DISTRIBUTION AND MIXTURE OF CAPE AND CUNENE HORSE MACKEREL, *Trachurus capensis* and *Trachurus trecae* in the Angola – Benguela front in relation to environmental and other factors

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To my wife, Gabriela Maria, and our two children, Nhari Yola and Jaime Olivio, for the hardships I put them through over the past two years while working on this thesis.

CONTENTS

Page no.

DECLARATION.. i

ACKNOWLEDGEMENTS.. ii

ABSTRACT.. iii

CHAPTER ONE

INTRODUCTION.. 1

1.1 Distribution.. 1

1.2 Environmental factors, characterization and movements.................... 5

1.4 Objectives.. 9

CHAPTER TWO

MATERIALS.. 11

2.1 Data.. 11

2.1.1 Survey data.. 11

2.1.2 Oceanographic data.. 14

CHAPTER THREE

ANALYSIS OF HORSE MACKEREL ACOUSTIC DENSITY VALUES (S_A) IN RELATION TO ENVIRONMENTAL AND OTHER FACTORS......... 16

Abstract.. 16

3.1 Introduction.. 16

3.2 Data analysis.. 17

3.3 Results.. 21

3.3.1 Model 3.1: Echo density (S_A) of the horse mackerel species combined in relation to environmental and other factors........................ 23

3.3.2 Model 3.2: Echo density (S_A) of the horse mackerel species combined in relation to environmental and other factors in the area of overlap of the two species in the southern Angola (13-20°S)............... 33

3.4 Discussion.. 38

CHAPTER FOUR

ANALYSIS OF HORSE MACKEREL CPUE DATA FROM SURVEYS IN RELATION TO ENVIRONMENTAL AND OTHER FACTORS........ 42

Abstract.. 42

4.1 Introduction.. 42

4.2 Data analysis.. 45

4.3 Results.. 47

4.3.1 Model 4.1: CPUE of the pooled horse mackerel species in relation to environmental and other factors.................................... 48

4.3.2 Model 4.2: CPUE of Cunene horse mackerel (*T. trecae*) in relation to environmental and other factors...................................... 57

4.3.3 Model 4.3: CPUE of Cape horse mackerel (*T. capensis*) in relation to environmental and other factors.. 65

4.3.4 Model 4.4: CPUE of Cunene horse mackerel (*T. trecae*) in relation to environmental and other factors only in the southern region 70

4.3.5 Model 4.5: CPUE of Cape horse mackerel (*T. capensis*) in relation to environmental and other factors only in the southern region...... 73

4.3.6 Model 4.6: CPUE of the pooled horse mackerel species in relation to environmental and other factors (with sea surface temperature).. 78

4.3.7 Model 4.7: CPUE of Cunene horse mackerel (*T. trecae*) in relation to environmental and other factors (with sea surface temperature) only in the southern region (overlap area)................................. 83

4.3.8 Model 4.8: CPUE of Cape horse mackerel (*T. capensis*) in relation to environmental and other factors (with sea surface temperature) only in the southern region (overlap area)................................ 87

4.3 Discussion.. 91

CHAPTER FIVE

RELATIVE FREQUENCIES OF TWO HORSE MACKEREL SPECIES IN MIXED CATCHES IN RELATION TO ENVIRONMETAL AND OTHER FACTORS.. 96

Abstract.. 96

5.1 Introduction.. 96

5.2 Data analysis... 98

5.3 Results... 100

5.3.1 Spatial distribution... 100

5.3.2 Temporal distribution.. 107

5.3.3 Distribution and mixture in relation to the sea surface temperature 114

5.4 Discussion.. 116

CHAPTER SIX

CONCLUSIONS.. 121

REFERENCES.. 128

APPENDICES... 134

DECLARATION

This dissertation reports the results of research that I carried out in the Marine Biology Research Institute, Zoology Department, at the University of Cape Town. It has not been submitted for any other degree or examination at any other university. Most of the data that are presented were provided by Nansen Programme through Angola Marine Research Institute (IIM) and by Ministry of Fisheries & Marine Resources of Namibia (NatMIRC). I participated in 9 of the 15 cruises in which acoustic data were collected and in 1 of the 12 cruises in which demersal data were collected. The Sea Surface Temperature data was obtained from METEOSAT through the IDYLE project. All opinions expressed, unless otherwise acknowledged, are my own.

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Date

ABSTRACT

The separation of horse mackerel species in the area north of the Angola–Benguela front is of special importance. Little information is available on the seasonal patterns of distribution of the different life history stages of *Trachurus trecae* (Cunene horse mackerel) and its mixture with *Trachurus capensis* (Cape horse mackerel) in the area north of the Angola-Benguela front. This thesis makes an analysis of survey data of horse mackerel catch per unit effort and acoustics data from R/V Dr. Fridtjof Nansen over twelve years in the region of the Angola–Benguela front. The main objectives are: to characterize the pattern of distribution and mixture of Cunene and Cape horse mackerel in the area around the Angola–Benguela front and to study the relationships between the distribution of *T. capensis* and *T. trecae* and the movements of the Angola–Benguela front. The role of sea surface temperature (SST) was also examined, assuming that this environmental parameter would be related to the seasonal variation in distribution of both species of horse mackerel, at least in the overlap area. The latitude 15°S was found to be the northern boundary of *T. capensis* but both species seem to follow the seasonal displacement of the Angola-Benguela front. The result shows that the mean intra-annual shift for the horse mackerel species in the area varies between two and three degrees. The shift farthest north for *T. capensis* is in the winter and farthest south in the summer. General linear models (GLMs) were applied, considering effects of year, season, area, depth, time and sea surface temperature (SST) on abundance estimates of horse mackerel such as survey catch per unit effort (CPUE) and acoustic density (S_A). The results of the GLM indicate that the depth, area, year and sea surface temperature have the strongest

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effects on variation in abundance of the horse mackerel species. Surprisingly, season is consistently the least significant effect in explaining the variation in CPUE in the GLMs. Thus, adequate estimates of CPUE and of acoustic abundance can be obtained in winter or summer. The two species are segregated by depth at the 95% confidence level in the region of overlap. However, the spatial pattern of the mixture between the two horse mackerel is not evident in all the data investigated. It seems to vary according to the year, temperature, day and night times but other factors are suggested to be incorporated in future studies.

Chapter One

Introduction

In the Benguela system there are two main species of horse mackerel *Trachurus capensis* and *T. trecae*. Given the commercial importance of these two species in the area, they are monitored through research surveys directed at estimating their abundance and distribution.

1.1. Distribution

The coastal waters of West Africa are inhabited by two species of horse mackerel: *Trachurus capensis* Castelneau, 1861 and *Trachurus trecae* Cadenat, 1949. *T. trecae* (Cunene horse mackerel) inhabits the subtropical and tropical zones of West Africa, occurring uninterruptedly between 26°N and approximately 17°30'S. *T. capensis* (Cape horse mackerel) is found in the northern hemisphere from the North Sea, along the western coast of Europe (as *Trachurus trachurus*) and West-Africa down to the Cape Verde Peninsula (Figure 1.1). *T. capensis* is caught in both Namibia and South Africa, and also in the south of Angola where its distribution overlaps with that of *T. trecae*. Both species of horse mackerel belong to the family Carangidae (Fréon, 1986 and Wysokiñski, 1986).

The Angolan coast has been characterized as consisting of two major faunal complexes: the "Guinea-tropical fauna" in the northern and central region and the "Benguela fauna" predominant off southern Angola (Da Franca, 1968). However the distributions of some elements from both faunal complexes may overlap around 14-15°S such as the Cape and Cunene horse mackerel (Figure 1.1).

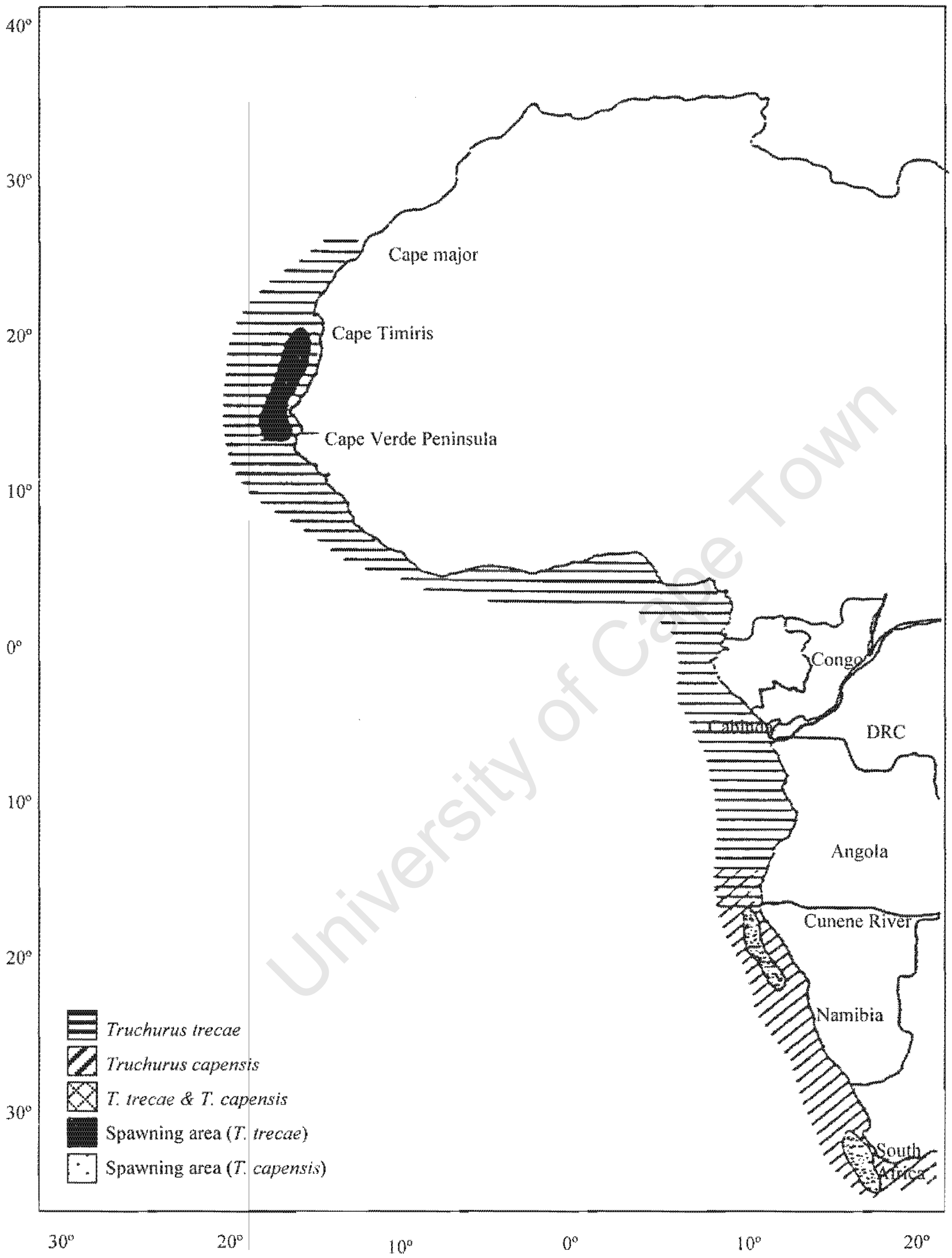


Figure 1.1: Distribution, nursery and spawning areas of *T. capensis* and *T. trecae* in the eastern Atlantic (modified from Sardinha, 1996).

Two major nursery and spawning areas of Cape horse mackerel are found off southern Africa: one, off Namibia and the other off South Africa. Off Namibia juveniles are found mainly inshore, the smallest fish living in the north near the Cunene River. As the fish mature they move offshore (Crawford *et al*., 1994).

Sardinha (1996) studied the allele frequencies of six polymorphic loci and the estimates of genetic distances between the Cunene and Cape horse mackerel, and concluded that they should be considered as separate species. The IDH (isocitrate dehydrogenase) enzyme system, especially the IDH-2 locus expressed in liver was shown to be one of the best diagnostic keys to differentiate between the species.

Both species of horse mackerel live in shoals and inhabit the near bottom zone of the shelf and its edge, as well as the pelagic zone. Considerable vertical movement has been recorded, with shoals rising to feed in surface waters at night and, conversely, moving downwards to spend the daylight hours near the bottom. Consequently horse mackerel may be caught by bottom and midwater trawls, and purse seines (Santos Dias, 1974 and Barange *et al*., 1998).

The resource is currently the most valuable pelagic stock in Angola and Namibia. Due to their commercial value horse mackerels have been a major target for research, and several surveys have been directed at estimating their abundance and distribution. These surveys have indicated that there is a clear latitudinal cline in the dominance of each species. While Cunene horse mackerel dominates the warmer areas of the Angola current, Cape horse mackerel is a typical dweller of the Benguela current system. However, there is an appreciable degree of mixture of the two species, on both sides of the Angola-Benguela front (Anon, 1998). The former USSR, which conducted fishing operations both south and north of the Cunene River, reported that between the Cunene River and 15°S the ratio of Cape to Cunene horse mackerel in the catches is 61% to 39% (Santos Dias, 1983b and Wysokiñski, 1987).

Cunene horse mackerel is caught mainly in the southern part of Angola where its distribution overlaps with that of Cape horse mackerel. The two species are not visually distinguishable and are collectively recorded in the Angolan commercial catches as carapau (Bianchi, 1986, Wysokiñski, 1986 and Cochrane and Tandstad, 2000).

From 1966-1970, catches of horse mackerel in the Convention area (ICSEAF) doubled when compared with the 1950s, equalling 200 000–300 000 tons, and increased to 500 000 tons in 1976. The largest horse mackerel catch in the area recorded in 1978 was approximately 966 000 tons. From then until 1984, catches remained at a level of 700 000–800 000 tons (Wysokiñski, 1986). One may conclude that over the last nearly 15 years the annual catch of horse mackerel in the area is less than 500 000 tons with a clear trend of decline with time (Anon, 1999). Research surveys undertaken in Angola from 1985 to 1996 have shown the mean estimated biomass to be 258 000 tons for *T. trecae*, and 23 000 tons for *T. capensis* (Cochrane and Tandstad, 2000).

A preliminary analysis of data from R/V "Dr. Fritdjof Nansen" (1986-1995) has shown that there is a marked seasonal effect on the distribution of these two stocks and on their degree of mixture. *T. capensis* is distributed further north in the cold season, as it accompanies the northward movement of the Benguela-Angola front. This is also the time when there seems to be a greater degree of mixture between the two species (Anon, 1997).

The separation of the horse mackerel species in the area of the Benguela-Angola front is of special importance. Little information is available on the seasonal patterns of distribution of the different life history stages of the Cunene horse mackerel. However, biological data and known distribution patterns suggest the existence of one self-sustained population of the Cunene species in Angola between Cabinda and the Cunene River (Anon, 1998). A migration of this species offshore was observed outside the normal distribution area, which made it difficult to detect with acoustic instruments (Bianchi *et al.*, 1997).

The frontal zone of both currents depends on the activity and range of one of these currents, horse mackerel stocks may move correspondingly and it is theoretically possible for them to go beyond the geographic boundaries established above. However, horse mackerel concentrations are fairly constant and therefore their migrations are usually caused by local environmental changes (De Campos Rosado, 1972, Hempel, 1982, Chavanche *et al.*, 1991 and Stensholt and Nakken, 1998).

1.2. Environmental factors, characterization and movements of the Angola – Benguela front

The Benguela system is one of the world's four major eastern boundary current regions where biological productivity is high due to wind-driven upwelling. This ecosystem is bordered at its northern end by the Angola counter–current and Coastal counter–current (Wysokiñski, 1987). The Angola–Benguela frontal zone (Figure 1.2) which is actually a series of fronts, is recorded between 14°S and 17°S throughout the year (Ritzhaupt, 1980 cited in Wysokiñski, 1987).

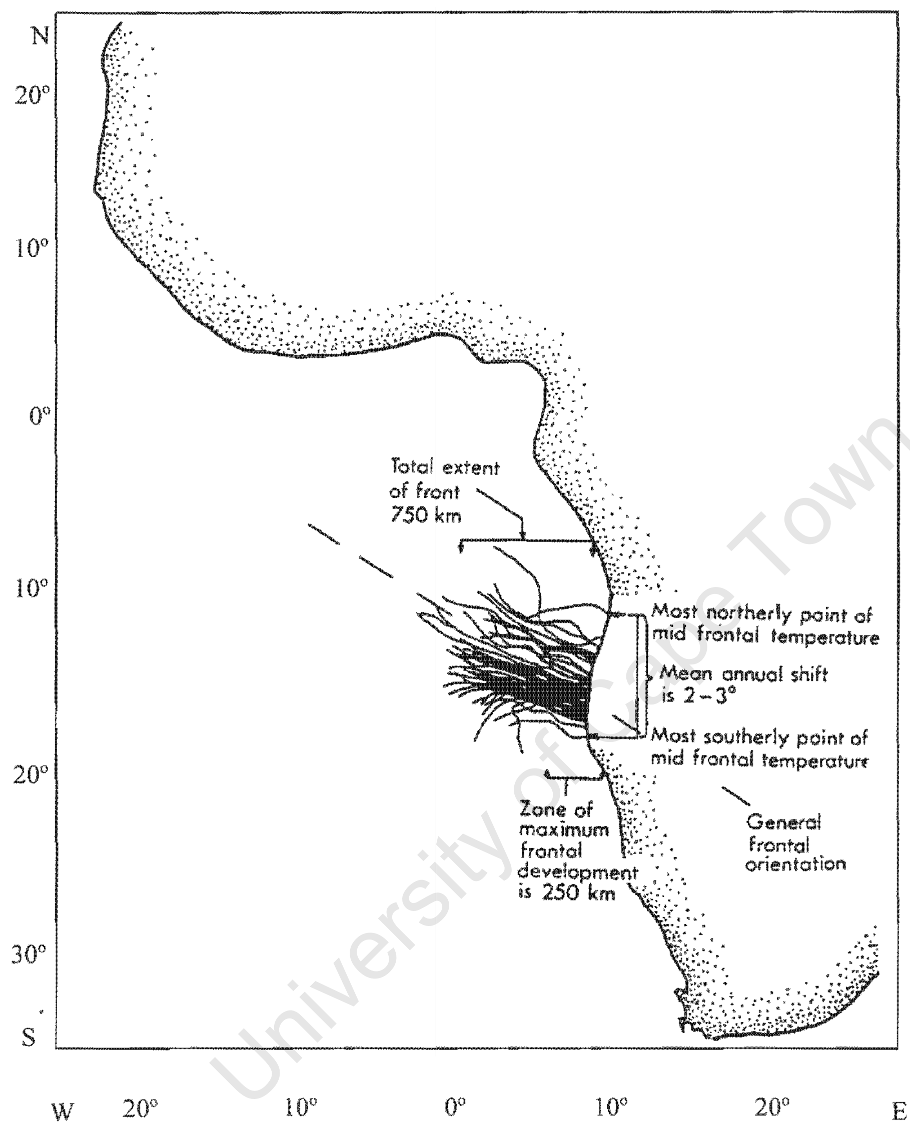


Figure 1.2: Superimposed positions for the mid-front isotherm of the Angola-Benguela front, 1982-1985 (from Meeuwis and Lutjeharms, 1990).

The Angola-Benguela frontal zone of the southeast Atlantic Ocean was investigated by means of satellite-derived weekly maps of sea surface temperature from 1982 to 1985 (Meeuwis and Lutjeharms, 1990). This investigation shows that the Angola-Benguela front is a permanent feature at the sea surface and is maintained throughout the year in a narrow band between 14° and 17°S, with a general west to east orientation (Figures 1.2 and 1.3).

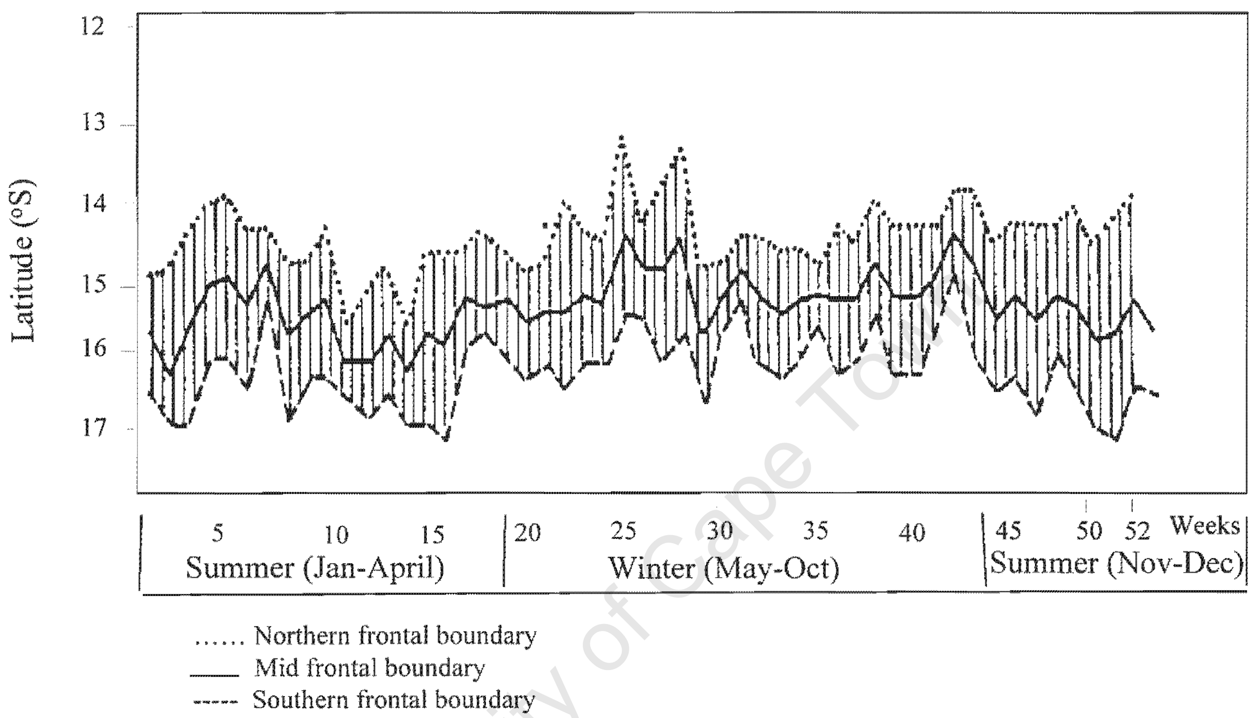


Figure 1.3: Average latitude at the coast of the mid front and the northern and southern frontal boundaries of the Angola-Benguela front, 1982-1985 (modified from Meeuwis and Lutjeharms, 1990).

Seasonal fluctuations of the front occur with regard to geographical location, width, seaward extent, temperature gradient and eddy formation in the frontal zone. The position of the front comes about as result of a combination of factors, the most notable being wind stress, coastal orientation, bottom topography and north and south movements of warm and cold water associated with the Angola Current and the Benguela upwelling system (Meeuwis and Lutjeharms, 1990). Some investigations on the vertical structure have been carried out using historical databases, but synoptic surveys of the front are rare (Anon, 1997). In the summer of 1997 the R/V "Dr. Fridtjof Nansen" carried out a survey to establish the position of the Angola-Benguela front. The front was defined from the horizontal distribution of sea surface temperature at 5 m depth. The results of this cruise confirmed previous studies done by Meeuwis and Lutjeharms (1990), Gammelsrod *et al.* (1998) and Stachlewska *et al.* (1999) on the front's position using SST data obtained by satellites.

Other physical parameters such as salinity and light seem to have little influence on the overlapping habitats of these species and show mainly seasonal variation (Nehring and Holzlöhner, 1982, Shannon and Agenbag, 1987, Abaunza *et al.*, 1994 and Moreno and Castro, 1994). However there still exist major gaps in the literature on the basic ecology of horse mackerel, such as the direction and timing of their migrations and their reproductive periods (Barange *et al.*, 1998).

The meteorological conditions off Angola suggest two main hydrographic seasons: the summer (December to April), characterized by stratified water masses, a strong thermocline at approximately 30 to 50 m depth and sea surface temperatures ranging from 28° to 30°C. The winter season (mainly June to October) is described as being less stratified, with lower surface temperatures (18° to 22°C) and with upwelling occurring. The upwelling takes place mainly in the south throughout the shelf, but is stronger in some localities, depending on the coastal configuration. The range of variation is also larger in the south than in the north (Figure 1.4). The strong seasonal signal characterizing the area is also expected to influence the distribution pattern of the main pelagic species and thus the abundance estimates and the related uncertainty (Bianchi *et al.*, 1997).

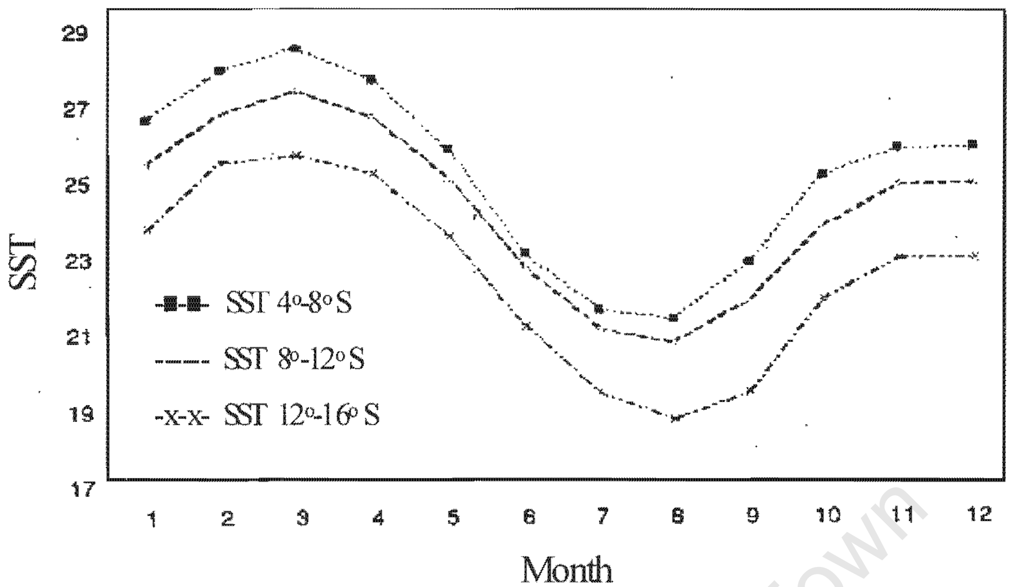


Figure 1.4: Seasonal pattern in sea surface temperature (SST) extracted from the COADs database (1964-1995) in the area between 4° and 16°S (modified from Cochrane and Tandstad, 2000).

1.3. Objectives

The overall objective of this study is to analyse existing data on the distribution and patterns of the stock mixture between Cape and Cunene horse mackerel in relation to environmental and other factors in the area northern Angola-Benguela front. This information can then be used to predict latitudinal boundaries and estimate the catches of the two species.

The specific objectives of this research are as follows:

- To characterize the pattern of distribution and mixture of Cunene and Cape horse mackerel in the area around the Angola-Benguela front.
- To characterize the movements and segregation behaviour of the two species (mixed or regularly separate schools/aggregations).

The study is expected to contribute directly to the knowledge of the distribution and movements of the two species of horse mackerel and on the dynamics of stock mixtures in the area. The increased understanding of the effects of changes in the physical characteristics of the Benguela system on the behaviour of the region's horse mackerels may form the basis for improving the capability to assess and manage these shared stocks in the Benguela region.

Chapter Two

Materials

2.1. Data

In this study, data from 15 acoustic cruises and 13 demersal cruises have been analysed to describe spatial and temporal patterns in the distribution of horse mackerel from northern Angola to Namibia. The data were provided by the Nansen Programme through the Angola Marine Research Institute (IIM) and Ministry of Fisheries & Marine Resources of Namibia (NatMIRC). The sea surface temperature (SST) data were obtained from METEOSAT satellite series images through H. Demarcq (IDYLE project). These data can plausibly be related to seasonal patterns of horse mackerel availability in the study area. The distributions of Cape and Cunene horse mackerel from 1985 to 1999 are presented and compared with results from previous studies on the movements of the Angola–Benguela front.

2.1.1. Survey data:

Acoustics: Acoustic surveys on pelagic fish were carried out twice per year during 1985, 1986, 1989, 1991, 1992, 1994-1995 and only one survey each year in 1993 and from 1997–1999 between the Cabinda (5°N) and Cunene Rivers (17°S) aboard the R/V Dr. Fridtjof Nansen. No surveys were conducted in 1987, 1988 and 1990. By conducting two surveys per year, data from both summer and winter were obtained. Unfortunately, two surveys were not conducted every year, resulting in unbalanced statistical design so that interaction effects were not testable on all data. Acoustic data on horse mackerel were also collected and used to estimate the biomass of Cape and Cunene horse mackerel for the Angolan coast. Supplemental trawls were used to distinguish between the species (Table 2.1). The available acoustic density data (S_A = mean echo-integrator values in n^2/nm^2) from 1995 to 1999 were used to investigate patterns between horse mackerel species distribution and environmental and other factors (area, depth, time, and sea surface temperature).

Table 2.1: Biomass estimates ('000 tons) for the two species of horse mackerel based on acoustic surveys for the Benguela – Cunene area (13-17°S) and for combined species for the total Angolan coast. The ratio *T. trecae*/total is calculated as (Total-*T. capensis*)/total. (Data collected aboard the R/V Dr F. Nansen)

Survey (No/year)	*T. capensis* (13-17°S)	*T. trecae* (13-17°S)	Combined species (Total Angolan coast)	Ratio *T. trecae*/total (Angolan coast)
1/1985	170	30	435	0.61
3/1985	220	50	400	0.45
4/1985	270	70	515	0.48
1/1986	40	130	285	0.86
1/1989	125	35	255	0.51
2/1989	135	25	380	0.64
4/1989	240	170	440	0.45
1/1991	310	100	510	0.39
1/1994	0	286	506	1.00
3/1995	63	68	403	0.84
3/1996	42	98	310	0.88
1/1997	23	210	425	0.95
1/1998	52	163	291	0.82
3/1998	206	118	324	0.36
2/1999	128	124	449	0.72

Demersal swept-area: Horse mackerel data were also collected from annual bottom trawl surveys carried out by R/V Dr. Fridtjof Nansen (1985-1999) to establish the occurrence of these species in the bottom zone. The objective of the surveys was to assess the demersal fish resources over the Angolan continental shelf, and to calculate catch per unit effort (CPUE) indices. Horse mackerel is considered as a bycatch of bottom trawls, which are directed at demersal species.

Catch per unit effort (CPUE): Detailed catch and effort data for pelagic and bottom survey trawls were available for 12 years (1985, 1986, 1989 and 1991-1999). Catch per unit effort was given in kg per hour and/or number of fish per hour of trawl. The data were grouped (Figure 2.1) by latitude on a scale of one degree from 5° to 20°S (e.g. from 5° to 5°59'; 6° to 6°59' to 20° S).

Finally data from other pelagic and demersal surveys conducted by R/V Dr. Fritdjof Nansen (from 15° to 20°S) off northern Namibia were also used to identify the southernmost boundary of the Cunene horse mackerel (Figure 2.1).

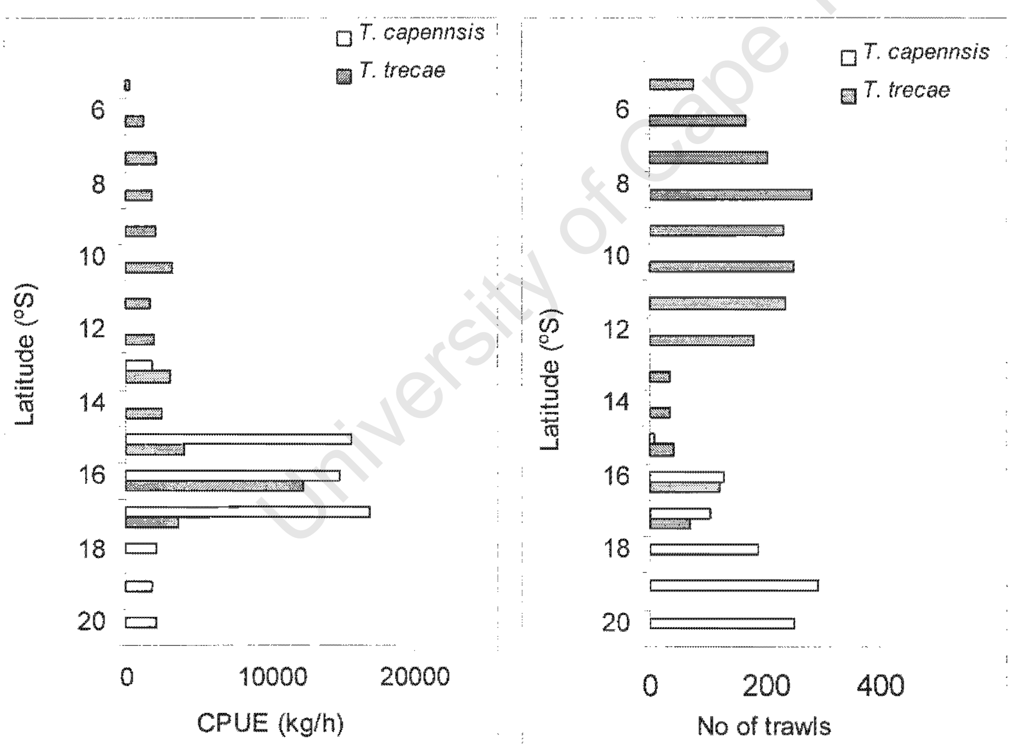


Figure 2.1: Mean CPUE (left) distribution by latitude and frequencies (right) based on pelagic and demersal surveys from 1985 to 1999 for the two horse mackerel species caught from northern Angola to Namibia (Data obtained aboard the R/V Dr. F. Nansen).

Note that the catch rate data used in this thesis are presented extensively in the appendices section.

Size composition: Size compositions were analysed by separating mixed trawls into small (<14 cm), medium (14-19 cm) and large (>20 cm) size classes.

2.1.2. Oceanographic data

Sea surface temperature (SST): Monthly mean SSTs were obtained from METEOSAT (5-20°S and from 10°E to the coast). Seasonal temperature averages were related to trawled catches of horse mackerel in the same time/space categories in an effort to explore both temporal and spatial temperature effects on these species (Table 2.2). Temperatures were recorded at one degree latitude intervals (e.g. from 5° to 5°59'; 6° to 6°59' to 20°S).

Table 2.2: Mean seasonal SST values (°C) in the areas and at trawls that catches were made (1989-1999) of the two horse mackerel species from latitude 5° to 20°S and from longitude 10°E to the Angolan coast.

Latitude	Summer (Nov – April)		Winter (May – Sept)	
(S)	*T. trecae*	*T. capensis*	*T. trecae*	*T. capensis*
5°	27.3		23.5	
6°	26.8		23.4	
7°	26.7		23.3	
8°	26.5		22.9	
9°	26.4		22.8	
10°	25.9		22.8	
11°	25.6		22.7	22.0
12°	25.4	26.1	22.1	
13°	24.4		19.9	19.3
14°	24.8		19.9	18.6
15°	23.3	23.8	19.6	18.9
16°	21.7	22.8	17.5	17.6
17°	20.9	20.3	16.5	16.6
18°				15.1
19°	16.5			14.9
20°				15.4

Empty space = No corresponding catch data.

From METEOSAT SSTs, minimumSST, maximumSST and range of SST = (maximum-minimum) were computed and related to the horse mackerel catch rates (CPUE) and echo integrator values using general linear models (Chapters 3 and 4). The SSTs were extracted for the latitudes and longitudes for which horse mackerel acoustic density data were available.

Chapter Three

Analysis of horse mackerel acoustic density values (S_A) in relation to environmental and other factors

Abstract

Biomass estimates from surveys carried out in the study area indicate that the two horse mackerel species fluctuate in their spatial and temporal distribution. Cunene and Cape horse mackerel appear to separate themselves in space perhaps to limit their competition for resources. Suitable models are needed to identify distribution patterns related to population dynamics, both for research and management purposes. These models are needed because the species can experience large fluctuations in biomass in response to environmental variability. Analyses of data from acoustic surveys conducted mainly in the winter are performed to investigate the main factors affecting the patterns of distribution of the horse mackerel species. Results indicate that sea surface temperature is a good indicator of horse mackerel availability. The data were too limited to be able to test the species-specific behavioural patterns that may occur in different areas. Survey sampling must be improved to optimise use of the data.

3.1. Introduction

The research vessel R/V Dr. Fridtjof Nansen has conducted acoustic surveys off Angola to estimate the abundance, biomass and distribution of the main pelagic stocks, the horse mackerels (*Trachurus trecae* and *Trachurus capensis*). Echo integrator values (S_A) are used in biomass estimation and as a measure of abundance of Angolan horse mackerel, although it is well known that environmental and other factors are believed to influence fish density (Anon, 1997). These factors may also reflect changes in the distribution of the stock. General Linear Models (GLMs) can be used to analyse echo integration values (S_A) as indices of stock densities (Borchers *et al.*, 1997 and Phiri and Shirakihara, 1999)). The theory of General Linear Models (GLM) is described in detail in Dunteman (1984) and, for an application in fisheries ecology, in Swartzman *et al.* (1992). For non-linear relationships, continuous predictors in a GLM analysis can be categorized into an arbitrary number of levels. A feature of GLM is that the effect of each predictor on the response can be ascertained, even if there is substantial covariation among predictors. Thus, the effect of each predictor is adjusted for all other predictors in the model.

Many relationships have been found using this modelling technique. These include relationships between environmental factors and egg density of western horse mackerel on the European continental shelf region of the Northeast Atlantic Ocean (Borchers *et al.*, 1997). The objective of this chapter is to compare distributional patterns between horse mackerel densities, using echo integrator information (S_A), and environmental factors and time factors.

Despite shortcomings in the S_A data (including the inability to identify the two species), the analyses are conducted to investigate the usefulness of the existing data by identifying missing information and allowing us to improve future assessments of these pelagic fish in the area.

3.2. Data analysis

General Linear Models are used to model trends in the horse mackerel echo integrator densities (S_A in m^2/nm^2 is the mean integrator value per 5 nm, available for 5 years

(1995–1999)) using a suite of environmental and other factors (season, area, depth, time and sea surface temperature). The acoustic data were extremely skewed (Figure 3.1a) and therefore log transformation of the dataset was performed to improve normality (Figure 3.1b).

a) Before **b) After**

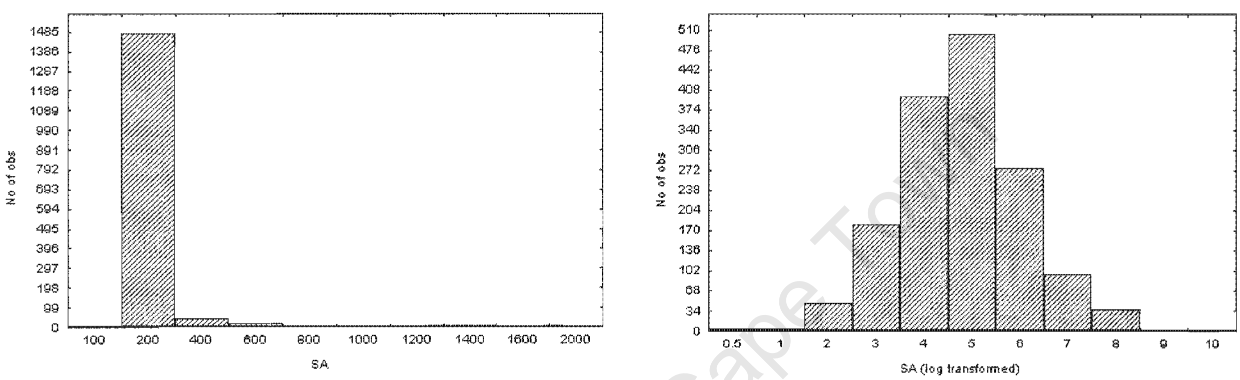


Figure 3.1: Horse mackerel acoustic densities (a = untransformed acoustic densities and b = log-transformed acoustic densities)

Two models each with main effects and 2-way interactions using Type III sum of squares were constructed. Model 3.1 represents the model for echo integrator densities (S_A) of both horse mackerel species over the whole area and Model 3.2 represents the model for echo integrator densities (S_A) of both horse mackerel species only in the area of overlap (southern area, 13-18°S). A common problem with GLM analysis of acoustic density data is that with several thousand degrees of freedom, most terms are significant. Therefore, only terms that contributed to an increase of more than 10% of the r^2 value were included in the model (e.g. if $r^2 = 20\%$ for a model with term A in it and then if removal of term A leads to an $r^2<18\%$ for the new model then the term should be returned to the model, but if $r^2>18$ % (i.e. change <10%) the term A is removed from the model). This is similar to the procedure used at ICCAT (International Commission for the Conservation of Atlantic Tunas) to build standardized CPUE models (Booth, 1998). Note that only main effects and 2-way interactions were included and no higher order interactions were considered. Non-significant main effects were retained in the final model if they were part of a significant interaction. Table 3.1 indicates each independent variable in the model with their respective number of categories. The univariate test of significance (Type III decomposition) modelling option were used for testing whether is significant. The final model chosen represents variables that explained most variation in horse mackerel S_A. Type III sums of squares were used for all analyses.

The backward stepwise approach used can be summarized in 3 steps:

1. Remove non-significant 2-way factors (*F*-test) sequentially, starting with the least significant.
2. Remove 2-way interactions, starting with those that contribute least to the r^2 (i.e. those with the smallest SS).
3. Keep removing terms until the r^2 changes by more than 10%. Main effects were only removed if they were not involved in an interaction and did not contribute more than 10% to the r^2 value.

Continuous independent variables such as latitude, depth, time of day and sea surface temperature were categorized to enable non-linear effects to be captured by the GLM (Table 3.1). The main effects of year, depth, time and area are discussed first, followed by the interactions.

Table 3.1: Summary of variables used in GLM models

Variable	Number of categories	Category description
Year	5	1995-1999
Area	3	north (6-9°S), centre (10-12°S) and south (13-18°S)
Season	2	summer (Nov-April) and winter (May-Oct)
Time	2	day (6h00-18h00) and night (18h00-6h00)
Bottom depth	4	shallow (0-100 m), inner shelf (100-200 m), outer shelf (200-300 m) and offshore (>300 m)
SST	4	<18°C, 18-21°C, 22-26°C and >26°C (only for 1989 and 1991-1999)

A standard GLM of the form:

$Ln(S_A) = \mu + \beta_{year} + \chi_{season} + \gamma_{area} + \lambda_{depth} + \delta_{time} + \omega_{SST} + \varepsilon_{i,jk,n}$, followed by the interactions between independent explanatory variables.

