Trends in the fishery and population traits of the Namibian stock of Cape horse mackerel *Trachurus trachurus capensis* (Castelnau, 1861)

By

Ipeinge E. Mundjulu

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Norwegian College of Fishery Science

Institute of Aquatic Bio-Sciences

University of Tromsø,

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DEDICATION

This work is dedicated to my Mother, Fiina Ndinelao Ipeinge and Father, Olavi Nekongo Ipeinge**,** and to my whole family for their undoubted love they have for me from the first day until this stage. I would like to say that, my achievements to the highest degree depend on you and I love you so much. To my beloved lovely late brother Josua, I wish you were here so that we could enjoy the fruits of my success, may your soul rest in peace.

ABSTRACT:

This study explored possible factors linked to the instability of the stock biomass of Namibian horse mackerel *Trachurus trachurus capensis* (Castelnau 1861) in recent years (2001-2007). The major focus of the analysis was the contrast of stock traits in years of low and high stock biomass, as perceived from research cruises performed annually between February and March. Stock traits analyzed included: recruitment and year class composition; spatial distribution of the stock; variations in fish body-mass condition and reflections on stock biomass; and maturation patterns and influences on spawning stock biomass. An additional analysis, also based on secondary data, explored the changes in effort capacity, activity and efficiency of the fishing fleet over a longer period of time.

Fish 0-3 years old dominate the stock at present, and the modes of the fish size composition appeared to be fairly stable along the years. Thus, length-growth seemed to proceed unaffected by changes in stock biomass. There was, however, a marked affluence of pre-recruits in the years of high stock biomass. Thus, stock biomass was related to recruitment (measured as fish <12cm), which varied by a factor of 20 between the years of high and low stock biomass. Study of the fish allometry showed a trend of decreasing b (exponent) and increasing a (proportionality constant), and this trend seemed to be temporal rather than density-dependent. This seemingly resulted in better condition of the fish, and increased stock biomass by up to 14%. Most of the fish during the survey period were found to be maturing. But, there was a strong declining trend in the calculated size at maturity, which did not seem to be immediately related to stock density. This resulted in a compensatory increase in the calculated spawning stock biomass with time. The spatial distribution of the stock has largely expanded after a reflux in 2002. This does not seem to be directly related to stock biomass, and may conceal migratory fluxes to/from a southern stock. The fishing fleets may have become more efficient at catching the fish, as the reduction in the fishing capacity is not reflected in the catches. Further, the nominal catch per unit effort showed stability and failed to reflect the decline in stock size, particularly in the last years of the series. The surveys seem to underestimate the occurrence of bigger sized fish, as compared to the midwater trawler fleet that more efficiently target the spawning stock. Contrastingly, purse-seiners efficiently target 1-year old fish. The catches of the different life-stages of horse-mackerel by both fleets seem to form a large phase-cycle that is partly conditioned by the occurrence of another species, the pilchard, and, thereby, by transference of effort of seiners between stocks. Rather than a single-species approach, a more strategic approach to management would probably be to consider a fishery system composed by two-prey and two-competing fleets, linked by strong economic and technological interactions.

KEY WORDS; Horse mackerel, stock-recruitment relationship, length frequencies, length at maturity, spatial distribution, growth condition, CPUE, technological creep.

1. INTRODUCTION

1.1 The fishery

Harvesting of horse mackerel (*Trachurus trachurus capensis)* in Namibian waters started in early 60s with midwater trawlers (Hampton 2003). Following exploitation by a great number of foreign midwater trawlers a purse seine fishery started in 1971 targeting juvenile horse mackerel (Boyer and Hampton 2001). Before the introduction of purse seine fleets, the average annual landing averaged 62 000t, with the highest catches reaching about 126 000t in 1965 (fig 1). After that, and partially because of the new seine fishery, the landings quickly expanded, reaching the all time high of 660 000t in 1982 (MFMR). Before independence in 1989, the total catches fell to 479 000t. At independence, in 1990, the Government of Namibia, through its Ministry of Fishery and Marine Resources, took control over the harvesting of marine resources. This led to a large decrease in the number of foreign vessels operating in the Namibian exclusive economic zone (EEZ). One of the policy aims was to reduce fishing pressure on horse mackerel, as well as on other fish stocks (Hampton 2003). From 1990, the landings were relatively stable at 400 000t upto 1993, thereafter from 1994, the landings further declined to 300 000t which has been relatively stable with small variation until 2006. The catches of 2007 were lowest catches of all time (191 000t) (fig 1).

Currently, horse mackerel is marked to be the biggest fishery in terms of landed volumes in Namibia (Hampton 2003,) (fig 1). The exploitation is still done by the midwater trawlers and purse seine vessels; whereas midwater trawlers target adult horse mackerel the purse seine fleet targets juvenile horse mackerel (Boyer and Hampton 2001, Hampton 2003. Most midwater trawlers (MW vessels) involved in the fishing operation are big in gross registered tonnage, and processing of the fish takes place onboard. Their catches (MW) is processed as whole frozen fish, but 10% of the volume is used for fish meal and approximately 5% is dried (Hampton 2003). Horse mackerel is regarded as a relatively low value fish and it is mostly exported to African states and eastern European countries, including Russia (Anon 2001).

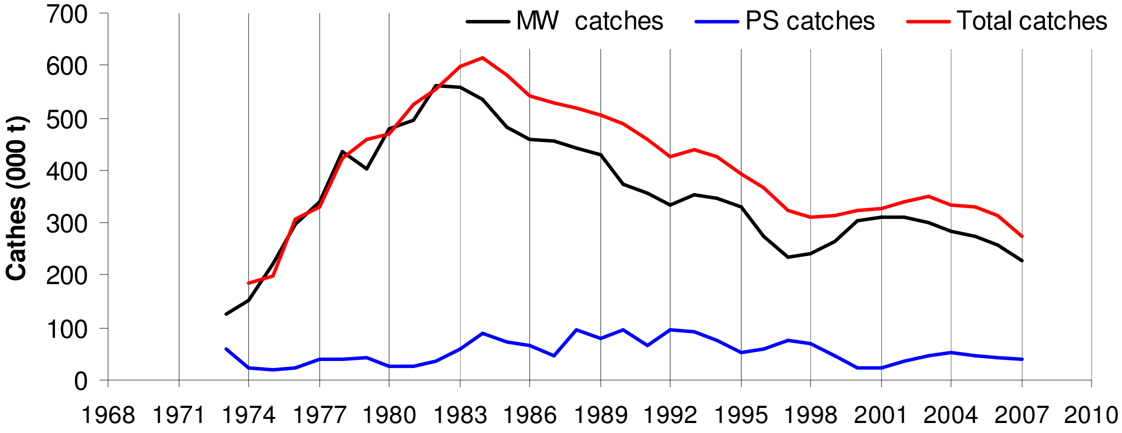

Figure1. Time series of landings of horse mackerel by the Midwater (MW) and Purse seine (PS) fleets in Namibia (MFMR)

1.2 Stock distribution and definition

It is believed that, there are two conspecific stocks of horse mackerel within the Benguela region (Hetch 1990). One stock spans northwards from central Namibia to southern Angola, while the other stock originates off the southern Africa's west coast (South Africa's Western Cape) (Hetch 1990, Naish *et al* 1991; Kerstan and Leslie 1994,). The two stocks are said to constitute two independent spawning units isolated by oceanographic features off southern Namibia (Naish 1991). Agenbag and Shannon (1988) provided evidence of the existence of a biological boundary created by the Luderitz upwelling at 24° 30'S. The northern stock of horse-mackerel, hereafter called the Namibian horse-mackerel, is the most important for Namibia, and is the target of the present study.

According to research surveys conducted in the Namibian waters (Krakstad and Kanandjembo, 2001), the highest concentrations of the horse mackerel are found between 17˚00 S-20˚00 S, that is, in the central and northern part of the country (Figure 1). The fish size distribution follows both the latitude and the isobaths: smaller fish are more abundant in the north, around the Kunene river, at depths shallower than 200m (Bauleth-D'Almeida *et al***.,** 2001). Adults are found further offshore over the 200m-500m isobaths (Bauleth-D'Almeida *et al.* 2000, 2001, 2003, Krakstad *et al.* 2002, and Kanandjembo *et al.,* 2004

1.3 General Biology

A study by Krakstad and Kanandjembo 2001 reported the maximum observed age and length of the Namibian horse mackerel to be 10 years and 51cm respectively. Systematic ageing studies and growth modeling performed by Wilhelm (2006) suggest that fish aged 1, 2 and 3 years have average lengths of 15.0 cm, 19.5 and 23.6cm, respectively. The estimates of the size at 50% maturity reported vary from 19-21 cm total length (Krakstad and Kanandjembo 2001) to about 17.5 cm for both sexes (Wilhelm 2006). The dynamics of the cohorts seem to be moderate, with a von Bertalanffy growth index (K) of 0.12-0.15, L_{inf} =51cm and t_0= -2.31, together with an instantaneous natural mortality rate of 0.4/year reported by the previous authors (Bauleth-D'Almeida 2007, unpublished report., Willem 2006)

A study by Barange *et al.* (2005) showed that schools of horse-mackerel perform diel feeding migrations in the water column: most adults approach the surface waters during the night to feed and descend to deeper waters during the day. About (95%) of the adult's diet consists of euphausiids and fish, but a wide-range of invertebrate prey is normally found. Juvenile horse mackerel feed greatly on copepods of the genus *Calanus*. Seals are an important predator of horse mackerel (Mecenero *et al*. 2006a) and they feed predominantly on juvenile fish. Other predators are the hakes, which are the most valuable fishery stocks in Namibia, and some sharks and rays (Bauleth-D'Almeida *et al* 2001).

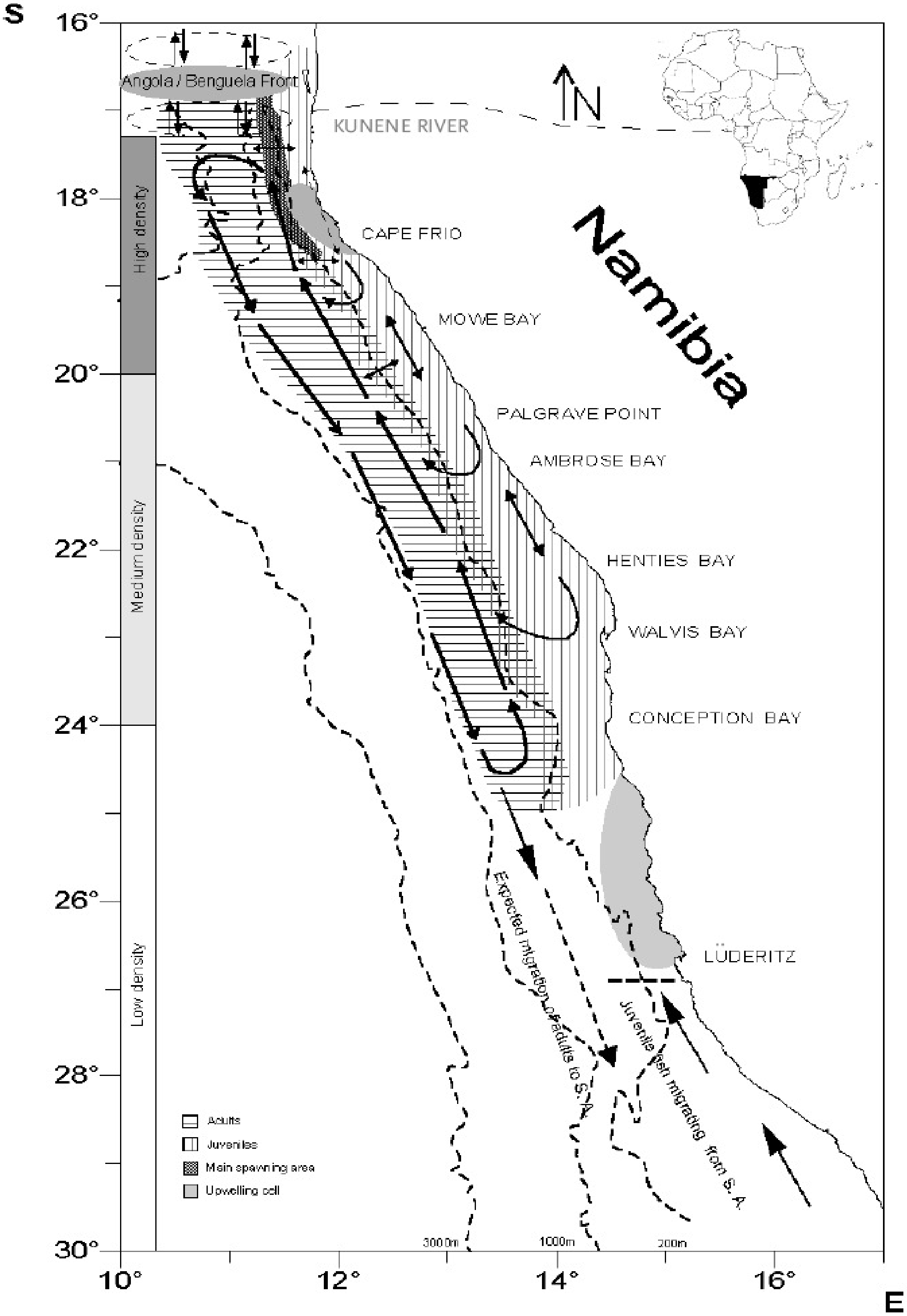

Figure 1. General distribution of Namibian Cape horse mackerel (Axelsen *et al.*, 2004)

2. STOCK ASSESSMENT AND MANAGEMENT

From the early 1970s to the late 80s, estimates of stock size were performed by means of Virtual Population Analysis (VPA) with basis on catch statistics obtained from commercial vessels targeting horse mackerel (Vaske *et al* 1989). By then, estimates of stock size were between 1.5 and 2.5 millions metric tons (Vaske *et al* 1989). This information is understood to be biased with regard to age length keys and catch data that were used at the time (Boyer and Hampton 2001). From 1980 to 1989, the International Commission for South East Atlantic Fisheries (ICSEAF) started regulating exploitation of the horse mackerel by setting catch limits, or Total Allowable Catches (TAC) (Boyer and Hampton 2001., Hampton 2003). By then, the annual catches were at their all times high, above 600 thousand tons (figure 3).

After Namibia gained independence in 1990, stock monitoring has been conducted through a combination of catch statistics from commercial vessel; the fishery-dependent information, and acoustics surveys from survey vessels, the fishery-independent data. The research information (surveys) forms, however, the keystone to the assessment and management procedures (Bauleth-D'Almeida *et al.* 2000, 2001, 2003, Krakstad *et al.* 2002; Kanandjembo *et al.,* 2004, 2005, 2006, 2007). The hydro-acoustics surveys are conducted every year during February and March. Stock assessment is done by means of two assessment methods; The VPA, an age based method, and acoustic biomass assessment (Krakstad and Kanandjembo 2001).

Fishing mortality for horse mackerel is set at 0.3M and 0.1M for adult and juveniles fish respectively (Krakstad and Kanandjembo 2001, Bauleth-D'Almeida *et al***.** 2001). Krakstad and Kanandjembo 2001 also stated that, fishing mortality for juvenile horse mackerel is set low to avoid recruitment overfishing. With regard to input controls, midwater fleets are only allowed to fish from a 200m isobaths and there is no restriction to purse seine vessels. In addition, midwater trawlers are required to have a 60mm mesh size with 50% retention of 23.5cm fish size while the purse seine are restricted to a 12,5mm mesh size and they are expected to leave any fishing grounds if their haul consists of fish that are less than 12.5cm. Mostly, 86% of the purse seine fishing is done in depths of less than 50m and 12% at 50-100m isobaths (Mecenero *et al* 2006).

