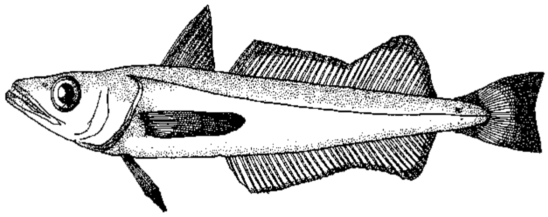
Recent Namibian Hake Assessment as forwarded from Namibian Scientists through the Namibian Hake Association to SADSTIA on 27 November 2022



3. Hakes (*Merluccius capensis* and *Merluccius paradoxus)*

State of the Stock	
Biomass (Total):	2.393 million tonnes (Model estimated).
Recruitment:	Above the long-term average (model estimate).
Distribution:	Entire shelf and slope (mostly between 100 and 600 m depth).
Recent harvest level:	The catches are below the RY level, hence sustainable
Overall stock indicator:	Above 1990 Reference Point, but below Bsp_{msy} level.

Summary

A Statistical-catch-at-age Analysis (SCAA) model, treating the two hake species (*Merluccius capensis* and *M. paradoxus*) as a single stock, was used to assess the status of the hake resources. Input data consists of all available catch information such as total catch, catch at age matrices from biomass surveys and commercial fishing, combined survey biomass estimates, weight-at-age, selectivity-at-age and maturity-at-age. Twelve model specifications were fitted to the combined hake data and results compared. The Best Case model, estimated the total biomass to be above the 1990 reference point, and a 22% and 36% growth in the total and spawning stock biomass, respectively since the last assessment in September 2021. However, the overall spawning stock biomass is still below the spawning stock biomass at maximum sustainable yield level (Bsp_{msy}) and needs to be rebuild to this level. Furthermore, recruitment has remained the same above the long-term average. The recent harvest level is sustainable since the catches are lower than the replacement yield, which should allow for the recovery of the stock to the desired level.

3.1 Introduction

Two species of hake, namely *Merluccius capensis* (Shallow-water Cape hake) and *Merluccius paradoxus* (deep-water hake) occur in the Namibian waters and are exploited by the bottom trawl (freezer and wet fleets) and the longline fishery. Commercial exploitation of the resource commenced in 1964 with the highest catch of 820 000 tonnes made in 1972. This level of high exploitation continued in the seventies and by the time of Namibian Independence in 1990, the catches had drastically declined to 132 000 tonnes, indicative of a depleted stock.

Since then the objective of the Namibian Government has been to rebuild the stocks to the maximum sustainable levels. Surveys were immediately initiated to determine the level of biomass on which the Total Allowable Catches (TACs) were based. The biomass was found to be on average around 700 000 tonnes and remained around this level until 1996 – 2009 when it dropped below this level.

Therefore, the strategy was first to rebuild the stock above the 1990 reference point. The second step is to rebuild the spawner stock biomass (Bsp) to a level where it supports the maximum sustainable yield. Simulations conducted in 2018 have indicated that for the Bsp to reach the Bspmsy level under the current harvest control rule of taking a TAC corresponding to 80% of the replacement yield will take more than 20 years. Hence, our current harvest control rule will not rebuild the stock to Bspmsy in less than 9 years as as Namibia has committed under the Marine Stewardship Council (MSC). It was therefore agreed that we we first rebuild the hake stock to 55% of the Bspmsy by the year 2025.

Studies of the biological, behavioural and ecological aspects are crucial to understanding the dynamics of fish populations and to ensure that they are exploited sustainably. Biological and demographic parameters, such as growth, mortality and abundance are critical for stock assessment and the determination of a total allowable catch.

These data described in this report are acquired from the commercial fisheries and annual surveys and are used in the Statistical catch at age stock assessment model .

