UNIVERSIDADE DO ALGARVE

FACULDADE DE CIÊNCIAS E TECNOLOGIA

SOME ASPECTS OF THE BEHAVIOUR OF PELAGIC SPECIES OFF ANGOLA AND ITS IMPLICATION ON BIOMASS ESTIMATION

(Tese provisória para a obtenção do grau de doutor em Ciências e Tecnologias das Pescas, especialidade de Biologia Pesqueira)

Filomena Vaz-Velho

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ALGUNS ASPECTOS DO COMPORTAMENTO DAS ESPÉCIES PELÁGICAS EM ANGOLA E IMPLICAÇÕES NA ESTIMAÇÃO DE BIOMASSA

Resumo

A pescaria de pelagicos contribui com 80% do total de pescado desembarcado e 75% de proteína animal da dieta alimentar da populção que vive na orla costeira de Angola. A estimação da abundância dos recursos pelágicos é efectuada, sobretudo através do método acústico que é sensível aos erros devidos ao efeito do comportamento dos peixes, particularmente os que redução à detecção dos peixes ao método acústico.

Este estudo descreve a variabibilidade interanual das principais espécies pelágicas da costa de Angola e o impacto do seu comportamento na estimação da abundância dos recursos. As duas principais espécies pelágicas, Carapau do Cunene e Sardinela spp tem dinâmica diferente. A biomassa de Sardinela nos últimos anos está estável, enquanto que a do carapau do Cunene está num nível crítico.

Relativamente ao comportamento, o carapu do Cunene tende a formar cardumes densos no fundo durante o dia. Durante a noite os cardumes dispersam-se à superfíce levando à obtenção de valores de densidade acústicos mais baixos. Em algumas condições os peixes evitam o navio verticalmente mergulhando para profundidades inferiores a 12m aquando da passagem do navio

Em geral, os resultados deste estudo vão ajudar a melhorar o conhecimento do comportamento das espécies pelágicas da costa de Angola e seu impacto na estimação da abundância e consequentemente melhorar o sistem de gestão.

Palavras-chave: Angola; Pelágicos; Acústica; Comportamento; Pesca; Estimação de Abundância

SOME ASPECTS OF THE BEHAVIOUR OF PELAGIC SPECIES OFF ANGOLA AND ITS IMPLICATION ON BIOMASS ESTIMATION

Abstract

Pelagic fish off Angola constitute about 80% of the total fish landed and 75% of animal protein in the diet of the coastal population. In Angola, the primary means for estimating abundance of small pelagic fish is through acoustic surveys, a method that is sensitive to errors caused by effects of fish behaviour, particularly those that may reduce the acoustic detectability offish.

This study describes the interannual variability of the fishery and stocks pelagic off Angola and their behaviour in relation to the abundance estimation. The dynamics of the two main pelagic species, Cunene horse mackerel and *Sardinela spp* off Angola differ. In recent years the biomass of *Sardinela spp* is at stable level, whereas the Cunene horse mackerel is at critical level.

It was observe that a relatively straightforward analysis of conventional acoustic survey data collected at a single- frequency combined with ancillary spatio-temporal information can provide useful indications on the identification of single- and multi species aggregations of small pelagic fish.

With regard to their behaviour, Cunene horse mackerel tend to concentrate in dense schools near the seabed, but at night they move into the pelagic zone, dispersing into widespread scattering layers. The present study found that under some conditions fish tend to avoid the vessel vertically, diving below 12 m depth as vessel was passing over the fish.

In general, the results of this study should help improve Angola improve the knowledge of the behaviour of pelagic species off Angola and the quality of the abundance estimations produced.

Key words: Angola, Pelagic, Acoustics, Behaviour, Fishery; Abundance estimation

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Chapter I General Introduction

Hydrographic regime off Angola

Angola has a coastline of 1650 km, and a continental shelf of 51000 km2 with a width varying from about 10 to 100 km, average width of about 30 km. The hydrographic regime off Angola is characterized by the cold northward-flowing Benguela current and the warm south-propagating waters of the Angola current (Figure 1).

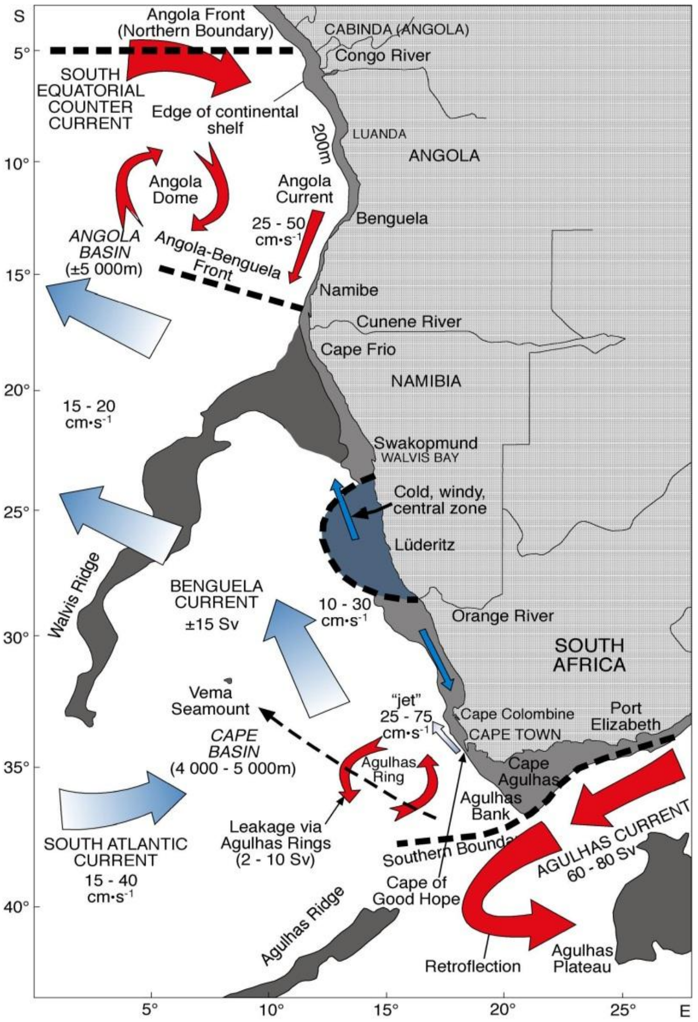

Figure 1: The hydrographic regime off Angola .

The Angola Current forms the eastern section of a large, cyclonic gyre in the Gulf of Guinea. In the upper layer (0-100 m), it seems to be formed mainly by the southeast branch of the South Equatorial Countercurrent and the southward-turning waters from the north branch of the Benguela Current. The influx of waters originating north of the equator is only moderate. However, in layers deeper than 100 m, northern waters become more important in feeding the Angola Current (Moroshkin et al. 1970).The Angola Current is fast, narrow, and stable flow that reaches 250-300 m depths and covers both the shelf regions and the continental slope. The water velocity at the surface from 9°S-16°S along the coast was found to be 50 cm s-1. At 25 m, it was greater than 70 cm s-1. Dias (1983a, 1983b). In March, at the surface, the velocity was on the order of 50 cm s-1. At 100 m, it was 70 cm s-1. These results suggest that there is temporal variability in the velocity of the current. According to Lass et al. (2000), Angola Current water usually has a temperature greater than 24°C and a salinity of more than 36.4 psu in the upper mixed layer. This water mass gradually becomes colder and less saline as it travels south (Lass et al. 2000).

The Benguela Current is the eastern boundary current of the South Atlantic subtropical gyre (Peterson and Stramma 1991, Wedepohl et al. 2000). It is one of four major eastern boundary current upwelling systems of world and although has some similar characteristics to the other eastern boundary upwelling areas, a unique feature is that it is bounded on both the equatorial and poleward extremities by warm Angola Current system in the north, and the Agulha Current in the south (Shannon and Nelson, 1996). The prevailing winds are responsible for strong Ekman transport and the resulting coastal upwelling of cool, nutrient-rich water that stimulates primary productivity (Boyer et al. 2000, Skogen 1999).

The northern boundary of Benguela ecosystem is the Angola-Benguela frontal zone. This series of fronts is a permanent feature at the surface, identifiable to a depth at least 200m and is maintained throughout the year within a relatively narrow band of latitudes, characteristically between 14°S and 17°S (i,e close to Cape Frio an the Angola- Namibia border). The frontal zone generally west-to-east orientation and appears to be maintained by a combination of factors, bathymetry, coastal orientation, stratification, windstress and opposing flows and Benguela Currents.

During the cold season (usually from May to October), the warm Angola Current water, with temperatures between 27 and 30°C, retreats to the northwest and is replaced by slightly cooler waters with temperatures between 20 and 26°C. This periodic southeast advance and northwest retreat of the Angola Current seems to be linked to the intensity of upwelling that occurs later off the Namibian coast (Meeuwis and Lutjeharms 1990, O'Toole 1980). These fluctuations in the Angola current are reflected in the movement of the position of the Angola-Benguela front, that can be displaced by more than 150 nm southwards during the warm season, relatively to its position during the cold period.

The area experiences episodic warming events similar to the seasonal El Niño cycle in the pacific off Peru (Shannon et al. 1996). These occur when extreme warming takes place in the tropical eastern Atlantic and warm water advected southwards along the Namibian coast. Benguela Niños occur on average every ten years. The last one was recorded in 1995 (Gammelsrøld et al. 1998). , and there are indications that another one is coming into being also in 2011.

Another feature that can be found near the Angola Current is the Angola Dome, a cyclonic eddy doming of the thermocline centred near 10°S and 9°E (Lass et al. 2000).. It is a cold water dome that is generated by a local maximum of Ekman suction (McClain and Firestone, 1993). The Angola Dome does not exist during the winter (Mazeika 1967), and its width and extension depend on the intensity and horizontal shear of the southeasterly trade winds (Signorini et al. 1999). The salinity of the water within the Angola dome (35.5 psu) is lower than that of the surrounding water (35.8-36 psu). According to Mazeika (1967), this may be due to vertical mixing of low-salinity Congo River water from the surface layer.

The hydrographical condition is believed to be important in determining the distribution and even the abundance of living marine resources off Angola. Small pelagic species exhibits seasonal, interannual and decadal- scale variability in their abundance, distribution and certain biological characteristics (Anon, 2010a). Much of this variability has been attributed to anthropogenic forcing, however, some of this variability can be also attributed to the high dynamic nature of the oceanographic condition off Angola. This affects the productivity of the region and the abundance and availability of most resources, but particularly of small pelagic fish.

Exploration of the sea in Angola

The Exclusive Economic Zone (EEZ) of Angola covers an area 330 000 km 2 accessible to marine fishing activities In the recent years Angola has become a major producer and exporter of oil in Africa, reducing considerably the fishing area in particularly in the northern area (Figure 3).

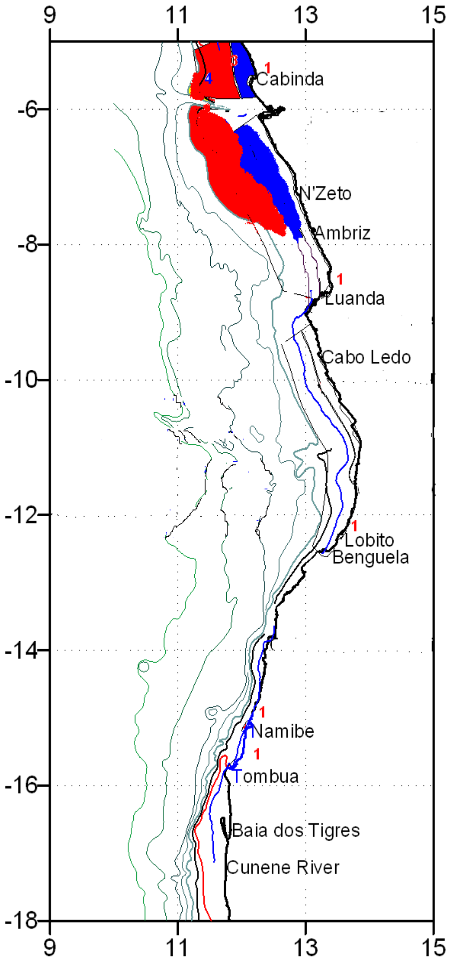

Figure 2: Angola cost line with main areas where the oil activity take place. 1: main fishing areas

At present the fisheries sector is the third main economic sector in Angola, following the oil and mining industries (diamonds), being the relative contribution of fishing to the GDP between 3 and 5%. The estimated rate of fish consumption in coastal areas is between 14 and 17 kg/ per habitant/year (Anon, 2003).

The small pelagic industry is the largest with respect to volumes, landing 80% of the total fish catches and the main source of animal protein (Anon,2003), and is consumed fresh and dry. The species are caught by the artisanal, semi-industrial and industrial fleets. The main commercial species commercial are the round sardinella (*Sardinella aurita*), the flat sardinella

(*Sardinella maderensis*), Cunene horse mackerel (*Trachurus trecae*), Cape horse mackerel (*Trachurus capensis*) and the South African sardine (*Sardinops sagax*).

Small pelagic species are distributed throughout the Angolan coast, with strong seasonal migrations associated with the seasonal relative movements of the Angola and Benguela currents. Cunene horse mackerel dominates the warmer Angola current, while Cape horse mackerel is associated with the cold Benguela current. The two species are mixed on fishing grounds in the Cunene – Benguela area and are shared with Namibia. The occurrence and abundance of the Cape horse mackerel in Angola waters follow the seasonal displacement of the Angola- Benguela front. There is also depth segregation between the two species off southern Angola, where they occur simultaneously. The Cunene horse mackerel dominates in the inner part of the shelf, while most of the Cape horse mackerel is found more offshore (Duarte, 2001). The two species of sardinela are distributed along the coast and probably constitute a resource which is shared with Congo and Gabon (Luyeye, 2002) and are usually found in the upper water layers and near the surface from shallow (10 m) inshore bays to the 200 m depth line. The flat sardinela is a more sedentary species inhabiting coastal, warm and often brackish waters while round sardinela is known to prefer upwelling areas and to migrate to avoid unfavorable environmental conditions. South African sardine and the round herring live in temperate waters from southern Angola to KwaZulu- Natal in South Africa

Small pelagic fish stocks in the Benguela ecosystem are characterized by high biomasses and productivity, but also by a very high variability in productivity and abundance, linked to the environmental instability typical of the region (Boyer and Hampton, 2001). In order to extract the most economic and social benefits from these fisheries, while safeguarding the sustainability of the fishery, a relatively close monitoring of the fishery and of the stock dynamics is necessary. This often requires a reliance on acoustic scientific surveys, as the best way to obtain short-term assessments of stock abundance and structure.

The scientific advisory process

In Angola it is national policy to utilize living marine resources on the sustainable basis for benefit of the nation, (Anon, 2004) aiming to optimise the economic and social benefits from the resource and to maintain the long-term biological sustainability of the stock(s) exploited.

Scientific recommendations for harvesting of all major resources are presented to the Fishery Technical Advisory Council where the scientists present to the Fisheries decision-makers and senior managers their assessment of the biological status of the resources and management recommendations for each resource. After this meeting takes place the Integrated Management Council where socio-economic factors and the industry’s perception of the state of the resources are discussed and considered in the management recommendation. The Minister of Agriculture and Fisheries and Rural Development, after consultation of senior managers within the Ministry submits the management measures to the Minister´s Council for final endorsement for publication on Presidential decree.

All catches of the major fisheries are limited by Total Allowable Catch (TAC) in conjunction with limited vessel rights.

Sound management of strongly fluctuating resources like the Angolan small pelagic fish stocks requires reliable information on population size, which for pelagic resources off Angola is estimated on hydroacoustic surveys that has been conducted annually since 1985 using the Norwegian research vessel ‘Dr Fridtjof Nansen’. Because the system for collecting detailed information from landings and catches is still not functioning adequately, especially in what concerns biological information, results from most catch-based stock assessment models are considered unreliable. Besides, the short life-span of small pelagic fish and the strong inter-annual variations in oceanographic conditions mean that productivity and abundance of these stocks can fluctuate strongly from one year to the next, depending not only on catch, but also on the hydrographic conditions and the strength of the incoming year-classes. Therefore, advice on the annual Total allowable Catch (TAC) depends strongly on the survey's results.

History of acoustic abundance estimation surveys in Angola

The early history of acoustic research in Angola can be viewed within the context of political status of the country. Assessment of the abundance of small pelagic fish stocks began in 1972, four years before the end of Portuguese colonial rule. A group from Missão de Estudos Bioceanlógicos e de Pescas de Angola conducted the first pelagic survey using Research Vessel (R/V) "GOA", equipped with SR3 and EH2E echo sounders (Campos Rosado, 1974). The surveys covered only the area around Lobito, 12°S and the biomass was estimated at about 320 000 tones.

After independence in 1975, the first series of pelagic acoustic surveys was conducted in 1978 by a group of Soviet biologists from the former URSS research institute "Atlant-Niro" in the framework of a bilateral agreement that existed between Angola and Soviet Union. R/V "ARGUS" carried out three surveys and was equipped with an echo sounder "Paltus- M" with an IC-I integrator. R/V "EVRICA" conducted two surveys and was equipped with an "FWGT-23" echo sounder. The biomass of pelagic species were estimated at around 700 000 tones.

In 1978, a bilateral agreement between Sweden and the Angolan Government was developed (Jardim, 2008). The bilateral agreement encouraged collaboration in research and the training of Angolan specialists. The Swedish support for research began with refurbishment of R/V GOA that provided to be very important for training of Angolan scientists and as a platform for collecting data. The R/V GOA was equipped with a Simrad EK 400 echo sounder, with monochrome screen. A series of acoustic surveys were conducted, but the surveys failed to estimate the biomass of the main pelagic species because the noise from the vessel increased the avoidance of the fish to fishing gear, making it almost impossible to get adequate length sample of the target species.

In 1985, the Nansen programme started in Angola and a series of surveys with R/V "Dr Fridtjof Nansen" were conducted. Up to 1991, surveys were conducted using a 38 kHz Simrad EK 400 echosounder combined with QD integrators (Sætersdal, 1993). In 1994, the new "Dr Fridtjof Nansen" research vessel was built, equipped with echo-sounder EK 500, and Bergen Echo Integration Unit for analysis and processing the acoustic data (Axelsen et al. 2007). Further details on the equipment are given in the next chapters. From 2007 the R/V "Dr Fridtjof Nansen" used a Simrad ER 60 Echo-sounder and echo post processing Large Scale Survey System (LSSS) software (Axelsen, 2007), that is able to handle the full resolution of raw acoustic data and to handle data in different files (Korneliussen, et al. 2006).

Estimation of abundance of small pelagic fish using the acoustic method (principles and basic equations)

Hydroacoustic is the principal methods for fisheries-independent estimation of abundance of schooling pelagic fish and is based on the principle that an echo sounder transmits short sound pulses in a concentrated vertical beam and receives echoes from targets in the sea (eg. MacLennan and Simmonds, 1992).

Echo integration based on a single frequency is commonly used to estimate fish stock abundance (eg. MacLennan and Simmonds, 1992). The frequency of 38 KHz often adopted is a compromise between the need for detection ranges of the order of hundreds of meters and the capacity to detect single fish and small animals (Korneliussen, 2003).The main advantage of the acoustic method is the ability to cover large sampling volume with relatively modest effort, providing high sample resolutions in the both horizontal and vertical planes (Axelsen et al. 2003). The method of fish stock abundance estimation from acoustic data combined with biological sample contains a series of assumptions (eg. MacLennan and Simmonds, 1992) Figure 3 illustrate estimation of the stock and how the results are used for management of the main pelagic species.

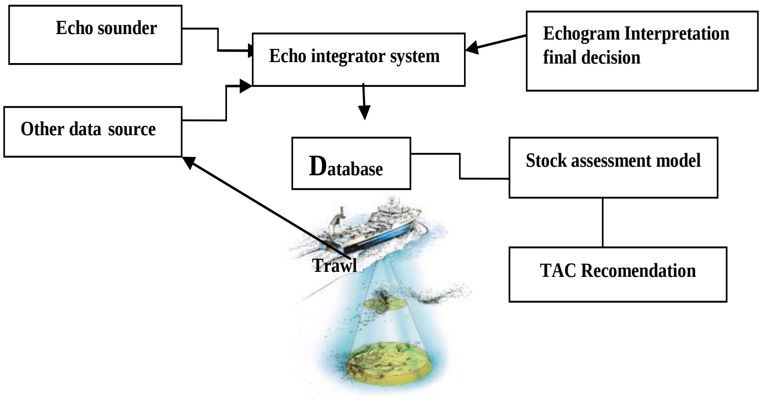

Figure 3: Schematic of model to integrate acoustic and trawl data for estimation of abundance of the stock (Kornelliussen,2003)

The reliability of acoustic abundance estimates is dependent on proper survey design and statistics for estimating fish abundance (Aglen, 1989).

The number of fish in each length class is estimated from:

$$Nt = A * SA * \frac{Pi}{\sum_{i=0}^{n} \sigma j \rho i} \qquad (1)$$

Where Nt is the number of fish in length group i, A the area covered by the target population (square nautical miles), S_A the average area backscattering (m^2 /nautical mile^{-2},) ,pi the proportion of fish in length group I and σ the acoustic backscattering cross section (m^2) of fish with length i.

Conversion from acoustic densities to absolute abundance requires knowledge of the acoustic acoustic backscattering cross section parameter. This parameter, equivalent of the target strength (TS), depends mainly on the acoustical backscattering area of swimblader, that is responsible for 90- 95%) of the acoustic of acoustic backscatter at 38 kHz due to high sound speed contrast between the seawater and the swimbladder (Foote, 1980a)

The linear domain of TS can be determined from the relationship acoustic backscattering properties (σ) of the target strength (TS e.g. MacLennan and Simmonds, 1992), that in linear domain can be determined from the relationship (Foote, 1980a, Love,1971):

$$TS = 10 \cdot \log\left(\frac{\sigma}{4\pi}\right) \quad (dB) \qquad (2)$$

The TS is usually species specific (MacLennan and Simmonds, 1992), proportional to the length and it is defined as

$$TS=20LogL+b20 \ (dB) \qquad (3)$$

The equation currently applied for pelagic species off Angola was originally derived for clupeoids (Foote et al. 1986; Foote 1987):

$$TS=20 \ LogL-72 \quad (dB) \qquad (4)$$

Errors and uncertainty in acoustic abundance estimation

An important question in all the surveys is the accuracy, both as absolute measure of abundance and as relative indices of changes in the abundance. The results of all surveys are subject to random and systematic errors (MacLennan and Simmonds, 1992). Measurement errors are those that relate to the actual measurement of the fish density along the vessel path, i.e. on the areas actually observed by the vessel. Estimation errors are those associated with the process of estimating total stock abundance from the observations made along the vessel track, and are usually within the realm of statistical errors. Both errors give an overoptimistic impression of survey accuracy with potentially serious consequences for management decision.

Different distribution pattern from one year to next may be associated with variation in behaviour which leads differences in the acoustic densities (Vabø, 1999). Understanding behavioural characteristics in relation to the specific ecosystem it is essential for deciding sampling strategy and/or for studying the reliability of weighting factors for global biomass estimation.

Attempts to quantify survey error for the date in the BCLME region have been conducted on the BENEFIT survey error workshop (Anon, 2000).For the pelagic surveys off Angola Target strength and target identification was identify as the major source of uncertainty in absolute estimates of the two main pelagic species.

In the Benguela Current system, In Situ measurements of Cape horse mackerel by visual scrutiny of target strength distribution were made off Namibia (Svellingen and Ona, 1999) and off South Africa (Barange and Hampton, 1994; Barange et al. 1996). All measurements were made at night, when the fish tend to disperse sufficiently for echoes from single targets to be isolated from multiple echoes. More recent (Axelsen, 2003) investigated also Cape horse mackerel target strength using a second EK 500 unit running an ES 38D ES 38 D submersible 38 kHz split-beam transducer.

The target strength/length relationship obtained from the different experiments varies considerably as can be seen from the B20 constant. The minimum and the maximum were set vary wide at -78 and -65 dB (Anon, 2000 ; Axelsen, 2003). The results leads that there is not evidences to reject the B20 (-72 dB) currently applied for pelagic species off Angola in favour of any others measured in the Benguela Current system.

Target Identification

In turn, acoustic techniques are generally limited by the incorrect partitioning of backscattered energy between species, particularly in multispecies environments (Misund, 1997) where schools are small, interspersed and have a low or varying catchability. Traditionally, direct net sampling near the acoustic transect has been conducted and on visual interpretation of echograms have used as identification methods for partitioning of backscattered energy between species (Rose and Legget, 1988). There are two central problems with this approach. First, net sample seldom reflect actual species or size composition due to the avoidance of the target and trawl selection (Gødo, 1994). This approach is also biased, by the differences in catachability between species (Lawson et al. 2001) and by the lower spatial or temporal resolution afford by trawl comparable in comparison to acoustic sampling (Massé and Retiére, 1995),

The visual inspection of simple-frequency echograms (typically 38 kHz) displayed with colour and code and intensity corresponding to acoustic densities, requires knowledge of the scatterings properties (Axelsen, 2007), behaviour of the target species (Olsen,1990; MacLeman and Simmonds,1992 ;Misund, 1999). The scrutiny of acoustic data is based on long- term experience (Korsbrekke and Misund, 1993) because the method is particularly sensitive to changes of personnel and thereby differences in interpretation that could lead to inconsistencies over time, representing a variable source of error that may be difficult to take fully in to account.

Numerous acoustic approaches have been taken in addressing the problem of acoustic target identification. In cases where single targets can be detected and length frequency distribution differ between species, in situ measurements of target strength distributions can often be used to identify species (Barange, et al. 1996) by analysing the shape of the frequency response of each species. In the situation, when the length frequency overlaps a common approach has sought to identify species via acoustically quantifiable differences in shoal features (Lawson et al, 2001). Other recent approaches include broadband (Rose and Legett, 1988) and multiple frequency techniques (Kornuliussen and Ona, 2002). These techniques are based on using different frequencies in target strength of scatterers .Although, the multifrequency approaches facilitates the classification echo-traces according to the frequency response or the difference in volume backscattering (MacLennan et al. 2002) across a frequency range, using a model predictions (Korneliussen, 2003) application this approaches requires a technique acoustic system on the survey vessels, and in BCLME region only the Norwegian research vessel Dr Fridjof Nansen has technology available. To address this fact, Reid et al.2000 suggest that the use of ancillary school information have shown a potential tool to improve the target identification. The features of shoals extracted from acoustic data and used for identification of species have generally fallen into four categories: positional (distance to nearest neighboring shoal), morphometric (e.g. shoal height, area), energetic (e.g. mean or variance of backscattered energy), and bathymetric (e.g shoal depth) may contribute additional ability for species target identification (MacLennan and Holliday, 1996 ; Scalabrin et al. 1996).

Behaviour

Pelagic fish behaviour plays a major part in acoustic fish stock assessment surveys (e.g. Fernö and Olsen, 1994), since it conditions the availability of the fish to the echo-sounder, and also the relation between fish abundance and echo intensity, Schooling fish behaviour has been studied since the beginning of century, but most of work was related with description of fish schools in tanks or aquaria (Pitcher, 1993). Even though the study of pelagic fish behaviour in the natural environment presents many complications, field studies began in the 1970s with development of acoustic methods (MacLennan and Simmonds, 1992). The studies of behaviour are relevant to acoustic estimation (Røttingen et al. 1994) as consequence of this upward/downward sink/ glide energy conservation energy strategy the fish exhibits a variety of body tilt angles which varies with depth and time of the day (Huse and Ona, 1996) who influences the acoustic target strength (TS) who is known to be a highly variable and sensitive parameter (Nakken and Olsen, 1977; Ona, 1990).

Vertical position and Vertical Migration

Vertical migrations affect the target strengths of fish (Foote, 1990; MacLennan and Simmonds, 1992) through the compression/decompression of the swimbladder (Foote, 1980a; Vabø, 1999) and changes in body posture (tilt angle) of the fish relative to the transducer (Nakken and Olsen, 1977; Foote 1987; Ona, 2001). Vertical migrations may also affect estimates indirectly through the increase of the effect of the so-called blind and dead zones (Fréon and Misund, 1999; Olsen et al. 1983a; Vabø, 1999). The hull mounted transducer operates at distance from the surface of about 5m and volume above this depth is not acoustically sample and therefore the surface blind zone is typically about 10-12m from the surface. Similarly, only part of the fish echo can be separated from the bottom echo. The separable part depends on the pulse length and the distance of the fish from the bottom (Aglen, 1994).

The interpretation of acoustic data can be further complicated by diel variation in the behaviour of fish. In daytime, pelagic fish are often found close to the bottom, thus potentially in the dead zone, or congregated in schools that have a patchy distribution, which leads to variability in the results. At night, pelagic fish usually leave the bottom and schools disaggregate (Fréon et al. 1996; Fréon and Misund, 1999). The aspect angle of individual fish day and night may be variable (e.g. Huse and Ona, 1996), and the fish assemblage in a discrete area, species, and size distributions, can change over the diel cycle (e.g. Neilson and Perry, 1990; Helfman, 1993).

Vertical migration appears to be a means by which pelagic organisms balance the competing objectives of growing quickly and minimizing predation risk (Michelson, et al. 1996). For many visual foragers, feeding efficiency is greatest at the higher light levels near the surface during the day (Pearre, 2003). Other visual predators, however, can also forage efficiently under such conditions the fish exhibit strong avoidance reaction affecting the shape, size and density of fish (Pitcher and Wyche, 1983).

Avoidance

Avoidance reactions are elicited by an instantaneous increase in the pressure gradients of low frequency from an approaching vessel (Olsen et al. 1983a; Fréon and Misund, 1999; Fernandes et al. 2000; Vabø et al. 2002). In the case of swimming bladder fish this organ transforms scalar pressure to particle motions that can be sensed by the otolith organ (Hawkins, 1986 ; Blaxter et al. 1981). This effect is more pronounced in the upper layer where the beam is most narrow and the stimuli from the vessel strongest (Aglen, 1994).

There are two effects to be considered, fish moving out of path of the vessel and fish swimming downwards, but remaining in the path of the acoustic beam. Recording have been shown that not only fish concentrated layer are affected by the noise vessel, concentration of adult herring, under path of the vessel, extending from about 10m below the surface down 40m, have completely disappeared, but rapidly returned again after its passage.

Combined techniques, using both echo sounder and sonar have already been suggested for study the vessel avoidance (Misund 1993).The sonar was mainly used for school counting, being directed horizontally at 90° from the vessel route (Soria et al. 1996) Although, this method is considered an important tool for counting the school on surface, this method is not a real success for using the estimation of biomass, because the actual volume sampled was is easy to evaluate .Close to the vessel at depth less than 100 m the beam is too narrow to be give an exhaustive view of the water volume.

Recently the availability of multi-beam sonars has allowed scientists to study the reaction of the schools to the vessel obtaining some contradictory results. While vessel avoidance in some situations does not represent any source of error at all (Fernandes et al. 2000) attributed to the noise-reduced vessel design, significant negative bias has been broadly documented (Olsen, et al 1993 Gerlotto and Fréon, 1992; Soria et al. 1996; Vabø et al. 2002). However, Røstad et al. (2006) reported also that the approaching vessel itself could attract fish and hence cause the echo abundance to be overestimated.

Rationale and structure of the thesis

It is thus difficult to exaggerate the social importance of a good management of the small pelagic fishery for Angola, especially given the importance of small pelagic fish (sardine and horse mackerel) in the diet of the poorer segments of the Angolan population. Extracting the maximum benefits from these fisheries requires taking into account the natural fluctuations in productivity and abundance of these stocks, but also the availability of a method to estimate this abundance and productivity with a relatively short time-lag.

Acoustic surveys in Angola were designed based only on the knowledge of distribution, abundance of fish and to the topology of the shelf without considering the natural variety of behaviour pattern that are adaptations to biological and environmental conditions. It is however recognized that acoustic surveys are highly sensitive to errors caused by effects of fish behaviour, particularly those that may reduce the acoustic detectability of fish.

In the Benguela Current System, a good number of studies has been carried out for species occupying the southern part of the Benguela ecosystem (e.g. Alexen,;Barange et al. 1996 and 2005; Coetzee et al. 2001). However, to date very little information is published about the dynamics of the fisheries for small pelagic fish, and likewise, very little is known about the estimation properties of the hydroacoustic method applied to small pelagic fish species off Angola.

General Introduction

The insertion of Angola on regional programme BENEFIT and BCLME provided a new vision for marine science, particularly on methodological and technical problems related to biomass estimation. In 2000 was conduct the first survey errors workshop where for each country was identified several aspects than can bias the survey estimates (Anon, 2000) and scientists were encouraged to understand how these bias affects the biomass.

This thesis intends to contribute to bridge these gaps through an analysis of existing data will addresses the complementary aspects of the dynamics of living marine resources in the Benguela current system, which contributes to understand interannual variability of the main stocks pelagic off Angola. The best methods for estimation the abundance of these stocks are those based on hydroacoustic abundance estimation methods. However, these methods are based on assumptions that time of the survey all the stock are available to be assessed. This assumption is never completely fulfilled due to limitation on of methods and natural behaviour of the fish stocks.

This thesis will also examine the behaviour aspects in relation to the abundance estimation of pelagic species off Angola. Main distinguishing features of the echograms assigned to the main species group, and establishment of an objective algorithm to assist in the classification of the echograms obtained in Angola; Quantification of differences in acoustic density generated by the change of behaviour and vertical distribution throughout the circadian cycle and the vessel avoidance off pelagic species off Angola.

Chapter II Resource and Ecosystem Variability, including regime shifts, in the Benguela current system

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ABSTRACT

Interannual and decadal-scale variability in abundance, distribution and biological characteristics are described for important living marine resources of the Benguela Current system including small pelagic fish, horse mackerel, hakes, snoek, rock lobster, Cape fur seals, Cape gannets and African penguins. Variability at the ecosystem level for the northern and southern subsystems is also described using trophodynamic indices that track structural changes in the ecosystem. Current understanding and analysis of observed variability in both resources and ecosystem is reviewed and the knowledge required for predicting resource and ecosystem variability and the causal factors that need to be considered are discussed. We highlight the need to improve understanding of the processes that are important in the Benguela Current ecosystem, to identify what controls those processes, and to quantify such controls (particularly those acting on lower trophic levels) and the roles of important species in the ecosystem. The kinds of predictions considered possible in the Benguela Current system are examined and the use of indicators to track ecosystem changes is assessed. A series of steps is suggested to improve understanding of ecosystem and fisheries dynamics and to monitor key aspects of the ecosystem.