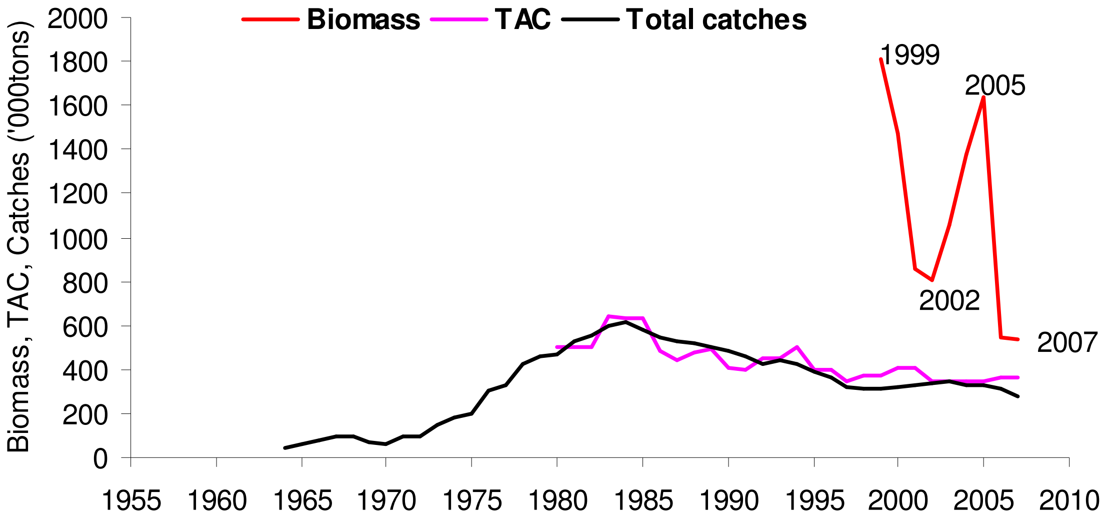

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Figure 3. Estimated total stock biomass, TAC and landings of the Namibian horse mackerel (MFMR)

While early accounts (Krakstad and Kanandjembo 2001, Bauleth-D'Almeida *et al***.** 2001) describe a conservative management scenario implemented to avoid recruitment overfishing, recent statistics cast some doubt about the policy actually implemented in recent years. Thus, while the stock biomass estimated in 1999-2007 varied about three-fold (coefficient of variation, CV, 42%) the TAC remained constant (CV, 6%), and seemingly too high in periods of low stock density (Figure 2). Strikingly, the TACs set in 2002 and 2007, the years of lowest estimated densities, were close or exceeded 50% of the stock biomasses. It is estimated here that this corresponded roughly to annual instantaneous fishing mortalities (F) of 0.6 and 1.2, respectively, in those two years, when F is calculated in terms of yield/biomass.

Against a background of highly variable stock size (assuming perfect estimates from research) the recorded catches show less variability (CV 16%) and, until recently, poor relationship with the perceived stock abundance (Figure 2). However, as the time-series indicates, since 2006 the estimated stock biomass plummeted to historical low values. From a theoretical perspective at least, a policy of a fairly constant TAC as shown, can be risky if it is not set at a conservatively low value (Caddy & Gulland 1983). Such a low conservative TAC would accommodate fluctuations in stock size, which can have totally natural causes (ecosystem or stock dynamics) but be amplified by the fishery in cyclic predator-prey like manner. One of the difficult issues in this regard is to separate the forcing environmental actions from the fishery pressure. However, little is known between the relationship of horse mackerel stock abundance and seasonal changes, sea surface temperature and oxygen (Krakstad and Kanandjembo 2001). Other sources of mortality, such as predation, cannot be ruled out, but consistent time-series of indicative data are difficult to obtain. Judging from the catches alone, however, this stock of horse-mackerel can hardly be classified as a spasmodic or irregular stock (in the sense of Caddy & Gulland 1983). Unlike the Namibian sardine, which allegedly suffer large environmentally-driven fluctuations, the trend in catches is apparently smooth and predictable. According to the same definitions this could be classified as a relatively regular stock.

3. PROBLEM STATEMENT

3.1 Research focus

Whatever the reasons may be, the available time-series gives an indication of a stock in the verge of collapse (in the fisheries sense) in the near past. In this work, it seemed reasonable to investigate if the fluctuations in the stock biomass might have been caused, or aggravated, by one, or a combination, of factors. The following are the research questions of this thesis:

RQ1. Changes in the geographic distribution

If by some density-dependent mechanism the fish become more concentrated in years of low abundance the stock may become increasingly vulnerable to predation and fishing.

RQ2. Changes in recruitment and year class composition.

Years with low stock biomass could be as a result of poor recruitment. In this case, the fishery may be heavily targeting the parental stock, and this can give rise to a negative feedback that causes a further reduction in next year's recruitment stock. This aspect can only be resolved after an analysis of the size composition of the catches of the two fleets with reference to the research survey.

RQ3. Changes in growth and condition of the fish

Changes in the perceived stock biomass can be also brought about by factors that may have a density-dependent or density-invariant effect. Is there an apparent change in size of the fish from year to year? Or does the condition of the fish (weight at length) increase with decreasing stock biomass, in a density-dependent fashion?

RQ4. Changes in maturation pattern and spawning stock biomass

How do sex-composition and maturation patterns vary from year to year? Does maturation size vary in a density-dependent or temporal manner? How does the perceived spawning stock biomass change as a function of time or stock biomass? Does a decreased maturation size of the fish respond immediately to variations in total stock size?

RQ5. Changes in fishing pattern and efficiency of the fishing fleet

The fishing fleets have become smaller, but how does this reflect in the nominal and effective fishing effort? Further, horse mackerel is known for its gregarious behavior (Mecenero *et al* 2006), and schools may remain an easy prey for midwater trawlers and seiners, irrespective of stock size, provided that the schools do not disperse. This aspect can be coarsely analyzed by comparison of trends in catch per unit effort.

RQ6. Interactions between the fishing fleets

How do trends in catches relate between fleets? Are there any signs of synergistic competition for fish that could re-enforce the perceived decline in the fishery?

3.2 Approach

The present work is a desktop study based on secondary data, the extensive survey reports produced by NATMIRC as well as catch and fleet statistics compiled by MFMR. As such, no novel data will be presented here, but it is still hoped that the analyses and findings contribute to better management of the fishery. The available data from research surveys sampling is very large (1999-2007), and a compromise had to be made between depth and generality of the study. These extensive data refer to the spatial distribution, size (length) composition, sex and maturity of horse mackerel. Thus, the present study will focus only on a selection of years of perceived high and low stock biomass. As shown in Figure 2, considerable high stock biomasses were measured in the years 1999, 2000, 2004 and 2005. Contrastingly, 2001, 2002, 2006 and 2007 were perceived as years of relatively low biomass. However, not all these years could be used for the analysis due to unavailability of data. Therefore, only 2003, 2004 and 2005 were here treated as years of perceived high stock biomass, and these were contrasted with the low biomasses of 2001, 2002 and 2007. Year 2006 data were not available. Although 2003 was in reality perceived as the year of median stock biomass (in this particular, short series) it is here included in the group of “high perceived biomass”.

Often along this report, the analyses are conducted in a fashion that highlights *temporal trends*. These results are then contrasted with analyses that focus primarily on *density-dependent effects*. The purpose of this strategy is to investigate whether population parameters (e.g. size at age, or maturation size) are likely to respond quickly to changes in the perceived stock biomass or rather respond to long temporal trends. It is an axiom of this study that the perceived stock biomasses, derived from acoustic surveys, correspond to the perfect information. It is known from the general literature that surveys are subject to error, sometimes considerable error (Bauleth D'Almeida *et al* 2001), and this will be taken into account, where possible, in the interpretation and synthesis of the findings.

4. MATERIALS AND METHODS

4.1 Data collection

The data used in this work were secondary data that were kindly made available to the author by the Ministry of Fisheries and Marine Resource of Namibia. Informal interviews were also held with fishery scientists with the aim of further clarification of the sampling methodology. Reports of in depth outline on how the surveys were being carried out are accessible at National Marine Information Research Center Namibia (NATMIRC).

4. 2 Types of data used

4.2.1 Length data

The length frequencies per length class were used to analyze the annual length class composition in catches of horse mackerel for surveys, purse seine and midwater trawlers. The survey length data were taken from appendixes of each year's horse mackerel cruise report. These data were already treated: the number of fish caught per length class were raised into an approximate number of fish per haul, stratum and total) by the scientists at NATMIRC. The equations and an in-depth description of survey methodology is well documented in annexes II and IV of both the 2005 and 2007 horse mackerel's cruise reports (Kanandjembo *et al.* 2005, 2007 and Uanivi U., (NATMIRC, pers. com, 2007). Length composition data of fish caught by midwater trawlers and purse seine fleets were also provided by Mr: Uanivi, a biologist at the horse mackerel department at NATMIRC. For midwater length frequencies, the numbers of fish caught per length class were also raised into an approximate number of fish per haul and total. However, similar length frequencies were not available for the seining fleet. For this fleet, the only length data secured were yearly samples ranging from about 140-600 fish collected at the reduction factories onshore. The overall representativeness of the fish length data from purse-seiners seems therefore less certain than for others. In summary, the length data used for the analyses of annual fish length composition were:

- ✓ Survey length data- Length frequency in number of fish (raised to millions)
- ✓ Midwater length data- Length frequency in number of fish (raised to millions), and
- ✓ Purse seine Length data- Length frequency of fish that were collected for biological sampling, following an assumed random selection.

4.2.2 Biological data

Biological analysis was only done with the survey data. Length at maturity as well as weight data were extracted from the horse mackerel surveys database obtained from NATMIRC.

4.2.3 Biomass data

In the survey reports the allometric relationships (of the type given by equation 1) are estimated for each stratum, and the observations are then combined to provide the final parameters for the area sampled. These global parameter derived in each cruise were here utilized to estimate the corresponding annual biomasses. The biomasses had sometimes to be re-calculated for different analyses, using the same methodology and parameters used by scientists at NATMIRC. Although there were some deviations, on average they were not greater than 0.01%, and these were deemed to be small rounding errors. The length data for Midwater trawlers was converted into biomass using the allometric relationships obtained in surveys in the same years.

4.2.4 Geographical information

The distribution of horse mackerel along the Namibian coast is demarcated into two zones, inshore and offshore coverage, which were further divided into strata (Appendix 5.). This information is available from each horse mackerel cruise report, and biomasses were calculated for each stratum using the overall allometric relationship..

4.2.5 Fishing effort

The fishing effort and CPUE for midwater trawlers were available from a report compiled by Uanivi U. 2007 which is available from NATMIRC. It was not possible to secure similar information for purse-seiners. In addition, part of the effort performed by seiners is directed towards pilchard rather than to horse-mackerel. The disaggregation of this effort into species would require additional information that was available here.

5. DATA ANALYSIS

5.1 Size composition

The number of fish caught per length class during surveys were raised into an approximate number of fish per haul by the scientists at NATMIRC. Equations and an in depth description of how this was done is document in annex II and IV for 2007 and 2005 horse mackerel cruise report (Kanandjembo *et al.* 2005, 2007). Equations used to raise the number of fish per length class into the approximate number of fish per haul for midwater is documented in Uanivi U unpublished reports 2007 and is available at NATMIRC. No alteration was done to these data.

For surveys, the length frequencies per length class per stratum were summed up to get the total number of fish per length class per year. Midwater length frequency were not separated per areas, as they were already available as the total number of fish per length class per year. No alteration was done in this case. For purse seine, the original length classes had 0.25 cm intervals, and these were summed up to the nearest 0.5cm. Histograms were used to plot the total length frequencies of each year, in order to determine the modal length for each fleet per year. In the simplest cases, statistics were calculated, and charts were drawn, using Microsoft-Excel. In addition, the median length and 5% and 95% percentiles for each fleet was calculated from the length frequency tables. This required the utilization of a statistical package (SYSTAT 10) that could easily handle frequency data

5.2 Stock biomass

5.2.1 Survey stock biomass

The general length-weight relationship is described by the allometric power function of length (eq. 1),

$$weight = a.length^{b}, \qquad (1)$$

Where *a* is the length-weight proportionality coefficient and *b*- is the allometric exponent and the overall allometric relationship were pooled to determine the allometric relationship for a particular year. The biomass per length class per stratum (equation 2) was based on equation (1):

$$B\ (t) = (N\times\ (a\times (L+0.25)^{b}) \qquad (2)$$

A correction factor of 0.25 cm was used because the fish length was measured to the nearest 0.5 cm.

where; B (t) - Biomass, N- Number of fish per length class, L- length class and *a* and *b*, are the parameters of the length-weight relationship. The factor 0.25cm was added to provide the mid-class size. The biomasses per length class per stratum were summed up to get the total biomass per year. The same procedures were used to calculate the biomass extracted by midwater trawlers given the total length composition of their catches. However, a correction factor of 0.5 cm was used here since the fish in midwater trawler catches were measured to the nearest 1 cm.

5.3 Reproduction and Maturity

During the cruises frequent samples of horse-mackerel are sexed and maturity stages determined according the criteria show in Table 1.

Table 1. Maturity stages of horse mackerel (classification by MFMR)

Maturity Stage	Females	Males
0 - Unknown	Maturity stage unknown.	Maturity stage unknown.
1 - Juvenile	Difficult to sex. Ovaries very small, thin, pale pink.	Difficult to sex. Testes very small, flat and leaf-like. White or pink.
2 - Immature	Ovaries less than ½ the length of body cavity. Pale pink to pinkish yellow. Almost transparent. No eggs visible.	Testes less than ½ the length of the body cavity. Testes start to thicken and become longer. White or pink.
3 - Maturing	Ovaries longer and thicker, more than ½ the body cavity. Colour pale yellow to darker yellow, sometimes reddish). Eggs visible, appear mainly as distinct granules.	Testes longer, thickened and more than ½ the body cavity. Colour white or pink.
4 - Ripe	Just before spawning. Ovaries filling the body cavity. Colour red. Gonads break easily and are more jelly-like. No longer opaque but almost transparent due to presence of ripe eggs throughout the ovary. Eggs are generally bigger than in stage 3. No eggs come out of the cloaca when a light pressure is applied to the belly.	Just before spawning. Testes almost filling the body cavity. Colour white or pink, posterior half (back half) of testes milky. No sperm comes out of the cloaca when a light pressure is applied to the belly.
5 – Spawning / Running	Eggs come out of the cloaca when a light pressure is applied to the belly. Transparent eggs throughout ovary.	Sperm comes out of the cloaca when a light pressure is applied to the belly. Testes milky.
6 - Spent	Ovaries long, flat and empty due to recent spawning of eggs. Dark red appearance, sometimes jelly-like. Difficult to distinguish from stage 7.	Testes long and flat, strap-like and very bloodshot. Difficult to distinguish from stage 7.
7 - Recovering	Ovaries more than half the body cavity. Still red in colour, but starting to thicken. Small eggs may be visible.	Testes more than half the body cavity. May still be bloodshot, but starting to thicken.

Only survey data were used for maturity analyses. A pivot table was used to calculate and plot the maturity stages per sex, as well as the overall fraction at each maturity stage. This was done to analyze the degree of maturity development along the years.

A logistic (symmetric) model was fitted to calculate the fraction of fish that were expected to be mature, following the methods of Wileman *et al.* 1996, described by Millar & Freyer (1999) (equations 3-7). The total number of matured fish per length class and the frequency of such length class are the input to the fit. Only fish considered to be stage 3 or above (Table 1) were considered to have achieved full maturity in that year. The model was run using solver in Microsoft excel for each year's maturity data set.