Where:

μ is the intercept

year is a factor with 5 levels (1995–1999); season is a factor with 2 levels (summer and winter); area is a factor with 3 levels (north, centre and south); bottom depth is a factor with 4 levels (shallow, inner shelf, outer shelf, offshore); time is a factor with 2 levels (day and night); SST is a factor with 4 categories (<18°, 18-21°, 22-26° and >26°C).

ε is the error term assumed to be normally distributed.

For the purposes of explanatory data analysis, echo integrator values (S_A) from 1995 to 1999 by month and season (Table 3.2) were plotted against sea surface temperature, and their responses were used to show the patterns that may exist between the two variables (Figures 3.2, 3.3 and 3.4).

Table 3.2: Available acoustic survey data

	Summer			Winter	
Year	February	March	July	August	September
1995				X	X
1996		X			
1997	X	X			
1998			X	X	
1999				X	

Table 3.2 shows that the monthly distribution of the horse mackerel data (S_A) is not regular in its seasonal coverage.

3.3. Results

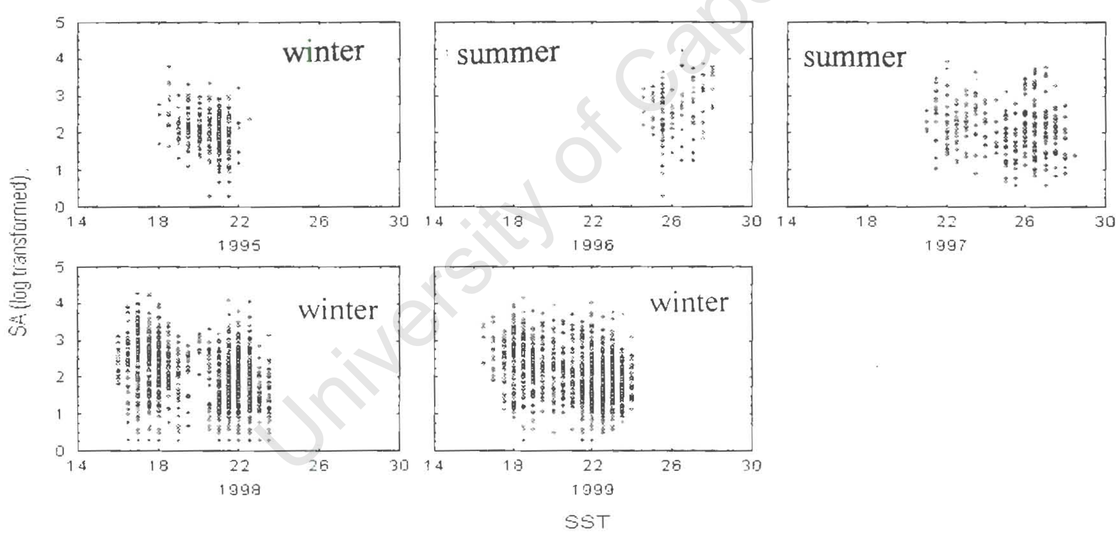


Figure 3.2: Annual mean integrator densities (S_A) in m^2/nm^2 (5 nm = 1 data point) of the acoustics data versus SST data from 1995 to 1999 for both species combined.

Figure 3.2 shows the dispersion of the data versus SST for each year. For example 1996 is only sampled during summer and 1995 only during winter. Two surveys per year is the minimum sampling to explore seasonal effects (and therefore a separate year effect). The above figure shows that both seasons were not sampled in the same year.

Two different patterns are visible in most of the years (Figure 3.2): the cool pattern defined with mean temperatures below 20°C and the warm pattern with mean temperatures above 21°C. The period between 1995 and 1996 was coincidently considered by Bianchi *et al.* (1997) and Gammelsrod *et al.* (1998), as a period of warm environmental conditions in the area.

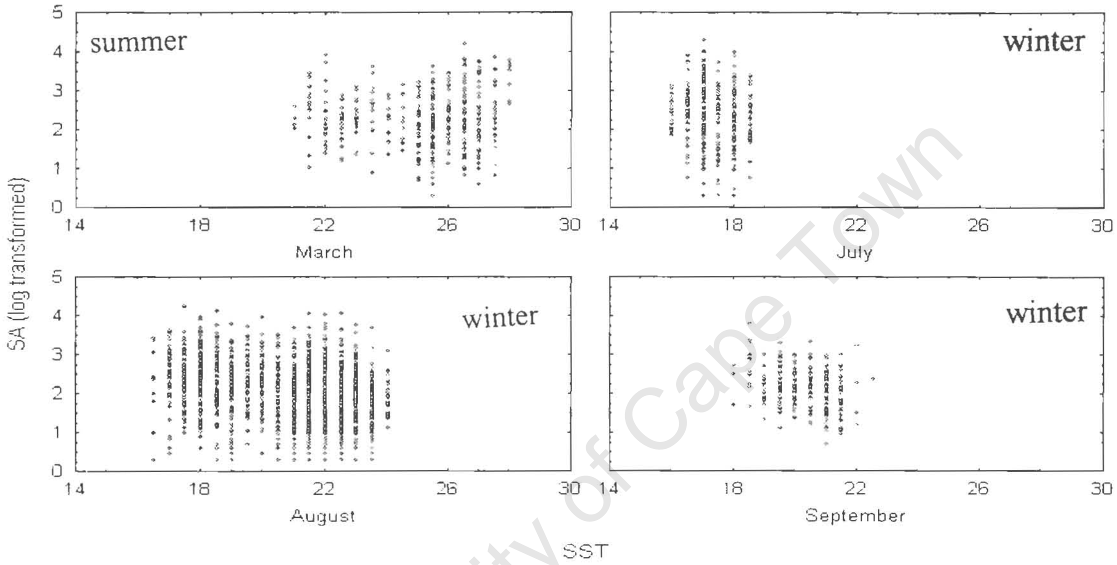


Figure 3.3: Pooled monthly mean integrator densities (S_A) in m^2/nm^2 (5 nm = 1 data point) of the acoustics data versus SST data from 1995 to 1999 for both species.

Figure 3.3 shows different relationships between echo density and sea surface temperature which may be due to seasonal sampling effects. There is also bias in the sampling due to differences in spatial coverage. In July there is lack of sampling in the "warm" northern region compared to August. This last point may be made with a cartographic display (Figure 3.4). Most of the surveys were conducted in winter and usually from south to north. Sometimes cruises started at the end of July and continued through August (Figure 3.4), and in one case the cruise started in August and crossed over into some days of September. Since in some cases a single survey was performed over consecutive months, it would not make sense to look for a month effect and to separate a single survey into two months. Thus, it is better to investigate a seasonal effect by pooling months for the same season.

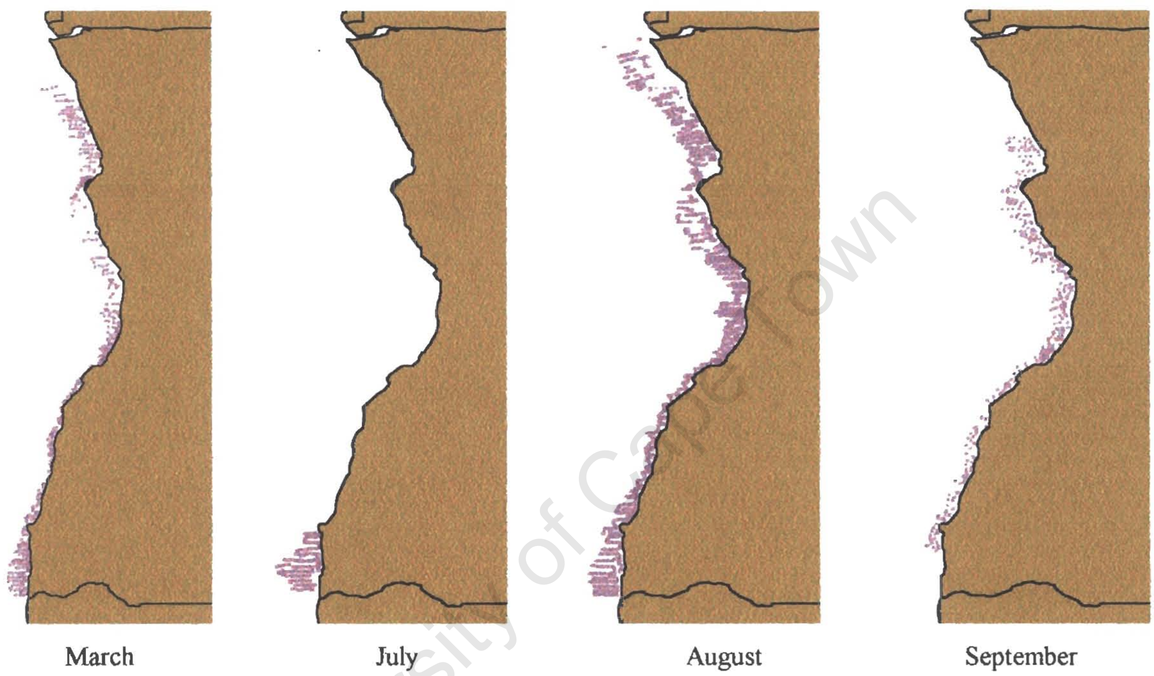
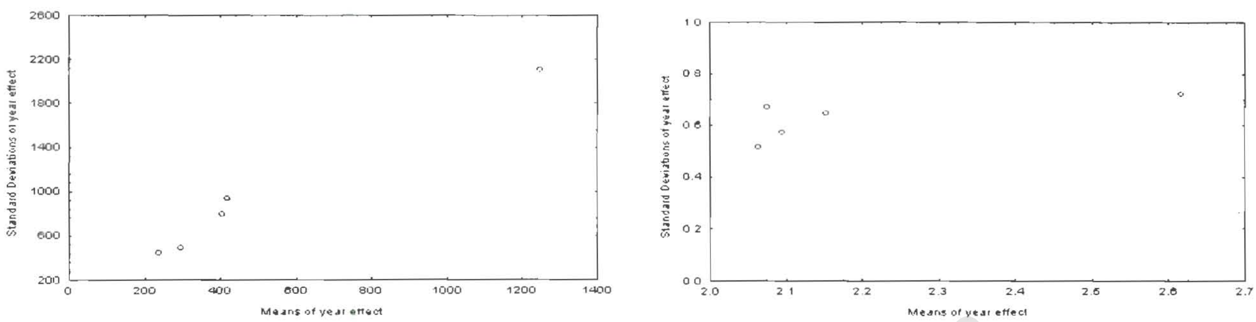


Figure 3.4: Spatial sampling for each month (all years)

3.3.1 Model 3.1: Echo density (S_A) of the horse mackerel species combined in relation to environmental and other factors over the entire coast of Angola

Figure 3.5a shows standard deviations plotted against means for the year effect in the model before (left) and after (right) transformation (the other variables are not shown because they have fewer categories (≤ 4) so that the relationship between standard deviation and means is difficult to discern). To check the normality assumption, observed versus expected probability plots are shown before (left) and after (right) log transformation of S_A values (Figure 3.5b).

a)



b)

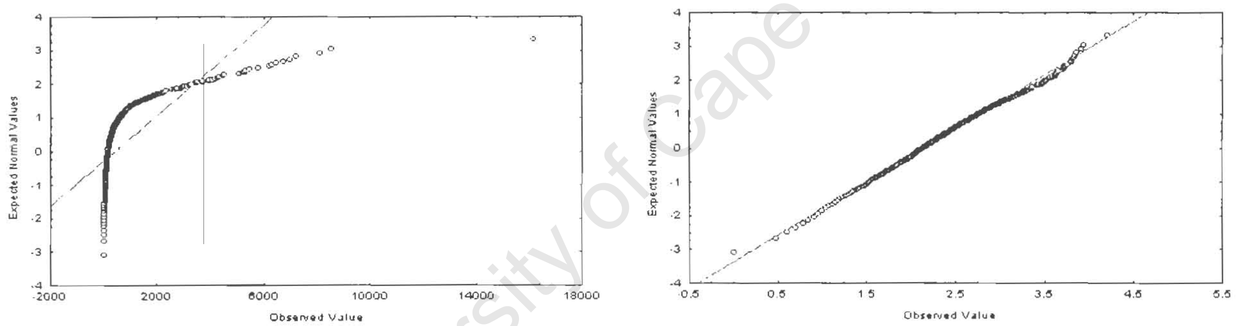


Figure 3.5: a) Means versus standard deviation values for the year effect before (left) and after (right) log transformation of echo densities (S_A) and b) observed versus expected before (left) and after (right) log transformation of S_A values.

Results of the overall GLM for horse mackerel density are shown in Table 3.3. Also shown is the order in which the terms were removed sequentially from the model (Table 3.4). These terms were either not significant (F-test) or contributed less than 10% of the r^2.

Note that the season variable was not included in the model and omitted from further analyses because there were missing cells in the design when it was included as an interaction.

Table 3.3: ANOVA table of full model with all main effects and two way interactions for both horse mackerel echo density (the removal step indicates the order that the terms were removed)

	Effect	SS	df	MS	F	p	Removal step
Main effects	Intercept	365.4	1	365.4	1205.9	0.0000	
	Year	5.1	4	1.3	4.2	0.0021	
	Area	0.1	2	0.0	0.1	0.8775	*
	Depth	2.4	3	0.8	2.6	0.0500	9
	Time	0.6	1	0.6	2.0	0.1535	
	SST	10.5	3	3.5	11.5	0.0000	
2-way interactions	Year*Area	6.8	8	0.9	2.8	0.0044	
	Year*Depth	4.1	12	0.3	1.1	0.3282	4
	Area*Depth	2.3	6	0.4	1.3	0.2657	3
	Year*Time	11.2	4	2.8	9.3	0.0000	
	Area*Time	0.3	2	0.1	0.4	0.6362	1
	Depth*Time	6.9	3	2.3	7.6	0.0000	7
	Year*SST	2.3	5	0.5	1.6	0.1719	6
	Area*SST	1.3	4	0.3	1.0	0.3832	2
	Depth*SST	8.1	9	0.9	3.0	0.0016	8
	Time*SST	1.7	3	0.6	1.9	0.1239	5
	Error	443.0	1462	0.3			

Type III decomposition (all 2-way interactions)
use all interactions
* left in the main effect in spite of non-significance, because one of its interaction is significant and in the final model.

Table 3.4: Order of terms removed from the model (terms were only removed if the r^2 decreased by <10%). For the model with all terms included $r^2 = 0.2722$

Order	Terms removed	r^2 (after removal)	Difference	% difference
1	Area*Time	0.2717	0.0005	0.0017
2	Area*SST	0.2694	0.0023	0.0084
3	Area*Depth	0.2648	0.0046	0.0174
4	Year*Depth	0.2563	0.0086	0.0335
5	Time*SST	0.2528	0.0035	0.0138
6	Year*SST	0.2486	0.0042	0.0168
7	Depth*Time	0.2378	0.0108	0.0453
8	Depth*SST	0.2275	0.0103	0.0455
9	Depth	0.2239	0.0035	0.0158
10	SST (returned)	0.2123	0.0116	0.0546

Results from the model (Table 3.5) show that with four main effect variables as well interactions between year and both area and time, r^2 = 22%. Table 3.6 represents the final model, after non-significant terms were removed (those that did not contribute substantially to the proportion of variance explained). Results from this table show the main effects of year, area, time and SST that are significant. Depth and season factors did not substantially improve the model, thus these factors did not have a major effect on horse mackerel echo densities. The main effects of year and area and their interactions (year*area) explain most of the spatial and temporal variation of horse mackerel density in the period 1995 to 1999.

Table 3.5: Test of the whole Model for both horse mackerel species together (final model)

Log of	Multiple r^2	SS Model	df Model	MS Model	SS Residual	df Residual	MS Residual	F	p
S_A	0.224	136.290	22	6.195	472.314	1509	0.313	19.79	0.000

Table 3.6: ANOVA table of the final model for both horse mackerel species

	Effect of	SS	df	MS	F	p
	Intercept	1875.5	1	1875.5	5991.8	0.0000
Main effects	Year	22.2	4	5.6	17.8	0.0000
	Area	11.0	2	5.5	17.5	0.0000
	Time	3.4	1	3.4	10.9	0.0010
	SST	7.1	3	2.3	7.5	0.0001
2-way interactions	Year*Area	21.8	8	2.7	8.7	0.0000
	Year*Time	10.7	4	2.7	8.6	0.0000
	Error	472.3	1509	0.3		

General relationships: the main effects

Year

The least square (LS) means for the year effect is of particular interest because in a standardized density series, it provides an index of annual abundance (Figure 3.4). The highly significant (p<0.0001) year effect means that there are significant differences in abundance of horse mackerel among years (Table 3.6). Results in this table suggest that the year effect explains the most variation in horse mackerel acoustic density of all the factors included in the model (largest sums of squares). Results from Figure 3.6 show the highest abundance of horse mackerel S_A in 1996. In general, the availability in echo density is fairly constant from year to year, with the notable exception of 1996.

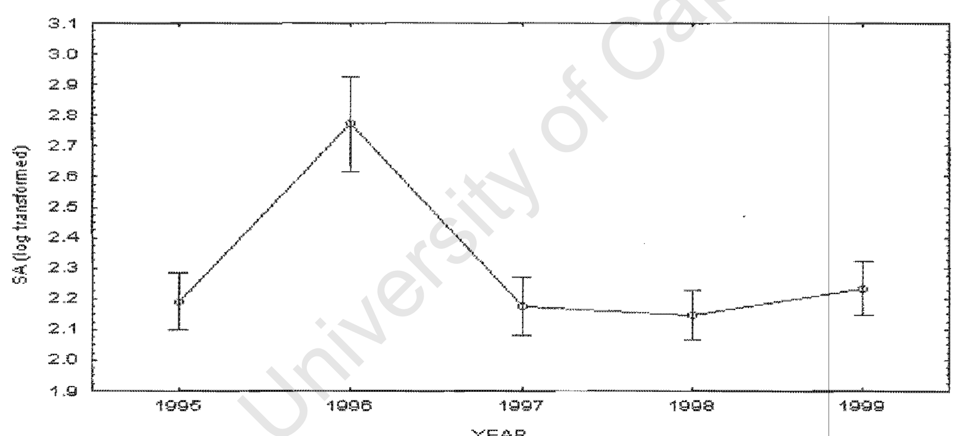


Figure 3.6: Effect of year on horse mackerel SA (both species combined) using the results of the GLM (model 3.1) to estimate (±SE) for each of the five years

Area

Results from Table 3.6 show that the area effect is significant ($p<0.0001$) and the sum of squares (SS) indicates that it is weaker than the year effect. Figure 3.5 shows that horse mackerel abundance increases from north to south. From this figure it is clearly seen that there is a high concentration of horse mackerel in the central and southern areas.

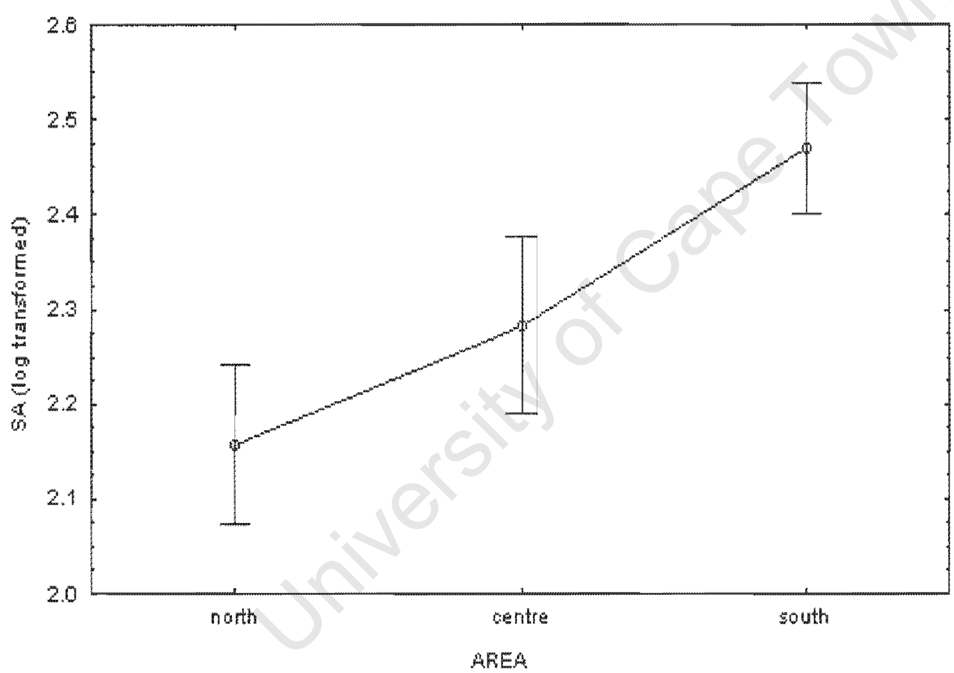


Figure 3.7: Effect of area on horse mackerel density (both species combined) using the results of the GLM (model 3.1) to estimate parameters (±SE) for each of the three areas

Time

Results from Table 3.6 show that the time effect is significant ($p<0.001$) but explains the least about echo density in comparison with the other factors in the model. The smaller sum of squares for this factor suggests that this factor is not as important as the others. It is retained in the final model as it is involved in a significant interaction. Figure 3.8 shows that horse mackerel density was slightly higher during the daytime than night.

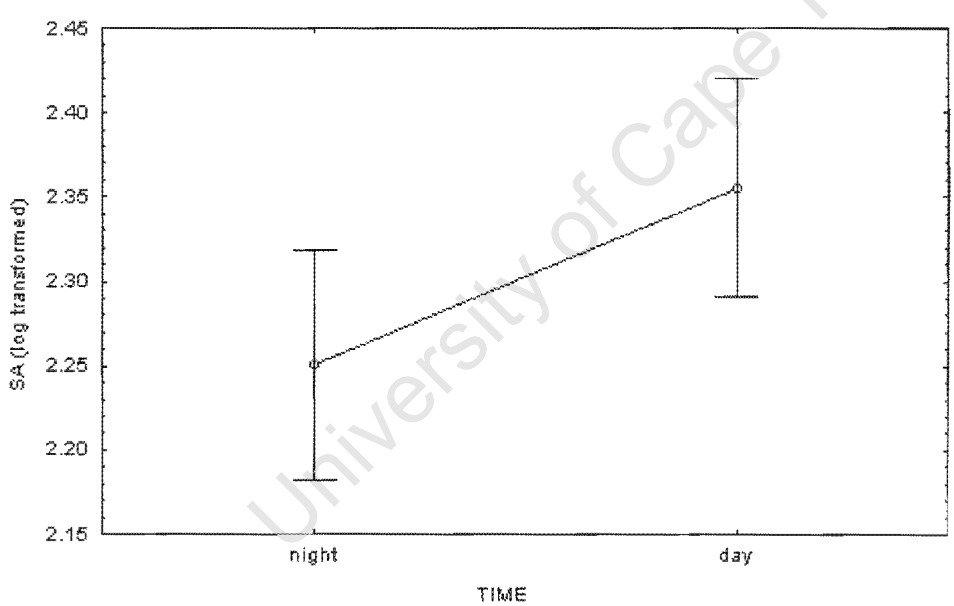


Figure 3.8: Effect of time on horse mackerel density (both species combined) using the results of the GLM (model 3.1) to estimate parameters (±SE) for each of the two times

Sea surface temperature (SST)

According to results from Table 3.6, one can assume that SST effects on acoustic densities are significant (very low p value). Figure 3.9 shows that the horse mackerel echo density is the highest in cool water (<18°C). In general, horse mackerel echo density decreases in water from 18-26 °C, and there may be a slight increase in very warm water (>26°C). This slight increase in abundance in warm water may be due to an increase in Cunene horse mackerel in warm waters.

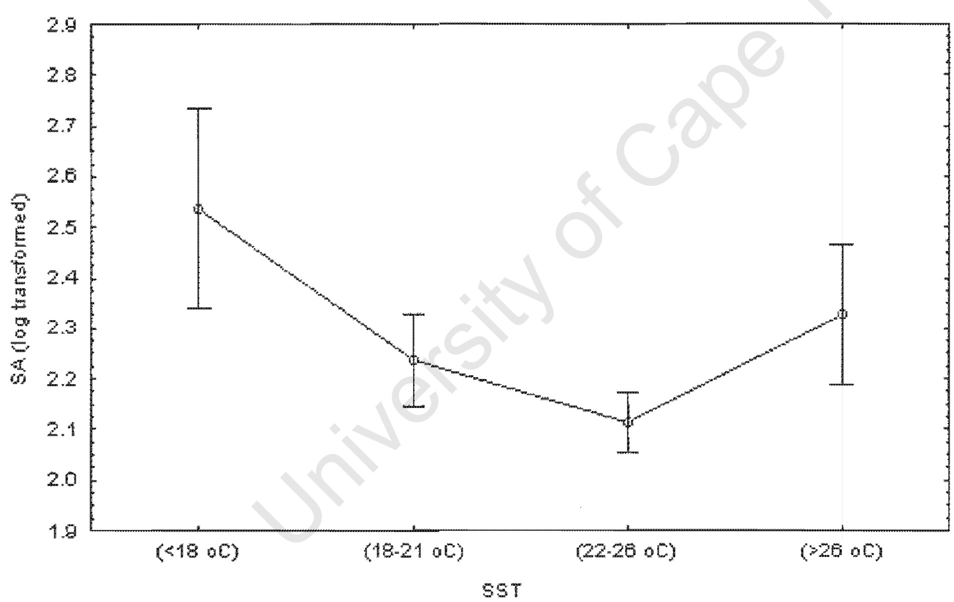


Figure 3.9: Effects of SST on horse mackerel echo density (both species combined) using the results of the GLM (model 3.1) to estimate (±SE) for each of the four ranges of surface temperature

Modification in the general trends: 2-way interactions

Year*area

Full model results (Table 3.6) show that the year*area interaction has a substantial effect on echo integration values. The year*area interaction describes the spatial variation of horse mackerel echo densities among years. Figure 3.10 shows that in general, horse mackerel density decreases from south to north except 1996. This year, the northern area had highest echo densities and the central and southern areas were approximately equal. Clearly, 1996 is giving the significant result for the year*area interaction (Figure 3.10).

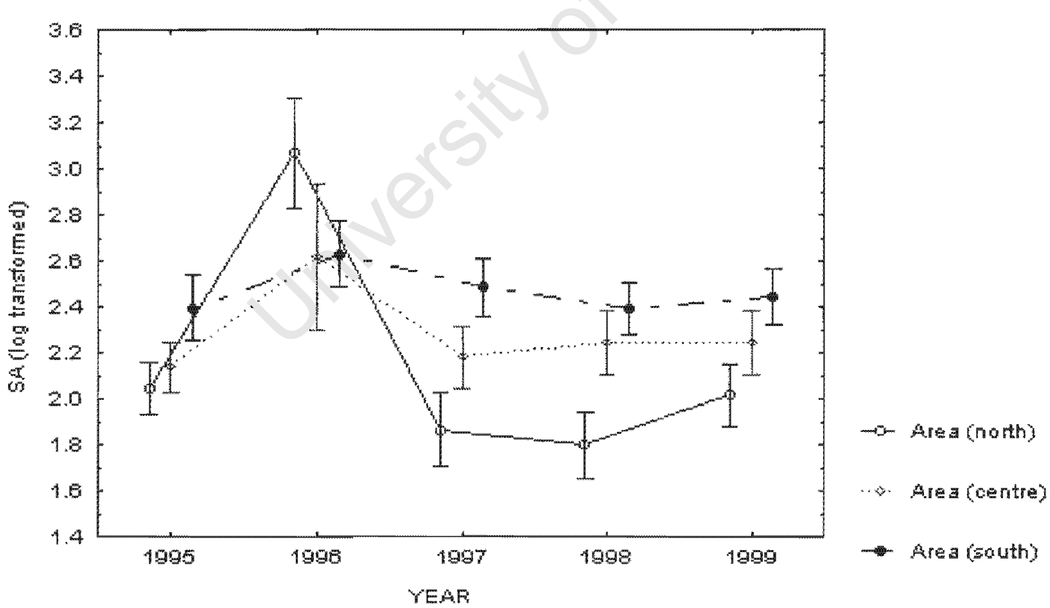


Figure 3.10: Effect of year*area interactions on echo of horse mackerel values (both species combined) using the results of the GLM (model 3.1) to estimate parameters (±SE) for each of the interactions of years and areas

Year*Time

Any interaction between the effects of year and time implies that the relationship between horse mackerel density and day and night changes from year to year. Results from Table 3.6 show that in general, statistically significant but less variation appeared between year*time interactions in 1995 and 1997-1999 (Figure 3.11). This figure shows that the general trend illustrates a higher abundance of horse mackerel in the day than at night time but 1996 was different. This year was also the different year for the year*area effect.

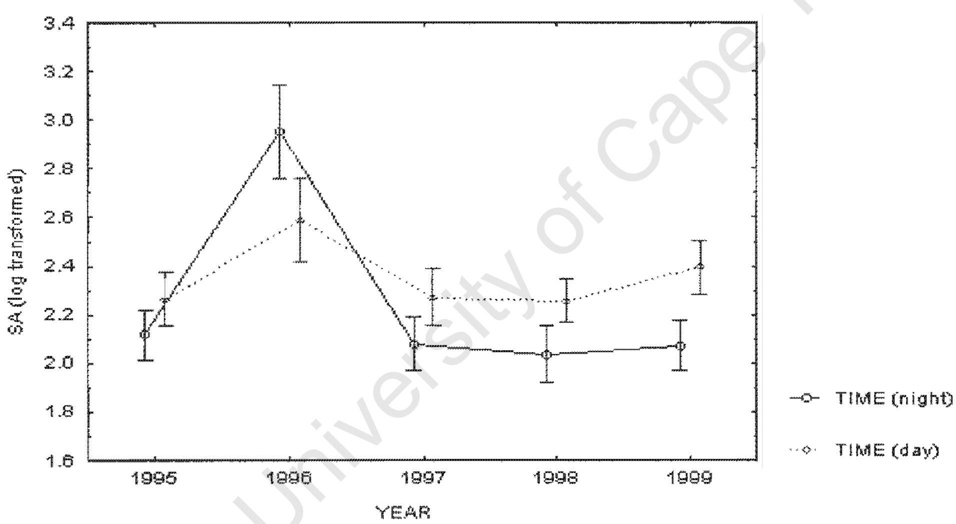


Figure 3.11: Effect of year*time interactions on horse mackerel echo values (both species combined) using the results of the GLM (model 3.1) to estimate parameters (±SE) for each of the years and times

3.3.2 Model 3.2: Echo density (S_A) of the horse mackerel species combined in relation to environmental and other factors in the area of overlap of the two species in southern Angola (13-17°S)

A GLM is applied to the echo integrator values of the two species of horse mackerel combined, in order to investigate the relationships between horse mackerel and environmental and other factors (year, depth, time and SST) in the area of overlap. Table 3.8 shows that there are no substantial effects on horse mackerel echo density in the southern area for single effects except for the sea surface temperature (SST). In contrast, the interactions year*time, depth*time, depth*SST are very significant ($p<0.01$). The proportion of variation explained by the model is ~19% (Table 3.7).

Note that although the univariate F-tests of significance for the main effects year, depth and time are not significant ($p>0.05$), they are retained in the final model as they are involved in significant interactions.

Table 3.7: Test of the whole Model for both horse mackerel species together in the southern area (final model)

	Multiple	SS	df	MS	SS	df	MS		
Log of	r^2	Model	Model	Model	Residual	Residual	Residual	F	p
S_A	0.193	39.008	27	1.445	163.427	551	0.297	4.871	0.0000

Table 3.8: ANOVA table of the final model for both horse mackerel species in the southern area

	Effect of	SS	df	MS	F	p
	Intercept	406.4	1	406.4	1370.0	0.0000
Main effects	Year	1.5	4	0.4	1.3	0.2713
	Depth	0.1	3	0.1	0.2	0.9219
	Time	0.6	1	0.6	2.2	0.1421
	SST	5.7	3	1.9	6.4	0.0003
2-way interactions	Depth*Time	7.7	3	2.6	8.7	0.0000
	Depth*SST	6. 6	9	0.7	2.5	0.0094
	Year*Time	9.9	4	2.5	8.3	0.0000
	Error	163.4	551	0.3		

In Table 3.8, the only significant main effect was sea surface temperature (SST) and this will be the only one discussed.

General relationships: the main effects in the southern area

Sea surface temperature (SST)

According to Table 3.8 the sea surface temperature is the unique significant main effect on horse mackerel echo density in the southern area. Sea surface temperature explains the most variation in the density of horse mackerel in the southern area out of the main effects examined. Figure 3.12 shows similar trends of echo densities distribution to Model 3.1 (all areas together). This shows that the major density of horse mackerel occurs at temperatures <18°C.

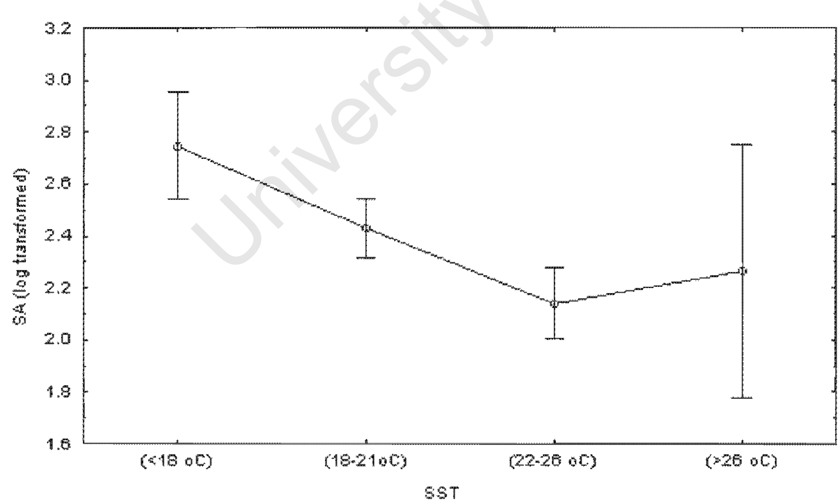


Figure 3.12: Effect of SST on horse mackerel density (both species combined) using the results of the GLM (model 3.2) to estimate parameters (±SE) for each of the four ranges of surface temperature in the southern area

Modification in the general trends: 2-way interactions in the southern area

Year*Time

The model (Table 3.8) indicates that the year*time interaction in horse mackerel densities is significant ($p<0.001$) meaning that the echo density of horse mackerel during the day and night in the southern area was not constant throughout the period 1995-1999. This, in part, reflects a daily pattern in stock density possibly caused by changes in the environment. Figure 3.13 shows that the density of horse mackerel was higher in the day than in night time for all years except 1996. This is a similar result to that for the whole area (model 3.1).

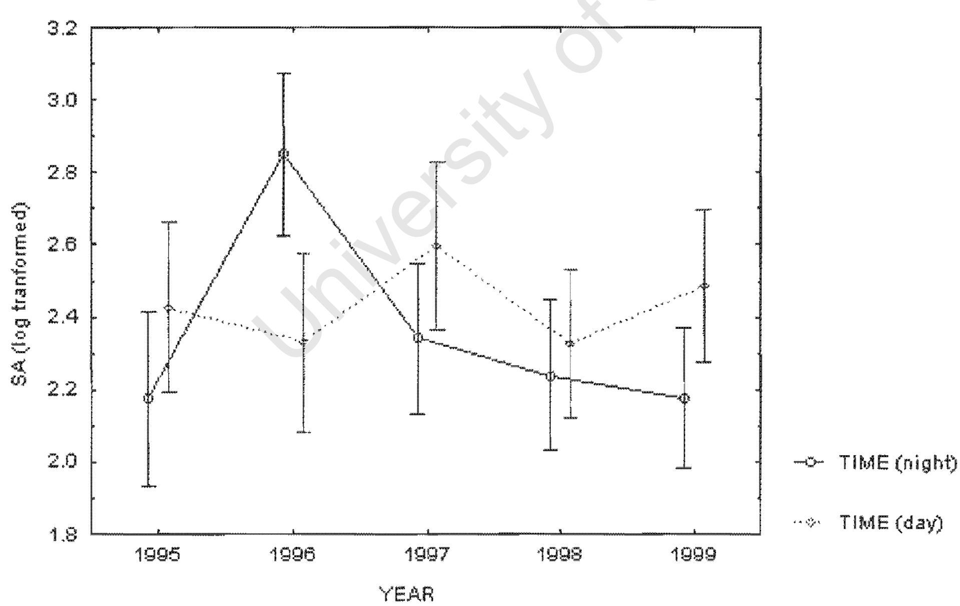


Figure 3.13: Effect of year*time interactions on horse mackerel S_A in the southern area (both species combined) using the results of the GLM (model 3.2) to estimate (±SE) for each of the interactions of years and times

Depth*Time

Results from model 3.2 (Table 3.8) indicate that the depth*time interaction is the interaction that explains second most of the fluctuation in horse mackerel echo density in the southern Angola area. The interaction between the effects of depth and time of day is highly significant ($p<0.0001$). Figure 3.14 shows that the day-night pattern of horse mackerel density is not constant throughout the depth zones. Horse mackerel density is generally greater by day, but is denser at night on the outer shelf (>300 m).

Note that depth interactions, depth*time and depth*SST are significant in this southern area model but not in Model 3.1 which covers the whole of Angola. This may indicate different depth preferences by the two horse mackerel species. If there is a different depth abundance of each species in each area then this would lead to significant depth*time interactions here. This will be investigated in more detail using the CPUE data for each horse mackerel species in the next chapter.

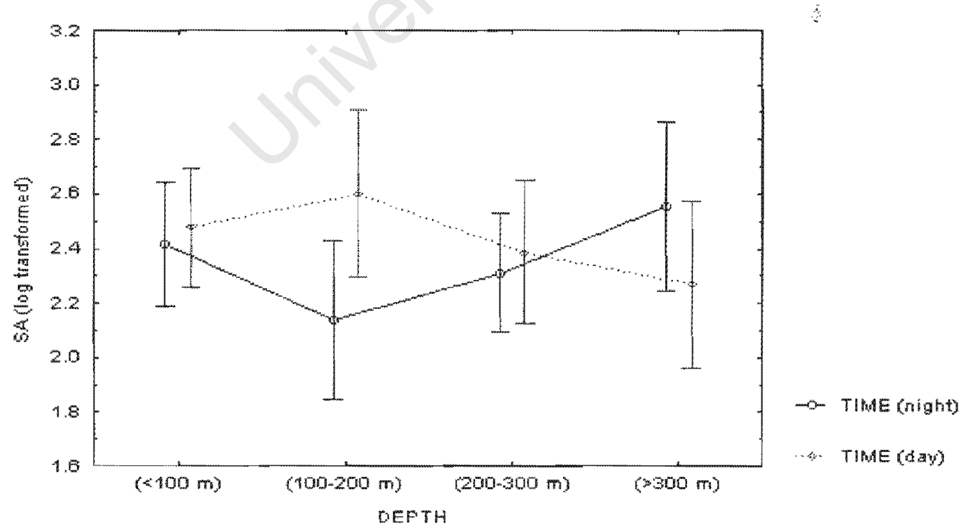


Figure 3.14: Effect of depth*time interactions on horse mackerel S_A in the southern area (both species combined) using the results of the GLM (model 3.2) to estimate (±SE) for each of the interactions of depths and times

Depth*SST

The interactions between depth and sea surface temperature in the horse mackerel model is significant ($p<0.01$) in the southern area (Table 3.8). Any interaction between the effects of depth and SST implies that the spatial echo distribution of horse mackerel species is not constant with sea surface temperature at each depth. Figure 3.15 shows that there is an interaction between depth and SST in ranges of lowest to warmest temperatures from shallow to deep depths, except at the outer shelf (>300 m) where the warmest surface temperature has the highest abundance.

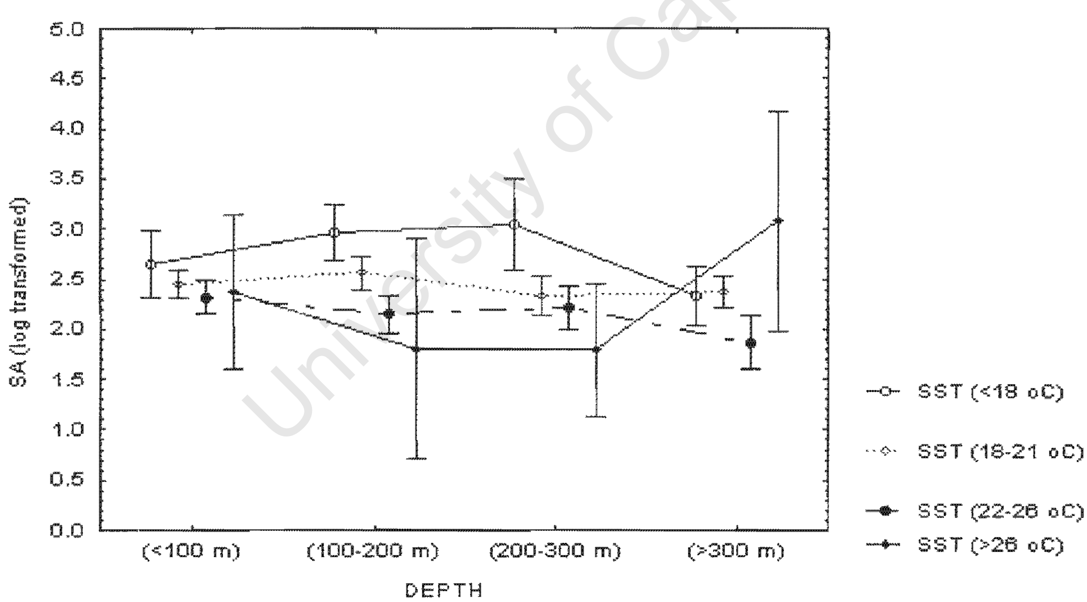


Figure 3.15: Effect of depth*SST interactions on horse mackerel S_A in the southern area (both species combined) using the results of the GLM (model 3.2) to estimate (±SE) for each of the interactions of the years and surface temperatures

3.4. Discussion

According to Tables 3.6 (all areas model) and 3.8 (southern area model), the main effects of all the factors tested in this study have a substantial impact on the echo integrator values in the pooled areas and a smaller effect in the southern area when treated separately. This may indicate that it is difficult to get general patterns because the data in the "all areas" model could be from either species. Thus, to obtain abundance of the horse mackerel from echo integrator values, detailed information on time and geographical position of the fish becomes indispensable. Unfortunately, two acoustic surveys were not conducted every year, making an unbalanced statistical design and precluding the effect of season from being included in the models.