3.2 Biology of hakes

3.2.1 Spawning & Distribution

Merluccius capensis spawning occurs throughout the year, with the main spawning period between July and October (Kainge *et al.* 2007, Jansen *et al.* 2015). Spawning takes place in demersal and mesopelagic zones, peaking offshore between 100 and 400 m depending on environmental conditions such as cross-shelf circulation, low oxygen layers, and mesoscale gyres (Sundby *et al*. 2001). Spawning most commonly occurs between 20°S and 27°S, and the larvae are found between 18°S and 24°S**.**

Strong evidence of spawning activities of *Merluccius paradoxus* in Namibian waters has not been confirmed (Burmeister 2005, Kainge *et al* 2007, Jansen *et al* 2015). Strømme *et al.* (2016) showed that *M. paradoxus* spawns between western Agulhas Bank and Elands Bay in South Africa and the main nursery ground is between Hondeklip Bay and the northern tip of Orange Banks (Fig. 3.1). The paper also concludes that *M. paradoxus* found in Namibia and along the south coast of South Africa (eastwards to Port Alfred) originate from these nursery grounds, and undertake long-range migrations, implying that the stock is shared between the two countries. Genetic studies by Henriques *et al.* (2016) confirmed that *M. paradoxus* constitutes a single stock between Namibia and South Africa, based on microsatellite markers. Figure 3.2 below shows inter-annual variability in the percentage of occurrence of *M. paradoxus* in the Namibian waters, as deduced from the biomass surveys covering the entire distributional range of the stock. The data illustrates that apart from 2005 and 2006 when about 70% of juveniles occurred in the Namibian waters, it is generally fish between 35 and 55 cm (40% occurrence) that frequent our waters.

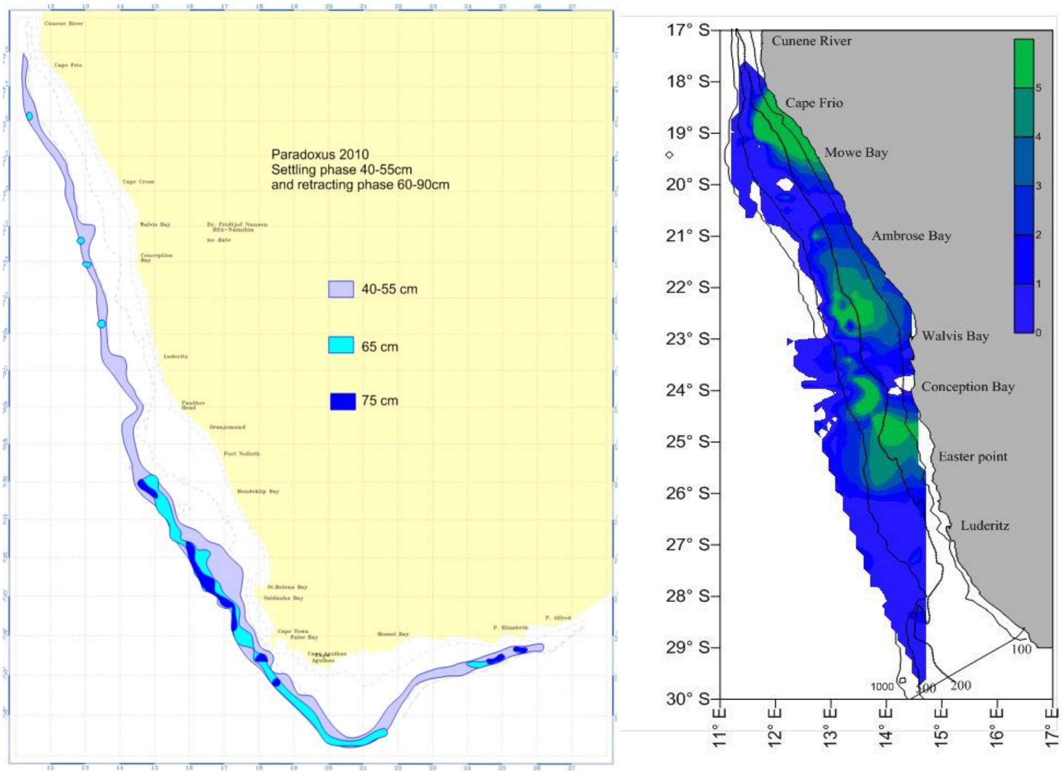


Figure 3.1*: Transboundary distribution of Merluccius paradoxus by size classes during January – February 2010. The smaller fish are overlaid on the bigger ones, demonstrating expansion from a central area (Saldanha – Hondeklip Bay). From Strømme et al (2016). The map on the right shows the spawning area for hakes based on results of gonodosomatic index (GSI)*

