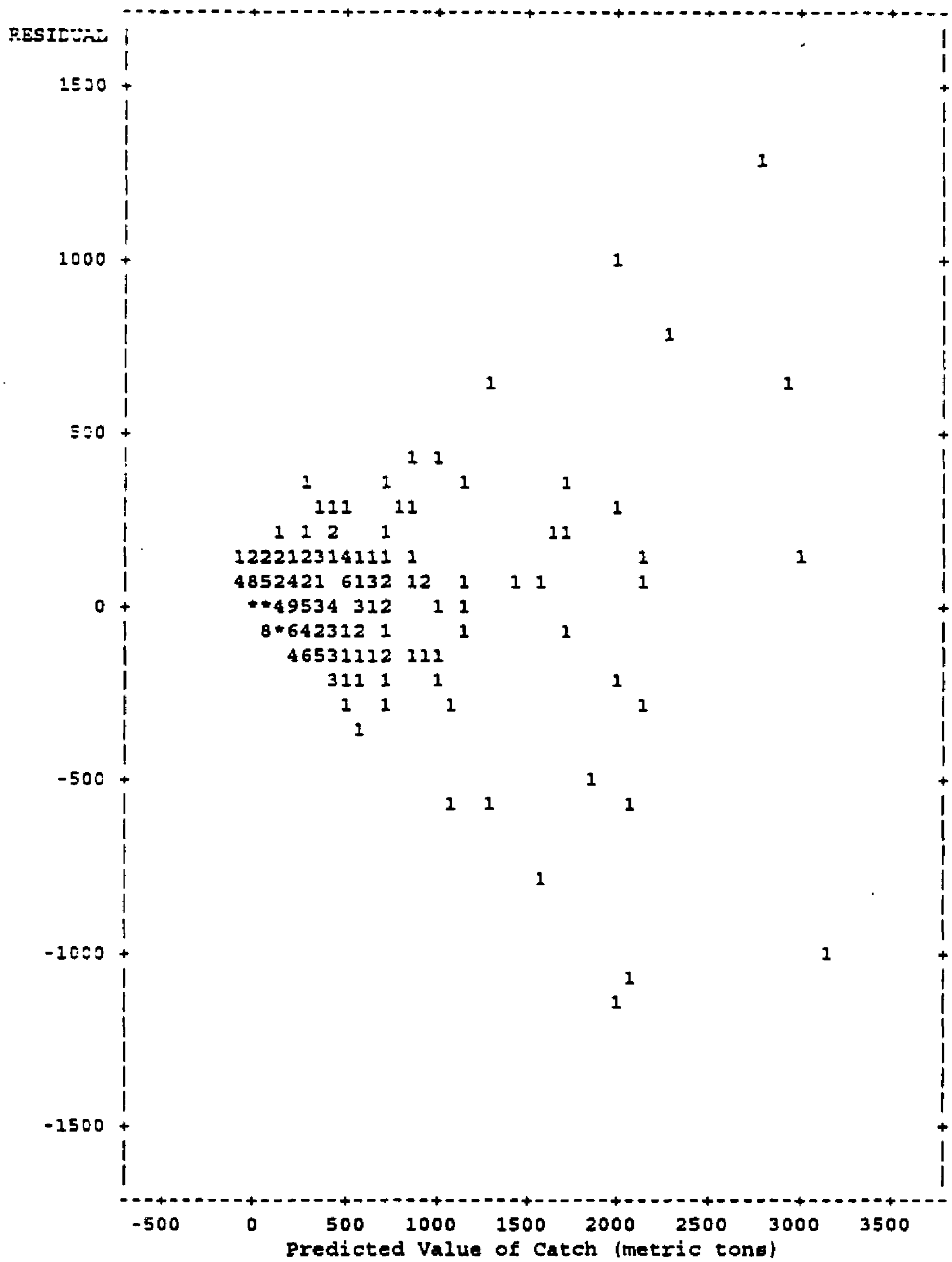


Figure 4.1. Residual plots for the Ordinary Least Square model with intercept (y=a + b*x).

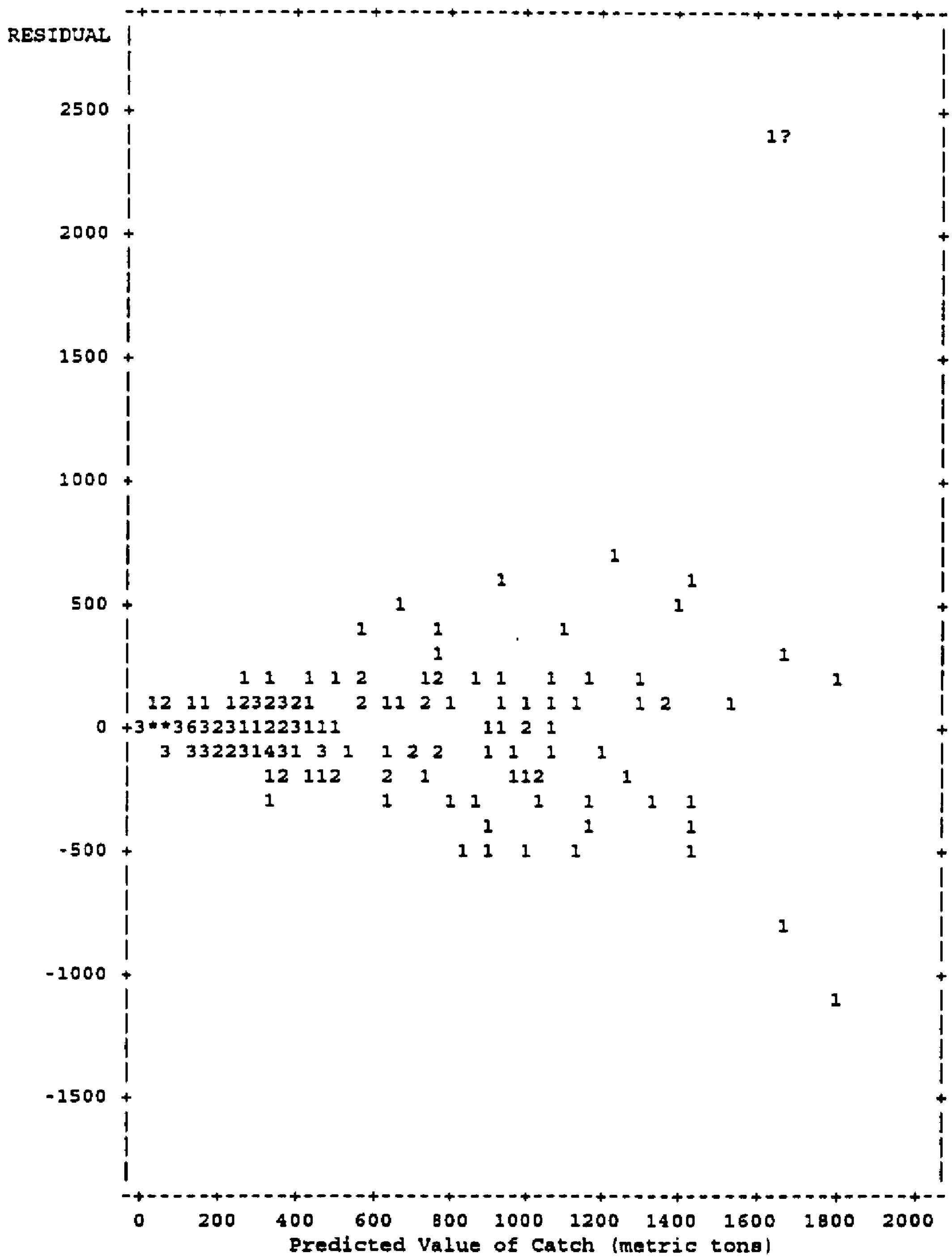


Figure 4.2. Residual plots for the Ordinary Least Square model without intercept (y=b*x).

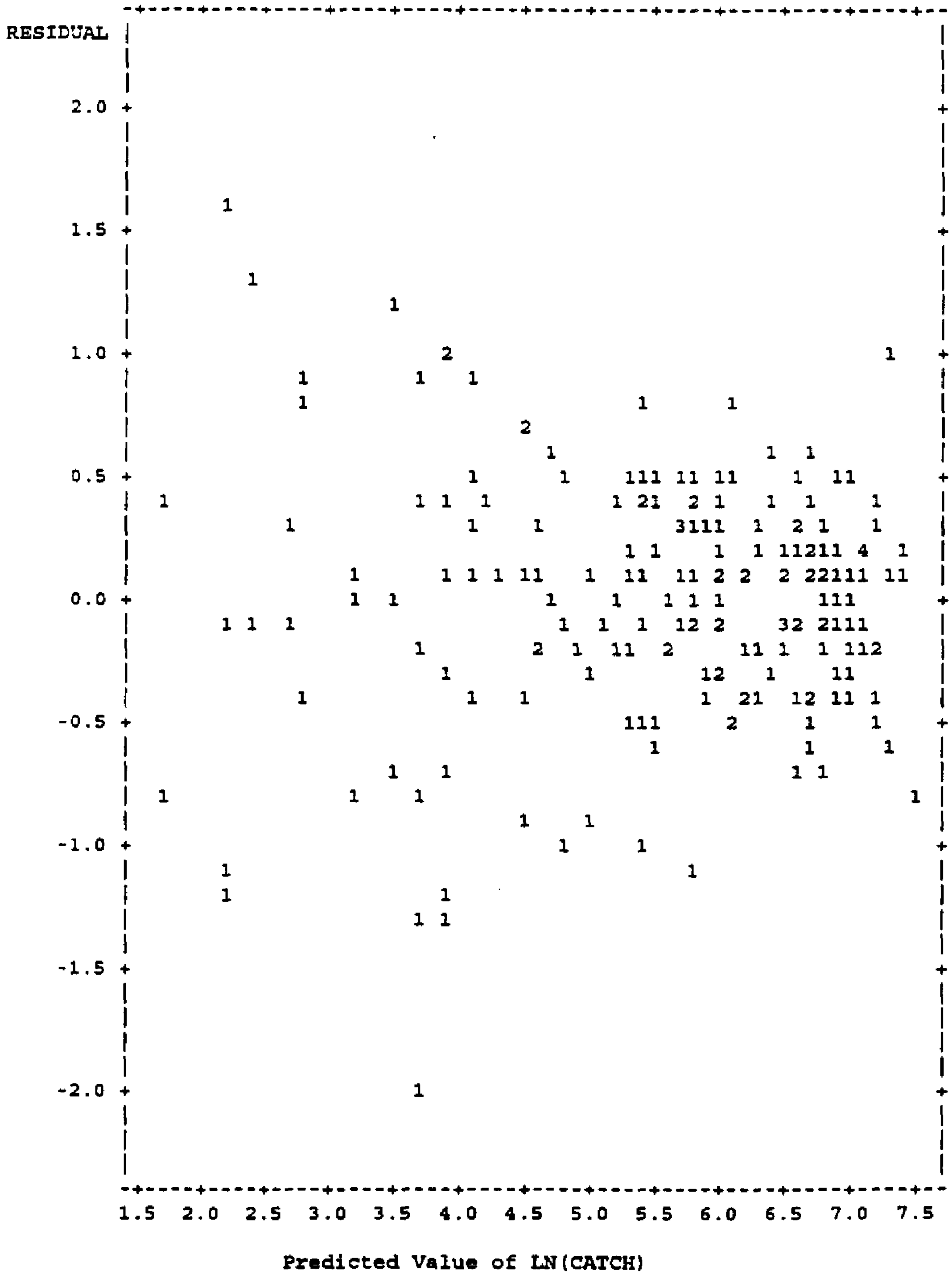


Figure 4.3. Residual plots for the full power model ($y=a*x^{bi}$) as presented in equation (5).

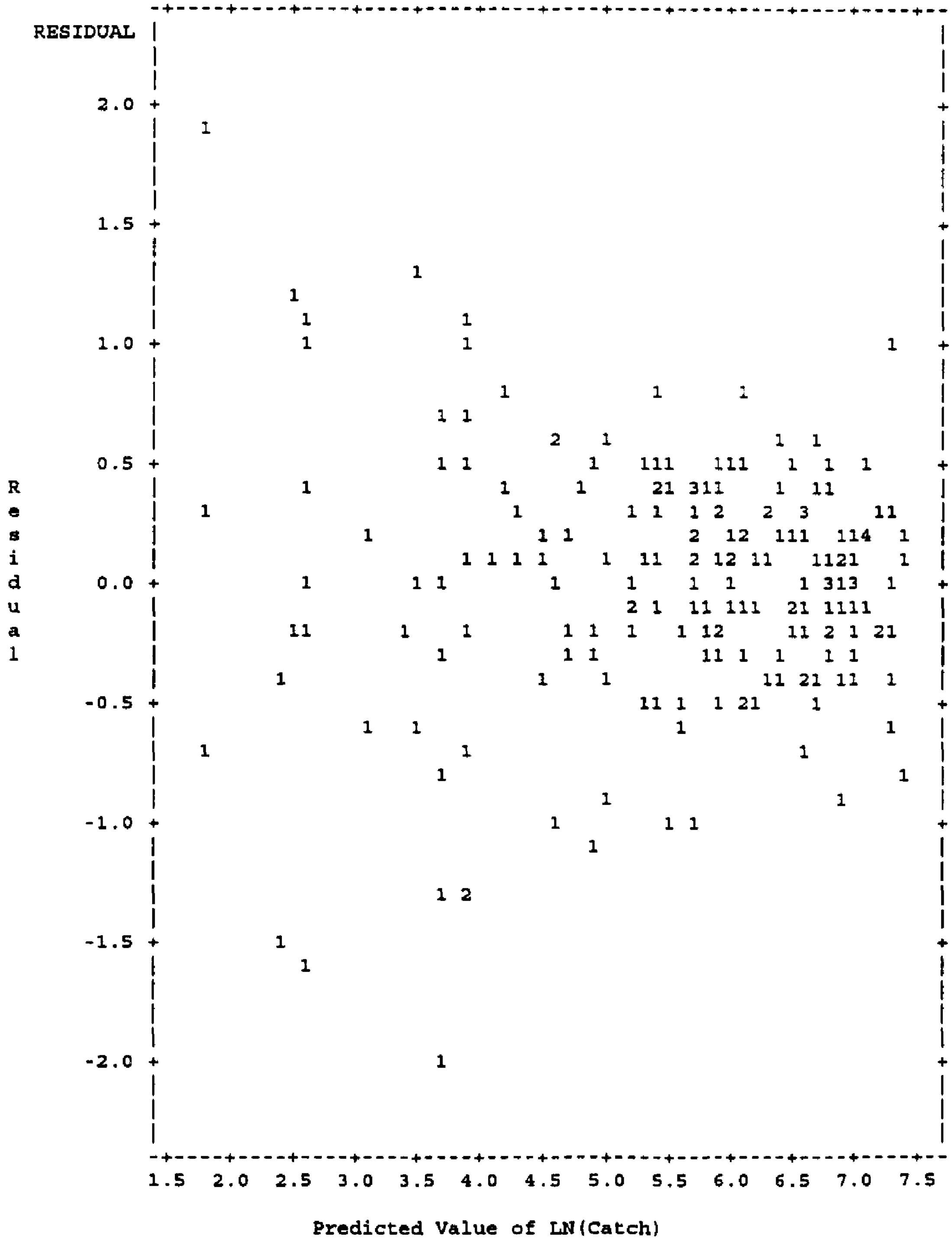


Figure 4.4. Residual plots for the restricted full power model ($y=a^*x^b$) as presented in equation (6).