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INTRODUCTION

The Benguela Current ecosystem is one of the world's major upwelling systems, and, as is typical of eastern-boundary upwelling systems, is characterized by high productivity. Located off the southwest coast of Africa, the Benguela is divided into northern and southern sub-systems that are separated by the permanent upwelling cell at Lüderitz (26°S). The northern Benguela extends from the Angola-Benguela front (usually located between 14°S and 16°S; Shannon et al,1987) to the Lüderitz upwelling cell, whereas the southern Benguela extends from Lüderitz to the Agulhas Bank off South Africa's south coast (Fig. 1). Conventionally, the geographic border between Namibia and South Africa at the Orange River mouth in the vicinity of 29°S is adopted as the division between the northern and southern Benguela ecosystems. Detailed reviews of various aspects of the Benguela upwelling system may be found in Shannon (1985), Chapman and Shannon (1985), Shannon and Pillar (1986), and Crawford et al. (1987). More recent studies for the southern Benguela are reported in Payne and Lutjeharms (1997), and for the northern Benguela in Payne et al. (2001), and a historical overview of human activities and their impacts on marine life in the Benguela is provided by Griffiths et al. (2004). Aspects of physical and biological variability exhibited by the Benguela Current system across a wide variety of temporal scales are described by Field and Shillington (2006).

The Benguela ecosystem supports large populations of living marine resources that are of substantial economic importance to the region. Fisheries for small pelagic fish species (including anchovy *Engraulis encrasicolus*, redeye round herring *Etrumeus whiteheadi*, sardine *Sardinops sagax*, and the sardinellas *Sardinella aurita* and *S. maderensis*), midwater fish species (Cape horse mackerel *Trachurus trachurus capensis* and Cunene horse mackerel *T.t. trecae*), demersal fish species (including the hakes *Merluccius capensis* and *M.*

paradoxus), west coast rock lobster (*Jasus lalandii*), and fisheries targeting other species, have been well established in the both the northern and southern Benguela for the past 50-100 years. Bottom trawling off South Africa was initiated in early 1900s, and the demand for canned and triggered by World War II provided the impetus for purse-seine fishing. Most of the catch was taken by local vessels before 1960, but distance- water fleets (eg. From the URSS, Japan ans Spain) but targeted hake and other demersal species fish began fishing in the Benguela ecosystem thereafter. Whereas South Africa declared 200-miles exclusive fishing zone 1977, distance- water fleets continued to harvest large quantities of living marine resources from Angolan and Namibian waters until the 1980s (Payne and Crawford 1989). Foreign fishing off Namibia for hakes and horse mackerel ceased after Namibia independence in 1990 (Boyer and Hampton, 1991), but substantial fishing by foreign vessels still occurs off Angola. Currently, the fishing sector is important to the economies of all three countries bordering the Benguela, particularly so for Namibia where this sector contributed 6.4% to that country’s GDP in 2001 (Molloy and Reinikainen, 2003). In Angola, the fisheries sector is the third most important economic sector, contributing between 3% and 5% to GDP and providing products for both local and export consumption. Fishing contributed 0.4% to South Africa’s GDP in 1998. In addition to the species listed above, many other fish, bird and marine mammal species together comprise the abundant fauna of the Benguela Current ecosystem.

The aim of this paper is to provide an overview of resource and ecosystem variability in the Benguela ecosystem. For the purposes of this review we have extended the definition of the Benguela ecosystem in order to include important resources that occur or may be harvested outside the boundaries indicated above. For example, whereas only the southernmost part of Angola falls within the Benguela ecosystem, most *Sardinella* spp. occurs and is caught to the north of the Angola-Benguela front but catch data for this resource is not spatially explicit.

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Similarly, the bulk of shallow water hake *M. capensis* occurs and is caught off South Africa's south coast. Descriptions are provided of interannual and decadal scale variability exhibited by the economically-valuable marine resources listed above from 1950 to 2003, a period for which a fairly substantial dataset exists. Additionally, variability exhibited by a few of the top predator species in the system is described, including Cape gannet (*Morus capensis*), African penguin (*Spheniscus demersus*), Cape fur seal (*Arctocephalus pusillus pusillus*), and snoek (*Thyrsites atun*). Descriptions of resource variability are grouped into three themes, namely variability in abundance, variability in distribution, and variability in biological characteristics, and examples are given where available. Variability exhibited at the ecosystem level by the northern and southern Benguela is described through indices that proxy ecosystem trophic structure, such as the ratio of demersal to pelagic catches and biomass, plots of catch versus trophic level of the catch, and the Fishing in Balance (FiB) index (see below). Current understanding and analysis of observed variability of resources in both the northern and southern Benguela ecosystems is reviewed, and the knowledge required for predicting resource and ecosystem variability and the causal factors that need to be considered discussed. The need to improve understanding of the processes that are important in the Benguela Current system, to identify what controls those processes, and to quantify such controls (particularly those acting on lower trophic levels) and the roles of important species in the ecosystem is highlighted. The kinds of predictions that are possible in the Benguela are examined, and examples of approaches to predict interannual variability in anchovy recruitment are briefly described. Finally, a series of steps is suggested to improve understanding of ecosystem and fisheries dynamics and to monitor key aspects of the Benguela Current system.

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RESOURCE VARIABILITY

Variability in abundance

Catches of most of the important resources of the northern Benguela have shown substantial reductions over the past 50 years. After peaking at over 1.5 million tons in the late-1960s and sustaining levels of around 0.5 million tons between 1960 and 1980, catches of small pelagic fish species in the northern Benguela have dwindled to current levels of less than 100 000 tons (Fig. 2), most of this being *Sardinella* spp. Rock lobster catches in the northern Benguela have also decreased, from over 5 000 tons annually before 1970, around 2 000t annually until 1990, and to a few hundred tons since then. Catches of hake in the northern Benguela peaked in the early 1970s (Figure 1) but decreased thereafter, and whilst not as severe a decline as those for small pelagics and rock lobster, annual hake catches made during the past decade have been less than a third of peak catches made in the early-1970s. However, hake catches have shown a slight increasing trend over the past decade. The large decreased for all these species are in contrast to catches of horse mackerel, which increased during the 1970s, peaked in the 1980s and after declining again have remained relatively stable since the 1990s at around 250-300 000 tons (Figigure 1). Catches of Cunene horse mackerel are much reduced compared to the 1950s and 1960s (Figure 1).

In the southern Benguela, rock lobster catches have shown a marked decline whereas catches of the other major resources have remained relatively stable (Figure 1). A replacement of sardine by anchovy in catches of small pelagics after the mid-1960s is evident, as is a reduction in the relative contribution to horse mackerel catches by the pelagic fleet after 1970, and an increase in snoek catches in the trawl (demersal and midwater) fishery after 1975. Snoek catches are significantly higher in the southern than in the northern Benguela whereas the reverse is true for horse mackerel catches, and catches of hakes were substantially lower in the southern compared to the northern Benguela but have been at similar levels for the past 15 years (Figure 1).

Catches of small pelagics, horse mackerel and hakes landed in the southern Benguela were substantially lower than peak catches of those resources landed in the northern Benguela. Currently, however, only landings of horse mackerel are higher in the northern than in the southern Benguela, and whereas catches of small pelagics are currently minimal in the northern Benguela they are at close-to-record highs in the southern Benguela.

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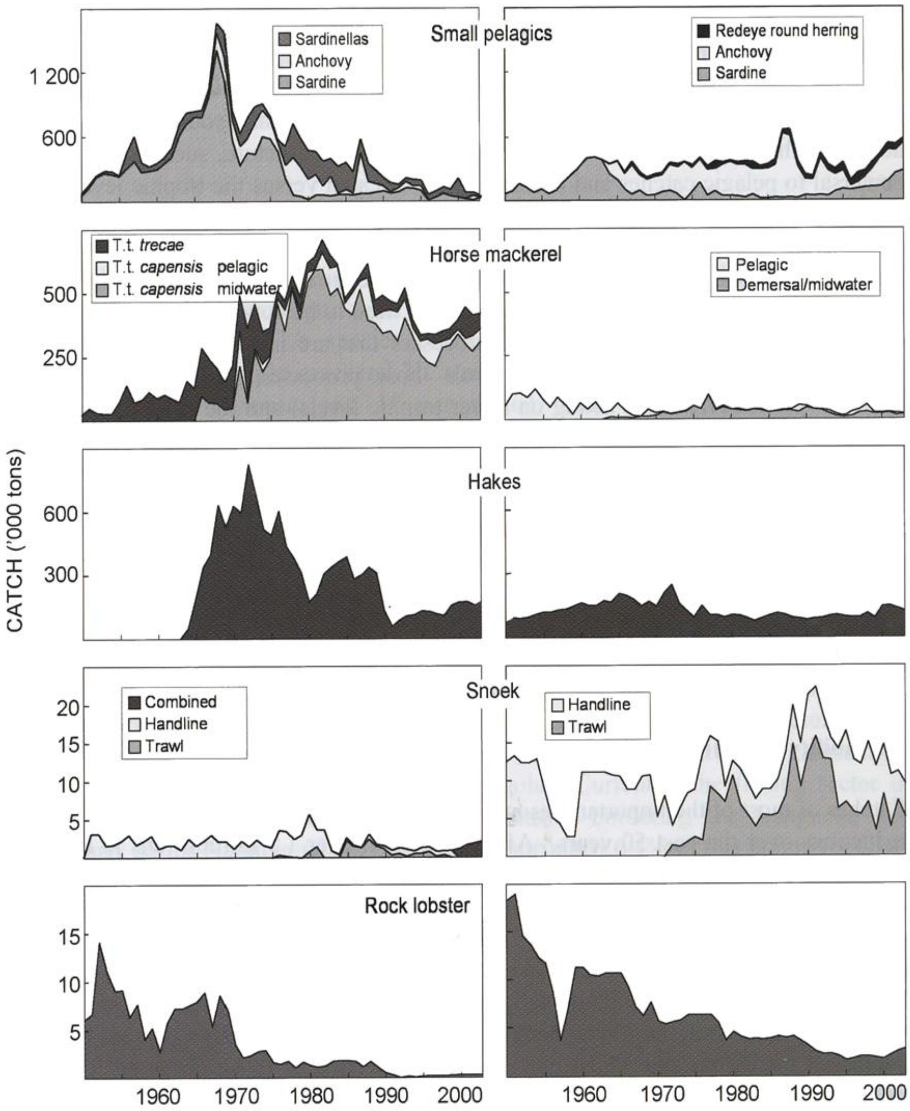

Figure1: Variability in annual catch of important living marine resources in the northern (left panels) an southern (right panel) Benguela for small pelagic species (anchovy, sardine and *Sardinella spp* in the northern, and anchovy, redeye, round herring, and sardine in the southern); horse mackerel (Cunene horse mackerel and Cape horse mackerel catches are shown for the northern Benguela and catches for Cape horse mackerel in the northern and southern are further divided in those taken by pelagic (or purse-seine) and mid water trawl or demersal fleet); snoek(hand-line and trawl are shown sperately, except for northern Benguela during 2000-2003 where catches are combined); and rock lobster. Plots are updates to those presented in Griffiths et al.(2004) using data supplied by Natmirc, MCM and IIM

Reliable and consistent biomass time-series estimated from surveys and/or population assessment models in both systems are available for sardine, hake, seals, and birds (gannets and African penguins; Figure. 2). Long-term trends in biomass have been consistent with fluctuations in catch for sardine and hake in both the northern and southern Benguela. A substantial decline in the biomass of northern Benguela sardine that occurred during the late-1960s and from which the population has not since recovered is apparent, although there were some signs of a recovery in the early 1990s (Figure 2). A decline in the 1960s of the southern Benguela sardine population, and a recovery in the late-1980s and 1990s, is also apparent, with this population currently at a size similar to that estimated before its collapse. Southern Benguela anchovy have shown moderate interannual variability in recruitment over most of the time series, with consequent inter-annual fluctuations in stock size, but strong recruitment that has lead to large population sizes has been observed since 2000 (Figure 2).

Considerable reductions in the estimated biomass of hakes in both the northern and southern Benguela are observed soon development of the industrial trawl fisheries (Figure 2). These were initiated around 1965 in the northern Benguela and had already started in 1950 in the southern Benguela, and have resulted in current population sizes of around one third and one fifth of those estimated in 1950, for the northern and southern Benguela, respectively. Whereas stock assessment models indicate that hake biomasss in the northern Benguela has remained at relatively constant levels around 1 million tons, estimates from swept area surveys (data not shown) show an increasing trend in the early 1990s, but due to adverse environmental conditions between 1993 and 1995 the biomass declined again and reached low levels in 1997 (van der Westhuizen 2001). The biomass of hake in 2003, although slightly improved from 1997, remains at low levels.

Fur seal abundance estimated from aerial census of pups increased in the northern Benguela dramatically between 1970 and 1990s at an annual rate of between 2 and 4 % as continuation of the recovery from historical overexploitation during 18th and 19th centuries. Subsequent to large interannual fluctuations (Figure 2) are linked to variably of food availability and environmental fluctuations (Roux 1998). By comparison, the seal population in the southern

Benguela has increased slightly since 1970 and appears to have reached relatively stable levels since 1985.

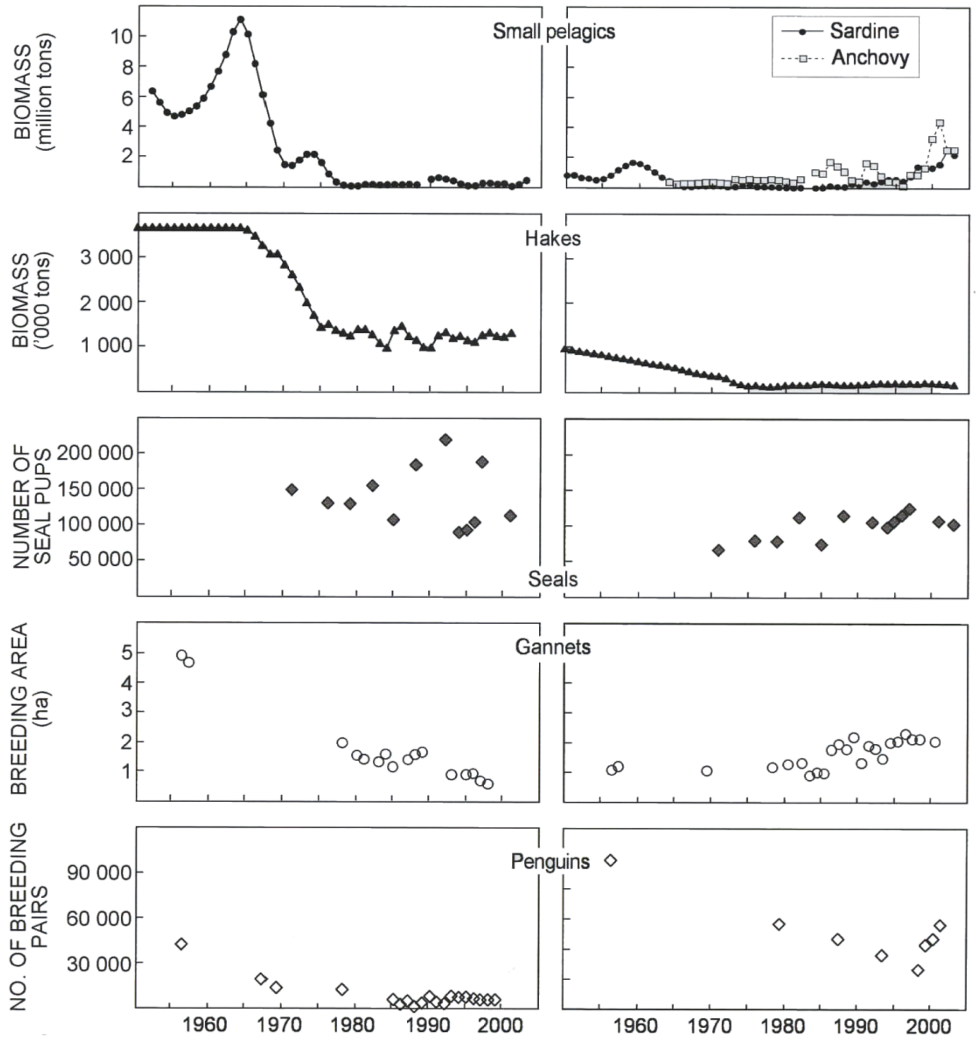

Figure 2.Variability in the abundance of important living marine resources in the northern (left panels) and southern (right panels) Benguela, derived from direct observations and/or model estimates. For small pelagic fish (sardine in the northern Benguela) biomass estimates before the break are from virtual population analysis [Thomas, 1986] and those after the break are from estimates made using acoustic survey data (updated from Boyer *et al*., 2001]).For sardine and anchovy in the southern Benguela, biomass estimates before the break are from virtual population analysis (Armstrong *et al*., 1983) and those after the break from estimates made using acoustic survey data (updated from Barange *et al*., 1999). Hakes (both species combined, and both time series are from population assessment models--Geromont et al. (2000)for the northern and Rademeyer and Butterworth (2003) for the southern Benguela). Top predators including Cape fur seals are estimated from the number of seal pups observed from aerial photograph censuses. Estimates of Cape gannets are based on the breeding area occupied by gannets at Ichaboe Island in the northern Benguela, and at Malgas Island and Lamberts Bay in the southern Benguela (Crawford 2005). Estmates of African penguins are based on the number of breeding pairs (Crawford and Whittington 2005).

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African penguins and Cape gannets are both breeding species endemic to South Africa and Namibia, and both are classified as Vulnerable (IUCN criteria). Between 1956 and 2000, Cape gannets underwent a dramatic decline in the northern Benguela, as indicated by the tenfold contraction in the area they occupied at breeding localities (Figure 2). In the southern Benguela, there has been a steady increase in gannet breeding area since the early 1980s (Figure 2). In the Benguela system overall the penguim population decreased by about 90% between 1910 and the early 1990s (Crawford,et al.2001).The total number of adult birds, estimated to have been 220 000 in 1978, declined to 179 000 in early 1990s and has increased again 201 000 in 2000 (Crawford and Whittington,2005). In northern Benguela the penguin population declined more than 74% between mid-1950s and the late 1990s (kemper et al. 2001) and has continued to decline at about 1,8% annually since mid-1990s (J. Kemper, Avian Demography Unit, UCT, pers comm.). In the southern Benguela in contrast, the large declined experienced between the 1950s and the early 1980s was followed by a steady increase during the late 1990s.

The substantial historic reduction in catches and biomass observed for important resources in Benguela Current system have been attributed primarily to overfishing, including collapse of sardine and rock lobster populations, and the substantial decline in hake population in both the northern and southern Benguela (Figures 1 and 2 Griffiths et al. 2004). Many resources are currently at population size substantially smaller than observed 50 years ago, although this is not the case for small pelagics in the southern Benguela. Fishing many also shorten the food thereby reducing ecosystem resilience (Hutchings, 2000). And increasing the time required for recovery of the community from perturbation such as fishing (Vasconcellos et al. 1997). Mean throphic path length in the northern Benguela food web (see Heymans et al.2004); Moloney et al. 2005) has decreased by 27% since the early 1980s, suggesting that the ecosystem has a reduced capacity to recover from perturbation in the current state in which it is functioning.

Environmental impacts that contributed to resource collapse, or acted to retard the recovery of a population, have been hypothesized. Boyer et al.(2001) concluded that unfavourable environmental conditions (e.g the Benguela Niño that occurred in 1995; see below) were important factors in the decline of northern Benguela sardine stock observed during the 1990s, although this must have been exacerbated by heavy fishing pressure during 1994 and 1995 (Boyer et al .2001).However, reduced fishing pressure since 2000 (TACs) varying between 0t and 25 000t between 2000 and 2003) has not resulted in a recovery of the stock (see section below on Ecosystem Variability). Trophic modelling studies have suggested that the observed changes in pelagic fish stocks in the southern Benguela were also environmentally driven, with effects propagated up the foodweb via the availability of mesozooplankton prey to anchovy and sardine (Shannon et al. 2004c). Fitting a dynamic model to available catch and biomass data series for the southern Benguela from 1978-2002,Shannon et al.(2004b) estimated that fishing patterns (a from of top-down control) explained only 2-3% of the variability observed in the time-series examined, whereas an environmental forcing function (bottom-up control) applied to phytoplankton production explained 4-12% of variability. For small pelagic fish in the southern Benguela, fishing mortality has been maintained at relatively low levels; since the mid- 1980s, anchovy and sardine fishing mortality ranged between 0.04 and 0.30 y^{-1}. (Cunningham and Butterworth 2004a, b), with the small values occurring when biomass was high in the 2000s. In contrast to most ecosystems in the world, the southern Benguela ecosystem has been managed at moderate levels of fishing. Thus it is not surprising that trophic interactions rather than fishing are believed to be responsible for the observed changes in the southern Benguela ecosystem in the 1980s-2000s. In particular the vulnerability of prey to predators could explain about 40%

of the observed variability in the time series examined (Shannon et al. 2004b; trophic interactions and the processes controlling trophic flow are discussed in more detail in the section on Predicting variability).Trophic interactions would be expected to be a dominant feature in upwelling ecosystems, because these systems are typically “wasp-waist” controlled (Cury et al.2000).

Some populations have recovered under conservative management strategies. For example the southern Benguela sardine has shown a remarkable recovery following implementation in the mid-1980s of a conservative fishing policy to rebuild the stock (De Oliveira 2002). However, the decadal-scale changes in abundance observed for sardine in the southern Benguela are characteristic of small pelagic species (Schwartzlose et al. 1999; Lehodey et al; in press),with cycles of alternate dominance of anchovy and sardine. Sardine in the California Current system show a 50-60 year time scale of population expansion and contraction (Baumgartener et al. 1996) a period somewhat longer than that observed for southern Benguela sardine (40 years). Decadal-scale changes in abundance of small pelagic fish and a variety of marine resources from a variety of systems have been linked to long-term changes in environmental forcing, and many studies have demonstrated ”that climate-related variability of fish populations is the rule rather than the exception” (Lehodey et al.in press).The current situation of large population sizes of both anchovy and sardine in the southern Benguela seems contrary to the hypothesis of alternating periods of species dominance (Schwartozlose et al. 1999), since both are currently at record high levels. However, data for anchovy exist only from the mid-1960s and we do not know historical combined stock sizes.

The southern Benguela has been characterised by large interannual variability in small pelagic fish biomass, and exceptionally high anchovy recruitment in 2000 and subsequent years (figure 2). The strong anchovy recruitment in 2000 was linked to within-season variability in local forcing (SE wind), which minimized advective loss during the critical period for successful transport of eggs and larvae from the Agulhas Bank spawning grounds to the west coast nursery grounds, and then maximized their food environment there through sustained upwelling in late summer (Roy et.2001), However, those particular environmental conditions have not since been repeated, yet subsequent anchovy recruitment and hence population size has remained high(figure 2).This suggests that processes other than environmental control egg and larval survival may have become important determinants of recruitment success (Roy et al. 2002), such as the increased egg production arising from a substantially larger spawner stock or changes in spawner distribution. The continued high anchovy recruitment since 2000 is no believed to be sustainable as density-dependent factors are likely to come into play, and evidence of reduced body lipid levels of anchovy recruits from 2000 and 2001 compared to previous years has been documented (van der Lingen and Hutchings 2005).

Adverse environmental events that occur at interanual or shorter times scales also impact on the resource abundance. Benguela Niños which occur about once every ten year are observed as instructions of warm water, saline surface waters onto the northern Benguela shelf, have been associated with widespread mortalities of sardine horse mackerel and Kob (*Argyrodomus inordorus*) off coasts of Angola and northern Namibia (Gammelsrød et al. 1998). Depletion of oxygen levels in near-shore environment of the southern Benguela have caused rock lobster “walkouts” and have results in significant local mortality (Cockcroft 2001)

Variability in distribution

Small pelagic fish in the Benguela ecosystem have shown extensive variability in terms of the spatial extent of their populations, with a positive relationship between biomass and distributional area reported for southern Benguela anchovy, which expands its distribution at large stock sizes (Barange et al.1999). Those authors found no such relationship for sardine, possibly arising from the relatively low sardine biomass levels observed during the period of their study. Further analysis that includes high sardine biomass levels has indicated that sardine also expand their spatial distribution at large stock size (J.C. Coetzee, MCM, pers. comm.). The distribution of sardine in the northern Benguela, has become very patchy following the decline of the stock (Hampton 2003); historically, the stock was distributed more or less continuously between 25ºS and 16º30’S, but during the past decade the stock has been distributed in few small patches along the northern part of the Namibian coast.

Both seasonal and decadal-scale variability in the distribution of *Sardinella* spp. off the Angolan coast have been reported. Seasonally, adult *S. maderensis* move northwards at the beginning of the cold season (winter; June to October) and southwards at the beginning of the warm season (summer; February to May; FAO 2000). On a longer time-scale, the core of the *S. aurita* population was located off Angola and this species dominated landings during the 1970s, whereas from the mid-1980s Angolan landings were dominated by *S. maderensis* (Binet et al. 2001).

Interannual variability in the distribution of the major spawning areas of Benguela small pelagics is evident. In the southern Benguela the western Agulhas Bank was the major anchovy spawning area between the mid-1980s and 1995, but an eastward shift in the distribution of anchovy spawners over the Agulhas Bank has been observed during annual surveys since 1996 (Figure. 3a), with the bulk of the population observed over the offshore regions of the central and eastern Agulhas Bank (van der Lingen *et al*., 2002)). The spawning location of southern Benguela sardine has shown even larger-scale variability, with both the South African south and the west coasts comprising the major spawning grounds during different periods. Crawford (1981) noted that in the early 1960s, sardine spawned along the west coast as well as on the south coast of South Africa, whereas sardine spawning was restricted to the south coast in 1965-1967, coinciding with decline in sardine abundance. In 1987 and 1988, and from 1994-2000, sardine spawning in early summer occurred principally off the west coast, whereas the central and eastern Agulhas Bank were the principal spawning sites from 1989-1993 and since 2001 (Figure 3b; van der Lingen et al. 2001). Given that the distance between these two sites of intense spawning is 600-1200km, this variability represents a substantial spatial shift. The switch from spawning off the west coast that occurred in mid 1990s was seen as consequence of increased population size, reminiscent of the situation during the 1950s and early 1960s (van der Lingen et al. 2001). The increase of abundance of sardine and anchovy, which enabled sardine to escape the "school trap" (Bakun and Curry 1999) that previously had forced them to school with the more abundant anchovy and hence adopt their strategy of spawning on the south coast (van der Lingen et al. 2001).However, the recent return to spawning by sardine principally off south coast, observed since 2001, is currently unexplained. This has occurred in tandem with what appears to be an eastward shift in the sardine population as evidenced by commercial fishing patterns(Fairweather et al., submitted) and resource surveys (Coetzee et al.2004).

In the northern Benguela, egg distributions of small pelagics are currently contracted, and eggs are observed at substantially lower concentrations than was the case when populations of these species were larger than at present. The main areas of sardine spawning in the northern Benguela were in the vicinity of Walvis Bay in spring and Palgrave Point in summer (Figure 3c; le Clus 1990b; O'Toole 1977), and the sardine stock showed some indications of a partial separation, probably of younger and older spawners, into a northern Namibian sub-stock and a central Namibian sub-stock (O'Toole 1977; King 1977; Thompson and Mostert 1974). The production of eggs in the Walvis Bay region declined substantially following the collapse of the sardine stock and a reduction in the age structure of the population in the early 1970s, although spawning still occurred in the waters off Palgrave Point (Crawford *et al.,* 1987). Ichthyoplankton surveys conducted in recent years have indicated that sardine egg and larval abundance in the vicinity of Walvis Bay is indeed very low, much lower than around Palgrave

Point (Figure 3e), and consistent with the hypothesis that sardine spawning off Walvis Bay has declined in importance or possibly ceased. Anchovy eggs are now located substantially further north than was the case in 1971/72 (Figure 3d, f).

The contraction in spawning area shown by anchovy and sardine in the northern Benguela at present low population sizes most likely reflects the relationship between abundance and the areal extent of the population´s distribution shown for these species in the southern Benguela. However, intense localized fishing pressure has also been implicated in changes in location of spawning by northern Benguela sardine. Historically, eggs and larvae spawned in the northern areas were believed to move south to a nursery area near Walvis Bay where they recruited into fishery (Thomas 1986), following which survivors returned to the north where they first spawned. Older sardine returned back to Walvis Bay, while younger spawners remained in the north.

Since the collapse of the stock in 1970s this migration pattern is believed to have broken down (Boyer et al. 2001), and it is likely that the previous intense spawning in central region was mainly by older adults (Crawford et al.1987). The decline in sardine spawning off Walvis Bay has also been attributed to the removal, via fishing, of larger, older fish (Daskalov et al. 2003), or to selective change in migratory behaviour in response to heavy fishing pressure in the vicinity of Walvis Bay (Bakun 2001). The consequence is that the stock currently consist of few age-classes (usually dominated by a single cohort) of young fish whose natal area is believed to be in the northern part of the Benguela ecosystem. MacCall´s (1990) basin hypothesis suggests that spawning would be expected to be contracted to the most favourable habitat when abundance (and hence density dependence) is low and the contraction in spawning by small pelagics in the northern Benguela may reflect this. However, the northern spawning ground of northern Benguela sardine appears to be sub-optimal compared to the southern spawning ground, at least in terms of likely offshore advective loss of spawn products, and hence could be considered as secondary spawning habitat (Bakun 2001). Similarly, modelling studies suggested that at low biomass levels anchovy and sardine in the southern Benguela spawned in sub-optimal areas, at least in terms of transport to the nursery area and possible offshore advection (Shannon 1998). These two examples contrast with MacCall´s (1990) hypothesis and indicate that changes in distribution of small pelagic at varying population levels are likely to also be influenced by changes in population age structure, and/or genetic makeup.

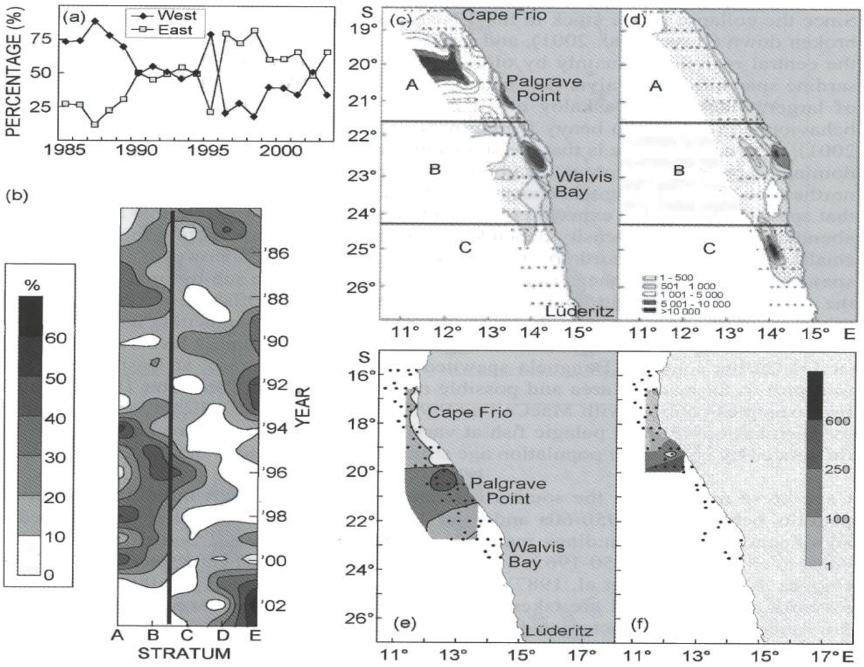

Figure 4: Variability through time in the distribution of small pelagic fish species in the Benguela ecosystem, showing (a) the relative distribution (% of total biomass) of southern Benguela anchovy spawners east and west of Cape Agulhas during pelagic spawner biomass surveys conducted by MCM each November over the period 1984-2003 (updated from van der Lingen *et al.*, 2002); (b) the relative distribution of eggs of southern Benguela sardine during pelagic spawner biomass surveys conducted by MCM each November over the period 1984-2003; the x-axis represents the coastline, which has been “straightened” and divided into five standard strata (A is the west coast north of Cape Columbine, B is between Cape Columbine and Cape Point; C is the western Agulhas Bank between Cape Point and Cape Agulhas, D is the central Agulhas Bank between Cape Agulhas and Mossel Bay, and E is the eastern Agulhas Bank east of Mossel Bay; the thick black, line indicates the approximate

position of Cape Point) and the percentage contribution to total egg abundance during the survey is shown for each strata in each year, with contouring used to interpolate between years and strata (updated from van der Lingen *et al.*, 2001); and the distribution of northern Benguela sardine (c) and anchovy (d) eggs observed during Cape Cross surveys conducted monthly from September 1971 to April 1972 (the cumulative total number of eggs collected per station over the 8 consecutive surveys are shown; from King, 1977) compared to sardine (e) and anchovy (f) egg distributions observed during an ichthyoplankton cruise in January 2004 (the number of eggs per sample are shown (data from E. Stenevik, IMR, *pers. comm.*)

Cape horse mackerel in the southern Benguela exhibited a shift in adult distribution patterns between the 1950-60s after 1970. Adult horse mackerel comprised a significant portion of landings made by the pelagic fishery off South Africa’s west coast over the period 1950-1965, with annual catches of this species averaging 60 000t (Fig. 2; Crawford 1987). Now however, only small (<10 000t) catches of juvenile horse mackerel are taken off the west coast, and the large schools of adult horse mackerel that were targeted there by the pelagic fishery have disappeared. Small catches of adult horse mackerel are caught by the mid-water and demersal trawl fisheries off the south coast, and current understanding of the life history of southern Benguela horse mackerel indicates that the west coast acts now as a nursery ground only, with fish migrating southwards and eastwards onto the Agulhas Bank as they grow (Barange *et al.*, 1998). The adult population that supported moderate catches off west coast during the initial years of South Africa´s pelagic fishery is assumed to have been a southern extension of large northern Benguela population, and the local depletion of horse mackerel off the west coast which resulted in changed distribution patterns has been linked to spatially-concentrated fishing effort (Griffiths et al.2004).