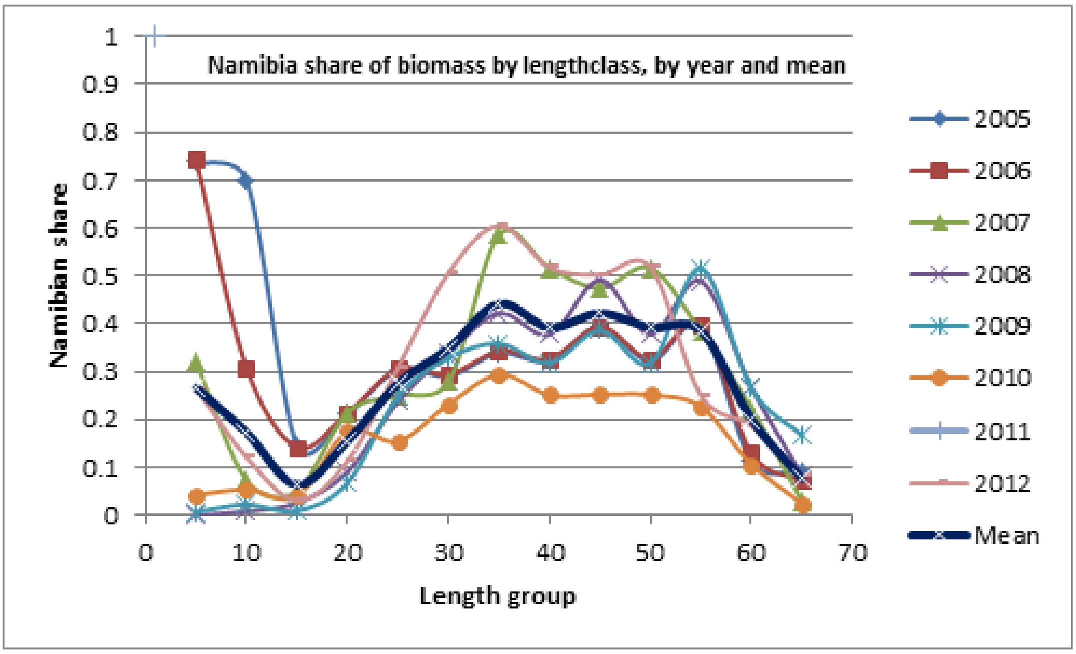


Figure 3.2*: Time series of occurrence of Merluccius paradoxus biomass based on the surveys in the years 2005–2012, and arithmetic mean for all these years. The lowest and highest estimates are in 2010 and 2012, respectively. From Strømme et al (2016).*

3.2.2 Growth

Biological parameters for hake are summarized in Table 3.1 below. Data show that *M. capensis* can reach a maximum length (L∞) of 114 cm and *M. paradoxus* around 109 cm. There is a difference of about 7 cm in the length at which the two species attains 50% maturity, with *M. capensis* attaining maturity earlier.

***Table 3.1**: Pooled data for Von Bertalanffy growth parameters, L_∞, K and t0 (1999-2022), weight-length parameters, a and b (1991-2022), maturity at age parameters (1999-2022) and maturity at length data (1994-2022).*

Biological parameters	***M. capensis***	***M. paradoxus***
Growth parameters (1999-2022):		
L_∞	114	109
K	0.109	0.096
t_0	-1.133	-1.593
Natural Mortality:	M – 0.35 to 0.4 (literature)	
Length-weight relationships (a*L^b) (1991-2022):	$W = 0.0080L^{2.97}$	$\mathbf{W = 0.0060L^{3.00}}$
Age at 50 % maturity (1999-2022)	1.3	2.4
Length at 50 % maturity (L50) (1994-2022):	21.6 cm	28.9 cm