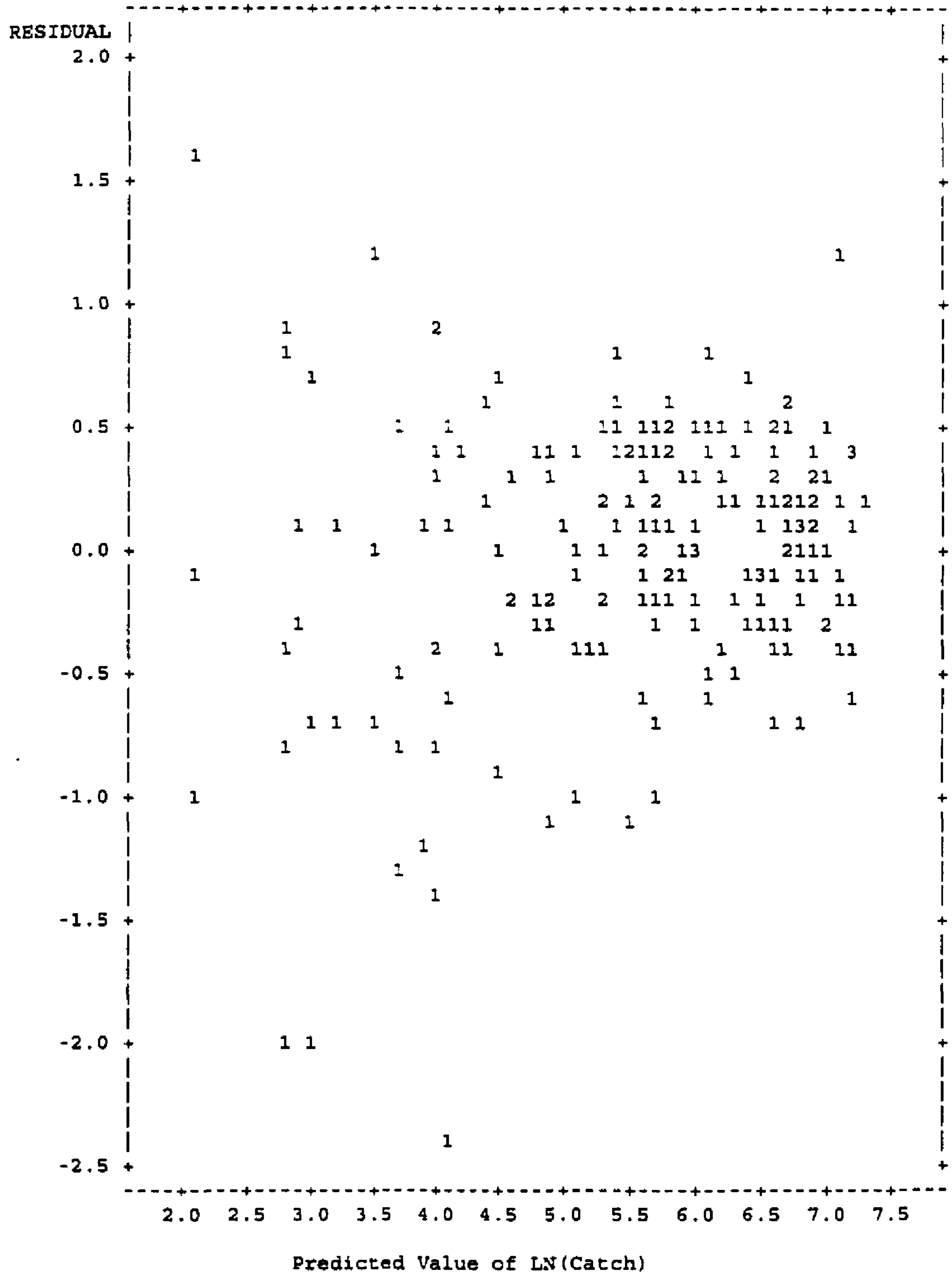


Figure 4.5. Residual plots for the restricted full power model (y=a*x).

Table 4.6. Analysis of covariance test results for differences in the slopes of catch per unit of effort estimates (LOGEFF) between hydrographic seasons and fishing zones within each year.

------------------------------- YEAR=1991 -------------------------------

Source	df	Mean Square	Pr > F
LOGEFF	1	146.68033	0.0001
SEASON*ZONE	8	16.63126	0.0001
LOGEFF*SEASON*ZONE	7	0.51152	0.0833
Error	179	0.27895	(df(error)=195)

------------------------------- YEAR=1992 -------------------------------

Source	df	Mean Square	Pr > F
LOGEFF	1	261.294	0.0001
SEASON*ZONE	8	24.981	0.0001
LOGEFF*SEASON*ZONE	7	0.314	0.6031
Error	269	0.402	(df(error)=285)

------------------------------- YEAR=1993 -------------------------------

Source	DF	Mean Square	Pr > F
LOGEFF	1	274.023	0.0001
SEASON*ZONE	8	31.300	0.0001
LOGEFF*SEASON*ZONE	7	0.509	0.1300
Error	238	0.314	(df(error)=254)

In summary, the regression approach given in equation (6) fits the data well and produces good estimates of CPUE. Although this method is recommended for estimating CPUE indices, an investigation of methods such as restriction and tangent, that yield CPUE values should be studied further. The regression method has the advantage of small standard errors for the estimates. Another advantage is that a given area and time period can be fixed as standard and variations of CPUE for other areas and time periods calculated accordingly. Ratio estimators (equation 9) would have outperformed this model only if the error variances were proportional to X (i.e., effort in days).

It also appears that the regression model given in equation (4) yields the best CPUE estimates. The fact that this relationship is curved certainly creates doubts about how CPUE's are usually estimated. For schooling fishes there is enough evidence to revise the way CPUE's are calculated. It is generally assumed that 1) CPUE is proportional to fish abundance; and 2) CPUE is deterministic. These assumptions can be met only when we resolve our grid scales and time intervals to be small enough that CPUE becomes proportional to fish density. Had this been the case, catch would be proportional to effort. Even then, there will be some areas where the CPUE average expectation is zero. The best method may involve updating CPUE estimates by using a Bayesian approach as suggested by Clark (1985).

Proportional allocation of effort

The procedures and results presented in the previous section were carried further to study the effect of proportional allocation of the fishing effort among species or species groupings assuming that the fishery is still in the ascending arm of the maximum sustainable yield. It should be noted that effort is usually recorded for the fishery as whole and rarely for individual taxa. That is, one does not really know the effort (nominal) exerted on an individual species within the multispecies fishery. This should have an impact on our modeling approaches and inferences, which would tend to underestimate the CPUE, especially for the species that are not dominant in the catch. Four types of allocation schemes to proportion total fishery effort among individual species and species groups were tried: 1) allocating the whole fishery effort for each species, i.e., if a species is caught in a day then count one unit (day) of effort (methodology presently used in fishery); 2) putting a threshold value, i.e., if a species proportion in the catch is more than 65%, then allocate all the effort for that particular species; 3) same as in number 2 above but with a threshold value of 50 %; and, 4) allocating the effort proportionally to the species according to its composition within the total fishery catch. The number of fishing hours per day were used as a weighting factor.

The last model allocation method (i.e., proportional) provides the best fit (Figures 4.6-4.9). Furthermore, using proportional allocation of effort seems to eliminate the curvature in the catch effort relationship mentioned in the previous section. It is strongly recommended that this method be considered as an useful

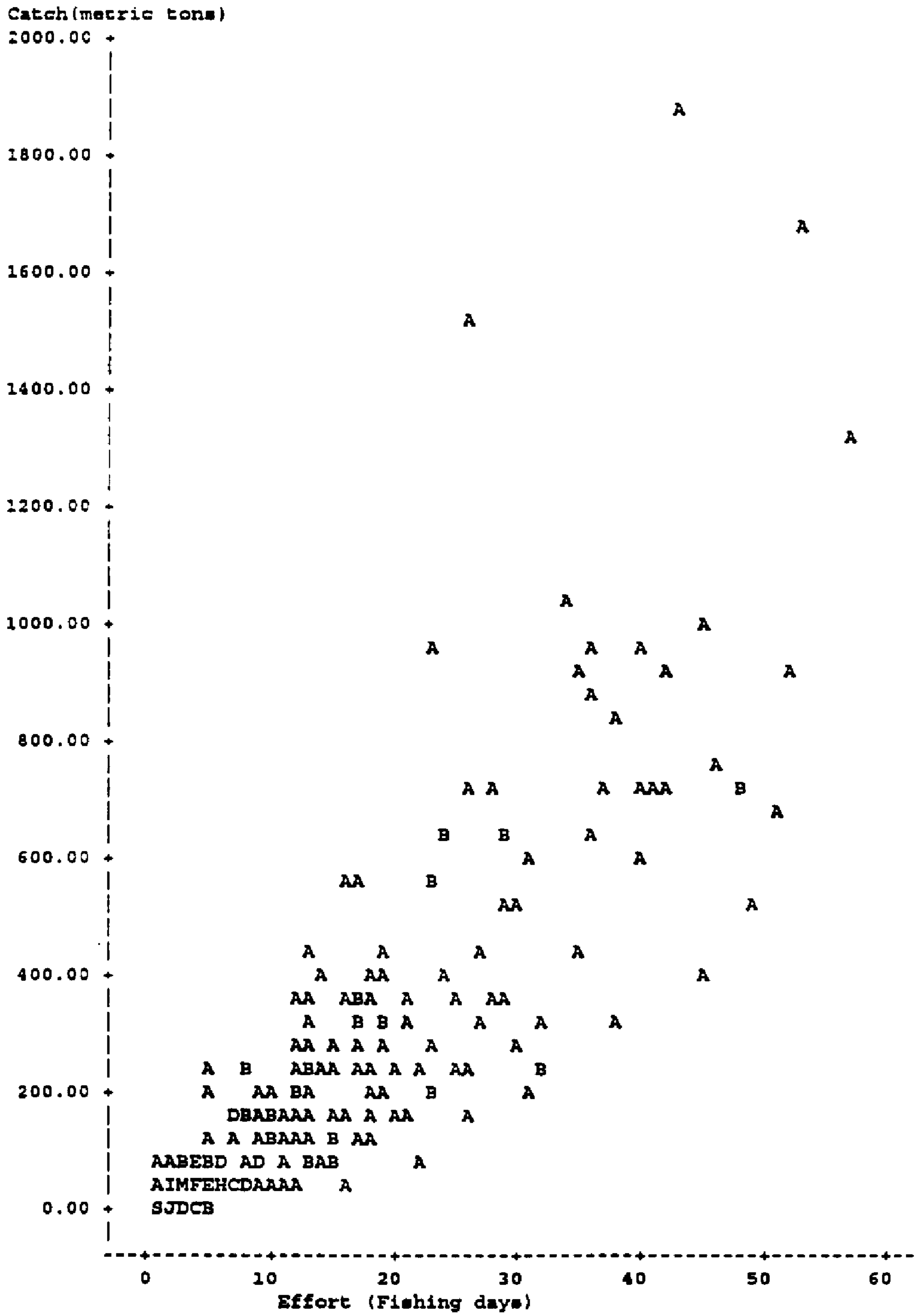


Figure 4.6. Plot of *Sardinella* spp. catch (metric tons) vs effort (fishing days) for allocation method 1 presented in the text (all fishery effort assigned to each species).

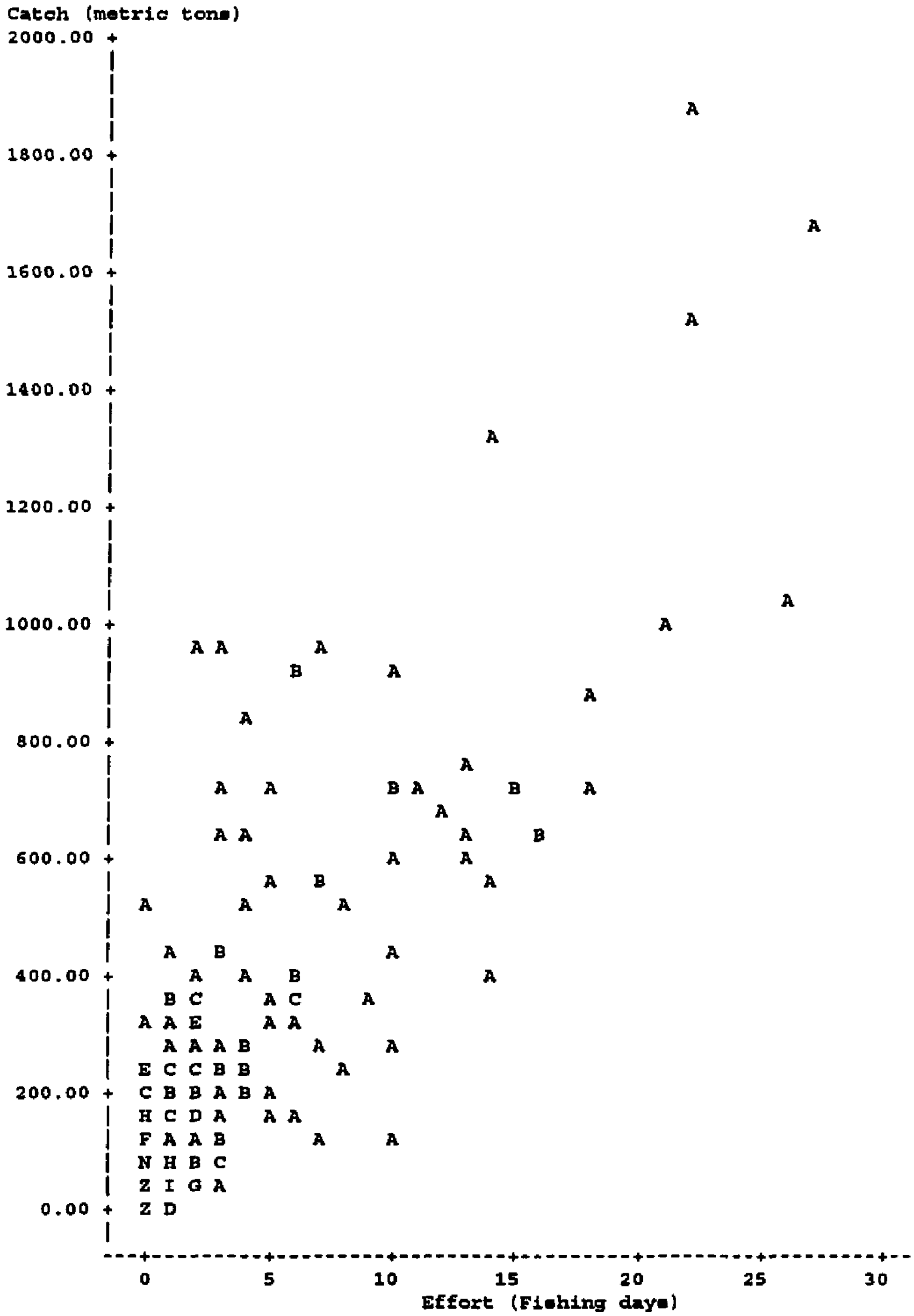


Figure 4.7. Plot of *Sardinella* spp. catch (metric tons) vs effort (fishing days) for allocation method 2 presented in the text (taxa composition has threshold value of 65% of the total fishery catch).