F_{mature} (L) = $e^{(a+b.L)}/1+e^{(a+b.L)}$ (3)

Where; e- exponent, a- alpha parameter, b- beta parameter, and L- fish length.
The model calculated L_{50}, L_{75}, L_{25} and the maturation range L_{75}-L_{25} by the following forms;
L_{50}; (size at maturation) = $-a/b$ (4)
Maturation range (MR); $L_{75}-L_{25} = 2\times LN\,(3)/b$ (5)
Where LN is the natural logarithm
$L_{75} = L_{50}+0.5\times MR$ (6)
$L_{25} = L_{50}-0.5\times MR$ (7)

The L_{50} trend was plotted in Microsoft excel. In order to measure the spread of the maturation curve, L_{25} was made the lower part of the error bars and the L_{75} represented the upper part of the error bars. In this way, steeper maturation curves have lower "error" bars. To calculate spawning stock biomass the fish were assumed to mature in a knife-edge manner, described uniquely by the annual L_{50}. The spawning stock biomass for each year was calculated as a fraction of the total biomass (eq. 8), to determine the fraction of the parental stock to the whole stock biomass.
%spawning stock biomass = spawning stock biomass/total biomass (8)

The total biomass, as well as the spawning biomass, extracted per midwater trawlers were calculated in the same way as above, using the total size composition of this fleet as the basic input data

5.4 Influence of fish condition on stock biomass

Fish condition (body weight related to length) may vary from year to year as a result of better or worse feeding opportunities, something that in principle can be detected in the annual allometric relationships (equation 1). Although it is possible to analyze these trends in overall condition by means of statistical tests of the combined parameters of the allometric relationship, this may not be very informative. An alternative permutation method, the calculation of pseudo-biomasses, was preferred here. A “pseudo-biomass” is here defined as the stock biomass for year X calculated with the (correct) length-distribution (survey) observed in year X and the (wrong) allometric relationship for year Y. The ratio between the true biomass, calculated with the correct allometric relationship for year X, and the pseudo-biomass for year(s) Y allows for more precise quantification of changes in condition factor alone, i.e. independent of changes in length-growth.

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5.5 ANALYSES OF FISHERY DATA

The available time-series of fishing capacity and activity for the midwater trawler fleet were analyzed for an extended period (1961-2007). To account for possible influences of technological development, the best and most descriptive time-series of nominal effort were corrected for possible technological creep using information from the literature (Kirkley 2004). The trends in catch rates of the Namibian horse mackerel were determined using the midwater trawlers fleet only. The average CPUE was plotted along years and simple trend lines were fitted. Following the usual assumption of constant proportionality between CPUE and stock size a linear distribution of the observations would be expected. If the fish form schools and their catchability remains constant and fairly independent of stock size, a curve with a ceiling, e.g. a power line or Cobb-Douglas function (Marchal *et al* 2006), would alternatively describe the relationship more adequately. This is also know as hyperstability. Only visual inspections of the fits were performed. Similar analyses could not be performed for the purse-seine fleet for lack of specific data, as described above.

To inspect the possible interactions between fleets, and the additional influence brought about by management controls two analyses were performed. A qualitative narrative of quota allocation to the two fleets was made with basis on fishery statistics and trends in captures. The management actions were attempted inferred from these numbers (individual TAC) because no descriptions of the yearly quota allocation processes were available. To analyze the biological interactions between the two fleets, partly conditioned by the abundance of a second resource, the pilchard, a bi-plot of the time-series of captures of horse-mackerel by the two fleets was performed. This bi-plot takes the shape of a phase-diagram, as e.g. suggested by Holling (1973) for two competing predators. The advantage of this visual representation is that it gives a suggestion not only of positive or negative relationships between the two predators /fleets, but also of the temporal sequence of these interactions.

6. RESULTS

6.1 Horse mackerel size composition

6.1.1 Surveys size composition

The size composition of horse mackerel between the years of low and high stock biomass is shown (fig. 4). During the years of perceived low stock biomass, the main modal length class was between 15-16cm fish which were about 2 years old, (assuming the growth described by Willem 2006 Appendix 1). Years 2002 and 2007, appeared to have a relatively unimodal length frequency distribution, however, year 2001 had bimodal length frequency distribution, where the pre-recruits (8cm, 0-year old fish) seemed to occur in moderate quantities to make up the lower modal frequency distribution.

Further, in years of perceived high stock biomass, the main modal length frequency distribution was also between 15-16cm fish, with the exception of 2005, which had 11cm fish, making up the main modal length class of that year. Years 2003&'04 had a bimodal length frequency distribution; the lower modal group had 12cm fish. This suitably, demonstrates a peak of good recruitment at lengths of 11-12cm which are the 1y old recruits (Wilhelm 2006), which an important part of the stock.

Moreover, the recruitment class, fish <12cm, can account upto 23% of the total stock biomass assuming that high recruitment was reached in 2005 when the stock biomass was the highest of all the years (table 2a). Further, comparison of the recruitment strength between 2005 & '07, years with the lowest and highest stock biomass, showed that, the recruitment strength in 2005 was 300100 billions of fish and 1268 billions fish in 2005 which (table 2b) corresponded to 382000 and 18000t biomass respectively. This, be a sign of recruitment variation between the highest stock biomass and the lowest stock biomass, showed that, recruitment varied by a factor of 20 both by the number of per-recruits and their biomass. The major variation in the fish size in the stock (surveys) was in the occurrence of smaller fish (recruitment stock)

Table 2a. Variation of the pre-recruits stock biomass, to the total stock biomass. The variation factor shows the variation in recruitment strength (per-recruits biomass), where year 2005 was made a reference point because it had the highest per-recruit stock biomass

Year	Total Biomass	Biomass of Pre-recruits (<12cm)	Variation factor of Pre-recruit biomass	% of Pre-recruits to total biomass
2001	856112	103000	27	12
2002	802172	24000	6	3
2003	1059300	33000	9	3
2004	1374707	115000	30	8
2005	1639979	382000	100	23
2007	534196	18000	5	3

Table 2b. Variation of the number of pre-recruits length class, to the total number of fish. The variation factor shows the variation in recruitment strength, where 2005 was made a reference point of the highest recruitment strength.

Year	Total No. of fish	No. of pre-recruits	Variation factor of No. Of pre-recruit	% No of pre-recruit to total No. Of fish
2001	30403	11325	38	37
2002	18180	1627	5	9
2003	19087	2381	8	12
2004	35862	7562	25	21
2005	50803	30010	100	59
2007	11876	1268	4	11

Overall, the survey length composition appeared to have several modal length frequency distributions, whereby these modes occur at relatively fixed sizes each year, in spite of changes in the total stock biomass. The largest modal group is usually made up of 15-18cm fish (2year olds), while the second main mode consist of 11-12cm fish (1year old), and the lowest modal distribution consist of 5-8cm (0-year old) and 21-23 (3year old). The older fish in the survey length is not clear to analyze because they are not that frequent in surveys catch sampling.

6.1.2 The fisheries

As mentioned before, the horse mackerel is exploited by two fleets, whose operations are restricted with regard to the isobathic zone in which they operate, as well as the mesh size. The midwater trawlers were expected to be catching the adult stock (23cm fish) and the opposite is true for the purse seine fleets (fish >12.5cm).

In this study, the Midwater's catches had a fairly constant length frequency distribution (20-26cm; 3year olds, with a possible mixing of 4 year old fish) regardless of the stock biomass. On other hand, the purse seine catches length frequency distributions were more variable with regard to the stock biomass. During the years of perceived high stock biomass, their catches had a unimodal length frequency between of 15-16cm fish (1year olds). But in poor years, their modal length frequencies varied more, the main modal was between 14-18cm, while in 2001, they showed less selectivity and targeted a range of fish sizes from 10cm to 21cm.

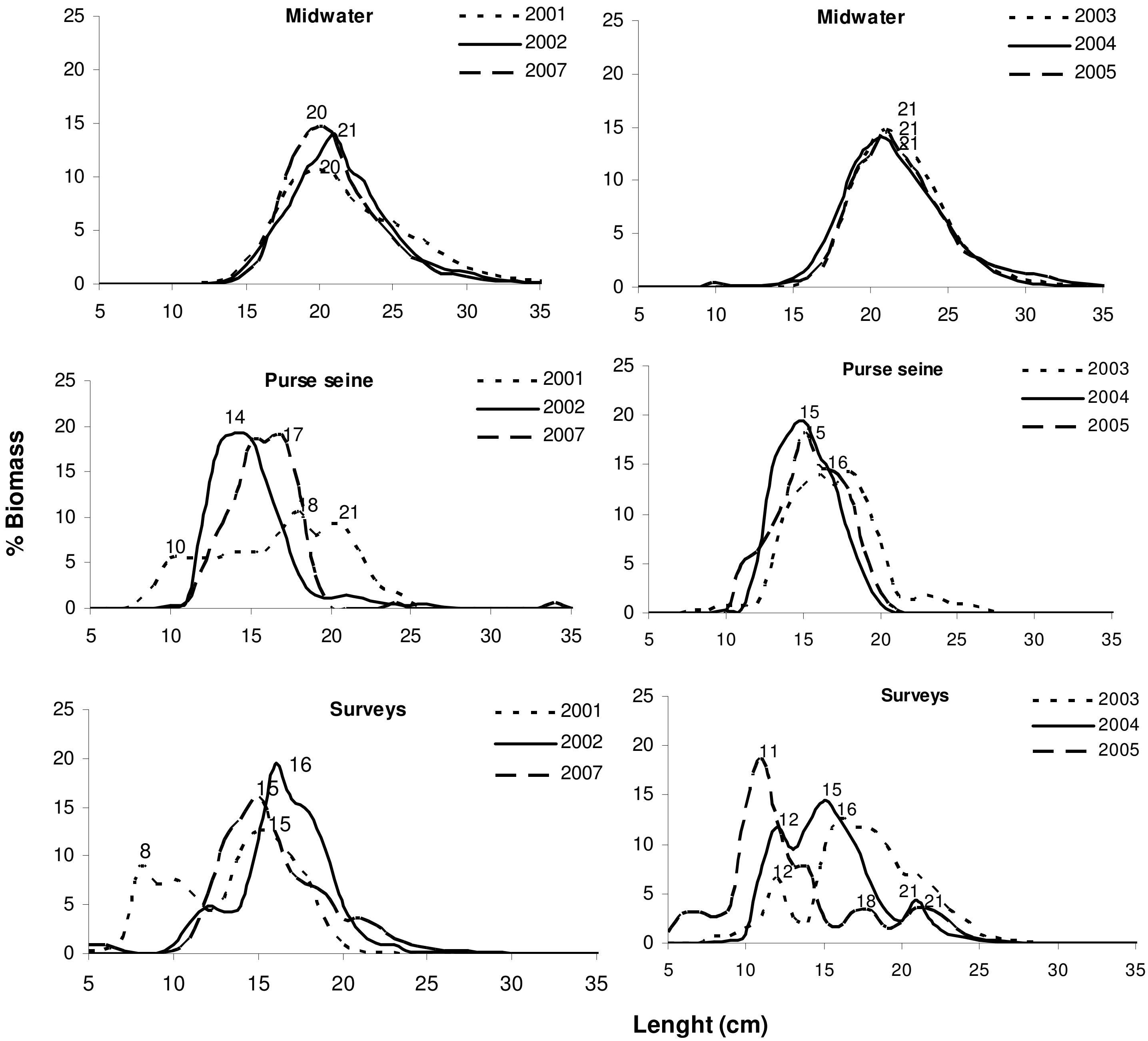

Figure4. Horse mackerel size composition. Years of low stock biomass Left, and vice versa

6.1.3 Median length

Generally, median length, be the evidence for size distribution along the years, showed that, there seemed to be a slight decline of the fish size distribution as measured in the surveys and the fisheries (figure 5). Despite the decline of the size distribution of the midwater, their ranges however seemed to be constant, 15-30cm fish. Further, the purse seine's size decline was allied with an inconsistency in the range size, predominantly with large fish.

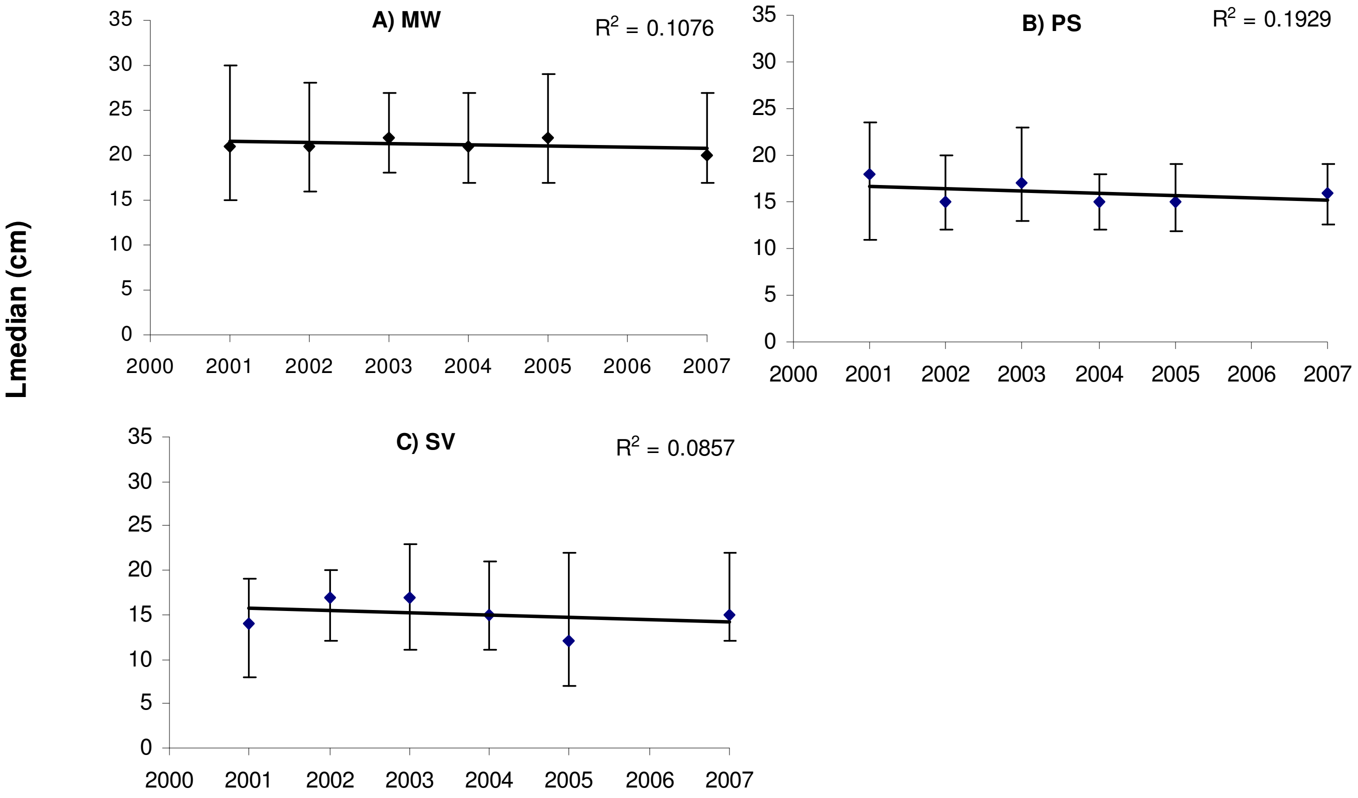

Figure5. Median length frequency of horse mackerel determined from the length frequency of the Midwater trawlers (MW), Purse seine (PS) and Acoustic surveys (SV).