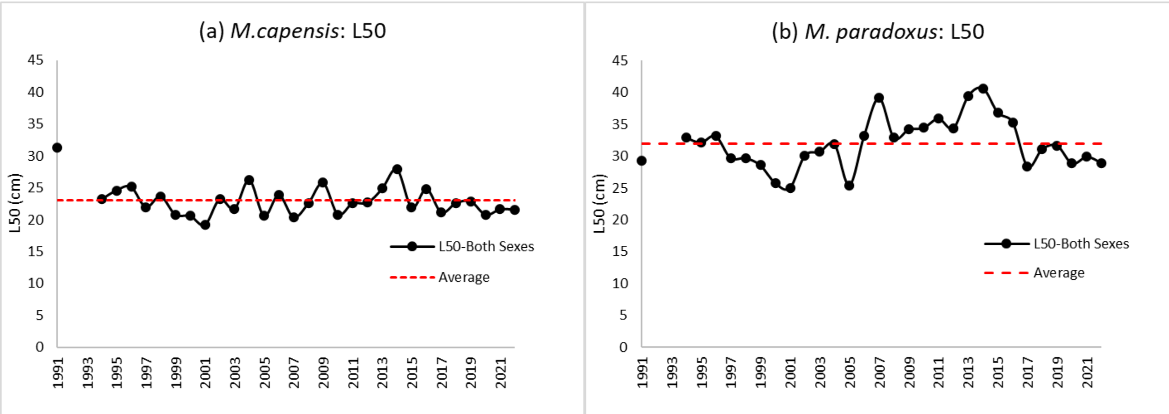


***Figure 3.3:** Trends in length at 50% maturity (L_{50}) (a) M. capensis and (b) M. paradoxus relative to an average value (dashed line).*

Maturity at length for *M. capensis* shows an average onset of 50% at a length of 21 cm (Fig. 3.3(a)) and a later onset in *M. paradoxus* at a length of 29 cm (Fig. 3.3 (b)). There is a downward overall trend from 2013 observed in both species. Whilst changes in maturation could be due to proximate environmental effects, consistent early maturation is mostly an adaptive ecological response attributed to high fishing pressure and consequent reduction in abundance. The constant removal of older and larger fish due to size-selective harvesting causes the established age truncation effect (Anderson et al. 2008). Jansen *et al*. 2016 noted that adult *M. capensis* die faster in Namibia than in South Africa, where the L_{50} of 53 cm is recorded and as such these fish are forced to mature earlier in Namibian waters. Arancibia (2015) and Singh *et al* (2001) also reported an L_{50} of 41cm for *M. paradoxus* in South Africa.

According to literature low size at maturity is associated with high K (as in Table 3.1), high reproductive output, short lifespan and a low asymptotic length (maximum length) (Jennings *et al*. 2009). Contrary to this, *M. capensis* in Namibia has a lower maturity at length (L_{50}) yet seems to have a longer lifespan, higher asymptotic length and lower K value. This is most likely a sampling bias as only the middle range *M. paradoxus* generally occur in the Namibian waters.

3.2.3 Feeding

The main food items for hake, based on stomach content studies, are planktonic crustaceans (euphausiids and decapods), cephalopods and fishes (mainly myctophidae, gobidae, and horse mackerel. Due to an overlap in space with adults, juvenile hake, are also prey for *M. capensis*) (Pillar & Barange 1997). Cannibalism whereby older *M. capensis* target younger *M. capensis* and younger *M. paradoxus* is well documented and was found to account for more than 70% of their diet. The hake species in general perform extensive vertical migration from near the bottom, where they spend the day, to mid-water or near the surface to feed at night (Pillar & Barange 1997, Huse *et al.* 1998, Macpherson and Gordoa 1994, Iilende *et al*. 2001, Ingólfsson *et al*. 2005, Johnsen & Iilende 2007), a mechanism enabled by the physiological adaptations of the swim bladder and blood system.

Hake trophic levels were estimated from food web models at 4.0 for small, 4.5 for large *M. capensis*, and 4.1 for large *M. paradoxus*, putting the species at a relatively high trophic level, similar to large pelagic fish, seals and seabirds. Stable isotope-based results, however, indicated that small hake (20–39 cm) of both species were trophically indistinguishable at around 3.3, indicating predominant zooplanktivory. The trophic levels of *M. capensis* and *M. paradoxus* of 60–70 cm were estimated at 3.4–3.6 and 3.7–3.8, respectively.