Deep water hake *Merluccius paradoxus* in the northern Benguela have shown variability in their distribution in recent years, with this species now being found further to the north than previously (NORAD-FAO/UNDP 1992, Burmeister 2001, Burmeister *et al*. 2002). Whereas previous published reports indicated that the abundance of this species was low north of

Lüderitz (27°S; Figure 5 Payne, 1989), high catches of this species are currently taken north of Walvis Bay, and *M. paradoxus* now comprises the majority of the Namibian hake catch, whereas in the 1980’s the majority of the catch was *M. capensis* (van der Westhuizen 2001). Survey maps from hake biomass surveys in the northern Benguela corroborate this (Burmeister 2001; Fig. 5b). This northward expansion in the distribution of deep-water hake has been attributed to an increase in population size (Burmeister 2001), hence hake also appear to show population-size effects on their distribution.

Shifts in the spatial distributions of predators have been apparent in both the northern and southern Benguela. Off Namibia, the large decline in African penguins has corresponded to a northward shift of breeding colonies: there has been a decrease (from 95% in 1956 to 18% in1999) in the proportion of African penguins breeding at localities south of Luderitz (Fig. 5c). Colonies at Ichaboe and Mercury Islands in northern Namibia were increase 1990s (Crawford et al. 2001), but the trend was reversed in 1995 at Ichaboe (Kemper et al. 2001) and in 1988 at Mercury Island (J.Kemper,Avian Demography Unit, UCT , pers comn). Colonies of African penguins along the west coast of South Africa decreased in size between 1956 and 1990 (Crawford *et al*. 2001), but some began increasing again towards the end of the century (e.g. Dassen Island, Fig. 5d).

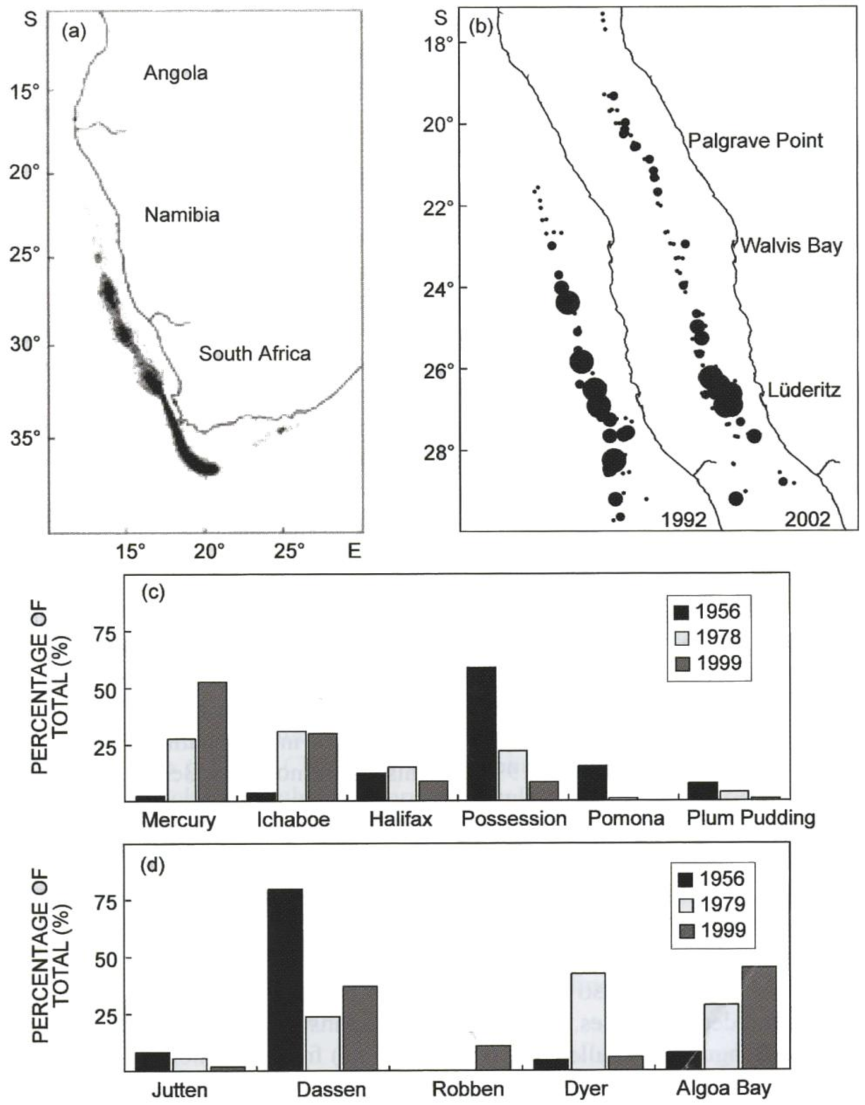

Figure 5: Variability through time in the distribution of some living marine resources of the Benguela, showing (a) the distribution by density of deep-water hake in the northern Benguela from catch data collected between 1977 and 1989 (from Payne, 1989) and (b) the distribution of hake (circles represent proportional CPUE [kg/hour] from all positive stations) along the Namibian coast during surveys conducted in 1992 (left; NORAD-FAO/UNDP 1992) and 2002 (right; Burmeister *et al*. 2002); and (c) the relative distribution per island (the % of the total number of breeding pairs on all of those islands is shown) of African penguin at six islands in the northern Benguela in 1956, 1978 and 1999 (R.J.M Crawford MCM, pers comm) and (d) the relative distribution per island (the % of the total number of breeding pairs on all of those islands is shown) of African penguin at four islands and one island group). [those in Algoa Bay] in the southern Benguela in 1956, 1979 and 1999 (R.J.M Crawford MCM, pers comm

New colonies of African penguins were established on Robben Island and at two land sites in False Bay (Crawford 1998) during the period of anchovy abundance in the mid-1980s. The colony at Dyer Island has undergone major declines since 1979, whereas colonies in Algoa Bay increased in size until the late 1990s (Crawford et al. 2001) but have recently decreased (Crawford and Whittington 2005). The eastward shift in pelagic fish distribution (Figure 4a) in the southern Benguela appears to have played a role in the spatial shifts of African penguins (Figure 5d); Crawford 1998).Seals in the northern Benguela have shown large spatial changes, whereas the distribution of seals in the southern Bengeula has been less variable. The proportion of pups counted at colonies in the northern Benguela increased at sites north of 25°S from less than 20% until the early 1980s, to 30-34% between 1989 and 1993, and to more than 40% since the mid 1990s (unpublished data, MCM and MFMR).

Environmental forcing is also strongly linked to changes in resource distributions at interannual and decadal scales. The occasional expansion of hypoxic bottom waters in the northern Benguela (so called low oxygen events) from their normal location on the inner shelf (Dingle and Nelson 1993; Kristmannsson 1994) to being widespread over shelf apparently displaces juvenile Cape hakes offshore from their typical inshore habitat, subjecting them to increase mortality from predation by larger hake and by commercial trawling (Hamukuaya et al.1998). In addition to resulting in faunal mortalities, Benguela Ninõs have been documented as impacting on the distribution of important northern Benguela resources forcing *Sardinella aurita* off Angola (Binet et al. 2001) and sardine off Namibia (Gammelsrød et al. 1988) southwards.

A large-scale movement of rock lobster in the southern Benguela, into the kelp forests between Cape Hangklip and Danger Point (on the western Agulhas Bank), was first noted in 1994 (Tarr et al., 1996), and coincided with the disappearance of the entire population of sea urchins *Parechinus angulosus* there. This massive increase in rock lobster numbers has occurred since the late 1980s, in an area stretching 150km east of Cape Hangklip, the main fishing grounds for abalone (*Haliotis midae*). Mayfield and Branch (2000) verified the substantial increase in rock lobsters in this region through interviews with recreational fishermen, diver surveys, and comparison with earlier surveys (in 1980) and reported a negative correlation between large (>68mm CL) rock lobster and sea urchin abundance, due to selective predation by the former on the latter. Reduction in sea urchin abundance has serious negative implications for abalone, since urchins provide shelter for and reduce predation on juvenile abalone (primarily by direct lobster predation) in areas where natural protection (crevices *etc.*) is minimal (Tarr 2000) Hence substantial changes in community structure have occurred from the mid-1980s to the present, apparently triggered by increases in rock lobster with consequent collapses of sea urchins and hence juvenile abalone. Large – scale environmental forcing over the past decade or so has been implicated in the shift in southern Benguela rock lobster to the more southern fishing areas and the movement of rock lobster onto the Cape south coast (Cochrane et al.2004).

Variability in biological characteristics

Long-term variability in reproductive characteristics has been reported for many of the Benguela’s living marine resources. Size at sexual maturity of southern Benguela sardine has changed in conjunction with population size, female fish maturing at a larger size at high population levels (1950-1963) and at a smaller size at low population levels (1965-87; Fig 6a; van der Lingen et al., submitted). A decrease in the age at maturity of northern Benguela sardine following the stock collapse was reported by Thomas (1986). Change in size at sexual maturity has also been reported for Cape horse mackerel in the northern Benguela, with a steady reduction in this parameter over the period 1977-83 (Wysokinsky, 1984) and fish currently maturing at an even smaller length than was the case then (Fig. 6b). A reduction in length at maturity of rock lobster in the southern Benguela in 1993/94 compared to earlier periods in the 1960s, 1970s and 1980s has also been reported (Fig. 6c; Cockroft and Goosen, 1995). Another reproductive characteristic, the number of African penguin chicks fledged per nest, has shown an increase from around 0.4 to 1.0 over the period 1989-2001(Fig. 6d; Crawford and Dyer, 1995).

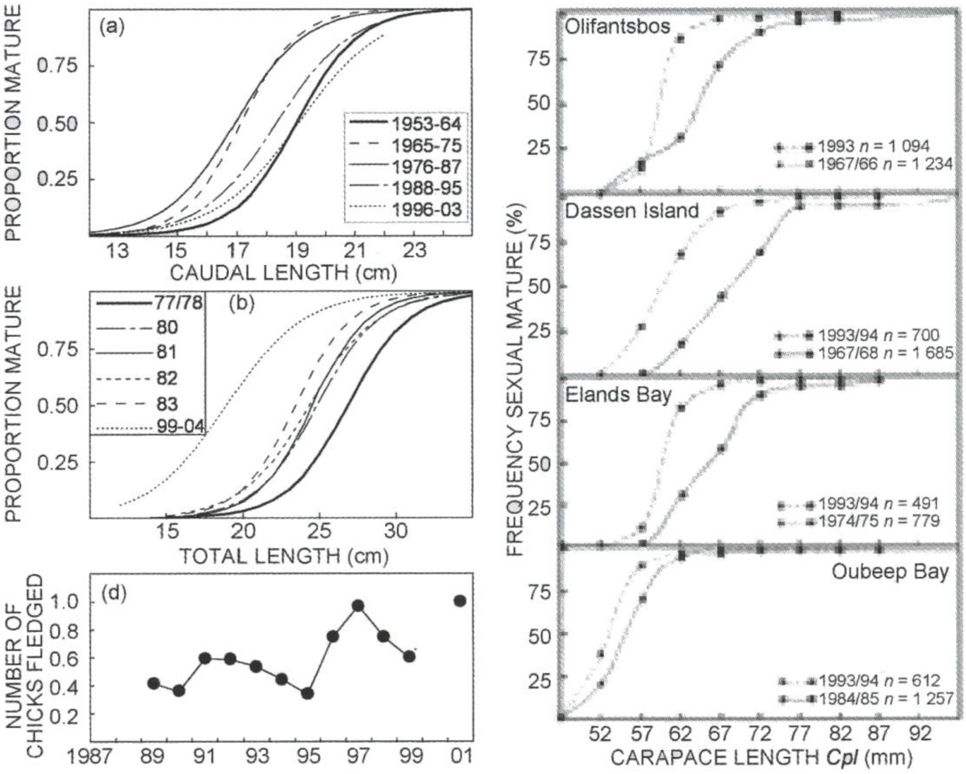

Figure 6: Variability in reproductive characteristics of some living marine resources of the Benguela ecosystem, showing (a) maturity ogives for female sardine in the southern Benguela for five periods between 1953 and 2003 (from van der Lingen *et al.*, in press); (b) maturity ogives for horse mackerel in the northern Benguela over the period 1977-83 (redrawn from data in Wysokinsky [1984]) and 1999-2004 (data used to plot the ogive are from A. Kanandjembo, NatMIRC, *pers. comm.*); (c) maturity ogives for female rock lobster from four locations in the southern Benguela in 1993/94 and earlier periods (from Cockroft and Goosen, 1995; reproduced with permission); and (d) reproductive success of African penguin (numbers of chicks fledged per nest) over the period 1987-2001 (updated from Crawford and Dyer 1995; note that the data point for 2000 is excluded because of the negative impact the Treasure oil spill had on penguin breeding success that year).

The diets of top predators (snoek, gannets, and seals) in both systems have varied over time. A switch in the relative dominance of sardine and anchovy in the diet of snoek in the southern Benguela occurred around 1964; before this snoek diet was dominated by sardine and after by anchovy (Fig. 7a; Crawford et al., unpublished manuscript). Most recent observations (1994-

97) showed equivalent dietary occurrence of the two prey species. Similarly, a change in the relative contribution of anchovy and sardine to the diet of Cape gannet in the southern Benguela occurred between 1987/88, before which anchovy clearly dominated gannet diet and after which sardine was generally the major dietary component (Schwartzlose et al., 1999). The diet of seals in the northern Benguela, whichs was dominated by sardine in mid-20th century, has changed dramatically after collapse of this stock (Mecenero and Roux 2002). Between the mid-1970s and mid-1980s seal diet was dominated by juvenile horse mackerel and pelagic goby (David 1987), and between 1994 and 2002 it was dominated by juvenile horse mackerel, juvenile hake and pelagic goby (*Suffogobius bibarbatus*) (Mecenero et al. 2006; Figure 7c).

Many other examples of biological variability in the Benguela Current system have been documented. The length distribution of both *Sardinella* species caught off Angola increased following a reduction in fishing pressure (Fig 8a, b; FAO 2000). Rock lobster in the southern Benguela showed reductions in somatic growth rates during the 1990s (Pollock et al. 1997). Long-term changes in condition factor of both northern and southern Benguela sardine have been observed, with condition factor being higher at low population size and lower at high population size (Fig. 8c,d; Le Clus, 1987; Kreiner et al. 2001; van der Lingen et al. in press). Northern Benguela sardine showed an increase in growth rate after the stock had collapsed (Thomas 1985), and also increased mortality rate and reduced age composition at low population size compared to high population size for this stock (Fossen et al. 2001).

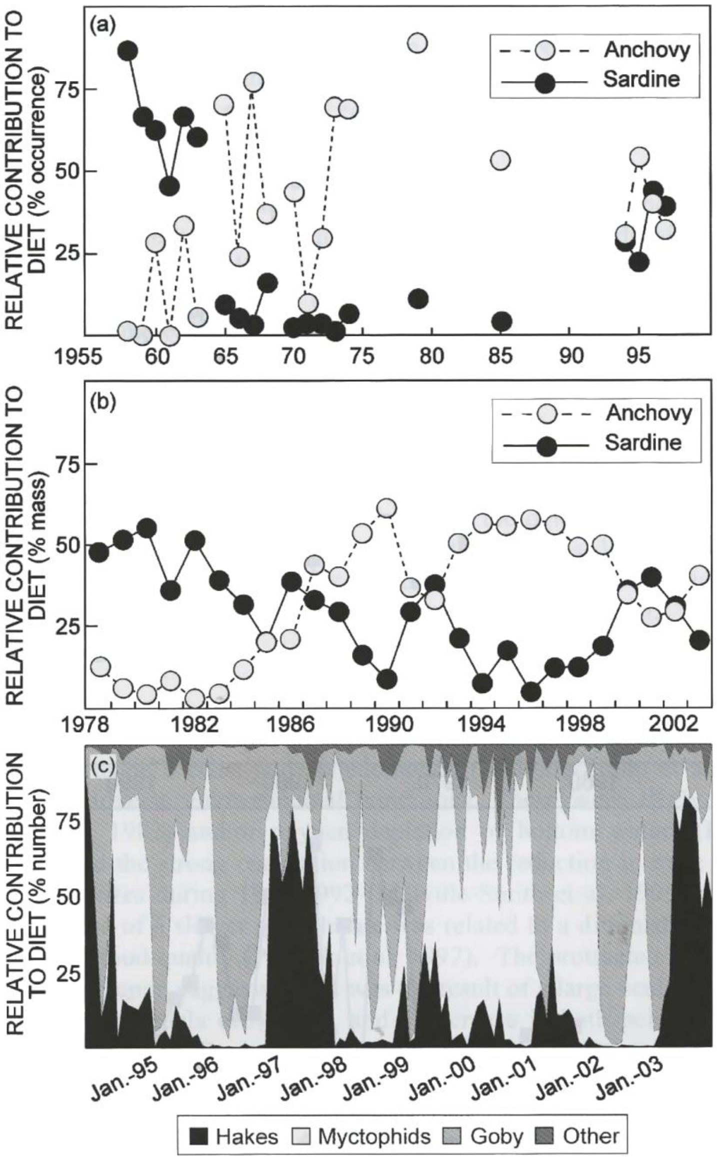

Figure 7: Variability in the diet of top predators of the Benguela ecosystem, showing (a) the relative contribution of anchovy and sardine in the diet of snoek in the southern Benguela at various times during the period 1950-2000 (% frequency of occurrence; data from M.H. Griffiths, formely MCM pers comm.); (b) the relative contribution of anchovy and sardine in the diet of Cape gannets in the southern Benguela (Lambert’s Bay and Malgas Island) over the period 1978-2003 (% mass; updated from Schwartzlose *et al.*, 1999); and (c) the seasonal and iterannual variability of the teleost portion of the diet of seals in the southern Namibia (numerical percentages) from 1993-1999 (J.- Roux, unpublished data).

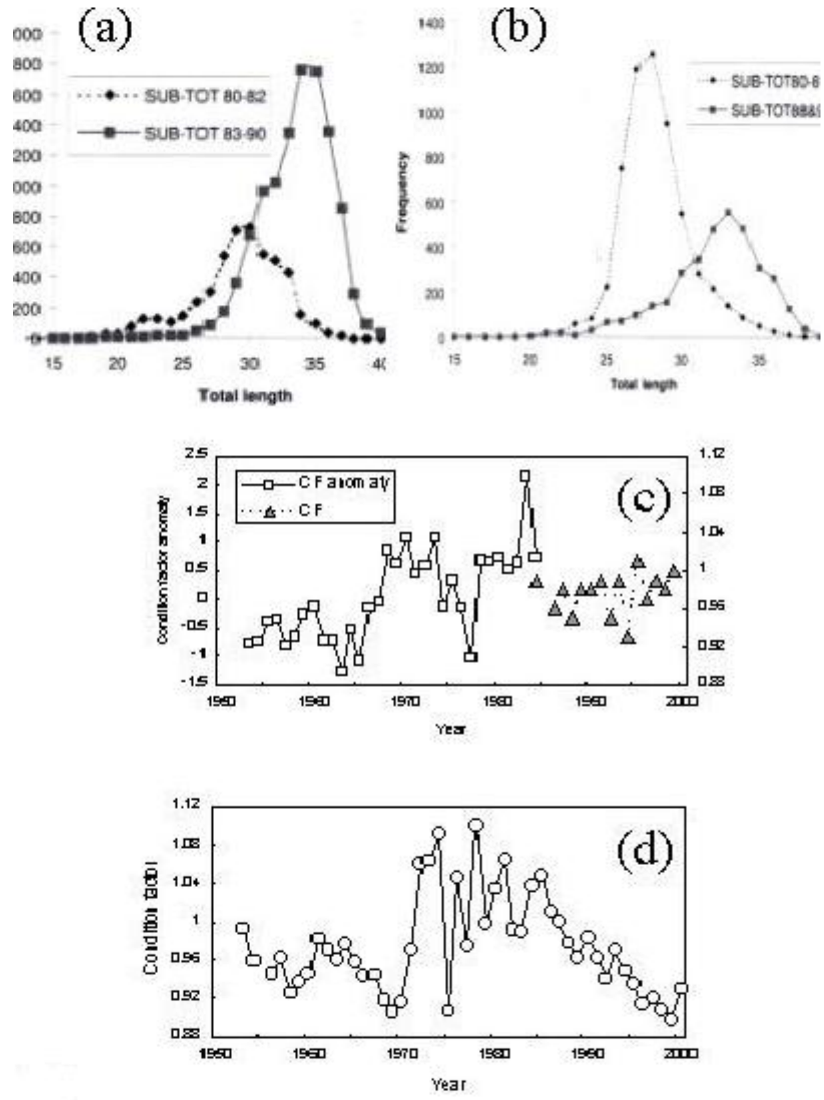

Figure 8: Variability in various biological characteristics of some living marine resources of the Benguela ecosystem, including an increase in length frequency distributions of (a) *Sardinella aurita* and (b) *S. maderensis* caught by the industrial fishery off Angola during periods of heavy (1980-82) and light (1983-1990) fishing pressure (from FAO 2000); and long-term changes in condition factor of (c) northern Benguela sardine (CF anomaly data are from Le Clus 1987 and CF data are from Kreiner *et al*., 2001) and (d) southern Benguela sardine (from van der Lingen *et al*., submitted).

Changes in biological characteristics of living marine resources of Benguela have been attributed to a variety of causes including fishing pressure, density dependence, an environmental effects including food availability. The removal of larger, older fish from the population through intense fishing pressure will impact fish size and age distributions. For example, modal length of catches of northern Benguela sardine was 26 cm TL between 1952 and 1957 (Matthews, 1960) and only 21 cm TL between 1997 and 2000 (Boyer et al. 2001). Reports of compensatory responses by fish to fishing, including reductions in age-at- maturity and/ or length-at-maturity, faster growth and increased fecundity, are becoming increasingly common for commercially exploited fish population in many systems (Rochet 1998 2000). Density-dependence appears to be strongly linked to variability in several biological parameters of sardine in the Benguela ecosystem, including growth rate (Thomas 1985), age- (Thomas 1986) and size- at maturity (Figure 8-5 van der Lingen et al submitted), condition factor (Figure 8-7c d; Kreiner et., 2001; van der Lingen et al. in press), and mortality rate (Fossen et al. 2001).

The decline in male growth rate (Pollock et al. 1997) and reduction in female size at sexual maturity (figure 7c) reported for southern Benguela rock lobster during the 1990s and shown to be a cost-wide phenomenon (Melville-Smith et al. 1995) has been ascribed to adverse environmental conditions. These were likely to be food limitation (Pollock 1982) and/or oxygen depletion of bottom waters (Pollock and Shannon 1987), and the strong correlation between the reduction in male growth rate and female brood sizes during 1987-1992 (Melville-Smith et al. 1995) suggests that the underlying cause of slower growth rate was related to a diminished food supply and/or a decline in food quality (Pollock et al .1997). The protracted and widespread nature of the phenomenon suggests that it was the result of a large-scale environmental perturbation in the Benguela ecosystem, and a decrease in both pelagic and benthic productivity in the southern Benguela associated with the El Niño years of 1990-1993 is believed to be the main cause of the phenomenon (Pollock et al. 1997).

Food availability exerts substantial effects on biological characteristics of marine resources. The increased fledging success of African penguins in the southern Benguela over past decade has been attributed to the increased abundance and availability of anchovy (Crawford and Dyer 1995). Similarly, the numbers of swift terns (*Sterna bergii*) breeding in the southern

Benguela over the period 1987-2000 were significantly related to the combined biomass of anchovy and sardine (Crawford 2003). Changes in diet of top predators typically reflect relative abundance of forage fish (Figure 7) , with good correspondence observed between relative anchovy an sardine population sizes in the southern Benguela and their contribution to the diet of snoek and Cape gannet. Similarly, the strong correlation between hake recruitment (estimated from trawl surveys) and the contribution of juvenile hake to the diet of seals at Atlas Bay (near Luderitz) in the northern Benguela suggests that most of interannual variability in dietary composition arises from variability in prey abundance (Mecenero and Roux 2002).

ECOSYSTEM VARIABILITY

High amplitude changes in community composition, species abundance and trophic structure are termed regime shifts and are thought to occur largely in response to oceanic and climatic changes (Collie et al. 2004). This broad definition does not cover temporal and spatial dimensions of a regime shift; alternative, more detailed definitions are provided in Table 1 of Jarre et al. (this volume).Changes in ecosystem states are not only environmentally driven but are also known to be responses to altered fishing pressure (Larkin 1996) and ecological and behavioural changes (Cury et al. 2003). Fish and other marine species respond to these changes by altering their population dynamics over 10-30 year periods (Beamish and Mahnken 1999).

Despite their (possibly) expected similarities, the northern and southern Benguela have shown distinctly different ecosystem dynamics (Figure. 1 and Figure. 9). Differences between the northern and southern Benguela may be related to the fact that the southern Benguela upwelling region is bounded by the shallow Agulhas Bank, comprised of a diverse demersal fish assemblage. Biological resources are affected by dramatically different environmental perturbations in the two systems. For example, the northern Benguela is regularly affected by low oxygen events, and by large-scale warm water events such Benguela Niños. In recent years, unusually large biomasses of pelagic fish have been attained in the southern Benguela, whereas the pelagic ecosystem in the northern Benguela has collapsed.

The ecosystem structure and trophic functioning of the northern Benguela in recent years seems to differ from the way in which the system functioned in the 1970s (Heymans et al.2004). Betwwen the late 1960s and the late 1970s, anchovy and sardine stocks were replaced by a by a suite of zooplanktivorous fish including horse mackerel, mesopelagic fish, pelagic gobies. It appeared as if sardine may be starting to recover towards the end of the 1980s and early 1990s, but recovery was curbed by unfavourable environmental conditions (Boyer et al. 2001). Most fish stocks in the northern Benguela underwent large declines towards the end of the 1990s at the time of major environmental anomalies (Boyer and Hampton 2001; Roux 2003) On the other hand, jellyfish *Chrysaora hysoscella* and *Aequorea aequorea* have attained large abundances (Boyer et al. 2001) and may have changed the energy flow through the northern Benguela food web (Heymans et al. 2004). Since the 1980s, the northern Benguela appears to have undergone a regime shift (Fig. 10a, b); unfavourable environmental effects have been exacerbated by heavy exploitation (Boyer et al. 2001), resulting in the collapse of the pelagic ecosystem there (Bakun and Weeks, 2004).

Exploitation of sardine, anchovy and subsequently hake and horse mackerel took place in the northern Benguela from 1950 onwards. Since Namibian independence in 1990, horse mackerel has continued to dominate total catches and there has been a moderate recovery of hake catches, but sardine catches have remained negligible.

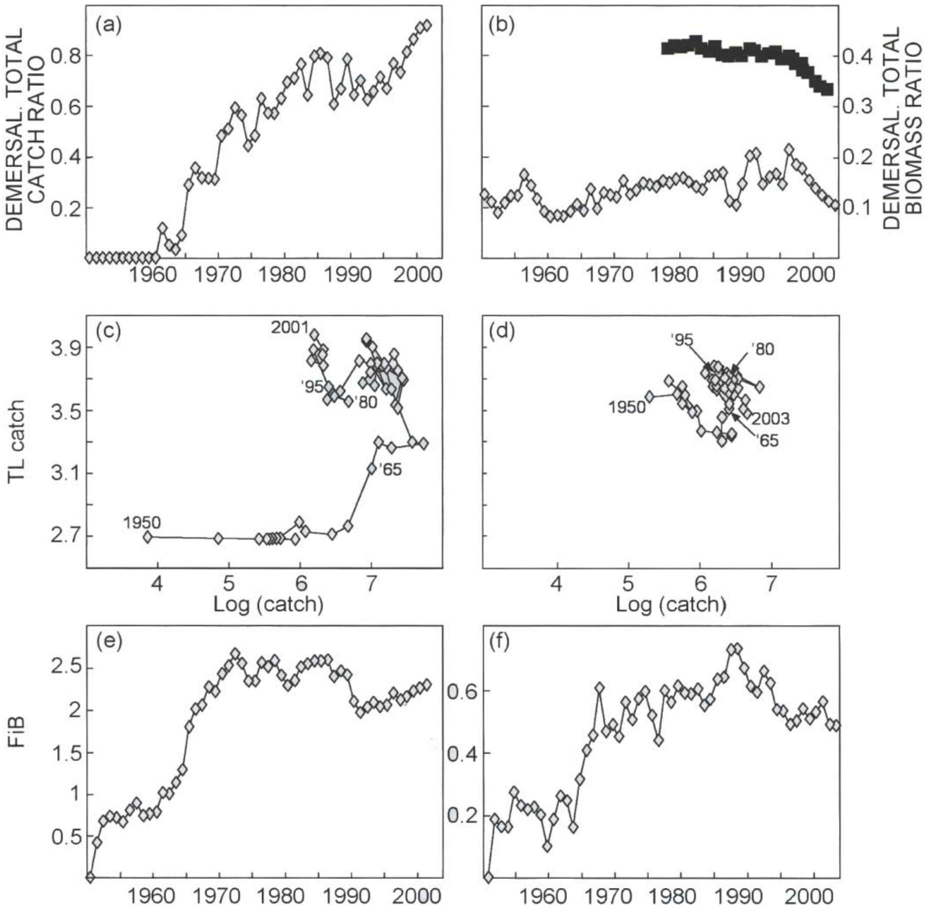

Figure 9: Variability in selected trophic characteristics of the northern (left panels) and southern (right panels) Benguela Current ecosystems, showing (a, b) the ratio of demersal catches to pelagic catches over the period 1950-2003 (note that catches from Angola are not included for the northern Benguela and that for the southern Benguela, also the corresponding demersal: total biomass ratio from a trophic model fitted to available time series for 1978-2002) is also shown; (c, d) the mean trophic level of annual catches plotted against the Log(catch) for data from 1950-2003; and (e, f) the FiB index over the period 1950-2003 (updated from Cury *et al.* 2005).

The combined species catch in each year can be represented on an ecosystem basis in terms of its mean throphic level. Throphic levels (TL) describe the positions of species in the food web. Primary producers are allocated to TL 1 and TL of a consumer is calculated as the mean TL of the prey it consumes, wheigheted by a contribution of the prey species to the diet of predator. Annual mean trophic levels of the catch in the northern Benguela reflected catches of sardine until the mid-1960s, increased from 1965 to 1972 as the hake (higher TL) fishery developed and sardine catches decreased, and levelled off thereafter despite the continued decline in sardine and the partial replacement of hake catches by horse mackerel (Fig. 9c).

changes in the mean trophic level of the catch are matched by a corresponding increase/decrease in catch size to take account of the higher ecological cost of fishing at higher trophic levels. In general, an increase in the FiB indicates an expansion of the fishery whereas a decrease indicates a collapse of the underlying food web or a geographic contraction of the fishery. Off Namibia, the FiB index increased between 1960 and 1972 (Fig. 9e), reflecting the rapid expansion of the pelagic fishery followed by growth in the trawl fishery as pelagic catches began to decline. Since 1972, there has been a small significant decrease in the FiB, as a result of decreased total catches dominated by horse mackerel (having a higher TL than small pelagic fish). In both the northern and southern Benguela, there was an increase in the proportion of the total catches that were comprised of demersal fish since 1950 (Fig. 9a, b), although the increase was much smaller in the southern Benguela. Since the collapse of the pelagic fisheries, Namibian catches are currently comprised almost entirely of horse mackerel and hakes. Because fish abundance declined in the northern Benguela, predation pressure on fish increased and predator biomass decreased between 1980 and 1999 (Cury et al. 2005a).

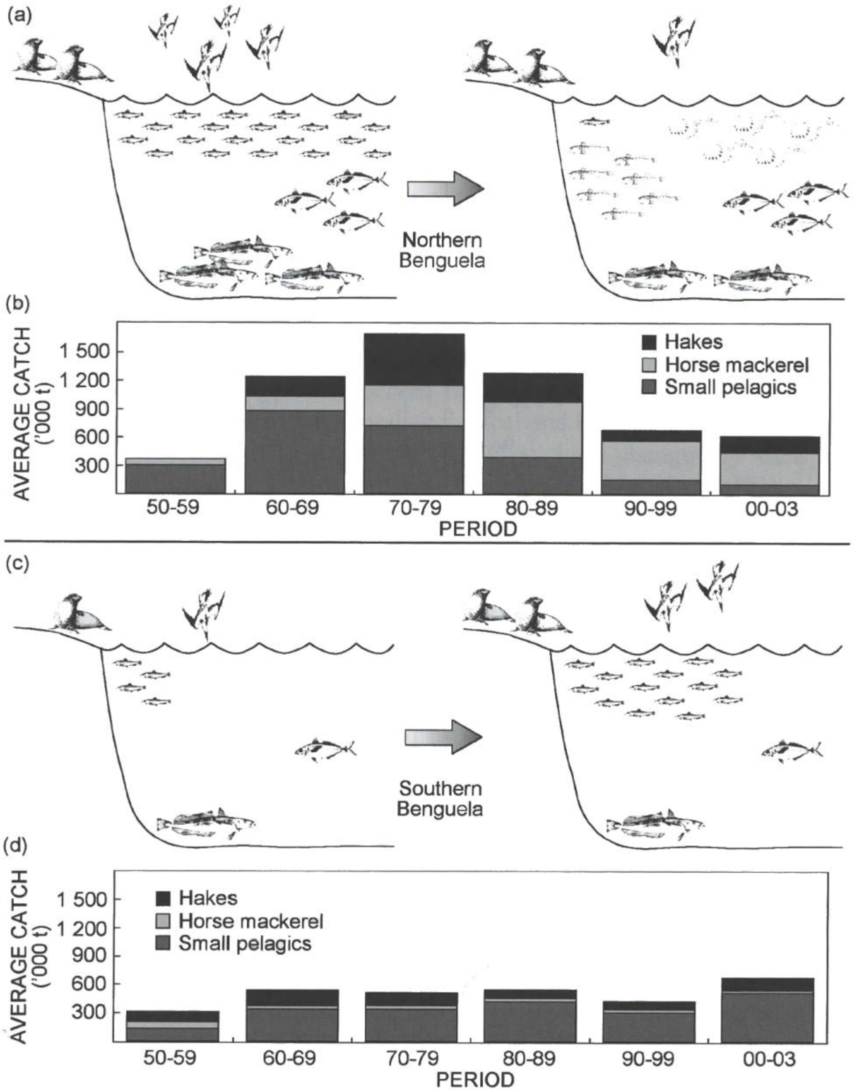

Figure 10: Changes in ecosystem structure and relative abundance of dominant living marine resources (a, c; small pelagic fish, horse mackerel, hakes, goby, jellyfish, Cape gannets and Cape fur seals are shown [not scaled to relative size] and the number of individuals approximately reflects relative abundance), and (c, d) average annual catches of small pelagic fish, horse mackerel and hakes by decade or half-decade (the last histogram shown average annual catches for the period 2000-2003) for the northern (upper figures) and southern (lower figures) Benguela. The two ecosystem states shown for the northern and southern Benguela approximate periods around 1970 (left hand side), and the current situation (right hand side). The relative and dimensionless (FiB) index (Pauly et al. 2000) remains constant when

Resources in the southern Benguela have also varied substantially between 1980 and 2004, but apparently without a shift to a completely new ecosystem state (Cury and Shannon, 2004). Despite the differences in fish (particularly small pelagic) stock sizes and catches between 1980 and the mid 1990s, the trophic models used by Shannon *et al*. (2003) failed to reveal a change in the overall functioning of the southern Benguela between 1980 and 1997. Cury and

Resource and ecosystem Variability, including regime shifts, in bengueal current system

Shannon (2004) argue that the southern Benguela experienced a pelagic species replacement rather than a clear regime shift to a different ecosystem state (Fig. 10c, d) because ecosystem functioning remained relatively constant over that period. Those authors interpreted the observed changes as variability within the natural limits of population size and geographical distribution. However, the southern Benguela ecosystem may well have been in a different state prior to the start of industrialized fishing in the 1950s, after which a substantial increase in total catches occurred (see Figure 33 of Griffith et al. 2004). Fishing can alter marine ecosystem structure (e.g. Pitcher 2000 and Pitcher and Pauly 1998), and it is likely that the northern Benguela underwent a rapid shift from pristine, or near- pristine, state following the advent of heavy fishing.