6.2 Stock biomass distribution

During the early years (2001) considered in this analysis, the stock distribution was relatively dispersed among strata 2-5, i.e. in the north and central sectors (table 3). From 2002, the stock become more confined to the north sector, in strata 3 (15°15S-21°00S) and 4 (19°00S 17°15S). From 2002 onwards the stock seems to have entered a phase of geographic expansion covering stratum 1-5, and this expansion was simultaneous with the increase in total biomass. Year 2005 seemed to have been an exceptional year, it had the highest stock biomass and the fish were found in all the strata, including inshore and offshore strata in the southern sector. This gave an initial impression that high stock biomass is associated with a relative dispersion of the stock. However, year 2007 contradicted this pattern when the stock, at it’s lowest size of all time, was still spread in all areas, except in stratum 6 in the south sector close to the coast.

Table3. Distribution of the horse mackerel stock biomass

	STRATUM					
	Offshore			**Inshore**		
Year	**1** 25°00’-22°00’	**2** 22°00’-19°00’	**3** 15°15S-21°00S	**4** 17°15’-21°00’	**5** 21°00’-23°00’	**6** 23°00’-25°00’
2001		33%	24%	19%	24&	
2002			73%	27%		
2003	10%	17%	30%	40%	3%	
2004	1%	5%	22%	70%	2%	
2005	6%	5%	16%	40%	27%	6%
2007	4%	12%	30%	43%	10%	
Avrg	4%	13%	28%	35%	12%	6%

Since, 2002 and 2005 had a comprehensively difference in stock dispersion, their stock distribution was compared by size between strata (fig 6 & 7). In 2002, all fish concentrated in the northern part, where the inshore concentration was higher than the offshore. Fish size 16-18cm (1 year old) fish dominated the offshore areas, while large fish were more abundant at the inshore areas, 17-19cm. The ranges showed that, the inshore areas constituted bigger fish from 13cm-25cm but the large fish were in few amounts. The offshore areas however, had a range that constituted of small fish from 10cm to as nearly as 21cm. The inshore coverage seemed to be a mixture of 0-2 year old, which were probably the juvenile and the spawning stock.

In 2005, the stock size distribution seemed to follow the migratory model presented by previous authors (Axelsen *et al.*, 2004). Whereby big fish inshore and a mixture small and big fish at the offshore area probably the spawning stock and the juveniles, in the north offshore area. As they grow bigger, they migrated to the central part, where 1 year olds were abundant in stratum 5, and they recruited to the inshore areas of stratum 5, and probably went back to the Northern part to their spawning grounds. Remarkable however, there were some pre-recruits 11cm fish, observed in the most southern sector (stratum 6), which probably migrated from South Africa because it is unlikely for the for small fish such as these to migrate from the northern part where spawning mostly takes place to the southern part. Further, these pre-recruits were the strongest year class during 2005 which made up 23% of the total biomass (382000t) where 12% of this was from stratum 1&6. Therefore it is reasonable to assume that, these pre-recruits may have contributed to the high stock biomass perceived in 2005. Then in 2006-07, the stock fell to the lowest level of all times. Further, in 2004 for example, there were no fish in stratum 6, however there were few in stratum 1 (1% to the total biomass), and the abundant size was 38cm fish, which is reasonable to say, because, they could have migrated from the northern part of Namibia and this goes for all other years as except 2005 (Appendix 2).

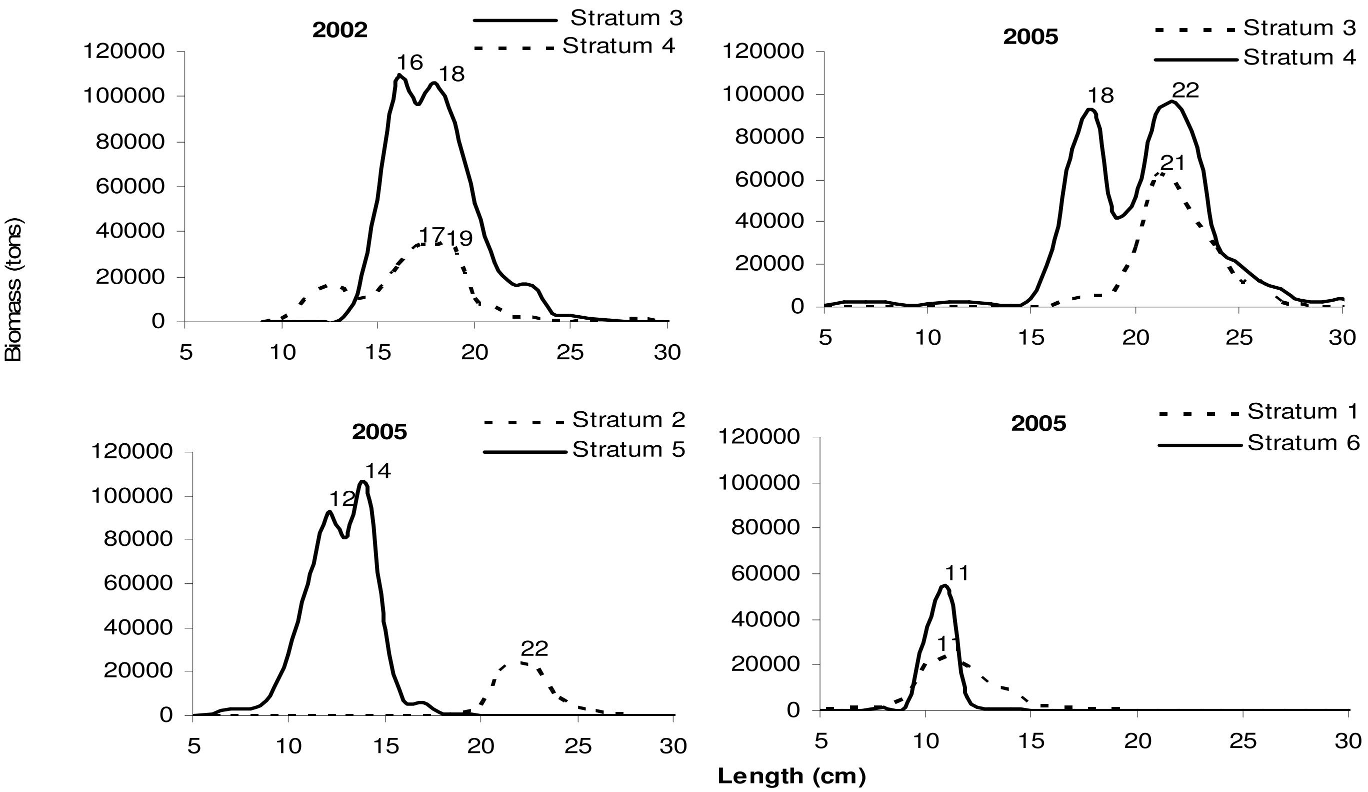

Figure 6. Size distribution of horse mackerel during the 2002& ’05 surveys.

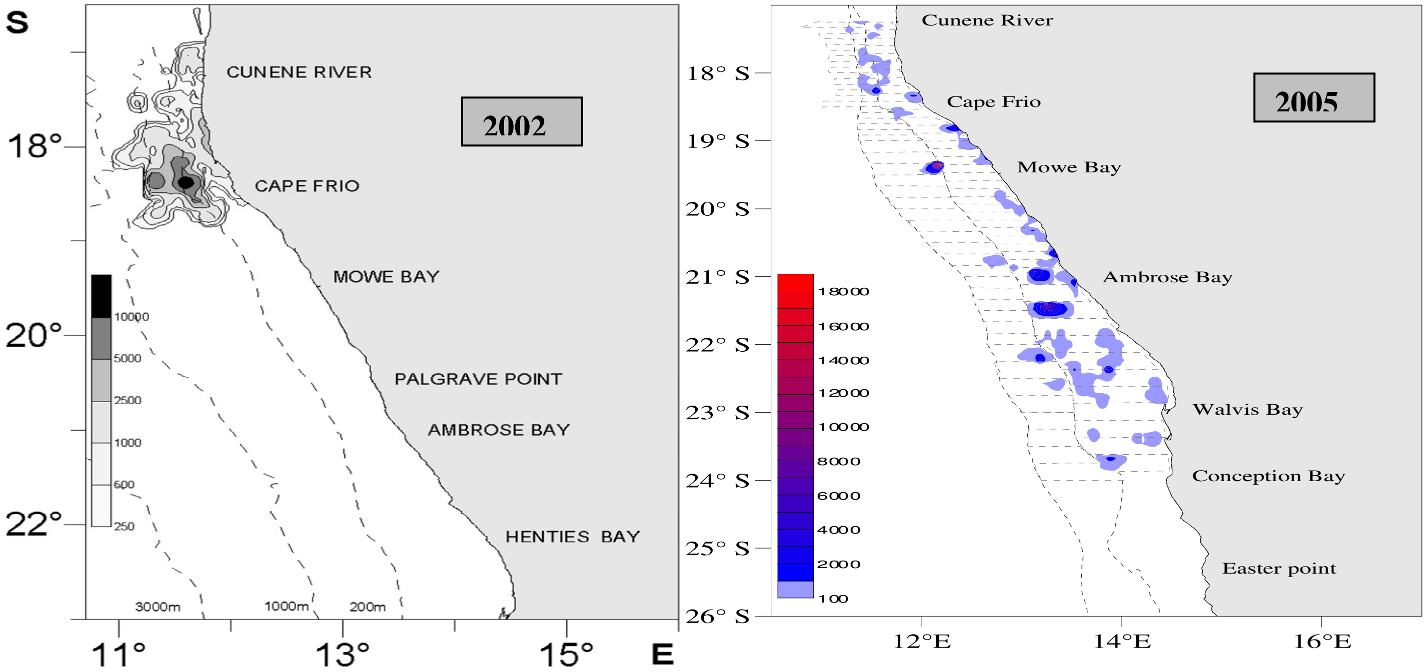

Figure7. Distribution of horse mackerel for 2002 &’05 (MFMR)

6.2 Influence of fish condition on stock biomass

The parameters of the overall length-weight relationship used to calculate the stock biomass appeared to vary slightly from year to year in manner that seemed independent of stock biomass (Table4). The data seemed, however, to conceal a temporal trend that is more difficult to explain (Figure 8). As expected from the two-parameter allometric model, the annual values of a and b showed a strong negative co-variation (R^2=0.97). Unexpectedly, however, the tabulated values of a tended to increase clearly with time, while the values of b decreased consistently in the same period. The original source of secondary data did not provide estimates of variance of the parameters, and it is therefore difficult to assess whether this trend is statistical significant. Still, it seems to be a consistent and substantial trend.

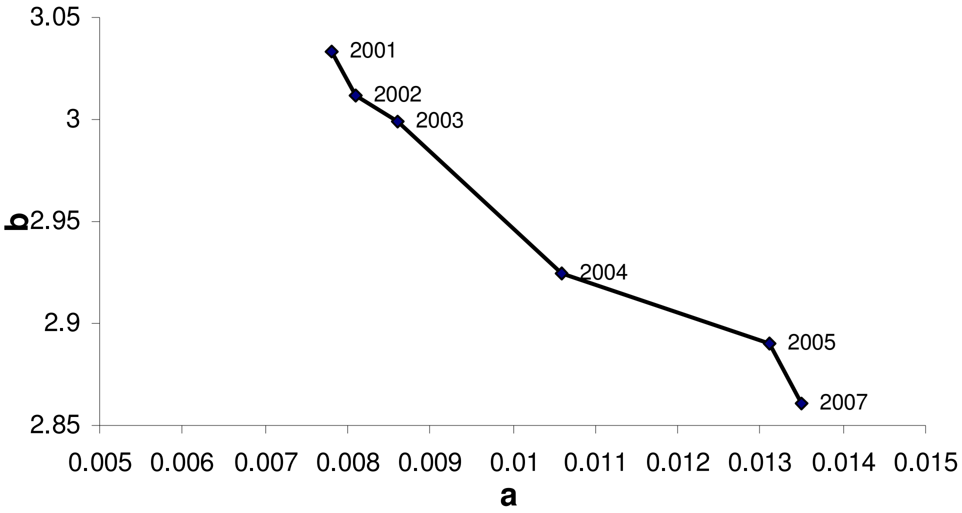

Figure8. Plot of the global parameters of the allometric relationship derived annually for the horse-mackerel during the sampling surveys.

An attempt was made to quantify the importance of the variations in the allometric parameters to total the total stock biomass. Different allometric relationships were utilized to derive five pseudo-biomasses in the years considered, using the correct length distributions for those years. The variability of these pseudo-biomasses is expressed as deviation of the true (reported) biomass (Table4). It seemed that the years 2005 and 2007 were years when the, fish had noticeably good growth condition. For instance, if these two allometric relationships had been used in 2002, the calculated pseudo-biomasses would have been approximately 14% and 8% higher than the stock biomass reported in that year (table4). Conversely, if the allometric relationships derived in the other years of the series had been used in 2005 or 2007 these biomasses would have been significantly reduced. There was no clear relationship between this apparent fish condition and the stock biomass: 2005 and 2007 were the years of highest and lowest biomass in the series and both corresponded to high apparent condition of the fish.

Table4. Calculation of pseudo-biomasses and their deviations from the true biomasses of horse-mackerel. As an example, if the allometry parameters obtained in 2005 were applied to the length-distribution of 2002 the biomass would be over-estimated by 13.7%..

			% Deviation						
Year	**a**	**b**	**2001**	**2002**	**2003**	**2004**	**2005**	**2007**	**Average**
2001	**0.008**	**3.033**	--	2.4	0.3	0.6	-10.4	-4.6	**-2.3**
2002	**0.008**	**3.012**	-2.1	--	-2.2	-1.7	-12.4	-6.9	**-5,1**
2003	**0.009**	**2.999**	0.4	2.4	--	0.6	-10.3	-4.7	**-2,3**
2004	**0.011**	**2.924**	0.5	1.6	-1.4	--	-10.8	-5.5	**-3,1**
2005	**0.013**	**2.890**	12.9	13.7	10.0	12.0	--	5.7	**10,9**
2007	**0.014**	**2.861**	7.2	7.6	3.9	6.1	-5.2	--	**3.9**

6.3 Maturity stages

It was difficult to perform an analysis of maturation with basis on cruise data alone, because this sampling was performed in a short period of the year (February - March). A more extensive data set would be required that covered the entire year to judge about changes in the total reproductive cycle as a function of time or stock biomass.

The present data (Figure 9) showed only small differences in both the distribution of maturity stages among sampled fish. Further, these distributions seemed to be similar in both males and females.

Both in poor year and good years the distributions were dominated by early maturing fish (stage 3). But, in all years, irrespective of stock size (contrast 2005 with 2002 or 2007) the distribution of higher stages, including resting stages remained largely unaffected. The overall distribution was thereby highly skewed, with a mode in stage 3. The most deviant pattern to this was observed in 2003 when the distribution was less skewed and more bell-shaped: stage 4 was also well represented. Although 2003 was the initial year of the 2003-2005 boom cycle in recruitment and stock biomass it is difficult to ascertain the importance of this distribution, which is rather limited in time to a single sampling.

Moreover, the sex composition indicated that, more males were caught at stage 3 than females, and yet this does not show a specific trend with regard to the stock biomass.. However, 2001 was the only year in which more females were caught at stage 3 during the surveys. This cannot however be singled out as the factor behind the low stock biomass, since the other two years with low stock biomass had similar maturity sex composition as the years of high stock biomass.