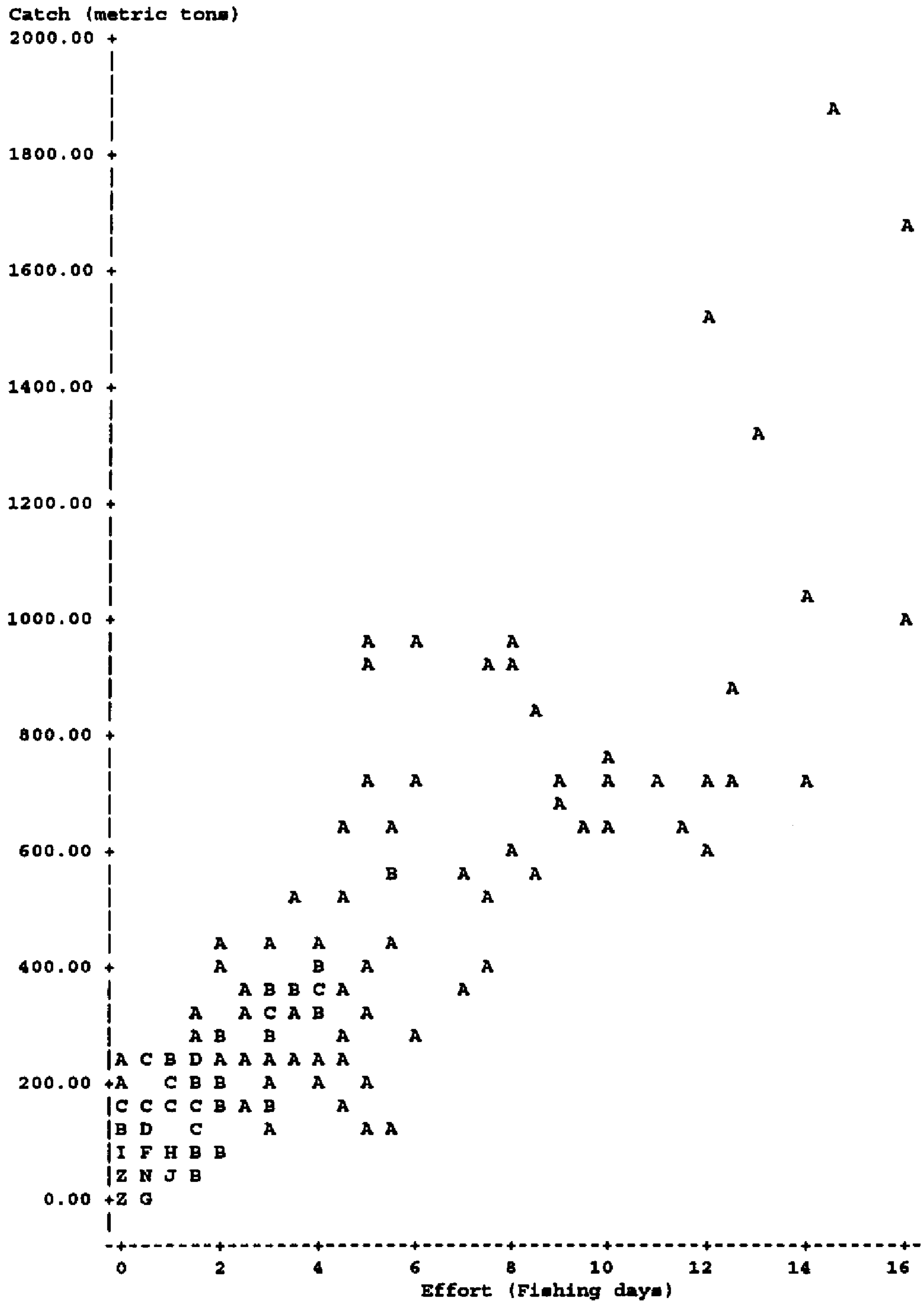


Figure 4.8. Plot of *Sardinella* spp. catch (metric tons) vs effort (fishing days) for allocation method 3 presented in the text (taxa composition has threshold value of 50% of the total fishery catch).

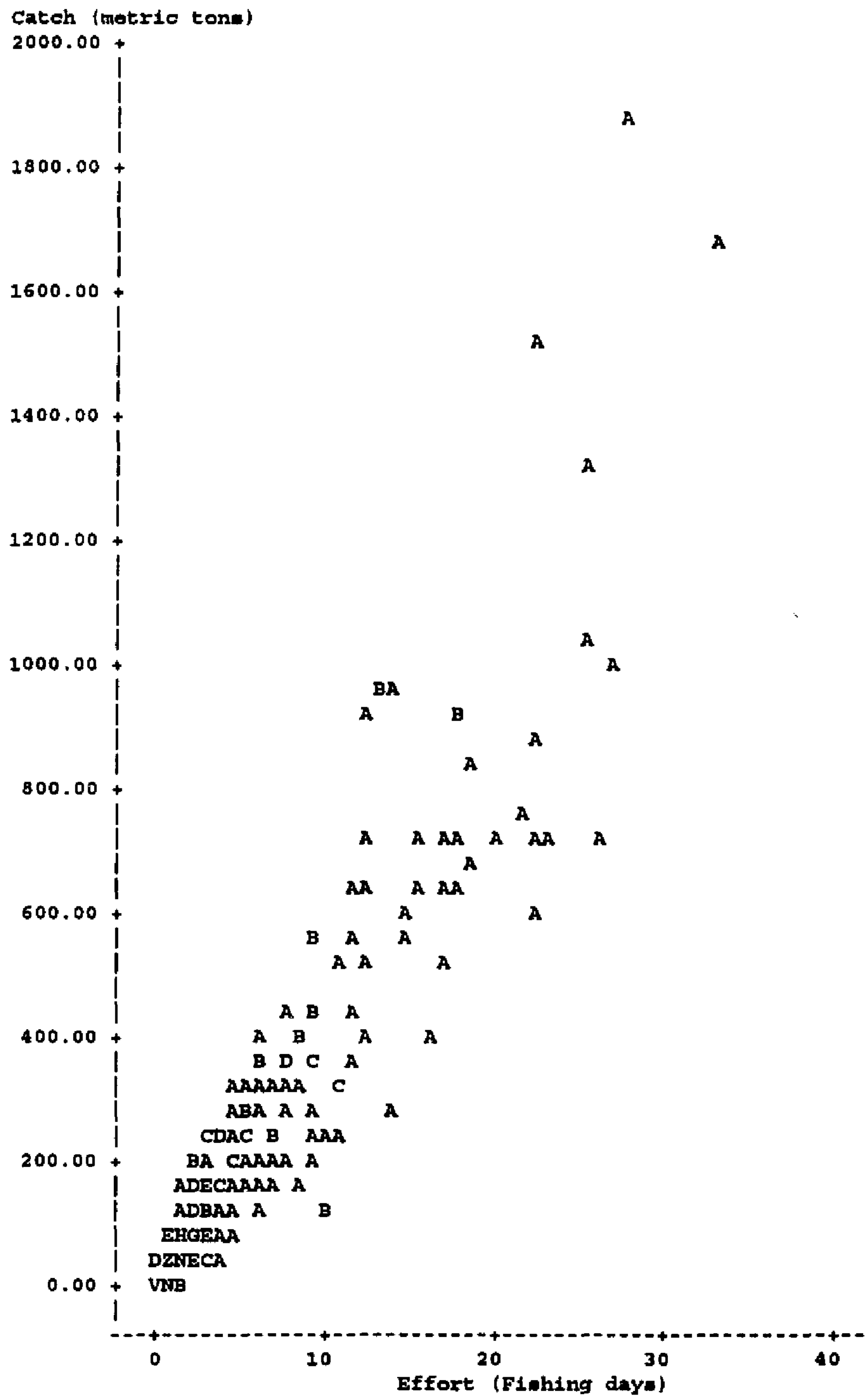


Figure 4.9. Plot of *Sardinella* spp. catch (metric tons) vs effort (fishing days) for allocation method 4 presented in the text (fishery effort computed proportionally to taxa composition).

tool for computing CPUE when the effort has not been partitioned adequately among species. Although the proposed method works well with these data, further investigations are needed to assess what impact it will have on the estimation of the management parameters in a fishery. The next chapter will address this question in more detail.

CHAPTER 5
Surplus Production Modeling

INTRODUCTION

Surplus production models, also called production models or biomass dynamic models, are basic tools used to establish safe harvest levels in a fishery when only catch and effort data are available. Many fisheries handbooks and textbooks provide a detailed explanation of these models and their underlying assumptions. Surplus production models have received wide applications in fisheries literature and in formulating fishery management plans by some agencies such as the International Convention for the Conservation of Atlantic Tuna (Beverton and Holt, 1957; Ricker, 1975; Brown et al., 1976; Clark, 1976; FAO, 1978; Pauly, 1979; Pope, 1979; Gulland, 1983; Hilborn and Walters, 1992).

One of the most common production models is the Schaefer model (Schaefer, 1954). This model assumes that the total growth rate of the population (i.e., biomass change over time) is equal to its logistic growth minus the catch rate (C). It also implies that: 1) the catch per unit effort (CPUE=U=metric tons/day) is proportional to the biomass (B=metric tons); and 2) catch rate (C=metric tons/day) is proportional to the effort (E=fishing days) and B:

$$\frac{dB}{dt}=rB\left(1-\frac{B}{k}\right)-C \qquad (1)$$

$$U=qB \tag{2}$$

$$C=qEB \tag{3}$$

where r is the intrinsic rate of increase of stock;
k is the maximum unfished biomass; and
q is the catchability coefficient (fraction of a fish stock which is caught by a defined unit of the fishing effort; Ricker, 1975).

By using equations (2 and 3), equation (1) can be rewritten and condensed in terms of CPUE change which might be of more interest to the manager (Schnute, 1977). First, we replace B in equation (1) by U/q (equation 2) and C by EU (equation 2 into 3):

$$\frac{d(U/q)}{dt}=r(\frac{U}{q})\ (1-\frac{U/q}{k})-EU \tag{4}$$

After rearrangement (q being a constant does not enter into the derivation), equation (4) becomes:

$$\frac{1}{q}\frac{dU}{dt}=\frac{U}{q}\ r(1-\frac{U}{qk})-UE \tag{5}$$

If we multiply both sides by (q/U), we get:

$$\frac{1}{U}\frac{dU}{dt} = r\ (1-\frac{U}{qk}) - qE = r-\frac{r}{qk}U-qE \tag{6}$$

Equilibrium form of the Schaefer model

Only when the conditions in a fishery change little from year to year, can it be assumed that the fishery is in equilibrium. In this case a plot of CPUE against effort will result in a line with a negative slope ($-kq^2/r$) as effort increases above zero, since by setting the right hand term of equation (4) to zero and after rearranging:

$$U = qk - (\frac{kq^2}{r})E \tag{7}$$

Under equilibrium conditions, a fish population grows until it reaches the carrying capacity of the environment (k). The surplus production generates a parabola that rises at a decreasing rate to a maximum at k/2; the surplus production is zero at biomass of zero and k at the higher end of the parabola.

Dynamic form of the Schaefer model

It is sometimes difficult to meet the assumptions that a fishery is in equilibrium. The models discussed below are non-equilibrium versions of the Schaefer model.

Schnute (1977) showed that integrating (7) over time steps of one year gave

$$\frac{e^{\frac{r}{qk}\bar{U}_i}-1}{e^{\frac{r}{qk}\bar{U}_{i-1}}-1} = \frac{r-q\bar{E}_{i-1}}{r-q\bar{E}_i} \frac{e^{r-q\bar{E}_i}-1}{e^{r-q\bar{E}_{i-1}}-1} (e^{r-\frac{r}{qk}\bar{U}_{i-1}-q\bar{E}_{i-1}})(e^{\varepsilon}) \tag{8}$$

where U_i is CPUE for year i,

U_{i-1} is CPUE for year i-1,

$\bar{U}_i=(U_i+U_{i-1})/2$,

$\bar{E}_i=(E_i+E_{i-1})/2$,

$\epsilon \sim NID(0,\sigma^2)$, i.e., the error terms are independant and normally distributed.

Schnute (1977) has also shown that equation (9) is a good approximation of equation (8) if an error term is added.

$$\ln(\frac{U_i}{U_{i-1}})=r - \frac{r}{qk}\bar{U}_i - q\bar{E}_i \qquad (9)$$

The above equation is a linear form of the Schaefer model in the form of a multiple regression with intercept (r) and slopes r/(qk) and q with respect to U and E. It is dynamic because it involves past information about the fishery; that is, not only does equation (9) take into account current year, but also past year CPUE are accounted for. Note that equation (9) can be derived directly by integrating equation (6) over time steps of one year.

Attempts to linearize the Schaefer model only give an approximation of the original functional form (equation 8). Nonlinear procedures often produce more accurate estimates for the parameters r, k and q (Schnute, 1977; Hilborn and Walters, 1992) but are computationally intense. They also require starting values for the parameters r, k and q which often can be found only by fitting a linear version of equation (9).

There are three objectives in this chapter. The first objective is to predict catch and effort levels in the Mauritanian-Senegalese pelagic fishery using a dynamic version of the Schaefer model (Schnute, 1977). The second objective is to investigate the effect of allocating the total fishery effort to each taxa in proportion to its contribution to the catch composition of the total fishery landings. The third objective is to put confidence intervals around the Maximum Sustainable Yield (MSY) estimates and to discuss their management implications. The results are contrasted with the results of an analysis using untransformed effort data.

MATERIAL AND METHODS

Catch and effort data

Yearly catch and effort data were provided by the Centre National de Recherches Oceanographiques et des Peches (CNROP), Nouadhibou, Mauritania. They consist of reported Mauritanian-Senegalese pelagic fishery landings from 1979 to 1993. Because the original catch data were often reported by species groups, individual species catch has been estimated using a data set generated by the CNROP that sampled the landings from German (1979-1984) and Rumanian and Russian fishing vessels (1985-1993). Given the various sizes of the fishing vessels and changes in the fishing fleets characteristics, Ould Soueilem (1992) standardized the effort (fishing days) and generated fishing power coefficients (unitless) which are presented in Table 5.1.

Table 5.1. Fishing power coefficients used for standardizing the fishing effort (days) of the pelagic fishing fleet in the Mauritanian-Senegalese region (after Ould Soueilem, 1992).

Vessel	Rumania	Russia	Germany
"BMRT"	-	0.74	-
"RTMA"	0.53	0.93	-
"RTMS"	1.00	1.34	1.39

Model fitting

The method adopted here uses Schnute's version of the dynamic Schaefer model (Schnute, 1977). From equation (9), if we let $Y=\ln(U_{i+1}/U_i)$; $Z_1=U_i$, the CPUE; and $Z_2=E$, the effort, then, the regression becomes:

$$Y = \beta_0 + \beta_1 Z_1 + \beta_2 Z_2 + \epsilon \qquad (10)$$

where the coefficients β_0, β_1 and β_2 correspond to r, -r/(kq) and -q, respectively.

The model was fitted using a multivariate approach that takes into consideration possible correlations among species catch and effort. Since the catch of one species is not independent of the catch of another species, and since effort is reported only for combined species or species groups, it is likely that the error terms are correlated. In such cases, Ordinary Least Squares (OLS) can be inconsistent (Srivastava and Giles, 1987; Johnson and Wichern, 1992). The model, therefore, was solved through simultaneous equations. This method, known as Joint Generalized Least Squares, Zellner's method, or "Seemingly Unrelated Regression" (SUR) uses estimates of the covariance of the error terms across the equations to increase the efficiency of the estimates (Zellner, 1962; Srivastava and Giles, 1987). The SUR method, which is mainly known to econometricians, has also been applied to fisheries data (Polovina, 1988).