Total catches in the southern Benguela have remained approximately stable since 1978. Sardine dominated catches until the mid 1960s, catches peaking in 1968 (Figure. 2; De Villiers 1985). As pelagic fish catches declined, catches of hake in the demersal trawl fishery increased, and in the late 1970s, midwater trawls began to target horse mackerel (De Villiers 1985). Anchovy replaced sardine in the pelagic fishery in the 1970s and 1980s. There has been a small decline in the mean TL of catches and the FiB index during the 1990s (Fig. 9f), reflecting the increase in sardine catches as the stock began to recover. Since the late 1990s both anchovy and sardine have been abundant, supporting larger populations of some predators such as seabirds (Figure. 2), although there is not evidence for a concomitant increase in primary productivity off South Africa between 1997-2003 (H. Demarqc, IRD, *pers. comm.*). Biomass of pelagic fish predators supported in the period 1990-1997 was 24% larger than that in 1980-1989. The sustainability of these high stock sizes of pelagic fish in the south is uncertain as density-dependent effects are expected to come into play, and unpredictable environmental events may also occur, influencing resource and ecosystem variability.

Large, dominant fish species are sustained at least partly because adult fish keep forage fish at sufficiently low abundances to limit competition with and/or predation on their own juveniles (Walters and Kitchell 2001). This has been termed the “cultivation effect”, and has been considered by Barkai and McQuaid (1988) as “predator-prey role reversal”. Cury et al. (2005b) explain how fishing large predatory fish may prevent successful stock rebuilding by releasing top-down control, thereby increasing the depensatory effects of predation on, or competition between small forage fish. Indeed, the two hake species are important predators in both the northern (roux and Shannon 2004) and southern Benguela (Shannon etal.2003) ecosystems. When testing an indicator of interaction strength using ecosystem models, hakes emerged as the group having the strongest interaction strength, i.e. a change in the biomass of hakes caused large changes in abundance of other species in the southern Benguela (Shannon and Cury 2003). Similarly, some minimal realistic model (MRM) scenarios of cannibalistic interactions between the two hake species and predation by seals on hake in the southern Benguela suggested that reducing seal populations via culling would result in increased inter-hake cannibalism and hence fewer hake overall (Punt and Butterworth, 1995).

PREDICTING VARIABILITY

We predict patterns using knowledge about processes. It is important to understand what processes are important in an ecosystem and what controls them, before being able to make predictions of resource and ecosystem variability. At present in the Benguela ecosystem, we have imperfect understanding of past variability, although a number of hypotheses have been proposed to explain observed changes in species abundances. This uncertainty is not surprising, because different components of the ecosystem are likely to be affected in different ways at different times, depending on their state and the state of the ecosystem. For example, a population at a low biomass might respond differently to the same environmental forcing than when it is at a high biomass. For depleted stocks, the effect of recruitment variability is much more important at low than at high stock levels. As a consequence of these factors, non-stationarity and non-linearity should be expected in ecosystem control processes. In this section we discuss the knowledge required for predicting resource and ecosystem variability, the causal factors that need to be considered, and the kinds of predictions that are possible.

What controls ecosystem functioning?

Identifying and quantifying the controls of ecosystem functioning and the roles of important species in the Benguela ecosystem is necessary because there is no general theory that can be ascribed to the functioning of marine ecosystems. Thus, and unlike in physics, our ability to predict ecosystem trajectories cannot depend on a few simple ‘laws of nature’; it is necessary to understand a complex set of processes that might operate differently under different conditions. There are several means of quantifying controls and their impact on marine systems.

Ecosystem manipulations have been used in lakes (Carpenter 2004), and in the marine environment they have been successfully applied to plankton ecosystems to examine the role of iron in controlling primary production (e.g. Boyd et al. 2000). Such manipulation experiments can be used to quantify processes that are assumed to be key for exerting controls. These could include quantifying predation processes through examination of stomach contents and isotopic studies to assign trophic levels to different species (*e.g.* Sholto-Douglas et al. 1991), or quantifying to what extent environmental effects are propagated up the food web by relating plankton dynamics to fluctuations in small pelagic fish, for example. Behavioural studies can test the extent and consequences of the school trap hypothesis, and reasons for changing migration patterns and distributions of key species.

Retrospective studies allow patterns to be identified, and can also be used to test hypotheses. Such studies include meta-analysis (Worms and Myers 2003; Richardson and Schoeman

2004), empirical studies (Cury et al. 2000; Daskalov 2002), multivariate time series analysis that considers both environmental variables and predator/competitor interactions (Stenseth et al. 2004), and spatial studies that use GIS to identify indicators of interactions (Drapeau et al. 2004; Fréon et al.2005).

The controls that operate in ecosystems can be further investigated using ecosystem models. Several simulation models exist of the Benguela ecosystem, including Ecopath with Ecosim models (Shannon et al. 2003; Heymans et al. 2004; Roux and Shannon 2004) that are based on the foraging arena hypothesis of predator-prey interactions (Walters et al. 2002), and a size-based predation model (OSMOSE) (Shin and Cury 2002, Shin et al. 2004). Models of lower trophic levels are in development (Eric Machu IRD, *pers. comm.*). Additional models can be constructed, such as dynamic trophic cascades (Herendeen 2004), and inverse models can be used with reconstructions of ecosystem flows (Vezina et al. 2004). Comparative studies among ecosystems (e.g. Moloney et al. 2005) can extend the data and knowledge base for understanding controls within a specific ecosystem.

Causal factors influencing resource and ecosystem variability

Environment-resource interactions can be synergistic or antagonistic, and changing the composition of the ecosystem will likely change the response of the ecosystem to environmental forcing (see above). It is important to understand controls of lower trophic levels, because these influence food quantity and quality, which can act as controlling mechanisms at high trophic levels. Not only must there be a match between an organism and its food in time (Cushing's [1978] match-mismatch hypothesis), but they should also match in space, and the food must be of a suitable quality (Beaugrand et al. 2003). For example, Winship and Trites (2003) reported that differences in the energy density and digestibility of prey (e.g. low energy gadis versus high energy forage fish) could have large effects on the prey biomass requirements of Alaskan Steller sea lion (*Eumetopias jubatus*) pups, such that they could starve in the midst of plenty. Cury et al. (2005) have proposed that an environmental index be developed to quantify bottom-up effects of environmental perturbations on food-webs.

The future effects of climate change are not fully known, and there is insufficient knowledge about local impacts. Removing top-down controls through overexploitation of many demersal fish communities may change the way climate affects fisheries. Thus the interaction between global forces, *i.e.* the effects of climate and overexploitation may be nonlinear and can act synergistically. As a result, the changing structure of marine ecosystems could lead to changing recruitment patterns of species that are valuable to fisheries (Beaugrand et al. 2003), and may enhance the overall impact of the environment on the ecosystem. When overexploited, ecosystems appear to be more frequently controlled by bottom-up forces, which makes it difficult to appreciate the true relative contribution of top-down versus bottom-up control forces in ‘balanced’ marine ecosystems.

There are hypotheses about some large-scale impacts of climate change in the Benguela ecosystem, including altered wind stress that would enhance coastal upwelling (bakun 1990; Bakun 1992; Shannon et al. 1996); an increased frequency of occurrence and intensity of Benguela Ninõs and the advection of warm tropical water (Siegfried et.al 1990); and an increase in sea surface temperature (Roux 2003). The possible impacts of climate change in the Benguela ecosystem can be addressed partly through modelling, by downscaling global models and linking these with three-dimensional hydrodynamic models of the region (*e.g.* PLUME, Penven et al. 2001). Individual-based based models can be used to test “scenario” cases and assess the impacts of oceanographic conditions on biology and ecology of key species, including their spatial dynamics (*e.g.* changes in spawning locality, Mullon et al. 2003). In addition, there might be unexpected interactions between fisheries exploitation and climate change, such as changes in a stock's resilience to exploitation under different climatic scenarios.

Regime shifts have been documented for the northern and southern Benguela (Cury and Shannon 2004). Regime shift (in the northern Benguela and elsewhere) have generally been assumed to be controlled mainly by environmental forcing, but it is possible that they can be induced by anthropogenic forcing (Steele 2004). For example, in the northern Benguela overexploitation of small pelagic fish (principally sardine) resulted in a radical restructuring of the food web and hence a very changed ecosystem (Cury and Shannon 2004Roux and Shannon 2004).

To date, the effects of pollution in the BCLME region have been mainly localised, although pollution is a serious threat for some species (*e.g.* oil pollution for seabirds). In general, pollution has probably had very little impact on the Benguela ecosystem in the past (Griffiths et al. 2004), but there is concern that its possible impacts in the future are being ignored, because of reduced research effort (O'Donoghue and Marshall 2003).

Making predictions

Predictions in ecosystems, as for any complex systems, are difficult to make, and should rather be replaced by the analysis of risks associated with anthropogenic actions or natural trends that occur in marine ecosystems. A number of risks for the dynamics of marine ecosystems can be associated with the depletion of pelagic fish stocks, which can produce local and global extinction of marine bird populations and to a lesser extent seal populations. In some cases, but not all, such depletions can lead to dysfunctional ecosystems, such as the case of present Namibian ecosystem (discussed above).

Studies of the northern and southern Benguela illustrate that the identification of bottom-up as well as top-down controls are key for predicting population trajectories. Patterns in marine ecosystems are produced by global change and/or subtle mechanisms that act at different scales and with different strengths depending on the structure of the ecosystem. Thus overexploitation as well as environmental changes strongly affect populations at different trophic levels, either directly in a more predictable way, or indirectly in a less predictable way. The environment plays a major role in influencing recruitment strength for pelagic fish. However, localized (in time and space) environmental events (e.g. those described by Roy et al. 2001) are difficult to predict but can play a major role in structuring (and restructuring) fish populations. In the case of the northern Benguela, it is difficult to predict when favourable succession of environment events could contribute to rebuild both sardine and anchovy populations. Daskalov et.al (2003) found that the functional response (through recruitment) of northern Benguela sardine stock to environment factors seems to have changed over time. This change could be linked to a shift between two environmental regimes between the mid-and late-1980s. Alternatively, it could be the result of fisheries-induced changes in the age structure of the stock that resulted in changing in spawning habitat. Both hypotheses however point to some non-linear biological response of the stock to either environmental variability of fishery pressure, or both. Because of strong trophic interactions, drastic changes at the pelagic fish population level can be expected to produce changes at higher trophic levels, *e.g.* for marine birds and mammals. The roles of those large populations of pelagic fish at intermediate trophic levels that fluctuate radically in size have important consequences for the functioning of marine ecosystems. Small pelagic fish in upwelling systems have been shown to play a pivotal role in the food web, so-called “wasp-waist” control (Bakun 1996, Cury et al. 2000). In terms of prediction we can definitively say that the substantial reduction of pelagic fish will lead to the collapses or drastic diminution of a number of other populations that prey upon them. At the other end of the spectrum is the role of pelagic fish in controlling their zooplankton prey, sometimes with feed-back effects. For example, Boyer et al. (2001) propose a mechanism that may retain the northern Benguela ecosystem in this current state. They propose that phytoplankton are significantly underutilized as a result of the small sardine stock size, and this increase detritus loads and worsen the low oxygen situation, further negatively affecting sardine spawning.

Marine bird numbers are strongly controlled by the abundance of pelagic fish; large pelagic fish populations often lead to improved survival for birds (and conversely). In this particular case predictions at the ecosystem level are possible and are reflected in the joint evolution of pelagic fish and top predators in the northern and southern Benguela. This prediction needs to be tuned spatially, knowing the distribution ranges of both predators and prey; in this case it is necessary to analyse the spatial distribution of the interactions, for example using a GIS (Drapeau et al., 2004; Fréon et al. 2005).

Not everything is predictable at the level of an ecosystem. Cape fur seals, a protected species, have become abundant in the southern Benguela ecosystem (present population size about 1.5 to 2 million animals), and are killing substantial numbers of different species of seabirds -- African penguin, Cape gannet, Cape cormorant, bank cormorant *Phalacrocorax neglectus* and crowned cormorant *P. coronatus*; (David et al. 2003). This predation process was well know for a long period, but was marginal in the past. Together with combination for breeding space, this predation process is now seen to endanger many protected bird population. This example illustrates that long term-predictions can be made regarding predator-prey relationships but that new processes or novelties can emerge and modify the complex dynamics of interactions. In the northern Benguela the almost complete collapse of pelagic fish resources led to a drastic reduction in the abundance of penguins and gannets. It has also resulted in an outburst of pelagic gobies and a reorganisation of the food-web dynamics, through the collapse of the pelagic food chain. The resulting degraded marine ecosystem, combined with further increases in upwelling intensity, appears to be creating additional sources of greenhouse gas emissions (Bakun and Weeks 2004).

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Potential predictions can be made from the ecosystem control theory (Cury et al. 2003), recognizing that that those predictions can be challenged by the complexity of the interactions. Biological/predation controls on ecosystem functioning can occur by means of bottom-up (control by plankton affected directly by the environment), top-down (control by predators) or wasp-waist (discussed above) mechanisms. But why do we observe drastic changes in major components under relatively stable productivity? why have both sardine and anchovy collapsed and do not recover in the northern Benguela? Questions such as these currently do not receive satisfactory answers, emphasizing the fact that prediction in marine ecosystems is in its infancy.

That said, attempts to forecast anchovy recruitment strength in the southern Benguela using expert systems were developed around a decade ago. Expert systems take into account qualitative and quantitative data from a number of factors simultaneously and manage well with short data series, take the form of a number of multiple-choice questions and a set of rules that logically infers predetermined decisions based on the answers to these questions. The rules take the form: IF (question answers) THEN (decision). Four expert systems have previously been developed for anchovy recruitment in the southern Benguela region. The first was devised using three environmental variables: wind frequency, wind velocity and sea-surface temperature (Bloomer et al. 1994). This was followed by a survey of expert opinion that formed the basis of both deterministic and probabilistic expert systems for anchovy recruitment (Korrûbel et al. 1998), which predicted “very likely below average” anchovy recruitment for 1994 that was validated by the observation of recruitment that was slightly below long-term average. Then, a rule-based deterministic model to forecast anchovy recruitment was developed using field data from the South African Sardine and Anchovy Recruitment Programme (SARP) conducted in 1994 and 1995 (Painting and Korrûbel, 1998); the predicted results compared very favourably with the final estimates of recruitment strength for 1994 and 1995. The most recent expert system (Miller and Field, 2002) uses five predictors (covering anchovy spawning, transport and nursery areas) in a deterministic model to provide a qualitative forecast of anchovy recruitment, and this system correctly hindcast recruitment in 89% of an 18 year time series (1985-2001), including two test years not used in model construction. Apart from that experts system however, none of the others has been applied to recent data, a situation that should be rectified given the recent exceptionally high recruitment estimated for southern Benguela anchovy. A proposed way to update these is given in van der Lingen et al. (this volume). Despite the success in hindcasting anchovy recruitment strength, however, success in making actual predictions remains elusive, suggesting that patterns in anchovy recruitment are not regular and/or that different factors impacting on recruitment may vary from year to year. (Hutchings et al. 1998). In addition, the expert system typically have used variables integrated over a year, whereas Roy et al. (2001) have shown that intra annual processes can be important in affecting recruitment, and there is a need to develop indices that take that account of episodic events. These indications further emphasize the expectation of non-stationarity and non-linearity in ecosystem control processes

Much recent work on marine ecosystem has focused on the development of indicators that index some aspect of ecosystem state and /or trajectory and that are useful for fishery management (curry and Christensen 2005).Such indicators (e.g. FiB see above) have the potential to simplify and quantify ecosystem complexity, and may enchance understanding of the dynamics of complex system through their tracking of repeatable patterns (Cury 2004). The identification and development of further indicators for the Benguela. Current ecosystem should be accorded a high priority, particulary given the move toward an ecosystem approach to fisheries currently underway in the Benguela current system (see Shannon et al. 2004a), such indicators could then be used to monitor key aspects of the ecosystem, which may permit analysis of risks associated with anthropogenic actions or natural trends that occur in benguela Current system (Shannon et al.2006). The potential for using indicators to describe and quantify changes in the state of the Benguela Current ecosystem is discussed in detail by Jarre et al. (this volume).

A way forward

We propose that five steps should be followed to permit an improvement in our ability to analyse risks associated with anthropogenic actions or natural trends that occur in Benguela Current system, and possibly make predictions. They are:

1. Identify different possible states of the ecosystem, including current states, and evaluate their desirability on a socio-economic basis. Ecosystem states might include pristine, small pelagic fish biomass high, saml pelagic fish biomass very reduced, etc.

2. Improve understanding of the control mechanisms that operate in the different possible ecosystem states (as described above) through, for example, studies that quantify throphic interactions between species and the functional response of predators to varying prey fields.

3. Develop and test hypotheses about factors causing ecosystem changes, and assess if or how the relative importance of hypothesized mechanisms may vary in time and space. Similarly, spatio-temporal variability in the relative importance of hypothesized mechanism impacting on resource variability should assessed (e.g. Cochrane and hutchings, 1995 for southern Benguela anchovy), although it is likely that in any one year several plausible, but different, factors impact on recruitment success, making it difficult to posit generalized hypotheses (Hutchings et al. 1988).

4. Identify the suite of indicators necessary to describe and quantify ecosystem changes; expert systems may also be useful in this regard.
5. Synthesise the information provide by indicators (e.g. through an expert system approach that can capture many aspects of change) and thereby monitor key aspects of the ecosystem. By identifying changes in ecosystem state, improve our ability to analyse risks and possibly make predictions.

CONCLUSIONS

Marine ecosystems are complex dynamics systems which present stable or semi-stable states. Indeed, most of these systems worldwide have displayed remarkable resilience, despite having been subjected to large scale perturbations both anthropogenic (fishing, pollution, habitat modification) and natural origin (climatic and oceanic variability), This resilience and general lack of widespread chaotic behaviour in marine systems implies the existence of sets of controls or feedback mechanisms which tend to bring back the system towards its equilibrium state(or “local attractor”) following a disturbance (see Jarre et al., in this volume). The most important of these feedback mechanisms are the demographic responses of the individual stocks to changes in abundance (density dependence effects, spawning stock&recruitment relationship) mediated by predator/prey relationship (trophodynamic control). Our (imperfect) theoretical and empirical knowledge of these mechanisms forms the basis of our efforts to manage fisheries and predict fish stock and ecosystem trajectories. However, after the system has been subjected to a change of state, or regime shift, there is evidence that it is under the influence of an altered set of feedback mechanisms. Therefore, it is very unlikely that predictions at the ecosystem level in one state could be inferred from observations of the properties of this system while in a previous state. Priority should therefore be given to understanding and predicting the limits to the stable equilibria we observe and the effects of the factors (natural as well as anthropogenic) that cause regime shifts and contribute to maintaining the system in altered state. We consider it likely that resource and ecosystem changes described above for BCLME result from a combination of factors, including both fishing and environmental variability. Many different, plausible hypotheses have been proposed to explain the mechanisms responsible for resource and/or ecosystem variability; these are not necessarily contradictory. Mechanisms can operate simultaneously but they can operate on different components of the ecosystem at the same different times and places, and in isolation or synergistically. What we currently lack is a consistent approach the simultaneously combines and "tests" all hypotheses; our five-step approach aims to do just that.

The importance of improving our understanding of the causes of variability in fish stocks and the need for further research into the factors that affect recruitment have been recognized, and the need to develop management advisory techniques that take account of dynamic recruitment fluctuations in a more effective way highlighted (Rothschild and Shannon, 2004). Those authors note that addressing the implications of regime shifts in fisheries management is directly relevant in the move towards an ecosystem approach to fisheries management.

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Chapter III Recent trends in Fishery and Abundance of pelagic species off Angola

Vaz Velho. F. and Barros. P. Recent trends in Fishery and Abundance of pelagic species off Angola off Angola. ***To be submitted***

Recent trends in fishery and abundance of pelagic species off Angola

ABSTRACT

The pelagic industry is the largest with respect to volumes landed and represent 80% of the total fish landed. These species are targeted by the purse seiner bottom trawl and artisanal fleet. sardinela is health state, but the decline trend observed in the last three years. Over the ten past years, the overall biomass of Cunene horse mackerel estimated by the research surveys has been declining markedly and actually the species is in a growth overfishing. The drastic management measures in place are not reflected in recovery of stock. The fishing pressure has been the reasons for increased total mortality of Cunene horse mackerel. For recovery the biomass of Cunene horse mackerel effort should be made to improve the mechanisms for control, monitoring and surveillance. In parallel an extensive research programme needs to be instituted to describe the controlling of natural mortality.

Keywords: Fisheries, pelagic, sardinela, Cunene horse mackerel, Cape fur seals, Angola.

Recent trends in fishery and abundance of pelagic species off Angola

Introduction

Angola has a coastline of 1650 km, and a continental shelf of 5100 square km and its average width is about 30 km. At present the fisheries sector is the third main economic sector in Angola following the oil and mining industries (diamonds), being the relative contribution of fishing to the GDP between 3 and 5%.

The oceanographic conditions in the Angola area are believed to be important in determining the distribution of the pelagic species. A main feature of the hydrographical conditions of Southern Angola is the upwelling process with a maximum in August-September (Pereira, 1991). These results in intensified primary production, and the existence of a thermal front with an average position at 15° S, however it moves seasonally to 14° S in the cold season and 16° S in the warm season.

The warm Angola current is strong in the warm (summer) season, characterized by more stratified water masses, and higher temperatures in the water column. Seasonal variations of the hydrographical conditions cause temporal and spatial variables of the distribution of pelagic species (Dias, 1983). In the Angola system, coastal fauna is characteristic of a sub-tropical zone, with a number of important pelagic resources, such as the Clupeidae (round sardinella, *Sardinella aurita* and flat sardinella, *S. maderensis*), the Carangidae (Cunene horse mackerel, *Trachurus trecae*, false scad, *Decapterus ronchus*, and the Atlantic bumper, *Chloroscombrus crysurus*) species.

On the contrary, the Benguela current is strong in the cold season (August-September) causing upwelling and colder surface waters. The large abundance of a few species characterizes the ichthyofauna of the pelagic zone in the southern region. The herring-like species, pilchard (S*ardinops sagax*), anchovy (*Engraulis encrasicolus*), Cunene horse mackerel (*T. trecae*) and Cape horse mackerel (*T. capensis*) are found mainly in the inshore waters and dominate the main pelagic resources.

Recent trends in fishery and abundance of pelagic species off Angola

The pelagic industry is the largest with respect to volumes landed making 80% of the total fish landed (Anon,2003) and industry includes the production of fishmeal, freezing, salted and dry fish and canning. The absence of a marketing infrastructure and a lack of investments have led to a serious decline in the fish processing industry (Anon, 2007). The production of the canned and fish meal has been decreased ie for the fishmeal decrease from 16 000 tones in 2000 to 6 000 tones in the recent years. The dry and salted fish products are used mainly in the informal national market. There are no reliable statistics on the number of employers involved in the small pelagic industry. There is estimation that salted and dry fish industry employs around 1654 land -based workers.

Many of the pelagic resources have been heavily exploited and it is believed that most of these declines are attributed to overfishing, although some fluctuations have probability been influenced to great or lesser extent by periodic environment perturbation (Fidel,2001) .

This overview gives a description of the major commercial pelagic resources, and of the attempt that have made, particularly in recent years, to manage them rationally and sustainably.

Source of data

The data analyzed in this publication come mostly from the databases of the Angolan National Directorate for Fisheries (Direcção Nacional das Pescas - DNP) and of the National Fisheries Research Institute (Instituto Nacional de Investigação Pesqueira – INIP). All companies holding an industrial fisheries license are required by law to submit monthly reports of total fishing effort (in fishing days) and total landings by commercial species of each vessel to DNP.

The database system was first implemented in 1995, but it is usually considered that only in 1998 was it fully operational. The data series used in this work cover the period from 1998 to 2009. The data available in the databases on commercial fisheries is in the process of reconciling the different sources of information, that used to be on different systems, and a thorough data quality control, to ensure full coverage and absence of duplication of information, cannot be carried out yet. However, the data used here is the best presently available, so final figures should not deviate significantly from those reported here.

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The databases of INIP hold mostly the information on the scientific surveys carried out in Angolan waters by research vessels, either Angolan or foreign vessels working under co-operation agreements with the Angolan government. These data usually report the catches per trawl haul per species, and often by sex. The data available include the years from 1984 to 2007, but only the data between 1994 and 2009 were used, since these come from a single vessel, and the surveys were carried out more regularly as part of a regular survey programme.

As a complement to the above-mentioned information, a data series on the landings of Benguela for sardinela and horse mackerel reported by ICSEAF between 1972 and 1984 for regions 1.1 and 1.2, extracted from the Reports of the International Commission for the South-East Atlantic Fisheries (ICSEAF) (Crawford *et al.*, 1987), was used.

Acoustic estimate for the pelagic species began in 1985, however only from 1994 the time series is more complete and to up to 1998, annually were carried out two surveys, in the summer (February- March) and the other in winter (July –August). From 1998 due to the availability of research vessel only the winter surveys were maintain. The decision to maintain the winter surveys was based on knowledge of the position of Benguela front, with associated more northward horse mackerel during the winter. The primary objective of the surveys has been to estimate an annual biomass index of sardinela and horse mackerel. Since 2002, the surveys have been similar during the time series. Transects have systematically been perpendicular to the coastline, with distance between transect line of 6 nautical miles.

Occurrence and stock identity

The major fisheries of small pelagic fish off Angola coast are those for sardinela, sardine and horse mackerel. Sardinela has a continuous distribution from Senegal to Angola, distributed from the shallow (10 m) inshore bays out to 200 meters (Luyeye, 2002). *S. maderensis* is a sedentary species inhabiting coastal, warm and often brackish waters, while *S. aurita* prefers upwelling areas and migrate to avoid unfavourable environmental conditions (Binet *et al.*, 2001). Historically, three stocks have been identified throughout the distribution area (Troadec and Garcia 1980), but it has been suggested that the population from South of Gabon to Angola is only one stock and the main spawning area is located in Mayumba (Congo- Brazaville) (Figure 1).

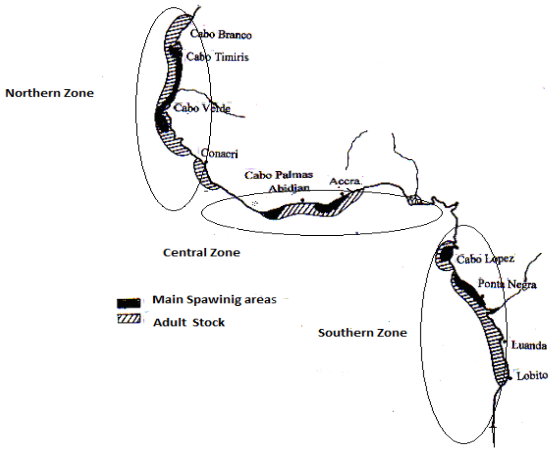

Figure 1. Sardinella spawning (Luyeye, 2002)

Two horse mackerel species *Trachurus trecae* and *Trachurus trachurus capensis* are found in Angolan waters; *T. treace* dominates the warmer Angola current, while *T. trachurus capensis* is associated with the cold Benguela current .The two species are mixed on fishing grounds in the Cunene – Benguela area. The occurrence and abundance of the Cape horse mackerel in Angola waters follow the seasonal displacement of the Angola- Benguela front and the latitude 15 ^{o}S is considered to be the northern boundary.

There is depth segregation between two species, Cunene horse mackerel dominating near shore, while most of the Cape horse mackerel is found more offshore (Duarte, 2001). Two main morphological features distinguish the two species. The Cunene horse mackerel its dorsal lateral line is shorter and the lateral line has shorter scuttles than Cape horse mackerel.

There are few investigations on population structure of Angola Cunene Horse mackerel. Sardinha and Naevdal (2002) based on protein electrophoresis study postulated that Cunene horse mackerel off Angola may be structured into two population, one in northern tropical waters (Cabinda to Luanda) and the other in southern from 14 ^{o} S and the low temperature and higher salinity in this areas could act as a barrier to gene follow between two population (Figure 2).

In Angola Cunene horse mackerel population are managed as one stock and given the importance of these biological for sustainable management of this resource and to confirm these results, under the Scientific Programme of Benguela Scientific Commission (BCC) is proposed a *project using a DNA mitochondrial*. If the results of Sardinha and Nævdal (2002) are confirmed, in the future it will be possible to manage the Cunene horse mackerel based into two management units.

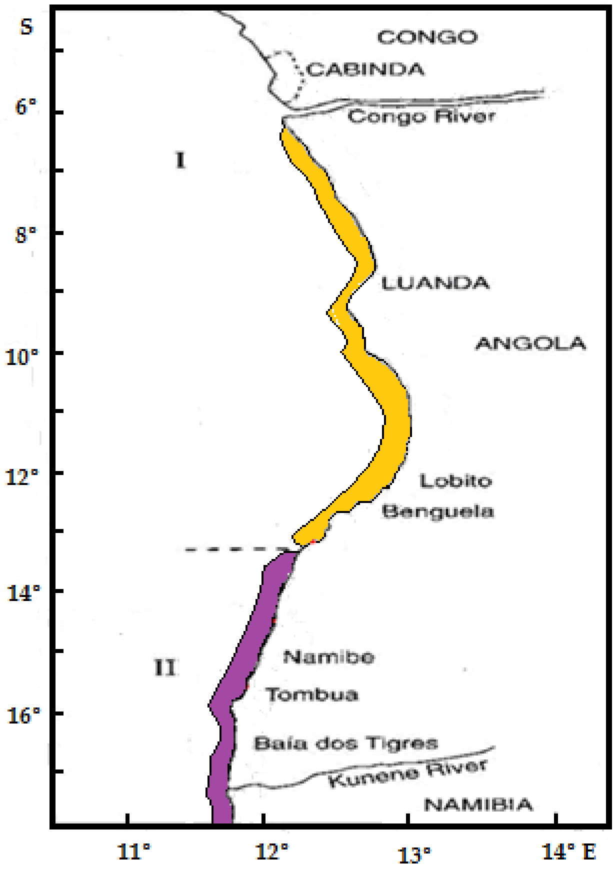

Figure 2. hypothesis of two different population of Cunene horse mackerel off Angola

There are studies in the South- East Atlantic that attempt to differentiate Cape horse mackerel stocks (Komorov 1971 ; Naish, 1990) and it is believed that at least there are three stocks of Cape horse mackerel (Hetch, 1990), but northern off Namibia and south Angola belong to the same stock (Naish, 1990).

Although a basic understanding of migration is essential to ensure adequate coverage and adequate survey design (MacLennen and Simmonds, 2002) migration pattern of Cunene horse mackerel is not well understood because due to financial constrains never has been conducted a horse mackerel eggs and larvae survey throughout the Angola coast.

It is known that 95% of population of Cunene horse mackerel in the sourthern region is composed by juvenile (fish length < 20cm) (Figure 3). According to the discussion on genetic structure of Cunene horse mackerel population this could be a different stock from the center and northern areas, which invalids the concept the southern region is the main growth area for Cunene horse mackerel.

In the northern and central areas the survey observation seems to indicate that juvenile areas are relatively close to the adult, because in the species composition of some of the trawls made at depth less than 40m s is recorded juveniles and adult fish. However, this observation needs to be taken with certain caution because it is believed that juvenile fish occurs inshore at depths less than 20m , which not cover by R/ V ´´ Dr Fridtjof Nansen´´.

Current Status of Fishery

Commercial fishing for small pelagic fish started during the early 1950s, with the main objective to develop the fishmeal industry. Until 1975 the small pelagic fishery was based on small wooden and well-equipped purse seiners with length of 20-25 m with 100-200 HP engines. In 1977, the former soviet purse seine fleet, consisting mostly of vessels with tonnage ´´classes of 5´´ (100-149.9 GRT) and ´´class 6´´ (150-249.9 GRT) as well as trawlers of ´´class 10´´ (2000 – 3999.9 GRT), started intensively exploiting the stock.

Despite, pelagic catch is considered underreporting, , since landings from purse seiners are not full covered , as well as the artisanal catches from less accessible areas, are not reported, from the evolution of the catch it is possible to observe four clear patterns that reflect different periods of the Angola pelagic fisheries (Figure 3). The pelagic catch before the independence (1975), was dominated by horse mackerel, reaching around 500 000 tones in 1974. After independence there was dropped in the catch, but with permission of Sovietic Union fishing vessels into the fisheries a substantial increase on the catch of sardinella was observed, mainly to feed the fish meal industry. In that period the catch of the two species were at some level, around 300 000 tones. From 1990 the bilateral agreement between Angola and the former

Sovietic Union terminate and was followed by a substantial dropped in the catch in the following three years. From 1993 to 2004 most of the Russels mid waters trawls still in the fisheries under a joint venture enterprises and new period of increasing the catch was observed. From 2004, Chinese purse seiners fishing vessels entry to the pelagic fishery leading to overfishing.