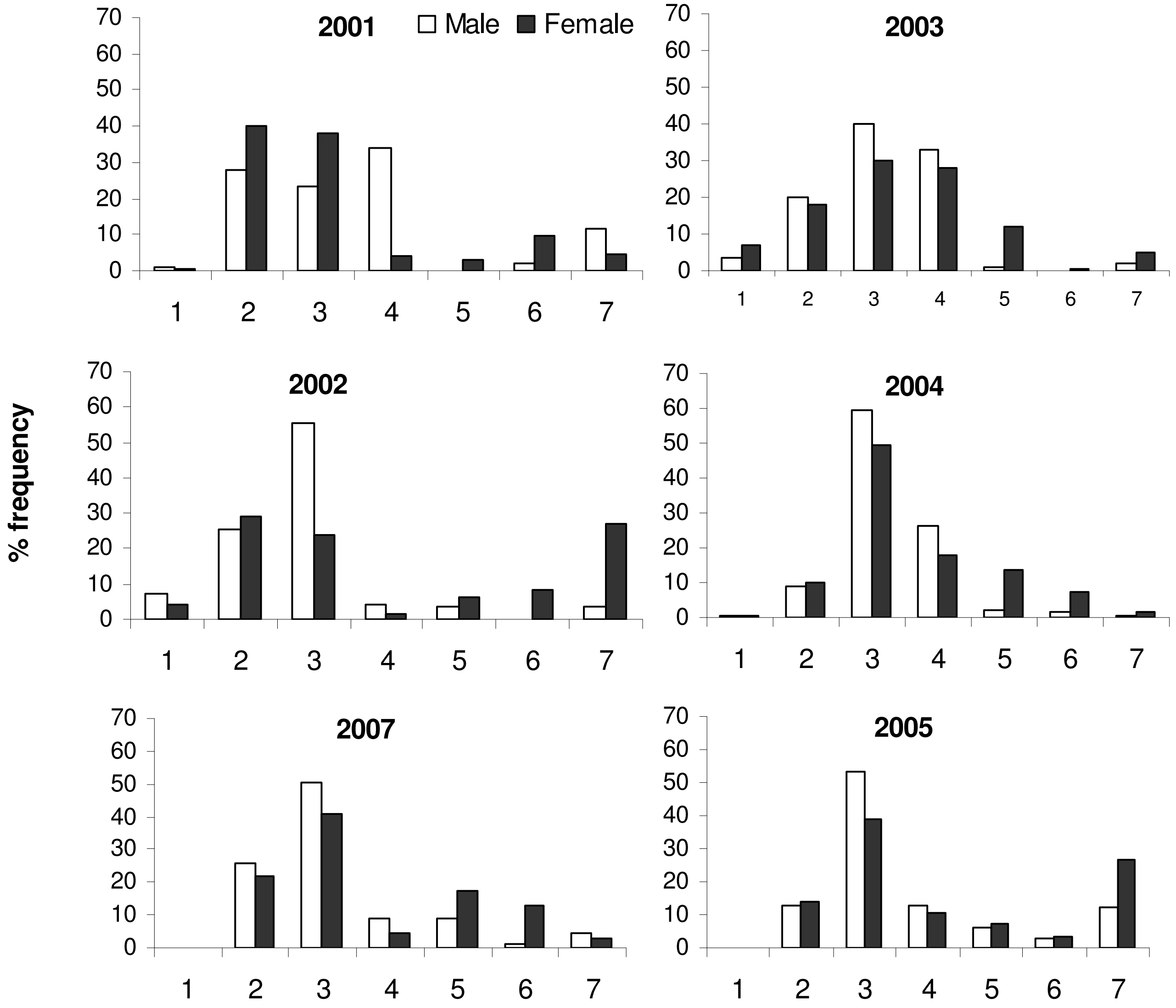

Figure9. Distribution of maturity stages by sex in horse-mackerel sampled during the cruise surveys performed in month-month of 2001 to 2007.

6.5 ***Length at maturity***

In the fit of the logistic (symmetric) maturation curve, fish that had reached maturity stage 3 was considered to be mature and pertain, thereby, to the spawning stock. There seemed to be a clear temporal trend in size at maturity: while became mature at a size of about 19,1-20,9cm in 2001 and 2002, afterwards, the size at maturity has consistently decrease to 16.5 cm in 2007 (Figure 10). A density-dependent relationship between stock size and size at maturity was thereby not immediately evident. In 2005 and 2007 the stock reached the largest and smallest perceived sizes, respectively, but L50 were very similar. A trend that was apparently correlated to the decrease in L50 was the decrease in maturation ranges, i.e. the difference between L25 and L75. It appears that as the maturation size got smaller so did the maturation range, that is the maturation curves got steeped. It is difficult to co-relate this trend to the stock biomass because; the declining trend is more in a chronological order despite the estimated biomass per year. Maturation curves of L50 of each year are depicted in appendix MM

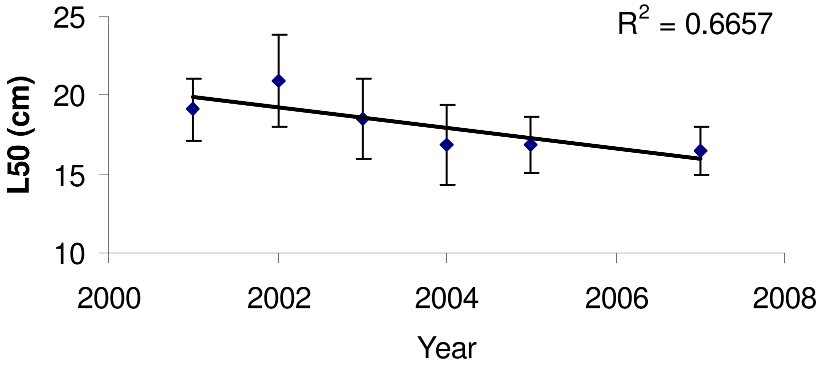

Figure10. Trends in maturation size (L_{50}) for the Namibian horse mackerel determined from survey data. The tips of the “error” bars indicate the L75 and L25, i.e. the upper and lower limits of the maturation range in the logistic curve.

6.6 Spawning Stock Biomass (SSB)

The observed temporal decrease in the maturation size (L50) had a dramatic effect in the estimates of spawning stock. From the estimated L50, the total SSB was calculated with basis on the total stratified length composition from the survey. Similarly, the total stratified estimate of the catches of the midwater fleet was converted into mature and immature components. The total SSB and the SB captured by the trawlers are given in Table 4.

It resulted that, in 2001 and 2002, the estimated total SSB was seemingly critically low, at around 100-140 thousand tons, something that corresponded to 13% and 18% of the total biomass respectively (table 5). With the concomitant increase in size of the perceived total stock to over 1600 thousand tons in a matter of a few years, and a decrease in L50 to 17 cm, the spawning stock soared to 1 million tons in 2005. This corresponded to more than 60% of the perceived total stock. In 2007 the stock greatly decreased, but since the L50 remained low the estimated SSB still reached a reasonable level of 370 thousand tons, corresponding to an all time high fraction of the total stock (70%).

The data indicate that the midwater fleet is probably far more efficient at capturing the spawners than the survey is at detecting them (Table 4). Thus, in 2001 and 2002 the estimated captures of the mature stock by the midwater trawlers far exceeded (>140%) the estimated size of the spawning stock by research. Thereafter, with a strong decline in the L50 and increase in SSB, the estimates of the captures by the trawlers decreased to more reasonable levels (27-41% of the total spawning stock).

Table5. Percentage of Spawning Stock Biomass (SSB) of survey to the total stock biomass and the midwater trawlers (MW) as well as the L50 derived from the surveys (SV) of horse mackerel

Year	**Total stock biomass (1000tons)**	**L50 (cm)**	**SV SSB**	**% of SV SSB to total stock biomass**	**MW SSB**	**% of MW SSB to SV SSB**
2001	861	19.1	114	13%	238	209
2002	803	20.9	147	18%	217	148
2003	1059	18.5	749	71%	323	43
2004	1375	16.7	907	66%	284	31
2005	1639	16.9	1002	61%	287	29
2007	534	16.5	374	70%	110	29
2006	546*		*Year not analyzed due to unavailable data			

Further, had the maturation size (L50) remained in 2007 at the same level of 2001, i.e. 19cm then, the SSB would account for 217 000t which 40% of the total stock and 97 000t which is 45% of this estimated SSB would have been exploited by the midwater trawlers (table 6). This shows that, the spawning biomass would increase if the L50 was declining, and vice versa.

Table6. Percentage of Spawning Stock Biomass (SSB) of horse mackerel and L50 derived from survey catches, and midwater trawlers. Here, it was tested how the SSB could have been if the L50 was constant at 19cm along the years.

Year	Total biomass (1000ts)	SV SSB	% of SV SSB to total biomass	MW SSB	% of MW SSB to SV SSB	L50 (cm)
2001	856112	113671	13	237802	209	19
2002	802172	268361	33	234883	88	19
2003	1059300	628722	59	313106	50	19
2004	1374707	452392	33	263539	58	19
2005	1639979	780120	48	273840	35	19
2007	534196	217368	41	97015	45	19

7. ANALYSES OF FISHERY DATA

7.1 Trends in commercial effort (MW, PS)

The best series of indicators of fishing effort available pertain to the midwater trawler fleet in the period 1991-2007 (Appendix, 4). Under the new management regime there was a substantial reduction of the nominal fishing capacity of this fleet, from 68 vessels at the onset to 13 vessels in 2007. The indicators of fishing activity suggest, however, that, this fleet underwent great operational changes. Contrasting only the initial and final triennia in the series, i.e. 1991-1993 and 2005-2007: the average number of fishing days per vessel doubled, from about 80 to 160 days, and the index of operation of the gear increased from about 9 h to 12 h per fishing day. This was achieved with performing less, but longer hauls, as these increased in duration from about 2.5 h to 4h, on average. As a result, the total number of nominal fishing hours of the midwater trawlers fleet decreased by only 19% along the period (Figure 11) despite the reduction in tonnage. This overall decline was, however, far from smooth: in reality, the number of fishing hours steadily increased until 2003 and only showed an abrupt decline thereafter.

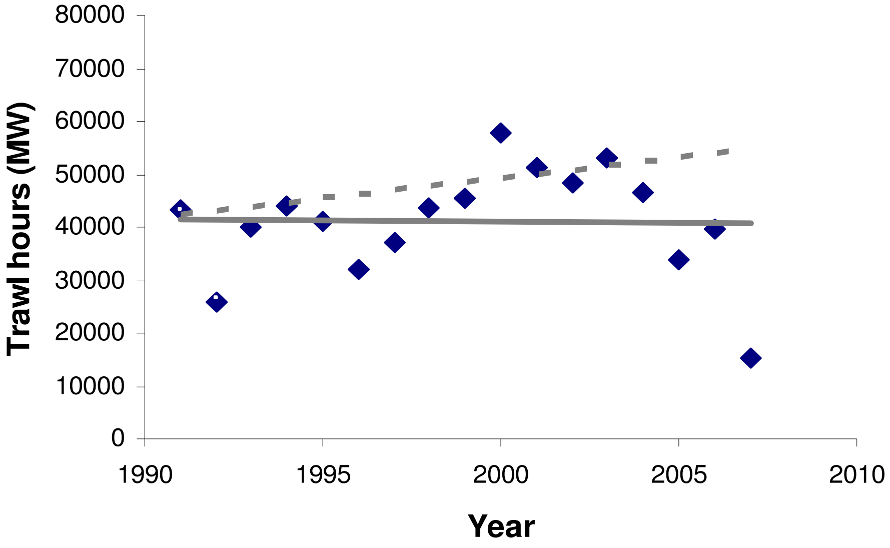

Figure 11. Nominal effort (trawling hours) of the midwater trawler fleet targeting horse-mackerel in the period 1991-2007. Data from Uanivi (MFMR) The full line shows the overall nominal trend for the period and the stippled line shows the simulated increase in effective effort obtained assuming a small to moderate (2%) annual increase in technological efficiency (fishing power).

The decline in fishing capacity seemed to be compensated for by an increase in nominal activity. This probably happened because the most efficient trawlers remained in the fishery. It is also highly likely that the fishing efficiency of these vessels, i.e. the catchability or the mortality rate inflicted on of horse-mackerel, has increased along the period 1990-2007, as it did for trawlers elsewhere. This can have been caused by changes in fisher behavior, and improvements in gear and vessel technology (Marchal 2006). This can be simulated using a small to moderate estimate of the increase in productivity brought about by technical and behavioral change suggested for similar fleets (Kirkley 2004). Assuming an improvement in productivity of 2% per year the expected values (number of hours fishing in effective technical units) in 2007 would be about 30% higher than in 1991 (trend lines in Figure 11). The fit of the line to the observations on the right side of the graph would also be considerably improved. This because the corrected observations would be lifted and compressed more on the right side of the graph than on the left side. An increase of this magnitude in effective effort is not trivial, but is not unlikely either.

With regard to the purse-seine fleet less information is available about changes in fleet capacity, activity and technological efficiency. According to Boyer and Hampton 2001, following the collapse of sardine stock in the 1970s, the fleet changed from small wooden-hulled vessels to large steel-hulled vessels. This change was caused by the need for long distance travelling in the search for sardine schools. Further change of the fleets was the use of refrigerated sea water to preserve the catches on board, which also allowed longer trips and search times. However it was from 1971 when the purse seine firstly had highest catches of horse mackerel. Before then, horse mackerel was not regarded as an economic viable resource. Nevertheless, the fleet capacity had declined from 38 purse-seiners to the currently operating 10 vessels (Krakstad and Kanandjembo unpublished report 2001).

7.2 Trends in indices of abundance (MW)

Owing to the unavailability of catch and effort data for the purse-seine fleets the trends in catch rates of the Namibian horse mackerel is here only exemplified using the trawler fleet. In contrast to the purse-seiners, this fleets targets mostly large fish for consumption, and in deep waters. Within any given year the catch rates of horse-mackerel are fairly constant seasonally, and the typical coefficient of variation of the monthly catch rates is only about 16%. Similarly, the annual catch rate of trawlers only declined from about 7.6 tons/ nominal fishing hour in the early 1990's to 6.8 tons/hour in the last triennium of the 1991-2007 series (Figure 12). This decline was, however, not smooth: the largest catch rates were observed at the start of the series and, remarkably, in the final part (2005-2007). The catch rates were lowest (< 6tons/hour) between 1995 and 2002. Despite the general declining trend, time alone seemed to be, thus, a poor descriptor of decadal trends in the index of abundance (R^2= 7%). In the short time-series (1999-2007) of perceived stock biomass data (Figure 3) the years 1999- 2000 and 2004-2005 are those of highest abundance (> 1200 thousand tons). This is not clearly reflected in the CPUE of this fleet: a high index of abundance only transpires in 2005. Contrastingly, 2006 and 2007 yielded above average CPUE, despite low perceived biomasses.