The main effect of sea surface temperature proved to be consistently significant in both S_A models (all areas together and southern area models), with warm SSTs associated with small acoustic values and vice versa. It is suggested that sea surface temperature is also responsible for the spatial variation of horse mackerel density in the period 1995-1999. Results from models 3.1 (Figure 3.9, all area model) and 3.2 (Figure 3.12, southern area model) show that at warmer temperatures there are relatively fewer horse mackerel. But results in Figure 3.6 showed highest availability of echo integrator values in the warmest available sampling data (1996). The unusual environmental conditions in 1996 pointed out by Bianchi *et al.* (1997) and Gammelsrod *et al.* (1998), and by the small number of data points in Figure 3.2 make it very difficult to assess whether this result reflects a general anomaly or not. However, the result in Figures 3.9 and 3.12 do not conflict with those of Bianchi (1986). They are reinforced because horse mackerel seem to be most abundant from Benguela (about 13°S) southward where the sea surface temperatures are cold and vary between 14-23°C (Da Franca, 1968, Santos Dias, 1983a, Toresen, 1995, Kostianoy, 1996, Bianchi *et al.*, 1997 and Gammelsrod *et al.*, 1998).

The results of the interactions between depth and both sea surface temperature and time in the southern region (model 3.2) may indicate movements of the horse mackerel species across the shelf according to conditions of daytime and/or temperature. This may be enhanced by the proportion of the horse mackerel in deeper water, which increased slightly over recent years (Anon, 1999).

According to Figure 3.8, horse mackerel are generally more abundant in the daytime (model 3.1) than night time. This result seems to be pertinent and also very difficult to explain because it contradicts that expected. In general catch rates are higher in the night than in the day but it is also true that most of the acoustic surveys were conducted in winter when the horse mackerel seems to be spread over the shelf in daytime and more visible to the echo-sounder. For that reason one may expect a higher density by day than at night time.

Figure 3.7 showed that the echo integrator values increase from the north to central and southern areas. From this it can clearly be seen that there is a high concentration of horse mackerel in the centre and especially in the south. The variation shown in Figure 3.5, may be related to the following:

- different environmental conditions between the areas
- movement of horse mackerel species from north to south or vice versa

From Figure 3.6, 1996 showed the highest abundance on echo integrator values adjusted by the other years. It seems to be related to a sampling effect; Table 3.2 and

Figure 3.2 show that the cruise was conducted in March (warmest month) and the echo densities were located at temperatures above 26°C. Biomass estimates of Cunene horse mackerel from the acoustic integration system in the March 1996 survey were the highest for the Cunene species in the south of Angola between 1994-1997 (Bianchi and Ostrowski, 2000). They were considered a result of the exceptionally high concentration of the Cunene species in the area between Benguela and the Cunene River. In the presence of unusual environmental conditions in the period 1995-1996 mentioned by those authors, one may conclude that the increased echo densities in 1996 are reflected by fish responses to environmental factors (such as migration of species, food availability, etc). For the slight variation shown in Figure 3.6, acoustic densities from 1997 to 1999 seem to be normal and probably may be related to changes in horse mackerel behaviour. For example some changes in fish schooling behaviour (e.g. the fish occurs school close to the surface of the water) would reduce the echo sounder is ability to detect them. Possible sources of bias related to acoustic surveys are well described in the literature (see MacLennan and Simmonds, 1992 and Fréon and Misund, 1999).

This chapter therefore highlights the fact that, because horse mackerel echo density values are not separated by species, they are limited in their applicability. Different species-specific behaviour patterns may occur in different areas but it was not possible to test for these because of limited data. Despite different temporal resolutions between instantaneous echo densities and sea surface temperature (5 days averages), the results from models show that SST is a good indicator of horse mackerel availability. 1996 was an unusual year, but other factors than surface temperature may have contributed to the high echo integrator values. The data were too limited to allow these factors to be identified. Survey design needs to be carefully planned, to enable maximum use of the data.

Chapter Four

Analysis of horse mackerel CPUE data from surveys in relation to environmental and other effects.

Abstract

The characteristics of the horse mackerel stocks in the area north of the Angola-Benguela front create difficulties in their assessment. In fact, a main prerequisite to assessing a stock is being able to identify catches taken from it which is not always possible. The problem is further exacerbated by the fact that the abundance of these two species in southern Angola is strongly related to environmental changes in two distinct systems (the Angola and the Benguela systems). Between 1985 and 1999, acoustic surveys carried out in winter and summer have been used to estimate the relative proportions of the two species that compose the horse mackerel "stock". These datasets, as well as data from demersal surveys, are reviewed to elucidate distribution patterns of the two horse mackerel species in relation to environmental and other factors. The results indicate that there is a segregation by depth between the two horse mackerel species in the area of overlap. The gear and time effects are shown to have a significant effect at the 95 % confidence level on the CPUE of Cunene horse mackerel and no significant effect on the Cape horse mackerel CPUE. Season is shown to have no significant effect at the same confidence level on variations in CPUE of the two horse mackerel species.

4.1. Introduction

The Angolan population of the Cunene horse mackerel (*Trachurus trecae*) extends from Cape Lopez (Congo) to Northern Namibia (Marchal, 1991). Southern Angola is the approximate southern border of the Cunene horse mackerel and also forms the northern border for the Cape horse mackerel (*T. capensis*). The two horse mackerel species are mixed on the fishing grounds in the Cunene-Benguela area in southern Angola and occur together in the catches (Bianchi *et al.*, 1997).

Use of CPUE alone as an index of abundance is prone to substantial error, especially in shoaling species (Cochrane and Tandstad, 2000). It is therefore important that information on both the amount of effort each year, and the spatial distribution of the effort is collected. This will allow determination of whether changes in CPUE are due primarily to changes in abundance of the stock, or whether they are due to changes in the distribution of the stock, species behaviour, area or time of fishing affecting the amount of effort (Cochrane and Tandstad, 2000). General Linear Models (GLM) can be used to analyse CPUE data to obtain an annual standardized index of stock abundance and to ascertain the relative importance of each of the predictors to CPUE (Borchers *et al.*, 1997, Swartzman *et al.*, 1994 and Cochrane and Tandstad, 2000). The objective of this chapter is to investigate relationships between horse mackerel abundance using catch rate information from surveys (CPUE) and ecological factors (season, area, depth and sea surface temperature).

4.2. Data Analysis

In this chapter, General Linear Models (GLMs) are used to model trends in the horse mackerel CPUE data from a suite of environmental and other factors. Catch rate data ($kg.hr^{-1}$) were collected by the Nansen Programme. Sea surface temperature was extracted from Meteosat images (H. Demarcq, the IDYLE project) and computed according to latitude indicated from horse mackerel catch data at one degree latitude intervals (5-20°S). Continuous predictors such as depth, sea surface temperature and time of day were categorized to enable non-linear effects to be captured by GLM. SST was used in only some of the analyses. Three ecological zones (north: 5-9°S, centre: 10-12°S and south: 13-20°S) were used in the analysis. Four depth categories were used: 0-100 m, 100-200 m, 200-300 m and >300 m to indicate the positions of the catches across the shelf from shallow to deep.

Preliminary data analysis indicated that CPUE data were skewed towards low catch rates (Figure 4.1).

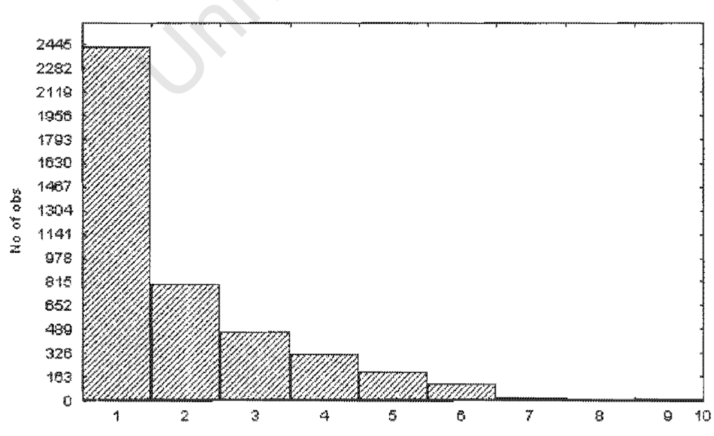


Figure 4.1: Frequency distribution of CPUE data for both horse mackerel species ($kg.h^{-1}$)

This suggests a log (X+δ) transformation would be appropriate. A number of preliminary GLM analyses were conducted to assess the effect of values of δ ($0.0001 * \overline{X}$, $0.001 * \overline{X}$, $0.01 * \overline{X}$, $0.1 * \overline{X}$ and $0.2 * \overline{X}$) to improve normality and also to reduce heteroscedasticity. It was found that $\delta = 0.1 * \overline{X}$ generally satisfied these GLM assumptions best, and was used for all GLMs. This transformation is also used at the International Commission for the Conservation of Atlantic Tunas (ICCAT) for their stock assessment work using CPUE (R.W.Leslie,.MCM, *pers. comm.*). In addition, the effect of environmental variables on CPUE is typically multiplicative, so a log transformation of the data is necessary to use an additive model such as GLM.

Eight models were constructed. Model 4.1 represents the model for the CPUE of both horse mackerel species pooled to compare results with the S_A model 3.1. Model 4.2 represents the model for CPUE of Cunene horse mackerel and Model 4.3 represents the CPUE of Cape horse mackerel, to allow the comparison of the two species and to elucidate the trends in models 3.1 and 4.1. Models 4.4 and 4.5 represent the models for CPUE of Cunene and Cape horse mackerel species in the southern area of overlap (13-20°S) to investigate similarities and differences between species in the area of overlap. Model 4.6 represents the CPUE model for both horse mackerel species pooled and with sea surface temperature included, for comparison with S_A model 3.1. Models 4.7 and 4.8 represent the models for CPUE of Cunene and Cape horse mackerel species in the southern area of overlap (13-20°S) with sea surface temperature included to be compared with the results in the S_A model 3.2.

Table 4.1 indicates each independent variable in the model with their respective number of categories. GLM models for CPUE were constructed in the same way as models for acoustic data (see methods in Chapter 3).

Table 4.1: Summary of data and variables used in models (GLMs)

Variable	Number of categories	Category description
Year	11	1985, 1986, 1989, 1991-1992 and 1994-1999
Area	3	north, centre and south
Season	2	summer (Oct-April) and winter (May-Sept)
Gear type	2	pelagic trawls and bottom trawls
Time	2	day (6h00-18h00) and night (18h00 to 6h00)
Bottom depth	4	shallow (0-100 m), inner shelf (100-200 m), outer shelf (200-300 m) and offshore (>300 m)
SST	4	<18°C, 18-21°C, 22-26°C and >26°C (only for 1989, 1991-1992 and 1994-1999)

Note that 1993 was excluded from the analysis because only a few trawls were conducted, leading to missing cells in the design.

The model building approach is described in detail for Model 4.1. Thereafter, only the final model is presented.

4.3. Results

A series of GLMs was built to assess the importance of various ecological factors (effects) on the surveys CPUE values. The table below shows whether different data were included in the models according to their availability.

Table 4.2: Summary of the data that were used to construct each of the eight GLMs relating CPUE of two species of horse mackerel to environmental and other factors

Model	Species	Period	Area	SST
4.1	Both	1985-1999	whole	without SST
4.2	*T. trecae*	1985-1999	whole	without "
4.3	*T. capensis*	1985-1999	whole	without "
4.4	*T. trecae*	1985-1999	south	without "
4.5	*T. capensis*	1985-1999	south	without "
4.6	Both	1989-1999	whole	with SST
4.7	*T. trecae*	1989-1999	south	with "
4.8	*T. capensis*	1989-1999	south	with "

4.3.1. Model 4.1: CPUE of the pooled horse mackerel species in relation to environmental and other factors (all areas)

Two primary assumptions of GLM are that the data should be normally distributed and that the standard deviations of each treatment group should be independent of its mean (homogeneity of variance assumption, Zar, 1984). To check the normality assumption, expected normal probability plots are shown before and after transformation of CPUE (Log ($X + 0.1 * \overline{X}$) Figure 4.2b). Standard deviations were plotted against parameter values for the year effect (after GLMs fitted), showing that standard deviations only vary by a factor of 50% after transformation of CPUE, whereas they vary by more than 500% before hand (Figure 4.2b).

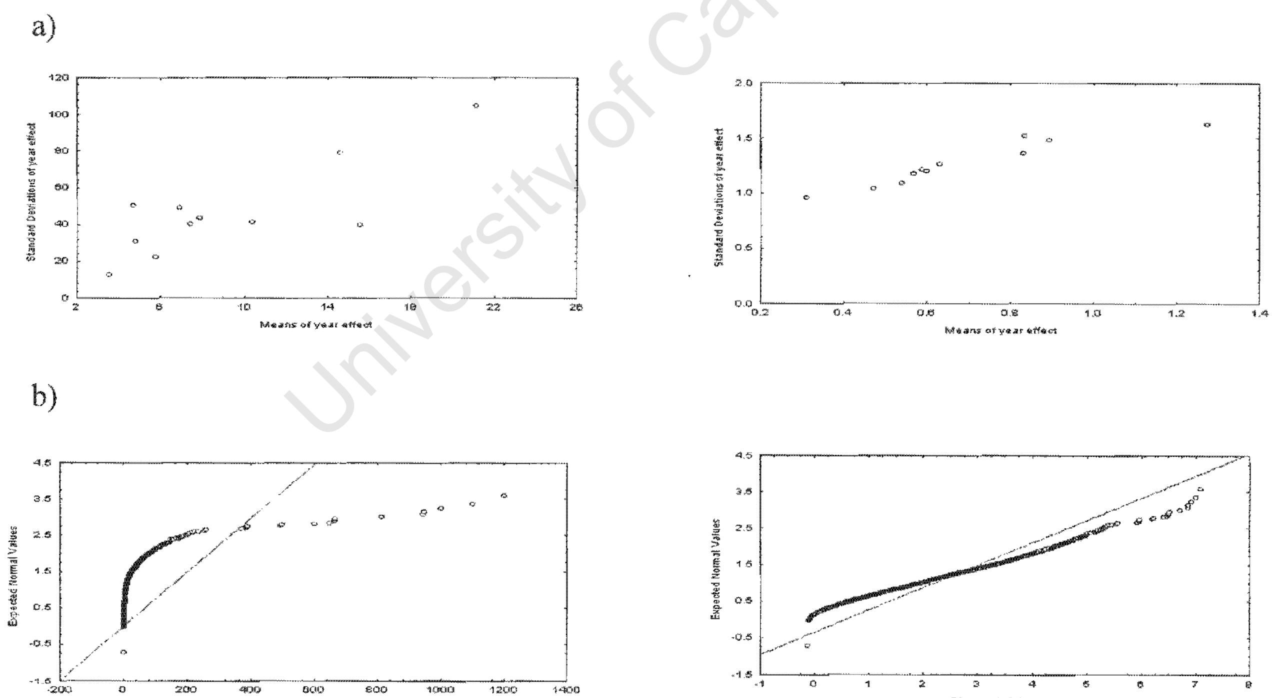


Figure 4.2: (a) Standard deviation versus mean values of the year effect before (left) and after (right) transformation of CPUE and (b) expected versus observed normal values for all groups (cells) in the design before (left) and after (right) transformation (log ($X + 0.1 * \overline{X}$)) of CPUE.

Figure 4.2a shows that standard deviations show reduced relationships with the mean for the year effect variable after transformation (the other variables are not shown because they have fewer categories (≤ 4) therefore the relationship between standard deviations and means is difficult to discern).

Table 4.3 shows results of the stepwise analysis for Model 4.1. The steps in the model development where terms were removed are also shown (final column). These terms were either not significant (*F*-test) or contributed less than 10% of r^2. The order of terms removed from the model and their effect on the r^2 is shown in Table 4.4.

Table 4.3: ANOVA table of model 4.1 with all main effects and two way interactions for both horse mackerel species (the removal step indicates the order that the terms were removed from the first stepwise analysis)

	Effect	SS	df	MS	*F*	*p*	Removal step
Main effects	Intercept	81.5	1	81.5	72.3	0.0000	
	Year	28.3	10	2.8	2.5	0.0052	
	Gear type	16.7	1	16.7	14.9	0.0001	13
	Area	107.7	2	53.8	47.8	0.0000	
	Season	2.4	1	2.4	2.1	0.1486	15
	Time	3.4	1	3.4	3.0	0.0846	12
	Depth	62.1	3	20.7	18.4	0.0000	
2-way interactions	Year*Gear	39.7	10	4.0	3.5	0.0001	9
	Year*Area	115.2	20	5.8	5.1	0.0000	17
	Gear*Area	6.7	2	3.3	3.0	0.0521	7
	Year*Season	64.9	9	7.2	6.4	0.0000	14
	Gear*Season	5.8	1	5.8	5.1	0.0234	6
	Area*Season	0.4	2	0.2	0.2	0.8478	1
	Year*Time	14.4	10	1.4	1.3	0.2379	2
	Gear*Time	56.6	1	56.6	50.2	0.0000	11
	Area*Time	17.1	2	8.5	7.6	0.0005	10
	Season*Time	2.3	1	2.3	2.0	0.1570	5
	Year*Depth	87.5	30	2.9	2.6	0.0000	
	Gear*Depth	4.4	3	1.5	1.3	0.2710	3
	Area*Depth)	68.1	6	11.4	10.1	0.0000	16
	Season*Depth	6.9	3	2.3	2.0	0.1076	4
	Time*Depth	8.3	3	2.8	2.5	0.0615	8
	Error	4780.8	4243	1.1			

Type III decomposition (all 2-way interactions)
use all interactions

Table 4.4: Order of terms removed from model 4.1 (terms were only removed if the r^2 decreased by <10%). For the model with all terms included was $r^2 = 0.3438$

Order	Terms removed	r^2 (after removal)	Difference	% difference
1	Area*Season	0.3437	0.0001	0.000
2	Year*Time	0.3418	0.0019	0.006
3	Gear*Depth	0.3412	0.0006	0.002
4	Season*Depth	0.3403	0.0010	0.003
5	Season*Time	0.3396	0.0007	0.002
6	Gear*Season	0.3392	0.0004	0.001
7	Gear*Area	0.3380	0.0012	0.004
8	Time*Depth	0.3368	0.0012	0.004
9	Year*Gear	0.3311	0.0057	0.017
10	Area*Time	0.3236	0.0075	0.023
11	Gear*Time	0.3155	0.0081	0.026
12	Time	0.3148	0.0007	0.002
13	Gear type	0.3040	0.0108	0.036
14	Year*Season	0.2942	0.0098	0.033
15	Season	0.2916	0.0026	0.009
16	Area*Depth	0.2768	0.0116	0.042
17	Year*Area (returned)	0.2620	0.0180	0.069

Type III decomposition

Table 4.5: Test of the whole model for both horse mackerel species together (final model)

	Multiple	SS	df	MS	SS	df	MS		
Log of	r^2	Model	Model	Model	Residual	Residual	Residual	F	p
cpueHM	0.277	2006.496	65	30.869	5246.265	4299	1.220	25.295	0.000

Type III decomposition
cpueHM = CPUE of the pooled horse mackerel species

Table 4.6: ANOVA table of the final model for both horse mackerel species together

	Effect	SS	df	MS	F	p
Main effects	Intercept	583.0	1	583.0	477.7	0.0000
	Year	78.3	10	7.8	6.4	0.0000
	Area	342.0	2	171.0	140.1	0.0000
	Depth	332.3	3	110.8	90.8	0.0000
2-way interactions	Year*Depth	107.2	20	5.4	4.4	0.0000
	Year*Area	110.1	30	3.7	3.0	0.0000
	Error	5246.3	4299	1.2		

Type III decomposition

This procedure allowed a compact model to be found that still explained a substantial proportion of the variance r^2 = 27.7% (Table 4.5). The final model was statistically significant (Table 4.6). The main effects of year, area and depth were retained in the final model as well their interactions, except for area*depth (Table 4.6). Interactions between year*depth and year*area imply that the spatial distribution of horse mackerel CPUE is not constant from year to year (Figures 4.6 and 4.7). Season, gear type and time factors did not substantially improve the model (r^2 improved by less that 10% by their inclusion) so that these factors do not have a substantial effect on CPUE.

For interpretative purposes, the main effects will be discussed first and then the interaction terms will be discussed to highlight the advances in the general relationship.

General relationships for both species pooled: the main effects

Year

Results from Table 4.6 show that the year effect is very significant ($p<0.0001$). Figure 4.3 shows the least squares (LS) means of horse mackerel CPUE for the year effect. This is the standardized abundance series for both horse mackerel species. The large standard errors highlight the large variation of sampling effort from year to year (of particular note is the low abundance in 1989 and 1995). This last is probably a reflection of the Benguela Niño in 1995. Bianchi *et al.* (1997) suggested that this event might have been responsible for the low horse mackerel biomass estimated in 1995. The greatest abundance was found in 1997.

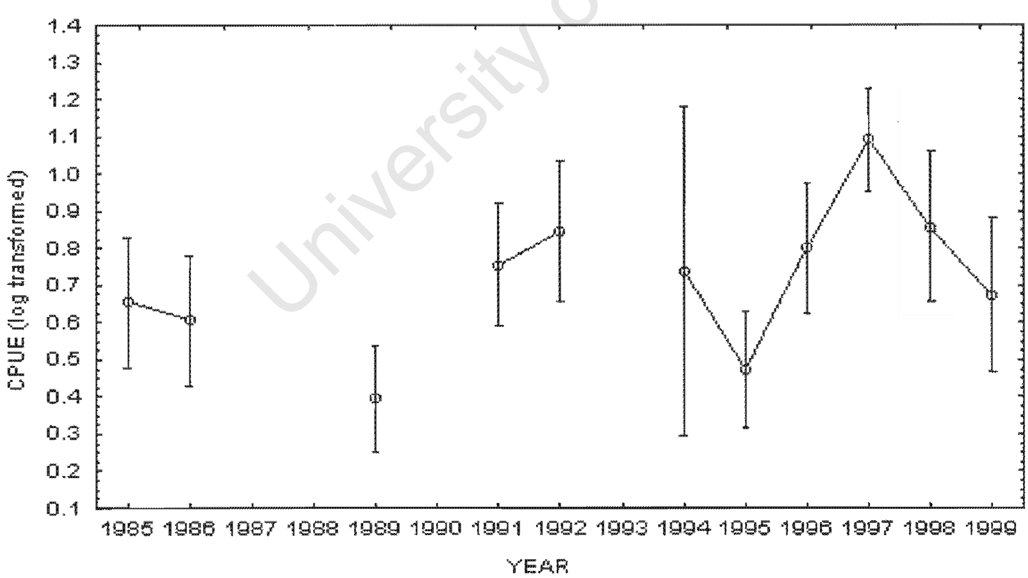


Figure 4.3: Effect of year on horse mackerel CPUE (both species together) using the results of the GLM (model 4.1) to estimate (±SE) for each of the eleven years

Area

Results from Table 4.6 show that the effect of area is very significant ($p<0.0001$) and this is similar to the results from echo integration values (S_A), (see Chapter 3). This may indicate that the distribution of horse mackerel species is characterized by changes in their behaviour between the three areas, showing a higher abundance of these species in the southern than northern areas. It is clear from Figure 4.4 that the mean CPUE increases to the south, if other factors are constant.

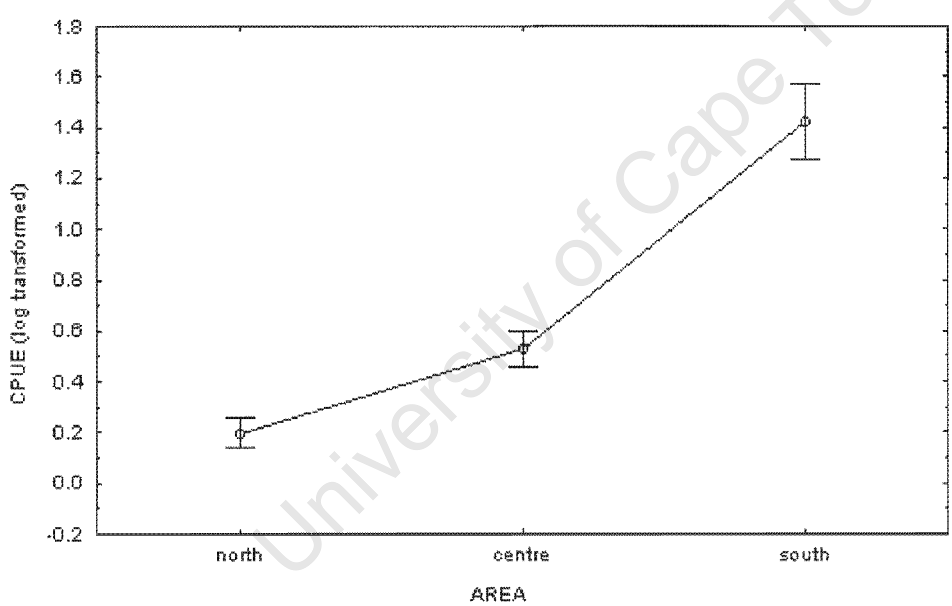


Figure 4.4: Effect of area on horse mackerel CPUE (both species together) using the results of the GLM (model 4.1) to estimate parameters (±SE) for each of the three areas

Depth

According to the results from the final model in Table 4.6, the main depth effect is very significant ($p<0.0001$). Figure 4.5 shows the CPUE accounted for by the depth effect. Horse mackerel CPUE increased slightly from inshore (0-100 m) to mid-shelf (100-200 m) and then decreased substantially in deeper water (>200 m).

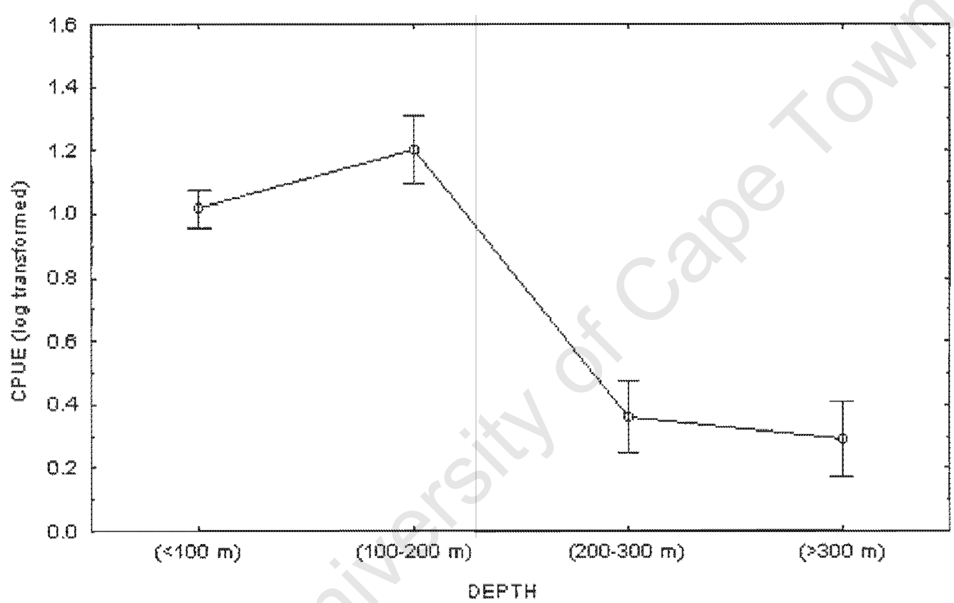


Figure 4.5: Effect of depth on horse mackerel CPUE (both species together) using the results of the GLM (model 4.1) to estimate parameters (±SE) for each of the four depths categories

Modification of the general trends for both species: 2-way interactions

Year*Area

Table 4.6 show that the year*area interaction is significant. There seems to be little variability in CPUE in the northern area (Figure 4.6), but in the south it is clear that the mean of horse mackerel CPUE fluctuates from year to year and in some years (e.g. 1991-1994). The plot indicates that most of the variability occurs in the southern area. This may possibly indicate some migration between central and south areas.

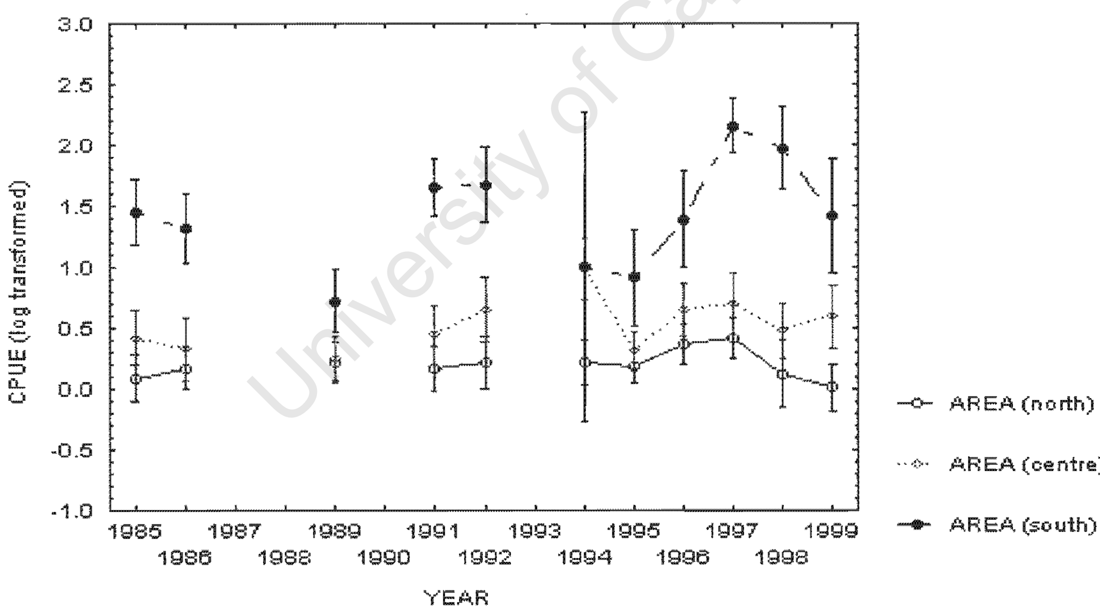
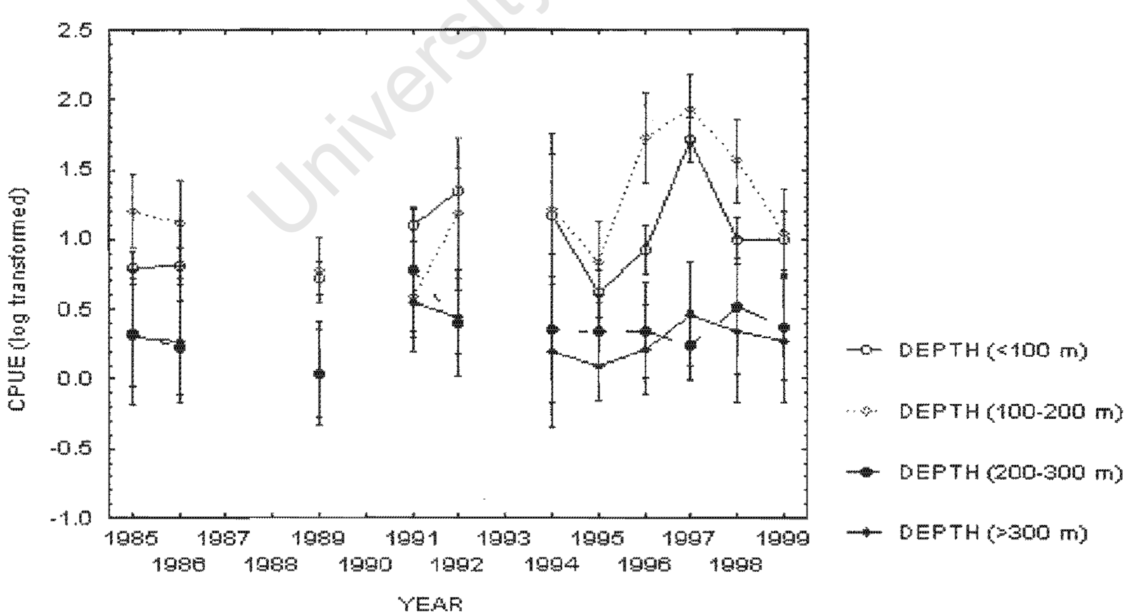


Figure 4.6: Effect of year*area interactions on horse mackerel CPUE (both species together) using the results of the GLM (model 4.1) to estimate parameters (±SE) for each of the interactions between years and areas

Year*Depth

Results from Table 4.6 show that the year*depth interaction is significant ($p<0.0001$). In general there seem to be at least 3 different patterns of annual horse mackerel CPUE by depth (Figure 4.7): first one from 1985-1986, with weak interactions; the second one in 1989, 1995 and 1999, where the interaction appear much weaker, and third one in 1991, 1992, 1994, 1997 and 1998 characterized with very strong variations from year to year mainly in shallow and mid waters. It is also true that according to the biology of the horse mackerel species (Bianchi, 1986), they inhabit depths between 0 and 200 m, although they may move further offshore in the presence of abnormal environmental conditions. Perhaps this is the main reason for the apparent difference in the depth effects between shallower and deeper waters zones.



4.3.2. Model 4.2: CPUE of Cunene horse mackerel (*T. trecae*) in relation to environmental and other factors

GLMs were applied to CPUE data for each horse mackerel species separately. The same procedure was followed for each horse mackerel species. The results from Table 4.7 show that n > 4320 data points were analysed by the full model. The proportion of variation explained by the model is ~20% (Table 4.7). This result indicates that year, gear, time, area and depth are significant to the model fit (at the 0.01 level) as well as the year*area, gear*time and area*depth interactions (Table 4.8). The main effect of season was not statistically significant, and very low level interactions appeared between year*season and area*season, so these are therefore omitted from the final model.

Table 4.7: Test of the whole Model for Cunene horse mackerel

	Multiple	SS	df	MS	SS	df	MS		
Log of	r^2	Model	Model	Model	Residual	Residual	Residual	*F*	*p*
cpuetrecae	0.203	1350.286	44	30.688	6148.57	4320	1.423	21.562	0.000

cpuetre = CPUE of trecae species (kg/h)

Table 4.8: ANOVA table for Cunene horse mackerel (final model)

	Effect	SS	df	MS	*F*	*p*
Main effects	Intercept	52.0	1	52.0	36.5	0.0000
	Year	208.9	10	20.9	14. 7	0.0000
	Gear	56.2	1	56.2	39.5	0.0000
	Area	41.3	2	20.6	14.5	0.0000
	Time	19.9	1	19.9	13.9	0.0002
	Depth	414.0	3	138.0	97.0	0.0000
2-way interactions	Year*Area	137.4	20	6.9	4.8	0.0000
	Gear*Time	109.2	1	109.2	76.7	0.0000
	Area*Depth	57.5	6	9.6	6.7	0.0000
	Error	6148.6	4320	1.4		

Type III decomposition

Table 4.8 shows the results of the full model with all 2-way interactions. In general, according to the results from the full model (Table 4.8), most of the interactions factors are significant but explain very little about the variation of CPUE of Cunene horse mackerel.

General relationships for *T. trecae* (all areas): the main effects

Year

Table 4.8 shows that year is the second most significant main effect on Cunene horse mackerel CPUE. Figure 4.8 shows a general increase in CPUE from 1985-1997 and then a decline in 1998-1999. This figure also shows 3 pronounced annual patterns in the abundance of the Cunene horse mackerel. Firstly 1985-1989 is characterized by reduced abundance with some fluctuation in 1986. Secondly 1991-1997 is characterized by an increase of Cunene horse mackerel CPUE from year to year with a notable drop in 1995. This drop in Cunene horse mackerel CPUE coincides with 1995 Benguela Niño event observed in the area. Thirdly 1997-1999 is characterized by slight decreases in Cunene horse mackerel CPUE. Figure 4.8 clearly shows the high abundance of the Cunene horse mackerel in the period 1996-1997.

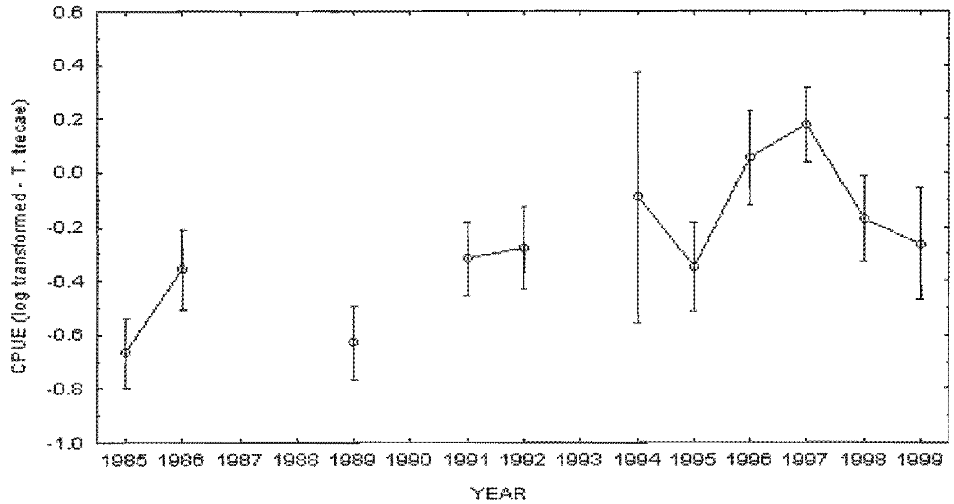


Figure 4.8: Effect of year on Cunene horse mackerel CPUE (all areas) using the results of the GLM (model 4.2) to estimate parameters (±SE) for each of the eleven years

Area

Table 4.8 shows a relatively weak effect of area on Cunene horse mackerel CPUE. Figure 4.9 highlights that the highest abundance of the Cunene horse mackerel is in central and southern Angola. This result confirms the findings of several authors who carried out assessments on horse mackerel species in Angola (e.g. Santos Dias, 1974, Da Franca, 1968, Wysokiñski, 1987, Toresen, 1995, Bianchi *et al.*, 1997).

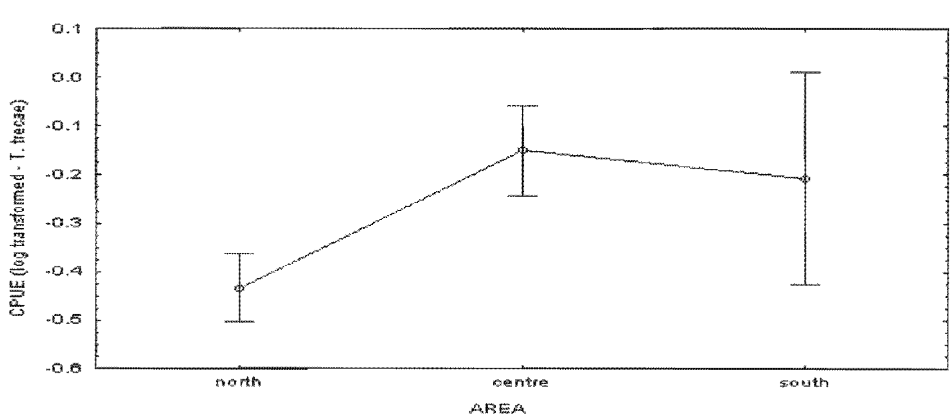


Figure 4.9: Effect of area on Cunene horse mackerel CPUE (all areas) using the results of the GLM (model 4.2) to estimate parameters (±SE) for each of the three areas

Figure 4.9 shows the lower abundance of Cunene horse mackerel in the northern area than other areas.

Depth

Results from Table 4.8 show that depth contributes substantially to the Cunene horse mackerel CPUE. Figure 4.10 shows that the abundance of Cunene horse mackerel decreases from shallow to the offshore waters. This also confirms the finding of Bianchi *et al.* (1997) and Cochrane and Tandstad (2000).

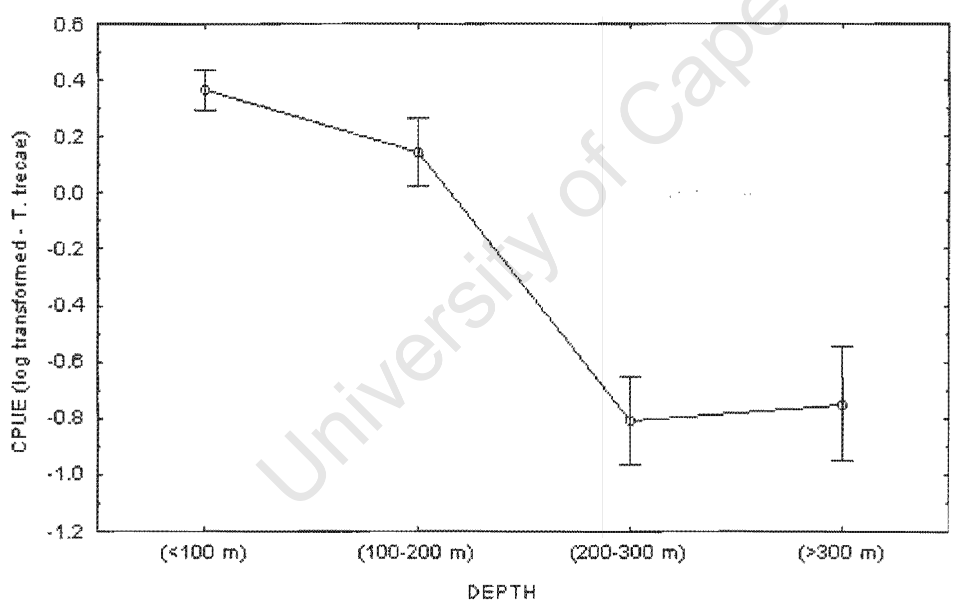


Figure 4.10: Effect of depth on Cunene horse mackerel CPUE (all areas) using the results of the GLM (model 4.2) to estimate parameters (±SE) for each of the four depths categories

Gear

Table 4.8 shows a weaker gear effect than the effects of year and depth on the mean Cunene horse mackerel CPUE. Figure 4.11 shows that the Cunene horse mackerel species has a greater susceptibility to the bottom trawl than the midwater trawl.

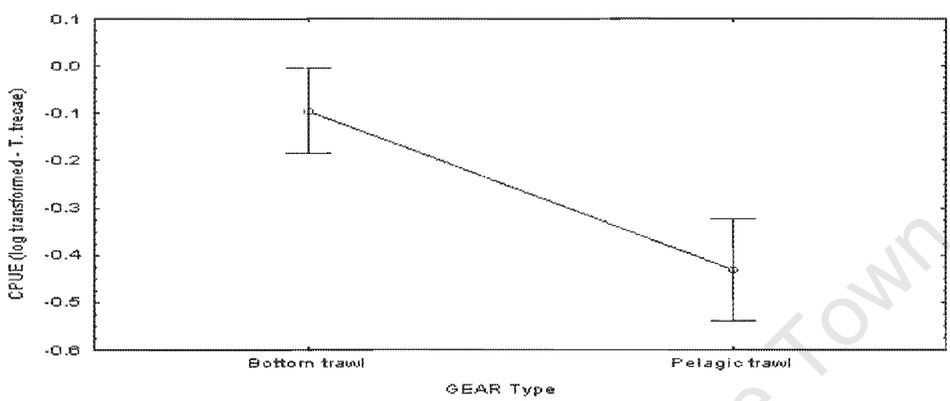


Figure 4.11: Effect of gear on Cunene horse mackerel CPUE (all areas) using the results of the GLM (model 4.2) to estimate parameters (±SE) for each of the two gears

Time

Table 4.8 shows that time (day, night) is a factor with a minor contribution in explaining the variation on Cunene horse mackerel CPUE. Figure 4.12 illustrates that the abundance of Cunene horse mackerel is higher in the night time than in daytime.