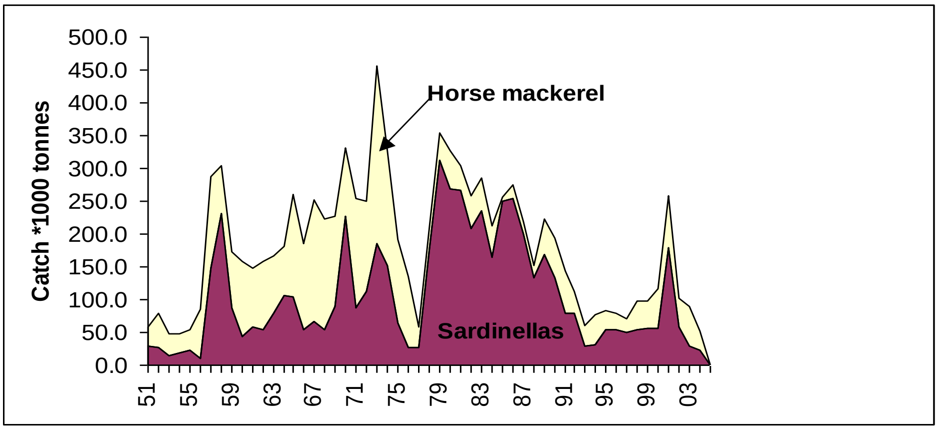

Figure 3**.** Reported catches for the main commercial pelagic resources

Changes in the Biomass of resources

The biomass of sardinela declined sharply during the Benguela Ninõ recorded 1995 (Gammelrød *et al*., 1998) followed by an increase in the next two years, where the biomass was estimated in 700000 tones (Figure 4). Actually the biomass is at level of 400 000 tones with decrease trend in the last two years. Until 2008 the bulk of sardinela biomass of was dominated by S. *maderensis* but in the survey carried out in 2010 was observed that both species of *Sardinella* contributed almost equally to the total biomass. By regions, *S. aurita* dominated in the south while *S. maderensis* both in the center and north regions. The observed relative increase has been facilitated by the cold-water occurrence inshore (Anon, 2010). The use of sardinela biomass estimation

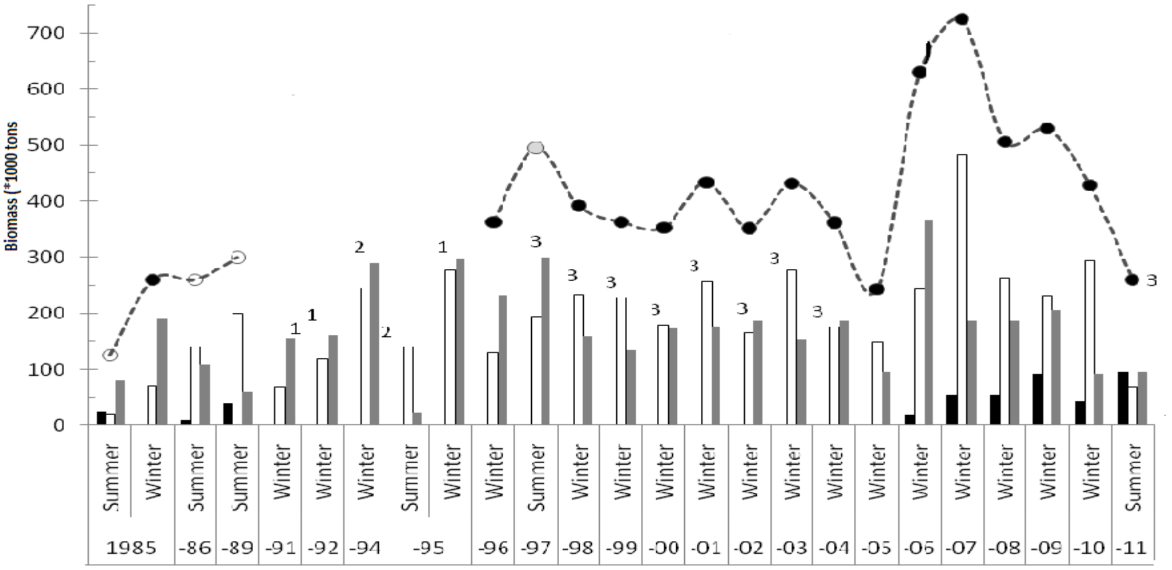

Figure 4 Biomass estimates of *Sardinella spp*. by regions and surveys (1 000 tons). 1: Data error (Southern region); 2: Southern region not surveyed; 3: Cabinda not surveyed.

The analysis of times series of biomass of the Cunene horse mackerel in Angola has shown that there are two distinct periods (Figure 4), from 1994 to 2000, when the biomass fluctuated around a level of about 300 000 t, with highest recorded in 1997, at around 400 000 t . From 2000 to the present the biomass level the Cunene horse has been twice as lower than the previous period and composed mainly by small fish (Lt < 21cm) indicating high fishing pressure on the adult stock (Figure 5). Although, the time series shows a decrease in the biomass in the last three years there are signs of good recruitment, which leads to the conclusion that the decline in the abundance of Cunene horse mackerel is associated with higher fishing pressure .

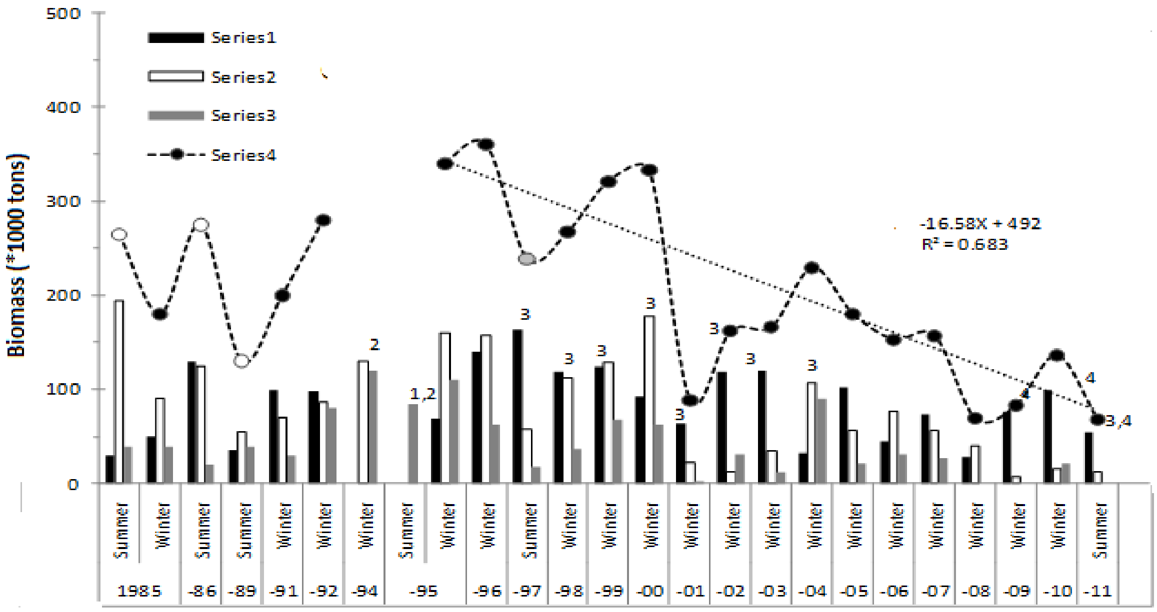

Figure 4 Biomass estimates of Cunene horse mackerel by regions and surveys (1 000 tons). 1 Data error (Central and Northern Regions); 2: Southern region not surveyed; 3:Cabinda not surveyed; 4: Fish density too low to estimate abundance (Northern Region).

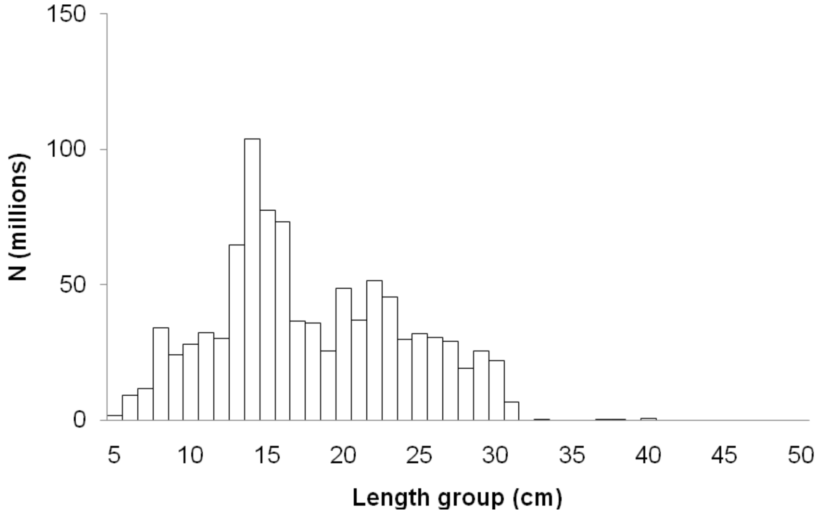

Figure 5. Overall total length distribution of the Cunene horse mackerel, *Trachurus trecae*

Recent trends in fishery and abundance of pelagic species off Angola

Other biological references also clearly indicate that the Cunene horse mackerel is under considerable pressure. The size at the first for this stock has been declining in the recent years, from 23 cm in 2006 to 14cm in 2010 .

The state of resource is reflected in the spatial distribution, in the northern (Congo river to Luanda) and the Central (Luanda- Benguela), the stock are found in very small patch areas.

The abundance of Cape horse mackerel should not be evaluated without considering the seasonal fluctuations of the Angola-Benguela front (ABF) position and the upwelling intensity in southern region who explains the fluctuation of the level of biomass. The northern position of the ABF in general facilitates the northward migration of Cape horse mackerel from Namibia into Angola.

Management Strategy

Most management in Angola pelagic fishery has relied on output control and only in recent years some forms of input control were introduced to manage the stocks. Output controls are limitations on the amount of fish permitted usually imposed as some form of quota either on total catchfor the fishery (e.g. total allowable catch, TAC). Controls on input are restrictions on the fishing effort, such as limits on vessel sizes, vessel numbers, or gear characteristics. Closures are considered input controls because they reduce total fishing effort or mortality by restricting access to a portion of the stock (Ward *et al*., 2001).

The Angola Fish Sector has adopted a number of objectives for pelagic fishery to be achieved over next five years. These objectives include the recover horse mackerel stock and to improve understanding of dynamics of pelagic resources by improving estimates of abundance and factors and mechanisms that controls the spatial and temporal distribution of the stocks.

Recent trends in fishery and abundance of pelagic species off Angola

The assessment of main pelagic species is carried by the INIP and various surplus production models were used. Application of such models requires a reasonably long time series of the total catch from the stock and an index of abundance of the stock during this time period. (Punt and Hilborn, 1996). For Angola pelagic resource, however, there is very little reliable data on effort in the fishery, so it is not possible to use the catch per unit effort (CPUE) as an index of abundance. It has therefore been decided to use the biomass estimates from surveys as biomass indices. The results of recent assessment show that the sardinella is currently not fully exploited and there is a room to increase the catch. This allowed in the last three years to increase the sardinella TAC to be increase to 250 000 tones. Horse mackerel is in a growth over fishing state with a very low level of Biomass (229 000 t). However, it is considered that horse mackerel fishery is complex to be managed, because of behaviour of the species that and be fished by purse seines, mid trawlers and large component as by catch on the demersal fishery.

Pelagic fisheries are managed according to TAC´s by species group and effort limitation. From 2001 the stock start to show strong signs of growth overfishing, but only in 2004, management measures were being taken to favour recovery of the overexploited horse mackerel (Anon, 2004). These include banning the mid water trawl fishing along the coast, any type of trawling in the southern region (13º to 17 ºS), reduce the TAC from 80 000 to 40 000 tones and established a two months close season for the purse seiners. Despite the introduction of these management measures, there has been not observed signs of recovery of Cunene horse mackerel, and the stock is currently believed to be at a critically low level. In 2010 drastic management measures were being taken, that included no allocation of TAC for horse mackerel and established a 10% of by- catch limit on the demersal fisheries. In addition, was recommended to develop a rebuilding plan for horse mackerel fishery.

Recent trends in fishery and abundance of pelagic species off Angola

The National Services of Surveillance (Serviços Nacionais de Fiscalização) is responsible for enforcing the Aquatic Fisheries Resources Act and other regulation and legislation and for manage Angola pelagic fisheries in a sustainable manner, are essential to improve the monitor and enforcement systems.

Ecological Interaction

It is known that small pelagic stocks are an important source of food for a number of species and its abundance can have impact on seabirds (penguins, cape gannets etc.) and seals that feed either directly on the pelagic fish or the associated prey fish species. Curry *et al*., (2000), pointed out that in Benguela Current region almost 55% of small pelagic species are eaten y top predators. For the Angolan pelagic the knowledge on the interaction between sea birds and seals is yet very limited, however, the fisherman complains that seals consumed large quantities of small pelagic species.

Currently in Angola the main trophic interaction of concern is the increase of population of Cape Fur seals (*Arctocephalus pusillus*) in the southern region (between 13^o S and 17 ^{o}15°' S). The first aerial census of Cape Fur seals numbers in Angola was conducted in December 2006 under the *Top Predator as Biological Indicator of Ecosystem change BCLME project*. In total 4378 pups were counted, confirming the status of Baía dos Tigres as seal breeding location (Meÿer ,2007). A further 17062 sub adult and adult seals were counted. The latter represents an underestimated of the number of these age classes in the region, since an unknown number of them would have at sea. The pup count is also underestimated of the pup number born since an unknown number have succumbed to mortality before the count.

The recent establishment of the breeding colony in the Baia dos Tigres and others in the north of Namibia are evidence that there has been a northward shift in the distribution of the Cape Fur seals in the northern Benguela (Meÿer ,2007).

Recent trends in fishery and abundance of pelagic species off Angola

Despite under the some project a field-work was carried out to collect samples of Cape Fur seals and otolihs of juvenile horse mackerel were present in the scats there has been yet not attempt to investigate potential linkage between the Cape Fur seals population and relative abundance of horse mackerel in the Baía dos Tigres. However studies carried out in South Africa that Cape Fur seals feeds on wide range of species and apparently concentrating on those that are locally abundant (Shaughnessy, 1985). Considering the observation of the survey the juvenile horse mackerel is dominant species in the Baia dos Tigres is, definitely the presence of seals in the area has impact on the abundance of horse mackerel.

Concluding remarks

The main pelagic resources of Angola are in different biological state. sardinela is health state, but the decline trend observed in the last three years should interpreted as signal that is required to follow the landings of these stocks carefully, and next years it is not advisable to increase the Total Allowable Catch.

The estimated of biomass show marked reduction in Cunene horse mackerel abundance. The combination of excessive and probably recruitment failure seems to have been the reason for present critical level of the stock and at present, harvesting level are set to enable to return to the biomass levels that will provide maximum sustainable yield. However, drastic management measures are in place the end of decade, the stock had no shown no sign of real recovery (Anon, 2010b), so it can be concluded that other processes have prevented the recovery the stock and they need to be understood .through the improvement of the research and management programmes.

The increase of Cape Fur seals population in last decade has been considered also one of reason for failure of the Cunene horse mackerel population to recover. The reduction on the available prey increases the predation pressure on the remaining individuals (Wootson, 1990). In the northern of Benguela current, Fossen *et al*., (2001) has been suggested that the increase in growth rate of predator could be explanation of increase rate of mortality of sardine and the increase of natural mortality indicates that sardine is heavily controlled by predation, subject to top-down regulation.

For Angola pelagic resources there are no any indication of natural mortality, and it is believed that changes in biological parameters have been drive by reduction of Cunene horse mackerel abundance caused by increase in total mortality. The fishing pressure has been at least the reasons for increased total mortality, in particular in last decade with entry the Chinese fleet to the fishery without any mechanism to control fishing activity, such us Satellite Vessel Monitoring system (VMS) and onboard observer officer.

Under fishery Sector programme for next five years one of the main objective is to rebuild Cunene horse mackerel to reach the level of biomass estimated in 2006 (500 000 tones). However to achieve this level a lot effort should be made to improve the mechanisms for control, monitoring and surveillance. In parallel an extensive research programme needs to be instituted to describe the controlling of natural mortality. The interdependency predators with the pelagic resource and intra specific interactions makes to be manage on an ecosystem basis.

Acknowledgements

This paper is the result of effort made by scientists of INIP and collaborating scientists along the years in collecting catch data from different sources, and participating in the annually series of pelagic survey carried out along the Angolan coast. Thanks are thus due to all members of pelagic and Statistic Section of INIP and to the Nansen Programme and all scientist who have participated in the surveys in Angola. Special thanks to Neville Sweidj and Kervern Cochrane to have encouraged this work

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Chapter IVIdentification of Acoustic Targets off Angola using General Discriminant Analysis.

Vaz Velho. F, Axelsen, B. E., Barros, P, and Bauleth d'Almeida. G. 2006. African

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Indemtification of acoustic targets off Angola using General Discriminat Anaylsis

Abstract

Pelagic fish species off Angola constitute about 80 % of the total fish landed and some 75% of animal protein in diet of coastal population. The primary means of estimating stock abundance is through acoustic surveys, a method that is sensitive to identification of echo traces. This paper describes commonly encountered pelagic aggregations in terms of acoustic proprieties and morphological and spatio-temporal descriptors. A knowledge base of reference observations validated by an experienced team of regional operators was used in stepwise General Discriminant Analysis (GDA) that sought to identify traits characteristic to common species groups. A range of descriptors provide significant discriminant power ($p<0.01$) and these were used to construct a classification algorithm. The resulting overall classification success emanating from the GDA was 46% when only considering the greatest posterior of group membership. This success rate increased to 62% to 71% respectively when including the second and third highest group membership probabilities. For Cape horse mackerel *Trachurus capensis* and *Sardinella*,spp., success rates of 80 % and 75 % were obtained when including classifications that fall into groups with probabilities ranging from greatest to third greatest respectively.

Key words: Hydroacoustics, pelagic, discriminant analysis, species identification.

Indemtification of acoustic targets off Angola using General Discriminat Anaylsis

Introduction

Angolan waters are rich in small pelagic fish, which are distributed along the entire coast and make up 80% of the total fish landed (FAO, 1997) and constitute some 75% of animal protein in the diet of the coastal population (Anon,2003). The main species found are round sardinella *Sardinella aurita*, flat sardinella *Sardinella maderensis*), Cunene Horse mackerel *Trachurus trecae,* Cape horse mackerel *Trachurus trachurus capensis* and South-African sardine *Sardinops sagax*. Other pelagic species commonly found include Atlantic bumper *Choloroscombrus chrysurus*, African moonfish *Selene dorsalis* and Bigeye grunt *Decapterus rhoncus*.

Acoustic surveying using the echo integration method is the principal tool for estimating the stock abundance of pelagic species and the survey estimates therefore form the basis for the recommendation of the levels of total allowable catch (TAC). The acoustic method relies on identification of echo traces and is sensitive to identification errors (Reid, 2000). The standard method involves partitioning the echo integrals according to the scattering characteristics of the targets and the species composition obtained from biological samples, usually obtained using sample trawls (e.g. MacLennan and Simmonds, 1992).

The underlying assumption of the method is that the targets measured acoustically are represented in the trawl catches, and such ground truthing is therefore sensitive to trawl sampling errors caused by e.g. size- and species specific avoidance behaviour (O'Driscoll, 2003). Other complicating factors include the degree of mixing and variations in the aggregation patterns of the target species and associated zooplankton communities, in contrast to single-species systems where fish are typically aggregated in large, separate schools (Rose and Leggett, 1988). The experience of the researchers is another important factor, and change of personnel over time represents an additional a source of error (Korsbrekke and Misund, 1993).

The Benguela region research community has recognized the need to develop techniques for identification of acoustic targets. Fish species recognition techniques based on discriminant function analyses of hydroacoustic data have earlier been reported by Lu and Lee (1995) Haralabous and Georgakarakos (1996), Horne(200) and Lawson *et al* (2001), who extracted species-specific information from single-frequency acoustic data. They described the school and aggregations structure of fish species such as , cod *Gadus morhua*, capelin *Mallotus villosus*, sardine, anchovy *Engraulis* spp., and round herring *Etrumeus* spp. in such a way that species groups could be detected automatically.

Other recent approaches include broadband (Rose and Legget, 1988) and multifrequency (Korneliussen and Ona, 2002) pattern recognition techniques. These techniques are based on utilizing the differences in target strength of scattering organisms at different frequencies to classify groups of scatterers, and have shown significant potential. However, both techniques add considerably to the technical requirements for the acoustic systems on the survey vessels, and few such vessels in southern Africa are currently have the technology.. In the Benguela region, investigations using simple discriminate analyses have shown potential to identify schools of anchovy *Engraulis encrasicolus*, sardine and round herring in >75% of cases (Coetzee, 2000 and Lawson *et al*., 2001).

The main objective of this study was to examine the acoustic characteristics of several known species and species groups over the Angolan continental shelf utilizing 38 kHz acoustic survey data, and to make use of species–specific traits in school or aggregation features to formulate prediction algorithms that can assist survey practitioners in allocation process at sea in order to reduce classification errors.

Material and Methods

The RV *Dr. Fridjof Nansen* has conducted routine (usually annual) acoustic surveys of pelagic fish species over the Angolan continental shelf since 1985. The present study examines data from surveys carried out in the period from 1997 to 2000 (Table 1) between the mouths of the Congo (6°00’ S) and the Cunene (17º15`S) rivers with transect lines perpendicular to the coast, spaced six nautical mile (nmi) apart, and extending offshore from 20 to 500 m bottom depth (Figure 1) (Axelsen *et al*. 2000). Biological sampling of acoustic targets was conducted using small pelagic (10-12 m vertical mouth opening) and demersal (~5 m) sampling trawls. Acoustic data were collected using a Simrad EK 500 echosounder running a keel-mounted 38 kHz transducer with 7.0º nominal alongship and athwartship beam angles. The echosounder was operated with a transmission power of 2000 W, a transmission rate of ~1.0 ping s^{-1}, a pulse duration of 1 ms, and a beamwidth of 3.8 kHz frequency band. Standard calibrations were performed during each survey using the standard sphere method (Foote *et al*., 1987). Acoustic data were logged and post-processed using the Bergen Echo Integrator system (BEI) (Knudsen, 1990).

Table 1. Acoustic surveys from which the data were extracted.

Year	Period	Season
1997	March- April	Warm
1998	March- April	Warm
1998	July- August	Cold
1999	July- August	Cold
2000	August- September	Cold

Selection of data subsets and computation of descriptors

Indemtification of acoustic targets off Angola using General Discriminat Anaylsis

The analysis required selection a set of acoustic reference records with known species compositions. In all, 18 different species group were defined according to common groups detected during the surveys (Table 2). From the Nan-SIS trawl database single species or mixed- species (two species) samples were identified. For single-species catches, only stations where the target species constituted ≥ 80% of the total catch (by weight) were considered. For mixed catches, each species had to constitute ≥ 20% each, and the sum of the two had to represent ≥ 80% of the total.

Table 2. Acoustic groups defined according to the corresponding species compositions of the trawl catches. Single species groups were defined as having a catch weight of the target species ≥ 80%, while for mixed-species groups, each species constituted at least ≥ 20% and together constituted ≥ 80% by weight of the total catch.

Species group	**Species composition**	**Number of observations**
	Single-species groups	
Cunene horse mackerel		16
Cape horse mackerel		5
Sardinella		36
Round herring		2
Demersal	Sparidae, Scianidae	33
Pelagic 2	Hairtail *Trichiurus lepturus*, False scad *Decaptereus rhonchus* , African moonfish	8
Lantern fish		18
Bigeye grunt		4
	Mixed-species groups	
Cunene horse mackerel/ bigeye grunt		5
Cunene horse mackerel /demersal		23
Cunene horse mackerel /lantern fish		10
Cunene horse mackerel/sardinella		4
Sardinella /pelagic1		9
Demersal fish /pelagic2		3
Sardinella/ pelagic2		21
Lantern fish /pelagic2		9
Pelagic 1/pelagic 2		4
Bigeye grunt/pelagic 2		3

An additional requirement for both groups was that the overall catch rate should exceed 10 kg/h^{-1}. The echogram sections corresponding to the position and depth of the reference trawl samples were scrutinized using Sonar Data Echoview© Software Version 2.20. As trawl operation tend to disturb fish aggregations of interest (Olsen *et al*, 1983, Vabø et. 2002), only observations made prior to trawling where it was ascertained with high probability that the acoustic data corresponded to the volumes trawled were considered for analysis.. A total of 213 acoustic reference observations were analysed.

In all, 11 descriptors were extracted from each echogram reference region (Table 3). These descriptors were categorized as acoustic, morphological or spatio-temporal. Acoustic descriptors included common acoustic variables such as mean backscattering strength S_v (dB) and area backscattering coefficient S_A(m^2nm^{-2}) (see MacLennan *et al*. 2002 for definitions), and morphological parameters described the spatial structure and shape of aggregations. Ancillary spatio-temporal variables include latitude, time of day (coded as day/night) and season. These acoustic references were exported using a minimum S_v threshold of –70 dB. The acoustic variables and bottom depth were log-transformed in order to attempt to normalize their distribution. No transformation was required for the other variables because their distributions tended towards normal.

Table 3: definitions of descriptors in General Discriminant Analysis

Descriptors	Name	Description	Units	Reference
		Acoustic		
S_v mean	S_v	Mean acoustic volume density	dB re $1m^{-1}$	
S_A		Area Backscattering coefficient	m^2nm^{-2}	
S_v standard deviation	LSD			
S_v Skweness	LSS			Zar (1984) equations 7.7 and 7.8
S_v of kurtosis	LKS			Zar (1984) equations 7.13 and 7.15
		Morphological		
Height	RH	Mean height of region	m	
Length	RL	Mean depth of cell region	m	
Vertical Roughness	LVR	Average change in S_v across the vertical dimension of the region	dB re $1m^2m^{-3}$ Horne (2000)	
Horizontal Roughness	LHR	Average change in S_v across the horizontal dimension of the region	dB re $1m^2m^{-3}$ Horne (2000)	
Roughness ratio	LHVR	Horizontal/ vertical roughness		
Global Roughness	GR	Geometric mean of horizontal and vertical roughness		
		Spatio-temporal		
Latitude			° S	
Bottom depth	BD		m	
Relative depth	RD	Region depth/ Bottom depth		
Distance from bottom	DB	Bottom depth - Region depth	m	
Season			Warm/ cold	
Period of the day			Day/ nigth	

Statistical analysis

The analysis aimed at obtaining reliable classification of the acoustic observations with a limited number of descriptors. The General Discriminant Analysis (GDA) method (Hill and Lewicki, 2006) was used for this purpose.

The first step of the analysis was to select of descriptors so that the best possible discrimination was achieved between groups. This was done in two steps. First, a correlation analysis was performed among all the descriptors considered. For variables that measured roughly the same quantities (e.g. S_v and s_A are highly correlate) only one of the variables was retained whenever the correlation coefficient between a pair of variables was :> 0.6,. The variable that was simpler to compute, or more commonly used in standard acoustic surveying was retained, and the other was discarded. If two variables measured different characteristics of the data (e.g. echo intensity and echo variability), they were kept for the next phase of the analysis, even if they were correlated. The variables that passed this first screening were used in a forward stepwise (GDA) in order to determine the subset of variables that best discriminated between species or species groups. The significance level for entry and removal of variables was set at $p< 0.05$, using Wilks' *Lambda* test (Manly, 1994). This will not reflect the true p-level of the models being analysed (Hill and Lewicki, 2006), but will be approximate enough to provide a guidance on what predictors to include. Only main effects (no interactions) were used in the model.

Once the set of predictors was selected, a preliminary assessment of the actual separation of the species groups by the fitted model was carried out. First, the mean and the standard deviation of each of the continuous predictors in each group were calculated. Second, the probability of a significant non-zero Mahalanobis distance (Huberty, 1994) was calculated for each pair of groups.

For the prediction of group membership of each observation, the GDA was run with uniform priors, i.e. all groups were given equal "*a priori*" probabilities, irrespective of their frequency in the training set. In this way, only the descriptors entered into the algorithm are considered when calculating the probabilities of group membership not the number of observations in each group.

To assign observations to groups, the maximum probability rule (Huberty, 1994) is usually used. This implies that an observation is assigned to the group to which it has the greatest probability of belonging. However, several authors (e.g. Huberty, 1994) recommend that the actual posterior membership probability vectors should be inspected, to assess the level of confidence in the classification obtained. In this work, we elaborated on this approach. For each observation classified, the algorithm predicted the probability of membership to each group. The groups were ranked in order of decreasing probability of membership, and the rank of the "right" group was calculated. If this rank was 1, 2 or 3 (meaning that the observations was assigned to the "right" group within the three greatest posterior probabilities).This classification was considered as "correct" by the first, second or third choice respectively of the algorithm. No minimum threshold probability level was applied.

A leave-one-out Jacknife cross-validation procedure (Huberty, 1994) was used to obtain an estimate of the classification success. The process of estimating the parameters of the classification rule was run as many times as there were observations. In each run, one observation was removed from the training set, and a classification rule was estimated from the remaining observations. The estimated rule was then applied to the observation withheld, and the success of this classification was recorded, following the procedure described above. A total of 213 runs were completed. The success of the classification procedure was calculated as the percentage of classifications that included the correct group in the first, second or third choices of the algorithm.

Results

Evaluation of descriptors

Correlations were observed between variables within each descriptor group (Table 4). Mean volume backscattering strength (S_v) was correlated with area Backscattering coefficient s_A (r= 0.89) and Sv Standard deviation (S_v SD, r = 0.87) as well as with Sv Skewness (S_v SS, r S_v r= -0.54) and Sv Kurtosis (S_v KS, r = - 0.58).

Table 4. Correlation matrix of the selected acoustical, morphological and spatio-temporal descriptors

Descriptor group	Parameters				
Acoustic	SA	SvSD	SvSS	SvKS	
Sv	0.89	0.87	-0.54	-0.58	
SA		0.76	-0.40	0.42	
Sv ,SD			-0.16	-0.23	
Sv, SS				0.71	
Morphological	VR	HVR	GR	RL	RH
HR	0.81	0.58	0.96	-0.91	-0.09
VR		-0.02	0.94	-0.04	0.04
HVR			0.32	-0.28	-0.21
GR				-0.13	-0.04
RL					0.48
Spatio-temporal	BD	RD	DB		
LAT	-0.04	-0.02	0.01		
BD		-0.5	0.96		
RD			-0.67		

As S_v and s_A are both related to the overall echo intensity, whereas SvSD, S_v SS and S_v KS are measures of different aspects of the distribution of this energy only s_A was omitted from the stepwise GDA. Among the morphological descriptors, horizontal and vertical roughness were also positively correlated with each other (r= 0.81) and with Global Roughness (r=0.96 and r=0.94, respectively). The height and length of the regions were not well correlated with each other (r = 0.48) nor with most other morphological descriptors except for the strong correlation between length and horizontal roughness.

The morphological descriptors finally selected for the GDA were the ratio between horizontal and vertical roughness (HVR) and region length (RL) and height, (RH). The three spatio-temporal variables, latitude, bottom depth (BD) and relative depth (RD), were not well correlated ($r \leq -0.50$) and were included in the second step of the analysis.

The stepwise GDA indicated that the variables S_v, S_vSD, Lat, RD, HVR and the three categorical descriptors contribute significantly to the discriminant power ($p < 0.01$), so these were selected for the model.

Table 5. Means and Standard deviations (in parentheses) of the continuous descriptors (see table 3 for definition) used in the GDA for each species group considered.

Species group	Sv	LAT	BD	Sv SD	HVR	RD
Cunene horse mackerel	-56.83	-13.94	1.83	-4.88	0.9	0.49
	(4.903)	(3.141)	(0.387)	(0.59)	(0.55)	(0.304)
Cunene horse mackerel / Bigeye grunt	-56.2	-9.2	1.6	-4.59	0.95	0.51
	(3.62)	(1.313)	(0.111)	(0.296)	(0.048)	(0.252)
Cunene horse mackerel/ Demersal	-57.42	-10.86	1.95	-4.8	1.19	0.87
	(4.332)	(3.111)	(0.222)	(0.446)	(0.638)	(0.151)
Cunene horse mackerel/ Lantern fish	-60.16	-12.99	2.51	-5.61	0.29	0.07
	(4.257)	(1.798)	(0.288)	(0.5)	(0.181)	(0.029)
Cunene horse mackerel/ Sardinella	-57.42	-13.98	1.61	-4.74	1.1	0.51
	(3.301)	(2.687)	(0.202)	(0.303)	(0.737)	(0.183)
Cape horse mackerel	-57.69	-16.97	2.08	-4.81	0.42	0.66
	(2.72)	(0.135)	(0.095)	(0.35)	(0.52)	(0.322)
Bigeye grunt	-56.33	-9.22	1.64	-4.78	0.84	0.81
	(3.58)	(1.622)	(0.08)	(0.355)	(0.238)	(0.193)
Bigeye grunt/Pelagic 2	-54.67	-7.25	1.83	-4.58	0.42	0.2
	(3.392)	(0.757)	(0.179)	(0.354)	(0.281)	(0.053)
Sardinella	-48.24	-10.66	1.64	-4.21	0.91	0.59
	(5.738)	(2.013)	(0.119)	(0.423)	(0.209)	(0.203)
Sardinella/ Pelagic1	-51.97	-10.04	1.76	-4.49	1.28	0.56
	(7.412)	(0.624)	(0.149)	(0.666)	(0.305)	(0.155)
Sardinella/ Pelagic 2	-52.4	-10.32	1.77	-4.38	0.63	0.37
	(7.459)	(2.064)	(0.309)	(0.74)	(0.481)	(0.229)
Lantern fish	-57.14	-12.15	2.39	-5.22	0.22	0.13
	(3.668)	(2.155)	(0.248)	(0.659)	(0.22)	(0.089)
Lantern fish/ Pelagic 2	-54.52	-9.12	2.25	-4.86	0.33	0.32
	(3.772)	(1.544)	(0.219)	(0.461)	(0.308)	(0.329)
Demersal	-56.18	-15.07	1.89	-4.77	1.11	0.81
	(5.703)	(1.9)	(0.181)	(0.51)	(0.385)	(0.192)
Demersal/ Pelagic 2	-56.36	-9.27	1.64	-4.68	0.31	0.67
	(4.947)	(2.686)	(0.318)	(0.407)	(0.187)	(0.302)
Pelagic 2	-56.37	-8.32	1.96	-4.86	0.44	0.28
	(2.858)	(1.341)	(0.363)	(0.701)	(0.31)	(0.196)
Pelagic1/ Pelagic 2	-55.12	-6.84	2.2	-5	-0.16	0.19
	(0.629)	(0.673)	(0.504)	(0.402)	(0.708)	(0.221)
Round herring	-53.42	-17.13	1.64	-4.33	1.73	0.72
	(0.617)	(0.049)	(0.102)	(0.06)	(0.037)	(0.055)

Species Separation

After running the GDA, seven significant roots (classification functions) were extracted. The means of these roots for each of the species groups investigated are presented in table 6. The first root separates clearly the group sardinella/pelagic 1 from all other groups. And the second group separate mostly the groups including demersal fish from those involving lanterfish and pelagic 1/pelagic 2.