If we were to consider a general case where we have n years of observations, m number of species, and p predictor variables, then the model in matrix notation (Johnson and Wichern, 1992) becomes:

$$\underset{(n*m)}{Y} = \underset{(n*(p+1))}{Z} \; \underset{((p+1)*m)}{\beta} + \underset{(n*m)}{\varepsilon} \qquad (11)$$

with the assumptions that 1) $E(\varepsilon_{(i)})=\mathbf{0}$; and

2) $Cov(\varepsilon_{(i)},\varepsilon_{(k)})=E(\varepsilon\varepsilon')=\sigma_{ik}\mathbf{I}$ (i,k=1,2,...,m)

where **0** is a zero matrix and **I** is an identity matrix.

For this specific case, n=13, m=6 and p=2 (U and E). Also from equation (11), it should be noted that: 1) there is an intercept; and 2) some elements of the vector β_i will be zero because certain explanatory variables will be absent from certain equations.

Actually, equation (11) is a multivariate regression model which is a general case of the SUR model. In other words, each equation corresponds to one species and is treated as a classical linear regression of the form:

$$Y_i = Z\beta_i + \varepsilon_i \text{ (I=1,.....m)} \qquad (12)$$

with $Cov(\varepsilon(I))=\sigma_{ii}\mathbf{I}$. However, the errors for different species response variables in the same year can be correlated (Johnson and Wichern, 1992). Note that equations (10) and (12) are equivalent.

The model was fitted using the raw standardized effort data and the effort calculated by proportional allocation (allocation method number 4) in the previous chapter. This was done to investigate the effects of these two treatments of effort on the MSY fits.

PROC SYSLIN (SAS, 1989) was used to solve the SUR model for individual species using a linear version of the Schnute's model (equation 9). The aggregate

models by species group (e.g, carangidae, clupeidae) were solved iteratively using PROC NLIN (SAS, 1989). The regression estimates from the Schnute's linear version (equation 9) were used as starting values for the latter model (equation 8). In all cases, output of the covariance matrix was used to calculate the variance around MSY.

RESULTS AND DISCUSSION

Derivation of an approximate asymptotic formula for computing confidence intervals around MSY

Because previous authors have apparently not fitted confidence intervals about their estimates of MSY, I derived the formula that is explained below. Given the model specifications are indeed correct, Least Squares Estimates of the parameters r, k and q will also be Maximum Likelihood Estimates (MLE). Thus, MSY (=rk/4) being the product of two MLE, is also an MLE because of the invariant properties of MLE. An approximate asymptotic variance for MSY can be found using Taylor series approximation, sometimes known as the delta method (Seber, 1982; Casella and Berger, 1990).

Consider n random variables $x_1,......,x_n$ with mean $\theta_1,......,\theta_n$ and define $\mathbf{X}=(x_1,......,x_n)$ and $\theta=(\theta_1,.....,\theta_n)$. Suppose there is a function g(**X**) whose derivatives exist, then a first-order Taylor approximation of the variance of the function g(**X**) about θ implies that:

$$Var_\theta\,[g(\mathbf{X})] \approx E_\theta\,([g(\mathbf{X})-g(\theta)]^2)$$

$$\approx \sum_{i=1}^{n} \left(\frac{\partial g}{\partial x_i}\right)^2 Var(x_i) + 2 \sum_{i>j} \left(\frac{\partial g}{\partial x_i}\right)\left(\frac{\partial g}{\partial x_j}\right) Cov(x_i, x_j) \quad (13)$$

Now consider that r and k are random variables with means a and b, respectively, then the function to be estimated is g(a,b)=a*b. It follows that the derivatives are (∂g/∂a)=b and (∂g/∂b)=a and a first-order approximation of the variance of MSY will be:

$$Var(MSY)=\{Var(rk/4)\}=\{(1/4^2)*Var(rk)\}$$

$$\approx\{(1/16)*[(b^2\ Var(a) + a^2\ Var(b) + 2*(ab)\ Cov(a,b))]\} \quad (14)$$

This formula applies when direct estimates of a and b are available (e.g, from a nonlinear fit of the data). However, if a linearized form of the Schaefer model is used (e.g., equation 7), the regression model produces estimates of r, q and r/(kq) with means a, b and c, respectively. In this case, one may use the following transformation:

$$MSY=rk/4=\{(1/4)*[a^2/bc]\} \quad (15)$$

Using the same reasoning as above, it follows that the derivatives are (∂g/∂a)=2a/bc, (∂g/∂b)=$-a^2/b^2c$ and (∂g/∂c)=$-a^2/bc^2$ and a first-order approximation of the variance of MSY will be:

$$Var(MSY)=\{(1/16)*Var(a^2/bc)\}$$

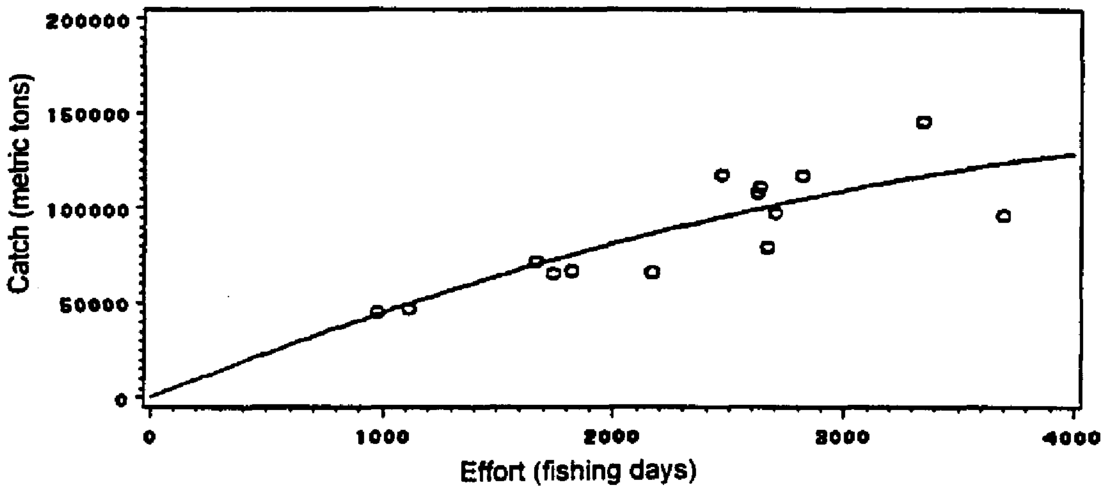
$$\approx\{(1/16)*(4*Var(a) + (a^2/b^2)\ Var(b) + (a^2/c^2)\ Var(c)$$

$$- [(4a/b)\ Cov(a,b)] - [(4a/c)\ Cov(a,c)] + [(2a^2/bc)\ Cov(b,c)])\} \quad (16)$$

All the terms involved in the above formulae are available in the covariance matrix of the parameters estimates and should be easily accessible, if someone is using a statistical computing package such as SAS, SHAZAM, SPSS.

Comparison of the partitioned and unpartitioned effort data

Four of the six individual species fitted the linear version of the Schaefer model (Figure 5.1-5.3). Models with raw effort data tend to give a relatively poor fit of the Schnute's version of the Schaefer model compared to the ones using partitioned effort (Figure 5.4). In most cases, the linear term was the only term significant and no curvature was observed. One possible cause of the relatively poor fit is that variations in effort (small range) provide us with poor contrast in the plane fitted by the regression. Also, the raw unpartitioned effort tends to mask the trends for under-represented species, i.e., species or species groups that have small contributions to the total multispecies fishery catch. Hence, it appears that using the unpartitioned total effort undoubtedly overestimates the optimal fishing effort (f_{opt}) and consequently the MSY estimate will be erroneous. Since the ultimate goal of any production model is to evaluate the impact of fishing pressure on the stock, the use of the raw effort data is inherently erroneous. On the other hand, MSY estimates for the partitioned data are more consistent. It appears, however, that the fitted parameters could be underestimating the species for which the effort is not large enough (Figure 5.2).



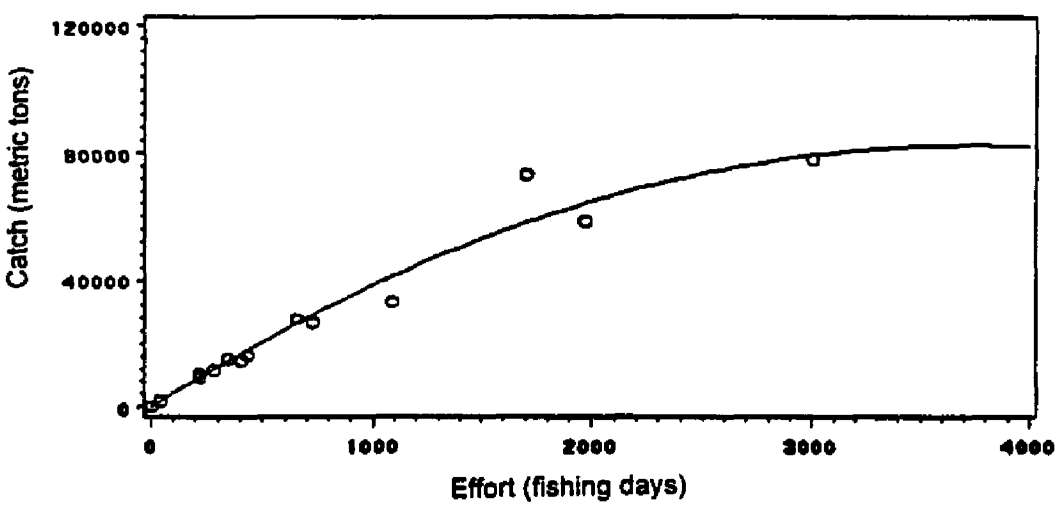
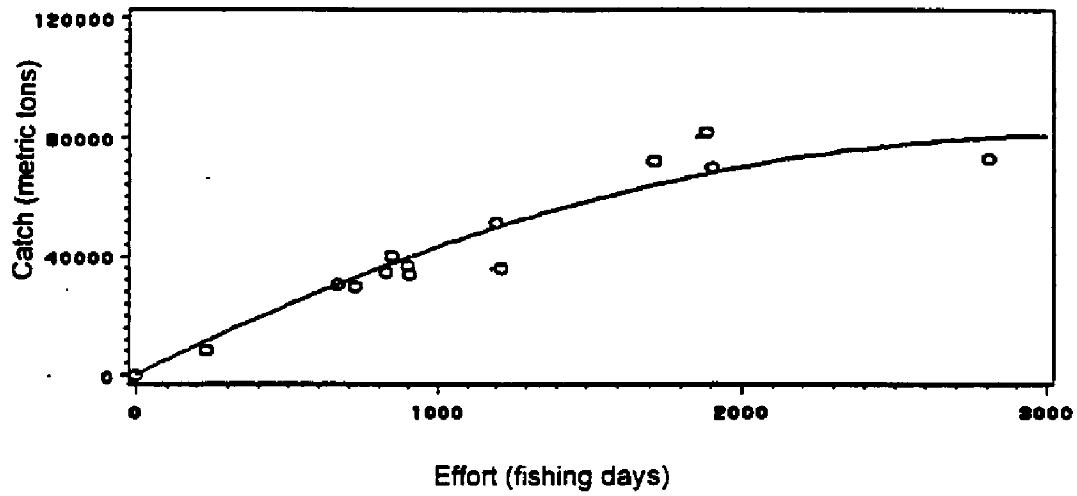


Figure 5.1. Fits of the Schnute's version of the dynamic Schaefer model for *Trachurus trecae* (top) and *Decapterus rhonchus* (bottom). Also shown are 95% confidence limits around the Maximum Sustainable Yield estimate.



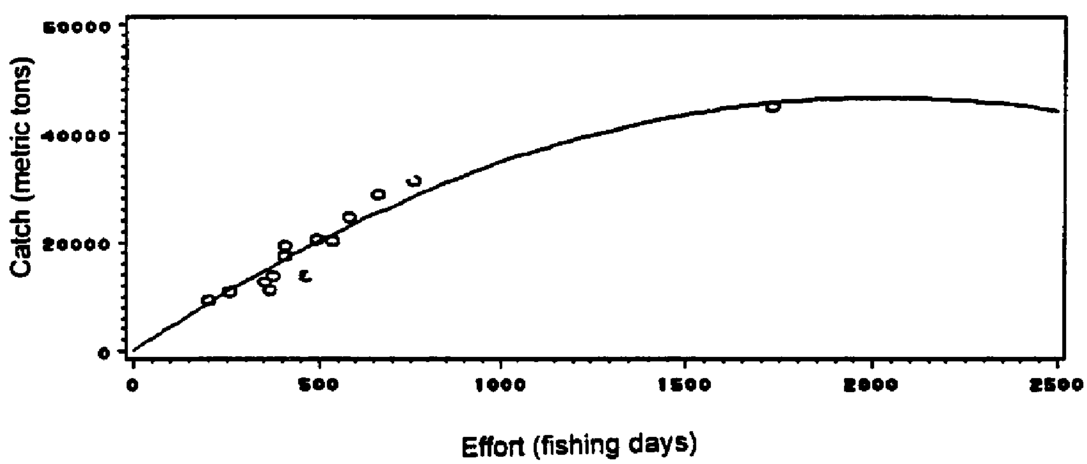


Figure 5.2. Fits of the Schnute's version of the dynamic Schaefer model for *Sardina pilchardus* (top) and *Scomber japonicus* (bottom). Also shown are 95% confidence limits around the Maximum Sustainable Yield estimate.