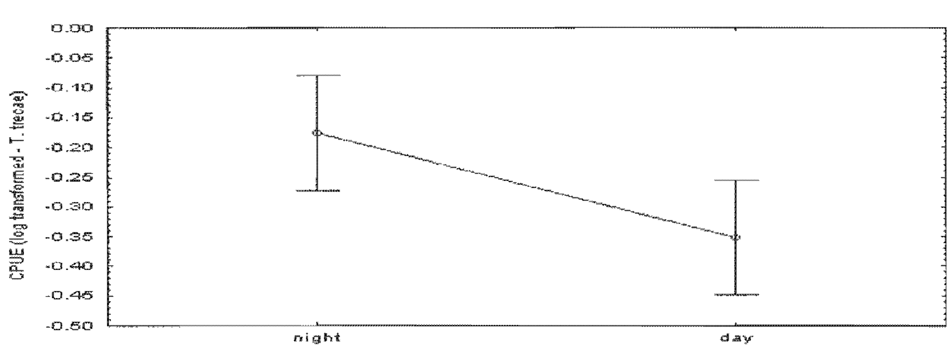


Figure 4.12: Effect of time on Cunene horse mackerel CPUE (all areas) using the results of the GLM (model 4.2) to estimate parameters (±SE) for each of the two times

Modification of the general trends for *T. trecae* (all areas): 2-way interactions

Year*area

Interaction between the effects of year and area implies that the spatial distribution of Cunene horse mackerel CPUE is not constant from one year to another. Results from the final model (Table 4.8) show that the year*area interaction is significant. Figure 4.13 shows that the CPUE is higher in the central and southern areas every year except in 1989 when the northern area was highest. 1986 stands out when the southern area had higher CPUE than other years. Cunene horse mackerel CPUE was the highest in the central area in 1994.

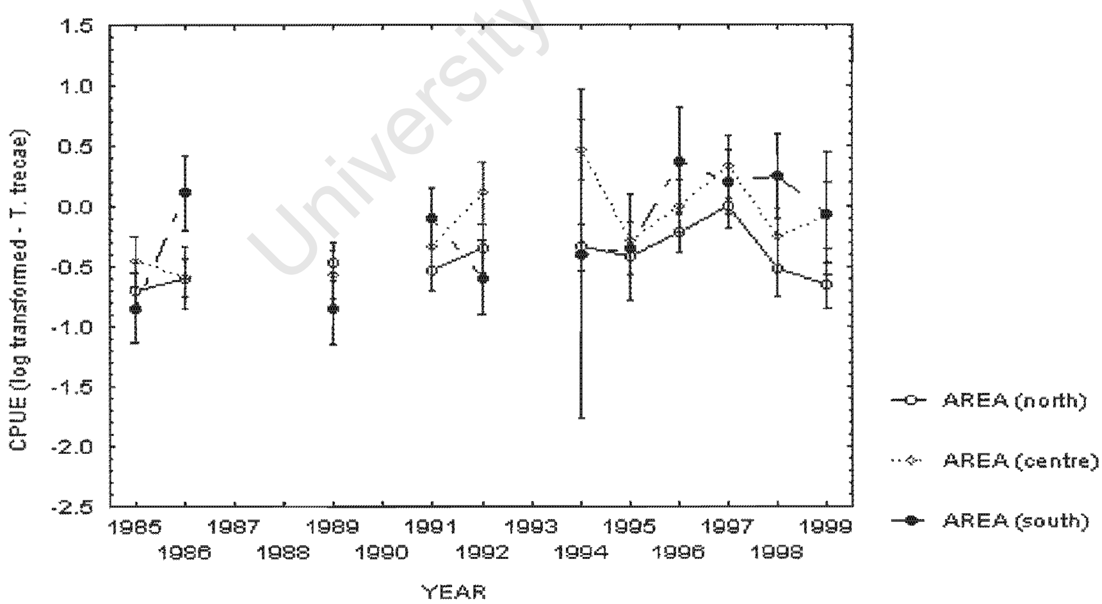


Figure 4.13: Effect of year*area interactions on Cunene horse mackerel CPUE (all areas) using the results of the GLM (model 4.2) to estimate parameters (±SE) for each of the years and areas

Area*depth

According to the results from the model 4.2 (Table 4.8), the area*depth interaction is significant but the trends in the plot (Figure 4.14) show little variation of Cunene horse mackerel CPUE between areas and depths except in the south where the same order is not preserved and CPUE is higher at >300 m than at 200-300 m. There is a substantial difference in northern area between depth (0-100 m) and depth (100-200 m) and also in the southern area with regard to depths of (<200 m) to (>200 m).

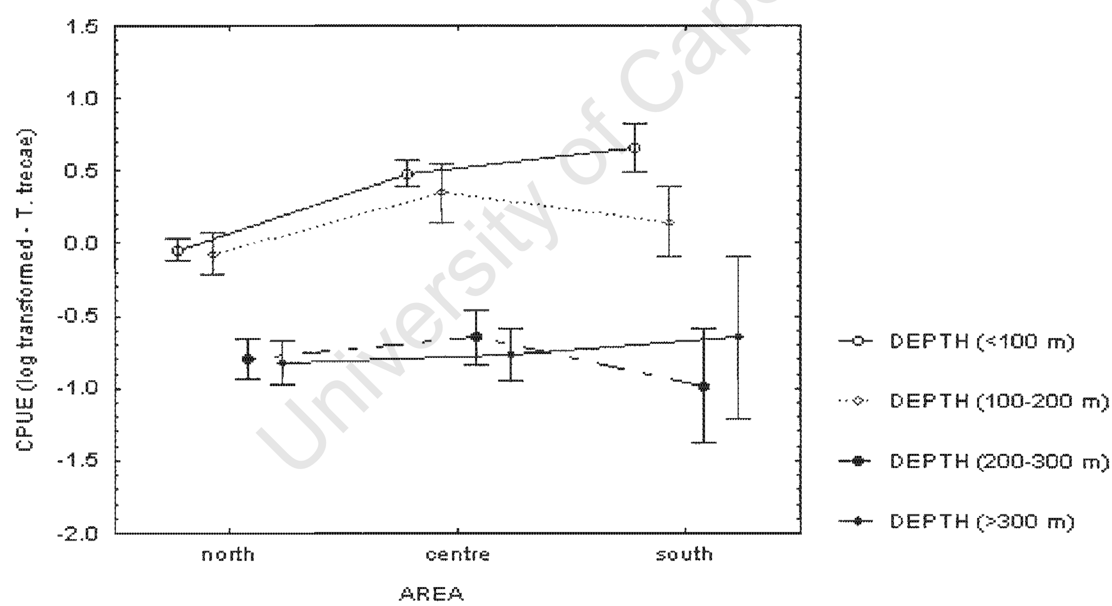


Figure 4.14: Effect of area*depth interactions on Cunene horse mackerel CPUE (all areas) using the results of the GLM (model 4.2) to estimate parameters (±SE) for each of the interactions between areas and depths

Gear*time

Results from the model (Table 4.8) indicates that the gear*time interaction is significant (p<0.0001). This result is expected because horse mackerel species show different behaviour between night and daytime (G. Burgos, NORAD, *person. comm.*). In general the horse mackerel species have similar behaviour to demersal species (deep dwelling) in the daytime and pelagic behaviour (surface dwelling) in the night time. Because of different behaviour, the most effective gear also changes according to the location of the target species. Figure 4.15 shows that the bottom trawl is more effective by day than night, and vice versa for the pelagic (mid water). Most pronounced differences among gear types occur in the daytime, when there is a large difference between bottom and pelagic trawls.

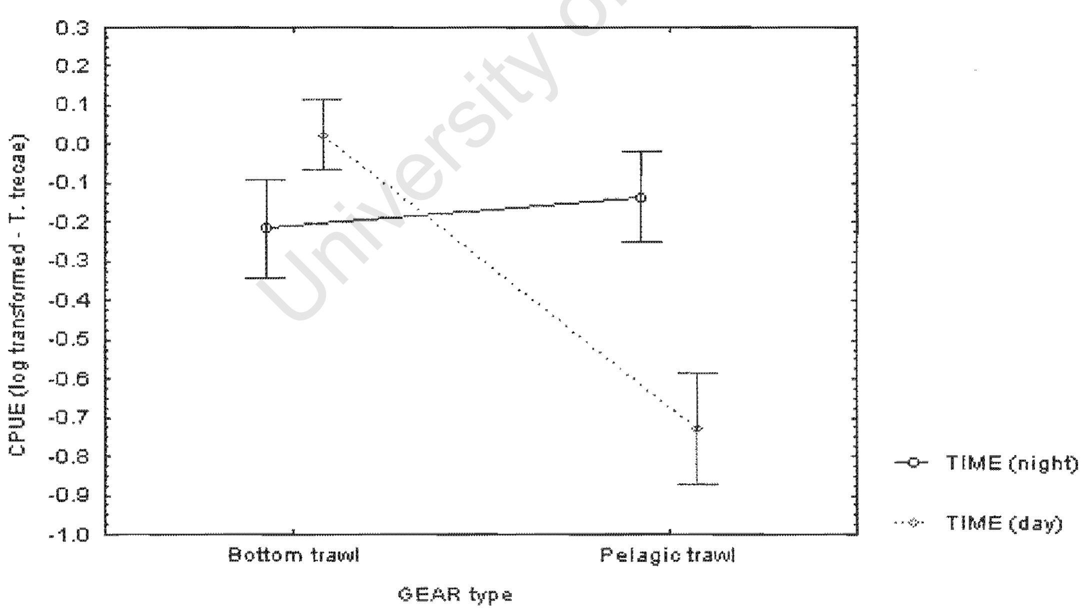


Figure 4.15: Effect of gear*time interactions on Cunene horse mackerel CPUE (all areas) using the results of the GLM (model 4.2) to estimate parameters (±SE) for each of the gears and times

4.3.3. Model 4.3: CPUE of Cape horse mackerel (*T. capensis*) in relation to environmental and other factors

A total of 4323 degree of freedom was used for the full model (Table 4.11). The percentage of the total variation of Cape horse mackerel CPUE accounted by the model is r^2 = 40.4% (Table 4.10). This r^2 is higher than 30%. It may indicate that the model fits the Cape better than the Cunene horse mackerel (Table 4.9). The higher r^2 may be due to including a large area where the fish does not occur.

Table 4.10: Test of the whole Model for Cape horse mackerel (final model)

Log of	Multiple r^2	SS Model	df Model	MS Model	SS Residual	df Residual	MS Residual	F	p
cpuecape	0.404	1754.05	41	42.782	2585.151	4323	0.598	71.541	0.000

cpuecape = CPUE of Cape species (kg/h)

Table 4.11: ANOVA table of the final model for Cape horse mackerel

	Effect	SS	df	MS	F	p
Main effects	Intercept	161.7	1	161.7	270.5	0.0000
	Year	86.8	10	8.7	14.5	0.0000
	Area	276.3	2	138.1	231.0	0.0000
	Depth	123.5	3	41.2	68.8	0.0000
2-way interactions	Year*Area	140.3	20	7.0	11.7	0.0000
	Area*Depth	227.0	6	37.8	63.3	0.0000
	Error	2585.2	4323	0.6		

Type III decomposition

Results from Table 4.11 show that the main effects of year, area and depth on Cape horse mackerel CPUE are significant in the model. This is similar to the Cunene horse mackerel, except the gear type and time effects were also significant for *T. trecae*. Table 4.11 also shows that the SS value for the area effect is very large because of the restricted distribution of the species in the south and it is for this reason that the r^2 is so much larger.

General relationships for *T. capensis* (all areas): the main effects

Year

Results from Table 4.11 show that the year effect is significant ($p<0.0001$) for the Cape horse mackerel CPUE. Figure 4.16 shows that Cape horse mackerel CPUE appears to have a major peak in 1992, with minor peaks in 1985 and 1997, and low points in 1986-1989 and 1995-1996.

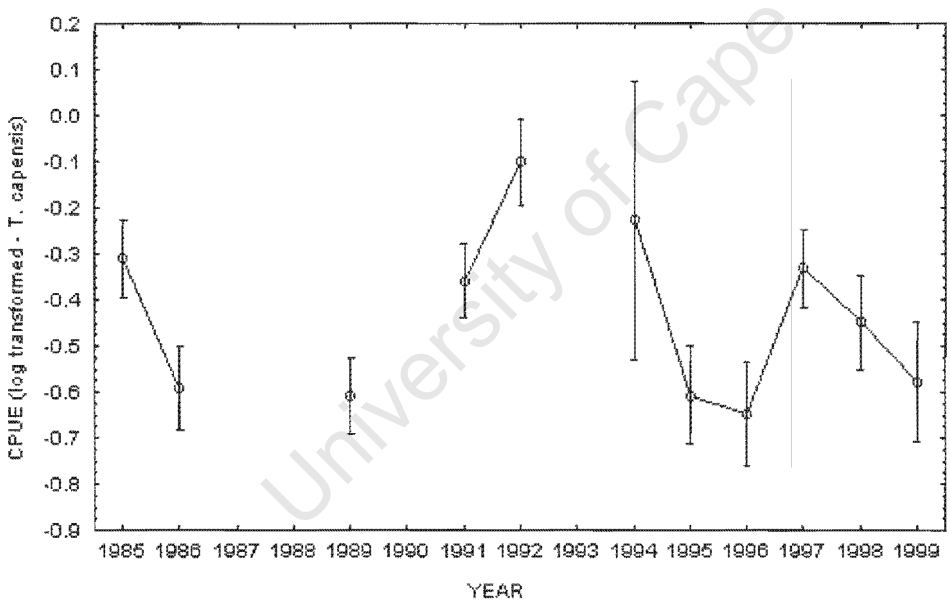


Figure 4.16: Effect of year on Cape horse mackerel CPUE (all areas) using the results of the GLM (model 4.3) to estimate parameters (±SE) for each of the eleven years

Area

According to Table 4.11, area has the strongest effect on Cape horse mackerel CPUE. Figure 4.17 shows that Cape horse mackerel is found mainly in the southern Angola area.

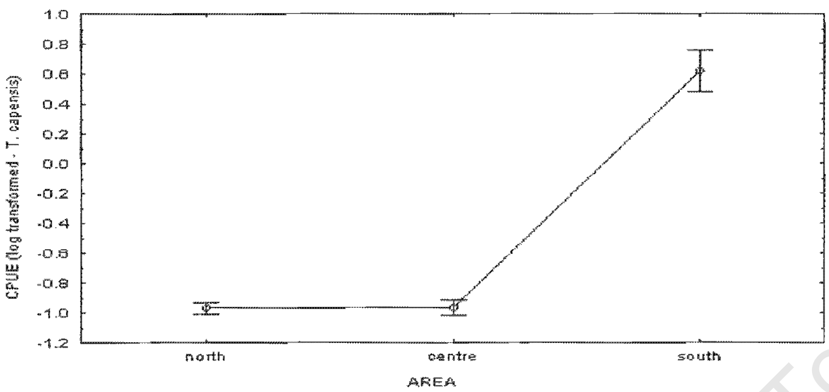


Figure 4.17: Effect of area on Cape horse mackerel CPUE (all areas) using the results of the GLM (model 4.3) to estimate parameters (±SE) for each of the three areas

Depth

Results from Table 4.11 show that the effect on Cape horse mackerel is highly significant ($p<0.0001$). Figure 4.18 shows that Cape horse mackerel is found in great abundance in the mid-shelf (100-200 m).

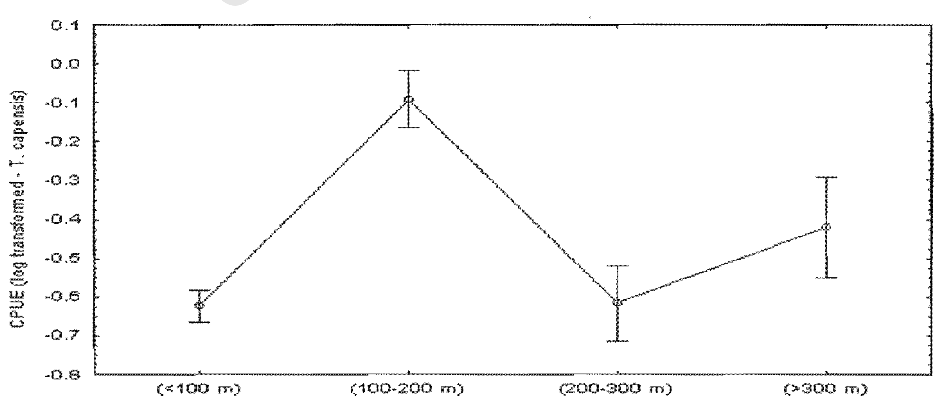


Figure 4.18: Effect of depth on Cape horse mackerel CPUE (all areas) using the results of the GLM (model 4.3) to estimate parameters (±SE) for each of the four areas

Modification of the general trends for *T. capensis* (all areas): 2-way interactions

Year*Area

The significance of the year*area interaction explains the annual variation between areas on horse mackerel CPUE. Figure 4.19 confirms that the occurrence of Cape horse mackerel is restricted mainly to the southern Angola area.

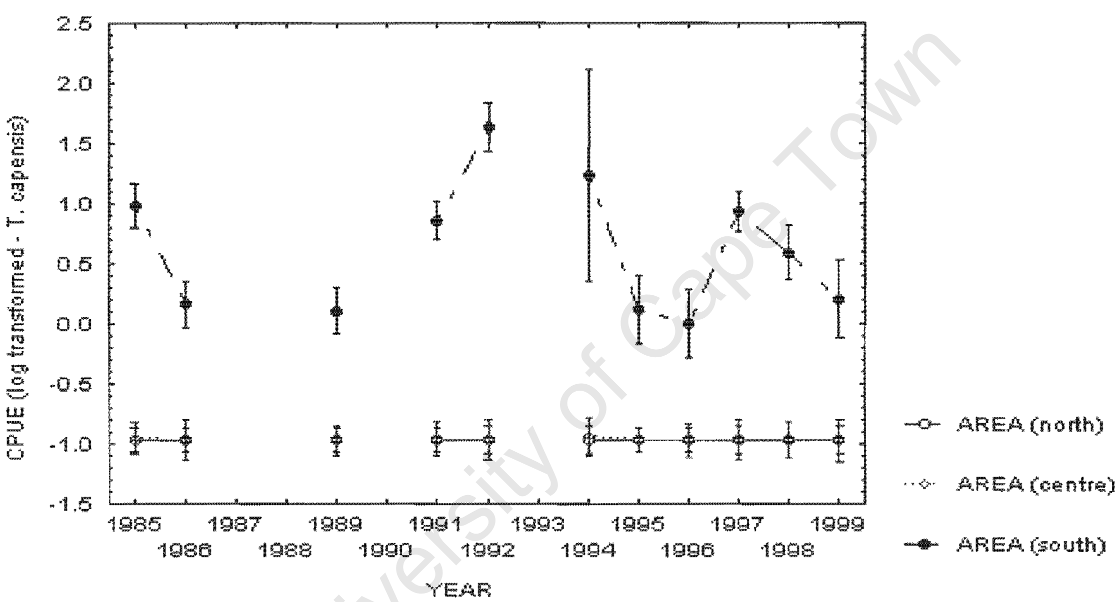


Figure 4.19: Effect of year*area interactions on Cape mackerel CPUE (all areas) using the results of the GLM (model 4.3) to estimate parameters (±SE) for each of the interactions between years and areas

This interaction shows that CPUE in the northern and central areas are constant ($\delta \cong 0$) and that CPUE in the southern area is variable. The year effect is entirely due to the variations in the southern area.

Area*Depth

According to Table 4.11 the area*depth interaction effect is high in the inner shelf (100-00 m). In general, the area*depth interaction is significant and explains more of the variation of Cape horse mackerel than other interactions in the model. The results of the interaction between area and both year and depth show that the interaction effects are entirely due to the strong area effect, since *T. capensis* does not occur in the northern and central areas (Figure 4.20). The interactions are therefore dropped from the model and only a main effects model used.

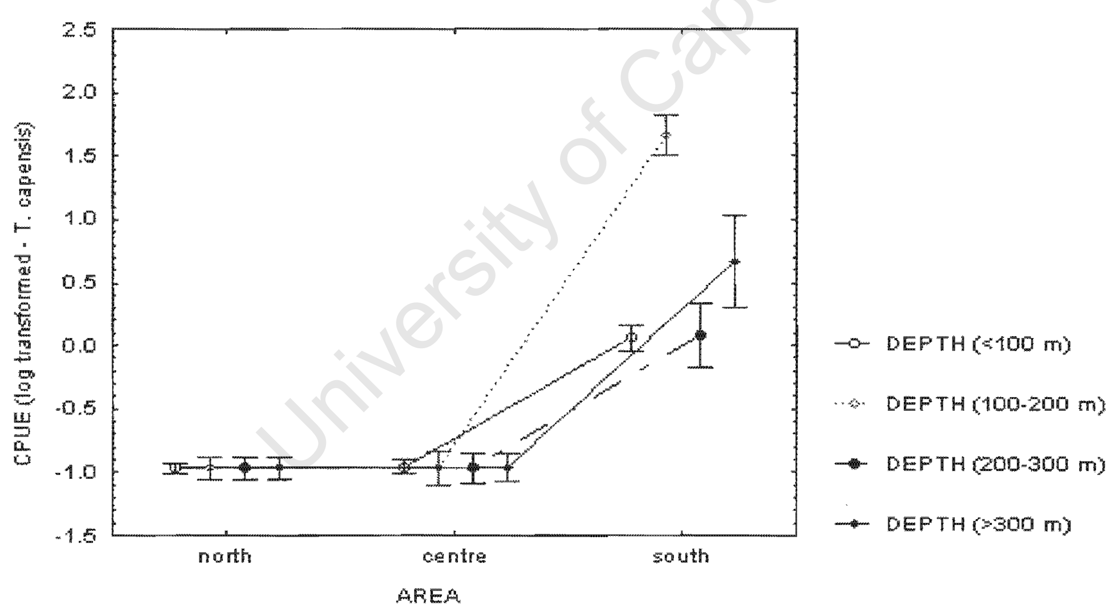


Figure 4.20: Effect of area*depth interactions on Cape horse mackerel CPUE (all areas) using the results of the GLM (model 4.3) to estimate parameters (±SE) for each of the interactions between areas and depths

Comparison of results from the model for each horse mackerel species

In comparing results from Tables 4.9 (*T. trecae*) and 4.11 (*T. capensis*), different patterns are shown between the two horse mackerel species. For example the gear type effects, time and gear*time interactions were significant for the Cunene horse mackerel and not significant for the Cape horse mackerel. Thus, in the presence of these differences between main effects and interactions between different factors it becomes very complex to compare distribution patterns of the two horse mackerel species in relation to these environmental and other factors. However there are similarities in the patterns of most of the main ecological and other effects like year, area, time, depth and SST effects that may help us to draw important conclusions. By limiting the comparisons between two horse mackerel species to the southern Angolan area, these will be investigated in more detail in Models 4.4, 4.5, 4.7 and 4.8. There are many other factors that have implications for movements of these species from one area to another that were not included in this analysis.

4.3.4. Model 4.4: CPUE of Cunene horse mackerel (*T. trecae*) in relation to environmental and other factors only in the southern region (overlap area)

Table 4.13 shows that the main effects of year, gear and depth on CPUE Cunene horse mackerel are significant ($p<0.001$). According to the full model results (Table 4.13), no interaction effects were found to be significant for on Cunene horse mackerel CPUE when the dataset is limited only to the overlap area. However in preliminary stepwise analyses, year and depth were found to have statistically weak significant interactions with time, but at a lower level and therefore they were excluded from the final model. The absence of interactions in the result is probably related to sampling effects because the dataset represents only about one week of total survey per year. This may also be the main reason for the low r^2 in Table 4.12 (r^2 =14%) for the full model. From the results in Table 4.12, the total number of observations are approximately 1/5 compared with the three areas in Model 4.2 (full model for *T. trecae*).

Table 4.12: Test of the whole Model for Cunene horse mackerel in the overlap area

	Multiple	SS	df	MS	SS	df	MS		
Log of	r^2	Model	Model	Model	Residual	Residual	Residual	F	p
Cpuetrec.	0.138	285.889	14	20.421	1790.241	739	2.423	8.430	0.000

Cpuetrec = CPUE of Cunene horse mackerel (kg/h)

Table 4.13: ANOVA table of the final model for Cunene horse mackerel species in the overlap area

	Effect	SS	df	MS	F	p
Main effects	Intercept	2.9	1	2.9	1.2	0.2700
	Year	146.2	10	14.6	6.0	0.0000
	Gear	44.3	1	44.3	18.3	0.0000
	Depth	155.2	3	51.7	21.3	0.0000
	Error	1790.2	739	2.4		

Type III decomposition

General relationships for *T. trecae* only in the southern area: the main effects

Year

Figure 4.21 shows that the annual effect on Cunene horse mackerel CPUE in the southern region is strong. There is not much difference in the year effect from the result in Model 4.2 (Figure 4.8, full *T. trecae* model). Results from Table 4.13 shows that the year is the variable that explains second most of the variation of Cunene horse mackerel in the southern area. There may be a slight increasing trend in Cunene horse mackerel CPUE in 1985-1996 (Figure 4.21). There seems to be less annual effect in the period 1996-1999.

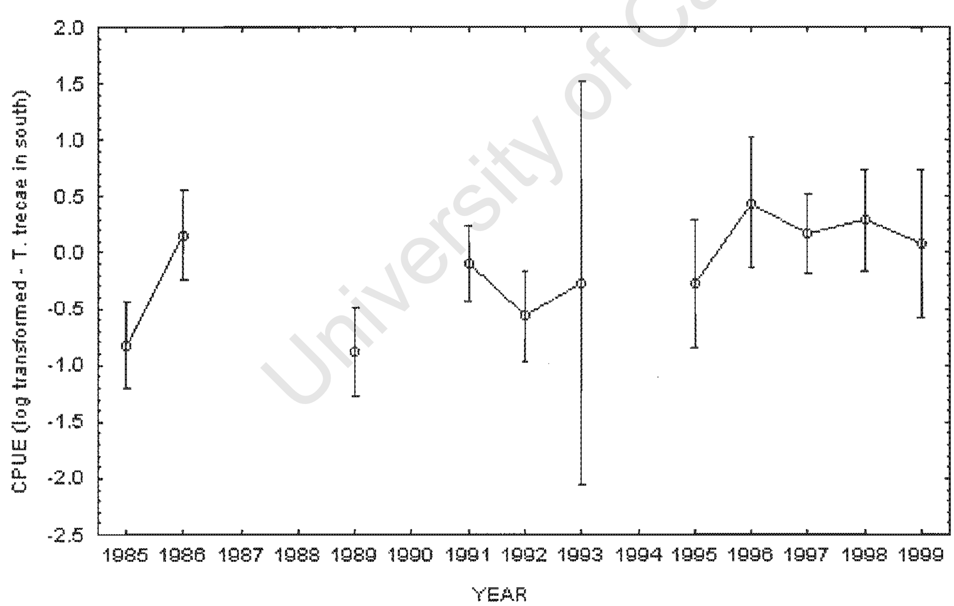


Figure 4.21: Effect of year on Cunene horse mackerel CPUE (in the southern Angola area) using the results of the GLM (model 4.4) to estimate parameters (±SE) for each of eleven years

Depth

According to the results from Table 4.13, depth contributes the most to the variation of Cunene horse mackerel CPUE in the southern region. The plot of depth effect on Cunene horse mackerel CPUE in the southern area (Figure 4.22) follows the same trend as Model 4.2 (Figure 4.10, full model for *T. trecae*).

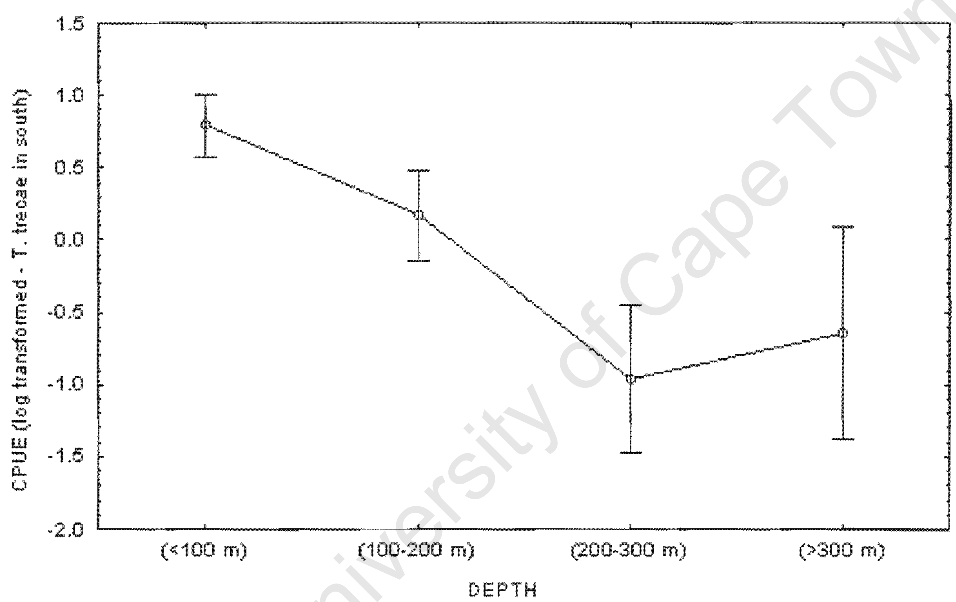


Figure 4.22: Effect of depth on Cunene horse mackerel CPUE (in the southern Angola area) using the results of the GLM (model 4.4) to estimate parameters (±SE) for each of four depths

Gear

The gear effect explains the least variation in Cunene horse mackerel CPUE in the southern area (Table 4.13). Figure 4.23 shows that higher Cunene horse CPUE is found in bottom trawls. Also the result follows the same trend as Model 4.2 (Figure 4.14).

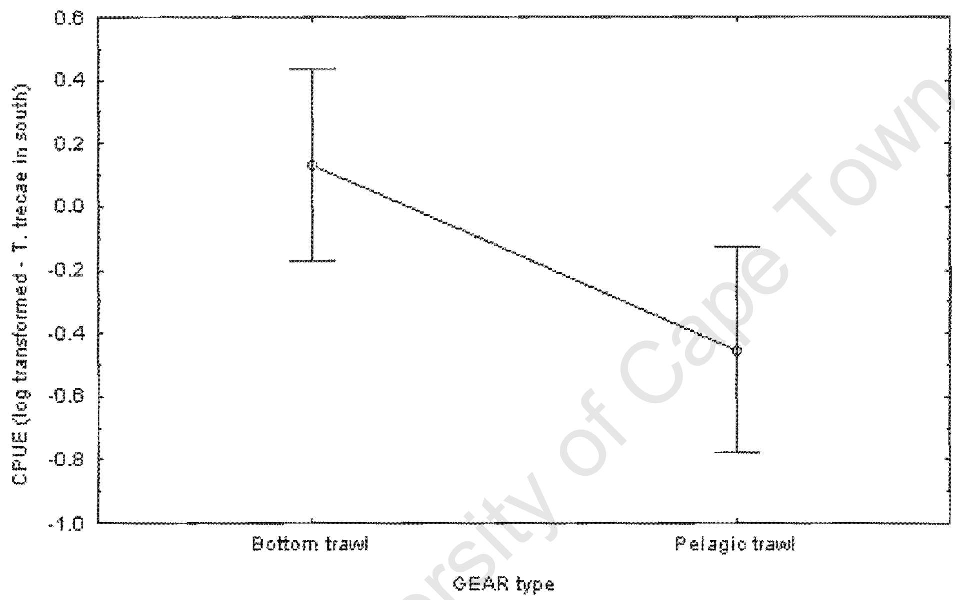


Figure 4. 23: Effect of gear on Cunene horse mackerel CPUE in the southern area using the results of the GLM (model 4.4) to estimate parameters (±SE) for each of the two gears

4.3.5. Model 4.5: CPUE of Cape horse mackerel (*T. capensis*) in relation to environmental and other factors only for the southern region

Table 4.15 shows that the difference in main effect variables between Model 4.4 and Model 4.5 is that the time effect is significant for the Cape horse mackerel and not significant for the Cunene horse mackerel. A similar interpretation applies to the gear effect that is not significant for Cape horse mackerel but is significant for Cunene horse mackerel. Seventeen percent (17%) of the variability in the data for by the model (Table 4.14). There is no difference in most of the explanatory variables between the distributions of the two horse mackerel species at least in the overlap area.

Table 4.14. Test of the whole Model for Cape horse mackerel in the overlap area (final model)

	Multiple	SS	df	MS	SS	df	MS		
Log of	r^2	Model	Model	Model	Residual	Residual	Residual	F	p
cpuecape	0.171	517.521	14	36.966	2511.005	739	3.398	10.879	0.000

Table 4.15: ANOVA table of the final model for Cape horse mackerel species in the overlap area

	Effect	SS	df	MS	F	p
Main effects	Intercept	28.9	1	28.9	8.5	0.0036
	Year	163.0	10	16.3	4.8	0.0000
	Time	59.4	1	59.4	17.5	0.0000
	Depth	225.0	3	75.0	22.1	0.0000
	Error	2511.0	739	3.4		

Type III decomposition

General relationships for *T. capensis* only the southern area: the main effects

Year

Figure 4.24 shows a similar shape with the year effect on Cape horse mackerel in Model 4.3 (Figure 4.16, full model for *T. capensis*). This indicates that the result in Model 4.3 reflects the high CPUE of Cape horse mackerel in the southern area. The year is also the second most important variable with a profound effect on Cape horse mackerel in the southern area.

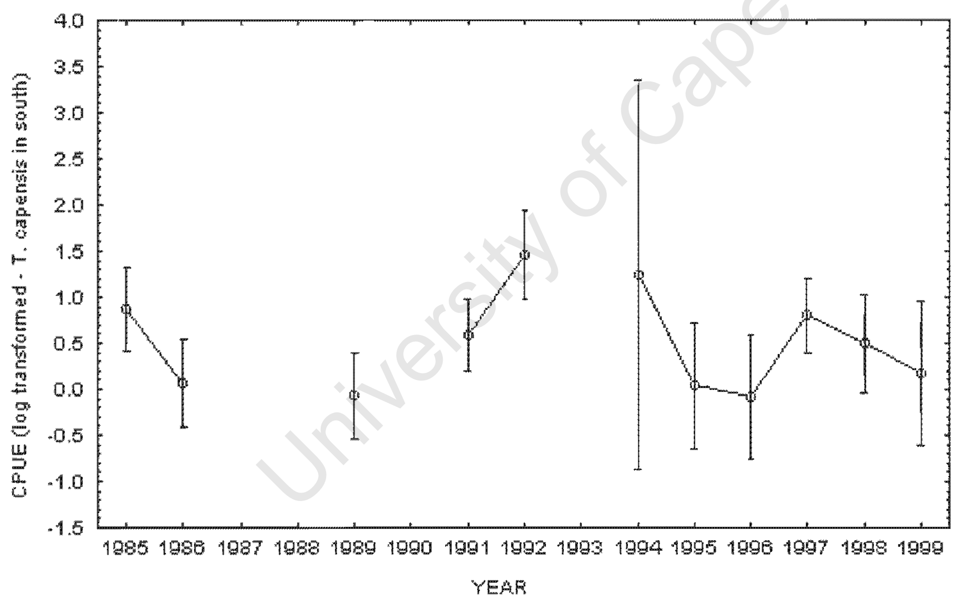


Figure 4.24: Effect of year on Cape horse mackerel CPUE (in the southern Angola area) using the results of the GLM (model 4.5) to estimate parameters (±SE) for each of eleven years

Depth

Depth represents the greatest effect on Cape horse mackerel CPUE in the southern region as it was for Cunene horse mackerel CPUE (Table 4.15). Figure 4.25 shows the depth effect on Cape horse mackerel CPUE remains similar to Model 4.3 (Figure 4.18, full model for *T. capensis*).

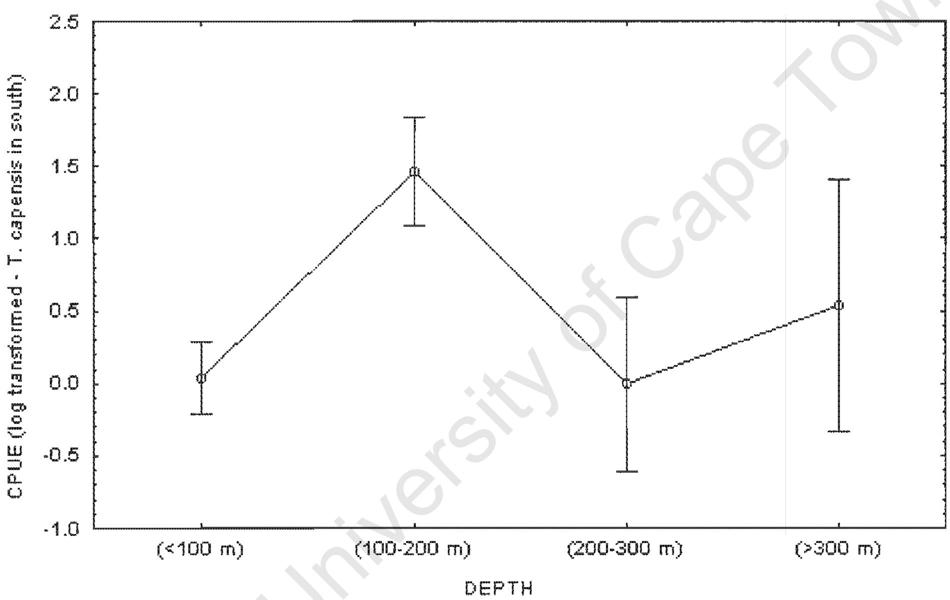


Figure 4.25: Effect of depth on Cape horse mackerel CPUE (in the southern Angola area) using the results of the GLM (model 4.5) to estimate parameters (±SE) for each of four depths

Time

According to the trend in Figure 4.26, there seems to be little difference with the plot in Model 4.3. The time effect explains the least of variation on Cape horse mackerel CPUE in the southern area (Table 4.15). It can be postulated that a higher CPUE of Cape horse mackerel means that more are available during day than night.

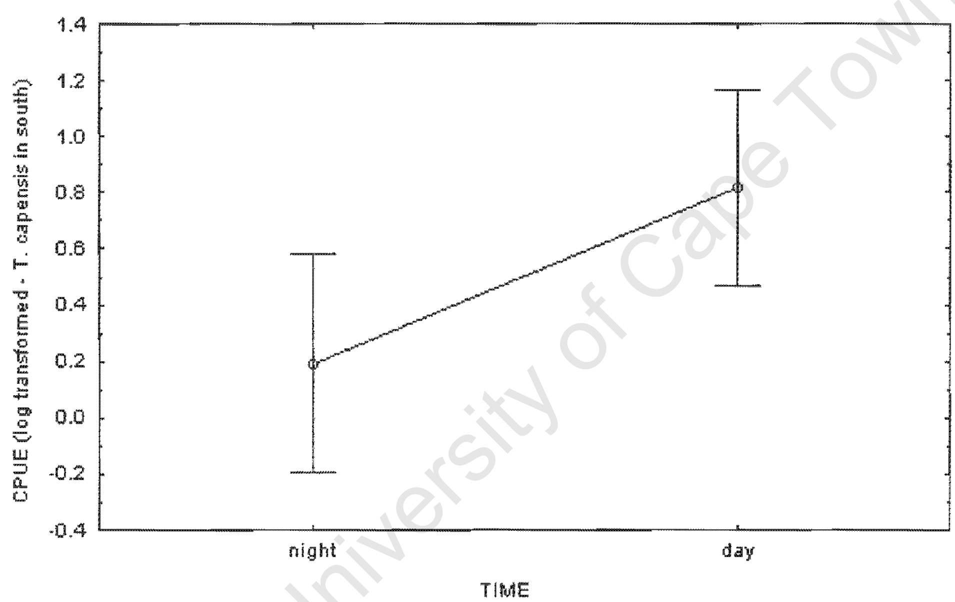


Figure 4.26: Effect of time on Cape horse mackerel CPUE in the southern area using the results of the GLM (model 4.5) to estimate parameters (±SE) for each of the two times

4.3.6. Model 4.6: CPUE of the pooled horse mackerel species incorporating sea surface temperature (SST) in all areas

Sea surface temperature was incorporated in the model in order to investigate the influence of temperature on horse mackerel CPUE. The years 1985 and 1986 were omitted from this analysis because satellite SST was not available. The final model with sea surface temperature accounts for about 27% of the variance in the data (Table 4.16). According to the results from the model (Table 4.17), the main effects of year, area, depth and SST are all significant. No substantial improvements were found in the main effects of season, time and gear in the stepwise analysis and therefore they were removed from the model. No interactions were considered in the model because the analysis was too unbalanced.

Table 4.16: Test of the whole Model for both horse mackerel species (final model with SST)

	Multiple	SS	df	MS	SS	df	MS		
Log of	r^2	Model	Model	Model	Residual	Residual	Residual	*F*	*p*
cpueHM	0.268	1557.501	16	97.344	4262.306	3356	1.270	76.645	0.000

Type III decomposition
cpueHM = CPUE of horse the pooled horse mackerel species

Table 4.17: ANOVA table of final model for both horse mackerel species (final model with SST)

	Effect	SS	df	MS	*F*	*p*
Main effects	Intercept	1089.7	1	1089.7	858.0	0.0000
	Year	112.8	8	14.1	11.1	0.0000
	Area	268.5	2	134.2	105.7	0.0000
	Depth	389.6	3	129.9	102.2	0.0000
	SST	99.0	3	33.0	26.0	0.0000
	Error	4262.3	3356	1.3		

Type III decomposition

Year

The year effect on horse mackerel CPUE also is significant when sea surface temperature is incorporated (Table 4.17). Figure 4.28 shows peak abundances of horse mackerel in 1991 and 1996 and a very low abundance in the period 1994-1995. This second period coincides with the warm environmental conditions in 1994-1996.