Table 6. Means of the species groups considered in the first seven roots (canonical functions) of the GDA

	Roots						
Species group	1	2	3	4	5	6	7
Cunene horse mackerel	0.8	0.45	0.84	-0.40	1.02	-0.23	0.00
Cunene horse mackerel / Bigeye grunt	-0.27	0.20	-2.00	-0.66	1.21	-1.18	-1.30
Cunene horse mackerel/ Demersal	0.70	-2.51	-0.06	2.02	-0.02	-0.18	-0.31
Cunene horse mackerel/ Lantern fish	1.29	2.26	2.31	0.45	-1.02	0.03	-0.43
Cunene horse mackerel/ Sardinella	-0.02	0.35	0.41	-1.89	2.22	-0.44	-1.25
Cape horse mackerel	0.49	-0.26	3.23	-0.89	0.89	-0.32	1.40
Bigeye grunt	0.17	-0.94	-1.80	2.02	1.13	-0.88	1.60
Bigeye grunt/Pelagic 2	0.41	2.12	-1.80	0.87	1.11	0.27	-0.16
Sardinella	0.39	-0.40	-2.02	-0.92	-0.98	0.11	0.10
Sardinella/ Pelagic1	-14.12	0.17	0.54	0.14	-0.20	0.02	-0.01
Sardinella/ Pelagic 2	0.49	0.92	-1.23	-0.52	0.44	-0.25	0.13
Lantern fish	1.10	2.23	1.52	0.36	-0.66	0.02	-0.03
Lantern fish/ Pelagic 2	0.78	1.41	-0.13	1.32	-0.55	-0.07	0.06
Demersal	0.75	-1.77	1.49	-0.79	-0.11	0.45	-0.01
Demersal/ Pelagic 2	-0.24	0.52	-1.49	0.15	3.15	3.13	0.19
Pelagic 2	0.51	1.61	-0.98	1.00	0.57	-0.17	0.35
Pelagic1/ Pelagic 2	0.42	2.72	-1.01	1.48	0.16	1.06	-0.10
Round herring	0.19	-0.94	2.06	-1.85	0.38	-3.07	0.54

The probabilities of significant Mahalanobis distances between the centroids of the different species groups (Table 7) show that some species groups overlap, particularly species mixtures involving lantern fish, pelagic 1 (*Illisha africana* and *Engraulis encrasicolus*) and pelagic 2, yielding relatively low discriminatory power. Still, it was decided to keep those groups, since pooling them into one single group would increase the within-group variance, and thus reduce the discriminating power of the algorithm for the remaining groups of interest.

Table 7: significance of Mahalanobis distance between centroids of the acoustic groups (see table 2 for definition). Blanks cells indicate distance significantly different from zero at p< 0.1%, whereas bold values indicate significance at 1% level. Ns indicates a distance between centroids of the corresponding pair of groups that is not significant. Values are percentages. The p-value are approximations

		Species group																	
Species group		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cunene horse mackerel	1					NS			NS										NS
Cunene horse mackerel / Bigeye grunt	2					NS			NS			NS					**0.3**		
Cunene horse mackerel/ Demersal	3						**0.2**												
Cunene horse mackerel/ Lantern fish	4						**0.1**						NS	**0.1**					
Cunene horse mackerel/ Sardinella	5	NS	NS						**0.4**			**0.2**				**0.3**			NS
Cape horse mackerel	6		**0.2**	**0.1**															NS
Bigeye grunt	7	NS	NS			**0.4**			NS								NS		
Bigeye grunt/Pelagic 2	8						NS			**0.1**		NS	**0.2**	NS		NS	NS	NS	
Sardinella	9								**0.1**										
Sardinella/ Pelagic1	10					**0.2**													
Sardinella/ Pelagic 2	11		NS						NS								NS	**1.0**	
Lantern fish	12				NS				**0.2**					**4.1**				**1.0**	
Lantern fish/ Pelagic 2	13				**0.1**				NS				NS				NS	NS	
Demersal	14																		NS
Demersal/ Pelagic 2	15					**0.3**			NS									**0.4**	
Pelagic 2	16		**0.3**				NS		NS			NS		NS				NS	
Pelagic1/ Pelagic 2	17								NS			**1.0**	NS	NS		**0.4**	NS		
Round herring	18	NS				NS									NS				

The discriminant function gave an overall success rate of 46 % when considering only the groups with greatest membership probability, but this rose to 62 % when the two greatest probabilities were considered, and to 71 % when considering the three greatest (Table 8). Among the main pelagic species, the algorithm separates Cape horse mackerel (80% success in greatest probability) better than Cunene horse mackerel, with 31% success in the greatest probability and 38% when considering the two or three greatest. The success rate of the sardinella aggregations was with the greatest probability only, increasing to 78 % and 86 % when the two and three highest greatest, respectively, were considered.

Table 8. Results from the discriminant analysis showing the overall correct classification rates (%) by acoustic groups predicted by the algorithm. Columns correspond to the percentage correct classifications obtained when considering only the highest probability of membership, the two highest probabilities and the three highest probabilities.

	Rank of correct classification		
Acoustic groups	1	1-2	1-3
Sardinella/ Pelagic1	89	89	89
Cape horse mackerel	80	80	80
Sardinella	75	78	86
Cunene horse mackerel/ Lantern fish	70	80	80
Pelagic 2/ Demersal	67	67	67
Demersal	67	70	76
Cunene horse mackerel/ Demersal	61	83	87
Bigeye grunt/ Pelagic2	33	67	67
Cunene horse mackerel	33	38	38
Bigeye grunt	25	25	75
Lantern fish	22	72	72
Cunene horse mackerel/ Bigeye grunt	20	40	40
Pelagic 2	13	13	75
Pelagic1/Pelagic 2	0	50	50
Sardinella/Pelagic 2	0	48	71
Cunene horse mackerel/ Sardinella	0	0	0
Round herring	0	0	0
Global	46	62	71

The overall classification matrix (considering only the classification with the highest probability) is given in Table 9. For most groups incorrectly classified observations were usually predicted as belonging to a mixed group containing the target species (single-species groups), or one of the target species (mixed groups). For Cunene horse mackerel, the algorithm only classified correctly (i.e gave greatest probability to the right group) 31 % of the time, whereas it classified it as mixed Cunene horse mackerel and bigeye grunt 13 % of the time.

Table 9. Results from discriminant analysis showing classification rates (%) by acoustic groups given by the algorithm when considering only the classification with highest probability

Observed Acoustic groups		Predicted group membership																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cunene horse mackerel	1	**31**	13	13	6				6							13	6	6	6
Cunene horse mackerel/ Bigeye grunt	2		**20**			20				20							20		20
Cunene horse mackerel/ Demersal	3	4		**61**				17		4					9				4
Cunene horse mackerel/ Lantern fish	4				**70**								10				20		
Cunene horse mackerel/ Sardinella	5	50	50																
Cape horse mackerel	6						**80**												20
Bigeye grunt	7			25				**25**									50		
Bigeye grunt/ Pelagic 2	8								**33**								30	30	
Sardinella	9		14	3				3		**75**		3			3				
Sardinella/ Pelagic 1	10		11								**89**								
Sardinella/ Pelagic 2	11	10	14					5	5	24			19				24		
Lantern fish	12	11			44				6				**22**	11			6		
Lantern fish/ Pelagic 2	13			22						11			11				33	22	
Demersal	14	6		6	6		3	3							**67**	3			6
Demersal/ Pelagic 2	15							33								**67**			
Pelagic 2	16								25			25		25			**13**	13	
Pelagic1/ Pelagic 2	17								25					25			50		
Round herring	18						50	50											

Discussion

Identification of targets is a major source of bias in acoustic fish abundance estimation (MacLennan and Holliday, 1990; MacLennan and Simmonds, 1992; Reid, 2000). The problem can be acute in areas with high levels of species diversity and mixing, such as Angola. The present study reports on efforts towards applying automated, more objective methods to assist operators during echogram scrutiny, which, if successful, will reduce species identification errors and hence improve the accuracy of the abundance estimates.

The overall success rate was 46 % in the first trial and 71 % if considering the three classifications with highest probabilities , which is relatively low compared with results of similar studies (Lu and Lee, 1996; Lawson *et al.*, 2001; and Hammond *et al.,* 1996). However, most other studies involved fewer species and primarily targeted single-species schools. Taking this into account, the overall success in the present study looks promising as a first step towards automated identification algorithms. Extending the reference data material and introducing additional discriminators or revising current discriminators may improve classifications further.

For single-species groups, success rates were reasonably good for Sardinella (75%) and Cape horse mackerel (80%). Sardinella schools were well defined, which together with the high acoustic volume densities made them readily distinguishable. Cape horse mackerel off Angola are dominated by small-size groups and they have only been found in the southern part, where it tends to form extended layers, or bands, with relatively high packing densities (Anon, 2004). The high success rate on this species is therefore related to both its acoustic and spatio -temporal characteristics. For other single-species groups, however, success rates were low when considering only the classification with the highest probability (pelagic 2 13%, lantern fish 22%, bigeye grunt 25% and Cunene horse mackerel 31%). These groups are all found along the entire coast, with correspondingly low discriminatory power offered by spatio-temporal variables. The classification success was better, however, when considering the classifications with the three highest likelihood values (72-75 %) for the three first groups, but not for Cunene horse mackerel (38%), which were found at comparatively low densities. Moreover, in most cases where the classification corresponding to the predictions made by the algorithm were wrong, the suggested categories involved the true species. For Cunene horse mackerel, 32% were classified as mixed groups involving Cunene horse mackerel and either bigeye grunt, demersal or lantern fish. Cunene horse mackerel carry out diel vertical migrations, and are therefore often associated with different groups during day (demersal, bigeye grunt) and night (lantern fish), and although the algorithm had rather poor success rate in identifying pure aggregations of Cunene horse mackerel, it was able to identify groups involving this species >60 % of the time. For Cunene horse mackerel therefore, the predictions only provide some indication that this species is present in a particular dataset, but there does not appear to be sufficient information in the acoustic and spatio-temporal descriptors to confirm classification classify reliably, and classifications in this category should be confirmed by trawling.. For this and some of the other species groups or mixed species groups, it will be most often be necessary to sample by trawl for correct species identification..

None of the round herring acoustic references were correctly classified. Classifications instead suggested the presence of Cape horse mackerel (50%) or bigeye grunt (50%). This is mostly likely a consequence of small sample size (just two observation). Little is known about the distribution and behaviour of round herring off Angola, although they appear in the trawl samples made during routine acoustic surveys. It appears that Cape horse mackerel and round herring co-occur in similar geographical areas and depth ranges off Angola. A preliminary analysis of length frequency data has indicated that the two species also share similar length compositions (15 and 19 cm mean total length for sampled round herring and Cape horse mackerel, respectively). Round herring and horse mackerel both have gas-filled swimbladders, so fish of comparable sizes could have similar acoustic properties. It is not possible to find a similar explanation for the species misclassification as bigeye, grunt, however.

Classification of single-species groups such sardinella, Cape horse mackerel and round herring could be improved by using a school detection algorithm (Lawson *et al.,* 2001) to extract reference data. This could add morphometric information about the schools such as shape (elongation, circularity, rectangularity), so adding acoustic discriminant power. Tis would also reduce the noise in the data, by ensuring that only the actual schools are included in each data set.

The use of Discriminant Function Analysis (DFA) has been questioned by some authors for identification of mixed groups (Lawson *et al.,* 2001;O’Driscool, 2003,). Their main concerns pertain to the possible effects of behaviour on the catchability of the species and therefore the possibility of biased species compositions in reference samples. The true species composition may well be biased by differences in size, swimming speed and behaviour of the sampled species (Gunderson 1993), and this could cause erroneous ground truthing of the initial training set. In the present study, the mixed acoustic groups have been defined quite broadly in order to investigate possible common denominators in compound groups involving wide ranges of associated species. The overall success rate was, however, relatively good for some of the mixed groups, e.g. for combinations of demersal/ Cunene horse mackerel, lantern fish/ Cunene horse mackerel and pelagic 2/ demersal.

Unfortunately, the algorithm was particularly unsuccessful in identifying the combination sardinella/ Cunene horse mackerel. This combination found was only at night, and both species then usually disperse in the pelagic zone near the surface. The low classification success rate could be related to the similarity in density and distribution between these two particular species. In this situation, the acoustic properties analysed in this work (S_v, and S_v SD) may be fairly similar. As there two species have widely overlapping distributional areas, the spatio-temporal parameters provide little additional information, yielding little or no overall discriminatory power.

The results from the present study demonstrates that a relatively straightforward analysis of conventional acoustic survey data collected at a single- frequency combined with ancillary spatio-temporal information can provide useful indications on the identity of single- and multi species aggregations pelagic fish. The classification algorithm was particularly successful for some single-species groups including sardinella and Cape horse mackerel, but for other groups, no unique classification functions were derived, resulting in seemingly random predictions. Whereas the algorithm does not assist in the classification of those groups, it may still provide operators with valuable cues as to when trawling for ground-truthing is most required.

The algorithm was only tested on data from the same years as the training sets, so it is not known if applied to data from subsequent years. The behaviour of fish may affect the acoustic properties of schools (Fréon and Misund, 1999), and behavioural patterns may differ between years. However, as a first trial involving a limited subset of the time series, the results on the multi-species aggregations are thought to be very promising. Inclusion of data from additional years, application of addition descriptors and including of input from school detection analyses may add considerable discriminatory power. In this work we used GDA, rather than the more classical DFA a decision that allowed incorporation of non-continuous explanatory variables such as period of day (day/night) or type of aggregation, so expanding the range of potential explanatory variables. The combination of the GDA approach presented here and other methods, in particular multi-frequency acoustic identification, may add considerably towards development of automated species identification systems that may in the future assist in improving the quality and reliability of acoustic survey programmes.

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Chapter V Day-night differences in Cunene horse mackerel (*Trachurus trecae*) acoustic relative densities off Angola

Vaz Velho.F,Barros. P and Axelson. B. E. ***submitted to ICES Journal of Marine Science, 67: 000*****–000**

Abstract

The assessment and management of the Cunene horse mackerel in Angola rely heavily on abundance estimates from hydroacoustic surveys. Acoustic data collected from 1994 to 1999 were analysed in order to quantify diurnal variation in relative acoustic densities at 38 kHz. The nautical-area scattering coefficient (s_A m^2 nautical mile^{-2}) was characterized by clear day-night differences: s_A values recorded during the day were significantly higher (mean s_A 135 m^2 nautical mile^{-2}) than the corresponding night-time values (mean s_A 83 m^2 nautical mile^{-2}). This pattern is associated with differences in behaviour and horizontal and vertical distributions between day and night: by day, the fish school near the seabed, and by night they move into the pelagic zone and disperse into widespread scattering layers. More than 40% of the total backscatter by day originated from a bottom channel 10 m deep, but at night this proportion decreased to <10%. The findings demonstrate considerable influences of behaviour and aggregation dynamics on acoustic measurements. Possible implications for estimates of acoustic abundance are discussed in the light of the differences.

Keywords: abundance estimates, acoustics, Cunene horse mackerel, diurnal behaviour, vertical migration.

Introduction

Off Angola, horse mackerel are harvested by industrial, semi-industrial, artisanal, and subsistence fleets, and is the most important fish species for human consumption. Two species are found in Angolan waters: Cunene horse mackerel (*Trachurus trecae*) and Cape horse mackerel (*Trachurus t. capensis).* The former species is distributed along the entire coast of Angola, with aggregations of juvenile fish extending south into Namibian inshore waters, whereas the latter is found off southern Angola, Namibia, and South Africa, in the colder Benguela Current ecosystem (Duarte, 2001).

Annual acoustic surveys targeting Cunene horse mackerel, Cape horse mackerel, flat sardinella (*Sardinella maderensis*), round sardinella (*Sardinella aurita*), and sardine (*Sardinops sagax*) are carried out in Angolan waters by the RV “Dr Fridtjof Nansen”, and they provide abundance estimates of all principal pelagic fish stocks. The estimates obtained from the surveys form the primary basis of the assessment and management of pelagic stocks. The acoustic method enables large volumes of water to be sampled with relatively little effort, and is therefore the generally preferred method of making direct estimates of the abundance of schooling pelagic fish (MacLennan and Simmonds, 1992). As for all methods, however, methodological limitations and sources of errors exist (Anon., 2003, 2004), and acoustic estimates may be affected by both target availability and errors related to identification and conversion from acoustic densities to biomass (Olsen, 1990; MacLennan and Simmonds, 1992; Fréon *et al*., 1993a; Axelsen *et al*., 2004).

Vertical migrations affect the target strength (*TS*) of fish (Foote, 1978; MacLennan and Simmonds, 1992) through compression/decompression of the swimbladder (Foote, 1980; Vabø, 1999) and changes in body posture (tilt angle) of the fish relative to the transducer (Nakken and Olsen, 1977; Foote, 1987; Ona, 2001). Vertical migrations can also affect estimates indirectly through depth-dependent changes in availability and

avoidance (Fréon and Misund, 1999; Olsen *et al*., 1983; Vabø, 1999). As a result, *TS* can vary appreciably throughout a 24-h cycle, with potential impacts on abundance estimates. Better knowledge of the behaviour of the species involved is therefore important for developing effective survey strategies and optimizing sampling during acoustic surveys (Coetzee *et al*., 2001). The overall aim of this paper is to analyse the patterns of variation in acoustic densities recorded for Cunene horse mackerel associated with diel vertical migrations, and to evaluate their potential effects on the acoustic estimates of abundance.

Material and methods

The acoustic-survey data collected in Angola by RV “Dr Fridtjof Nansen” from 1994 to 1999 were analysed using the standard echo-integration method (MacLennan and Simmonds, 1992). The surveys covered the area between the Congo (06°00’S) and Cunene Rivers (17º15’S), with transect lines running perpendicular to the coast. The transect lines were spaced approximately 6 nautical miles (hereafter miles) apart, extending offshore from 20 to 500 m bottom depth (Figure 1). Only data collected north of 12°S were included in the analysis, in order to exclude data from regions in which the distributions of Cunene and Cape horse mackerel overlap.

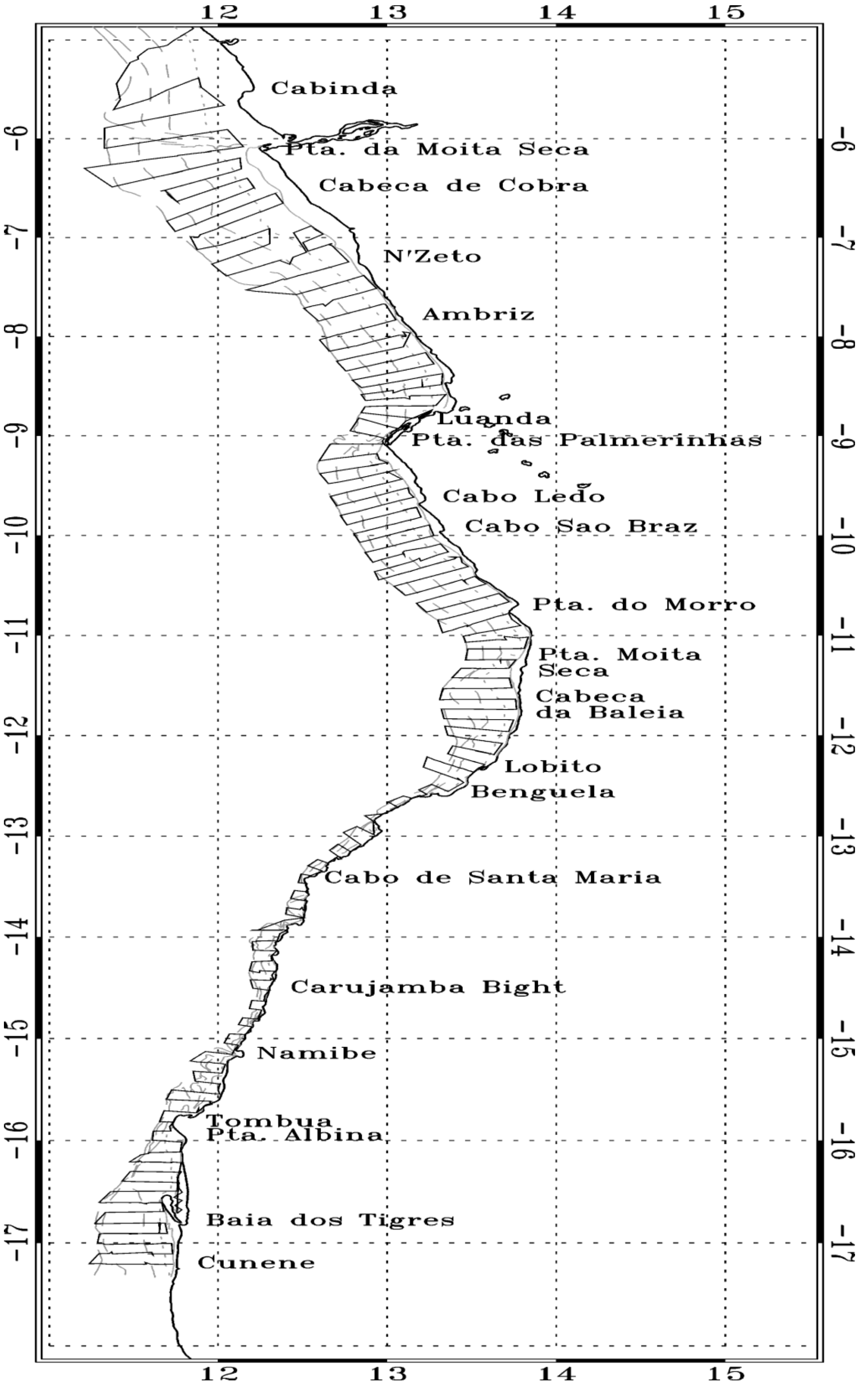

Figure 1. Course track surveyed (day and night). Latitude is shown in °S and longitude in °E.

Values of nautical-area backscattering coefficient s_A (m^2 nautical $mile^{-2}$; definitions in MacLennan *et al.*, 2002) were obtained using a Simrad EK 500 echosounder, running a keel-mounted 38 kHz transducer with seven nominal alongship and athwartship beam angles. The echosounder operated at a transmission power of 2000 W, ~1.0 pings s^{-1}, a 1 ms pulse duration, and 3.8 KHz reception bandwith. Acoustic data were logged and post-processed using the Bergen Echo Integrator system (BEI; Knudsen, 1990). The elementary sampling distance unit (ESDU) was set at 5 miles. Net samples of acoustic targets were obtained using pelagic (Akrehamn, 10–12 m vertical opening) and demersal (Gisund Super, 5 m vertical opening) sampling trawls.

Analysis

Vertical migration in pelagic fish is closely related to the diel solar cycle (Fréon *et al.*, 1993b)**.** As the data were gathered at various times of the year, the correlation between recorded time (UTC) and solar time was not constant between surveys, so recorded time was converted to solar time. For each observation, the time of sunrise and sunset at the given date and position were computed using standard astronomical formulae, as provided by Meeus (1998). The time-stamps of each ESDU were then standardized into the solar scale, sunrise corresponding to 06:00 and sunset to 18:00. Each day was further divided into four periods, "dawn" from 30 min before sunrise to 30 min after sunrise, "day" from 30 min after sunrise to 30 min before sunset, "dusk" from 30 min before sunset to 30 min after sunset, and "night" from 30 min after sunset to 30 min before sunrise.

Within each ESDU the data were grouped into two sets: the bottom channel, covering the water column from the sounder-detected bottom up to 10 m above the bottom, and the pelagic channel, corresponding to the water column from 10 m above the bottom up to the upper integration limit set in the BEI software (13 m below the surface). The pelagic channel was further divided into 10 m subinterval depth strata. In order to determine the vertical variation in acoustic densities, the relative depth (RD) of the centre of mass of the echo-recordings was computed for each ESDU:

$$\mathrm{RD}_i = \frac{1}{D_i} \sum_j D_{i,j} \frac{s_{A_{i,j}}}{s_{A_i}} \,, \qquad (1)$$

where $D_{i,j}$ is the mid-depth of depth stratum j of ESDU i, $s_{A_{i,j}}$ the s_A-value allocated to horse mackerel in depth stratum j of ESDU i, s_{A_i} the total s_A allocated to horse mackerel in ESDU i, and D_i is the average bottom depth at ESDU i.

The proportion of the total echo allocated to horse mackerel in the bottom interval (PB) was calculated for each ESDU:

$$\mathrm{PB}_i = \frac{s_{A_{i,b}}}{s_{A_i}} \,, \qquad (2)$$

where $s_{A_{i,b}}$ is the s_A allocated to horse mackerel in the bottom channel of ESDU i, and s_{A_i} is the total s_A allocated to horse mackerel in ESDU i.

The acoustic densities may vary appreciably between consecutive ESDUs, given the characteristics of the geographic distribution of fish, so in order to recognize differences in acoustic densities recorded by day and by night, spatial variation in acoustic density had to be taken into account. A Relative Acoustic Density Index (RADI) was therefore calculated for each ESDU i:

$$\mathrm{RADI}_i = \frac{s_{A_i} - \overline{s_{A_{24i}}}}{\overline{s_{A_{24i}}}} \,, \qquad (3)$$

where s_{A_i} represents the s_A values allocated to horse mackerel in ESDU i, and $\overline{s_{A24i}}$ indicates the average ESDU s_A value allocated to horse mackerel during the 24-h period around the mid-time of the ESDU analysed.

To analyse time-patterns through the 24-h diel period, the relative indices derived from the ESDUs (RD, PB, RADI) were binned in 2-h intervals. This interval length ensured that sufficient EDSUs were included to provide meaningful summary statistics, while maintaining an adequate time resolution. Differences in acoustic densities may also be related to patterns in the spatial aggregation (patchiness), and to behavioural modulation of the *TS* (Nakken and Olsen, 1977; Foote, 1978). To investigate the effect of time of day on the level of patchiness of the acoustic recordings of Cunene horse mackerel, the data were divided into intervals, and a Relative Presence Index (RPI) was calculated for each interval:

$$\mathrm{RPI}_j = \frac{P_j - P_{24j}}{P_{24j}} , \qquad (4)$$

where P_j is the proportion of positive ESDUs in time-interval j, and P_{24j} is the proportion of positive ESDUs in the 24-h period centred on the mid-point of time interval j.

To test the diel-period effect, it was essential to compare only neighbouring day and night periods. The average s_A values obtained during each day were compared with the average s_A values from the nights immediately before and after, and the average values obtained during each night were compared with the average s_A from the two neighbouring days. Similarly, the proportion of positive ESDUs (RPI) in each day were compared with the same proportions in the preceding and following nights. The proportion of positive ESDUs in each night were also compared with the corresponding proportion in the two neighbouring days. The dawn and dusk periods, which were short and usually only included one ESDU each, were excluded from the analysis. For each survey, the endpoint day or night periods were excluded from the analysis, and only periods in which Cunene horse mackerel were present in at least one ESDU in a set of day and night periods were included.

In order to test the null hypothesis of no difference between RADIs by day and night, a paired-comparison randomization test was used (Manly, 2006). The test statistic used was the number of positive differences between the average s_A recorded by day and the corresponding night period (sign test). The same methodology was used to test the null hypothesis of no effect of period (day–night) on the proportion of positive ESDUs (RPI).

Results

The diel variability in measured s_A indicates substantial day–night differences in s_A over the 24-h cycle. The RADI shows a pattern of increase from dawn, relative stability during the morning (up to 13:00), then a decrease in the afternoon to minimum values at night (Figure 2a). On average, s_A values measured by day were 125% higher than the corresponding night values ($p < 0.001$). The RPI showed a similar pattern, with mean value and variability increasing during the morning up to midday, and the lowest values at night (Figure 2b). The proportion of positive ESDUs observed by day was significantly (60%, $p < 0.001$) higher than the corresponding night-time values.

The observed difference in average acoustic density between day and night was matched by a marked difference in depth (Figure 2c) and aggregation characteristics (Figure 3). Generally, Cunene horse mackerel concentrated in dense schools near the seabed by day, but at night they dispersed widely in the pelagic layers.

The observed differences in aggregation characteristics are reflected in the evolution of the relative depths of horse mackerel by day (Table 1). The fish migrated from relative depths of 20–40% at night (95% *CI*), corresponding to mean absolute depths of 42–46 m, to relative depths of 70–80% by day (98–110 m). The proportion of acoustic densities recorded in the 10 m bottom channel followed a similar pattern. At night, 3–8% (95% *CI*) of the s_A attributed to Cunene horse mackerel was found in the bottom channel, increasing gradually to 35–40% by day.

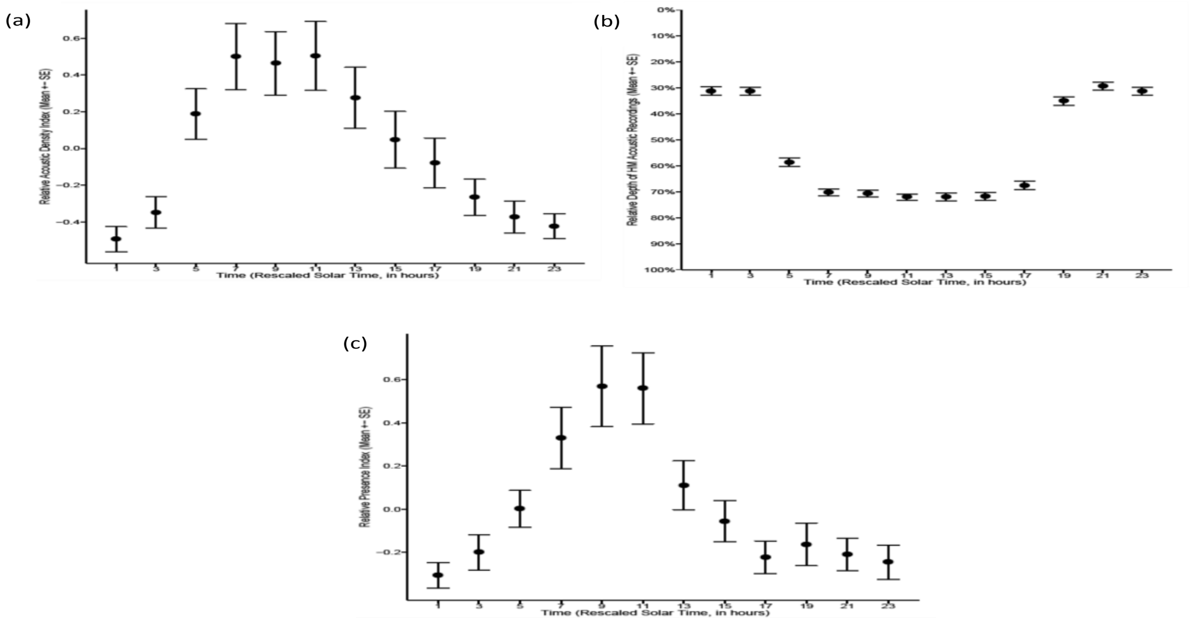

Figure 2. (a) Relative Acoustic Index (RAI), (b) Relative Depth (RD), and (c) Relative Presence

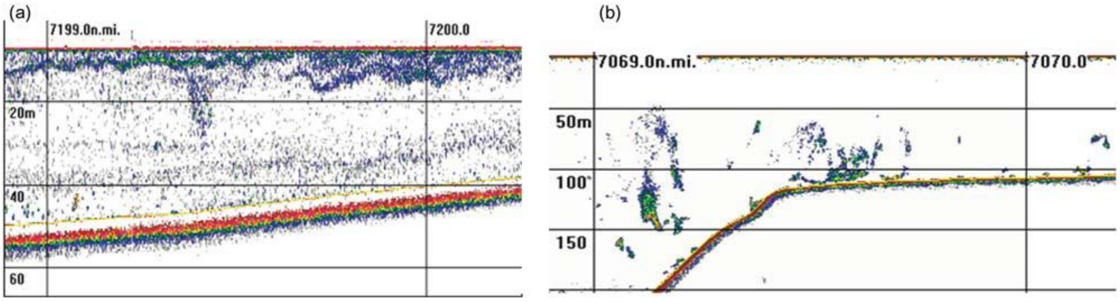

Figure 3. Typical acoustic recordings of horse mackerel by (a) day, and (b) ni ght

Table 1. Means ± s.e. of Cunene horse mackerel acoustic recordings during the four diel periods

Parameter	**Dawn**	**Day**	**Dusk**	**Night**
Number of valid ESDUs	534	3 281	506	3 158
(RADI)	0.14 (±0.183)	0.31 (±0.068)	–0.10 (±0.110)	–0.42 (±0.036)
(RPI)	0.06 (±0.110)	0.35 (±0.064)	–0.28 (±0.080)	–0.25 (±0.052)
Relative Depth (RD)	0.49 (±0.002)	0.71 (±0.006)	0.54 (±0.021)	0.31 (±0.007)
Proportion of total s_A allocated to bottom channel	0.15 (±0.016)	0.36 (±0.006)	0.18 (±0.019)	0.05(±0.005)
Proportion of s_A allocated to upper pelagic	0.15(±0.016)	0.05(±0.003)	0.09(±0.011)	0.18(±0.006)
Proportion of ESDUs with all the Cunene horse mackerel recordings in the upper pelagic layers	0.05(±0.009)	0.01(±0.002)	0,04(±0.008)	0.10 (±0.005)

Discussion

Consistently higher values of s_A were obtained for Cunene horse mackerel by day than by night when comparing consecutive day and night periods, a difference that can be attributed to diurnal changes in the vertical distribution and aggregation patterns. By day Cunene horse mackerel tended to concentrate in dense schools near the seabed, but at night they moved into the pelagic zone, dispersing into widespread scattering layers. The differences in acoustic density between day and night may be related to the lower packing density by night. However, the differences may also be attributable to changes in the angular orientation of the fish (Weston and Andrew, 1990; Pearre, 1997). Fish that are densely aggregated tend to polarize (Pitcher, 1983), with the result that tilt-angle distributions become more uniform (Blaxter and Batty, 1990; Axenrot *et al.*, 2004). This maximizes the acoustic energy reflected back to the transducer (Foote and Nakken, 1978), increasing individual values of *TS* (Foote, 1987). Behaviourally induced changes in *TS* may therefore be one explanation for the relatively high values of s_A recorded by day.