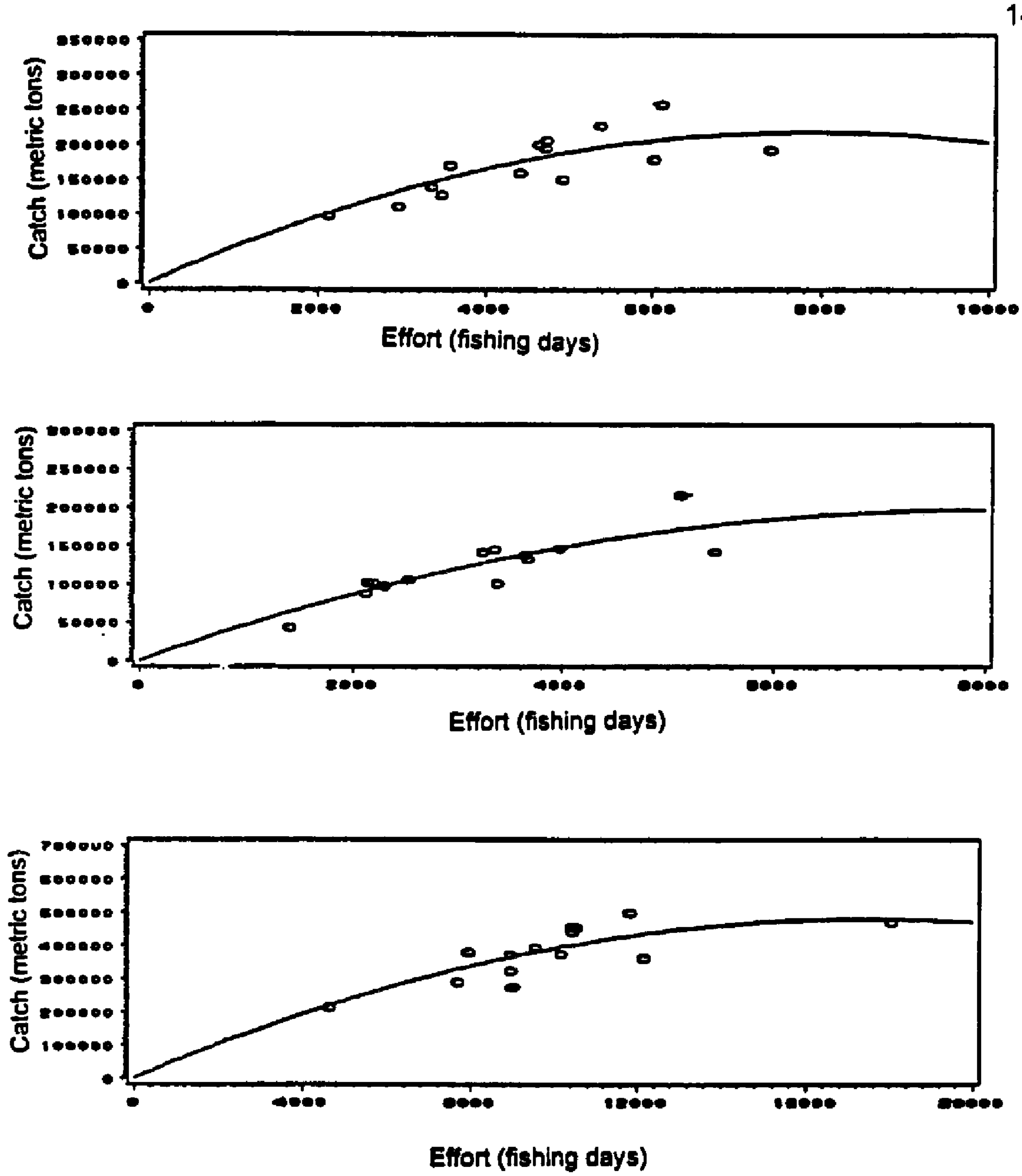


Figure 5.3. Fits of the Schnute's version of the dynamic Schaefer model for carangidae (top), clupeidae (middle) and total multispecies fishery catch (bottom). Also shown are 95% confidence limits around the Maximum Sustainable Yield estimate.

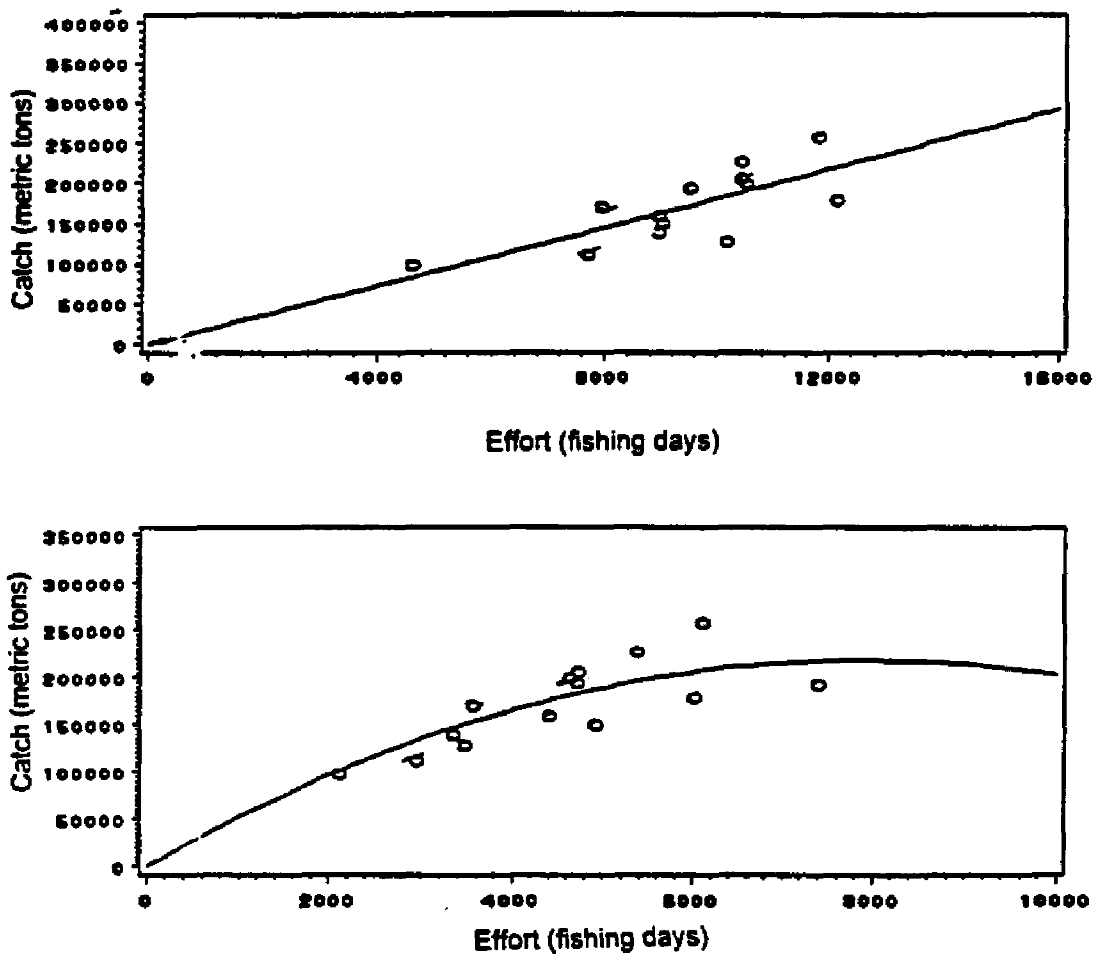


Figure 5.4. Fits of the Schnute's version of the dynamic Schaefer model for carangidae using total fishery effort (top) and proportionally allocated effort (bottom).

For example, *Sardina pilchardus* and *Scomber japonicus* have MSY's of about 85,000 and 46,000 metric tons, repectively. It is possible that increases in effort will result in increases in catch and generate higher estimate of MSY.

To evaluate the appropriateness of using the SUR over the OLS model, I analyzed the correlation matrix of the independent variables for the unpartitioned data. Considerable correlation between species catch and effort was observed (Table 5.2). For instance, the CPUE for *Sardina pilchardus* is highly associated with the CPUE for *Sardinella maderensis* and to a lesser extent *Scomber japonicus*. However,*Sardina pilchardus* shows a strong negative correlation with *Sardinella aurita* CPUE and weak negative association with *Trachurus trachurus* CPUE. Also, it seems that *Sardinella aurita* has a negative correlation with *Scomber japonicus*. The fact that catch has been aggregated over a year makes interpretation of these results difficult because of the known seasonal variations. These cross model correlations may simply reflect the fleet's fishing strategy as alluded to in Chapter 3. Nonetheless, statistically these results are an indication of the appropriateness of the SUR model over the OLS model for the unpartioned data. Had the cross model correlations been negligible, SUR and OLS models would be equivalent. In the presence of cross model correlations, however, using the SUR model considerably reduces the standard errors (Srivastava and Giles, 1987).

Table 5.2. Cross model correlation for the seemingly unrelated regression for the linear fit of the surplus production model applied to the pelagic fishery catch in the Mauritanian-Senegalese region (data source: Centre National de Recherches Oceanographiques et des Peches).

SPECIES	Sp	Sa	Sm	Dr	Tte	Tta	Sj
Sardina pilchardus(Sp)	.	-0.68	0.78	-0.13	0.02	-0.23	0.40
Sardinella aurita (Sa)		.	-0.32	0.56	-0.46	0.47	-0.60
Sardinella maderensis (Sm)			.	-0.08	-0.13	-0.12	0.25
Decapterus rhonchus (Dr)				.	-0.36	0.40	-0.22
Trachurus trecae (Tte)					.	0.07	0.64
Trachurus trachurus (Tta)						.	0.64
Scomber japonicus (Sj)							.

Aggregate species models

Because no previous similar study has been conducted on individual species in the area, there is no basis for comparison for these results. In this regard, models for aggregate catch of carangidae, clupeidae and total pelagics were considered. The results are given in Table 5.3 and Figure 5.3. Clupeidae include only the two *Sardinella* species (*S. aurita* and *S. maderensis*) and does not include *Sardina pilchardus* because no data were available from the Sahara region (north of Mauritania) in which most of the fishing pressure is located (Ould Soueilem and Fonteneau, In press). Carangidae include the two *Trachurus* species (*T. trachurus* and *T. trecae*).

The MSY estimate for carangidae is around 220,000 metric tons (Table 5.3). The lower and upper bound ranges from 160,000 to 277,000 metric tons. The MSY for total pelagic fishery catch (excluding *Sardina pilchardus*) is about 479, 000 metric tons with lower and upper 95% confidence limits of 370,000 and 590,000 metric tons. Clupeidae showed much larger variations around the estimate for MSY which is about 200,000 metric tons. The lower and upper 95% confidence limits are 84,000 and 310,000. These wide confidence limits around Clupeidae MSY are probably due to a projection outside our existent data range, for the fishery is believed to be still on the ascending arm of the parabola describing the Schaefer model.

To get more accurate parameters estimates, the models for aggregate species were solved iteratively. The nonlinear procedure used is the DUD method

Table 5.3. Maximum sustainable yield (MSY) and associated ninety five percent confidence limits (95% CL) and standard errors (STD) estimates for the linear fit of the surplus production model applied to the pelagic catch in the Mauritanian-Senegalese region (data source: Centre National de Recherches Oceanographiques et des Peches).

Species group	MSY(metric tons)	95% CL Lower limit	95% CL Upper limit	STD
Carangidae	218,352	159,529	277,174	27616
Clupeidae	196,708	84,022	309,394	48994
TOTAL pelagic	479,404	369,782	589,026	47662

(SAS, 1989) that is less precise than other methods such as Marquardt. The convergence of the parameters was achieved rather quickly in all cases. With the Clupeidae calculation, the nonlinear fit yielded negative estimates for the MSY and hence was not reported (Table 5.4). For carangidae, although MSY estimates are very close to the linear version estimates, the non-linear fit provided narrower confidence limits around MSY with limits ranging from 187,000 to 300,000 metric tons (Table 5.4). The nonlinear fit for the total pelagic fishery (minus *Sardina pilchardus*) provided narrower confidence intervals for the MSY as well. The lower and upper 95% confidence limits for the total pelagic fishery are 383,000 and 498,000 metric tons.

The estimate calculated for the carangidae MSY is close to the one reported in an earlier study (Ould Soueilem and Fonteneau, In press) which used the method of Fox (Fox, 1970) to estimate the MSY at about 300,000 metric tons. Ould Soueilem and Fonteneau (In press) also indicated that the Clupeidae MSY was 760,000 metric tons and the total pelagic fishery MSY was around 1.2 million metric tons. This total fishery estimate is twice that calculated in Table 5.3. There are two possible reasons why their MSY estimates are so large. First, the authors used the total fishery effort instead of partitioning the effort among species groups (Clupeidae case). Their estimated optimal effort was, hence, estimated far beyond the range of our existing data. Second, they used an equilibrium version of the surplus production model which might contribute to the MSY's overestimation, for the fishery is most likely in the ascending arm of the surplus production curve.

Table 5.4. Maximum Sustainable Yield (MSY) and associated ninety five percent confidence limits (95% CL) and standard errors (STD) estimates for the nonlinear fit of the surplus production model applied to pelagic catch in the Mauritanian-Senegalese region (data source: Centre National de Recherches Oceanographiques et des Peches).

Species group	MSY(metric tons)	95% CL Lower limit	95% CL Upper limit	STD
Carangidae	242,525	184,654	300,395	25161
Clupeidae	-	-	-	-
TOTAL pelagic	498,862	382,359	598,364	43262

The authors point out, however, that their MSY estimates are probably influenced by the species abundances being largely affected by environmental variabilities. It would be interesting to put a confidence interval on these estimates for a more plausible comparison.

Note on environmental and economic factors

Attempts to incorporate a coastal upwelling index (CUI; see Chapter 2) as an index for environmental variations into the model presented in equation (11) were conducted. Those attempts, however, gave unrealistic results probably because of the following reasons. First, in Chapter 3 it was noted that the fishing strategy is fundamental in determining catch composition. For example, although vessel types 1 (Rumanian) and 2 (Russian) have identical physical characteristics, their yields are different even when such factors as fishing zone and hydrographic season are accounted for (Chapter 3). Furthermore, it was shown that the fleet tends to stay in fishing zones where species availability is not maximal. That is, the majority of the fleet stays in the southern zone when the *Sardina pilchardus* abundance is maximal in the northern zone. The cross-model correlation matrix (Table 5.2) indicated that CPUE's for individual taxa were interrelated which might be a reflection of the fleet's fishing strategy (or associations in species life history). Second, the catch was not reported originally by species. The gross errors involved when partitioning the aggregate catch into species may account for the spurious correlations reported.

The results were also not satisfying when I tried to incorporate economic incentives into the model by including dummy variables for species values (price weightings). In fact, given that the vast majority of the fleet is composed of what once was known as the "Eastern Block" countries which had socialistic economic philosophies, it was hypothesized that the fleet had adopted fishing strategies that did not necessarily maximize their profit. Contrarily, catch was mainly driven by a "mass production" economic policy. Incorporating an environmental or economic factor is rather a straightforward extension of the model presented. However, the available data did not allow plausible results. Although in the short term, such a model is very realistic, further investigations are needed.

CONCLUSION

The procedures used in this chapter can be outlined as follow. First, fishing effort should be allocated adequately among species or species group. The proportional allocation (allocation method 4) yielded significantly improved estimates in these specific cases. The CPUE calculation involved the restricted power model presented in Chapter 4 and used $\log_e$-transformed CPUE data. Then, the nonequilibrium Schnute's version of the Schaefer model was fitted using equation (12). This can be done linearly or nonlinearly. The parameter estimates from the linear fit (equation 9) can be used as starting values to solve the nonlinear fit (equation 8). Then confidence limits around the MSY can be calculated from equation (14). If only a linear fit is used, the confidence intervals around the MSY can be found by applying equation (16). The nonlinear fit is

preferred to the linear fit. Also, the nonequilibrium version should always be fitted first. The equilibrium version (equation 7) can be derived subsequently. The variance formulae derived for the MSY confidence intervals may not work well if the parameter estimates are not well behaved. In such case, a second or third order Taylor series approximation may be needed.

In summary, it is strongly recommend that these results and procedures be used to continue to monitor the fishery both at the aggregate level and at the individual species or species group level using proportional allocation of effort. The variance around the MSY estimate and the large discrepancy in MSY estimates between the present study and the Ould Soueilem and Fonteneau (In press) study highlight the need for cautious informed management decisions.

SUMMARY

In the first chapter, the physical, biological and chemical characteristics of the study area were presented. The area is under the influence of the trade winds which largely regulate the physical processes in the area. The Mauritanian and Sahara Currents as well as the upwelling process bring together water masses with different physical and chemical properties. The flow regime as well as topographic considerations makes the area suitable for the presence of highly diverse fish biomass.