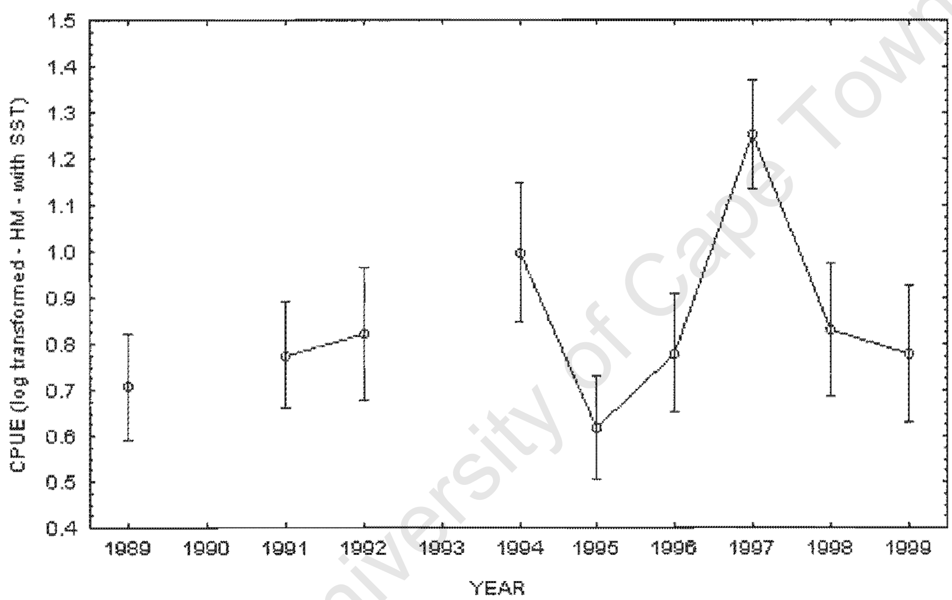


Figure 4.28: Effect of year on horse mackerel CPUE (both species pooled – with SST included) using the results of the GLM (model 4.6) to estimate parameters (±SE) for each of the 9 years available

Area

Table 4.17 the area is the second most important factor that has a substantial effect on horse mackerel CPUE when the sea surface temperature is incorporated in the model. No significant interactions were found between area and sea surface temperature during preliminary analyses (Moreno and Castro, 1994). Figure 4.29 shows that the abundance of horse mackerel species decreases from north (warmer) to the south (cooler) areas.

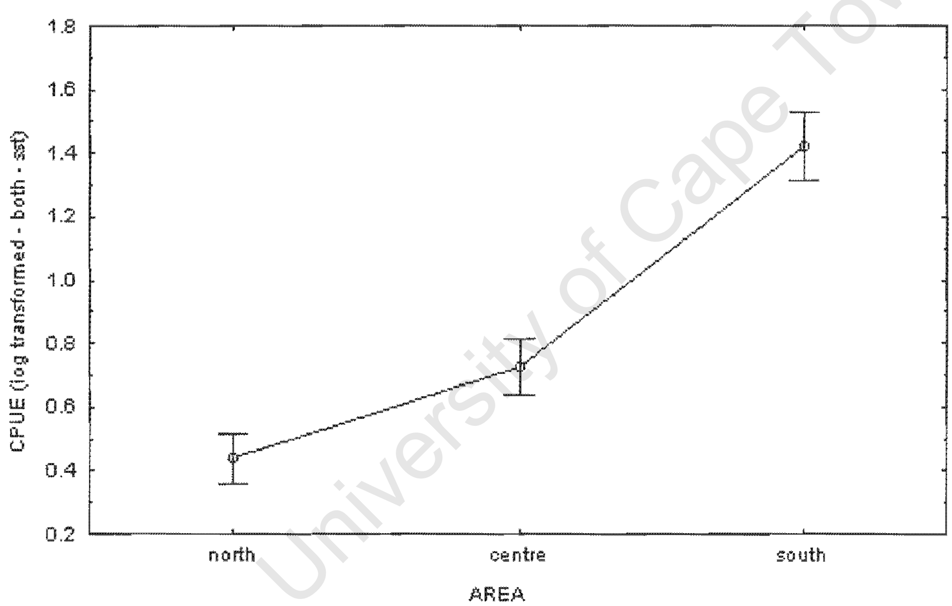


Figure 4.29: Effect of area on horse mackerel CPUE (both species pooled – with SST included) using the results of the GLM (model 4.6) to estimate parameters (±SE) for each of the three areas

Depth

Results from Table 4.17 show a very strong depth effect on the combined horse mackerel model with sea surface temperature. Figure 4.30 shows greater abundance of horse mackerel at depths 0–200 m (inner shelf).

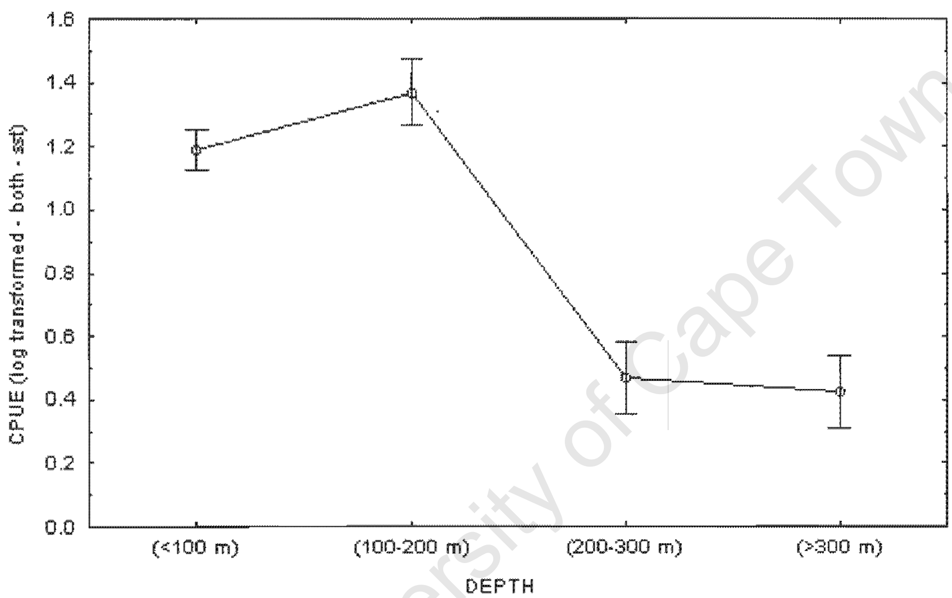


Figure 4.30: Effect of depth on horse mackerel CPUE (both species pooled – with SST included) using the results of the GLM (model 4.6) to estimate parameters (±SE) for each of the four depths

4.3.7. Model 4.7: CPUE of Cunene horse mackerel (T. trecae) incorporating sea surface temperature in the overlap area

Table 4.18: Test of the whole Model for Cunene horse mackerel in the southern area (final model with SST)

	Multiple	SS	df	MS	SS	df	MS		
Log of	r^2	Model	Model	Model	Residual	Residual	Residual	F	p
cpuetrec	0.167	266.942	14	19.067	1330.200	551	2.414	7.898	0.000

Type III decomposition
cpuetrec = CPUE of Cunene horse mackerel

Table 4.19: ANOVA table of final model for Cunene horse mackerel in the southern area (final model with SST)

	Effect	SS	df	MS	F	p
Main effects	Intercept	0.3	1	0.3	0.1	0.7276
	Year	127.7	8	16.0	6.6	0.0000
	Depth	96.6	3	32.2	13.3	0.0000
	SST	79.7	3	26.6	11.0	0.0000
	Error	1330.2	551	2.4		

Type III decomposition

Table 4.19 shows that the main effects of year, depth and sea surface temperature on CPUE of Cunene horse mackerel are very significant ($p<0.0001$) in the overlap area. About 17% of the variability in the data is accounted for by the final model in the overlap area when SST is included as a variable sea surface temperature for Cunene horse mackerel (Table 4.18). It suggests that sea surface temperature has a substantial impact on Cunene horse mackerel CPUE in the southern region.

General relationships for both species pooled (all areas): the main effects

SST

Results from the final model (Table 4.17) show that the effect of sea surface temperature (SST) on horse mackerel CPUE is weaker than other factors in the model. Figure 4.27 shows that the horse mackerel CPUE decreases from <18°C to 26-30°C. This trend confirms that more horse mackerels are found in cooler water. The cooler water (<18°C) is usually found in the south. This pattern will be investigated further in the next two models (model 4.7 and 4.8).

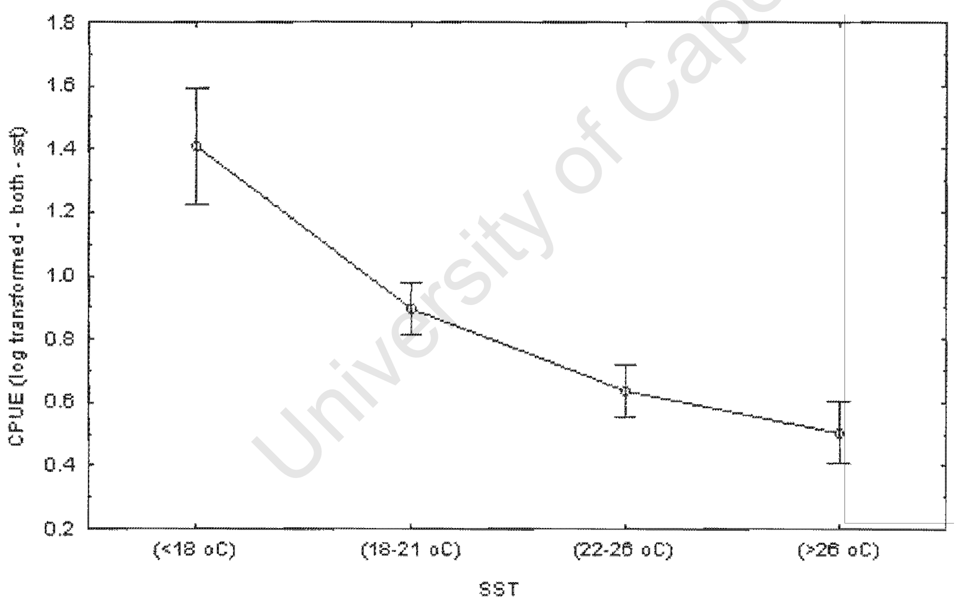


Figure 4.27: Effect of SST on horse mackerel CPUE (both species pooled – with SST included) using the results of the GLM (model 4.6) to estimate parameters (±SE) for each of four ranges of SST

General relationships for *T. trecae* (south with SST): the main effects

SST

Table 4.19 shows a strong sea surface temperature effect on the Cunene horse mackerel CPUE for the southern region. Greater abundance of Cunene horse mackerel occurs at temperatures of 18-26°C (Figure 4.31). This figure also shows that the Cunene horse mackerel CPUE is the lowest at temperatures below 18°C.

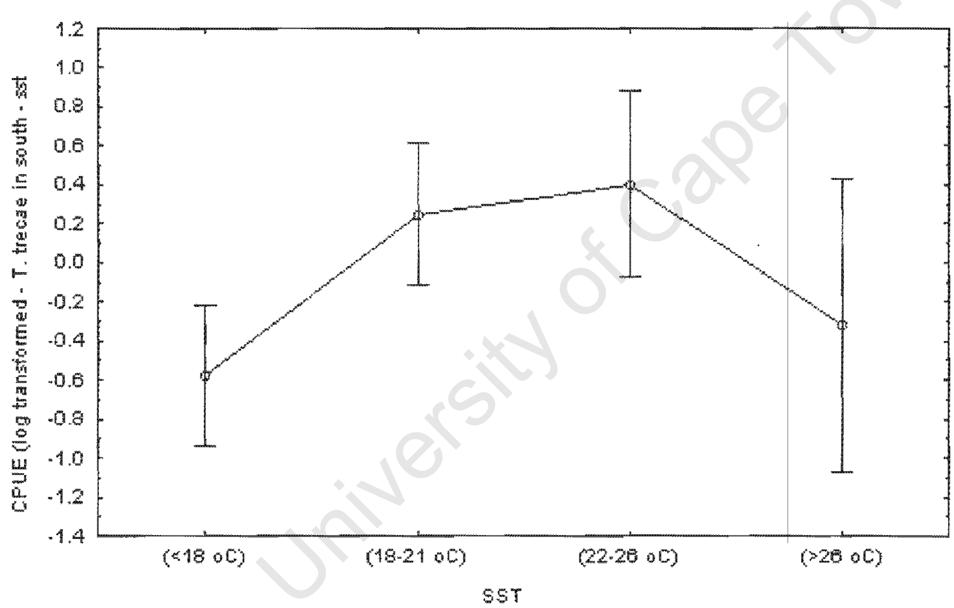


Figure 4.31: Effect of SST on Cunene horse mackerel CPUE in the southern area using the results of the GLM (model 4.7) to estimate parameters (±SE) for each of the four categories of surface temperature

Year

Table 4.19 shows a strongest annual effect on the Cunene horse mackerel CPUE for the southern region with sea surface temperature. Figure 4.32 shows that there may be a slight increasing trend in Cunene horse mackerel CPUE in the period (1995-1999). This figure also shows that the Cunene horse mackerel CPUE peaked in 1991 and 1996, and dropped in the period 1992-1995. Note that, the wider confidence limits in 1994, may be indicative of fewer observations.

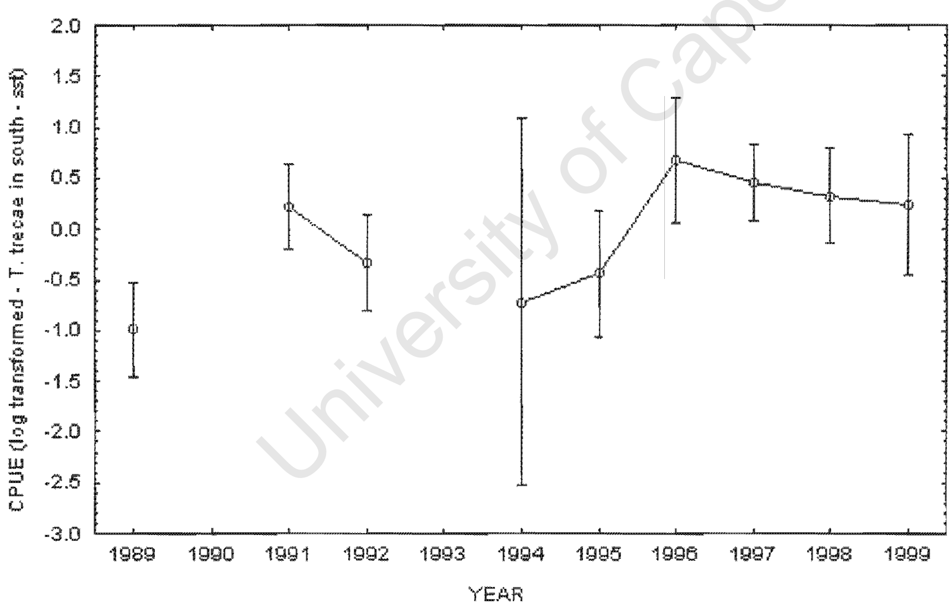


Figure 4.32: Effect of year on Cunene horse mackerel CPUE in the southern area (with SST) using the results of the GLM (model 4.7) to estimate parameters (±SE) for each of the 9 years

Depth

According to the results in Table 4.19, the depth effect is very significant on Cunene horse mackerel CPUE in the southern area. The plot of the depth effect on Cunene horse mackerel CPUE in the southern area (Figure 4.33) still keeps the same trend as Model 4.2 (full model for *T. trecae* Figure 4.10) and 4.4 (full model for *T. trecae* in the southern area without SST Figure 4.22). In general, the Cunene horse mackerel CPUE in the southern area is higher in shallower waters than in deeper waters (Figure 4.33).

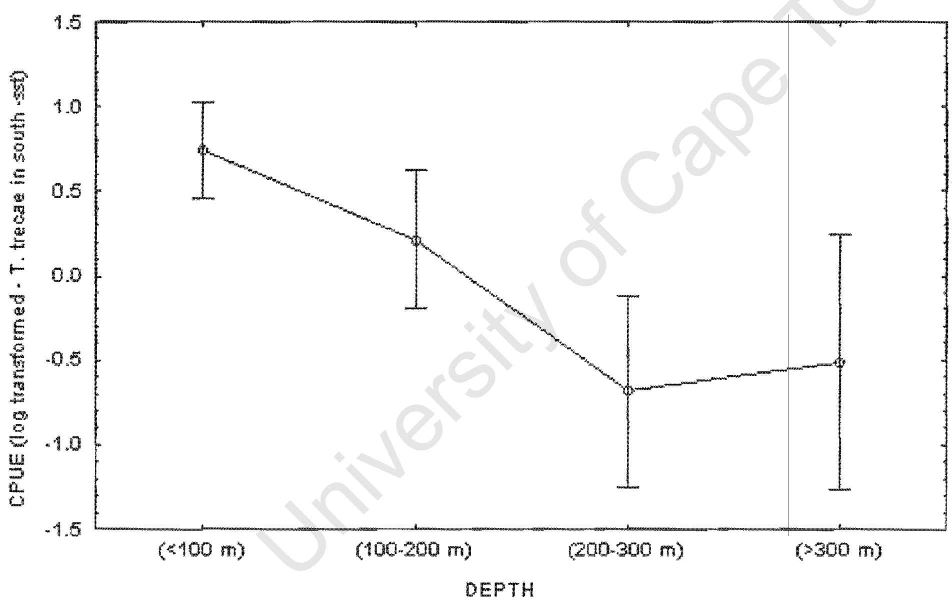


Figure 4.33: Effect of depth on Cunene mackerel CPUE (in the southern area – with SST included) using the results of the GLM (model 4.7) to estimate parameters (±SE) for each of the 4 depths

4.3.8. Model 4.8: CPUE of Cape horse mackerel (*T. capensis*) incorporating sea surface temperature in the overlap area

Table 4.21 also shows that the main effects of year, depth and sea surface temperature on CPUE of Cape horse mackerel are highly significant (p<0.0001) in the overlap area model. The final model for Cape horse mackerel in the overlap area with sea surface temperature accounts for about 26% of the variance in the data (Table 4.20). This result suggests that sea surface temperature has a stronger impact on Cape horse mackerel CPUE than Cunene horse mackerel in the southern area.

Table 4.20: Test of the whole Model for Cape horse mackerel in the southern area (final model with SST)

	Multiple	SS	df	MS	SS	df	MS		
Log of	r^2	Model	Model	Model	Residual	Residual	Residual	F	p
cpuecape	0.257	602.383	14	43.027	1739.605	551	3.157	13.628	0.000

Type III decomposition
cpuecape = CPUE of Cape horse mackerel species

Table 4.21: ANOVA table of final model for Cape horse mackerel in the southern area (final model with SST)

	Effect	SS	df	MS	F	p
Main effects	Intercept	3.8	1	3.8	1.2	0.2712
	Year	78.1	8	9.8	3.1	0.0020
	Depth	186.2	3	62.1	19.7	0.0000
	SST	259.2	3	86.4	27.4	0.0000
	Error	1739.6	551	3.2		

Type III decomposition

General relationships for *T. capensis* (south with SST): the main effects

SST

The strongest main effect on the Cape horse mackerel model for the southern area is SST (Table 4.21). This result explains the importance of the influence that sea surface temperature may have on variation of Cape horse mackerel abundance in the overlap area. Figure 4.34 shows that the Cape horse mackerel CPUE decreases from low (<18°C) to high temperatures (>26°C).

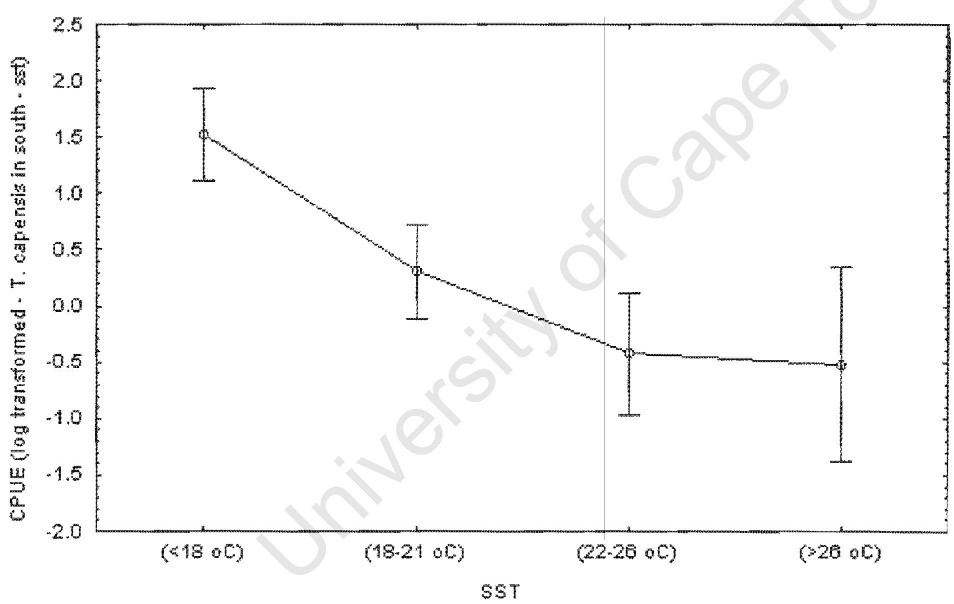


Figure 4. 34: Effect of SST on Cape horse mackerel CPUE (in the southern Angola area with SST incorporated) using the results of the GLM (model 4.8) to estimate parameters (±SE) for each of the four ranges of SST

Year

Table 4.21 shows that the annual effect on the Cape horse mackerel model for the southern region with sea surface temperature is significant (p<0.005). Figure 4.35 shows that there may be a slight decreasing trend in Cape horse mackerel CPUE over the whole period. This figure also shows that the Cape horse mackerel CPUE dropped substantially in 1995, 1996 and 1999. The wide confidence limits in 1994, are possibly due to fewer number of observations.

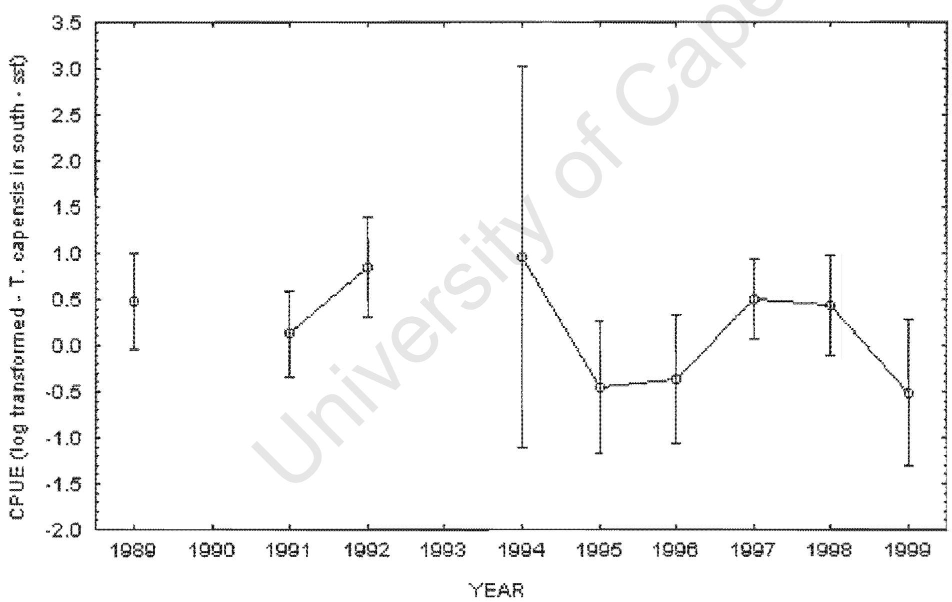


Figure 4.35: Effect of year on Cape horse mackerel CPUE (in the Angola southern area – with SST) using the results of the GLM (model 4.8) to estimate parameters (±SE) for each of the 9 years

Depth

Results from Table 4.21 show a very strong depth effect on Cape horse mackerel model with sea surface temperature in the southern area. Figure 4.36 shows the greatest abundance of Cape horse mackerel at depths of 100-200 m. There may be a slight increase in Cape horse mackerel CPUE from outer shelf depths of (200-300 m) to offshore (>300 m).

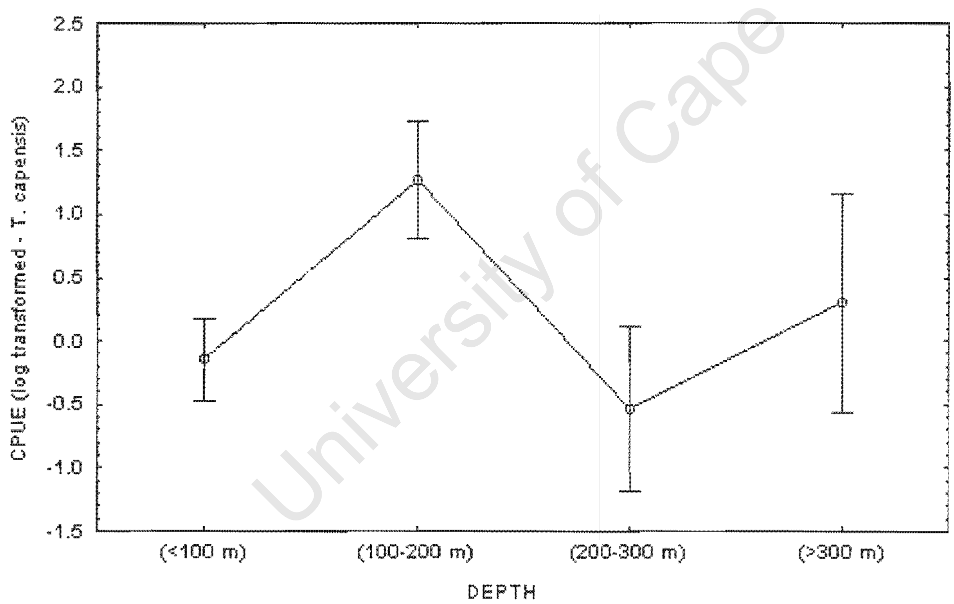


Figure 4.36: Effect of depth on Cape horse mackerel CPUE (in the southern area – with SST included) using the results of the GLM (model 4.8) to estimate parameters (±SE) for each of the four depths

4.3 Discussion

Results from models 4.1 (pooled spp.), 4.2 (*T. trecae*), 4.3 (*T. capensis*) and 4.6 (pooled spp. with SST) for the whole area are discussed first. The southern area (Angola-Namibia front) models 4.4, 4.5, 4.7 and 4.8 are discussed separately.

Whole area

The effect of years on horse mackerel CPUE distribution is of interest. The *p* value calculated on the year effect ($p<0.0001$) for each horse mackerel model is below the acceptance limit (0.05) meaning that there are highly significant differences among the mean year values as adjusted by the model (see models 4.2 and 4.3). The year effect was substantially stronger on Cunene horse mackerel than on Cape horse mackerel in the full area, but there is not much difference in the overlap area. In general from all models, 1995 represents lowest values of CPUE and it coincides with the Benguela Niño event that occurred in that year (Gammelsrod *et al.*, 1998). The lowest values for the Cape species were from 1994 to 1996. It is the period considered by Bianchi *et al.* (1997) and Gammelsrod *et al.* (1998), to have had abnormally warm environmental conditions.

There is no significant difference at $p>0.05$ in the adjusted seasonal means from models. However, this result contradicts the expectation that, in general, biomass estimated from acoustic densities by R/V Dr. Fridtjof Nansen are usually higher in winter than in summer (Anon, 1999).

Results from models 4.1 and 4.3 show that the area effect is highly significant and stronger than the two temporal effects analysed above. The LS means of CPUE for the Cunene species increases from the north to south. Comparison showed that the mean of

Cape horse mackerel CPUE is higher than Cunene horse mackerel CPUE in the southern area. The result confirms those of Wysokiñski (1986), Toresen (1995) and Bianchi *et al.* (1997), that the abundance of the Cape species in the south is greater than the Cunene horse mackerel.

The depth analysis showed that Cunene horse mackerel CPUE is high in the inshore stratum (0-100 m) and Cape horse mackerel CPUE is higher in the mid-shelf stratum (100-200 m). This result agrees with that postulated by Bianchi (1986), who suggested that Cape horse mackerel occurs deeper than Cunene horse mackerel species.

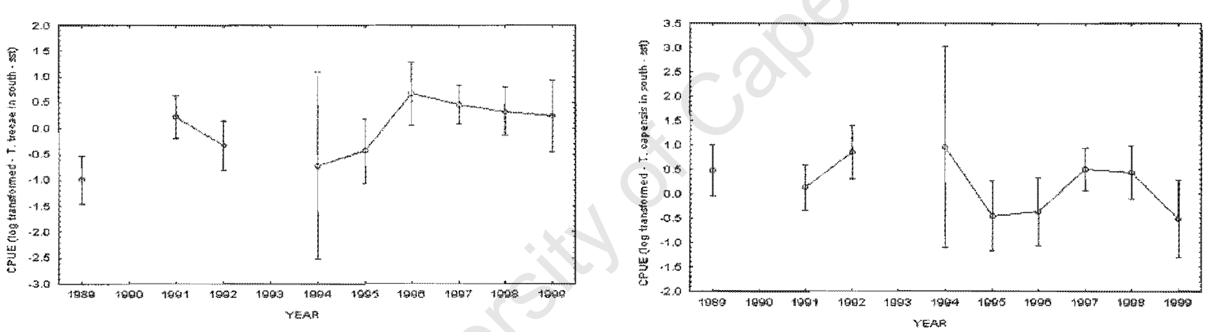
In general there was no substantial significance of the gear effect on horse mackerel CPUE models. However the graphic trend suggests that the Cunene horse mackerel is more susceptible to the bottom trawl gear (model 4.2).

Results from models 4.1 (pooled spp), 4.2 (*T. trecae*) and 4.3 (*T. capensis*) showed very strong interactions between year and both area and depth. This may possibly indicate some migration between areas (north-south) and between depths (onshore-offshore).

According to Maravelias (1997), temperature is a major factor in influencing fish behaviour. Fish tend to congregate in thermal ranges that offer them opportunities to optimise their activities and this is manifest in their abundance and distribution. According to results from model 4.6 (Table 4.17), the SST effect on horse mackerel species is significant but explains very little about the variation of horse mackerel abundance within the area studied.

Southern area (overlap area)

Again here, the year effect is the variable that explains most of the effect on horse mackerel CPUE variation in the overlap area. Results in Figures 4.32 (Cunene horse mackerel, model 4.7) and 4.35 (Cape horse mackerel, model 4.8) show that during 1991, 1995, 1996 and 1999 the year effect was stronger on Cunene horse mackerel CPUE than on Cape horse mackerel CPUE in the overlap area. In these years the Cunene horse mackerel CPUE was higher than that of the Cape horse mackerel. However, there is a clear difference of year effect on the two horse mackerel species in the southern area (Figure 4.37), the two species often showing opposite trends.



Figures 4.37: Results of the year effects (left) from model 4.7 (*T. treace*) and (right) from model 4.8 (*T. capensis*) in the southern area

The results from the full models (Tables 4.13 and 4.15) showed that the gear effect is significant for Cunene and not significant for the Cape horse mackerel CPUE. This is an indication of greater variation in the Cunene horse mackerel CPUE between the two gears (pelagic and bottom trawls) than for the Cape horse mackerel CPUE. In comparing results from these tables (4.13 and 4.15) the time effect was significant for Cape horse mackerel and not significant for Cunene horse mackerel CPUE. This suggests that the abundance of the Cape horse mackerel varies more by day and night than that of Cunene horse mackerel.

Results from Figures 4.33 and 4.36 shows that the depth effect is more pronounced for Cape horse mackerel than the Cunene species. However, there seems to be a clear depth segregation between the two horse mackerel in the depth range (0-100 m) and similar trends in CPUEs for deeper zones in the southern Angola area are present. In the overlap area Cunene horse mackerel seems to be more abundant in shallow water and Cape horse mackerel is more abundant in mid-shelf (Figures 4.33 and 4.36). This trend does not conflict with that observed by several authors who conducted studies on horse mackerel (Da Franca, 1968, Wysokiñski, 1987, Toresen, 1995 and Bianchi *et al.*, 1997). However, there are many other factors that influence fish behaviour that were not tested in this study.

The results in Models 4.7 (Cunene horse mackerel with SST) and 4.8 (Cape horse mackerel model with SST) show an effect of cooler sea surface temperature (<18°C) on Cape horse mackerel CPUE. It is seen that Cunene horse mackerel CPUE increases in temperatures 18-21°C, but declines above 26°C. This result supports the suggestion of Bianchi (1986) that temperatures between 18-26°C indicate an optimal for environment Cunene horse mackerel (Figures 4.38).

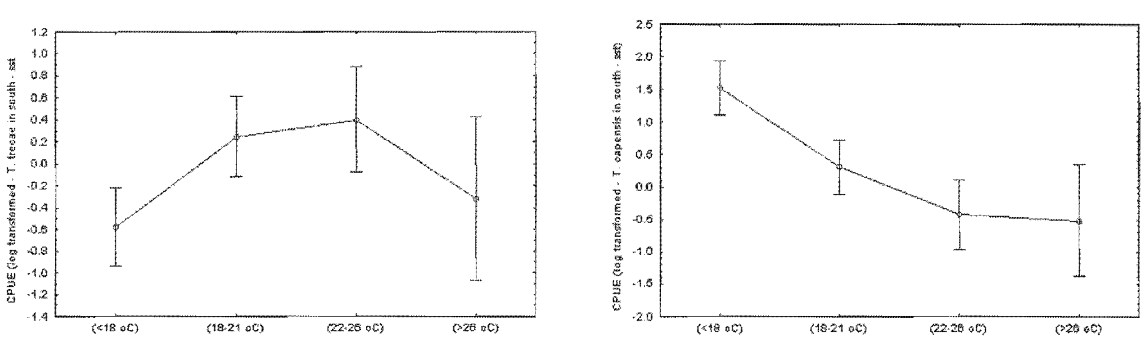


Figure 4.38: Results of the SST effects (left) from model 4.7 (*T. trecae*) and (right) from model 4.8 (*T. capensis*)

Unfortunately, CTD data were not available for these cruises. Nonetheless this type of data could contribute substantially to similar or future studies, providing information on the bottom conditions and the vertical distributions of temperature. For example, such data would allow one to investigate vertical patterns of horse mackerel in relation to the variation of temperature at different layers of the water column.

The Cape horse mackerel model with sea surface temperature (model 4.8) showed a greater improvement in r^2 with SST than can be found for the Cunene horse mackerel in Model 4.7. This may indicate that the effect of sea surface temperature in the overlap area is stronger on Cape horse mackerel CPUE than Cunene horse mackerel.

Surprisingly, the season is consistently the least significant effect. Thus, adequate estimates of CPUE and of abundance can be obtained in either season.

Chapter Five

Relative frequencies of two horse mackerel species in mixed catches in relation to environmental and other factors

Abstract

To characterize the distribution and mixture of the horse mackerel species, this chapter discusses the distribution and mixture of the two horse mackerel species based mainly on trawls (pelagic and bottom trawls) in which they occur in the period 1985-1999. The statistical results using Microsoft Excel worksheets and plots focus on comparison of distributions and mixtures between the two horse mackerel species, mainly in the overlap area of the Angola-Benguela front. The total CPUE was used to represent the abundance of the two species as a base case. These were then converted to percentages for each of the two horse mackerel species to define the relative abundance of each species in the southern region. The results from GLM in the previous chapters are taken into account to support the discussion of findings between the different analyses. The results of the analysis will also contribute to interpret the effect of sea surface temperature on horse mackerel distribution.

5.1 Introduction

The oceanographic conditions in the study region are believed to be important in determining the distribution and mixture of Cape and Cunene horse mackerel species. Some results and conclusions by Stachlewska *et al*. (1999), suggest that the frontal zone is characterized by a seasonal fluctuation of its geographical position and by multiple fronts, which are common especially in summer when the southward flow of the Angola water is strongest. The resource is considered the most valuable pelagic stock in the area. Thus, the first objective of this chapter is to characterise the distribution and mixture of Cunene and Cape horse mackerel in the area around the Angola-Benguela front. The second objective is to establish the connection between the distribution of the horse mackerel species and the movements of the Angola-Benguela front, using results from previous studies on the movements of the Angola front (Figure 5.1).

This is because in that year there had been two acoustic surveys, one in the summer and one in the winter in that area.

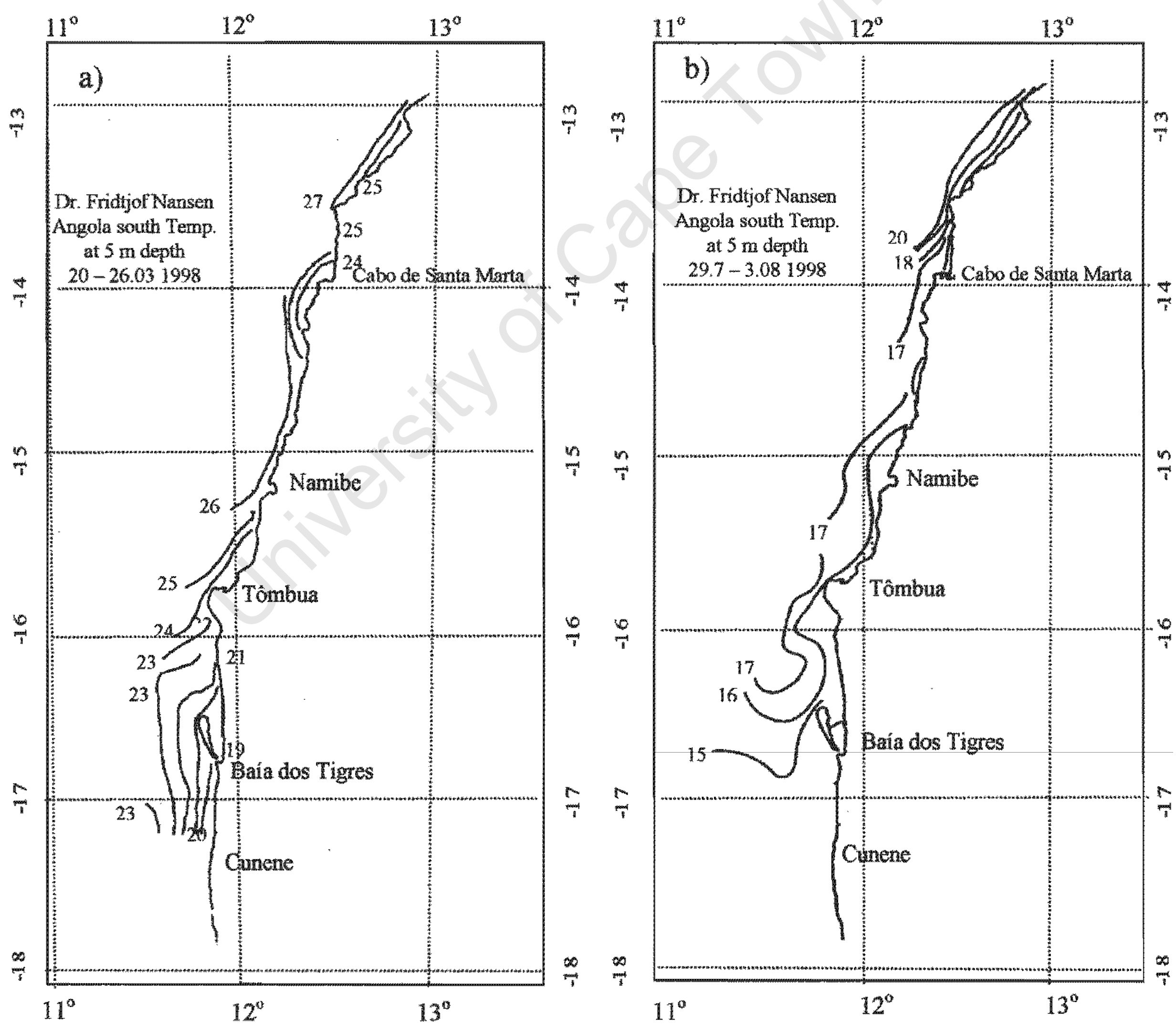


Figure 5.1: Horizontal distribution of temperature at sea surface (5 m depth) in 1998 (°C) in the south (a = summer and b = winter, from Anon, 1998).

5.2. Data analysis

All statistical analyses of existing catch rate data (CPUE) and sea surface temperature data, were performed using standard statistical techniques (Microsoft Excel, 1997). The horse mackerel distribution data were compiled, organised and analysed from survey catches. These data have been organised according to the position of the catches occurring in both Angolan and northern Namibian waters and utilised in the following manner:

Spatial distribution: The latitudes of the trawls where both species of horse mackerel occurred were recorded to investigate their distribution over the Angolan shelf. This was especially important in mixed trawl catches. Size compositions were analysed by separating mixed trawls into small (<14 cm), medium (14-19 cm) and large (>20 cm) size classes. Then the co-occurrences of both species were divided into three depth strata (<50 m; 50-200 m and >200 m depth) to investigate the degree of segregation of the two horse mackerel species using mixed catch data. Undoubtedly, other depth strata could be used with equal effectiveness, but this is an arbitrary choice. Subsequently the Chi-square test was chosen to analyse the data for the present study (Zar, 1984).

Temporal distribution: Temporal data were used to elucidate monthly and seasonal patterns and movements of two the horse mackerel species.

The data were provided by the Nansen Programme through the Angola Marine Research Institute (IIM) and Ministry of Fisheries & Marine Resources of Namibia (NatMIRC). All information was processed using basic statistical and graphical methods. After extraction of data using the Nan-sis database (Nansen Survey Information System vers. 8.94), the data were entered into Excel spreadsheets and used for further analysis. Some plots from STATISTICA were also used for interpretive purposes. The sea surface temperatures were extracted from Meteosat images (H. Demarcq, the IDYLE project) and recorded at one degree latitude intervals (5-20°S) to relate to horse mackerel catch data.

From CPUE data obtained from the Nansen Survey Information System (Nan-sis), the percentage relative abundance of the two horse mackerel species was calculated using the following formula:

1. % of horse mackerel species (a) = (CPUEa/(CPUEa+CPUEb))*100 and
2. % of horse mackerel species (b) = (CPUEb/(CPUEa+CPUEb))*100

where: a and b are *T. trecae* and *T. capensis* respectively

Note that the use of relative abundance was to compare only the proportion between the two horse mackerel species from mixed trawls in the overlap area.

5.3. Results

5.3.1 Spatial distribution

The latitudinal occurrence of Angolan horse mackerel (trawls in which present) from 1985 to 1999 of each species by month showed differences in the distribution between the two horse mackerel species (Table 5.1). The same trend is shown in the latitudinal Namibian horse mackerel occurrence from 1990 to 1998 by month (Table 5.2). It confirms that the distribution of Cunene horse mackerel is wide over the Angolan coast, while the Cape horse mackerel is concentrated between 16° and 17°S.