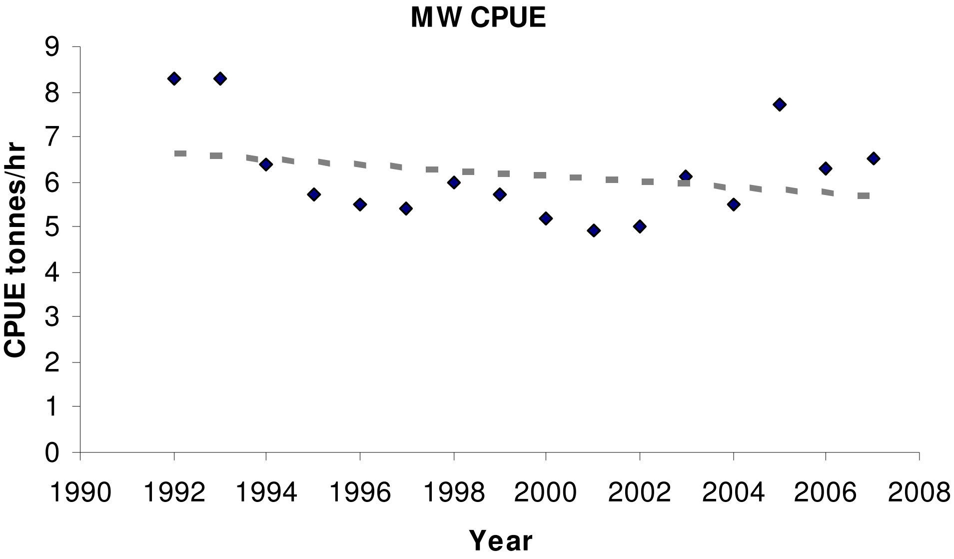

Figure12. Nominal catch per unit effort (CPUE, tons pr trawling hour) for the Namibian horse mackerel by the midwater trawler fleet (Uanivi U., MFMR 2007)

The same short time-series (1999-2007) of perceived stock biomass data was used to assess the adequacy of the fishery-dependent index of abundance to predict stock size. The available data gives evidence of poor proportionality between the two quantities with regard to the trawler fleet (Figure 13). Despite a good contrast in the stock biomass (dispersal along x-axis) it seems highly unlikely that a straight line with origin at zero would reasonably fit the data. A power line forced close to zero, with a biomass exponent (elasticity) of 0.63 gives a more intuitive fit.

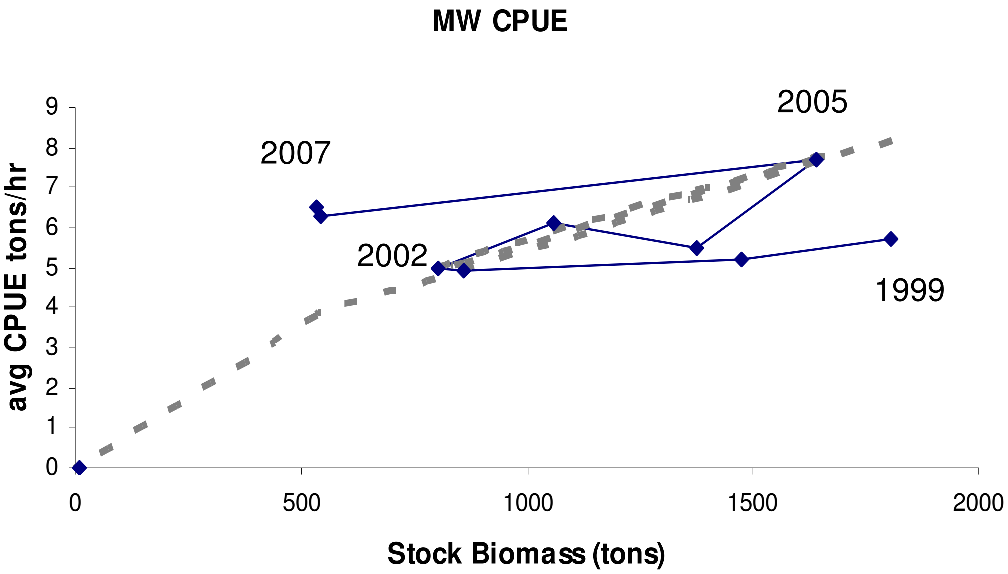

Figure 12. Nominal annual CPUE of the trawler fleet as a function of perceived stock biomass of the Namibian horse mackerel. A power line forced through the origin was fitted and is shown as stippled line. The full line connects the observations chronologically along the time series (1999-2007).

There is some evidence that the time series of annual catch rate data is non stationary, as there are trends in the position of the observations (lines connecting points in Figure 12), and this breaks the assumptions of the regression. One way to interpret this auto-correlative pattern is to assign it a temporal significance: observations of annual harvest rates in the period 1999-2004 seem to be positioned at a lower ceiling than those made in 2005-2007. As a consequence, two power lines fitted independently to the two periods would make more meaningful relationships than the singular line suggested here for all observations. The overall biological interpretation of this finding is that the un-corrected catch rates of the commercial fleet are poor indicators of the stock abundance, and have become even poorer in recent years when the stock is perceived to be in weaker condition.

7.3 Re-visiting TAC practices and fleet outputs

The history of output control in the horse-mackerel fishery seems to stretch as far back as 1980, according to the available information (Appendix 6), and until 1994 only the output of the trawler fleet seemed to be regulated. As a consequence of the non-regulated catches of the purse-seiners the total TAC was frequently exceeded, with as much as 160 thousand tons, in this period. But, years of poor performance towards the set TAC were also recorded. Since 1995, the quota for trawlers has been typically set at 300-350 thousand tons, but this fleet has consistently under-performed by, on average, 50 thousand tons. This is a very considerable volume, and by 2007, its under-performance reached a maximum of 160 thousand tons. Since 1995 the purse-seine fleet has been under a regime of output control with regard to horse-mackerel, and the typical TAC reached 50 thousand tons. Until 2001 the purse-seiners did not seem to extract their quota, and fell short of the TAC by about 30 thousand tons, on average. Between 2000 and 2002 they exceeded a now reduced TAC of 40 thousand tons by about 10 thousand tons, on average. In 2006 and 2007 purse-seiners also failed to achieve their stipulated quotas of 35-45 thousand tons.

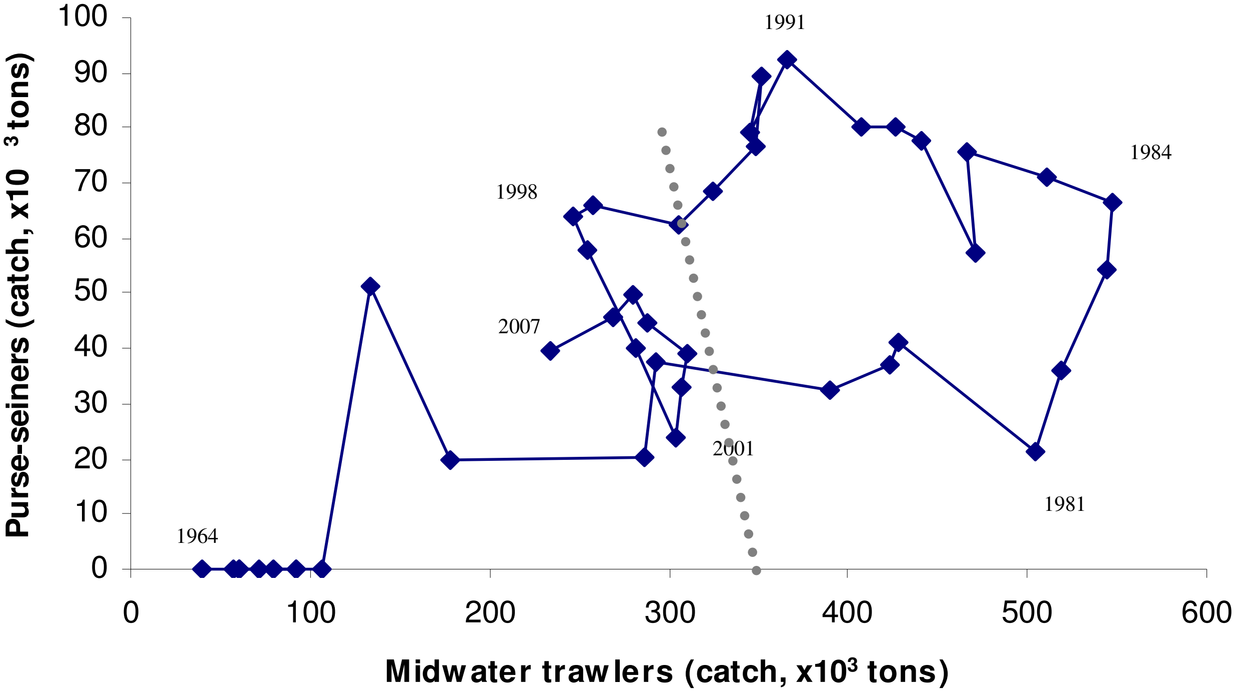

Figure 14. Phase portrait of the catches of Namibian horse-mackerel by purse-seiners and midwater trawlers. The observations represent 4-year running averages of a time-series of landings starting in 1961. The stippled line roughly indicates the position of the average track of the TAC for the combined fleets since 1995.

A bivariate plot of the catches of the both fleets shows what is seemingly shaped like a limit cycle where the catches of one fleet frequently constrain the catch of the other (figure 14). The time-series were smoothed, by means of simultaneous 4-year running averages, to remove excessive noise. A few phases can be clearly identified in the fishery: in the 20 years preceding 1981 there was a fast and significant increase in the catches of the trawler fleet to volumes exceeding 500 thousand tons. Concomitant with the collapse of the massive pilchard fishery in 1977/1978 (Sumaila and Stephanus 2006) there was a period of strong increase in the catches of juvenile horse-mackerel by purse-seiners. By 1984 the fishery as a whole seemed to have achieved the end of its expansive phase. In the ensuing period until 1991, the catches of juveniles by the purse-seine fleet were maintained at high levels, apparently at the expense of a major reduction of in the catches of the trawler fleet. A sharp decline in the catches of the purse-seiners in 1991-1995 seemed to coincide with a short-lived bonanza in the pilchard fishery, which definitely collapsed thereafter. This second collapse of the pilchard fish has been judged to be a consequence of adverse environmental conditions (Sumaila and Stephanus 2006). From then on, a decline in the catches of purse-seiners occurred, but this was seemingly not caused by the quota control (TAC were not attained in the period). This decline corresponded to a period of increase in the catches of trawlers, which by 2000-2001 were close to achieve again their allocated TAC. From 2000 to 2006 the purse-seiners again increased their catches, often exceeded their TAC, and the trawl fishery seems to have entered a new loop of declining catches. By 2007 the fishery seemed to have entered into a stage off bounds of the previous limit cycle, and catches of both fleets are now very low, and fall short of the stipulated quotas by great amounts. This last trend does not give any indication as to what path or cycle may be followed in the future.

8. DISCUSSION

The main aim of this study was to analyze the possible factors that could have cause massive fluctuation of horse mackerel stock biomass determined by the research surveys in the Namibian water. The analysis was looking at following aspects;

- ◊ *Changes in recruitment and year class composition*
- ◊ *Changes in the geographic distribution*
- ◊ *Influence of fish condition on stock biomass*
- ◊ *Changes in maturation pattern and spawning stock biomass*
- ◊ *Changes in fishing pattern and efficiency of the fishing fleet*

8.1 Changes in recruitment and year class composition

8.1.1 Year class composition

The size distribution of the survey, showed that, the main modal length frequency group was fluctuating between the years regardless of the stock biomass, however, the major with regard to stock biomass, in the surveys stock size, was the occurrence of the lower modal group, the smaller fish (recruitment stock) that were more allied to high stock biomass. Further, this recruitment stock, could account for 23% of the stock biomass, and extreme vary by a factor of 20 both by recruitment and their biomass as compared to the lowest stock biomass. Therefore, it more likely that, these years class compositions are an indication that the stock biomass was highly correlated to the recruitment stock. This analysis however, could not be revealed in the fishery catches, because, regulation do not allow them to catch all the length classes.

Further, the median length calculated was relatively declining however, the coefficient of determination for the median length trends were not persuasive enough, to describe this trends along the years, most likely due to the short time series of the data (fig DD). On the other hand, it was evidently that the L50 was declining along years, because it had a more reliable coefficient of determination that explains the variability of L50 along the years.

It is believed that, decline of the length at maturity is an indication of the decline of the stock abundance (Beacham 1987). This is because; high fishing mortality often restricts fish stock to reach certain sizes in their life time. As a result, fish stocks become more confined at certain few length classes in their lifetime. This reduction can negatively affect fish stock in a number of ways; decline of length at maturity is relatively proportional to the body size and it is believed that large fish have carries more eggs, which are big and often bears large larvae which have high chance of survival (Tripple 1995) whereas, small fish carries less and small eggs and their larvae do not have as much chance of survival as those for big sized fish. On the other hand, early maturity has an advantage of a compensatory response whereby early maturity result in early production of the eggs (Tripple 1995). However, the Namibian horse mackerel natural mortality is known to be higher than the fishing mortality (Krakstad and Kanandjembo 2001), therefore the compensatory response can be compromised because, there could be high larvae mortality.

8.1.2 Recruitment patterns (Spawninig stock biomass (SSB)

Logically, one should expect an autocorrelation between the recruitment and spawning stock biomass whereby, a higher spawning stock biomass will significantly yield high recruitment (Kazumi Sakuramoto 2005). However, fish stocks have biological limits of withstanding the amount of fishing mortality that can be applied to the stock (Myers *et al* 1994). Depending on the fishery selectivity, if by some how, the fishery is heavily targeting the parental stock, the adult population could be reduced to extreme low levels that it would not have the reproductive ability to replenish the stock (Myers *et al* 1997).

The result under this section had a lot of inconsistency, where.:

1. In 2001 & ‘02, the estimated SSB from the surveys seemed to be under-estimated, because, the midwater trawlers caught more SSB than the total SSB estimated by the surveys; therefore, making the survey SSB as a reference to the exploited SSB was erroneous in this case.
2. In 2005, the total estimated SSB was 60% of the total stock was the highest of all the years considered in this analysis. Further, the midwater trawlers only took 28% of the SSB, therefore, high spawning success was expected during this year which was supposed to boost the following year’s stock biomass. Illogically, the unexpected occurred, the total stock biomass fell extremely to low level of all time in 2006 & ’07. The fishery did not show signs of overfishing, therefore, it notoriously difficult to discuss these peculiars results. However, migratory analysis showed that, the southern sector stock which was responsible for the boom of the stock biomass in 2005, could have migrated back to South Africa. But this alone cannot account for the extreme down fall of the stock in 2006 & ’07.

A study by Bauleth-D’Almeida *et al***.** (2001), compared the research surveys length composition with the commercial fleets (midwater trawlers and purse seine) catches length composition of Namibian horse mackerel. The study concluded that, the research surveys catch composition were smaller in size as compared to the midwater catches and this was further confirmed in this study. However their study further indicated that, the research vessel's speed is kept relatively low (average 3.5 knots) as compared to commercial vessels (5knots), and only horse mackerel of less than 23cm can be caught with this speed.. Since the surveys SSB was made as a reference point in this analysis, it is possible that the SSB was under-estimated. With these results, there was no evidence of recruitment overfishing in this fishery.

8.2 Is change in the geographic distribution of the stock related to stock biomass?

In fishery, spatial distribution of fish may perchance, reveal the abundance of the stock whereby, the more abundant the stock, the larger the area it covers (Atkinson *et al* 1997, Meyer *et al* 1996). This demonstrates that, as the stock declines, the area that it covers also shrinks. This aspect is further demonstrated by the horse mackerel stock over the past years. The stock became more confined toward areas of 15°15S-21°00S and17°15'-21°00'. However, environmental factors such as, oceanic currents (water flow) can cause ontogeny migratory and the fish can be placed at certain areas, where they are usually not known to inhabit (Jonsson 1991). This could have been the reason for pre-recruits the were belived to migrate from South Africa.

8.3 Influence of fish condition on stock biomass

Fish productivity, such as growth and recruitment patter is believed to be proportional to the condition factor, whereby the fish stocks in good condition are likely to have good growth, better weight as compared to stock with poor condition (Rätz and Lloret 2003).