The second chapter explored the timing and structure of water temperature and wind. The Mauritanian shelf is a transition zone between a northern region with permanent upwelling and a southern region with seasonal upwelling. Using empirical orthogonal function analysis, it was shown that discrepancies in SST between these two regions increased over time. Warming in the southern EEZ from 1985 to 1993 is connected to long-term successive cooling and warming trends in SST in the Northwest African coast. Also periodicities in the monthly SST were identified at one, 2 and 5-6 years. The peak in spectral density at 1 year reflects the seasonal signal. The peak at 2 years is believed to represent atmospheric processes in the tropical Atlantic, while the 5-6 year peak may represent the above mentioned cooling and warming trends. This latter speculation, however, warrants further investigation. In addition, there was a

strong relationship between SST at 18-20°N and CUI computed at the coastal station of Nouadhibou. This may allow for adequate predictions of oceanographic processes over the Mauritanian shelf from coastal stations.

The third chapter gave a detailed description of the catch and effort. Multivariate and univariate analyses of variance revealed complex spatial and temporal patterns in species yields and are largely influenced by hydrographic conditions. For instance, Carangidae dominate the catch particularly during the transitional water seasons (June-July and November-December), while Clupeidae are mostly represented during the cold (January-May) and warm (August-October) water seasons. The *Sardina pilchardus* makes up a large portion of the catch in the northern fishing zone and during the cold water season. Fishing strategy was a key factor in determining differences in species yields between vessels. Rumanian vessels tend to target Clupeidae more than the Russian vessels. which tend to follow Carangidae concentrations.

The fourth chapter emphasized two methods for calculating the CPUE. The regression approach is more appropriate for modeling purposes while the ratio estimators is a sampling based approach. Among the regression models investigated (i.e., simple linear regression, with and without intercept, and full and restricted full power models), the power model was found to be the more appropriate model because it provides more reliable CPUE estimates than the commonly used simple linear regression. Likewise, proportional allocation of the fishing effort based on the contribution of the species or species groupings to the

total fishery catch was shown to be the best method for computing CPUE in this specific case. The other methods of partitioning the effort, which were based on assigning threshold values to compute the effort, did not allow adequate partitioning of the effort among species or species groupings. Methods that incorporate additional information (such as number of schools, number of trawl hauls) should be investigated as tools that improve CPUE reliability.

In chapter five, the fisheries management implications of proportionally allocating the fishing effort among species or species groups were evaluated using a Schnute's version of the Schaefer model. It was shown that the approach using proportional allocation of fishing effort is conservative assuming the fishery is still in the ascending arm of the MSY. The nonlinear fit of the Schaefer model outperformed the linear fit and is recommended for use whenever possible. The method provided relatively good fit results based on confidence intervals around MSY for which a new variance formula was derived. This variance formula is a handy tool that should be used to make guided management strategies. The procedures used in this chapter can be outlined as follow. First, fishing effort should be allocated adequately among species or species group. The proportional allocation (allocation method 4) yielded a significantly improved estimates in this specific case. The CPUE calculation involved the restricted power model presented in Chapter 4 and used $\log_e$-transformed CPUE data. Then, the nonequilibrium Schnute's version of the Schaefer model is fitted using equation (12). This can be done linearly or nonlinearly. The parameter estimates from the

linear fit (equation 9) can be used as starting values to solve the nonlinear fit (equation 8). Then confidence limits around the MSY can be calculated from equation (14). If only a linear fit is used, the confidence intervals around the MSY can be found by applying equation (16). The nonlinear fit is preferred to the linear fit. Also, the nonequilibrium version should always be fitted first. The equilibrium version (equation 7) can be derived subsequently. The variance formulae derived for the MSY confidence intervals may not work well if the parameter estimates are not well behaved. In such case, a second or third order Taylor series approximation may be needed.

The link between environmental variables (e.g., CUI) and catch was investigated but gave unrealistic results and, therefore, was not established in the model. Likewise, economic variables such as price indices were also considered. It was concluded that the fleet's fishing strategy, a dominant driving force, which determines catch composition, can override hydrographic considerations and does not necessarily aim at maximizing profit. Such links require a more suitable catch data set and should be the subject of further research.

REFERENCES

Allain, Ch., 1970. Observations hydrologiques sur le talus du Banc d'Arguin en decembre 1962 (Campagne de la "Thalassa" du 2 novembre au 21 decembre 1962). Rapp. P-v. Réun. Cons. Int. Explor. Mer 154: 86-89.

Allen, J.S., and R.L. Smith. 1981. On the dynamics of wind-driven shelf currents. Phil. Trans. Roy. Soc. Lond. A302: 617-634.

Andersen, K. P. 1964. Statistical aspects of abundance estimates. In Gulland, J. A. (ed.). On the measurement of abundance of fish stocks. Rapp. Int. Cons. Explor. Sea 155: 15-18.

Anderson, T.W. 1984. An introduction to multivariate statistical analysis (2nd ed.), John Wiley, New York, 675p.

Ansa-Emmin, M. 1982. Fisheries in the CINECA region. Rapp. P.-v. Réun. Cons. int. Explor. Mer 180: 405-422.

Arfi, R. 1985. Variabilité interannuelle d'un indice d'intensité des remontées d'eau dans le secteur du Cap Blanc (Mauritanie). Can.J.Fish. Aquat. Sci. 42:1969-1978.

Arfi, R. 1987. Variabilité interannuelle de l'hydrologie d'une region d'upwelling (bouée Bayadere, Cap Blanc, Mauritania). Oceanol. Acta. 10(2):151-159.

Bak, R. P. M., and G. Nieuwland. 1993. Patterns in pelagic and benthic nanoflagellate densities in the coastal upwelling system Along the Banc d'Arguin, Mauritania. In Wolff, W. J., J. van der Land, P.H. Nienhuis and P. A. W. J. de Wilde (eds.). Ecological studies in the coastal waters of Mauritania. Hydrobiologia 258:119-130.

Bakun, A. 1975. Daily and weekly upwelling indices, west coast of North America, 1967-73. NOAA Tech. Rep. NMFS SSRF-671, 103p.

Bakun, A., D.R. Mclain, and F.V. Mayo. 1976. The mean annual cycle of coastal upwelling off western north America as observed from surface measurements. U.S. Fish. Bull. 72(3): 843-844.

Barton, E.D., A. Huyer, and R.L. Smith. 1977. Temporal variation observed in the hydrographic regime near Cabo Corveiro in the northwest African upwelling region, February to April 1974. Deep-Sea Res. 24: 7-23.

Barber, R. T., and R. L. Smith. 1981. Costal upwelling ecosytems. pp. 31-68. In A. R. Longhurst (ed.). Analysis of marine ecosystems. Academic Press, London.

Barton, E.D., P. Hughes and J.H. Simpson. 1982. Vertical shear observed at contrasting sites over the continental slope off NW Africa. Oceanol. Acta 5(2): 169-178.

Beverton, R.J.H., and S.J. Holt, 1957. On the dynamics of exploited fish populations. Fisheries Investment Series 2, vol. 19, U.K. Ministry of Agriculture and Fisheries, London, 533p.

Bibby, J. 1977. The general linear model: A cautionary tale. In O'muircheartaigh C.A. and C. Payne (eds.). The analysis of survey data. vol. 2: Model fitting. John Wiley and Sons, Ltd., New York, 255p.

Bigg, G. R. 1993. Comparison of coastal wind and pressure trends over the tropical Atlantic: 1946-1987. Intern. J. Climatology 13:13,000-13,011.

Bishop, J.M. 1984. Applied Oceanography. John Wiley & Sons, Inc., New York, 252 p.

Blackburn, M. 1979. Zooplankton in an upwelling area off northwest Africa: Composition, distribution and ecology. Deep-Sea Res. 26A: 41-56.

Boely, T. 1982. Les ressources en poissons pélagiques des côtes ouest-africaines entre la Mauritanie et le fleuve Congo (Résumé). Rapp. P.-v. Réun. Cons. int. Explor. Mer 180: 423-431.

Boely, T., and P. Fréon. 1980. Coastal pelagic resources. Fish resources of the Eastern Central Atlantic. I. The resources of the Gulf of Guinea from Angola to Mauritania. FAO techn. pap. 186.1: 13-76.

Boely, T., J. Chabanne, P. Fréon, and Stéquert. 1982. Cycle sexuel et migrations de Sardinella aurita sur le plateau continental ouest-africain, des Iles Bissagos à la Mauritanie. Rapp. P.-v. Réun. Cons. int. Explor. Mer 180: 350-355.

Boje, R., and M. Tomczak. 1978. Ecosystem analysis and the definition of boundaries in upwelling regions. pp. 3-11. In Boje, R. and M. Tomczak (eds.). Upwelling ecosystems. Springer-Verlag, New York.

Brown, B.E., J.A. Brennan, M.D. Grosslein, E.G. Heyerdahl, and R.C. Hennemuth. 1976. The effect of fishing on the marine finfish biomass in the Northwest Atlantic from the Gulf of Maine to Cape Hatteras. Int. Comm.NorthwestAtl. Fish. Res. Bull. 12: 49-68.

Brink, K. 1985. Some aspects of physical processes in coastal upwelling. In Bas, C., R. Margalef and P. Rubies (eds.). Int. Symp. W Afr., Inst. Inv. Pesq., Barcelona 1985, 1:5-14.

Bryden, K.H., D. Halpern, and R.D. Pillsbury. 1980. Importance of eddy heat flux in a heat budget for Oregon coastal waters. J. Geophys. Res. 85: 6649-6653.

Bulatov, R. P. 1986. Variabilité interanuelle de la température de l'eau sur la coupe transatlantique du tropique du Cancer. Recherches physiques et océanographiques dans l'Atlantique tropical. Ed. Nauka: 148-157 p.

Bulgakov, N. P., A.B. Polonsky, Yu. I. Popov, Yu. V. Artamonov, and V.P. Nikiforova. 1985. Variability of the temperature field off the north-western coast of Africa. Int. Symp. Upw. West Afr., Ins. Inv. Pesq., Barcelona 1:79-92.

Burkov, V. A., R. P. Bulatov, and V. G. Neiman. 1973. La circulation a grande échelle des eaux océaniques. Oceanologie 13(3): 395-403.

Casella, G., and R. L. Berger. 1992. Statistical inference. Wadsworth & Brooks/ Cole Advanced Books and Software, Pacific Grove, California, 650p.

Chavance, P. 1988. Description de l'activité des flottilles pélagiques industrielles en 1987 dans la ZEE mauritanienne. Bull. Centr. Nat. Rech. Océanogr. et Pêches, Nouadhibou 17: 1-29.

Chavance, P. 1990. Description de l'activité des flottilles pélagiques industrielles en 1988 dans la ZEE mauritanienne. Bull. Centr. Nat. Rech. Océanogr. et Pêches, Nouadhibou 20: 66-87.

Chavance, P. 1991. La pêcherie industrielle des espèces pélagiques côtières. pp. 138-140. In Chavance, P. and M. Girardin (eds.). L'environnement, les ressources et les pêcheries de la ZEE mauritanienne. Centr. Nat. Rech. Océanogr. et Pêches, Nouadhibou.

Chavance, P., and M. Girardin (eds.). 1991. L'environnement, les ressources et les pêcheries de la ZEE mauritanienne. Centr. Nat. Rech. Océanogr. et Pêches, Nouadhibou, 227p.

Chavance, P., I. Ba, and S. Krivospitchenko. 1991a. Les ressources pélagiques. pp. 28-72. In Chavance P. and M. Girardin (eds.). L'environnement, les ressources et les pêcheries de la ZEE mauritanienne. Centr. Nat. Rech. Océanogr. et Pêches, Nouadhibou.

Chavance, P., Loktionov, Y., and M. Mahfoudh. 1991b. Importance des saisons de transition hydrologique et impact des anomalies climatiques sur l'activité d'une flottille industrielle pélagique en ZEE mauritanienne. In Cury, P. and C. Roy (eds.). Pêcheries Ouest Africaines: Variabilité, Instabilité et Changement. ORSTOM/ISPM/CNROP/CRODT/CROA/FRUB. ORSTOM Ed.: 246-258.

Chatfield, C. 1980. The analysis of time series: an introduction. Chapman & Hall, London, 268p.

Chester R., H. Elderfield, J.J. Griffin, L.R. Johnson, and R.C. Padgham. 1972. Eolian dust along the eastern margins of the Atlantic Ocean. Mar. Geol. 13(1): 91-106.

Chu, P.S. 1984. Time and space variability of rainfall and surface circulation in the northeast Brazil - tropical Atlantic sector. J. Meteorol. Soc. Jpn., 62: 363-370.

Clark, C. 1985. Bioeconomic modelling and fisheries management. Wiley, New York, 291p.

Cochran, W. G. 1977. Sampling techniques (3rd ed.). Wiley, New York, 428p.

Conover, W. J., 1980. Practical nonparametric statistics. Wiley, New York, 493p.

Cool, L.V., Y.A. Romanov, B.S. Samoilenko, and Y.A. Shichkov. 1974. Recherches sur la circulation atmospherique dans les latitudes tropicales nord-atlantiques. Polyg. Hydro. de l'atl. Ed. Nauka 70: 20-45.

Cook, D. 1984. Glossary of technical terms. In May, R.M. (ed.). Exploitation of marine communities. Dahlem Workshop Reports. Life Siences Research Report 32. 336p.

Coste, B., and H.J. Minas. 1982. Analyse des facteurs regissant la distribution des sels nutritifs dans la zone de remontee d'eau des cotes Mauritaniennes. Oceanol. Acta. 5(3): 315-324.

Craddock, J. M. 1965. A meteorological application of principal component analysis. The Statistician 15 (2):143-156.

Craddock, J. M. 1973. Problems and prospects for eigenvector analysis in meteorology. The Statistician 22:133-145.

Csirke, J. 1988. Small shoaling pelagic stocks. pp. 271-302. In Gulland J. A. (ed.) Fish population dyanamics: the implications for management (2nd ed.). Wiley-Interscience, New York.

Csirke, J., and G.D. Sharp. (eds.). 1984. Reports of the Expert Consultation to examine changes in abundance and species composition of neritic fish resources. San Jose, Costa Rica, 18-24 April, 1983. A preparatory meeting for the FAO World Conference on Fishery Management and Development, FAO Fish. Rep. 291(1): 102 p.

Cuq, F. 1993. Remote sensing of sea surface and coastal features in the area of the Golfe d'Arguin, Mauritania. In Wolff, W.J., J. van der Land, P.H. Nienhuis and P. A. W. J. de Wilde (eds.). Ecological studies in the coastal waters of Mauritania. Hydrobiologia 258:33-40.

Cury, P., and C. Roy (eds.) 1991. Pêcheries Ouest Africaines: Variabilité, Instabilité et Changement. ORSTOM/ISPM/CNROP/CRODT/CROA/FRUB. ORSTOM Edit. 525p.

Diester-Haass, L. 1978. Sediments as indicators of upwelling. pp. 261-281. In Boje, R., and M. Tomczak (eds.). Upwelling ecosystems. Springer-Verlag, New York.

Domain, F. 1980. Contribution a la connaissance de l'ecologie des poissons demersaux du plateau continental senegalo-mauritanien. Les ressources demersales dans le contexte general du golfe de Guinee. These d'Etat, Univ. Paris VI. 350p.

Dubrovin B., S. Ould Dedah, and M. Mahfoudh. 1990. Variabilité saisonniere de la température des eaux superficielles du plateau continental mauritanien. Centr. Nat. Rech. Océanogr. et Pêches, Nouadhibou.