Table 5.1: Latitudinal-monthly occurrence (trawls in which present) for each species of horse mackerel based on Angola surveys data from 1985 to 1999. (Data provided by the Nansen Programme through IIM).

Lat. (S)	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
5°			8	0	9	0			18	0					26	0	9	0					8	0
6°			14	0	26	0			39	0	4	0			57	0	19	0			1	0	6	0
7°			11	0	36	0			49	0	3	0			83	0	11	0			2	0	9	0
8°			14	0	44	0	1	0	62	0	11	0	15	0	86	0	23	0			8	0	16	0
9°	1	0	32	0	29	0	1	0	41	0			21	0	70	0	27	0			12	0		
10°	0	0	25	0	36	0			51	0			15	0	80	0	30	0			14	0		
11°			28	0	26	0			56	0	6	0	15	0	60	0	33	0			11	0		
12°			22	0	22	1	4	0	45	0	13	0	5	0	36	1	26	0			10	0		
13°					6	0	4	0	2	0					13	1	11	1			1	0		
14°			7	2	5	0	2	0	4	0	1	0			5	2	11	3			3	0		
15°	2	0	4	2	6	2	6	1	1	0	3	1	1	0	11	8	25	19			8	0		
16°	24	10	22	33	43	15	28	24			39	24	6	8	9	29	33	57			19	31		
17°	10	11	5	10	5	4	3	7			5	13	0	3	2	13	2	18			2	9		
18°															0	13								
19°															0	12					1	0		
20°															0	10								

T : *T. trecae* and C : *T. capensis*
Empty space = No data

From this table we can see that there were no cruises in October from 1985 to 1999. One survey was carried out to study the northern Angola-Benguela front fully in August 1997. March and August were the most regularly sampled months.

Table 5.2: Latitudinal-monthly occurrence (trawls in which present) for each species of horse mackerel based on Namibian survey data from 1990 to 1998. (Data provided by the Nansen Programme through NatMIRC).

Lat. (S)	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
15°			0	0						0	1	0											1	0
16°			13	0						0	18	19									6	12	18	4
17°			0	45	0	11				19	2	55							0	13	0	20	0	13
18°			3	53	0	29				32	0	79							0	19	0	37	0	32
19°			0	37	0	42				45	0	62							0	20	0	38	0	14
20°			0	56	0	25				33	0	46					0	10	0	8	0	49	0	12

T : *T. trecae* and C : *T. capensis*
Empty space = No data

Table 5.2 shows that fishing surveys did not cover the months evenly. There were no Namibian surveys in January, April, July and August in the north of Namibia with regard to horse mackerel species. December and February (summer) and May-June (winter) have been the months with most regular cruises.

The mixture between the two species in the studied area is not regular and it seems to fluctuate from year to year (Table 5.3). Table 5.3 shows the distribution and mixture of horse mackerel species. The Cape species distribution clearly increases from the south of Angola to northern Namibia. The main occurrences of the Cunene species were in the central and northern Angolan waters. This relative latitudinal distribution is therefore of importance to us, because it might be possible to separate future commercial landings between the two horse mackerel species in the northern area of the Angola-Benguela front from the knowledge of the latitudinal catch position (Table 5.3 and Figure 5.2).

Table 5.3: Summary of latitudinal occurrence and its percentage for each species of horse mackerel

Lat.	Occurrence			No total	% of occurrence		
(°S)	*T. trecae*	*T. capensis*	Mixture	of trawls	*T. trecae*	*T. capensis*	Mixture
5°	78	0	0	82	95	00	00
6°	166	0	0	170	98	00	00
7°	204	0	0	212	96	00	00
8°	280	0	0	282	99	00	00
9°	233	0	0	240	97	00	00
10°	251	0	0	256	98	00	00
11°	235	0	0	241	98	00	00
12°	182	1	1	188	97	01	01
13°	35	0	2	38	92	00	05
14°	35	4	3	42	83	10	07
15°	42	6	27	75	56	08	36
16°	161	162	115	439	37	37	26
17°	16	244	31	291	05	84	11
18°	0	294	3	297	00	99	01
19°	1	271	0	274	00	99	00
20°	0	249	0	252	00	99	00

Note that the mixed trawls were subtracted from total of horse mackerel trawls (Total = trecae + capensis + mixed).

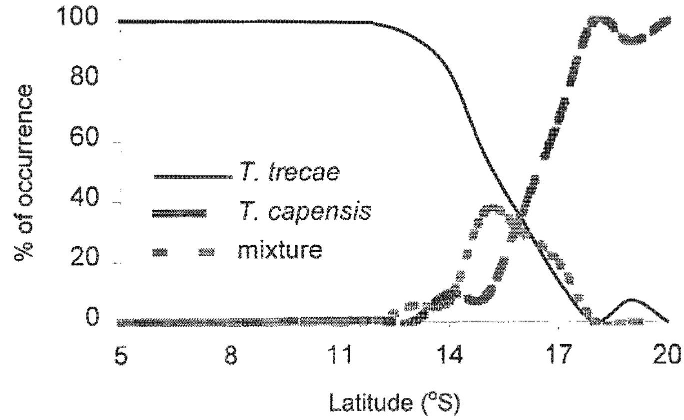


Figure 5.2: Percentage occurrence of the two horse mackerel species in trawls from surveys of R/V Dr. F. Nansen from 1985 to 1999 for the total Angola-Namibia front area.

Figure 5.2 shows trends in the spatial distribution with latitude and the greater mixture between both species in the area between 14° and 18°S. Different distribution patterns between the two horse mackerel species are very clear in this figure.

The latitudinal Angolan and Namibian horse mackerel occurrence by season and by species in the study period follows the same trends in the area between 15° and 18°S (Table 5.4). The distribution of the two horse mackerel species by depth in the overlap area is arranged into three selected strata (Table 5.5).

Table 5.5: General latitudinal - seasonal occurrence (trawls in which present) of two horse mackerel species for the Angolan and northern Namibian areas. (Data provided by the Nansen Programme through IIM and NatMIRC).

Lat.	Angola survey data (1985-1999)				Namibia survey data (1990-1998)			
(S)	Summer (Nov-April)		Winter (May-Oct)		Summer (Nov-April)		Winter (May-Oct)	
	T. trecae	*T. capensis*	*T. trecae*	*T. capensis*	*T. trecae*	*T. capensis*	*T. trecae*	*T. capensis*
5°	25	0	53	0				
6°	47	0	119	0				
7°	58	0	146	0				
8°	83	0	197	0				
9°	74	0	159	0				
10°	76	0	175	0				
11°	65	0	170	1				
12°	58	1	125	1				
13°	11	0	26	2				
14°	17	2	21	5				
15°	26	5	41	28	1	0	1	0
16°	136	113	87	118	37	16	18	19
17°	25	41	9	47	0	89	2	87
18°				13	3	151	0	130
19°				13	0	131	0	127
20°				10	0	142	0	97

Empty space = No data

Table 5.5: Horse mackerel occurrence in the same depth interval (0-500 m depth) in the overlap area. (Data from Nansen Programme through IIM and NatMIRC).

Depth	Species	Mean CPUE (kg/h)	Variance	SD	% of total CPUE	Occurrence *
(< 50 m)	*T. trecae*	722.18	1006980.16	1003.48	35.09	115
	T. capensis	165.54	52829.45	229.85	6.92	43
(50-200 m)	*T. trecae*	356.73	107672.60	328.13	19.53	239
	T. capensis	666.90	367329.10	606.08	31.91	251
(>200 m)	*T. trecae*	209.63	54184.98	232.78	17.21	29
	T. capensis	384.04	641044.60	800.65	23.78	43

Occurrence * = Trawls in which present

Table 5.5 shows the statistical summary results calculated from Nan-sis based on horse mackerel CPUE data in the overlap area (see Appendices I, II, III and IV).

The observed frequency of occurrence at each depth category from Table 5.5 was tested, using a two-way contingency table (X^2). The formula can be expressed as:

$$X^2 = \sum_{i=}^{a}\sum_{1}^{b}\frac{(Observed - Expected)^2}{Expected}$$

Where a and b are species and depths respectively.

The contingency table (X^2-test) of mixed schools of two horse mackerel species within the three different depths in the overlap area shows a significant difference between the species at 95% confidence level (Table 5.6).

Table 5.7: Two-way contingency table (X^2-test) of occurrence of the two horse species at three different depth strata (data from Table 5.5).

b = depth / a = species	(< 50 m)		(50 – 200 m)		(> 200 m)		Total
	expected	observed	expected	observed	expected	observed	
T. trecae	84	115	261	239	38	29	383
T. capensis	74	43	229	251	34	43	337
Total	158		490		72		720 = N

Null hypothesis (H_0): There are no differences in occurrence by depth between the two horse mackerel species in the southern region of Angola.

The expected occurrences were calculated, using the formula below:

$$\text{Expected} = \frac{(\sum Row) * (\sum Column)}{N}$$

df (degrees of freedom) = (2-1) (3-1) = 2

$X^2 = 32.9088$, $p<0.05$. Therefore reject H_0 and accept H_1 (The occurrences of the two horse mackerel species differ in proportions at three depths). This may indicate that there is depth segregation between the species. It is reinforced by results of analyses of the mixed trawl catches, where both species had approximately the same size in each depth category but differ in proportions at three depths (Figure 5.3).

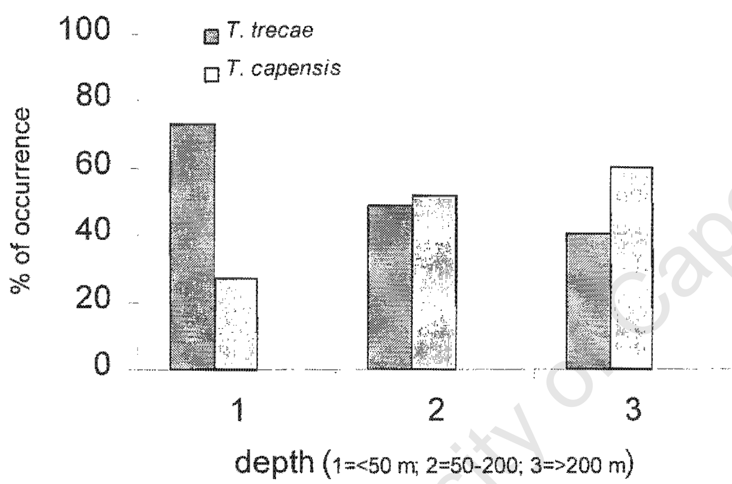


Figure 5.3: Percentage of relative occurrence by depth based on mixed trawl hauls from R/V Dr. F. Nansen surveys of two horse mackerel species for the southern Angolan area (from 13° to 18°S, data from Table 5.5).

Figure 5.3 shows that the percentage of the Cunene horse mackerel in mixed trawl catches was greater in shallow water and decreases from mid-shelf to offshore, while for Cape horse mackerel species the trend seems to be opposite.

The plots of temperature distribution (SST) on each degree of horse mackerel catches by latitude are detailed in the next section (5.3.3) and they showed lower values of temperature (from 14° to 24°C) for *T. capensis* than for *T. trecae* (from 19° to 28°C).

5.3.2 Temporal distribution

The mean annual and seasonal catch rates (kg/hour and/or number of fish/hour) vary between species. Figure 5.4 shows that there is a peak in 1992 for Cape horse mackerel and another one in 1993 for Cunene horse mackerel. There were peaks in 1998 for both species of horse mackerel. This also shows the lowest CPUE for Cape horse mackerel in the period 1994-1996.

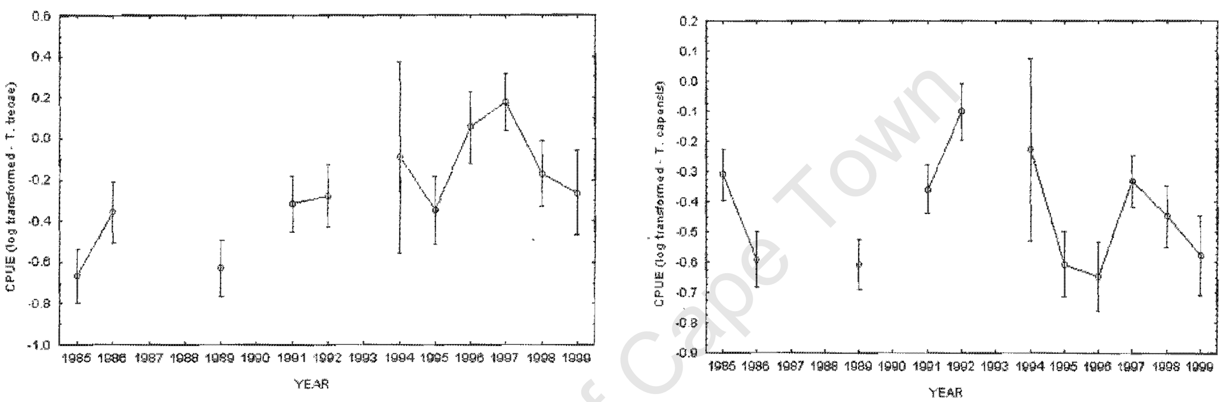


Figure 5.4: LS mean annual CPUE (kg/h) from GLMs model 4.2 and 4.3 (Chapter 4) for each species of horse mackerel based on R/V. Dr. F. Nansen surveys catch rate data from 1985 to 1999.

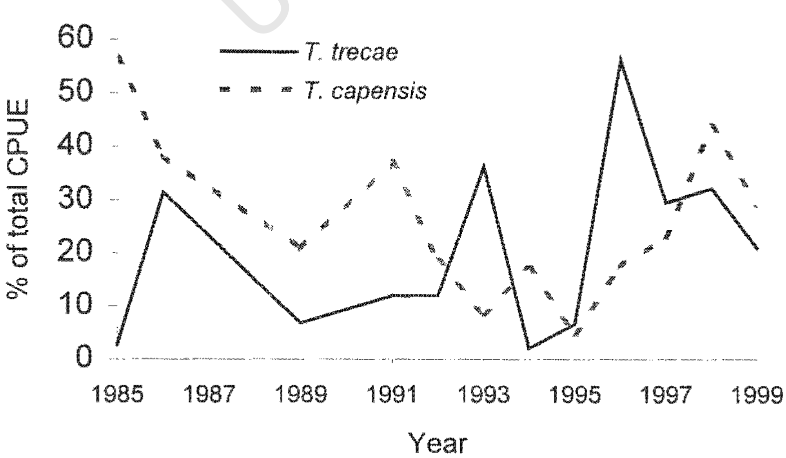


Figure 5.5: Percentage annual of total CPUE from R/V Dr. F. Nansen surveys of two horse mackerel species for the southern Angolan area (from 13° to 18°S).

The Figure 5.5 shows that the annual percentage of total catch was clearly dominated by the Cape horse mackerel species in the overlapping area from 1985 to 1992 and from 1998 onwards. A major abundance of Cunene horse mackerel species were noted in 1993, 1996 and 1997.

From Figure 5.6 below, it is clear that there were no surveys in 1987, 1988 and 1990. The distribution of positive trawl catches for the two horse mackerel species was not even by month. It varies from 1985 to 1993. From 1994 to 1999 there were surveys at each season at least, with two observed modes in Figure 5.6, the first one around March and the second around August.

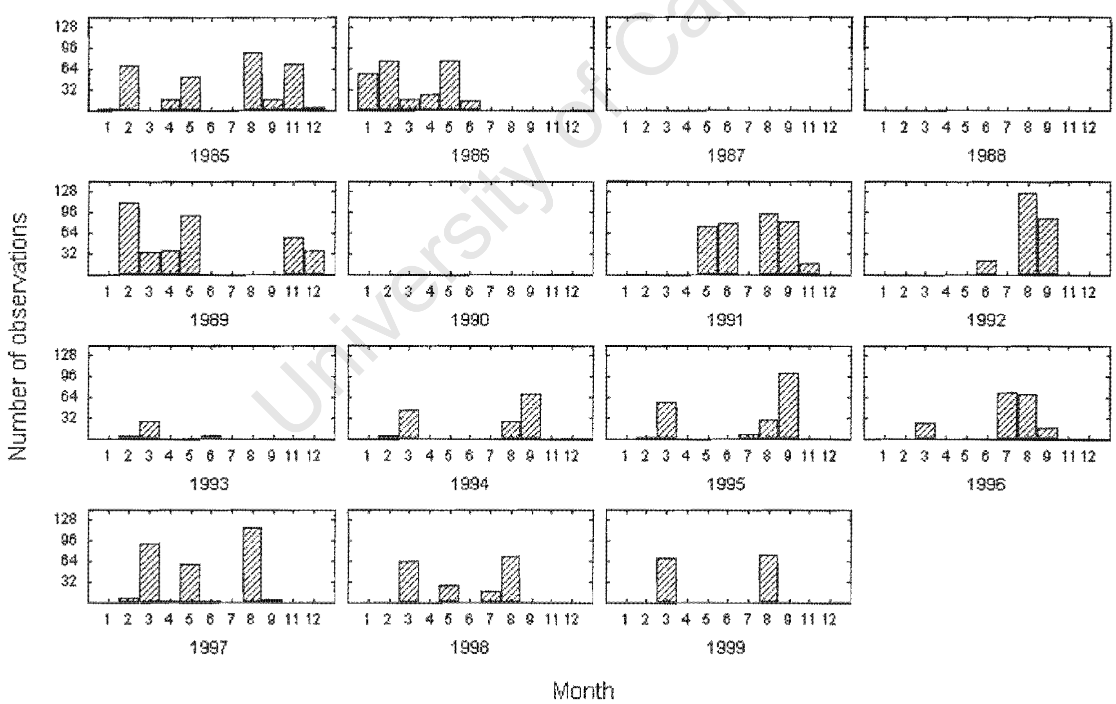


Figure 5.6: Monthly occurrence (observations) for both horse mackerel species pooled, based on positive trawl survey catches by the Dr. Fridtjof Nansen in Angolan waters from 1985 to 1999. (Empty years and months = no data).

Figure 5.6 shows that the surveys have been carried out with some inconsistencies in time, and according to Bianchi and Ostrowski (2000), this was mainly due to the lack of a long term co-operation programme between Angola and the Nansen Programme. As a result, there have been a number of different projects (the first in 1985-1986; the second in 1989; the third in 1991-1993 and an extended project from 1994 onwards). Each species distribution from each survey by season and latitude has been plotted (Figures. 5.7and 5.8), the mean of CPUE for each horse mackerel species increases during the winter season and in the coolest southern area of Angola (16–17°S).

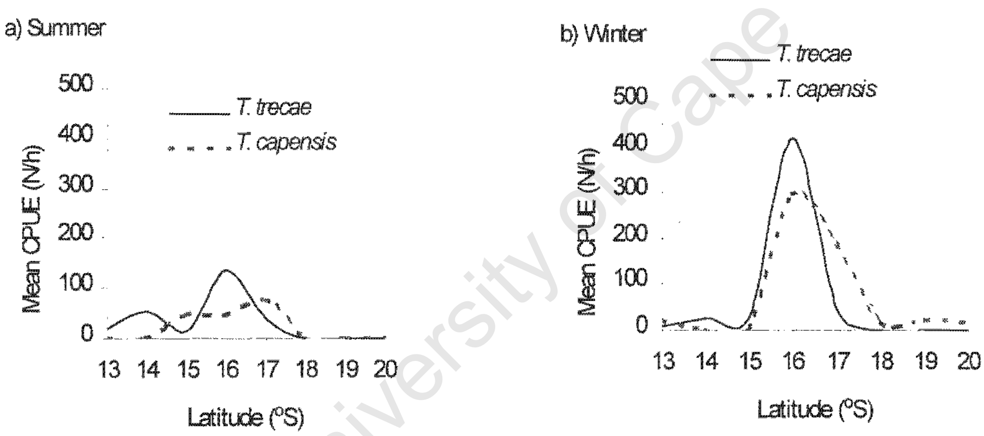


Figure 5.: Mean seasonal CPUE (N/h) based on surveys of RV Dr. F. Nansen from 1985 to 1999 for the horse mackerel species in the southern Angolan area (a = summer (Nov-April) and b = winter (May-Oct).

Figure 5.7 shows the seasonal movement of the two horse mackerel species where *T. trecae* seems to increase from the summer to winter. *T. capensis* also increases in the winter. The comparison in Figure 5.8 below, shows changes in the distributional occurrence between the two seasonal periods in southern Angola: while in the summer the occurrence of Cape species was further south (from 14°S), in the winter Cape horse mackerel shifted about 2 degrees northward (from 12°S). However, this may also be a reflection of the winter season when the Cape horse mackerel moves northward of the Angola-Benguela front.

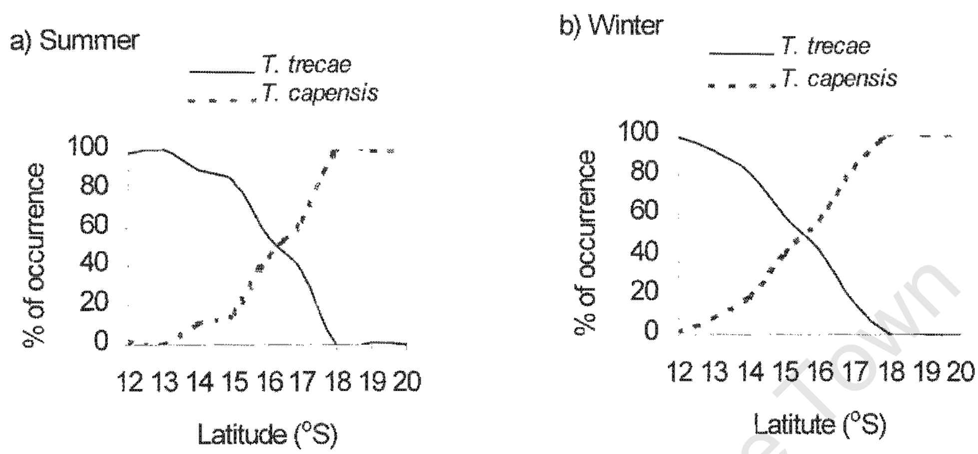


Figure 5.8: Percentage of relative seasonal occurrence between the horse mackerel species based on survey data of RV Dr. F. Nansen from 1985 to 1999 in the southern Angolan area (a = summer (Nov-April) and b = winter (May-Oct).

Figure 5.8 shows that there are no substantial differences in relative occurrence for the two horse mackerel species between summer and winter periods.

The results of the Chi-square tests for the whole mixed sample by size and depth from 1994 to 1999 (available sampled data) are summarized in the Table 5.9. For the whole size range by depth, H_0 was rejected at $p<0.05$ except in the shallow water stratum in the summer time, where there was no significant difference ($p>0.05$ between the size distributions of two species. However, in all mixed catches horse mackerel species analyzed have generally different mean body lengths (Table 5.8a,b,c).

5.3.3 Size composition distribution

Table 5.8a: General size composition of mixed sample catches (number of fish sampled) for two horse mackerel species from 1994 to 1999. (Based on survey data of R/V Dr F. Nansen)

Length class (cm)	Depth (m)			
	0 - 49		>50	
Species →	*T. trecae*	*T. capensis*	*T. trecae*	*T. capensis*
<14 (Small)	255	399	52	45
14 – 19 (Medium)	100	20	589	574
>20 (Large)	134	163	952	710
Total	489	582	1593	1329

Table 5.8b: Summer season size composition of mixed sample catches (number of fish sampled) for two horse mackerel species from 1994 to 1999. (Based on survey data of R/V Dr F. Nansen)

Length class (cm)	Depth (m)			
	0 - 49		>50	
Species →	*T. trecae*	*T. capensis*	*T. trecae*	*T. capensis*
<14 (Small)	29	90	11	6
14 – 19 (Medium)	2	10	296	217
>20 (Large)	0	0	247	105
Total	31	100	554	328

Table 5.8c: Winter season size composition of mixed sample catches (number of fish sampled) for two horse mackerel species from 1994 to 1999. (Based on survey data of R/V Dr F. Nansen)

Length class (cm)	Depth (m)			
	0 - 49		>50	
Species →	*T. trecae*	*T. capensis*	*T. trecae*	*T. capensis*
<14 (Small)	226	309	41	39
14 – 19 (Medium)	98	10	293	357
>20 (Large)	134	163	705	605
Total	468	482	1039	1001

Table 5.9: A summary of the Chi-square test of mixed sample catches of data in Table 5.8a,b,c by size between the two horse mackerel species at different depths.

Data from	Season	Depth (m)	Variables	df	X^2 (values)	Probability
Tab. 5.8a	All years	0-49	Size x species	2	79.954	$p< .05$
	All years	50-500	" x "	2	12.198	" " "
Tab. 5.8b	Summer	0-49	" x "	2	1.836	$p> .05$ NS
	Summer	50-500	" x "	2	94.333	$p< .05$
Tab. 5.8c	Winter	0-49	" x "	2	83.378	" " "
	Winter	50-500	" x "	2	13.299	" " "

df = degrees of freedom
X^2 = value of the chi-square estimated
$p(0.05)$ = probability level

From this table one can conclude that there were significant differences at $p<0.05$ by depth between three size classes of the two horse mackerel species in the annual sampled fish from mixed trawl catches. The same finding was observed in the winter. However, in summer there were no significant differences between the sizes of two horse mackerel species in the surface stratum (0-49 m depth).

Results in Table 5.8, show that there are more small Cape horse mackerel in mixed schools of the two horse mackerel in the overlapping area, whereas there are more medium and large Cunene horse mackerel. The length frequency distributions show some differences in the mixed trawls, the length range sampled being from 6 to 38 cm for Cunene horse mackerel, while the size range for the Cape horse mackerel species was from 8 to 36 (Figure 5.9).

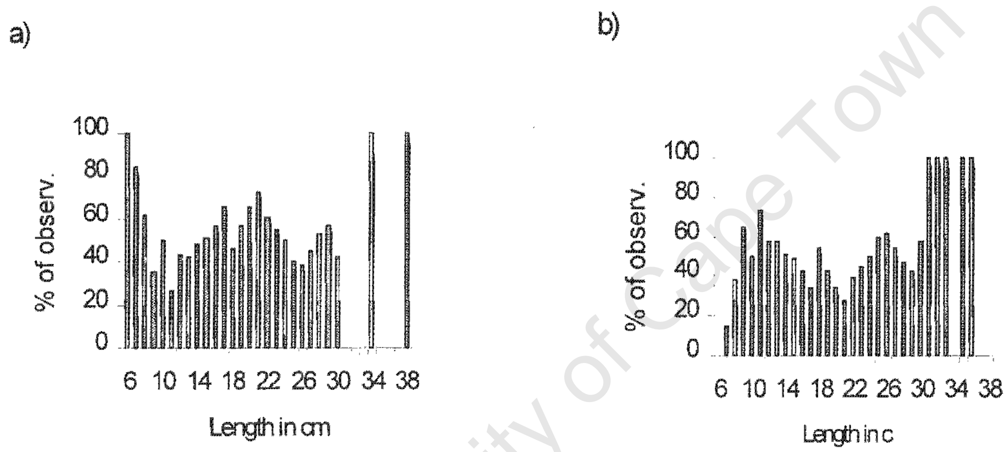


Figure 5.9: Length frequency distribution (% of total sampled fish) from mixed samples of two horse mackerel species (a = *T. trecae* and b = *T. capensis*).

Figure 5.9 confirms once again that in general there are some differences in size between the two species in the mixed catches. In fact it shows that the schooling behavior of most of pelagic fish tends to be by size groups.

5.3.3 Distribution and mixture in relation to the sea surface temperature

The trends of distribution of the two horse mackerel species in the study area are presented in a paired figure for the Angolan and Namibian survey data (Figure 5.10). This shows that the occurrence of *T. trecae* seems to increase from south to north in Angola, while *T. capensis* is characterized by a few occurrences between 12°S and 15°S, but greater relative abundance from 16°S southwards.

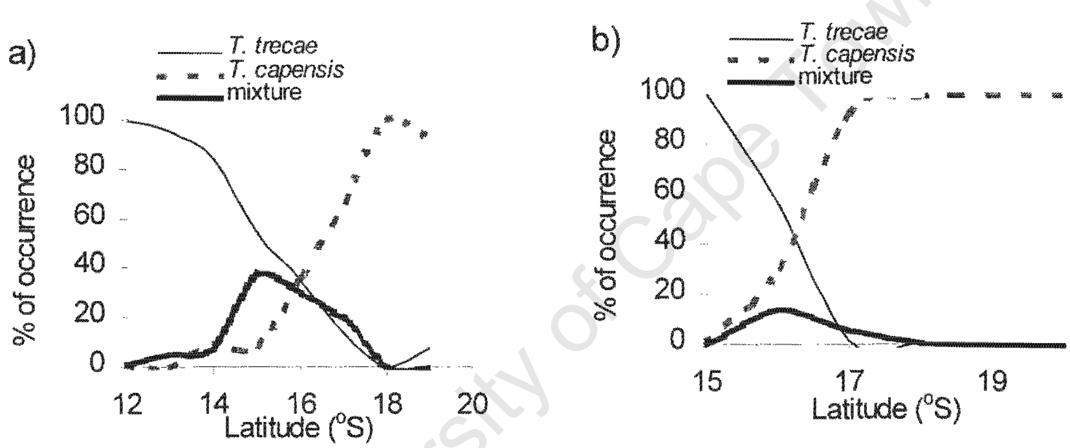


Figure 5.10: Percentage trends of relative occurrence based on surveys of R/V Dr. F. Nansen for the two horse mackerel species in the overlap zone (a = Angolan data from 1985 to 1999 and b = Namibian data from 1990 to 1998).

Figure 5.10 shows that there is a mixture between the two horse mackerel species in the latitudes 13-18°S. From this figure (both Angolan and Namibian source data) it is clear that the percentage of Cape horse mackerel increases from 16°S southwards.

The sea surface temperature (SST) data were collected from Meteosat images for each trawl in which horse mackerel were caught, separated by year/month, latitude/month and season/latitude (Figure 5.11). The seasonal temperature distribution shows an area of cooler sea surface water between 15–17°S. The area is known to be the region of the Benguela front (Kostianoy, 1996, Gammelsrod *et al.*, 1998). The presence of Cunene and Cape horse mackerel was associated with sea surface temperatures between 14 and 24°C. No Cunene species was found at temperatures below 16°C and no Cape species was found at temperature above 26°C (Figure 5.11).

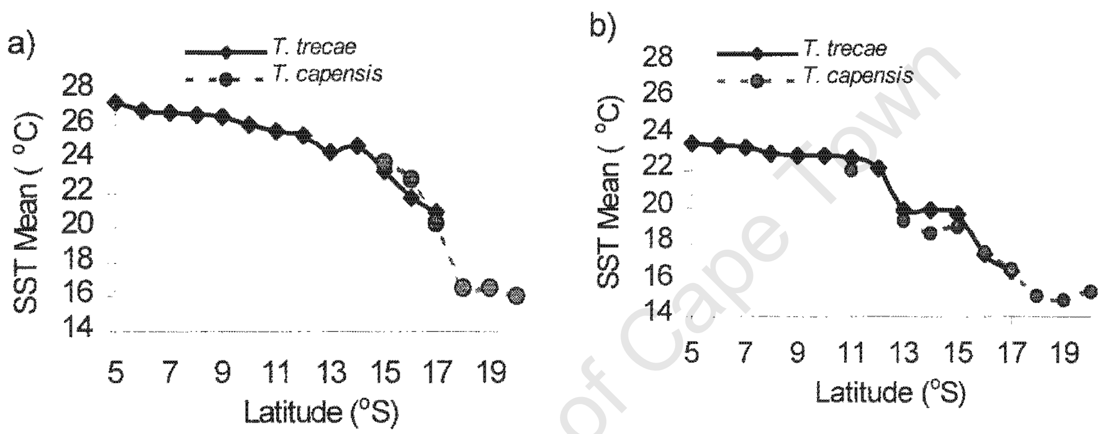


Figure 5.11: Mean seasonal temperature based on METEOSAT SST values from 1989 to 1999 on all horse mackerel catches from latitude 5° to 20°S (a = summer and b = winter).

A strong latitudinal gradient of temperature is observed from 12°S in winter, that is 2 degrees latitude north of the position that is shown in summer (about from 14°S). Sea surface temperature at the positions of the horse mackerel catches was not constant for the period of study and the variation among the seasons is clearly considerable (Figure 5.11).

5.4. Discussion

Initially, data on distribution of the two species in Angola and Namibia define the boundaries for two horse mackerel fairly well (Figure 5.2). Cape horse mackerel in southern Angola migrate according to the position of the Angola-Benguela front and therefore constitute a fluctuating and truly shared resource for Angola and Namibia.

The numbers of observations by trawl in which horse mackerel occurred show great variations in both species seasonally and interannually (Figures 5.7 and 5.8). Generally, more than 50% of the biomass is usually found in the central area from 9–13°S. The analyses of size composition (Table 5.9), on sample catches where a mixture for two species was noted and separated into small (10-13 cm), medium (14-19 cm) and large (>20 cm) sizes, did not differ markedly between seasons, but seemed to vary with depth. In this case, the contingency table tests of 3 size-classes on mixed sample catches by depth for the two horse mackerel species reveal large significant difference of occurrence of the two species between shallow and deep strata (Tables 5.8 and 5.9). No statistical difference was found in the size composition of the species in summer at 0-49 meters depth. This most likely indicates a similar pattern of distribution and mixture of the young fish of both species, probably due to an increase of the water temperature in summer in the overlapping zone.

The results do not show any general pattern for the Cunene horse mackerel. However, it appears that the Cunene horse mackerel concentrates in the central region (from 13° to 9°S) in the summer period, while in the winter the species retreats to the northern region. The Cape horse mackerel seems to follow the seasonal displacements of the

Angola-Benguela front (Figure 5.8). The abundance estimates from echo integration values and biomass of the species by R/V Dr. F. Nansen increase during the winter; this may be indicative of a shift of the Cape horse mackerel from Namibian waters northwards (southern Angola) in winter. However, the results of the GLMs indicate that season does not affect abundance between the two horse mackerel species in the overlap area. The seasonal-latitudinal distribution was useful to check if the apparent shift was linked to a different spatial distribution for the two horse mackerel species (i.e. Cunene horse mackerel concentrates in the central and southern areas in the summer period, while in winter the species retreats to the northern region). The result suggests that the two modes are linked to variations in abundance of the Cunene horse mackerel and Cape horse mackerel due to changes in environmental conditions in the area around the northern front of the Benguela Current.

Analysis of spatial distribution by latitude reveals a large mixture of the two horse mackerel species in the area between 16° and 17°S (Figure 5.2), but the depth distribution across the shelf shows that Cape horse mackerel dominate in that area mainly in the deep depths (Figure 5.3). This shows that *T. trecae* were found in greater proportion in the shallow stratum than *T. capensis*. This may partially be a consequence of the difficulty to separate the juveniles of the two species. The mixture between the two species is greater in the winter season than in the summer season (Figure 5.7). It may indicate that there is a major movement of Cape horse mackerel to the north of the Angola-Benguela front in the winter period. It supports the finding of Bianchi *et al.* (1997), who found that in general, the mixture of these species has been observed along the coast between Benguela and the Cunene River with major occurrences of juveniles for all surveys from 1989 to 1997. This observation also does not contradict the findings of Wysokiñski (1986) who pointed out that the majority of mixture between the two horse mackerel species in the southern Angola area is between 16° and 17°S. The proportional estimate is 46.4% for the Cunene horse mackerel and 53.6% for Cape horse mackerel respectively (Appendix II).

The coolest SSTs in the overlap area were at latitude 16–18°S corresponding to temperature values of <18°C. The high frequency of mixed catches occurred in temperatures between 18° and 21°C, indicating that the main pattern of two horse mackerel species were concentrating in the cooler Angola area (warmest Namibia area) in the south of Angola and north of Namibia (latitude 16–18°S). There seems to be a close relationship between horse mackerel and the movement of Angola-Benguela front where, according to Meeuwis and Lutjeharms (1990), the latitudinal locations of the northern and southern frontal boundaries show clear annual and interannual variations. This can be seen in Figure 1.2, where during that study period the position of the northern frontal boundary fluctuated between 12.6° and 15.5°S while the position of the southern boundary varied between 15° and 17.2°S. Results from the 1998 survey of the horizontal distribution of SST shown in Figure 5.1a (summer) clearly reveal the Angola-Benguela front. It is seen as a maximum temperature gradient forming a tongue like shape. It leaves the coast near Tombua (~15.30°S), where it is replaced by cool, upwelled water. The warm Angola water penetrates further south to the latitude of the Cunene River (~17°S) where it meets cooler water from the Benguela Current (Anon, 1997). Figure 5.1b (winter) showed a strong horizontal gradient of temperature corresponding to the Angola Benguela front north of Cape of Santa Marta (between 14-13°S), that is, 1.5 to 2 degrees latitude north of the position that was recorded in summer (between 15-16°S). The same trend was notable in a spatial and temporal shift of the two horse mackerel species, mainly on Cape horse mackerel (Figure 5.12a).

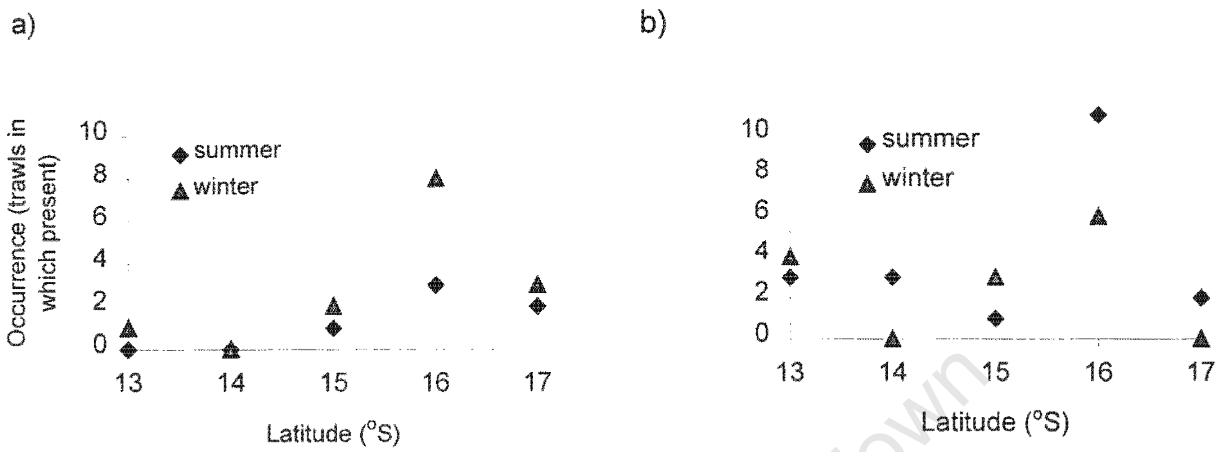


Figure 5.12: Latitudinal occurrence of horse mackerel species (trawls in which present) based on two pelagic surveys (R/V Dr. F. Nansen) in 1998 in the south (a = *T. capensis* and b = *T. trecae*).

Figure 5.12a) shows an example of Cape horse mackerel movement that was 2 degrees latitude more to the north in winter than was observed in summer of the same year (from 15° to 13°S). However for the Cunene horse mackerel (Figure 5.12b) that shift was only 1 degree northward in winter than in summer. It is an indication that there is a close relation between movement of the horse mackerel and the position of the Angola-Benguela front (Figure 5.1). It also clear in Figure 5.12a that in winter (14 trawls) there is a greater occurrence for the Cape horse mackerel than in summer (6 trawls), while the Cunene horse mackerel occurrence seems to be higher in summer (19 trawls) than in winter (13 trawls, Figure 5.12b). The plots of temperature distribution (SST) on each degree of horse mackerel catches by latitude (Figure 5.11) showed lower values of temperature (14°-24°C) for *T. capensis* than for *T. trecae* (19°-28°C). The same range tendency was found in conclusions from previous investigations with regard to the overlap area of the two horse mackerel species (e.g. Santos Dias, 1974, 1983a, 1983b, Da Fonseca Baptista, 1977 and Anon, 1997).

Abstract (Chapter 5)

To characterize the distribution and mixture of the horse mackerel species, this chapter discusses the distribution and mixture of the two horse mackerel species based mainly on trawls (pelagic and bottom trawls) in which they occur in the period 1985-1999. The statistical results using Microsoft Excel worksheets and plots focus on comparison of distributions and mixtures between the two horse mackerel species, mainly in the overlap area of the Angola-Benguela front. The total CPUE was used to represent the abundance of the two species as a base case. These were then converted to percentages for each of the two horse mackerel species to define the relative abundance of each species in the southern region. The results from GLM in the previous chapters are taken into account to support the discussion of findings between the different analyses. The results of the analysis will also contribute to interpret the effect of sea surface temperature on horse mackerel distribution.

Introduction

The oceanographic conditions in the study region are believed to be important in determining the distribution and mixture of Cape and Cunene horse mackerel species. Some results and conclusions by Stachlewska *et al.* (1999), suggest that the frontal zone is characterized by a seasonal fluctuation of its geographical position and by multiple fronts, which are common especially in summer when the southward flow of the Angola water is strongest. The resource is considered the most valuable pelagic stock in the area. Thus, the first objective of this chapter is to characterise the distribution and mixture of Cunene and Cape horse mackerel in the area around the Angola-Benguela front. The second objective is to establish the connection between the distribution of the

Chapter Six

Conclusions

The distribution pattern and mixture of the Cunene and Cape horse mackerels are characterised as a permanent feature in the northern area of the Angola–Benguela front and are maintained within the latitudes 14° and 18°S (Figure 5.2). There are some seasonal changes in the distribution of the horse mackerel in these areas (Figures 5.6 and 5.12). The shift farthest north of Cape horse mackerel is in the winter and farthest south in the summer. Generally, the mixture between the two horse mackerel species has been observed in the region south of Angola and north of Namibia with major occurrences of both small and medium sized fish. This is indicative of a close relation to the frontal zone between the warm Angola current and the cool Benguela current, which is a zone rich in phytoplankton nutrients and zooplankton food for horse mackerel (Gammelsrod *et al.*, 1998). The distribution of horse mackerel in the area around the Angola–Benguela front is characterized by the occurrence of Cunene horse mackerel along the Angolan coast, where it appears to concentrate in the central and southern regions in the summer period, while in winter the species retreats to the northern region. The latitude 15°S was found to be the northern boundary of Cape horse mackerel species but they seem to follow the seasonal displacements of the Angola–Namibia front. The results show that the mean annual shift for the horse mackerel species in the area varies between 2 and 3 degrees latitude.

There seems to be depth segregation between the species with Cunene horse mackerel dominating the near shore areas while most Cape horse mackerel are found offshore. The pattern of association of the two species may vary according to time of year. In fact the seasonal migration pattern for these species is not as clear as other pelagic fish (e.g. *Sardinella spp.*; Marchal, 1991), but greatest mixture between the species has been observed in the area between 16° and 18°S.