Another explanation for the differences observed may be movements of the fish into blind zones near the surface and seabed, reducing the availability of the fish to the echosounder and leading to underestimation of their densities (MacLennan and Simmonds, 1992; Fréon *et al.*, 1993b). By day fish tend to aggregate near the seabed, and some loss of signal may be caused by fish occupying the bottom dead zone (Ona and Mitson, 1996). Similarly, some loss of echo strength may be due to targets entering above the upper blind zone (~13 m deep) at night. However, blind-zone errors are considered to be relatively low (<5%; Axelsen *et al*., 2004) for Cape horse mackerel in Namibia (Anon., 2003, 2004), so because bias effects would be negative for both daylight and night-time results, these should not have contributed much to the differences observed in the present study.

At night, horse mackerel generally aggregate less densely and are less polarized than by day (Pitcher and Parrish, 1993), resulting in reduced values of *TS* (Huse and Ona, 1996). Mesozooplankton rise at night, and pelagic fish and mesozooplankton therefore often form dense, mixed layers in the upper pelagic at night. These aggregations may produce strong echoes which, combined with the reduced *TS* of fish at night, may increase the probability of missing fish targets, according to Vaz Velho *et al*. (2006), who studied this effect and considered it to be moderate (Anon., 2003, 2004; Axelsen *et al*., 2004). The considerable differences reported here are therefore more likely to have been caused by changes in packing density and/or *TS* between day and night.

The main points of interest in this work are the causes of day–night differences, and how such effects impact estimates of abundance. The results demonstrate the close link between behaviour and aggregation characteristics on the one hand, and the acoustic densities recorded on the other. Nevertheless, the differences are not necessarily indicative of the magnitude of the error in the estimates. In routine surveying, echo densities are averaged for both day and night periods. Similar proportions of daytime and night-time ESDUs are to be expected in the datasets (Table 1), and assuming no differences in *TS* between day and night, this should not lead to systematic errors in the abundance estimates. If the differences observed are primarily a consequence of night-time dispersion rather than to changes in *TS*, reduced acoustic densities resulting from dispersion at night could be compensated for by correspondingly larger distribution areas.

If the *TS* differs between day and night, however, estimates of abundance may be affected. The *TS* used in the surveys was first derived for clupeids (Foote *et al*., 1986), and has been applied to both clupeids and carangids in the Benguela region (Anon., 2003, 2004). The implicit assumption in employing this *TS* is that it reflects an average situation for the species to which it is applied. If the *TS* is different between day and night, the main question concerns the extent to which the *TS* employed is representative of the day or night situation. For datasets containing equal proportions of day and night data, the bias would correspond to the deviation between the *TS* conversion applied and the actual daytime and night-time average *TS* values.

Particularly dense patches are sometimes encountered by day, and datasets obtained only by day may be characterized by a few very high values that may influence the mean values significantly. For sardine (*Sardinops sagax*) and round herring (*Etrumeus whiteheadi*), Coetzee *et al*. (2001) found that the biomass estimates may decrease by up to 25% and the variance by 90% if a single very high value is removed. Extreme patchiness is often associated with low levels of abundance (Pitcher, 1983), which is the case for the Cunene horse mackerel (Anon., 2007). The amplitude of this type of error may therefore increase as stock levels fall.

A higher proportion of zero s_A values was recorded by night than by day, but the proportion of ESDUs where Cunene horse mackerel was detected in the upper pelagic layers was greater by night. This suggests an underestimation of how much aggregation patterns of Cunene horse mackerel differ by day and night or that fish are more difficult to detect by night. For this reason, we regard the differences in acoustic densities as being associated primarily with differences in *TS* and in aggregation pattern, rather than packing densities.

Ideally, therefore, values recorded by day and by night should be converted separately. However, this would require knowledge of the differences in *TS* and probability of detection between day and night, and this question still needs to be answered. As horse mackerel vertical distribution varies considerably in the course of a 24-h cycle, the effects of depth and time of day need to be evaluated separately. Future studies should investigate more closely the *TS* of horse mackerel, and in particular the possible effects of depth and time of day (Vabø, 1999; Axelsen, 2007).

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Day-nigth differences in Cunene horse mackerel (Trachurus trecae) acoustic relative densities off Angola

Chapter VI Feeding habits of Cunene horse mackerel (*Trachurus Trecae*) off Angola

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Feeding habitas of Cunene horse mackerel (*Trachurus trecae*) off Angola

Abstract

The diet of Cunene horse mackerel *Trachurus trecae* in Angolan waters is poorly known. Diet composition and daily rations were investigated from pelagic and bottom trawl samples collected during the Angola stock assessment surveys in the period from 2000 to 2003. Fish size was found to influence the diet of composition of Cunene horse mackerel, with gut contents of small fish (12 cm to 20 cm total length) being comprised primarily of fish larvae (96 % by weight) while large fish (21-48 cm) stomachs contained mainly euphausiids (85 %), followed by copepods (7 %) and other crustaceans (6 %). Geographical differences were also found: Cunene horse mackerel caught in the northern region fed largely on euphausiids, while fish from the central region fed mostly on euphausiids (33 %) and copepods (30 %), and fish in southern region had predominantly euphausiids (46 %), copepods (35 %) and other crustaceans (15 %) in their stomachs. Feeding periodicity was also found to be size-dependent, with smaller fish having increased stomach content masses in the periods 12-14 hours and 18-20 hours while larger fish had feeding peak in the period 12-16 hours. The rate of gut evacuation of small fish was estimated to be somewhat higher for small fish (0.36 h^{-1}) than for large horse mackerel (0.33 h^{-1}). Using the Elliot and Persson methods, the daily ration was estimated at 3.35 % day^{-1} for small fish and 2.39 % day^{-1} for large fish, and was also found to be different between geographical regions

***Keywords*:** Cunene horse mackerel, feeding periodicity, rate of gut evacuation, daily ration, Diet

Introduction

Horse mackerel is harvested by industrial and semi-industrial fleets and is the most important fish species for human consumption in Angola. Two species are found in Angolan waters, Cunene horse mackerel (*Trachurus trecae*) and Cape horse mackerel (*Trachurus trachurus capensis).* The former of these is distributed along the entire coast of Angola, with aggregations of juvenile fish protruding southwards into Namibian inshore waters, while the latter is found off southern Angola, Namibia and South-Africa in the colder Benguela Current system (Duarte, 2001). In addition, horse mackerel represents also an important food resource for fish, particularly for hake (Konchina 1986, Andronov 1983, Roel and McPherson 1988, Kilongo 2001), large–eye dentex (Kilongo *et al*., 2007), as well as for various seals and whales (David 1987, Sekiguchi *et al*., 1992).

The diet of Cape horse mackerel off Namibia and South Africa is comprised primarily of large zooplankton (Krzeptowski 1982, Andronov 1985, Pillar and Barange 1998, Axelsen, *et al*., 2004, Barange *et al*., 2005). Most of these studies report that horse mackerel feed during the day and (peak) afternoon. Pillar and Barange (1998), Axelsen *et al*. (2004) and Barange *et al*., (2005) all discussed the link of feeding periodicity and diel vertical migration, essentially concluding that the diel vertical distribution of Cape horse mackerel is primarily food- and temperature driven off Namibia, and less food-related off South Africa.

Despite the economic and ecological importance of Cunene horse mackerel, relatively little is known about its ecology. For Cunene horse mackerel there have been relatively few attempts to investigate the diet, and only considering the frequency of occurrence of prey (e.g. Kilongo, 1997). The study by Kilongo (1997) indicates that Cunene horse mackerel feeds mainly on euphausiids and copepods, but does not make any inference regarding the feeding periodicity. Diel vertical migration is important as it impacts on the availability for acoustic and trawl sampling, and may thus ultimately affect biomass estimates (Fréon and Misund 1999, Olsen *et al*., 1983, Vabø, 1999, Axelsen *et al*., 2004, Vaz-Velho *et al.*, 2010). The main purpose of the present study was to describe the diet and feeding patterns of Cunene horse mackerel, and compare it to similar studies for Cape horse mackerel

Material and Methods

The data reported here were collected during routine acoustic surveys with R/V "Dr. Fridjof Nansen" in the period 2000 to 2003 during the austral winter (July-August). The surveys covered the Angolan continental shelf between the Congo River (6^o 00'S) and the Cunene River (17^o 15'S), with transect lines running perpendicular to the coast and spaced by about six nautical miles (nmi) that extended between the 20 m and 500 m isobaths.

The trawl samples were obtained using pelagic ("Åkrehamn", 10-12 m nominal vertical mouth opening) and demersal ("Gisund Super", 6 m vertical opening and 18-20 m trawl width, wingtip to wingtip). All catches were separated by species and weighted. In cases of very large catches subsamples were taken and scaled to total catch according to standard procedures (Sparre and Venema, 1998). For all target species, total length (cm) was measured for random subsamples of around 200 fish per sample, rounded down to the nearest cm.

Biological sampling

Onboard the ship, random sub-samples of 5 Cunene horse mackerel per 1 cm length group were collected for stomach content analysis. Total length (rounded down to the nearest cm), wet mass (accuracy: 0.1 g), sex, gonad maturity stage (GMI), and total gonad weight of each fish sampled were measured and recorded before removing the stomachs. After removal, the stomach weight was recorded and its fullness was categorized according to a visual fullness scale of 0 (empty) to 4 (full) for each specimen. In total, 2,858 stomachs were examined

(Table 1). Individuals suspected of codend feeding based on presence of fresh food in the esophagus and mouth were excluded from the analysis.

Table 1. Number of trawls samples where Cunene horse mackerel were caught and the corresponding number of stomachs by region and year.

Year	Region	Nº Stations	Nº Stomachs	% stomachs with food
2000	Northern	20	359	62
	Central	23	476	33
	Southern	9	137	11
	Sum	*52*	*972*	*35*
2001	Northern	16	145	71
	Central	27	143	62
	Southern	28	142	70
	Sum	71	430	68
2002	Northern	15	242	31
	Central	28	160	63
	Southern	27	270	53
	Sum	70	672	49
2003	Northern	14	280	70
	Central	24	170	83
	Southern	17	334	11
	Sum	*55*	*784*	*55*
2000-2003	Northern	65	1026	59
	Central	102	949	60
	Southern	81	883	36
	TOTAL	**248**	**2858**	**52**

All stomachs containing food were placed in 4% buffered formaline for further analysis ashore. In the laboratory, the stomachs were washed, to remove the excess formalin, and opened. The content was damp dried on absorbent paper in order to remove excess liquid. Prey items were separated and identified into major taxonomic groups: copepods, euphausids, fish larvae and crustaceans (mostly shrimp) that could not be identified to species levels due to degree of digestion. Shiphonophores, mysids and nematods were present in the diet in small proportions only and were therefore gathered in an “others” prey category.

Data analysis

The diet composition was described in terms of the relative proportion in weight of each prey category found in the stomachs. The horse mackerel were divided into two size classes: fish <21 cm total length (small fish), according to the Angola fishery legislation the unfishable part of horse mackerel population, and >21 cm total length (large fish), which can be legally captured, landed and sold. In order to analyse latitudinal effects on the diet of the Cunene horse mackerel, the sampling area was subdivided according to three different oceanographic regime ones: the warm Angola Current, Angola north (5-9° S), the intermediate Angola current, Angola central (9-13° S), and the Angola-Benguela Front area, Angola south (13°00’ - 17°15´ S).

The feeding periodicity was investigated using the two types of data available: the average stomach fullness index (Andronov, 1985) and the average mass of stomach content expressed as percentage prey item category (Pillar and Barange 1998, van der Lingen, 2002). The data were plotted into two-hour time periods (GMT) in order to reduce sample variation while maintaining adequate time-scale resolution.

The daily consumption (ration) was estimated using the Elliot and Persson (1978) model, which according to Pillar and Barange (1998) is based on the amount of food consumed between each sampling period (C_t) as:

$$C = \sum^{k=n-1} \left[\frac{\left(\bar{s}_{k+i} - \bar{s}_k * e^{-Rt}\right) * Rt}{1 - e^{-Rt}} \right] \qquad (1)$$

Where $\bar{s}_k$ is the geometric average of the amount of food in the stomach at time k and R is the rate of gut evacuation. The gut evacuation rate (R) was estimated in the period that the feeding rate was low, fitting an exponential function to the average of the mass of the stomach content.

Results

Diet composition

Fish size was found to influence the diet composition of Cunene horse mackerel (Figure 1), with gut contents of small fish (12-20 cm total length) having approximately 97 % of fish larvae while euphausiids, and copepods represented <2 % of the diet. Larger fish (21-48 cm total length) fed mainly on euphausiids (85 %), while copepods and crustaceans made up 7 % and 6 % of the diet, respectively. Fish larvae were infrequent (<2 %) in the diet of large Cunene horse mackerel.

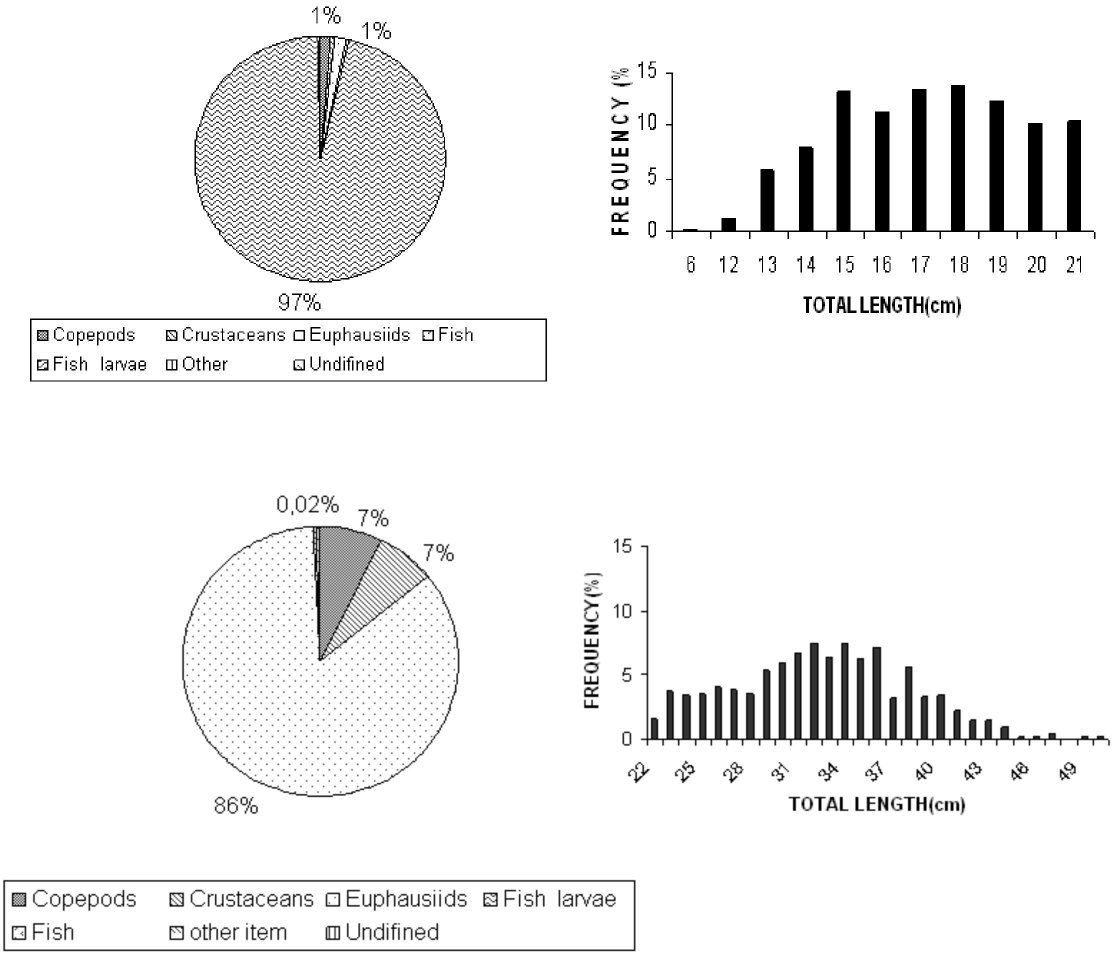

Figure 1. Relative abundance of different prey types, expressed as percentage weight of all

prey in the stomachs of Cunene horse mackerel

The results also show a latitudinal effect on diet of large Cunene horse mackerel (Figure 2). In the northern region these fishCunene horse mackerel, reached sizes of 50 cm total length and fed largely on euphausiids, followed by crustaceans and copepods, that represented respectively 14 % and 11 % of the diet. In the central region large Cunene horse mackerel ranged from 21 cm to 46 cm total length, with well defined peaks at 32 cm and 36 cm total length. In this region Cunene horse mackerel fed in approximately similar proportions on euphausiids (33 %) and copepods (30%). Fish larvae and crustacean represented respectively 12 % and 11 % of their diets. In the southern region the length distribution of large Cunene horse mackerel ranged from 21 cm to 46 cm total length, with peaks at 23 cm and 25 cm. The diet of these fish in this region was dominated by euphausiids (46%), while copepods and crustaceans represented respectively 35% and 15% of the total.

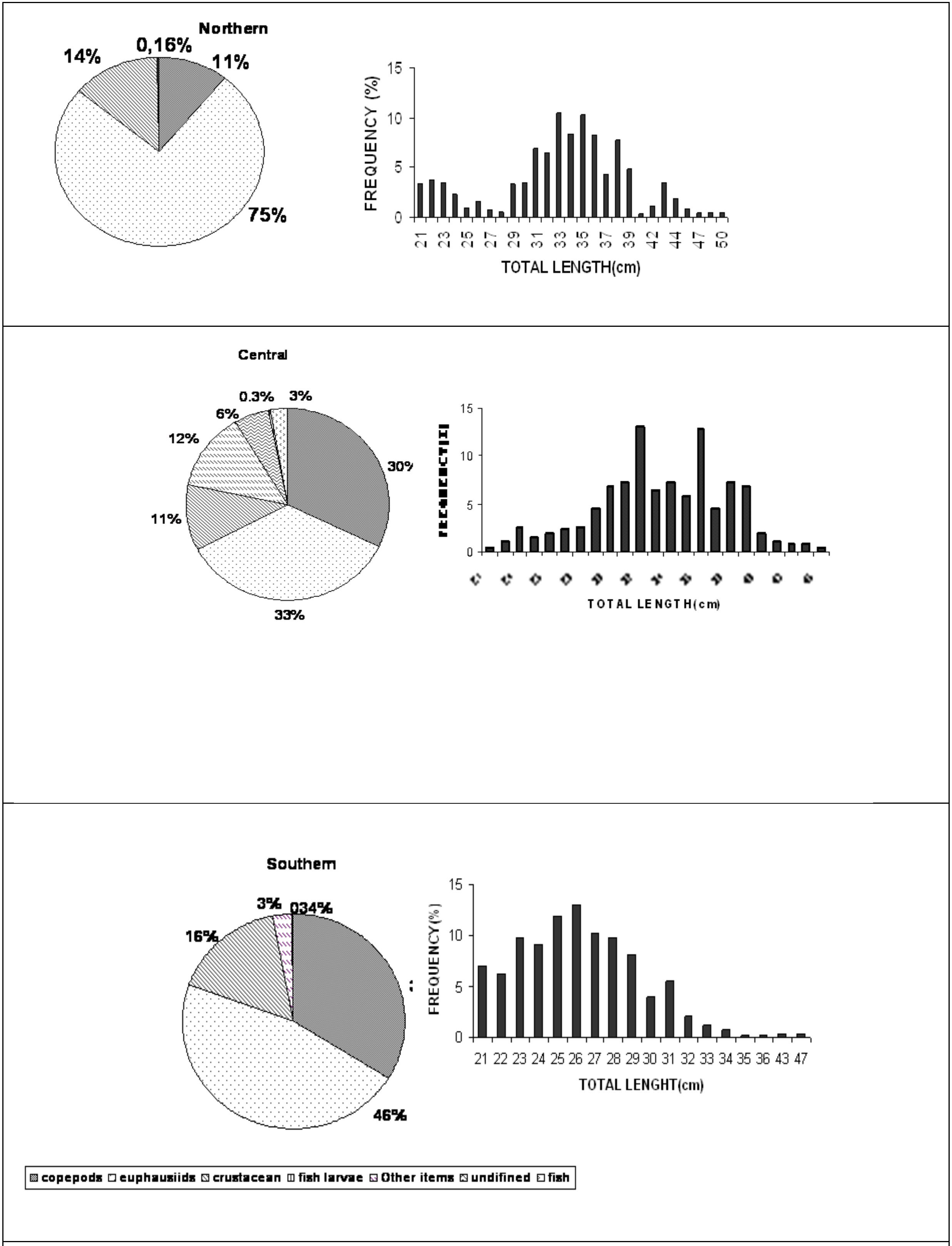

Figure 2. Relative abundance of different prey, expressed as percentage weight of all prey in the stomachs of large Cunene horse mackerel (fish < 21cm) collected in the different regions

Feeding periodicity

Feeding periodicity was found to be size-dependent (Figure 3), with smaller fish showing an increase in mean stomach content and during the periods 12-14 hours and 18-20 hours GMT. For the larger fish the two feeding indices showed different patterns: the mean prey mass showed minimum values before 12 hours, while the maximum occurred in the period 12-16 hours. The analysis of the stomach fullness index indicated a more continuous feeding activity that peaked early morning and during the period 12-16 hours.

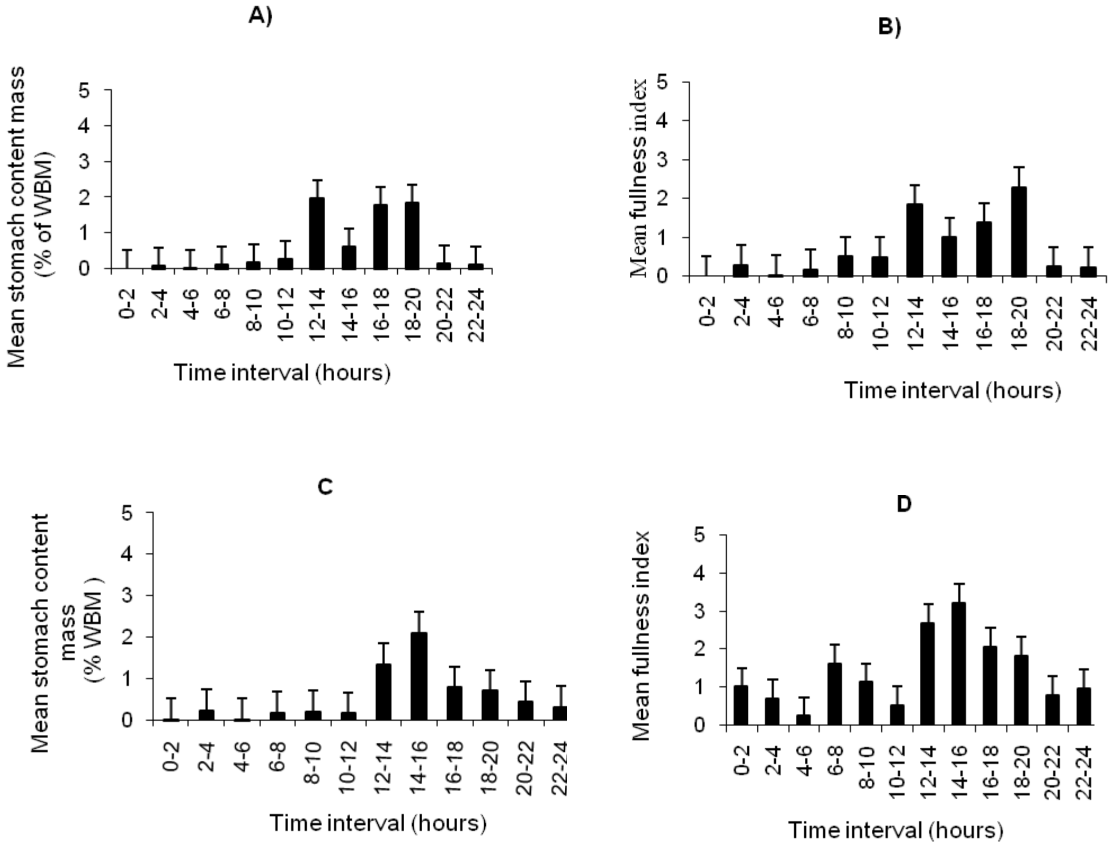

Figure 3. Relationship between time, grouped into 2 hours intervals, and mean stomach mass and mean stomach fullness index of Cunene horse mackerel. (A) small fish (Fish <21 cm and (B) large fish (fish >21cm). Error bars denote 1 SD.

Gut evacuation and daily ration

The mean gut evacuation rates were estimated at 0.3596 h^{-1} for small fish and 0.3281 h^{-1} for large fish (Figure 3). Applying these gut evacuation rates, the daily rations were estimated at 3.35 % day^{-1} for small fish and 2.39 % day^{-1} for large fish. The results also indicated that the daily ration decreased towards the south (Table 2). The daily ration calculated for small fish in the northern area had a very high value (7.64% day^{-1}).

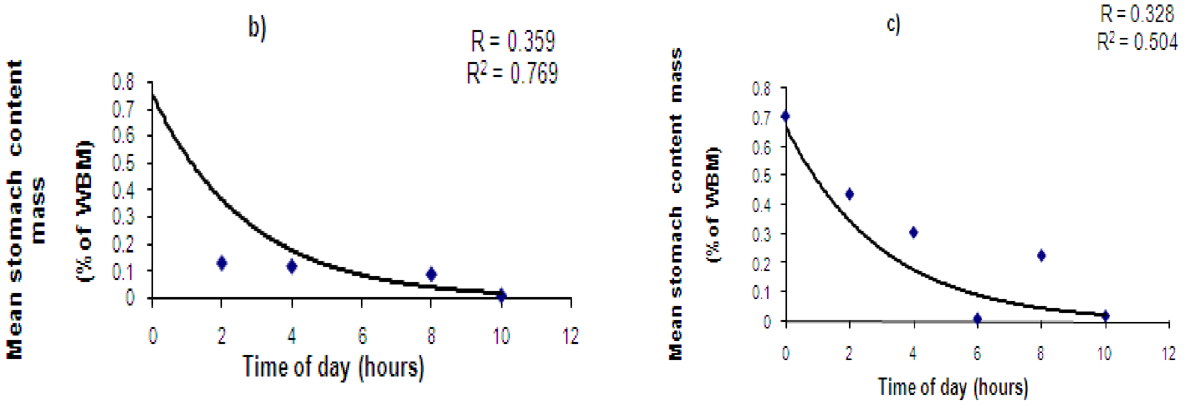

Figure 4. Exponential decline in the stomach content mass after cessation of feeding at 20 hours., (b) small Cunene horse mackerel (fish <21cm) and (c) Large horse mackerel (fish>21cm).

Table 2. Mean estimated daily consumption rate (day^{-1}) of Cunene horse mackerel by region. Small fish: <21 cm total length, large fish: >21 cm total length.

Region	**Small fish (<21 cm total length)**	**Large fish (<21 cm total length)**	**All**
Northern	7.64	3.68	5.66
Central	3.10	3.10	3.10
Southern	2.51	1.28	1.90
MEAN	**4.42**	**2.69**	**3.55**

Discussion

The composition of the diet of Cunene horse mackerel changes as the fish grow. Smaller specimens of Cunene horse mackerel were found to feed on fish larvae. This result is different from those found for Cape horse mackerel (Venter 1976, Konchina 1986), reports indicating that the diet of juvenile (<20 cm total length) Cape horse mackerel consisted of small zooplankton such as copepods (*Calanus* sp.).

As the fish grows, the proportion of zooplanktivorous species in the diet increases, mainly copepods and euphausiids. Similar findings have been reported for Cape horse mackerel in Namibia (Andronov, 1985, Axelsen *et al*. 2004) and South African Cape horse mackerel (Crawford 1989, Pillar and Barange 1998, Barange *et al*., 2005).

The diet composition of Cunene horse mackerel also varies geographically. Although the northern and central regions of Angola share similar meteorological features (Fidel 2001, Filipe 2007) with the influence of warm, equatorial and Angola current, and also were characterized by similar length structures, the diets in the northern region were strongly dominated by the euphausidis while in the central region adult Cunene horse seemed to feed on whatever was available. Whether in the northern region this is related to the prevalence of zooplankton in the water column is difficult to explain because data on characterization of zooplankton community for this region are very scarce. Several studies conducted in the central region of Angola (Luanda-Benguela) have reported the dominance of copepod species in the water column (Verheye 2001, Silva 2005, Camalandua 2007), supporting that at least in the central region Cunene horse mackerel did not show any preferential feeding. The southern area is characterized by strong wind-driven coastal upwelling, inducing biological productivity (Shanon 1985, Harddman-Moutford *et al*., 2003) and the zooplankton is dominated by copepods (Verheye 2001, Silva 2005). It is however important to point out that although eupahusiids represented 46 % of the diet composition, the proportion of copepods on diet could be somewhat higher as the 16 % crustacean diet group (digested mass) could include some copepods

The present study describes for the first time the dietary composition of Cunene horse mackerel. The characteristics of the study did not allow to study the effect of the selection of prey size, but this will be a important effect to investigate. In fact, it has been reported that Cape horse mackerel in the southern Benguela ecosystem, tends to select the largest particles available to it (Makupata 2002).

The feeding periodicity in Cunene horse mackerel was also found to be size-dependent, with small fish showing a peak in feeding activity at early afternoon and at dusk, while large horse mackerel tend to show maximum feeding in the afternoon. This is consistent with the findings of Pillar and Barange (1998), Andronov (1983, 1985), and Barange *et al*., (2005) for Cape horse mackerel, and indicates that Cunene horse mackerel is also a daytime feeder.

A number of studies have linked feeding periodicity in marine organisms with diel vertical migration (Bailey 1989, Bulman and Blaber 1986, Hobson 1973), which is driven by the availability of prey, synchronized to the light cycle (Neilson and Perry 1990). Diel variation in the vertical migration of zooplankton from central and southern areas off Angola showed that higher biomasses were found at night-time (Postel *et al*., 2001) when large proportion of Cunene horse mackerel disperse in the surface layers (Vaz-Velho *et al*.,. 2010). However, this study shows that during the night-time period feeding activity is minimal and apparently ceases at about 20 hours. Other studies have also shown that some feeding at night could be related with full moon (Hunter 1968). During the day-time, when feeding activity reaches the peak (between 14-00 to 16-00 hours) Cunene horse mackerel forms schools near the bottom (Vaz-Velho *et al*.,. 2010). This study thus also confirmed that Cunene horse mackerel feeds in the day time when it is near the bottom, a pattern similar to that found for Cape horse mackerel.

The gut evacuation rates found for Cunene horse mackerel in the present study are similar to those estimated for Cape horse mackerel using the same methodology and, according to Pillar and Barange, 1998 following the general pattern of active fish feeding on zooplankton. The gut evacuation rate of small fish is relatively higher than large fish. This difference could be related with food preference of the two groups. Jobbins, (1981) and Van der Lingen, (1998) reported that the gut evacuation rate depends on the size of the prey. The meals of small fish are probably composed of smaller prey items that are evacuated from the stomachs more rapidly than meals of large prey. The daily ration of Cunene horse mackerel is within the range estimated for others strong swimmers zooplanktivorous pelagic species (Pillar and Barange, 1998). In general, it is relatively lower than those estimated in South Africa and Namibia for Cape horse mackerel (Andronov, 1985; Pillar and Barange, 1998). This could be interpreted as indicating that Cunene horse mackerel need less food to obtain energy to grown

The lowest daily ration was estimated in the southern area, an effect which could be connected with temperature. For *Trachurus trachurus* the appetite was found to be highly dependent on water temperature (Temiming and Hermern, 2001) and for many fish, feeding rates decrease as temperatures drop (Tyler, 1971). In the northern area Cunene horse mackerel the daily ration of small fish is out of the range defined for horse mackerel. This is may be related to the negative correlation between abundance of prey and predators (Bertrand *et al.*, 2004).

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Chapter VII Vessel avoidance in small pelagic fish off Angola

Vaz Velho. F, Axelsen,B. E, Barros .P and J. Krakstad.Vessel avoidance in small pelagic fish off Angola. To be *submitted*

Abstract

Minisurvey experiments comparing acoustic densities of loose aggregations of sardinella in shallow waters showed that vessel avoidance may affect acoustic abundance estimates. The densities recorded using Dr. Fridtjof Nansen were on average 19 % lower than the reference values obtained using a man-over-board boat, suggesting a 19 % negative bias. The results show that the fish dove from the blind zone at the surface to below the upper integration limit, and hence the avoidance reaction made the fish acoustically detectable, reducing the bias from the shallow distribution of the fish. These results show that the effects of avoidance in shallow areas may be different from those described earlier for deeper areas.

Keywords: sardinella, vessel avoidance, acoustic, survey error

Introduction

Impacts of fish behaviour on estimates of abundance have been demonstrated for all presently available assessment methods (Fernö and Olsen, 1994). In acoustic abundance estimation, vessel avoidance has been shown to in some cases may not represent any problem at all (Fernandes et al., 2000), it may in other instances represent a significant source of bias (Olsen et al., 1983a, Misund and Aglen, 1992, Freon et al., 1993, Morgan et al., 1997, Vabø, 1999), even if in some cases it may not represent a significant problem (Fernandes *et al*., 2000). This is also believed to be the case for sardinella *Sardinella maderensis*, which is one of the main targets for the pelagic assessment surveys in Angola (Misund *et al*., 1998).