In this analysis, the allometric parameters varied with what seemed to be a substantial (although not statistical testable) pattern. This pattern seemed to reflect a temporal trend, of decreasing b (exponent) and increasing a (proportionality constant), rather than a density-dependent effect. The pseudo-biomasses derived from these relationships showed that, the fish condition significantly influenced to total stock biomass. This is clearly illustrated by the estimated stock biomass in 2005, which on average showed that, 11% of the stock biomass was due to good fish growth as compared to other year's stock biomass and the stock biomass in this year was actually high. Further, 2007 displayed good growth as compared to all other years with the exception of 2005. On average; it showed that, 4% of the stock biomass was due to good fish growth, but, the stock biomass, was however the lowest of all the years.

8.4 FISHERY DATA ANAYLSIS

8.4.1 CPUE

In fisheries, catch per unit effort (CPUE) is known to be the most commonly used index of relative stock abundance in fisheries stock assessment (Dana R. Haggarty and Jacquelynne R. King 2006, King M 1995). Generally, it is assumed that assumed, the catch per unit effort is proportional to the stock abundance. However, this phenomenon received a lot of critics, of which some called it “false” (Hilborn and Walters 1992, Hutching and Myers 1994). The Namibian horse mackerel forms shoals (Mecenero 2006) and have a tendency of aggregating at specific areas in accordance to their feeding and spawning migrations/seasons. The confinement was observed in the spatial distribution of the stock. This can have several consequences for management, the worst of them being that the harvest rate of the commercial fleets bears little relationship with the stock abundance since may be easily available to the commercial fleet, even when the stock abundance is low. This study further confirmed this, when the CPUE did not show a proportional relationship to the horse mackerel stock abundance. Poloheimo and Dickie 1964 argued that, for schooling species, CPUE could only be used if it was determined by the rate of encountering the schools but not the fish densities in the school. On the contrary, the Namibian horse mackerel cpue is determined by the time it took a vessel to catch a certain number of fish, which in this case, the fish were often in shoals.

8.4.2 Changes in fishing pattern and efficiency of the fishing fleet

Global fishing technology is believed to have increased at an annual rate of 9% (Kirkley *et al* 2004). Fishing vessels has more advance, fish finding equipments, excellent communication system, and onboard processing factory that enable them to process fish at fishing grounds. This is no exception with the Namibian fleets exploiting the horse mackerel stock. The purse seine has evolved from a wooden hulled to a steel hull, with refrigerated sea water equipment which enabled them to go further onshore and stay longer at fishing grounds with preserved catches. This aspect is not investigated in this study, however, this is reflected in the extreme decline of fishing vessels, but the catches however, were not reflected in this change.

9. CONCLUSIONS

The year class composition showed that, the stock of Namibian horse-mackerel is strongly recruitment driven. Gross estimates of recruitment strength (for fish <12 cm) indicate that recruitment can vary by a factor of 20 between years of poor and good recruitment both in the number of fish and biomass. A good year-class of pre-recrutis can account for for up to 23% of the total stock biomass, as for instance in 2005. In a bad year (e.g. 2007) the pre-recruits account on for about 3% of the total biomass. No changes in the length composition of the stock were immediately apparent in the size distributions analyzed, irrespective of stock size or year. Changes in length at size (growth) did not, therefore, seemed to influence stock biomass, overall however, the length distribution was seemed to be declining along the years.

The condition of the fish seems, however, to have increased following a one-way temporal trend, rather than in a density dependent manner. In a year of good body mass condition the perceived gain in stock biomass can be as high as 14%. This was related to consistent temporal changes in the parameters of the allometric relationship. In a matter of six years, the stock showed strong variations in geographic patterns of distribution. Following a year (2002) of contraction to the northern sector, the stock soon expanded, and by 2005 covered all sectors, both inshore and offshore. These patterns were seemingly temporal, and maybe associated to environmental factors not investigated, rather than to stock biomass. In 2005 at least, the distribution horse-mackerel seemed to follow the ontogeny migratory model usually assumed for the stock. The distribution of pre-recruits, however, was bi-polar, with 0-year fish detected both in the north and south sectors. The anomaly in the distribution pattern gives rise to suspicions that the strong variations in recruitment, and even in stock size, may be associated with movements in and out of Namibian waters. Migrations may challenge the assumptions of the Namibian stock as a singular management unit. Further studies of historical data on stock sizes and composition along the Namibian and South African zones are called upon. A common management policy may be required

There seemed to be a consistent declining trend in size at maturity of horse-mackerel in a very short period of time, from about 20 cm in 2001 to 16.5cm in 2007. This change was density-invariant, at least in the short time-scale investigated.

The decline in size at maturity had a positive compensatory effect in the perceived spawning stock biomass of the stock, which reached 70% of the total stock in 2007. But, the perceived maturation size seems to be very low now with respect to maximum size, and this may raise doubts about further compensation, and recruitment success, in the future given the high natural mortality assumed for horse mackerel.

Limited data exists about the fishing activity (effective effort) and trends in technological efficiency of the purse-seine fleet. This fleet targets small, immature, horse-mackerel as a secondary (buffer) species, seemingly in years of low pilchard abundance. The utilization of horse-mackerel to reduction seems to be, however, an economically inefficient strategy for the management of the horse-mackerel stock.

The midwater trawler fleet targets very selectively and efficiently mature horse-mackerel. In some years the catch of mature fish largely exceeded the perceived spawning stock biomass.

Gross estimates indicate that despite that large reduction in capacity of the trawler fleet since the early 1990's, the effective effort of this fleet (compounded by postulated technological creep) may be now higher than ever before.

Harvest rates of the trawler fleet (and probably of the purse-seiners) show clearer signs of hyper-stability. Thus, harvest rates remain high even at low perceived stock sizes, a feature that is known to have lead to serious recruitment failures in other world fisheries. Further, this feature seems to have worsened in recent years, as suggested in a temporal (auto-correlative) trend in the data.

Despite the hyper-stability, which may lead to misinterpretations of data, the long-term historical trends in the catches of horse-mackerel do not give rise to suspicions of it being a very irregular stock, like the more environmentally-driven pilchard. This gives hope with regard to the assessment and management of the stock using traditional, and simple, concepts and mechanisms.

The TAC regime under which the fishery operates seems, however, fairly stiff and mal-adjusted to the cycles in the fishery. These features became particularly evident in research data for recent years: the stock of horse-mackerel suffered large fluctuations but TAC remained unaltered, at seemingly unachievable, and risky, levels.

The horse-mackerel fishery is a type of sequential fishery whereupon each fleet targets a life-stage of the prey. The long-term variations in the catches can probably be parsimoniously accounted for by a strategic model of two independent prey and two competing fleets. The historical catch data strongly suggests the presence of phase-cycle(s).

Realization of the competitive nature of the pilchard and horse-mackerel fisheries calls upon a totally new management regime. Given the rupture of the pilchard stock in the recent past, and the apparently eminent serial-depletion of the horse-mackerel fishery today, management has little alternatives to this holistic approach. In a multi-goal oriented approach, management must balance the necessities of the two fleets at sea, the economics and employment issues of the shore-based canning and reduction industry, as well as exports of horse-mackerel, conservative biological points for the two species, and the environmental uncertainty related to the pilchard fishery.

10. RECOMMENDATIONS

The horse mackerel stock biomass fluctuation as well decreased landing needs urgent attention in order to successfully monitoring and assessment. The biomass estimate from acoustics is believed not to be accurate (Bauleth D'almeida *et al* 2001). This inaccuracy is associated with technical errors on the research survey vessels. Consequently, it is believed that, the stock biomass of the Namibian horse mackerel is under-estimated. However, if the stock biomasses were being underestimated all along, then, why did the catches remain constant and currently declining for the past 7 years? What lesson has to be learned from the above mentioned conclusions? Little attention is given to the possibility that, the stock composition could have contributed to these fluctuations. Therefore it is time to give more attention to the stock composition and re-visit the management practices that are currently in effect before the worst case scenarios occurs.

Alternative management could be focused on bilateral stock assement between Namibia with its neighbors South Africa and Angola. The migratory behavior, although it is not know to be frequent, it needs to be closely monitored, and conservation measure from each country must be put in place. Technological advancement of vessels must be limited, for sustainability, because, if the vessels become more advanced, their capacity of catching the last shoal of fish is always higher before reaching economic extinction. Further more, the mesh size has to be re-sized due to a reduction in total length and length at maturity. As mentioned before, the TAC regimen under which the fishery operates needs to be revised, to a more conservative measure, because currently it does not account for the stock fluctuation.

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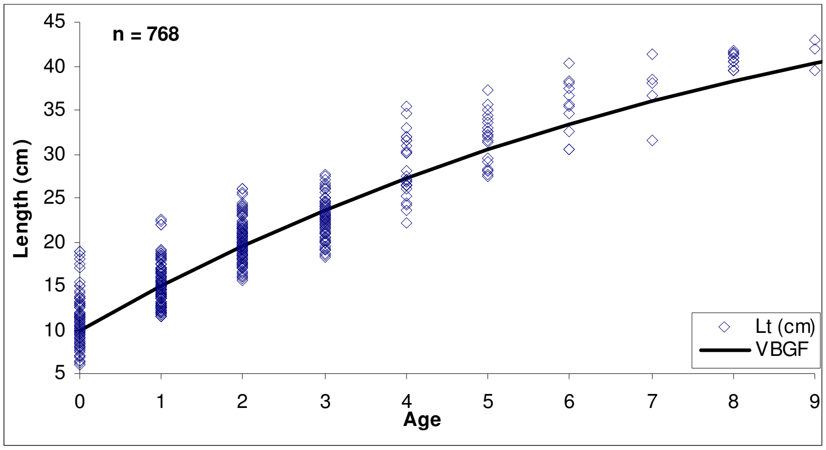
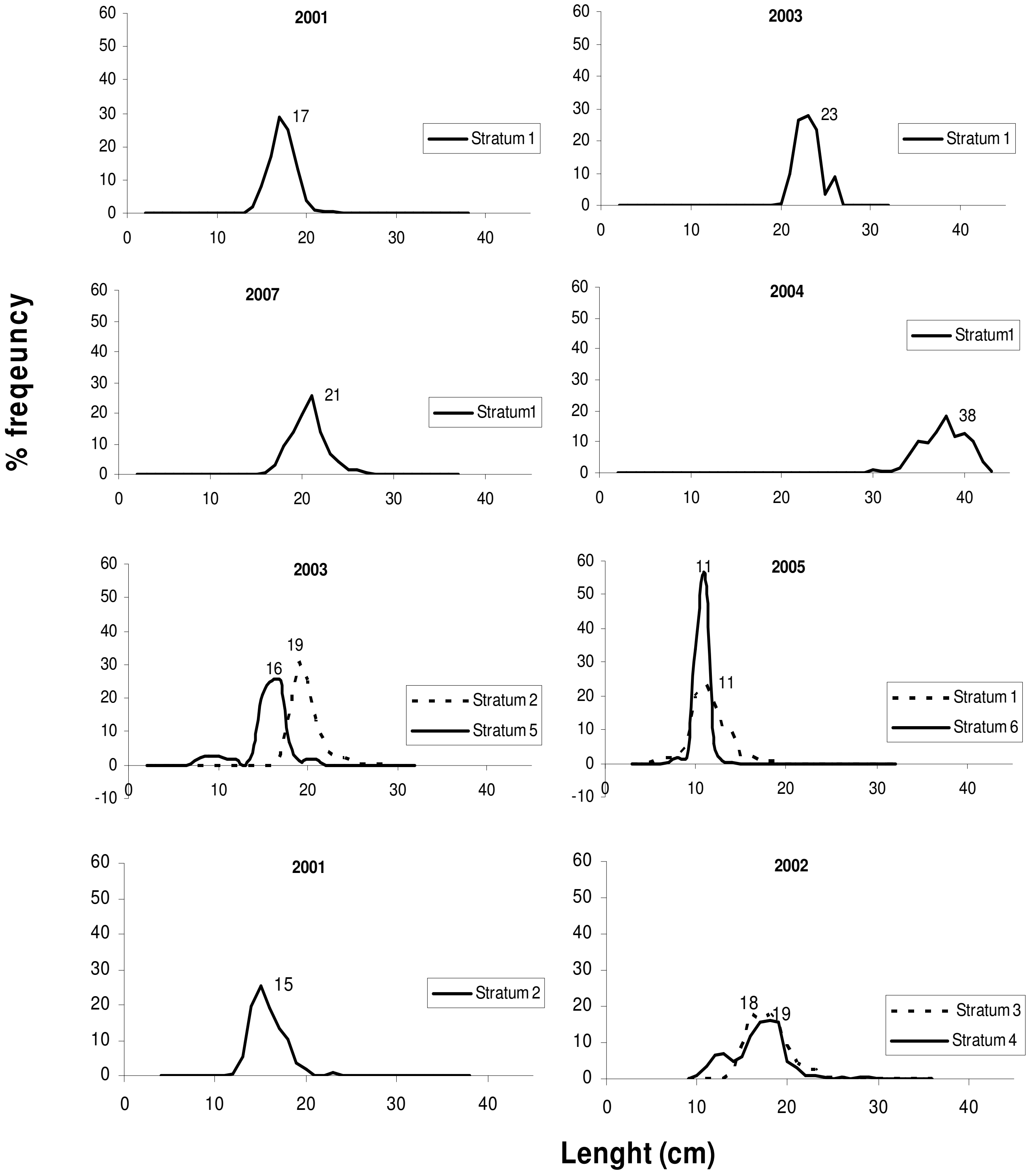
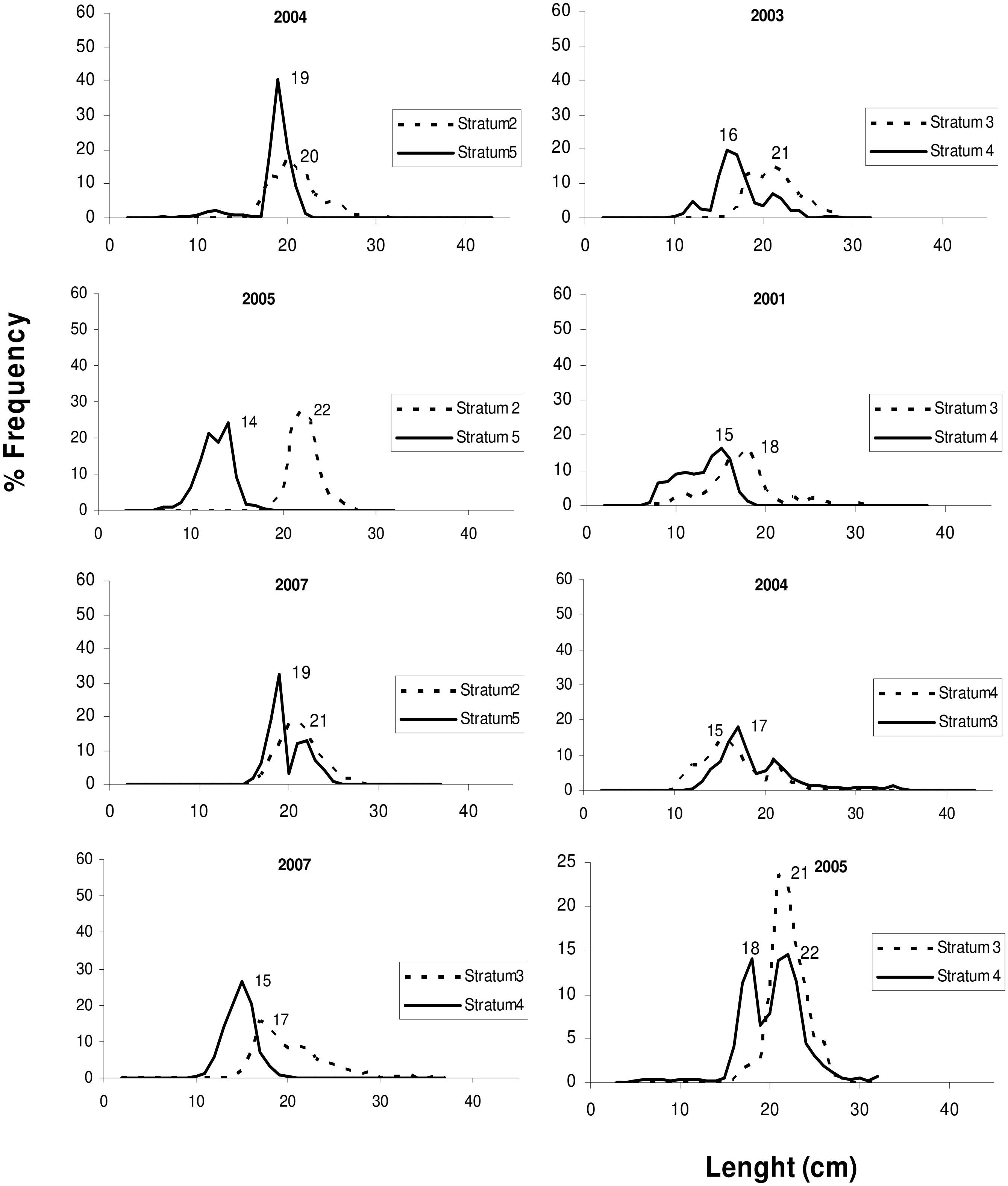
APPENDIX 1. LENGTH AGAINST AGE DATA AND VON BERTALANFFY GROWTH FUNCTIONS (VBGF) OF THE NAMIBIAN HORSE MACKEREL FROM 2004 SURVEY DATA (WILLEM 2006)