General linear models, on main effects of year, season, area, depth, time and sea surface temperature (SST) were applied to the abundance estimates of horse mackerel such as acoustic densities (S_A) and survey catch per unit effort (CPUE). The results suggest that the depth, area, year, and sea surface temperature (SST) effects are responsible for most of the observed differences in abundance of two horse mackerel species in the Angola–Benguela front. However, there are many environmental parameters like wind, cloud cover, colour of ocean, etc that were not tested in this study and it is also unlikely that fish distribution is determined by physical factors alone. Therefore, it is important to also include some biotic factors such as food availability, spawning areas and predator abundance to ascertain the distribution and movement patterns of horse mackerel. Surprisingly, the season is consistently the least significant main effect in survey CPUE and S_A (GLM) models. Thus, adequate estimates of survey CPUE, acoustic density (S_A) and of abundance can be obtained in either season. It is suggested that similar analyses of commercial CPUE be conducted in the future in order to compare with the present results, as currently CPUE and S_A are estimated from two months of survey per year. It may be more realistic to use CPUE values that reflect an effort over a longer period such as throughout the fishing season, although there are additional problems with using CPUE data from commercial vessels such as under reporting, under estimation of search time, etc. Tables 6.1 and 6.2 show a summary of individual relationships based on SS-values of each ecological factor (from final GLM models) by order of each most important factor affecting the horse mackerel abundance.

Table 6.1: Summary of model results for horse mackerel (acoustic density-S_A)

Model	Species	Main effect						Interaction			
		year	season	time	area	depth	SST	year * area	year * time	depth * time	depth * SST
3.1	Both (everywhere)	1	E	6	3	-	5	2	4	-	-
3.2	Both (south)	5	E	6	-	7	4	-	1	2	3

The numbers (1, 2, etc.) represent the order of contribution based on sum of square (SS) for each factor for respective models
The (-) = discarded from final model (not significant)
E = excluded from analysis

Table 6.2: Summary of model results for horse mackerel (CPUE) (period because SST not available in all years)

Model	Species	Period	Main effect							Interactions			
			year	season	time	gear	area	depth	SST	year * area	year * depth	area * depth	gear * time
4.1	Both (everywhere)	85-99	5	-	-	-	1	2	E	3	4	-	-
4.2	*T. trecae* (everywhere)	85-99	2	-	8	6	7	1	E	3	-	5	4
4.3	*T. capensis* (everywhere)	85-99	5	-	-	-	1	4	E	3	-	2	-
4.4	*T. trecae* (south)	85-99	2	-	-	3	-	1	E	E	E	E	E
4.5	*T. capensis* (south)	85-99	2	-	3	-	-	1	E	E	E	E	E
4.6	Both (sst) (everywhere)	89-99	3	-	-	-	2	1	4	E	E	E	E
4.7	*T. trecae* (south – sst)	89-99	1	-	-	-	-	2	3	E	E	E	E
4.8	*T. capensis* (south – sst)	89-99	3	-	-	-	-	2	1	E	E	E	E

The numbers (1, 2, etc.) represent the order of contribution based on sum of square (SS) for each factor for respective models
The (-) = discarded from final model (not significant)
E = excluded from analysis

The main effects of all the tested factors in Table 6.1 have a significant relationship with horse mackerel density in the pooled areas model (3.1) and less in the southern area model (3.2). On the contrary, these also showed that interactions between year*time, depth*time and depth*SST had substantial impact on the echo density in the southern area model and less in the combined areas. Unfortunately, the available echo integrator values are not separated by species but different behaviours may occur in different areas according to species. Despite different temporal resolution between instantaneous echo densities and sea surface temperature (5 day averages), the results from models showed that SST has a substantial effect on horse mackerel whenever included in the analysis. Table 6.2 shows that of all the ecological factors tested in this study, depth, area, year and sea surface temperature were found to be the primary factors in determining horse mackerel abundance and distribution by the CPUE GLM analyses. Individual relationships for each horse mackerel abundance against each ecological factor were observed in the overlap area but, in all CPUE horse mackerel models, depth and sea surface temperature were seen to be the most important factors affecting the horse mackerel.

The annual effect had a consistent significant effect on variation of the horse mackerel CPUE in all models. The interactions between area and both year*area and area*depth are the most important affecting the abundance of horse mackerel over all areas. It is, therefore, important to continue investigating additional factors that may influence horse mackerel in the northern Angola area. Despite echo density representing abundance and survey catch the supplementary method for the identification and separation between the species, Figure 6.1 below shows that for the comparable models with echo density+SST (models 3.1 and 3.2) and survey catch+SST (models 4.1 and 4.6), the effects of area and sea surface temperature on horse mackerel follow the same trends between two sources of data. The year effect peaked in 1996 for the acoustic density data but for the CPUE it peaked in 1997. Some reasons can be postulated for this different trend, for example available echo density in 1996 represents only one season (summer) and survey catch both seasons (summer and winter). A check in the total combined biomass for both species estimated from acoustic density by R/V Dr. Fridtjof Nansen in summer 1996 was 310 000 tons (see Table 2.1), while 425 000 tons was estimated in winter 1997. The available echo density in 1997 in the plot refers to a survey conducted in summer (see Table 3.2). Thus, it is not possible to draw a conclusion from the different results between the models.

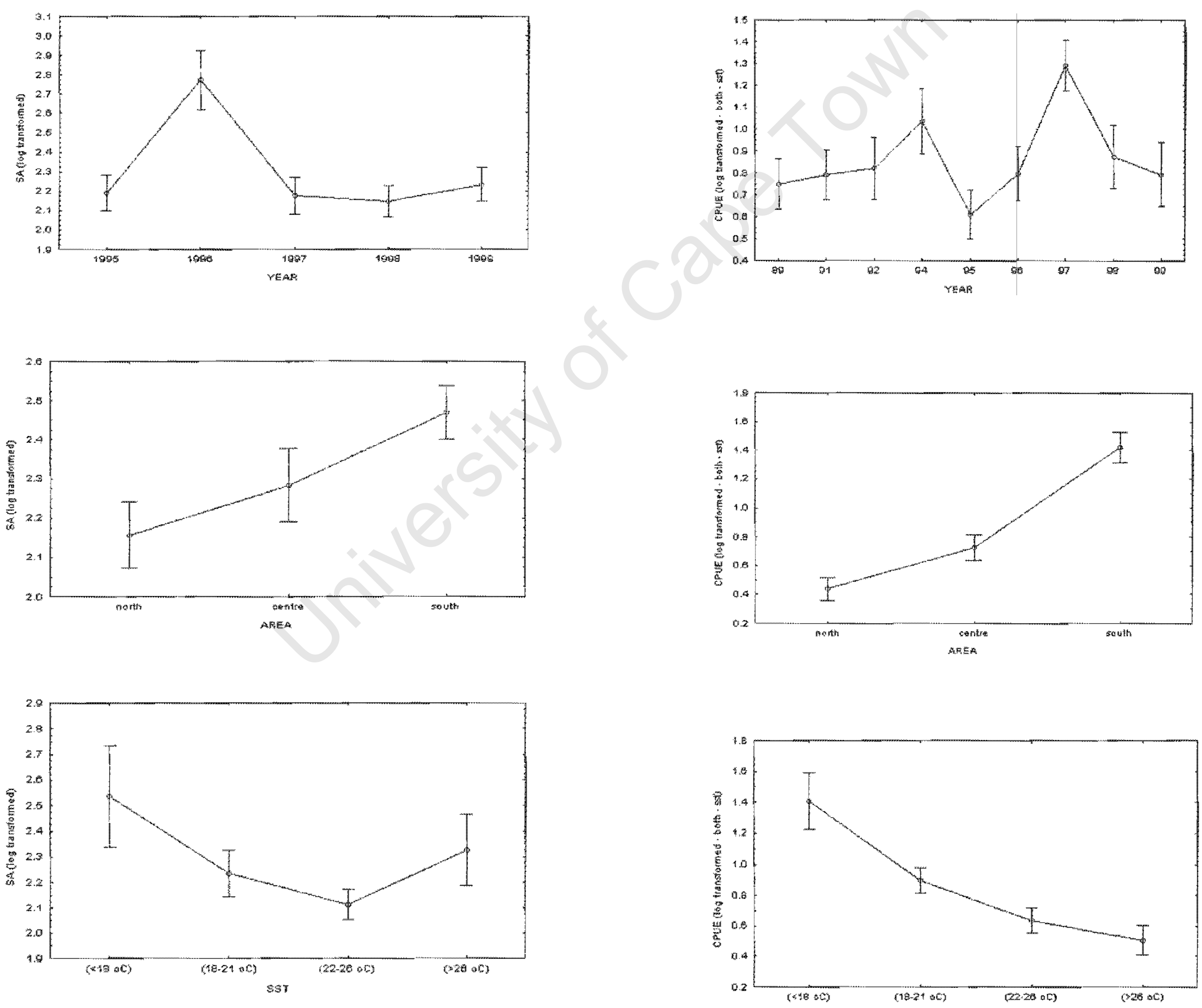


Figure 6.1: Results of the GLM estimates for the main effects including SST on both horse mackerel data, left (on acoustic values, the model includes: year, area, SST and day/night) and right (on CPUE, the model includes: year, area, SST, depth and gear).

From Figure 6.1, it is clear that that most horse mackerel were caught in the central area and southward and in temperatures less that 26°C. Other tested factors such as time (day, night) and gear had a minor contribution in explaining horse mackerel density and CPUE variation. Therefore the identification of strong associations of fish with particular habitat conditions is essential.

The most important feature of the horizontal distribution of sea surface temperature is the presence of the Angola–Benguela front that produces a strong horizontal gradient. This is seen especially between 15° and 17°S (Meeuwis and Lutjeharms, 1990). According to Stachlewska *et al.* (1999), the Angola-Benguela front is well defined and shows variability in strength and geographic position (Figure 5.1). This showed that the latitudinal position and strength of the front are correlated.

Two predominant patterns appearing in horse mackerel distribution with sea surface temperature (Figure 5.14), where the range of temperature seemed to vary according to the season and area: The cold pattern defined by horse mackerel species maybe close to offshore (<22°C) mainly for Cape horse mackerel and the most of adults. The warm pattern defined by species confined closer to inshore (>22°C), mainly for the Cunene species and the majority of juveniles.

Based on the above, studies on feeding behaviour and ecological significance such specific characteristics of migrations for the two horse mackerel species in the area, are recommended for improving the core survey sampling at least in the mixture area. The lack of targeted surveys on juvenile horse mackerel is evident in the study area and the assessment of those young fish remains questionable.

The GLM provided reasonable fits to the spatial distribution of the Cape horse mackerel, with mid-shelf depth and interaction between depth*sea surface temperature being the primary determining factors for the horse mackerel abundance in the overlap area.

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APPENDICES

Appendix I: Season-latitude by trawls (pivotable data analysis)

	Season-latitude by trawls				
Season	Latitude (S)	*T. trecae*	*T. capensis*	*Trachurus spp.*	Grand Total
Winter (May-Oct)	5°	53	0	4	57
	6°	120	0	0	120
	7°	149	0	5	154
	8°	195	0	6	201
	9°	167	0	2	169
	10°	177	0	8	185
	11°	173	1	3	177
	12°	127	1	3	131
	13°	24	2	0	26
	14°	18	5	0	23
	15°	36	25	1	62
	16°	85	113	3	201
	17°	8	47	0	55
	18°	0	13	0	13
	19°	0	13	0	13
	20°	0	10	0	10
Winter Total		1332	230	35	1597
Summer (Nov-April)	5°	32	0	0	32
	6°	45	0	0	45
	7°	57	0	0	57
	8°	93	0	0	93
	9°	91	0	0	91
	10°	93	1	0	94
	11°	81	0	0	81
	12°	91	2	1	94
	13°	12	0	0	12
	14°	17	1	0	18
	15°	27	5	0	32
	16°	150	115	1	266
	17°	26	41	1	68
	18°	0	0	0	0
	19°	1	0	0	1
	20°	0	0	0	0
Summer Total		816	165	3	984
Grand Total		2148	396	38	2582

Appendix II: Annual abundance of horse mackerel in the southern area (13°-18°S)

Year	Species	All hauls (a)				Trawls in which present (b)			
		Trawls (No)	Mean CPUE (kg/h)	% of total	%of rel. abund. (c)	Trawls (No)	CPUE kg/h	Total CPUE (kg/h)	% of total
1985	*T. trecae*	78	47.7	2.6	4.4	20	3724.0	17319.0	21.5
(70)	*T.capensis*		1024.4	56.5	95.6	61	79904.4	116268.0	68.7
1986	*T. trecae*	72	531.9	34.2	54.8	52	38299.2	93592.2	40.9
(57)	*T. capensis*		439.5	38.1	45.2	28	31642.2	70053.0	45.2
1989	*T .trecae*	76	63.4	6.8	24.6	42	4814.7	40744.6	11.8
(66)	*T .capensis*		194.0	20.7	75.4	51	14747.6	49631.3	29.7
1991	*T. trecae*	40	182.4	12.0	24.4	17	7295.2	29785.3	24.5
(34)	*T. capensis*		563.4	37.1	75.6	27	22535.9	51340.4	43.9
1992	*T. trecae*	306	129.0	11.6	39.3	138	39478.2	167207.0	23.6
(172)	*T. capensis*		205.9	18.6	60.7	43	63002.6	115247.0	54.7
1993	*T. trecae*	39	1062.2	36.2	80.8	28	41426.1	79603.6	52.0
(33)	*T. capensis*		252.5	8.6	19.2	15	9846.6	30822.6	32.0
1994	*T. trecae*	3	55.5	2.0	10.5	3	166.5	8264.3	2.0
(3)	*T. capensis*		474.3	17.2	89.5	1	1423.0	8000.0	17.8
1995	*T. trecae*	32	256.1	6.8	57.4	14	8193.7	16461.0	49.7
(22)	*T. capensis*		189.7	4.1	42.6	10	6071.6	15144.7	33.6
1996	*T. trecae*	34	686.7	56.1	76.3	15	23346.6	33228.6	68.4
(20)	*T. capensis*		213.1	17.4	23.7	8	7244.1	22486.6	32.2
1997	*T. trecae*	44	877.6	29.5	56.0	28	38614.5	83237.7	44.6
(40)	*T. capensis*		688.4	23.1	44.0	20	30287.3	83145.6	36.4
1998	*T. trecae*	58	1002.0	32.1	42.4	33	58113.8	86106.2	66.9
(48)	*T. capensis*		1363.7	43.8	57.6	20	79093.9	118509.2	66.7
1999	*T. trecae*	26	239.8	20.9	41.8	19	6236.2	18786.3	33.2
(24)	*T. capensis*		334.0	29.2	58.2	9	8684.6	15670.2	55.4
Total	*T. trecae*	808	5134.3			409	269711.8	674335.7	
	T. capensis		5942.9			293	354483.6	696318.6	

a): based on all hauls in the specified area (Angola south)
b): based on horse mackerel hauls. In brackets are the total number of trawls in which the horse mackerel was present.
c): Percentage of relative abundance between both species (% rel = (% of cpue)/(% of cpue1 + % of cpue2)). Where cpue1 and cpue2 are means of *T. trecae* and *T. capensis* respectively, based on all hauls within the limits specified.

Note: Overall mean (1985-1999) = Sum of annual means of total catch: (85-99) = 5134.3 (*T. trecae*) and 5942.9 (*T. capensis*).

Percentage of relative abundance = (5134.3/(5134.3+5942.9))*100 = **46.4%** for *T. trecae* and 5942.9/(5134.3+5942.9))*100 = **53.6%** for *T. capensis*.

Appendix IIIa: Annual abundance of horse mackerel by depth (0-49 m) in the southern area (13°-18°S)

Year	Species	All hauls (a)				Trawls in which present (b)			
		Trawls (No)	Mean CPUE kg/h	% of total	%of rel. abund. (c)	Trawls (No)	CPUE kg/h	Tot.CPUE kg/h	% of total
1985	*T. trecae*	23	39.0	6.7	29.6	15	896.4	8149.0	11.0
	T. capensis		92.7	16.0	70.4	11	2132.7	7683.0	27.8
1986	*T. trecae*	19	336.0	45.0	78.3	17	6383.0	13173.2	48.4
	T. capensis		92.9	12.4	21.7	2	1765.4	2280.0	77.4
1989	*T. trecae*	24	143.6	29.0	92.1	17	3445.4	11278.4	30.6
	T. capensis		12.3	2.5	7.9	11	295.2	2691.8	11.0
1991	*T. trecae*	30	186.8	13.0	89.5	24	5605.1	19038.8	29.4
	T. capensis		22.0	1.5	10.5	8	659.0	7625.7	8.6
1992	*T. trecae*	10	215.2	37.8	99.8	8	2151.6	5684.6	37.8
	T. capensis		0.5	0.1	0.2	3	5.0	438.4	1.1
1993	*T. trecae*	16	358.8	13.1	98.9	10	5740.8	21543.8	26.6
	T. capensis		3.9	0.1	1.1	2	62.1	305.0	20.4
1994	*T. trecae*	2	83.1	2.1	10.5	2	166.1	8035.0	2.1
	T. capensis		711.5	17.7	89.5	1	1423.0	8000.0	17.8
1995	*T. trecae*	5	1015.7	4.8	78.0	1	5078.4	6748.2	75.3
	T. capensis		289.8	1.4	22.0	1	1449.0	6748.2	21.5
1996	*T. trecae*	8	1008.1	71.3	99.9	7	8065.0	11316.3	71.3
	T. capensis		1.0	0.1	0.1	1	8.1	1780.1	0.5
1997	*T. trecae*	10	942.4	66.5	75.9	4	9424.2	13294.1	70.9
	T. capensis		298.7	21.1	24.1	2	2986.8	9975.4	29.9
1998	*T. trecae*	9	3692.0	81.3	88.9	6	33227.6	39272.3	84.6
	T. capensis		461.1	10.2	11.1	1	4150.0	667.0	62.2
1999	*T. trecae*	9	645.7	50.6	100.0	4	2582.7	5108.0	50.6
	T. capensis		0.0	0.0	0.0	0	0.0	0.0	0.0
Total	*T. trecae*	165	8666.4			115	82766.3	162641.7	
	T. capensis		1986.4			43	14936.3	48194.6	

a): based on all hauls in the specified area (Angola south)
b): based on horse mackerel hauls (number of trawls in which the horse mackerel was present).
c): Percentage of relative abundance between both species (% rel = (% of cpue)/(% of cpue1 + % of cpue2)). Where cpue1 and cpue2 are means of *T. trecae* and *T. capensis* respectively, based on all hauls within the limits specified.

Appendix IIIb: Annual abundance of horse mackerel by depth (50-200 m) in the southern area (13°-18°S)

Year	Species	All hauls (a)				Trawls in which present (b)			
		Trawls (No)	Mean CPUE kg/h	% of total	%of rel. abund. (c)	Trawls (No)	CPUE kg/h	Tot.CPUE kg/h	% of total
1985	*T. trecae*	63	97.8	4.6	8.1	16	6164.1	20274.0	30.4
	T. capensis		1116.5	52.5	92.0	44	70341.3	103275.0	68.1
1986	*T. trecae*	48	526.3	40.8	79.2	37	25261.2	55578.0	45.4
	T. capensis		138.2	10.7	20.8	25	6633.0	40823.0	16.2
1989	*T. trecae*	64	55.1	4.5	19.8	33	3527.5	46992.4	7.5
	T. capensis		223.1	18.1	80.2	34	14280.0	46561.8	30.7
1991	*T. trecae*	80	295.2	17.6	29.4	50	23616.2	66920.6	35.3
	T. capensis		707.2	42.2	70.6	52	56580.0	115471.0	49.0
1992	*T. trecae*	43	102.4	3.4	6.8	16	4504.2	24488.3	18.4
	T. capensis		1412.4	46.8	93.2	35	62143.6	108068.7	57.5
1993	*T. trecae*	23	977.7	31.8	69.7	16	22487.8	54809.6	41.0
	T. capensis		425.4	13.8	30.3	13	9784.5	30517.6	32.1
1994	*T. trecae*	1	1.0	0.43	100.0	1	1.0	229.3	0.4
	T. capensis		0.0	0.0	0.0	0	0.0	0.0	0.0
1995	*T. trecae*	18	157.1	27.5	44.7	10	2827.6	9303.1	30.4
	T. capensis		194.3	34.0	55.3	6	3497.5	7859.5	44.5
1996	*T. trecae*	30	861.0	25.3	46.1	18	25830.5	63108.2	40.9
	T. capensis		1008.6	29.7	54.0	17	30256.8	73534.1	41.2
1997	*T. trecae*	22	605.6	50.95	76.3	11	13322.4	19934.5	66.8
	T. capensis		188.1	15.8	23.7	6	4137.3	12511.2	33.1
1998	*T. trecae*	38	466.1	17.6	19.0	23	17710.7	36755.3	48.2
	T. capensis		1981.7	74.7	81.0	13	75304.1	75063.5	100.0
1999	*T. capensis*	14	135.5	9.9	18.2	8	1897.1	8282.5	22.9
	T. trecae		607.4	44.4	81.8	6	8502.9	14910.2	57.0
Total	*T. trecae*	444	4280.8			239	147150.3	406675.8	
	T. capensis		8002.9			251	341461.0	628595.6	

a): based on all hauls in the specified area (Angola south)
b): based on horse mackerel hauls (number of trawls in which the horse mackerel was present).
c): Percentage of relative abundance between both species (% rel = (% of cpue)/(% of cpue1 + % of cpue2)). Where cpue1 and cpue2 are means of *T. trecae* and *T. capensis* respectively, based on all hauls within the limits specified.

Appendix IIIc: Annual abundance of horse mackerel by depth (<200 m) in the southern area (13°-18°S)

Year	Species	All hauls (a)				Trawls in which present (b)			
		Trawls (No)	Mean CPUE kg/h	% of total	%of rel. abund. (c)	Trawls (No)	CPUE kg/h	Tot.CPUE kg/h	% of total
1985	*T. trecae*	16	129.1	16.0	21.7	3	2066.2	3597.0	57.4
	T. capensis		465.2	57.7	78.3	8	7444.0	7512.0	99.1
1986	*T. trecae*	19	365.1	21.1	22.8	5	6938.2	30768.4	22.6
	T. capensis		1239.2	71.6	77.2	3	23545.4	30776.0	76.5
1989	*T. trecae*	6	0.9	1.4	3.1	3	5.4	229.9	2.4
	T. capensis		28.7	45.6	96.9	6	172.4	377.8	45.6
1991	*T. trecae*	11	385.4	28.1	86.9	2	4240.0	6443.0	65.8
	T. capensis		58.2	4.2	13.1	8	639.7	10027.1	6.4
1992	*T. trecae*	8	120.0	13.2	52.9	1	959.8	1278.0	75.1
	T. capensis		106.8	11.8	47.1	5	854.0	6739.9	12.7
1993	*T. trecae*	0	0.0	0.0	0.0	0	0.0	0.0	0.0
	T. capensis		0.0	0.0	0.0	0	0.0	0.0	0.0
1994	*T. trecae*	0	0.0	0.0	0.0	0	0.0	0.0	0.0
	T. capensis		0.0	0.0	0.0	0	0.0	0.0	0.0
1995	*T. trecae*	7	40.1	39.3	65.9	3	280.8	409.6	68.5
	T. capensis		20.8	20.4	34.1	3	145.3	537.0	27.1
1996	*T. trecae*	6	543.2	18.4	99.3	3	3259.2	8813.2	37.0
	T. capensis		3.7	0.1	0.7	2	22.4	7831.5	0.3
1997	*T. trecae*	0	0.0	0.0	0.0	0	0.0	0.0	0.0
	T. capensis		0.0	0.0	0.0	0	0.0	0.0	0.0
1998	*T. trecae*	10	665.5	17.2	20.0	4	6655.0	10078.5	66.0
	T. capensis		2655.6	68.6	80.0	5	26556.0	36317.5	73.1
1999	*T. trecae*	6	266.1	51.7	90.7	5	1596.7	2965.4	53.8
	T. capensis		30.3	5.3	9.3	3	181.7	760.0	23.9
Total	*T. trecae*	89	2515.4			29	26001.3	64583.0	
	T. capensis		4608.5			43	59560.9	100878.8	

a): based on all hauls in the specified area (Angola south)
b): based on horse mackerel hauls (number of trawls in which the horse mackerel was present).
c): Percentage of relative abundance between both species (% rel = (% of cpue)/(% of cpue1 + % of cpue2)). Where cpue1 and cpue2 are means of *T. trecae* and *T. capensis* respectively, based on all hauls within the limits specified.

Appendix IV: Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
5°	1985	16	1.71			1.71
		29	31.97			31.97
		40	17.6			17.6
		46	5.13			5.13
		51	2			2
		57	3			3
		61	12.6			12.6
		69	204			204
		105	0.4			0.4
	1985 Total		296.21			296.21
	1986	52	16.6			16.6
		55	4.2			4.2
		60	45			45
		70	1.05			1.05
		84	204			204
		85	288			288
		89	72			72
		111	75.2			75.2
		112	0.3			0.3
		117	34			34
	1986 Total		740.35			740.35
	1989	16	0.24			0.24
		25	9.6			9.6
		30	0.11			0.11
		38	17.6			17.6
		42	2.4			2.4
		44	0.2			0.2
		63	24			24
		69	50			50
		76	23			23
		77	183.7			183.7
		78	2.4			2.4
		88	2.6			2.6
		91	9			9
		94	1.8			1.8
		95	36.8			36.8
		76	23			23
		77	183.7			183.7
		78	2.4			2.4
		88	2.6			2.6
	1989 Total		492.65			492.65

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
5°	1991	12	1.6			1.6
		20	0			0
		36	0.6			0.6
		43	10.4			10.4
		47	0			0
		52	13.75			13.75
		54	4			4
		57	0.6			0.6
		80	2			2
		90	3.1			3.1
		96	0.8			0.8
		103	7.4			7.4
		116	0.6			0.6
		130	0.7			0.7
	1991 Total		45.55			45.55
	1992	27	34.32			34.32
		33	0.14			0.14
		45	672			672
		47	1			1
		71	32			32
		87	40.2		0.04	40.24
		99	3.2		1.6	4.8
		116	7.2		5.2	12.4
		120	6.12			6.12
		156	1.2			1.2
		159	3.6		0.6	4.2
	1992 Total		800.98		7.44	808.42
	1994	53	37.4			37.4
		59	4.6			4.6
		64	1.78			1.78
		83	199.31			199.31
		96	27.68			27.68
		168	0.04			0.04
		170	0.42			0.42
		181	16.2			16.2
	1994 Total		287.43			287.43
	1995	94	43.7			43.7
		211	2.76			2.76
	1995 Total		46.46			46.46
	1996	303	2.84			2.84
	1996 Total		2.84			2.84
5° Total			2712.47		7.44	2719.91

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
6°	1985	13	2			2
		20	146			146
		26	87			87
		31	4			4
		39	125			125
		45	0.2			0.2
		52	415.8			415.8
		68	49.6			49.6
		70	10.46			10.46
		76	2.1			2.1
		80	0.2			0.2
		89	3.2			3.2
		102	4			4
		103	22.2			22.2
		105	7			7
		106	0.67			0.67
		110	0.4			0.4
		112	1.6			1.6
		116	2			2
		289	4.2			4.2
	1985 Total		887.63			887.63
	1986	66	8.6			8.6
		71	25.4			25.4
		76	112.8			112.8
		77	1.6			1.6
		80	41.6			41.6
		84	29.6			29.6
		85	1.38			1.38
		86	1.2			1.2
		88	23.76			23.76
		89	33.6			33.6
		90	2.4			2.4
		91	1.2			1.2
		96	7			7
		105	6.6			6.6
		108	0.4			0.4
		112	12			12
		113	8.8			8.8
		134	28			28
	1986 Total		345.94			345.94
	1989	16	0.8			0.8

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
6°	1989	62	2.4			2.4
		64	243.2			243.2
		65	3.5			3.5
		68	6.5			6.5
		70	2.9			2.9
		71	0.8			0.8
		76	2370			2370
		77	4.8			4.8
		81	364			364
		84	225.2			225.2
		88	1400			1400
		92	780			780
		99	384			384
		100	2.4			2.4
		109	16			16
		110	10.8			10.8
		114	112			112
		500	4.8			4.8
	1989 Total		5934.1			5934.1
	1991	14	10.08			10.08
		22	108.6			108.6
		43	0	0		0
		63	28			28
		66	22			22
		73	20.8			20.8
		78	3.8			3.8
		86	2.6			2.6
		105	4			4
		112	2.08			2.08
		113	18			18
		117	5.4			5.4
		125	108.6			108.6
	1991 Total		333.96	0		333.96
	1992	12	0			0
		13	6			6
		20	0			0
		23	8.8			8.8
		24	84			84
		50	0.4			0.4
		76	100			100
		83	42.66			42.66

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
6°	1992	90	0.38			0.38
		109	20			20
		119	120			120
		153	31.5			31.5
		202	1.4			1.4
	1992 Total		415.14			415.14
	1994	20	13.8			13.8
		23	35.6			35.6
		40	0.3			0.3
		47	43.64			43.64
		58	16.5			16.5
		61	1096.2			1096.2
		66	89.1			89.1
		69	38.8			38.8
		72	25.7			25.7
		79	1.52			1.52
		112	92.8			92.8
		116	0.94			0.94
		122	24.36			24.36
		139	278.4			278.4
		142	56.58			56.58
		1174	1.41			1.41
	1994 Total		1815.65			1815.65
	1995	21	0.38			0.38
		37	0.96			0.96
		41	706.6			706.6
		46	96.54			96.54
		70	28.7			28.7
		80	1.28			1.28
		88	165			165
		89	0.19			0.19
		105	1.28			1.28
		136	0.74			0.74
		210	1.44			1.44
	1995 Total		1003.11			1003.11
	1996	25	123.74			123.74
		39	1344.62			1344.62
		64	20.16			20.16
		70	70.94			70.94
		79	11.68			11.68
		87	121			121

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
6°	1996	91	2.58			2.58
		118	301.1			301.1
		122	235.78			235.78
		127	47			47
		156	29			29
		167	16.8			16.8
		168	36.8			36.8
		480	0.22			0.22
	1996 Total		2361.42			2361.42
	1997	39	0.31			0.31
		42	16.5			16.5
		43	17.6			17.6
		63	378.6			378.6
		75	164.4			164.4
		78	24			24
		80	891.58			891.58
		91	38.34			38.34
		94	21.8			21.8
		118	1.71			1.71
		127	15.7			15.7
		144	1.94			1.94
		155	0.17			0.17
	1997 Total		1572.65			1572.65
	1998	40	0.6			0.6
		48	180.6			180.6
		69	4884			4884
		112	0.24			0.24
		117	104.8			104.8
		120	26			26
		179	42			42
	1998 Total		5238.24			5238.24
6° Total			19907.84	0		19907.84
7°	1985	13	185.6			185.6
		17	24.9			24.9
		29	21.6			21.6
		32	192			192
		36	17.64			17.64
		41	14.4			14.4
		42	11.34			11.34
		68	67.6			67.6
		72	38.5			38.5

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
7°	1985	73	59.9			59.9
		91	69.8			69.8
		92	15.6			15.6
		98	0.4			0.4
		103	162			162
		111	1323			1323
		121	16			16
		230	3.75			3.75
	1985 Total		2224.03			2224.03
	1986	40	18			18
		43	9			9
		48	2.2			2.2
		52	27.9			27.9
		57	388.6			388.6
		59	121			121
		61	402.9			402.9
		62	129.6			129.6
		65	43			43
		69	1.6			1.6
		71	13.8			13.8
		80	12.8			12.8
		82	107.2			107.2
		86	8.4			8.4
		88	1.6			1.6
		95	1526.5			1526.5
		98	26.4			26.4
		103	173.8			173.8
		107	145.6			145.6
		110	176			176
	1986 Total		3335.9			3335.9
	1989	17	2.25			2.25
		19	4			4
		23	0.9			0.9
		32	0.7			0.7
		43	6.76			6.76
		51	1.64			1.64
		53	132			132
		56	0.2			0.2
		57	25.2			25.2
		60	1.6			1.6
		65	19.8			19.8

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
7°	1989	66	0.5			0.5
		68	34.6			34.6
		70	0			0
		72	3			3
		75	3			3
		78	27.5			27.5
		85	76.8			76.8
		89	6.2			6.2
		90	66			66
		91	22.8			22.8
		92	667.37			667.37
		94	364			364
		95	43.88			43.88
		97	183			183
		99	550			550
		102	35.4			35.4
		105	1			1
		108	11.6			11.6
		127	0.4			0.4
	1989 Total		2292.1			2292.1
	1991	18	19.8			19.8
		23	70.8			70.8
		27	36			36
		35	0.36			0.36
		71	32			32
		78	2.81			2.81
		80	89.14			89.14
		83	1121.4			1121.4
		85	124.5			124.5
		87	38.4			38.4
		92	147			147
		100	348			348
		101	216			216
		102	1041.1			1041.1
		128	51.6			51.6
		154	21			21
		156	2.42			2.42
		183	18			18
	1991 Total		3380.33			3380.33
	1992	14	5.1			5.1
		17	30.8			30.8

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
7°	1992	22	1			1
		31	608			608
		39	0		5.6	5.6
		48	0		0.7	0.7
		60	645.4		1.54	646.94
		80	33.2		0.04	33.24
		85	14.4			14.4
		99	10			10
		103	2282			2282
		126	197		181	378
		430	0			0
		913	3.6			3.6
	1992 Total		3830.5		188.88	4019.38
	1994	30	1.02			1.02
		49	26.08			26.08
		52	0.12			0.12
		79	3.8			3.8
		81	646.52			646.52
		83	0.89			0.89
		110	1.94			1.94
		111	772.67			772.67
		112	62.16			62.16
		113	51.4			51.4
		140	2.85			2.85
		150	58.4			58.4
	1994 Total		1627.85			1627.85
	1995	24	27.9			27.9
		28	443.8			443.8
		30	119.32			119.32
		35	255.5			255.5
		65	469.5			469.5
		67	0.22			0.22
		76	677.4			677.4
		81	78			78
		84	5.86			5.86
		95	150			150
		103	33.2			33.2
		110	7.94			7.94
		112	3.36			3.36
		116	2.72			2.72
		148	0.78			0.78
		152	12.9			12.9

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
7°	1995 Total		2288.4			2288.4
	1996	24	0.92			0.92
		25	6.2			6.2
		30	5.2			5.2
		40	17.55			17.55
		58	65.66			65.66
		74	579			579
		79	95.64			95.64
		98	68			68
		125	203.2			203.2
		126	83.88			83.88
		142	111.1			111.1
		149	144.2			144.2
		196	154.84			154.84
		252	20.26			20.26
		257	147.2			147.2
		264	1.59			1.59
	1996 Total		1704.44			1704.44
	1997	23	1772.08			1772.08
		24	7.48			7.48
		31	0.08			0.08
		33	6.3			6.3
		36	97.17			97.17
		46	0.44			0.44
		58	37.7			37.7
		60	934.15			934.15
		68	23.03			23.03
		71	95.96			95.96
		73	1683			1683
		74	142.8			142.8
		77	92.4			92.4
		79	235.46			235.46
		83	1520.24			1520.24
		85	616			616
		98	5292.94			5292.94
		106	4772.43			4772.43
		112	365.79			365.79
		114	1693.44			1693.44
		117	109.92			109.92
		121	0.6			0.6
		134	212.08			212.08
		151	20.4			20.4

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
7°	1997	157	26.32			26.32
		213	76			76
	1997 Total		19834.21			19834.21
	1998	36	9.82			9.82
		48	67.95			67.95
		90	204.02			204.02
		93	117			117
		100	0.6			0.6
		120	0.66			0.66
		135	105.52			105.52
		179	10.5			10.5
		192	17.7			17.7
		361	3.86			3.86
	1998 Total		537.63			537.63
7° Total			41055.39		188.88	41244.27
8°	1985	20	0.2			0.2
		21	1.72			1.72
		37	25.2			25.2
		40	2.2			2.2
		43	78.73			78.73
		45	51			51
		47	9.4			9.4
		48	381.6			381.6
		56	5			5
		62	2302.8			2302.8
		63	7.4			7.4
		66	322.4			322.4
		72	4			4
		73	55			55
		76	1.8			1.8
		77	140.4			140.4
		78	2.4			2.4
		81	1404			1404
		85	968			968
		88	68.2			68.2
		89	344.6			344.6
		90	1.4			1.4
		97	6			6
		99	1.5			1.5
		104	77			77
		105	158			158
	1985 Total		6419.95			6419.95

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
8°	1986	24	0			0
		36	20			20
		39	3.2			3.2
		42	10.8			10.8
		44	93.2			93.2
		52	4			4
		54	0.36			0.36
		55	0.8			0.8
		63	59.2			59.2
		67	242.4			242.4
		68	44.4			44.4
		69	351.1			351.1
		71	139.7			139.7
		73	98			98
		75	21			21
		77	30			30
		78	33			33
		79	98			98
		80	32			32
		83	219.22			219.22
		84	216			216
		90	46			46
		91	31.6			31.6
		93	16			16
		95	28			28
		96	135			135
		97	420			420
		99	92.4			92.4
		100	182			182
		105	306			306
		107	78			78
		110	34.2			34.2
		113	54.4			54.4
		148	44			44
		157	22.4			22.4
	1986 Total		3206.38			3206.38
	1989	21	1.44			1.44
		27	3.12			3.12
		28	72			72
		37	11.6			11.6
		41	3.6			3.6
		43	0.04			0.04

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
8°	1989	50	105.65			105.65
		52	6			6
		53	1851.6			1851.6
		58	12.92			12.92
		59	2025.18			2025.18
		60	1893.6			1893.6
		61	392			392
		62	197.2			197.2
		63	4.03			4.03
		64	126			126
		65	48.96			48.96
		66	5.4			5.4
		68	1.6			1.6
		69	1.66			1.66
		71	2			2
		72	29.6			29.6
		74	54			54
		76	11.2			11.2
		78	3.3			3.3
		81	12.4			12.4
		90	303.26			303.26
		91	257.2			257.2
		95	6			6
		99	96			96
		102	418			418
		106	43.2			43.2
	1989 Total		7999.76			7999.76
	1991	14	0			0
		20	8.4			8.4
		21	12			12
		22	137			137
		23	1.13			1.13
		29	56			56
		33	0.04			0.04
		34	0			0
		43	779.4			779.4
		48	36			36
		51	64			64
		55	3.6			3.6
		56	266			266
		60	20			20
		61	75.8			75.8

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
8°	1991	62	75			75
		65	16			16
		70	342.32			342.32
		73	13.1			13.1
		76	182.6			182.6
		80	45.6			45.6
		81	0.2			0.2
		83	26			26
		88	409			409
		90	81			81
		99	60			60
		100	352.17			352.17
		102	903.11		248.47	1151.58
		106	508.79			508.79
		112	308			308
		156	231.6			231.6
		164	28.8			28.8
		200	21			21
		201	0.08			0.08
		239	0.7			0.7
		240	88			88
	1991 Total		5152.44		248.47	5400.91
	1992	23	56			56
		27	408			408
		33	792			792
		44	100.4			100.4
		46	104			104
		47	6.2			6.2
		48	0.75			0.75
		53	374			374
		65	39.2		0.08	39.28
		73	8			8
		88	485		28	513
		92	1.1			1.1
		95	33.4		16.2	49.6
		96	25.2		1.06	26.26
		122	0.02			0.02
		124	11.6			11.6
		139	820			820
		157	78			78
		225	1.6			1.6
		248	72			72

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
8°	1992 Total		3416.47		45.34	3461.81
	1994	36	82.5			82.5
		38	62			62
		48	149.8			149.8
		58	745.5			745.5
		61	9.6			9.6
		68	111.2			111.2
		74	21.42			21.42
		107	11.37			11.37
		116	410			410
		124	180		2.7	182.7
	1994 Total		1783.39		2.7	1786.09
	1995	31	2282.6			2282.6
		36	402.5			402.5
		55	145.86			145.86
		74	373.8			373.8
		82	467.43			467.43
		88	1.02			1.02
		92	60.1			60.1
		95	41212.5			41212.5
		96	10.6			10.6
		109	8.24			8.24
		133	220			220
		165	2790			2790
		177	41.3			41.3
		203	69.4			69.4
		214	57.84			57.84
	1995 Total		48143.19			48143.19
	1996	25	104.1			104.1
		26	46.59			46.59
		34	89.68			89.68
		36	9.44			9.44
		38	321.3			321.3
		60	7.3			7.3
		70	193.96			193.96
		76	43			43
		82	2.7			2.7
		88	20.7			20.7
		89	27.1			27.1
		120	665.04			665.04
		121	250.6			250.6
		128	77.5			77.5

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
8°	1996	128	77.5			77.5
		152	226.9			226.9
		166	1351.26			1351.26
		168	198			198
		248	21.2			21.2
		252	46.5			46.5
		253	32.4			32.4
		296	52.2			52.2
		680	8.2			8.2
	1996 Total		3795.67			3795.67
	1997	21	63			63
		22	52.71			52.71
		25	56.9			56.9
		29	9.34			9.34
		43	588.8			588.8
		58	905.64			905.64
		60	8.32			8.32
		63	94.5			94.5
		68	139.6			139.6
		71	864			864
		72	3.52			3.52
		76	29.2			29.2
		81	31.1			31.1
		83	72			72
		90	0.14			0.14
		92	2.61			2.61
		93	160			160
		102	125.86			125.86
		103	529.1			529.1
		105	24.2			24.2
		115	317.8			317.8
		122	22.45			22.45
		124	188.5			188.5
		131	375.72			375.72
		143	11.02			11.02
		149	45.6			45.6
		152	616.54			616.54
		181	1468.8			1468.8
		264	3.5			3.5
		271	5.6			5.6
	1997 Total		6816.07			6816.07
	1998	23	3			3

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
8°	1998	31	1.73			1.73
		49	5.4			5.4
		55	22.4			22.4
		57	24.58			24.58
		72	221.25			221.25
		81	8.65			8.65
		90	409.78			409.78
		98	16			16
		104	3371.14			3371.14
		107	182			182
		120	2.7			2.7
		190	4.4			4.4
		213	10.92			10.92
		240	9.3			9.3
		319	16.8			16.8
	1998 Total		4310.05			4310.05
8° Total			91040.59		296.51	91337.1
9°	1985	19	1			1
		22	16			16
		24	11.8			11.8
		32	14			14
		38	0.5			0.5
		50	63.6			63.6
		52	9.57			9.57
		59	3443.68			3443.68
		64	93.9			93.9
		66	263.16			263.16
		76	217.6			217.6
		80	250			250
		100	1493			1493
		107	882			882
		119	0.8			0.8
		525	80			80
	1985 Total		6840.61			6840.61
	1986	15	7.5			7.5
		16	7.7			7.7
		17	0.48			0.48
		45	4.6			4.6
		51	12.8			12.8
		55	0			0
		59	12			12
		61	34			34