Dubrovin B., M. Mahfoudh, and S. Ould Dedah. 1991. La ZEE mauritanienne et son environnement géographique, géomorphologique et hydroclimatique. In Chavance, P. and M. Girardin (eds.). L'environnement, les ressources et les pêcheries de la ZEE mauritanienne. Centr. Nat. Rech. Océanogr. et Pêches, Nouadhibou, 23: 6-27.

Ekman, V. W. 1905. On the influence of the earth's rotations on ocean-currents. Arkiv för matematik, astronomi, och fysik 2: 1-53.

FAO, 1978. Some scientific problems of multispecies fisheries. Report of the expert consultation on management of multispecies fisheries, Rome, 20-23 September 1977. FAO Fish. Tech. Pap. 181, 42p.

Fedoseev, A. 1970. Geostrophic circulation. Rapp. P-v. Réun. Cons. Int. Explor. Mer 159: 32-37.

Fischer, W., G. Bianchi, and W.B. Scott (eds.) 1981. Fiches FAO d'identification des especes pour les besoins de la peche. Atlantic Centre-Est. Zones de peche 34, 47. Canada Fonds de depot. Ottawa, Ministere des pecheries et oceans, Canada, en accord avec la FAO., 1-7: variable pages.

Fox, W.W. 1970. An exponential surplus-yield model for optimizing exploited fish populations. Trans. Am. Fish. Soc. 99: 80-88.

Fraga, F. 1974. Distribution des masses d'eau dans l'upwelling de Mauritanie. Tethys 6:5-10.

Fraga, F., E. Barton, and O. Llinas. 1985. The concentration of nutrient salts in "pure" north and south Atlantic central waters. Int. Symp. Upw. West Afr., Ins. Inv. Pesq., Barcelona 1:25-36 p.

Fréon, P., and B. Stéquert. 1979. Note sur la présence de Sardina pilchardus (Walb.) au Sénégal: étude de la biométrie et interprétation. Cybium, 3rd ser. 6: 345-349.

Fréon, P., B. Stéquert, and T. Boely. 1982. La pêche des poissons pélagiques côtiers en Afrique de l'Ouest des Iles Bissagos au nord de la Mauritanie: description des types d'exploitation (Résumé). Rapp. P.-v. Réun. Cons. int. Explor. Mer 180: 399-404.

Garcia, S. 1982. Distribution, migration and spawning of the main fish resources in the northern CECAF area. CECAF/ECAF Series, 82/25. FAO, Rome, 9p, 11 charts.

Gillbricht, M. 1977. Phytoplankton distribution in the upwelling area off northwest Africa. Helgolander wiss Meeresunters 29: 417-438.

Gostan, J., and P. Guibout. 1974. Sur quelques mesures de courant effectuées dans la zone d'upwelling de Mauritanie, en voisinage et á l'intérieur d'un canyon. Tethys 6:349-361.

Gulland, J. A. 1955. Estimation of growth and mortality in commercial fish populations. Fish. Invest. Minist. Agric. Fish Food U.K. (Series 2), 18 (9): 46p.

Gulland, J. A. 1956. On the fishing effort in English demersal fisheries. Fish. Invest. Minist. Agric. Fish Food U.K. (Ser. 2), 20 (5): 41p.

Gulland, J. A. 1964. Catch per unit effort as a measure of abundance. In Gulland (ed.). On the measurement of abundance of fish stocks. Rapp. Int. Cons. Explor. Sea 155: 8-14.

Gulland, J. A. 1983. Fish stock assessment. Vol. 1. A manual of basic methods. FAO/ Wiley Series on Food and Agriculture, New York, 223p.

Hagen E., and R. Schemainda. 1987. On the zonal distribution of South Atlantic Central Water (SACW) along a section of cape Blanc, Northwest Africa. Oceanol. Acta 6: 61-70.

Hagen E., and A.M. Gurina. 1985. A diagnostic case of meso-scale upwellings within a layer near the sea surface off Cape Blanc in summer 1972. pp 101-108. In Bas, C., R. Margalef and P. Rubies (eds.). Int. Symp. W Afr., Inst. Inv. Pesq., Barcelona. vol. 1.

Halpern, D. 1977. Description of wind and upper ocean current and temperature variations on the continental shelf off Northwest Africa during March and April 1974. J. Phys. Oceanogr. 7: 422-430.

Hartley, H. O., and A. Ross. 1954. Unbiased ratio estimates. Nature 174: 270-271.

Hastenrath, S., and M.-C. Wu. 1982. Oscillation of upper-air circulation and anomalies in the surface climate of the tropics. Arch. Meteorol. Geophys. Bioklimatol. Ser. B, 31:1-37.

Hay, W.W., and J.C. Brock 1992. Temporal variation in intensity of upwelling off southwest Africa. pp. 463-497. In Summerhayes, C.P., W.L. Prell and K.C. Emeis (eds.). Upwelling systems: Evolution since the early miocene. Geol. Soc. Spec. Publ. 64: 519p.

Hayward, D.F., and J.S. Oguntoyinbo. 1987. The climatology of West Africa. Hutchinson Barnes and Noble Books, Totowa, New Jersey, 271 p.

Hempel, G. (ed.). 1982. The Canary current: studies of an upwelling system. Rapp. P.-v. Réun. Cons. int. Explor. Mer 180: 455p.

Herbland, A. 1978. Heterotrophic activity in the Mauritanian upwelling. pp. 155-166. In Boje, R., and M. Tomczak (eds.). Upwelling ecosystems. Springer-Verlag, New York.

Herbland, A., R. Leborgne, and B. Voituriez. 1973. Production primaire, secondaire et regeneration des sels nutritifs dans l'upwelling de Mauritanie. Doc. Scient. Centre Rech. Oceanogr. Abifjan, 4:1-75.

Herbland, A., and B. Voituriez. 1974. La production primaire dans l'upwelling de Mauritanie en mars 1973. Cah. ORSTOM ser. Oceanogr. 12: 187-201.

Herbland, A., and B. Voituriez. 1982. Vitesses verticales et production potentielle dans l'upwelling de Mauritanie en mars 1973. Rapp. P-v. Réun. Cons. Int. Explor. Mer 180: 131-134.

Hirsh R.M., J.R., Slack, and R.A. Smith. 1982. Techniques of trend analysis for monthly water quality data. Water Resour. Res. 18(1): 107-121.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment. choice, dynamics and uncertainty. Chapman & Hall, Inc., New York, 570p.

Huntsman, S.A., and R.T. Barber. 1977. Primary production off northwest Africa: the relationship to wind and nutrient conditions. Deep-Sea Res. 24: 25-33.

Huyer, A. 1976. A comparison of upwelling events in two locations: Oregon and Northwest Africa. J. Mar. Res. 34(4): 531-546.

John, H.-C. 1982. Horizontal and vertical distribution of sardine and other fish larvae. Rapp. P.-v. Réun. Cons. int. Explor. Mer 180: 359-364.

Johnson, R. A., and D. W. Wichern. 1992. Applied multivariate statistical analysis (3rd ed.), Prentice-Hall, Inc., New Jersey, 642p.

Jones, B.H., and D. Halpern. 1981. Biological and physical aspects of a coastal upwelling event observed during March-April 1974 off northwest Africa. Deep-Sea Res. 28A: 71-81.

Josse, E. (ed.) 1989. Les ressources halieutiques de la ZEE mauritanienne: description, évaluation et aménagement. Rappot du 2e Groupe de travail CNROP/FAO/ORSTOM, Nouadhibou, Mauritanie, 12-22 novembre 1988. Rome, FAO, COPACE/PACE Séries 89/48, 237 p.

Josse, E., and P. Chavance. 1988a. Evaluation accoustique des ressources en poissons pelagiques et semi-pelagiques de la region du plateau et du talus continental de la ZEE mauritanienne. Resultats de la campagne ND8710P du N/O N'Diago. 26 octobre au 8 novembre 1987. Arch. Centr. Nat. Rech. Oceanogr. et Peches, Nouadhibou, 26: 63p.

Josse, E., and P. Chavance. 1988b. Evaluation accoustique des ressources en poissons pelagiques et semi-pelagiques de la region du plateau et du talus continental de la ZEE mauritanienne. Resultats de la campagne ND8802P du N/O N'Diago. 28 fevrier au 13 mars 1988. Arch. Centr. Nat. Rech. Oceanogr. et Peches, Nouadhibou, 25: 58p.

Josse, E., and Garcia S. (eds.). 1986. Description et évaluation des ressources halieutiques de la ZEE mauritanienne. Rapport du Groupe de travail CNROP/FAO/ORSTOM, Nouadhibou, Mauritanie, 16-27 septembre 1986. Rome, FAO, COPACE/PACE Séries 86/37, 310 p.

Kirichek, A. D. 1971. Water circulation in the north-eastern part of the tropical Atlantic. Int. Counc. Explor. Sea C.M. 1971/C:7., Hydrogr. Comm., 8pp.

Konijn, H.S. 1973. Statistical theory of sample survey design and analysis. North Holland Pub. Co., Amsterdam, 429p.

Krivospitchenko, S. G. 1979. Le maquereau Scomber japonicus devant le littoral saharien. COPACE/PACE Séries 78(10): 130-133.

Krivospitchenko, S. G., and L.N. Domanevski. 1984. Le maquereau (Scomber japonicus). Recheches sovietiques sur les chinchards et les maquereaux de la zone nord du COPACE. COPACE/TECH/84/59: 22-60.

Krivospitchenko, S. G., and B. I. Dubrovin. In press. Deplacements du maquereau en fonction de l'environnement devant la cote mauritanienne. Centr. Nat. Rech. Océanogr. et Pêches, Nouadhibou.

Kuipers, B. R., H. J. Witte, and S. R. Gonzales. 1993. Zooplancton distribution in the coastal upwelling system along the Banc d'Arguin, Mauritania. In Wolff, W. J., J. van der Land, P.H. Nienhuis and P. A. W. J. de Wilde (eds.). Ecological studies in the coastal waters of Mauritania. Hydrobiologia 258:133-150.

Kullenberg, G. 1978. Light-scattering observations in frontal zones. J. Geophys. Res. 83(C9): 4683-4690.

Kundu, P. K., and J.S. Allen. 1976. Some three-dimensional characteristics of low-frequency current fluctuations near the Oregon coast. J. Phys. Oceanogr. 6: 181-199.

Leborgne, R.P. 1973. Etude de la respiration et de l'excretion d'azote et de phosphore des populations zooplanctoniques de l'upwelling mauritanien (mars-avril 1972). Mar. Biol. 19: 249-257.

Leborgne, R.P. 1978. Ammonium formation in Cape Timiris (Mauritania) upwelling. J. Exp. Mar. Biol. Ecol. 31: 253-265.

Lepple, F. K. 1975. Eolian dust over the North Atlantic Ocean. Ph. D. Dissertation, University of Delaware, Newark, 270p.

Letaconnoux, R., and A.E.J. Went (eds.). 1970. Symposium sur les ressources vivantes du plateau continental atlantique Africain du Détroit de Gibraltar au Cap Vert. Rapp. P.-v. Réun. Cons. int. Explor. Mer 159: 289p.

Llinas, O., F. Fraga, and E.D. Barton. 1985. Nutrient distribution in the central water mass front near Cabo Blanco, October, 1981. Int. Symp. Upw. West Afr., Ins. Inv. Pesq., Barcelona 1: 26-36.

Loktionov, Y. 1989. Contribution a l'analyse d'intensite de l'upwelling pres du Cap Blanc (Mauritanie) a partir des temperatures d'eau a la station "standard" Bayadere. Bull. Centr. Nat. Rech. Océanogr. et Pêches, Nouadhibou, 18: 1-9.

Loktionov, Y., and M. Mahfoudh. 1989. Analyse des variations de la température de l' eau de surface le long des côtes mauritaniennes. In Josse, E. (ed.). Les ressources halieutiques de la ZEE mauritanienne: description,

évaluation et aménagement. Rappot du 2e Groupe de travail CNROP/FAO/ORSTOM, Nouadhibou, Mauritanie, 12-22 novembre 1988. Rome, FAO, COPACE/PACE Séries 89/48, 237 p.

Longhurst, A. R. 1981. Analysis of marine ecosystems, Academic Press, London. 741p.

Maigret, J., and B. Ly. 1986. Les poissons de mer de Mauritanie. Ed. Sciences Nat: 85 p.

Maigret, J. 1972. Campagne experimentale de peche des sardinelles et autres especes pelagiques (juillet 1970-octobre 1971). I. Observations concernant l'oceanographie et la biologie des especes. Rep. Islam. Mauritanie, Ministere des Peches et Mar. March., Lab. Peches, Nouadhibou, SCET International: 148p.

Manríquez, M., and F. Fraga. 1982. The distribution of water masses in the upwelling region off Northwest Africa in November. Rapp. P-v. Réun. Cons. Int. Explor. Mer 180: 39-47.

Marchal, E. 1991a. Location of the main West African pelagic stocks. pp 187-191. In Cury, P. and C. Roy (eds.). Pêcheries Ouest Africaines: Variabilité, Instabilité et Changement. ORSTOM/ISPM/CNROP/CRODT/CROA/FRUB. ORSTOM Ed.

Marchal, E. 1991b. Un essai de Caractérisation des poissons pélagiques côtiers: cas de Sardinella aurita des côtes ouest-africaines. pp 192-200. In Cury, P. and C. Roy (eds.). Pêcheries Ouest Africaines: Variabilite, Instabilite et Changement. ORSTOM/ISPM/CNROP/CRODT/CROA/FRUB. ORSTOM Ed.

Martinez, R. , T. T. Packard, and D. Blasco. 1987. Light effects and diel variations of nitrate reductase activity in phytoplankton from the northwest Africa upwelling region. Deep-Sea Res., 34(5/6):741-753

May, R.M. (ed.). 1984. Exploitation of marine communities. Dahlem workshop reports. Life Siences Research Report 32: 336p.

McLain D.R., R.E. Brainard, and J.G. Norton. 1985. Anomalous warm events in eastern boundary Current Systems. CalCOFI Rep. 26: 51-64.

Michelchen, N. 1980. Estimates of large-scale atmospheric pressure variations in the upwelling area off Northwest Africa. pp 17-20. In Richards, F.A. (ed.). Coastal upwelling. American Geophysical Union, Washington, D.C.

Milliman, J.D. 1977. Efffects of arid climate and upwelling upon the sedimentary regime off southern Spanish Sahara. Deep-Sea Res. 24: 95-103.

Minas, H. J., L. A. Codispoti, and R.C. Dugale. 1982. Nutrients and Primary Production in the Upwelling Region off Northwest Africa. Rapp. P-v. Réun. Cons. Int. Explor. Mer 180: 148-183.

Minas, H.J., and J.M. Peres (eds.). 1974. Analyse de l'ecosysteme des upwellings. 2ᵉ Conference, Marseille 28-30 Mai 1973. Tethys 6(1-2):461p.

Mittelstaedt, E. 1976. On the currents along the Northwest African coast south of 22° North. Dt.Hydrogr. Z. 29 (3): 97-117.

Mittelstaedt, E. 1982. Large-scale circulation along the coast of Northwest Africa. Rapp. P-v. Réun. Cons. Int. Explor. Mer 180: 50-57.

Mittelstaedt, E., 1983. The upwelling area off northwest Africa - A description of phenomena related to coastal upwelling. Prog. Oceanogr.12: 307-331.