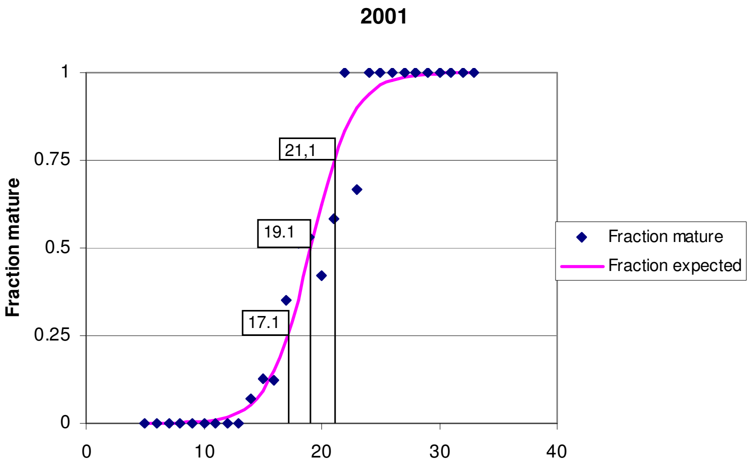


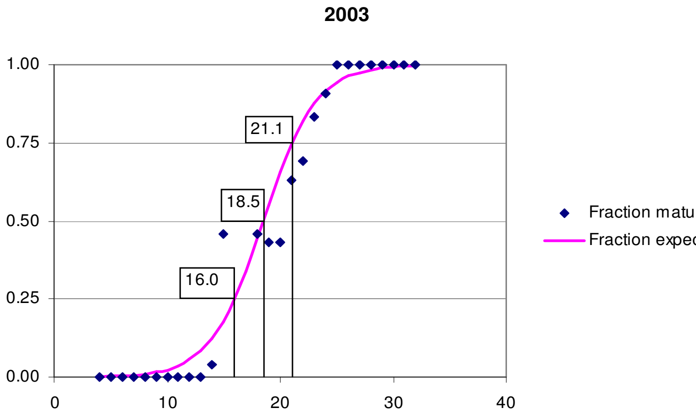
APPENDIX 2. FISH DISTRIBUTION BY STRATUM

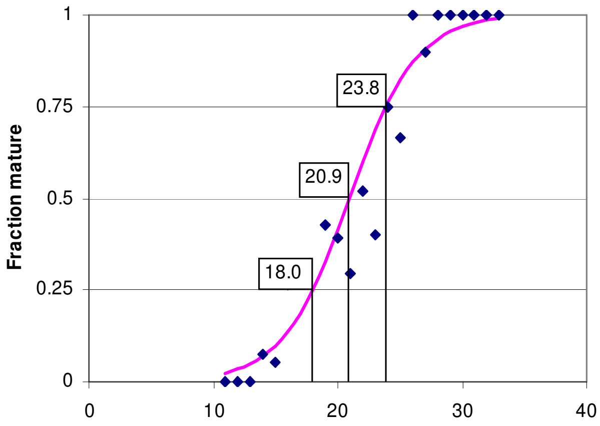


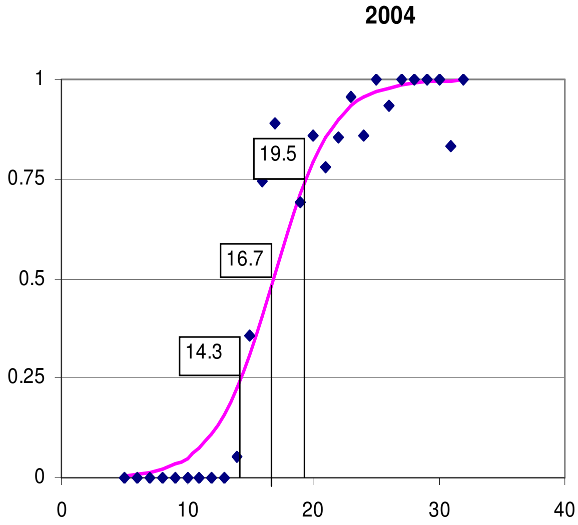

% Frequency
2004
19
20
Stratum2
Stratum5
2003
16
21
Stratum 3
Stratum 4
2005
14
22
Stratum 2
Stratum 5
2001
15
18
Stratum 3
Stratum 4
2007
19
21
Stratum2
Stratum5
2004
15
17
Stratum4
Stratum3
2007
15
17
Stratum3
Stratum4
2005
21
18
22
Stratum 3
Stratum 4
0
10
20
30
40
50
60
0
5
10
15
20
25
0
10
20
30
40
Lenght (cm)

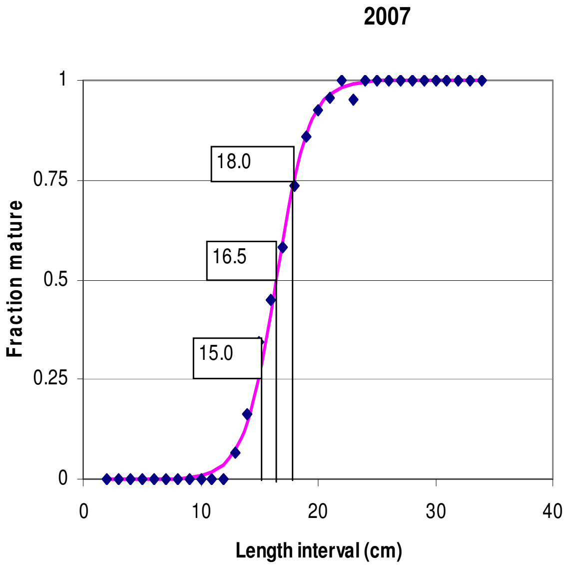
APPENDIX 3. MATURATION CURVES

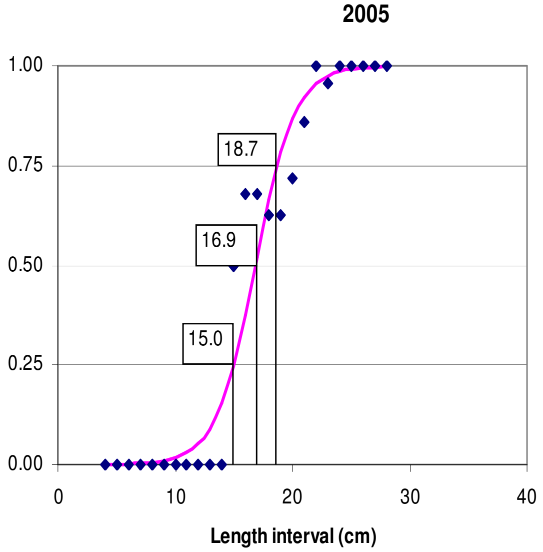








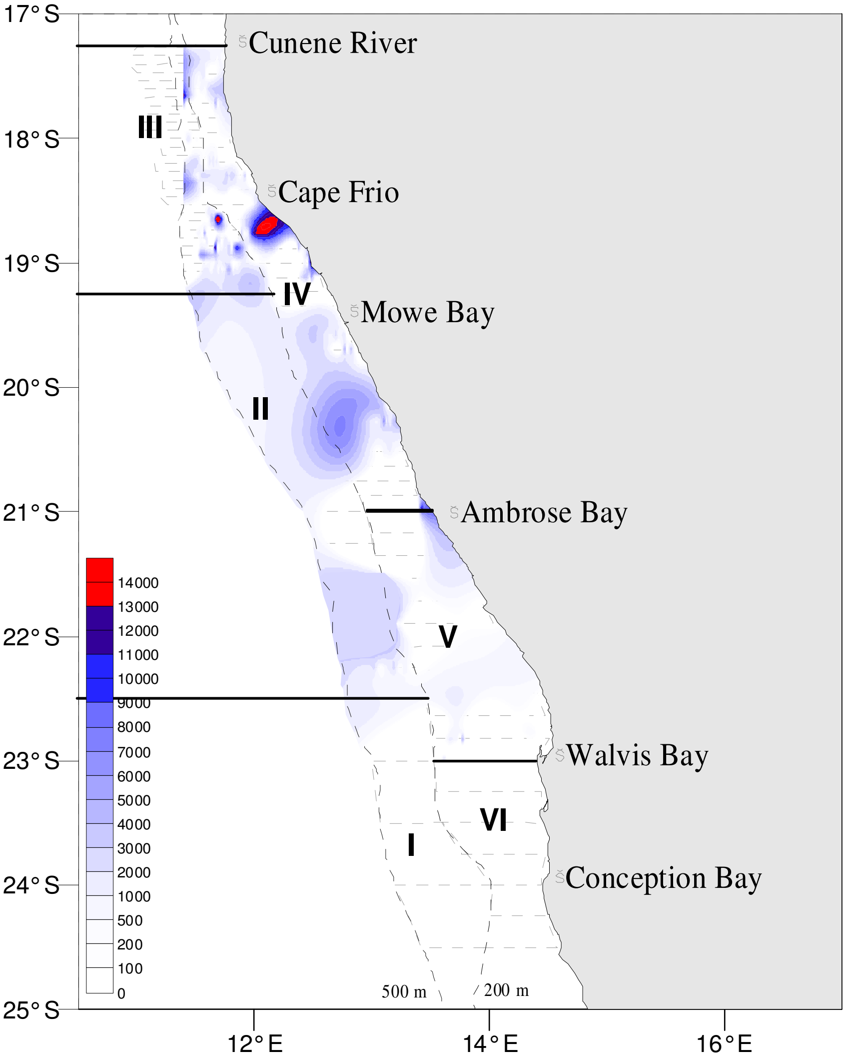




APPENDIX4. EFFORTS IN THE MIDWATER FISHERY (MFMR 2007)

Year	Fishing days	Boats operating	No. of trawls	Processed catch (tonnes)	Trawl hours
1991	5164	68	20015	291317	43111
1992	3111	46	10285	206173	25955
1993	4462	44	13911	326250	40155
1994	4494	32	15023	276430	44164
1995	3558	24	11889	232777	41107
1996	3224	28	10992	175755	31978
1997	3094	22	10094	201501	37175
1998	3603	24	11435	260244	43602
1999	3583	23	11264	259248	45583
2000	4216	22	13757	295608	57933
2001	3785	23	12063	252281	51293
2002	3414	20	11070	242912	48302
2003	3815	23	12011	315878	52929
2004	3265	23	10488	251218	46708
2005	3022	19	8968	268815	33684
2006	3381	17	10166	253713	39781
2007	1273	13	3783	96072	15160

APPENDIX 5. AREA COVERAGE OF HORSE MACKEREL STOCK SURVEYS (MFMR)



APPENDIX6. HORSE MACKEREL FISHERY TREND (MFMR)

	Landings				Quota	
Year	Midwater	Pelagic	total Catch	TAC	Midwater Quota	Pelagic
1961	47		47			
1962	23		23			
1963	21		21			
1964	71		71			
1965	126		126			
1966	100		100			
1967	72		72			
1968	69		69			
1969	47		47			
1970	51		51			
1971	77	140	217			
1972	51	22	73			
1973	250	12	262			
1974	154	31	185			
1975	255	14	269			
1976	484	24	508			
1977	281	82	363			
1978	538	10	548			
1979	388	33	421			
1980	507	39	546	500		
1981	586	4	590	500		
1982	592	68	660	500		
1983	493	107	600	641		
1984	519	88	607	630		
1985	438	22	460	630		
1986	416	85	500	485		
1987	514	34	548	440		
1988	393	170	563	472		
1989	381	32	413	497		
1990	342	85	427	410		
1991	351	83	434	400	465	
1992	310	116	426	450	450	
1993	401	74	475	450	450	
1994	331	33	364	500	500	
1995	259	51	310	400	350	50
1996	229	91	320	400	310	90
1997	212	88	300	350	250	100
1998	286	25	311	375	300	75
1999	294	27	321	375	325	50
2000	336	21	357	410	360	50
2001	299	23	322	410	360	50
2002	297	61	358	350	310	40
2003	308	52	360	350	310	40
2004	248	42	290	350	310	40
2005	268	44	312	350	310	40
2006	254	44	298	360	315	45
2007	163	28	191	360	325	35

APPENDIX7. MEDIAN LENGTH OF HORSE MACKEREL

Year	**Biomass**	**Lmedian**	**error up**	**error down**	**L95%**	**L5%**
2001	861	21	9	6	30	15
2002	803	21	7	5	28	16
2003	1059	22	5	4	27	18
2004	1375	21	6	4	27	17
2005	1639	22	7	5	29	17
2007	534	20	7	3	27	17

Purse seine fleets

Year	Biomass	**LMedian**	**error up**	**error down**	**L95%**	**L5%**
2001	861	18	5	7	23	11
2002	803	15	5	3	20	12
2003	1059	17	6	4	23	13
2004	1375	15	3	3	18	12
2005	1639	15	4	3	19	12
2007	534	16	3	3	19	13

Survey fleet

Year	Biomass	**Lmedian**	**error up**	**error down**	**L95%**	**L5%**
2001	861	14	5	6	19	8
2002	803	17	3	5	20	12
2003	1059	17	6	6	23	11
2004	1375	15	6	4	21	11
2005	1639	12	10	5	22	7
2007	534	15	7	3	22	12

APPENDIX8. MATURATION LENGHT OF HORSE MACKEREL

	L50	**L75**	**L25**	**error up**	**error down**	**Biomass**
2001	19.11	21.08	17.14	1.97	1.97	861.00
2002	20.92	23.83	18.01	2.91	2.91	803.00
2003	18.53	21.05	16.00	2.53	2.53	1059.00
2004	16.89	19.46	14.32	2.57	2.57	1375
2005	16.86	18.69	15.03	1.83	1.83	1639
2007	16.47	17.97	14.97	1.50	1.50	534