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
9°	1986	65	138			138
		70	332.4			332.4
		78	128.4			128.4
		80	1645			1645
		93	138.6			138.6
		125	958.8			958.8
	1986 Total		3420.28			3420.28
	1989	19	1.2			1.2
		30	6.6			6.6
		33	0.2			0.2
		36	1.2			1.2
		51	0.04			0.04
		52	56.4			56.4
		55	118.4			118.4
		58	115.88			115.88
		65	18.4			18.4
		70	140			140
		73	21			21
		74	1.2			1.2
		76	0			0
		78	257.31			257.31
		79	258.6			258.6
		80	130.24			130.24
		83	49.84			49.84
		84	15.84			15.84
		85	69.4			69.4
		88	55.5			55.5
		95	60.8			60.8
		97	368			368
		100	15900			15900
		101	750			750
		102	26.88			26.88
		107	33			33
		120	0.1			0.1
		135	10.4			10.4
		138	1.17			1.17
		167	0.96			0.96
	1989 Total		18468.56			18468.56
	1991	19	1			1
		20	15			15
		23	46			46
		25	18			18

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
9°	1991	26	37.4			37.4
		27	1.75			1.75
		35	24			24
		40	2.12			2.12
		45	25			25
		47	37.2			37.2
		48	38.08			38.08
		62	294			294
		67	312			312
		68	1.4			1.4
		69	0.8			0.8
		70	626.25			626.25
		75	145.2			145.2
		84	128.25			128.25
		85	148.2			148.2
		90	14.6			14.6
		101	3976			3976
		104	4600			4600
		105	20			20
		106	8.86			8.86
		115	10.4			10.4
		120	7.2			7.2
		122	3.4			3.4
		196	10.67			10.67
	1991 Total		10552.78			10552.78
	1992	13	18			18
		14	98.8			98.8
		15	0.6			0.6
		17	0		2	2
		20	20			20
		28	326.65			326.65
		29	18.4			18.4
		41	0		0.04	0.04
		58	144			144
		71	2132			2132
		72	604			604
		81	510.4			510.4
		82	96.2			96.2
		99	313.2			313.2
		102	447			447
		105	664.54			664.54
	1992 Total		5393.79		2.04	5395.83

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
9°	1994	25	88.52			88.52
		34	101.76			101.76
		45	39.18			39.18
		52	50.9			50.9
		64	62.7			62.7
		66	5.28			5.28
		67	1844.88			1844.88
		71	8			8
		74	14.16			14.16
		85	470.5			470.5
		92	822			822
		112	867.3			867.3
		113	30.76			30.76
		114	41.52			41.52
		147	57.38			57.38
		153	4.98			4.98
		207	25.4			25.4
	1994 Total		4535.22			4535.22
	1995	15	38.02			38.02
		17	1.48			1.48
		20	0.12			0.12
		29	1438.3			1438.3
		35	9.68			9.68
		51	0.94			0.94
		56	8.54			8.54
		66	3.1			3.1
		77	434.98			434.98
		80	100.48			100.48
		102	4.28			4.28
		103	52.49			52.49
		104	35.76			35.76
		108	17			17
		113	0.5			0.5
		116	15.12			15.12
		119	318.5			318.5
		150	752.58			752.58
		175	53.1			53.1
		178	2.7			2.7
		219	85.06			85.06
		244	1.18			1.18
		246	47.8			47.8
		283	8.1			8.1

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
9°		342	5.6			5.6
	1995 Total		3435.41			3435.41
	1996	19	1.66			1.66
		20	5.35			5.35
		24	23.1			23.1
		30	21.98			21.98
		33	4095			4095
		35	0.52			0.52
		39	193.3			193.3
		40	237			237
		42	409.84			409.84
		45	489.6			489.6
		47	305.1			305.1
		49	4.38			4.38
		50	47.67			47.67
		51	1355.88			1355.88
		57	287.51			287.51
		59	28.41			28.41
		63	86.48			86.48
		64	45.4			45.4
		76	153.6			153.6
		83	2.58			2.58
		86	261.6			261.6
		93	97.68			97.68
		94	232.8			232.8
		115	28			28
		116	0.08			0.08
		168	118.8			118.8
		181	103.5			103.5
		195	1968.75			1968.75
		219	69.5			69.5
		258	10.62			10.62
		305	1.1			1.1
		898	0.02			0.02
	1996 Total		10686.81			10686.81
	1997	23	1.32			1.32
		32	0.27			0.27
		40	4.29			4.29
		42	10.57			10.57
		44	102.3			102.3
		45	72.49			72.49
		47	54.44			54.44

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
9°	1997	57	110.36			110.36
		60	11.26			11.26
		63	89.42			89.42
		68	869.03			869.03
		73	75.14			75.14
		79	81.55			81.55
		82	1046.1			1046.1
		94	34.2			34.2
		111	313.5			313.5
		129	13			13
		166	481.4			481.4
		167	12.19			12.19
		183	0.3			0.3
		217	314.6			314.6
	1997 Total		3697.73			3697.73
	1998	25	42.86			42.86
		30	1.23			1.23
		41	140			140
		59	0.97			0.97
		68	71.25			71.25
		72	0.93			0.93
		88	27.26			27.26
		103	1.06			1.06
		110	574.76			574.76
		113	0.6			0.6
		114	0.6			0.6
		117	11.67			11.67
		168	0.2			0.2
		173	93.58			93.58
		268	1.75			1.75
	1998 Total		968.72			968.72
9° Total			67999.91		2.04	68001.95
10°	1985	14	11			11
		19	0.48			0.48
		21	69.73			69.73
		23	23.2			23.2
		24	34			34
		27	3.2			3.2
		31	8.5			8.5
		35	77.6			77.6
		39	49.2			49.2
		43	4			4

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
10°	1985	50	196.4			196.4
		51	17.78			17.78
		61	941.6			941.6
		64	75.6			75.6
		68	4.5			4.5
		70	182.4			182.4
		75	0	173.6		173.6
		77	21.4			21.4
		79	16.35			16.35
		93	1330.38			1330.38
		97	71			71
		100	100.8			100.8
		104	0.6			0.6
		114	656			656
		211	1.6			1.6
		260	1.8			1.8
	1985 Total		3899.12	173.6		4072.72
	1986	25	2.4			2.4
		32	8.4			8.4
		41	1.2			1.2
		53	444.96			444.96
		64	12			12
		70	249			249
		71	88.6			88.6
		72	33.6			33.6
		74	496			496
		82	347.4			347.4
		83	1386			1386
		96	205.2			205.2
	1986 Total		3274.76			3274.76
	1989	10	44.4			44.4
		21	154.8			154.8
		23	0.1			0.1
		25	48			48
		30	1.2			1.2
		35	19.4			19.4
		46	6.5			6.5
		48	138			138
		65	1.7			1.7
		67	1605.46			1605.46
		69	0.4			0.4
		70	4			4

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
10°	1989	71	241.92			241.92
		72	154			154
		78	0.4			0.4
		83	6.8			6.8
		85	142.4			142.4
		86	197.6			197.6
		90	0.8			0.8
		95	676.8			676.8
		96	86.4			86.4
		101	52.4			52.4
		110	22			22
		119	1.4			1.4
		121	1018.78			1018.78
		150	2.88			2.88
	1989 Total		4628.54			4628.54
	1991	18	130.7			130.7
		22	26.4			26.4
		24	12			12
		40	59.4			59.4
		43	499.92			499.92
		44	22.6			22.6
		54	61.2			61.2
		57	40.94			40.94
		58	9.55			9.55
		62	2.7			2.7
		70	99.4			99.4
		71	309.6			309.6
		78	33.4			33.4
		80	220			220
		84	5.33			5.33
		93	3887.4			3887.4
		98	585			585
		103	12370.6			12370.6
		107	401			401
		112	0.7			0.7
		352	0.6			0.6
	1991 Total		18778.44			18778.44
	1992	16	44.2		0	44.2
		17	368.5		10.06	378.56
		21	6			6
		22	70			70
		29	160			160

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
10°	1992	31	15.6		7.2	22.8
		41	56.8		15.6	72.4
		45	720		921.6	1641.6
		65	760		24	784
		66	1558.2			1558.2
		79	187.2			187.2
		83	80			80
		85	1170			1170
		86	180			180
		90	12.6		0	12.6
		98	66.4			66.4
		103	56.4			56.4
		105	105.6			105.6
		113	22.06			22.06
		119	560			560
	1992 Total		6199.56		978.46	7178.02
	1994	20	151.2			151.2
		23	81.48			81.48
		28	3			3
		40	2991.46			2991.46
		42	8			8
		43	56.48			56.48
		47	651			651
		50	4.62			4.62
		51	23.36			23.36
		52	329.76			329.76
		56	3732			3732
		59	318.12			318.12
		71	136.6		0.04	136.64
		80	3752.42			3752.42
		82	20453.69			20453.69
		90	1257.93			1257.93
		99	289.64			289.64
		110	2.48			2.48
		115	2416			2416
		117	656.96			656.96
		123	934.88			934.88
		193	10.04			10.04
	1994 Total		38261.12		0.04	38261.16
	1995	24	1.12			1.12
		27	465.6			465.6
		29	359.72			359.72

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
10°	1995	31	60.9			60.9
		32	819.46			819.46
		40	278.2			278.2
		42	49.06			49.06
		50	139			139
		53	37.4			37.4
		71	3.46			3.46
		78	257.28			257.28
		80	1.62			1.62
		88	70.8			70.8
		98	109.67			109.67
		100	3.02			3.02
		103	1.36			1.36
		105	134.4			134.4
		108	1.71			1.71
		110	12			12
		113	4.2			4.2
		129	8.36			8.36
		210	34.84			34.84
		212	151.96			151.96
		243	5.22			5.22
	1995 Total		3010.36			3010.36
	1996	25	217.3			217.3
		26	55.68			55.68
		30	233.19			233.19
		44	86.98			86.98
		46	206.6			206.6
		49	721.8			721.8
		52	809.8			809.8
		57	684.2			684.2
		61	202			202
		69	12.2			12.2
		72	577.5			577.5
		75	104.2			104.2
		76	83.9			83.9
		86	0.48			0.48
		90	134.7			134.7
		96	72.2			72.2
		108	14.66			14.66
		124	26.1			26.1
		128	4308.36			4308.36
		150	153.69			153.69

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
10°	1996	185	1.32			1.32
		238	15.06			15.06
		240	5.82			5.82
	1996 Total		8727.74			8727.74
	1997	19	1481.81			1481.81
		27	18			18
		29	230.81			230.81
		38	1590.42			1590.42
		39	8.57			8.57
		45	596.49			596.49
		46	5.36			5.36
		50	167.73			167.73
		69	120.06			120.06
		70	410.4			410.4
		78	1017.94			1017.94
		79	374.1			374.1
		96	555.43			555.43
		100	1709.1			1709.1
		101	93.2			93.2
		114	145			145
		115	1452			1452
		117	1186.31			1186.31
		118	2286.57			2286.57
		130	960			960
		160	1020.8			1020.8
		171	1012.84			1012.84
		199	11.9			11.9
		205	117.6			117.6
		317	4.8			4.8
	1997 Total		16577.24			16577.24
	1998	22	25.95			25.95
		23	18.5			18.5
		25	2.34			2.34
		32	1.29			1.29
		39	32.59			32.59
		45	28.8			28.8
		50	111.6			111.6
		57	216			216
		60	0.02			0.02
		62	574.58			574.58
		64	576.9			576.9
		66	3.16			3.16

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
10°	1998	68	284.87			284.87
		73	12.55			12.55
		76	529.81			529.81
		103	567.93			567.93
		109	48.2			48.2
		112	421.75			421.75
		125	158.29			158.29
	1998 Total		3615.13			3615.13
10° Total			106972	173.6	978.5	108124.11
11°	1985	15	0.9			0.9
		18	18			18
		20	34.8			34.8
		22	31.2			31.2
		23	40			40
		26	7			7
		28	93.8			93.8
		30	118.56			118.56
		31	6.8			6.8
		34	13.6			13.6
		35	0.12			0.12
		36	1.2			1.2
		38	89.8			89.8
		40	4			4
		45	162			162
		47	190			190
		50	21			21
		51	30.52			30.52
		52	21.93			21.93
		57	19.3			19.3
		61	52.8			52.8
		64	64.2			64.2
		65	140.87			140.87
		67	46			46
		70	78.6			78.6
		73	114.8			114.8
		75	93.6			93.6
		79	2.4			2.4
		82	15.81			15.81
		93	30			30
		98	4.2			4.2
		106	299.6			299.6
		117	0.06			0.06

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
11°	1985 Total		1847.47			1847.47
	1986	34	0.4			0.4
		35	1.8			1.8
		36	3			3
		48	12			12
		50	365.6			365.6
		55	24.4			24.4
		67	22			22
		80	506			506
		82	15.6			15.6
		87	110.88			110.88
		92	4.8			4.8
		104	785.6			785.6
		108	14			14
	1986 Total		1866.08			1866.08
	1989	20	2.04			2.04
		25	3.1			3.1
		26	224.4			224.4
		33	0.8			0.8
		50	31.1			31.1
		52	0.1			0.1
		54	8.2			8.2
		58	0.6			0.6
		61	1632			1632
		62	180.2			180.2
		64	195			195
		70	120.8			120.8
		85	38			38
		87	803.62			803.62
		88	600			600
		89	313.6			313.6
		98	739			739
		100	199.5			199.5
		105	2.4			2.4
		110	150.4			150.4
		111	39			39
		112	299			299
		113	45.6			45.6
		116	74			74
	1989 Total		5702.46			5702.46
	1991	19	21			21
		25	0.2			0.2

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
11°	1991	26	513.33			513.33
		36	24.21			24.21
		42	0.3			0.3
		48	1.2			1.2
		49	85.8			85.8
		53	826			826
		58	9			9
		60	28.6			28.6
		74	196.8			196.8
		75	731.4			731.4
		85	268.93			268.93
		89	0.12			0.12
		99	26			26
		100	149.4			149.4
		103	1600			1600
		104	1284			1284
		106	0.1			0.1
		250	0	18		18
	1991 Total		5766.39	18		5784.39
	1992	20	106.2			106.2
		21	1.6			1.6
		22	120.31		5.54	125.85
		35	0		0.03	0.03
		47	52.8			52.8
		64	19.8			19.8
		80	5220			5220
		88	405			405
		101	14			14
		144	784			784
		151	21			21
		246	10.8			10.8
	1992 Total		6755.51		5.57	6761.08
	1994	24	2.46			2.46
		25	3.2			3.2
		29	198.55			198.55
		40	1474.8			1474.8
		44	26			26
		54	606.67			606.67
		62	525.32		12.36	537.68
		71	277			277
		75	3294.92			3294.92
		80	23.68			23.68

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
11°	1994	96	882.27			882.27
		105	146.02			146.02
		114	240			240
		127	531.75			531.75
		128	472.5			472.5
		203	659.5			659.5
		206	237.77			237.77
	1994 Total		9602.41		12.36	9614.77
	1995	17	18.2			18.2
		18	8.38			8.38
		23	0.02			0.02
		30	149.46			149.46
		31	155.54			155.54
		32	0.34			0.34
		33	78			78
		36	21.32			21.32
		58	77.4			77.4
		60	104.26			104.26
		64	1.92			1.92
		66	19.26			19.26
		72	192			192
		78	34.8			34.8
		84	59			59
		86	16.6			16.6
		108	16.96			16.96
		112	65.1			65.1
		167	1339.8			1339.8
		176	139.5			139.5
		179	56			56
		214	37			37
		244	67.2			67.2
		245	71.4			71.4
		323	156.6			156.6
		325	46.5			46.5
	1995 Total		2932.56			2932.56
	1996	27	99			99
		31	14.22			14.22
		34	82.4			82.4
		36	100.06			100.06
		39	283.8			283.8
		44	38.54			38.54
		48	46.66			46.66

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
11°	1996	49	390.6			390.6
		53	8.04			8.04
		58	670.74			670.74
		62	701.4			701.4
		79	248.2			248.2
		81	0.48			0.48
		82	86.96			86.96
		87	804.56			804.56
		91	2464.02			2464.02
		103	648			648
		108	2.42			2.42
		111	195.49			195.49
		126	42.2			42.2
		160	176.7			176.7
		194	127.8			127.8
		220	10.48			10.48
		222	54			54
	1996 Total		7296.77			7296.77
	1997	22	6.42			6.42
		26	27.31			27.31
		30	0.51			0.51
		35	58.96			58.96
		38	172.45			172.45
		41	111.1			111.1
		43	12.74			12.74
		45	1078.57			1078.57
		68	235.5			235.5
		74	77.63			77.63
		75	1956			1956
		78	59.09			59.09
		80	18.33			18.33
		93	112.97			112.97
		95	720			720
		107	2536.5			2536.5
		126	1135.74			1135.74
		139	0.4			0.4
		147	128.4			128.4
		189	27.45			27.45
		201	53.33			53.33
		251	158			158
		252	0.75			0.75
		279	8.4			8.4

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
11°	1997 Total		8696.55			8696.55
	1998	27	4.05			4.05
		32	6.32			6.32
		33	504.6			504.6
		35	557.47			557.47
		38	15.09			15.09
		41	69.88			69.88
		47	16.4			16.4
		50	23.65			23.65
		57	0.45			0.45
		60	265.77			265.77
		65	7.14			7.14
		70	114.8			114.8
		80	26.72			26.72
		86	1.46			1.46
		91	576.8			576.8
		97	0.34			0.34
		108	4.74			4.74
	1998 Total		2195.68			2195.68
11° Total			52661.88	18	17.93	52697.81
12°	1985	21	40			40
		31	98.14			98.14
		32	19			19
		34	1.8			1.8
		44	32.2			32.2
		51	3.8			3.8
		55	0.48			0.48
		57	70			70
		58	26.55			26.55
		63	225			225
		64	360			360
		67	778.8			778.8
		69	8.2			8.2
		70	490	4.2		494.2
		75	265.8			265.8
		76	135.6			135.6
		77	1639			1639
		83	93.84	2.88		96.72
		86	28			28
		91	14.36			14.36
		97	13.68			13.68
		98	46.15			46.15

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
12°	1985	99	20.6			20.6
		100	64.4			64.4
		103	300			300
		104	98.4			98.4
	1985 Total		4873.8	7.08		4880.88
	1986	21	6.4			6.4
		33	6.8			6.8
		37	24			24
		40	102.94			102.94
		41	55.2			55.2
		45	27.2			27.2
		54	4.8			4.8
		56	18.4			18.4
		57	5.86			5.86
		59	3.6			3.6
		60	12			12
		61	0.66			0.66
		63	3.6			3.6
		64	251.2			251.2
		69	46			46
		72	0.96			0.96
		83	456			456
		84	4485.6			4485.6
		85	1425			1425
		91	1.6			1.6
	1986 Total		6937.82			6937.82
	1989	25	25.2			25.2
		29	2.4			2.4
		38	4.31			4.31
		40	4.5			4.5
		42	55.65			55.65
		44	494.35			494.35
		46	9.6			9.6
		51	0		62.7	62.7
		55	55.12			55.12
		57	11.2			11.2
		61	35			35
		64	54			54
		70	15			15
		74	0.06			0.06
		81	144.4			144.4
		86	44.51			44.51

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
12°	1989	90	0.5			0.5
		94	176.4			176.4
		97	72.96			72.96
		101	0.26			0.26
		103	18			18
	1989 Total		1223.42		62.7	1286.12
	1991	24	1.6			1.6
		25	29.6			29.6
		32	22			22
		33	36.43			36.43
		35	98.4			98.4
		37	10.5			10.5
		42	45.6			45.6
		54	289			289
		57	65			65
		64	40.32			40.32
		71	3.6			3.6
		73	4922.4			4922.4
		81	24.6			24.6
		86	135.2			135.2
		88	480.6			480.6
		89	1.4			1.4
		95	64.5			64.5
		102	161.6			161.6
	1991 Total		6432.35			6432.35
	1992	18	227.7		88.2	315.9
		20	1160			1160
		25	2604.2			2604.2
		54	362			362
		62	28.74			28.74
		83	39			39
		93	108			108
		100	400			400
		219	21			21
		318	100			100
	1992 Total		5050.64		88.2	5138.84
	1994	35	54.25			54.25
		62	3008			3008
		72	0	145.5		145.5
		74	438			438
		88	262.27		0	262.27
		93	257.06			257.06

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
12°	1994	105	0		0	0
		109	7.6			7.6
		199	104.05			104.05
		231	192.18			192.18
	1994 Total		4323.41	145.5	0	4468.91
	1995	27	334.56			334.56
		35	17.56			17.56
		37	20.34			20.34
		39	129.58			129.58
		44	0.64			0.64
		47	13.58			13.58
		58	0.03			0.03
		67	0.48			0.48
		79	101.52			101.52
		84	434			434
		89	54.4			54.4
		93	169.26			169.26
		94	194.2			194.2
		103	32.97			32.97
		106	2057.94			2057.94
		176	926.71			926.71
		214	102			102
		219	0.52			0.52
		341	58.8			58.8
		350	28.96			28.96
		355	5878.6			5878.6
		360	2.88			2.88
		457	3.08			3.08
	1995 Total		10562.61			10562.61
	1996	37	1.5			1.5
		38	106.2			106.2
		43	9			9
		62	24.8			24.8
		68	199.36			199.36
		76	31.9			31.9
		83	804.3			804.3
		90	0.7			0.7
		100	20.1			20.1
		105	1014.04			1014.04
	1996 Total		2211.9			2211.9
	1997	33	88.33			88.33
		35	1079.92			1079.92

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
12°	1997	37	621.54			621.54
		41	11.52			11.52
		42	406.83			406.83
		44	228.31			228.31
		48	288.76			288.76
		61	39.68			39.68
		66	9.18			9.18
		68	427.9			427.9
		69	30.86			30.86
		79	178.8			178.8
		83	697.2			697.2
		88	891.62			891.62
		100	833.24			833.24
		104	429			429
		106	143.22			143.22
		202	18.9			18.9
		329	0.54			0.54
	1997 Total		6425.35			6425.35
	1998	26	111.27			111.27
		29	10.84			10.84
		45	80.6			80.6
		51	9.36			9.36
		52	27.88			27.88
		53	404			404
		70	443.82			443.82
		71	899.38			899.38
		72	362.5			362.5
		79	1428.75			1428.75
		81	25.03			25.03
		91	202.5			202.5
		97	13.85			13.85
		104	55.86			55.86
		109	198.28			198.28
		110	28.5			28.5
		629	370.76			370.76
	1998 Total		4673.18			4673.18
12° Total			52714.48	152.58	150.9	53017.96
13°	1985	35	34.8			34.8
		110	1500			1500
	1985 Total		1534.8			1534.8
	1986	112	3.6			3.6
	1986 Total		3.6			3.6

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
13°	1989	50	525			525
		63	484.05			484.05
		92	672			672
		95	350			350
		96	16			16
	1989 Total		2047.05			2047.05
	1991	93	1140.95			1140.95
		100	7.2			7.2
		106	87.2			87.2
		113	67.2			67.2
	1991 Total		1302.55			1302.55
	1992	93	8.1			8.1
		135	4.32			4.32
	1992 Total		12.42			12.42
	1995	99	328.65			328.65
		105	70.3			70.3
		692	132			132
	1995 Total		530.95			530.95
	1996	109	930.43			930.43
		112	1976.02			1976.02
		134	3544	1668		5212
		195	1123.2			1123.2
	1996 Total		7573.65	1668		9241.65
	1997	99	3657.68			3657.68
		118	956.4			956.4
		129	461.4			461.4
		225	51.9			51.9
		227	65.07			65.07
		468	4.3			4.3
	1997 Total		5196.75			5196.75
	1998	92	1.2			1.2
		108	189.9			189.9
		116	258	141		399
		122	105			105
		125	1024.8			1024.8
		453	83.4			83.4
		604	146			146
	1998 Total		1808.3	141		1949.3
13° Total			20010.07	1809		21819.07
14°	1985	17	5.2			5.2
		34	0	3.2		3.2
		75	1230			1230

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
14°	1985	93	219.6			219.6
		124	181.6			181.6
		230	443.2			443.2
	1985 Total		2079.6	3.2		2082.8
	1986	14	8.64			8.64
		18	14			14
		63	15.08	17.42		32.5
		86	147			147
		97	54			54
	1986 Total		238.72	17.42		256.14
	1989	21	4.8			4.8
		77	9			9
		99	3			3
	1989 Total		16.8			16.8
	1991	19	295.2			295.2
		47	37.34			37.34
		72	264.6			264.6
		84	200.4			200.4
		102	375.4			375.4
		108	165.6			165.6
	1991 Total		1338.54			1338.54
	1992	76	135			135
	1992 Total		135			135
	1995	75	0.02			0.02
		100	1026.1			1026.1
		133	0	27.12		27.12
		349	0	96.88		96.88
	1995 Total		1026.12	124		1150.12
	1996	86	1020	6.98		1026.98
	1996 Total		1020	6.98		1026.98
	1997	88	428.4	7.56		435.96
		105	49.8			49.8
		120	2382.11			2382.11
		126	3808.93			3808.93
	1997 Total		6669.24	7.56		6676.8
	1998	89	229.5			229.5
		103	1.38			1.38
		118	90.22			90.22
	1998 Total		321.1			321.1
14° Total			12845.12	159.16		13004.28
15°	1985	20	63			63
		34	38			38

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
15°	1985	40	7			7
		45	49.68			49.68
		80	0.6			0.6
		87	0	184		184
		90	448			448
		94	186			186
		100	0.02			0.02
		113	900			900
		300	197			197
	1985 Total		1889.3	184		2073.3
	1986	19	1.6			1.6
		69	573			573
		85	41			41
		106	0	283.51		283.51
		113	91			91
	1986 Total		706.6	283.51		990.11
	1989	32	76.8	2.5		79.3
		86	75			75
		94	87.82			87.82
		95	128.8			128.8
		96	82.97			82.97
		98	388.74			388.74
	1989 Total		840.13	2.5		842.63
	1991	26	33.6	3.2		36.8
		33	115.6			115.6
		40	244.2			244.2
		61	5.6			5.6
		65	2			2
		67	86			86
		81	44	12		56
		85	33.8	104		137.8
		88	120.4	50.4		170.8
		90	342			342
		95	5.48			5.48
		101	152	12		164
		104	174.6	195.6		370.2
	1991 Total		1359.28	377.2		1736.48
	1992	24	9			9
		60	6.27	3.27		9.54
		78	356.8	178.4		535.2
		80	43.2	3.6		46.8
		83	576	120		696

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
15°	1992	86	1167.6	75.6		1243.2
		102	506.8	515		1021.8
		105	75.56	159.56		235.12
		507	959.8	318.2		1278
	1992 Total		3701.03	1373.63		5074.66
	1995	16	0		1.26	1.26
		38	957.1	1.88		958.98
		94	0	14.5		14.5
		97	341			341
		102	148.76	21.28		170.04
		110	35.89	254.93		290.82
		125	0.78	94.84		95.62
	1995 Total		1483.53	387.43	1.26	1872.22
	1996	89	0.12			0.12
		93	3060.81			3060.81
	1996 Total		3060.93			3060.93
	1997	46	163.8			163.8
		77	3189.93			3189.93
		78	2247.54			2247.54
		100	743.33	428.61		1171.94
		110	3414.76	116.58		3531.34
		124	75.79	1089.47		1165.26
		271	0	21		21
	1997 Total		9835.15	1655.66		11490.81
	1998	24	155.2			155.2
		47	11.06			11.06
		55	307.32			307.32
		128	0	29040		29040
		511	6422.14	1044.34		7466.48
		1265	0	308.8		308.8
	1998 Total		6895.72	30393.14		37288.86
15° Total			29771.67	34657.07	1.26	64430
16°	1985	9	0	5.2		5.2
		19	58			58
		21	124	33		157
		22	7.9	6.2		14.1
		27	0	1836.54		1836.54
		30	110.4			110.4
		34	6.65	42.56		49.21
		36	78	37.4		115.4
		43	5.8			5.8
		45	0	30		30

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
16°	1985	55	0.4	37		37.4
		56	0.6			0.6
		65	0	200		200
		70	0	0.26		0.26
		81	304.8	326.4		631.2
		90	0	42.8		42.8
		96	0	380		380
		98	1173.6	1282		2455.6
		99	0	139.71		139.71
		100	0	123		123
		104	5.32	512.92		518.24
		106	0	90		90
		107	0	63.8		63.8
		112	0	224		224
		113	0	1048.8		1048.8
		114	0	1822.5		1822.5
		115	0	6.2		6.2
		120	0	13800		13800
		121	0	338		338
		124	0	15		15
		127	0	1072		1072
		130	0	2560		2560
		131	0	7272		7272
		133	6.6	35.3		41.9
		135	0	1026		1026
		137	0	6344		6344
		164	0	1.2		1.2
		615	0	960		960
		800	0	207.2		207.2
		999	1426	4110		5536
	1985 Total		3308.07	46030.99		49339.06
	1986	18	344			344
		19	18			18
		20	0	928.8		928.8
		23	165			165
		24	36			36
		30	230.4			230.4
		35	4			4
		42	4100			4100
		43	3278	0		3278
		47	26.6			26.6
		48	40			40

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
16°	1986	49	252			252
		57	2.6			2.6
		69	384	60		444
		70	269.4			269.4
		76	585			585
		77	5105.2	385.8		5491
		82	14	11		25
		83	576	61.2		637.2
		88	2263.6	100.6		2364.2
		90	1449	408.6		1857.6
		97	117.64	470.25		587.89
		98	388.2	7.2		395.4
		102	1649.6			1649.6
		103	64			64
		105	200.8	32.8		233.6
		108	22.4			22.4
		109	120	25.2		145.2
		110	787.95	12.75		800.7
		112	798	21.8		819.8
		114	3250	810		4060
		127	103.2	20.4		123.6
		140	60			60
		146	567			567
		179	47.88			47.88
		440	0.72			0.72
	1986 Total		27320.19	3356.4		30676.59
	1989	17	610.68			610.68
		18	0.9	4.6	2.6	8.1
		19	0	10.15		10.15
		20	283.96			283.96
		21	86.77			86.77
		22	0.34			0.34
		26	13.85			13.85
		28	0	2.8		2.8
		31	64			64
		35	5			5
		37	0.44	0.06		0.5
		38	140	12.6		152.6
		40	1705.6			1705.6
		42	465.28	258.64		723.92
		46	2.1	0.2		2.3
		55	3.9	89.49		93.39

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
16°	1989	63	0	830		830
		69	7.2	12.86		20.06
		70	0	8.4		8.4
		71	1.4	25.2		26.6
		72	31.6			31.6
		73	0	201.94		201.94
		75	8.4			8.4
		83	3			3
		88	18			18
		92	4.7	1.88		6.58
		97	70	42		112
		100	0	1233.6		1233.6
		101	0	840		840
		107	0	263.4		263.4
		108	500	3383		3883
		112	180	3030		3210
		115	23.2	440		463.2
		120	168.6	94.4		263
		121	17.49	109.03		126.52
		124	144	1589.91		1733.91
		132	10.4	72		82.4
		133	0	1323.52		1323.52
		137	0	35		35
		187	0	17.76		17.76
		200	0	1.2		1.2
		306	4.5	51.5		56
		700	0.6	93.5		94.1
		800	0.34	8.44		8.78
	1989 Total		4576.25	14087.08	2.6	18665.93
	1991	9	6.4			6.4
		16	334.8			334.8
		18	88.24			88.24
		19	424.69			424.69
		20	428.4			428.4
		30	1024.5			1024.5
		34	127.78	67.8		195.58
		37	0	252		252
		39	81.8			81.8
		40	0	121.5		121.5
		41	64.05	11.1		75.15
		44	7.8			7.8
		45	1.33			1.33

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
16°	1991	46	7			7
		48	21.75	183		204.75
		50	42.4			42.4
		51	80.6			80.6
		55	0.2			0.2
		59	324			324
		67	328	130		458
		70	1910.8			1910.8
		74	410	22		432
		75	22.2			22.2
		76	2122.4	1562.4		3684.8
		77	158.4			158.4
		81	0	327.6		327.6
		82	1473	789		2262
		84	18	15		33
		85	1601.6	1601.6		3203.2
		86	1453.4			1453.4
		87	1285.2			1285.2
		88	0	360.4		360.4
		90	17	8.4		25.4
		96	4554	764.9		5318.9
		99	144	12.96		156.96
		101	3541	783.2		4324.2
		102	0	273.6		273.6
		103	924	3540		4464
		104	18.8	6.2		25
		107	0	401.2		401.2
		117	0.8	248.8		249.6
		121	14.4	546		560.4
		122	0	3587.2		3587.2
		130	0	804.8		804.8
		131	0	966		966
		151	0.6	1.2		1.8
		157	0	294		294
		164	0	1765		1765
		193	26.4	199.2		225.6
		198	0	92.6		92.6
		220	12	18		30
		298	0	6.6		6.6
		333	0	36.46		36.46
		525	4228			4228
		681	0	180		180

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
16°	1991 Total		27329.74	19979.72		47309.46
	1992	10	549			549
		13	377.18			377.18
		18	193.8			193.8
		26	0	2.6		2.6
		28	0	69.6		69.6
		29	366	2.4		368.4
		31	152			152
		33	93.6			93.6
		43	3192	3.04		3195.04
		44	1050			1050
		52	777	1971.2		2748.2
		54	552	2136		2688
		56	0	2178		2178
		60	44.8	462		506.8
		62	237.4	934.6		1172
		63	6000	1250		7250
		68	44	297		341
		74	0	1406.2		1406.2
		75	0	82		82
		77	0	21.39		21.39
		78	7.5	149.63		157.13
		79	0	540		540
		80	2.67			2.67
		81	5.6	16.4		22
		82	0	27.6		27.6
		87	0	2355.6		2355.6
		88	0	878.6		878.6
		89	0	2444		2444
		95	0	0.15		0.15
		100	0	3352.2		3352.2
		101	0	327.6		327.6
		104	0	1148		1148
		107	0	5818.4		5818.4
		116	0	2052		2052
		119	0	3670.4		3670.4
		132	0	45000		45000
		269	0	20		20
		345	0	13.2		13.2
		425	146.09	117.91		264
		999	0	502.6		502.6
	1992 Total		13790.64	79250.32		93040.96

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
16°	1993	11	266.4			266.4
		12	157.8	0.72		158.52
		13	119.7			119.7
		20	0.24			0.24
		22	51			51
		34	508.24			508.24
		40	55.56			55.56
		41	3600			3600
		42	981.82			981.82
		51	14300			14300
		52	1396.55	1158.62		2555.17
		63	28.8			28.8
		73	2406.6			2406.6
		81	791.8			791.8
		96	19.1			19.1
		97	1555.6	123.5		1679.1
		100	0	115.6		115.6
		101	56.52	1154.92		1211.44
		103	1147.6	45.6		1193.2
		109	0	272.73		272.73
		110	0	3552		3552
		115	228.8			228.8
		116	63.48	805.16		868.64
		123	147.8	1726.4		1874.2
		130	85.2	17		102.2
	1993 Total		27968.61	8972.25		36940.86
	1994	15	150.22	1423.02		1573.24
		17	15.9			15.9
	1994 Total		166.12	1423.02		1589.14
	1995	13	0		580.2	580.2
		18	0		397.8	397.8
		32	5078.4	1449		6527.4
		37	6.9			6.9
		77	66.09	2558.76		2624.85
		85	0		0.24	0.24
		91	1.68	572.6		574.28
	1995 Total		5153.07	4580.36	978.24	10711.67
	1996	11	600			600
		14	176.1			176.1
		17	3049.6			3049.6
		20	5542.65	2983.2		8525.85
		34	0.05			0.05

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
16°	1996	45	655.88	3.64		659.52
		56	240.6			240.6
		61	821.25	405		1226.25
		77	0	0.92		0.92
		99	605.92			605.92
		118	0	1832.6		1832.6
		124	0	223.8		223.8
	1996 Total		11692.05	5449.16		17141.21
	1997	16	3060			3060
		20	1255.07	8.14		1263.21
		22	2562			2562
		40	219			219
		41	2004.84			2004.84
		60	0	1883.6		1883.6
		77	2450.22			2450.22
		79	180.9			180.9
		88	0	11925.38		11925.38
		94	2908.29	256.29		3164.58
		112	1803	1960.38		3763.38
		115	0	50.4		50.4
		124	0	140.4		140.4
		184	0	2813.19		2813.19
	1997 Total		16443.32	19037.78		35481.1
	1998	16	44.18			44.18
		20	43.33			43.33
		25	32982.08	4150		37132.08
		29	4.15			4.15
		36	42			42
		48	0.31			0.31
		50	21.78			21.78
		57	1209.56			1209.56
		72	85.4			85.4
		78	921.6	184.32		1105.92
		98	1102.8			1102.8
		102	1467.33	23081.67		24549
		112	40.06			40.06
		114	0	6388.67		6388.67
		115	2139.44	20.48		2159.92
		119	0	1611.43		1611.43
		135	6708.56			6708.56
		181	0	6289.14		6289.14
		372	0	22180		22180

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
16°	1998	842	3.41	966.73		970.14
		1300	0	274.62		274.62
	1998 Total		46815.99	65147.06		111963.05
16° Total			184564.1	267314.14	980.84	452859.03
17°	1985	14	173.16	13.03		186.19
		22	91.8	95.6		187.4
		26	50	30		80
		65	0	0.8		0.8
		67	0	37		37
		87	0	2184		2184
		106	0	94		94
		115	0	144		144
		120	0	3900		3900
		135	0	72		72
		137	0	20000		20000
		140	0	1017.6		1017.6
		174	0	3945		3945
		193	0	1260		1260
		450	0	792		792
		500	0	114.75		114.75
	1985 Total		314.96	33699.78		34014.74
	1986	35	93.8	836.6		930.4
		37	80			80
		40	648			648
		54	25.6	629		654.6
		57	305	2653.6		2958.6
		89	1760			1760
		95	117	24.4		141.4
		102	0	57.72		57.72
		137	0	7		7
		145	78.66	117.99		196.65
		147	308.8	414.8		723.6
		255	9.6			9.6
		285	6562	23438		30000
		370	0	4.8		4.8
		500	324.9	102.6		427.5
	1986 Total		10313.36	28286.51		38599.87
	1989	39	0	3		3
		46	0.32	0.6	0.52	1.44
		70	0	43.2		43.2
		86	0	5		5
		100	0	3		3

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
17°	1989	113	0	147.6		147.6
		116	0	232.4		232.4
		122	0	64.8		64.8
		132	0	158.4		158.4
	1989 Total		0.32	658	0.52	658.84
	1991	20	340.8	16.8		357.6
		23	1912.8			1912.8
		38	28.8	3.6		32.4
		68	58.8			58.8
		73	132	77		209
		84	0	304.6		304.6
		88	0	4685		4685
		99	0	48.6		48.6
		100	0	1110.2		1110.2
		103	0	467.74		467.74
		114	0	11066.4		11066.4
		135	0	30.4		30.4
		138	0	105		105
		141	0	10413		10413
		142	0	3000		3000
		146	0	5978		5978
		147	0	121.8		121.8
		201	0	81.6		81.6
		298	0	5.8		5.8
		350	0	6.23		6.23
	1991 Total		2473.2	37521.77		39994.97
	1992	31	24	12		36
		62	0	42.3		42.3
		69	0	233.6		233.6
		77	0	3538		3538
		99	0	18634		18634
		100	0	6645		6645
		167	0	131.6		131.6
		895	0	21.36		21.36
	1992 Total		24	29257.86		29281.86
	1993	32	0	61.38		61.38
		75	31.06	251.54		282.6
		99	227.76			227.76
		150	0	482		482
		154	1.16	79.46		80.62
	1993 Total		259.98	874.38		1134.36
	1994	80	0.98			0.98

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
17°	1994 Total		0.98			0.98
	1997	22	336			336
		24	87.75			87.75
		63	0	6620.45		6620.45
		66	0	11557.6		11557.6
		82	0	2364.87		2364.87
		106	0	28		28
		112	0	369.24		369.24
		114	0	534.76		534.76
		131	0	1119.26		1119.26
		153	46.24	545.87		592.11
		169	0	555		555
		176	0	2021.4		2021.4
		218	0	2051.25		2051.25
		258	0	227.86		227.86
		286	0	1.38		1.38
		304	4.2			4.2
		310	0	11.1		11.1
		325	0	4.2		4.2
	1997 Total		474.19	28012.24		28486.43
	1998	42	1128			1128
		100	0	410		410
		110	0	570		570
		122	1144.67	179.67		1324.34
		182	0	2090.32		2090.32
		187	0	7387.71		7387.71
	1998 Total		2272.67	10637.7		12910.37
17° Total			16133.66	168948.24	0.52	185082.42
18°	1997	81	0	2223.6		2223.6
		90	0	1528.8		1528.8
		116	0	1139.55		1139.55
		129	0	1358.32		1358.32
		151	0	971.26		971.26
		156	0	550.8		550.8
		182	0	395.8		395.8
		226	0	2180.1		2180.1
		252	0	3.68		3.68
		283	0	335		335
		296	0	16.2		16.2
		311	0	637.6		637.6
	1997 Total		0	11340.71		11340.71
18° Total			0	11340.71		11340.71

Appendix IV (cont.): Catch rate (kg/hour) by latitude-year and depth (1985-1998)

Latitude (S)	Year	Depth (m)	Species			Grand Total
			T. trecae	*T. capensis*	*Trachurus spp.*	
19°	1989 Total		38.8			38.8
	1997	60	0	43.2		43.2
		70	0	79.2		79.2
		75	0	3441.18		3441.18
		104	0	1857		1857
		132	0	1416		1416
		163	0	742.92		742.92
		180	0	4231.11		4231.11
		185	0	722.14		722.14
		195	0	479.4		479.4
		213	0	82.4		82.4
		240	0	175		175
		260	0	1.94		1.94
		338	0	16.2		16.2
	1997 Total		0	13287.69		13287.69
19° Total			38.8	13287.69		13326.49
20°	1997	60	0	24		24
		115	0	1668.79		1668.79
		130	0	1710		1710
		149	0	8073.26		8073.26
		150	0	388.5		388.5
		178	0	1421.32		1421.32
		198	0	1269.33		1269.33
		229	0	150.84		150.84
		256	0	470.32		470.32
		334	0	1.6		1.6
	1997 Total		0	15177.96		15177.96
20° Total			0	15177.96		15177.96
Grand Total			698430.7	513038.15	2624.82	1214093.69

Empty spaces in species columns = No data