The effects of vessels on fish behaviour, and specifically on vessel avoidance, are broadly documented (Anon. 1995), both with respect to effects caused by vessel-radiated noise (Olsen, 1971, Olsen et al., 1983, Aglen, 1985, Freon and Gerlotto, 1988, Gerlotto and Freon, 1988, Ona and Toresen, 1988a), Gerlotto et al., 1990, Misund and Aglen, 1992) and light (Halldorsson and Reynisson, 1983, Levenez *et al*., 1990), and also for effects of trawls and other sampling gear (Mohr, 1964, 1969, Aglen, 1985, Ona and Thoresen, 1988b), Ona and Godø, 1990, Misund and Aglen, 1992, Morgan *et al*., 1997, Suuronen *et al*., 1997).

In acoustic abundance estimation, effects of vessel avoidance can be grouped into two main types; within-beam effects, where the targets remain within the beam during passage of the surveying vessel but change their angular orientations; and out-of-beam effects, where fish move out of the acoustic detection range (Olsen et al., 1983). Avoidance effects differ, however, between species, size-groups and seasons, and are affected by depth, light and temperature, as well as biological factors such as species/size and packing density (Olsen 1971; Misund 1994; Engås *et al*., 1995; Misund *et al*., 1996).

It is therefore necessary to evaluate to what extent vessel avoidance is likely to affect survey data for each given species and survey situation, taking into account factors such as noise pattern of the ship (Mitson, 1989, Anon., 1995), bottom depth, light conditions, and fish depth and density (Anon., 1995, Vabø 1999).

Management of small pelagic species such as sardinella in Angola depends strongly on abundance estimates obtained from acoustic surveys, and it is therefore important to gain quantitative knowledge about the impact of avoidance errors on acoustic estimates. sardinela often inhabit shallow areas (20-40 m bottom depth), where avoidance effects may be different from deeper areas. The present study was aimed at studying near-surface schooling and to report *in situ* effects of the presence of a research vessel on recorded acoustic densities of loosely aggregated, small pelagic fish off Angola.

Materials and methods

Two mini-survey experiments targeting pelagic aggregations of sardinela were conducted north of Lobito, Angola (Fig. 1) in the period 29 April – 2 May 2001. The experiments were conducted with the Norwegian R/V “Dr. Fridtjof Nansen” (DFN) in combination with the vessel’s man-over-board boat (MOB) (5.3 m long, 50 HP outboard engine). The MOB was equipped with a Simrad EY500 portable echosounder operating running a 38 kHz transducer (ES38-12), while the DFN operated a Simrad EK500 echosounder in combination with a keel-mounted 38 kHz transducer (ES38B). The setting of the acoustic equipment and calibration coefficients are given in Table 1.

Table 1 Acoustic settings and calibration coefficients.

Simrad EK500 menu	Settings
Carrier frequency	38 kHz
Mode	Active
Transducer type	ES 38B
Transducer sequence	Off
Transducer depth (m)	8
Absorption coeff. (dB/km)	10
Pulse Length	Long
Bandwidth	Narrow
Max. Power (W)	2000
2-Way Beam Angle	-21.0
Sv. Transducer Gain	27.37
TS. Transducer Gain	27.49
Angle sens. Along.	21.9
Angle sens. Athw.	21.9
3 dB Beamwidth Along	7.0
3 dB Beamwidth Athw.	6.7
Alongship offset	0.14
Athwartship offset	-0.02
Sound velocity (ms^{-1})	1498

Both experiments were carried out at daytime, experiment 1 between 11.00 and 14.00 (UTC time) and experiment 2 between 07.00 and 09.30. The MOB was operated at a distance of approximately 0.4 nautical miles (nm) ahead of the DFN (Fig. 2). The operation of the MOB was assisted via radio communication (portable VHF), using distance and bearing information of the MOB obtained from the radar on the DFN. The speed of the MOB was about 5 knots, which is the maximum speed that the MOB can operate the EY500 unit reliably with. The bottom depth in the study area was 20-50 m.

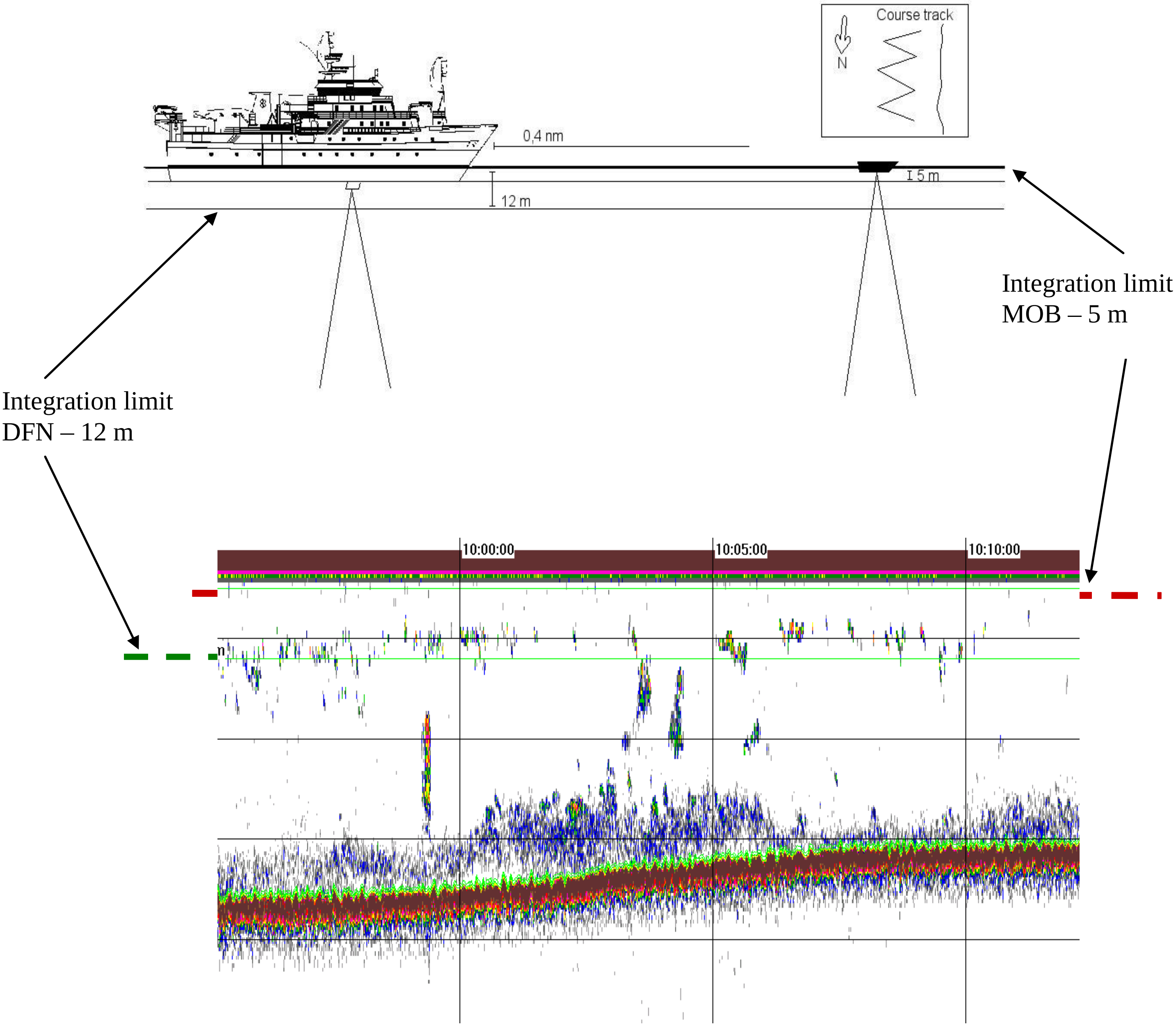

Figure. 2 Experimental set-up during the experiments

A sample of the surveyed fish aggregations was obtained on 30 April at 16.00 hours (local time), using an Åkrehamn pelagic sampling trawl fitted with Thyborøn 125” combi otter boards (7.41 m^2, 2030 kg). The codend mesh size was 24 mm (stretched mesh @ 5 kg pressure). The trawl was fished with the headrope at 10 m depth, giving an effective fishing depth interval of 10-20 m. The bottom depth was about 30 m.

The two vessels have different minimum upper integration limits, as the draft of DFN is about 7.5 m with the drop keel in lowered position, while the transducer rig for the MOB reaches 0.5 m down. These differences give minimum upper integration limits of about 12 m and 5 m for the DFN and the MOB, respectively. In order to obtain comparable estimates, two sets of s_A values were calculated from the MOB records; one from 5 m to the bottom, and another one from 12 m down to the bottom (Fig. 2). The datasets were matched according to the distance between the vessels during operation as determined using the radar, and then integrated over 5 min intervals in order to account for spatial variability in fish density. A total of 40 5-min intervals were computed, 21 from experiment 1 and 19 from experiment 2.

The 5-min intervals recorded using DFN were compared with those from the MOB using both 5 m and 12 m upper integration depths, hence comparing both equivalent sample volumes (DFN vs MOB_{12m}) and total sample volumes (DFN vs MOB_{5m}). Two separate paired comparison randomisation tests (Manly, 1997) were used to test the null hypothesis of no difference between the DFN and the MOB at the two upper integration limits. The test statistic used was the number of s_A intervals over which the DFN value was smaller than the corresponding value of the MOB (two-tailed sign test: Conover, 1980). A total of 10 000 randomisations was used. The significance level p was determined as the estimated probability that the observed number of 5-min integral pairs in which the DFN value was lower than the corresponding MOB value would occur due to chance alone, if there was no difference in S_A-values between the two vessels.

Results

Visual scrutiny of the acoustic records suggested that the surveyed population consisted of a mix of sardinella *S. maderensis* and other pelagic species. This was confirmed by the trawl sample, which contained a mix of *S. maderensis* (22 %) other small pelagic (73 %) and some demersal (5 %) species (Table 2). The true ratio of the sardinella was, however, probably considerably higher, as it actively avoids the fishing gear and therefore is generally difficult to catch, particularly during the day (Misund et al., 1998).

Table 2 Absolute (kg/h) and relative (%) catch rates for the trawl sample.

Species	(kg/h)	(%)
Chloroscombrus chrysurus	140.3	50.2
Sardinella madarensis	61.7	22.1
Selene dorsalis	24.6	8.8
Trichiurus lepturus	12	4.3
Sphyraena guachancho	9.2	3.3
Pomadasys jubelini	8.5	3
Galeoides decadactylus	6.9	2.5
Panulirus regius	3.8	1.4
Other pelagic species	12.4	4.4
Total	279.4	100

The matched echograms from the two vessels are shown for both experiments in Fig. 3. The overall integration results obtained using the DFN and the MOB show a consistent pattern across the two experiments. Lower densities are recorded with the DFN than the MOB when the 5 m upper integration limit was used, but higher densities when using the 12 m limit (Table 3).

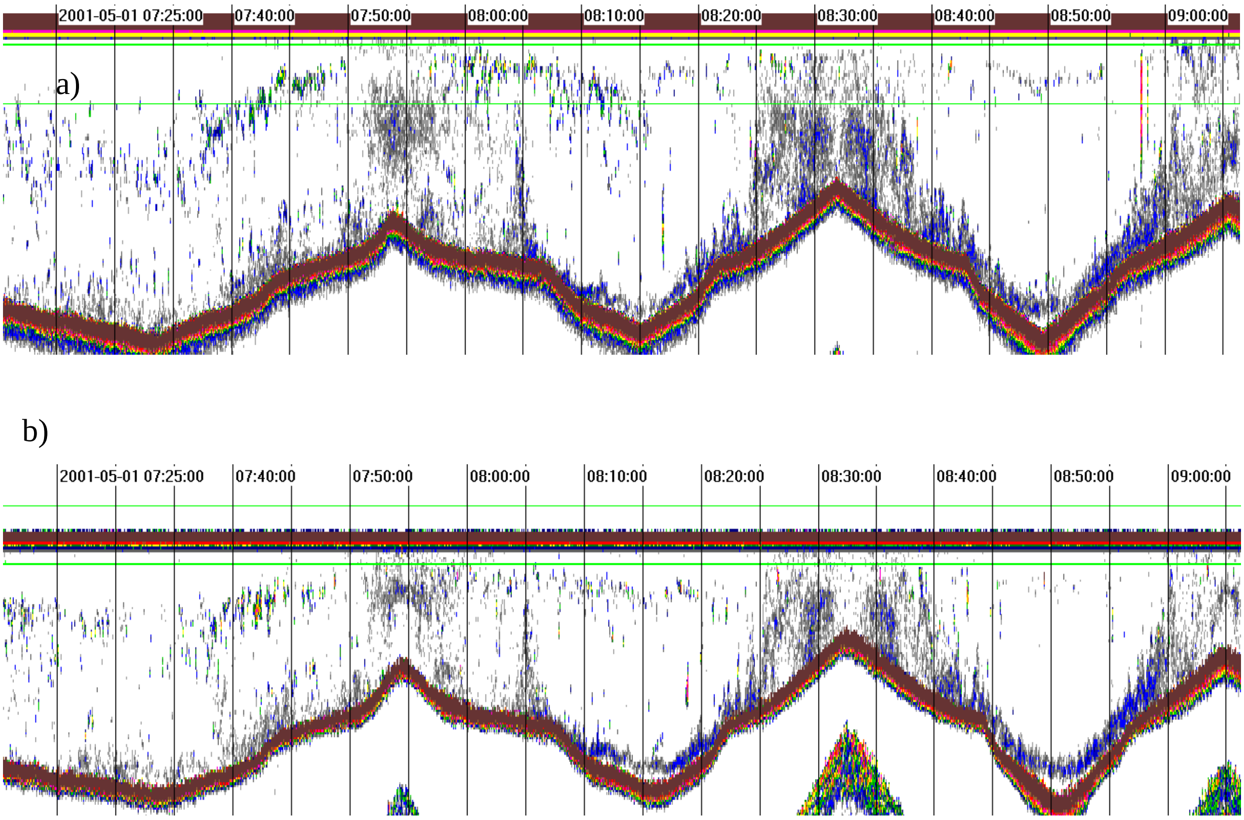

Figure. 3 Sv echograms showing comparative echo integration at 38 kHz using the man-over-board boat (MOB) (a) and the “Dr. Fridtjof Nansen” (DFN) (b). The green lines at 5 m and 12 m water depth show the two upper integration limits used for the MOB (5 m and the 12 m) and for the DFN (12 m). Note that the send mark is shallower at the MOB echogram (2-4 m) than on the DFN echogram (8-10 m).

Table 3 Comparative echo integration using the R/V "Dr. Fridtjof Nansen" (DFN) and the man-over-board boat (MOB) with different upper integration ~ limits (subscript). Average s_A (m^2/nm^2) is given with corresponding standard error of the mean in brackets.

Experiment	DFN_{12m}	MOB_{5m}	MOB_{12m}
1	818 (79)	984 (266)	805 (185)
2	1265 (212)	1589 (346)	968 (167)
overall	1030 (113)	1272 (218)	882 (124)

The average S_A-recordings from DFN were 19% lower than those of the MOB when considering the 5 m upper integration limit (Table 3). However, only 55% of the 5-min integrals from DFN were lower than the corresponding values from the MOB at 5 m integration. This percentage is not significantly different from the 50% expected under the null hypothesis (Table 4).

Table 4 Comparison of e s_A (m^2/nm^2) recordings from DFN and from the MOB using the two different upper integration depths .

Comparison	N^a	$N_{lower}{}^b$	p^c
DFN vs MOB_{5m}	40	22 (+5.0 %)	0.63
DFN vs MOB_{12m}	40	13 (-17.5 %)	*0.04

When comparing the DFN records with those from the MOB integrated from 12 m, it was seem that the average S_A-recordings from DFN were 17% higher than the average S_A-values from the MOB. In this case, up to 67.5% of the DFN 5-min integrals were higher than the corresponding MOB values, a percentage significantly different from 50% (Table 4).

Discussion

In this experiment, DFN recorded 19 % less fish than the MOB when considering the total sample volume of the MOB (5 m upper integration limit) and 17 % more fish than the MOB when considering equivalent sample volumes (12 m), but the number of intervals in which the s_A recorded with the DFN was lower was only significantly different from 50 % using the 12 m integration limit. The finding that fish avoid the survey vessel is supported by a range of other studies, both on sardinella (Fréon *et al.*, 1993, Gerlotto and Fréon 1992) and other pelagic species such as herring (Olsen *et al.*, 1983, Misund and Aglen 1992, Vabø 1999). Fish are known to avoid vessels both horizontally and vertically (Olsen *et al*,. 1983), and the results show that the fish in the present study avoided the vessel vertically, diving below 12 m depth as the DFN was passing over the fish. The avoidance behaviour compensated, at least in part, for the presence of fish above the upper integration depth, which otherwise would have represented a negative bias. Rather than representing an error, the avoidance behaviour in this case actually reduced the overall error level. The remaining difference between the 5 m-integrated MOB and the DFN may be explained by horizontal avoidance and/or steeper tilt angle of the fish, which would be expected if the fish dove (Barange and Hampton, 1994). However, any significant degree of out-of-beam avoidance should produce a higher reduction in s_A than that observed (Misund *et al.*, 1998) due to the narrow acoustic beam at short ranges (0.54-1.39 m from 5 m to 12 m depth for ES38B). Our findings are thus consistent with Gerlotto and Fréon (1992), who showed that sardinella distributed shallower than 20 m tended to avoid vessels vertically, and that the tilt angle was not very steep.

The effects of vessel avoidance on acoustic biomass estimates are known to vary between different situations regarding e.g. season, depth and density (Mohr, 1969, Olsen, 1971, Misund, 1994, Engås *et al.*, 1995, Misund *et al.*, 1996, Fernandes *et al.*, 2000). Migrating schools generally react stronger than feeding schools (Mohr, 1969, Misund, 1994, but see Olsen 1971). Mohr (1969) reported herring to react strongly to both vessel and gear during spawning migration, while Fernandes *et al.*, (2000) showed that North Sea herring did not exhibit any detectable significant avoidance during a mini-survey experiment.

It has been shown that fish tend to avoid in the direction of the sound propagation of the noise at the position of fish (Medwin and Clay, 1998, Olsen *et al*., 1983). Expected direction of evasive movements will therefore depend both on the distance from the ship and from the surface, as well as the noise propagation diagrams of the vessel within the frequency band that triggers the avoidance reactions (Mitson, 1989). In broad terms, this means that fish in front of the vessel will tend to be herded between the side-lobes of the vessel noise, fish closer to the vessel will tend to dive, while fish located on either side of the vessel would be expected to head further off from the ship (Olsen *et al*., 1983).

The bottom depth may play an important role in several ways: it represents an absolute boundary for the fish and act as an agent that will alter the generalized sound intensity diagram of the ship due to sound reflection from the bottom (Medwin and Clay, 1998). In simple terms, shallower bottom depths cause the side lobes of the vessel, and hence the herding effect towards the front of the ship, to increase. Effectively therefore, fish are herded in front of the ship to greater extents in shallow waters. Since small pelagic species targeted during conventional assessment surveys cannot sustain swimming speeds in excess of 10 knots, or even 5 knots as in the present study, the survey vessel will eventually pass over fish herded in front of the vessel. Our findings confirm that the surveyed fish avoided the DFN, providing some evidence that vessel avoidance may affect acoustic records of loose, shallow water aggregations of sardinella. In order to obtain more general results on the effects of vessel avoidance on biomass estimates, the experiments should be repeated and broadened to include other factors such as species mixing, target densities, vertical distribution and season, in particular regarding the situation of high-density surface schools of sardinella often encountered during assessment surveys.

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Chapter VIII GENERAL DISCUSSION

Fishery and resource Fluctuation

In chapter II, the dynamics of this fishery and of their supporting stocks during the last few decades was reviewed. It was concluded that the dynamics of marine living resource differ in the southern and the northern of Beguela Current system. In recent years unusually large biomasses of pelagic fish have been attained in the southern Benguela, whereas the pelagic ecosystem in the northern Benguela collapsed (Chapter II). A regime shift has been documented in the northern Benguela current that has been assumed to be controlled by mainly by environmental forcing, but there is a possibility (Cury and Shannon, 2004) that can be also induced by anthropogenic forcing (Steele 2004). Most of pelagic species in the northern Benguela are in the overexploited status, mainly sardine and Cunene horse mackerel, whereas sardinela stocks seem to be in relatively good shape (Chapter III). The landings of small pelagic species in Angola have reached a peak of 700 tons in the early 1980s, but have since declined appreciably, and today they do not exceed 200 tons (Chapter III). This reduction in landings off small pelagic are mainly associated with decrease in the abundance of horse mackerel that is considered to be seriously overexploited, and the fishery is seriously limited by a set of management measures targeting the recovery of the stock to sustainable levels. In addition the landings of sardinela are decreasing because the fishery has difficulty to catch appreciable amounts, possibly due to behavioural changes that make the schools less available to actual fishing gears used by the purse-seiners (Anon, 2010a).

The decline of Cunene horse mackerel off Angola have been attributed to a variety of causes including fishing pressure, density dependence and ecosystem changes mainly in the northern of Benguela Current system. The removal of larger fish through the intense fishing pressure impacts in the fish and age distribution. Currently, 90% of the bulk of the biomass of Cunene horse mackerel comprises fish< 21 cm. Density- dependence appears to be strongly linked to variability in several biological parameters of Cunene horse mackerel including length of maturity (Anon, 2010b) and condition factor (Barradas and Vaz Velho 2005).

The hydroacoustic surveys run off Angola by R/V "Dr. Fridtjof Nansen" since 1985 are an essential element for the production of scientific advice for the management of small pelagic fish stocks. To be able to correctly interpret the results of these surveys in the light of producing advice for fisheries management, however, it is essential to have knowledge of the natural dynamics of the ocean system and of the species dependent on it, as well an in-depth understanding of the limitations and characteristics of the abundance estimates produced.

This thesis provides an insight into the dynamics of the Angolan fishery for small pelagic fish, as well as into how behavioural characteristics of pelagic fishes of Angola, mainly horse mackerel, induce biases into the acoustic abundance estimation through information obtained in annual acoustic monitoring surveys.

Estimating the abundance of small pelagic fish from acoustic surveys

Target identification

The higher species diversity observed in Angolan waters is the most serious threat for target identification based on the frequency separation alone (Axelsen, 2007). Different taxonomic group have similar acoustic properties, and in such situation the results obtained in this thesis demonstrates (Chapter IV) that is a relatively striaforward analysis of conventional acoustic survey data collected with a single-frequency narrowband echosounder looks promising for species identification of schools over a large spatial area and a time-span of four years. The inclusion of ancillary variables can substantially improve species identification. In fact, with this approach success rate in order of 70-80% were obtained for single-species group, namely sardinela and Cape horse mackerel, which relatively similar with result found by Lawson, et al. 2001 for schools of anchovy, sardine, and round herring in the southern Benguela region. For Cunene horse mackerel, however, the success rate was relatively low. This reduced success rate can be attributed to the school behaviour that varies appreciably in space and time, with concomitant variation in school morphology, acoustic structure and position in the water column.

Vertical distribution and migration

Chapter V describes in detail the day–night differences in relative acoustic densities of Cunene horse mackerel. The diel variation on nautical-area scattering coefficient (s_A, m^2 nautical mile^{-2}) followed the expected pattern, as the Sa allocated to Cunene horse mackerel during the day was on average about 40% higher than at night. This difference between day and night estimates is considerable higher than that of other pelagic species like herring (Huse and Korneliussen, 2000). In general, this type of dynamics will influence the total acoustic density estimation of a species through several concurrent processes. One of these is the change in acoustic target strength (TS) of a swimbladdered fish that can happen for two main reasons. First, the size of the swimbladder will decrease with depth, causing reduced TS (e.g. Horne, 2003). Secondly, vertical fish movement is often associated with a change in tilt angle and thereby different TS compared to stationary fish (Hazen and Horne, 2003). In this case, the explanation would be that during the day fish are aggregated and polarized and the tilt angle distribution is more uniform and therefore maximal acoustic energy is reflected back towards the transducer. During the night, however, Cunene horse mackerel show a less organized behaviour, resulting in a more variable tilt angle, that may cause a substantial reduction in the echo abundance, as has been demonstrated in the model experiments developed for fish in Barents Sea (MacLenan and Simmonds 1992; McClatchie et al. 1996 ;Huse and Korneliussen, 2000), McClatchie et al. (1996) examined the relationship between standard deviation of tilt angle distribution and the average target strength. They conclude that when standard deviation increase 5 to 15 degrees, the average target strength decrease be about 2-3 dB. This corresponds to about 37% - 50% reduction in echo abundance.

Another possible explanation is related with the partitioning of backscattered energy for different group of species. At night the fish are disperse and identification of acoustic targets by discriminant analysis shows that in this period is not possible to identify clearly the combination of sardinela and Cunene horse mackerel in the mixed layers (Chapter IV). Therefore, in such situation, it is possible that a greater proportion of backscattered energy is allocated to sardinela, leading to underestimation of horse mackerel, since it is believed that sardinela has a stronger echo than horse mackerel.

Understanding the stimuli leading horse mackerel to the observed diel vertical migrations is also important to enhance our ability to predict the situations where this is most likely to affect acoustic abundance estimates. Habitat occupation by schools and school clusters is patchy and frequently reshaped by decisions aiming to minimize predation risk and maximize feeding potential (Pitcher et al. 1996; Misund and Beltestad 1998; Haugland and Misund, 2004). Horse mackerel schooling behavior follows the diel pattern of ambient light levels with looser aggregations and upward migration during the night (Chapter V), similar patterns were observed for other species of small pelagic fish. Fréon et al. (1993b) ; Beare et al.(2000) report on observations of clear diel migrations with a loss of concentration and school polarization during the night periods, while Giannoulaki et al .(1999) describes the movement towards the surface layers during the night. As other horse mackerel species, Cunene horse mackerel prey on zooplankton and crustacean and are subject to predation by other species (e.g. Kilongo, 1977). This study also confirmed that horse mackerel feeds mostly in the day time when is in the bottom (Pillar and Barange 1998; Barange et al. 2005), with maximum feeding activity between 14-00 to 16-00 hours (paper VI). During the night-time period the feeding activity is minimal and apparently ceases at about 20 hours GMT. Some feeding activity during the night is probably related with full moon (Hunter 1968), confirming the importance of light for feeding.

Avoidance

Avoidance behaviour differs substantially among setting and species, year class, biological states, environment condition and physical aspects of the vessel such us vessel speed, and the visual stimuli it emits (Olsen, 1990; Mitson, 1993). The magnitude ranges from a strong avoidance reaction (Olsen *et al.*, 1983a) to no reaction at all. Vessel avoidance behaviour may bias recorded acoustic densities by diving causing vertical displacement of densities and reduced mean tilt angle (Olsen *et al.*, 1983a). This kind of avoidance can only be detected by the lowering of the echo intensity (Røstad, et al.2006). This behaviour may also function by horizontal avoidance, with dilution of number of schools available for measurements by vertical echosounder (Misund and Aglen, 1992; Misund 1993 ; Soria et al. 1996).

The avoidance was in this thesis described as a vertical and horizontal reaction to the passage of vessel (Chapter VII). The results of this work confirm that the surveyed fish avoided the R/V “Dr Fridtjof Nansen”, providing some evidence that vessel avoidance may affect acoustic records of loose, shallow water aggregations of sardinella. The finding that fish avoid the survey vessel is supported by a range of other studies, both on sardinella (Fréon et al. 1993; Gerlotto and Fréon 1992) and other pelagic species such as herring (Olsen et al. 1983a; Misund and Aglen 1992, Vabø 1999). Most of these studies report avoidance behaviour that leads to reduced echo intensity and thus to negative bias in abundance estimation. This will indeed be the case if fish move out of the echosounder detection window, or change tilt angle in a way that reduces the intensity of the echo returned to the transducer. However, this is not always the case. In the work reported in this thesis, it was shown that at least in some conditions (shallow bottom, near-surface distribution of fish, and a given species mix), vessel avoidance may in fact lead fish from the upper dead zone into the detection window of the echosounder, and contribute to a more reliable estimation of abundance. Of course, this effect cannot be taken for granted in most situations, and care must still be exercised to reduce unwanted avoidance, but given the widespread observations of surface-distributed sardinela in Angolan surveys, and the fact that many of these fish often do concentrate on shallower areas (especially juveniles), it is clear that the effect of avoidance in these conditions should be further investigated.

In order to obtain more general results on the effects of vessel avoidance on biomass estimates, the experiments should be repeated and broadened to include other factors such as species mixing, target densities, vertical distribution and season, in particular regarding the situation of high-density surface schools of sardinella often encountered during assessment surveys.

Avoidance may also have an impact on other parts of the abundance estimation process, other than total echo intensity. An important part of acoustic surveys is trawl sampling for identification of fish species and measurement of species characteristics, such us fish length and weight (MacLennan and Simmond, 1992). The noise generated from a vessel and the gear fishing operation may have considerable effect on success of the catch. During day-time surface-distributed schools tend to avoid the gear sideways when being approached by the warps or the trawl doors (Misund et al. 1999) and this brings differences in the day and night estimations of the length frequency distribution, that may have important impacts on the acoustic estimates.

Consequences for management of small pelagic fisheries of Angola

Cunene horse mackerel *Trachurus trecae* and sardinella (*Sardinella aurita* and *S. maderensis*) are the most important small pelagic species off Angola. Both species support one of the oldest fisheries in this area, and are by their nature highly fluctuating even in the short term, associated to year-to-year environmental fluctuations (Chapter III). Because of their social and economic importance, and the need to adjust exploitation to the fluctuating abundance, an accurate assessment, especially on fluctuation of abundance is considered to be crucial in getting advice for effective and efficient fisheries management.

Reliable survey time series depends on standardized procedures to minimize the variability in abundance indices over time. Changes in the environment, variation in fish behaviour and distribution influence the relationship between the survey estimates and the true population size and structure. The need to understand the dynamic of pelagic species behaviour in the BCLME region was boosted in the year 2000 under the Benguela Environment Fisheries Interaction and Training Programm (BENEFIT) when a workshop *on survey errors* (Anon, 2000) was held. The main aim of the workshop was to identify a number of sources of error in acoustic surveys in BCLME region and made a first attempt to quantify the individual and combined effects on estimates of absolute abundance. The workshop recommended to conduct a studies through field experiments and analyzing of existing date, on the major source of error in the acoustic survey of the most important commercial resources in the region (horse mackerel, sardinella, sardine and anchovy) For Angolan pelagic species, the major sources of error were related with uncertainty in target strength, target identification, diurnal fish behaviour and near surface schooling (Anon, 2000). The fish close to the surface are normally not detectable because the downward-looking transducers on the survey vessel are located at depths of several meters, and record near field is unreliable (MacLennan and Simmonds, 1992; Aglen, 1994).

Sardinela is currently not fully exploited and level of stock is estimated in 420 mil tonnes with more uniform distribution, being *S. aurita* 47% tonnes and *S. maderensis* 53% of the total biomass. The two species of sardinella school together (Luyeye, 2002) with significant changes in behaviour during the day (Misund et al.1999). Visual and sonar observation have shown that around 50% of sardinella schools are at surface during the day, particularly in the warm season (Misund et al. 1999) and cannot be detected acoustically. During the *survey* *error workshop* undetected targets and vessel avoidance was recognized as major potential source error (Anon, 2000) representing a negative bias on the sardinella biomass estimation, with a likely range between 20 and 40%.

Final considerations and future research

The fisheries sector in Angola is key economic sector and pelagic species contributes for food security, proverty alleviation and job recreation and plays an important role to achieve the United Nations Millennium Development Goals. Ecosystem understanding to ensure the sustainability of marine resources become increasingly important for fisheries management and even more important is to implement a precautionary approach based on the best scientific knowledge.

During the past decade results from acoustic surveys are important components in modern assessment of fisheries resources and have in many cases replaced unreliable commercial CPUE time series (Gunderson 1993). In many countries, the results from acoustic surveys are interpreted in principle as absolute (Røttigen et al. 1994). Within acoustic survey methodology there is an incessant call for improving in order to reduce the uncertainty of acoustic abundance estimates. Absolute estimates may then be obtained when ´´true´´ target strength is employed and systematic behaviour errors are understood and subtracted from recorded acoustic densities (Vabø, 1999). Estimates are presented in biomass and number of individuals and .target strength is important to convert acoustic energy and fish density (Foote, 1987).Target strength was seen by Anon, (2000) as the major source of error in the acoustic estimation in the BCLME region particularly in the case of horse mackerel where direct in situ estimates made for Cape horse mackerel in South Africa (Barange and Hampton, 2004; Barange et al. 1996) and Namibia (Axelsen et al. 2003) range over an order of magnitude. Under the BENEFIT project in 2002 was attempt to estimate the target strength of Cunene mackerel using a EK 500 echosounder running a ES 38D submersible 38 kHz split beam transduce (Svellingen and Ona 1999). However, unfortunately, in the central and northern area was not finding a suitable aggregation of Cunene horse mackerel to run the experiment.

Target identification was also identified as the great challenge (MacLennan and Holliday, 1996) and the combination of General Discriminant Analysis (GDA) on common features of the acoustic recordings (Chapter IV) and on multi-frequency acoustic recordings, may add considerably toward development of automated species identification system. Currently, transducers operating at frequencies of 18, 38, 120 and 200 khz are available on the ecosounder of R/V “Dr Fridtjof Nansen”. Accordingly, the next step in the target identification project is to apply the multi-frequency approach as with this tool will be possible to incorporate other sound-scattering organisms, such us plankton.

Another major disadvantage when analysing trends in aggregated data is the lack of detailed behavioural data to explain the proximate causes for the observed patterns. Future survey methods should combine different methodologies to continuously monitor the survey condition and implement these observations in the standard density measures. For instance, the extent of vessel avoidance by fish is likely to vary between years and may have an effect on the biomass estimates of many pelagic species (e.g. Vabø et al. 2002; Ona et al. 2007). Until now, variable vessel avoidance has been ignored in the standard survey procedures. However, by examining artificial echograms constructed from sonar data, it is possible to quantify the effect of vessel avoidance on abundance estimates (Ona et al. 2006) and thereby adjust the survey estimates.

The observed diel variation in acoustic backscattering associated to the diel migration behaviour has serious implications for the consistency of the results of acoustic surveys. It is important to understand the mechanisms behind the observed variation, and the estimation of appropriate correction factors is an important task for future research. This could be done by further investigations on fish held in captivity under controlled condition. Based on such results, diurnal modulated TS models can be developed (McClatchie et al.1996).

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