Mittelstaedt, E., 1991. The ocean boundary along the Northwest African coast: Circulation and oceanographic properties at the sea surface. Prog. Oceanogr. 26: 307-355.

Mittelstaedt, E., D. Pillsbury, and R. L. Smith. 1975. Flow patterns in the Northwest African upwelling area. Dt.Hydrogr. Z. 28: 145-167.

Morel, A. 1978. Available, usable, and stored radiant energy in relation to marine photosynthesis. Deep-Sea Res. 25: 673-688.

Morel, A. 1982. Optical properties and radiant energy in the waters of the Guinea Dome and the Mauritanian upwelling area in relation to primary production. Rapp. P-v. Réun. Cons. Int. Explor. Mer 180: 94-107.

Myers, R. H. 1986. Classical and modern regression with applications. Duxbury Press, Boston, 459p.

Nelson, D. M., and J. J. Georing. 1977. Near-surface silica dissolution in the upwelling region off northwest Africa. Deep-Sea Res. 24: 65-73.

Nelson, D. M., and J. J. Goering. 1978. Assimilation of silicic acid by phytoplankton in the Baja California and northwest Africa upwelling systems. Limnol. Oceanogr. 23(3): 508-517.

Nelson, D.M., and H. L. Conway. 1979. Effects of the light regime on nutrient assimilation by phytoplankton in the Baja California and Northwest Africa upwelling systems. J. Mar. Res. 37(2): 301-318.

Neshyba S. J., Ch. N. K. Mooers, R. L. Smith, and R. T. Barber (eds.). 1989. Poleward flows along eastern ocean boundaries. Coastal and Estuarine Studies 34: 374p.

Nieland, H. 1982. The food of Sardinella aurita (Val.) and Sardinella eba (Val.) off the coast of Senegal. Rapp. P.-v. Réun. Cons. int. Explor. Mer 180: 369-373.

Nieuwolt, S. 1977. An introduction to the climates of the low latitudes. John Wiley & Sons, Inc., New York, 207 p.

Ould Dedah, S. 1993. Wind, surface water temperature, surface salinity and pollution in the area of the Banc d'Arguin, Mauritania. In Wolff, W.J., J. van der Land, P.H. Nienhuis and P. A. W. J. de Wilde (eds.). Ecological studies in the coastal waters of Mauritania. Hydrobiologia 258:9-20.

Ould Soueilem, M. M. 1992. Contribution to the study of pelagic fishery in the Mauritanian 200 mile EEZ (description, stock assessment, by-catch, and management). M.S. Thesis, Univ. of Washington, Seattle, 113p.

Ould Soueilem, M. M., and A. Fonteneau. (eds.) In Press. Groupe de travail sur l'evaluation et l'amenagement des pecheries. CNROP Du 20 au 26 Novembre 1993.

Overko, S.M. 1971. Size composition of Trachurus trecae stock in the shelf waters of the north-western African coast. Cons. Int. Explor. Mer, Pelagic Fish Com. C.M. 1971/J:3 p.

Packard, T.T. 1979. Respiration and respiratory electron transport activity in plankton from the Northwest African upwelling area. J. Mar. Res. 37(4): 711-739.

Packard, T.T., and Blasco. 1974. Nitrate reductase activity in upwelling regions. 2. Ammonia and light dependance. Tethys 6:269-280.

Paloheimo, J. E. and L. M. Dickie. 1964. Fishing success. In Gulland, J. A. (ed.). On the measurement of abundance of fish stocks. Rep. Int. Cons. Explor. Sea 155: 152-163.

Pauly, D. 1979. Theory and management of tropical multispecies stocks: A review, with emphasis on the Southeast Asia demersal fisheries. ICLARM Stud. Rev. 1, 35p.

Peters, M. 1976. The spreading of water masses of the Banc d'Arguin in the upwelling area of the northern Mauritanian coast. Meteor Forsch-Ergebn A.18: 78-100.

Picaut, J. 1985. Major dynamics affecting the eastern tropical Atlantic and Pacific Oceans. CalCOFI Rep. 26: 41-50.

Polovina, J.J. 1989. A system of simultaneous dynamic production and forecast models for multispecies or multiarea applications. Can. J. Fish. Aquat. Sci. 46: 961-963.

Pope, J. 1979. Stock assessment in multispecies fisheries, with reference to the trawl fishery in the Gulf of Thailand. South China Sea Fish. Develop. Con. Programme, SCS/DEV/79/19: 106p.

Preisendorfer, R.W., and C.D. Mobley. 1988. Principal component analysis in meteorology and oceanography. Elsevier Science Publishers B.V., Amsterdam, 425 p.

Ralston, S., and Polovina 1982. A multispecies analysis of the commercial deep-sea handline fishery in Hawaii. U.S. Fish. Bull. 80(3): 435-447.

Reyssac, J. 1976. Phytoplankton recolte par le Laurent-Amaro au large des cotes du Senegal et de la Mauritanie. Bull. de l' I.F.A.N., T. 38 (ser.A), 1:13p.

Reyssac, J. 1977. Hydrologie, phytoplancton et production primaire de la baie du Levrier et du Banc d'Arguin. Bull. de l' I.F.A.N., T.39 (ser. A), 3: 487-554.

Richman, J., and A. Badan-Dangon. 1983. Mean heat and momentum budgets during upwelling for the coastal waters off Northwest Africa. J. Geophys. Res. 88(C4): 2626-2632.

Richard, F.A. (ed.) 1980. Coastal upwelling. American Geophysical Union, Washington, D.C., 529 p.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191: 382p.

Romanov Y. A., and V. I. Bishev. 1974. Variabilité des paramètres météorologiques dans le polygone atlantique. Polyg. Hydro. de l'Atl. Ed. Nauka, 70: 90-100.

Rowe, G.T., C.H. Clifford, and K.L. Smith, jr. 1977. Nutrient regeneration in sediments off Cape Blanc, Spansish Sahara. Deep-Sea Res. 24: 57-63.

Roy, C. 1990. Réponses des stocks de poissons pélagiques à la dynamique des upwellings en Afrique de l'Ouest: Analyses et modélisation. Thèse d e Doctorat. Université de Bretagne Occidentale, Fac. des Sc., 147p + appendix.

SAS Institute Inc. SAS/STAT, SAS/ETS 1989. User's Guide, Release 6.03 Edition. Cary, NC: SAS Institute Inc., 1989.

Saville, A. 1980. The assessment and management of pelagic fish stocks. A symposium held in Aberdeen, 3-7 July 1978. Rapp. P.-v. Réun. Cons. int. Explor. Mer 177: 517 pp.

Schaefer, M.B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Inter - Am. Trop. Tuna Comm. Bull. 1: 25-26.

Scheaffer, R. L., W. Mendenhall, and L. Ott. 1990. Elementary survey sampling (4th ed.). Duxbury Press, Boston, 390p.

Schemainda, R., and D. Nehring. 1975. The annual cycle of the space-temporal dislocation of the North-West African upwelling region. Comm. 42, 3rd Int. Symposium. Upwelling Ecosystems, Kiel, 25-28 August 1975.

Schemainda, R., D. Nehring, and S. Schulz. 1975. Ozeanologische Untersuchungen zum Produktionspotential der nordwestafrikanischen Wasserauftriebsregion 1970-1973. Geod. Geoph. Veröff., R IV, H. 16, 88p.

Schnute, J. 1977. Improved estimates from the schaefer production model: theoretical considerations. J. Fish. Res. Board Can. 34 (5): 583-603.

Seber, G. A. F. 1982. The estimation of population abundance and related parameters (2nd ed.). Griffin and Co. Ltd., London, England: 654p.

Servain, J. 1991. Simple climatic indices for the tropical Atlantic Ocean and some applications. J. Geophys. Res. 96(C8):15,137-15,146.

Servain, J., and D. M. Legler. 1986. Empirical orthogonal function analysis of tropical Atlantic sea surface temperature and wind stress: 1964-1979. J. Geophys. Res. 91:14,181-14,191.

Smith, R.L., 1968. Upwelling .Oceanogr. Mar. Biol. Ann. Rev. 6:11-46.

Smith, R.L., 1978. Poleward propagating perturbations in currents and sea levels along the Peru coast. J. Geophys. Res. 83(C12): 6083-6092.

Smith, R.L. 1980. A comparison of the structure and variability of the flow field in three coastal upwelling regions: Oregon, Northwest Africa, and Peru. pp 107-118. In Richards, F.A. (ed.). Coastal upwelling. American Geophysical Union, Washington, D.C.

Smith, S. J. 1980. Comparison of two methods of estimating the variance of the estimate of catch per unit effort. Can. J. Fish. Aquat. Sci. 37: 2346-2351.

Smith, S. L., and T. E. Whitledge. 1982. Regeneration of nutrients by zooplancton and fish off Northwest Africa. Rapp. P-v. Réun. Cons. Int. Explor. Mer 180: 206-208.

Smith, W. O. Jr., R. T. Barber, and S. A. Huntsman. 1977. Primary production off the coast of northwest Africa: Excretion of dissolved organic matter and its heterotrophic uptake. Deep-Sea Res. 24: 35-47.

Speth, P., and H., Detlefsen. 1979. Empirical orthogonal functions of sea level pressure and sea surface temperatures for the upwelling area off Northwest Africa. Dt. Hydrogr. Z. 32: 131-145.

Speth, P., and H., Detlefsen. 1982. Meteorological influences on upwelling off Northwest Africa. Rapp. P-v. Réun. Cons. Int. Explor. Mer 180: 29-34.

Srivastava, V. K., and D. E. A. Giles. 1987. Seemingly unrelated regression equations models: Estimation and inference. Statistics: Textbooks and Monographs. 80: 374p.

Strickland, J. D. H., R. W. Eppley, and B. Rojas de Mendiola. 1969. Phytoplankton populations, nutrients and photosynthesis in Peruvian coastal waters. Bol. Inst. Mar. Peru 2:1-45.

Stuart, R. D. 1961. An introduction to Fourier analysis. Chapman and Hall, London, 128p.

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The oceans, their physics, chemistry and general biology. Prentice-Hall, Englewwod Cliffs, New Jersey, 1087pp.

Sukhatme, P. V., B. V. Sukhatme, S. S. Sukhatme, and C. Asok. 1984. Sampling theory of surveys with applications. (3rd ed.) Indian Soc. Agric. Statist., New Delhi, India and Iowa State Univ. Press, Ames, Iowa, 526p.

Szekielda, K.H. 1976. Fast temperature changes in the upwelling area along the North West coast of Africa. J.Cons. Int. Explor. Mer 36(3):199-204

Szekielda, K.H. 1978. Eolian dust into the northeast Atlantic upwelling area along the North West coast of Africa. Oceanogr. Mar. Biol. Ann. Rev. 16:11-41.

Tin, M. 1965. Comparison of some ratio estimators. J. Amer. Statist. Ass. 60: 294-307.

Treguer, P., and P. LeCorre. 1979. The ratios of nitrate, phosphate, and silicate during uptake and regeneration phases of the Moroccan upwelling regime. Deep-Sea Res. 26A: 163-184.

Tchernikov, P., and P. Chavance. 1986. Transport d'Ekman dans la region du Cap Blanc, 1983-1986. Bull. Centr. Nat. Rech. Océanogr. et Pêches, Nouadhibou 14(1): 1-6.

Tomczak, M., Jr. 1973. An investigation into the occurrence and development of cold water patches in the upwelling region off NW Africa (Roßbreiten-Expedition 1970). Meteor Forschungsergebnisse (A) 21: 1-24.

Tomczak, M., Jr. 1977. Continuous measurement of near-surface temperature and salinity in the North West Africain upwelling region between Canary Islands and Cape Vert during the winter of 1971-1972. Deep-Sea Res. 24: 1103-1119.

Tomczak, M., Jr. 1981. An analysis of mixing in the frontal zone of south and north Atlantic central water off Northwest Africa. Prog. Oceanogr. 10: 173-192.

Tomczak, M., Jr. 1982. The distribution of water masses at the surface as derived from T-S diagram analysis in the CINECA area. Rapp. P-v. Réun. Cons. Int. Explor. Mer 180: 48-49.

Tomczak, M., Jr., and P. Hughes. 1980. Three dimensional variability of water masses and currents in the Canary Current upwelling region. Meteor Forschungsergebnisse (A) 21: 1-24.

Van Camp, L., L. Nikjaer, E. Mittelstaedt, and P. Schlittenhardt. 1991. Upwelling and boundary circulation off Northwest Africa as depicted by infrared and visible satellite observations. Prog. Oceanogr. 26: 357-402.

Vives, F. 1974. Le Zooplancton et les masses d'eau des environs du Cap Blanc. Tethys 6 (1-2):313-318.

Walsh, J.J. 1976. Models of the sea. pp. 388-407. In Cushing, D.H. and J.J. Walsh (eds.). The ecology of the sea. Blackwell Scient. Publ., Oxford, 467p.

Wang, J. J., and J. J. Walsh. 1976. Objective analysis of the upwelling ecosystem off Baja California. J. Mar. Res. 34(1): 43-60.

Wanthy, B. 1983. Introduction a la climatologie du golfe de Guinee. Oceanogr. Trop. 18(2): 103-138.

Weare, B. C. 1977. Empirical orthogonal analysis of Atlantic Ocean surface temperatures. Quart. J. R. Met. Soc. 103:467-478.

Weichart, G. 1970. Kontinuierliche registrierung der temperatur und der phosphat-konzentration im oberflachenwasser des nordwestafrikanischen Auftrieb-gebietes. Dt. Hydrogr. Z. 23(2): 49-60.

Weichart, G. 1974. Meereschemische Untersuchungen im nordwestafrikanischen Auftriebsgebiet 1968. Meteor Forschungsergebnisse (A) 14: 33-70.

Whitledge, T. E. 1978. Regeneration of nitrogen by zooplankton and fish in the Northwest Africa and Peru upwelling ecosystems. pp. 90-100. In Boje, R. and M. Tomczak (eds.). Upwelling ecosystems. Springer-Verlag, New York.

Wolff, W. J., J. van der Land, P.H. Nienhuis, and P. A. W. J. de Wilde.1993. The functioning of the ecosystem of Banc d'Arguin, Mauritania: A review. In Wolff, W.J., J. van der Land, P.H. Nienhuis and P. A. W. J. de Wilde (eds). Ecological studies in the coastal waters of Mauritania. Hydrobiologia 258:211-222.

Wolter, K., and S. Hastenrath. 1989. Annual cycle and long-term trends of circulation and climate variability over the tropical oceans. J. Climate 2:1329-1351.

Wooster, W.S., A. Bakun, and D. R. McLain. 1976. The seasonal upwelling cycle along the eastern boundary of the North Atlantic. J. Mar. Res. 34(2):131-141.

Wozniak, St. 1970. Some observations on upwelling in the area of Cape Blanc, June-August 1963. Rapp. P-v. Réun. Cons. Int. Explor. Mer 154: 74-78.

Yasunari, T. 1989. A possible link of the QBO's between the stratosphere, troposphere and sea surface temperature in the tropics. J. Meteorol. Soc. Jpn. 67: 483-493.

Zellner, A. 1962. An efficient method of estimating seemingly unrelated regression equations and tests for aggregation bias. JASA 57: 348-368.

VITA

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DOCTORAL EXAMINATION AND DISSERTATION REPORT

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Title of Dissertation: Modelling a Multispecies Schooling Fishery in an Upwelling Environment, Mauritania, West Africa

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

8/28/95