3.3 Survey biomass estimates

3.3.1 Swept-area biomass surveys

Swept-area biomass surveys for hake are conducted annually to obtain an index of abundance, determine the geographical distribution and collect biological information used in the stock assessment model. These surveys were conducted since 1990 either on board research vessels or inter-calibrated commercial vessels using a standard method of biomass estimation based on depth stratification (100 – 600 m). No survey was conducted in 2019 due to vessel-related problems, and in 2021 the survey was conducted on the F/V Blue Sea 1. The stations covered during the 2022 survey are shown in Figure 3.4.

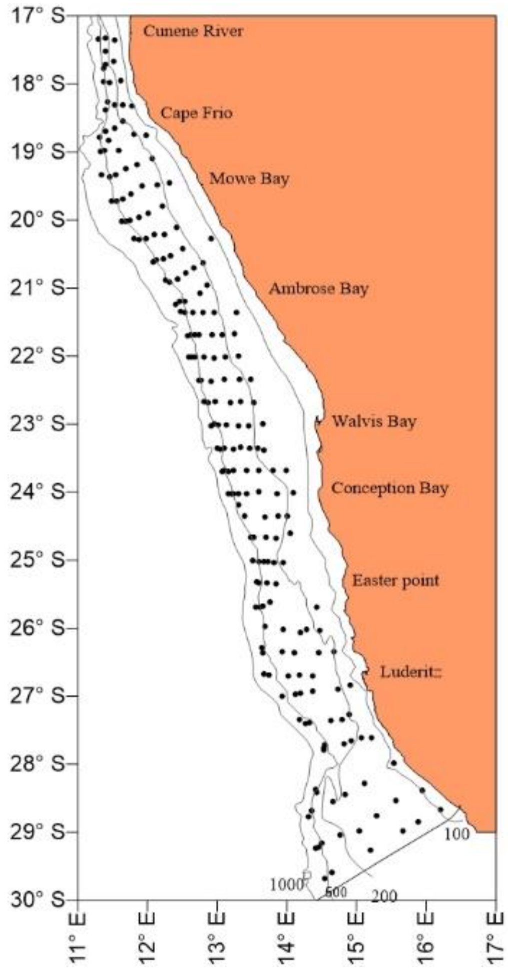
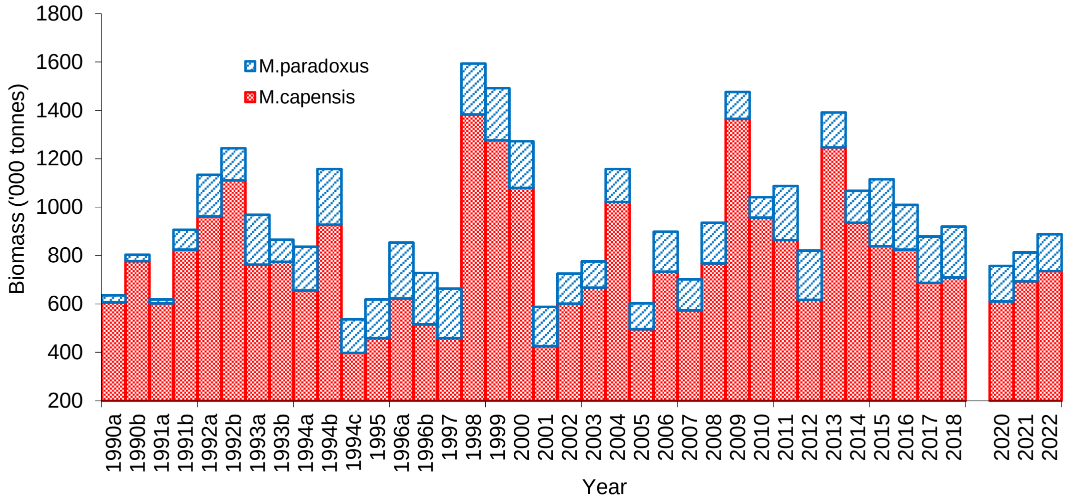


Figure 3.4: *Stations layout of the entire region covered during the 2022 hake swept-area biomass survey (with depth contours of 100, 200, 500 and 1000 m).*

3.3.2 Combined survey biomass estimates

The total biomass of hake (both species combined) increased by 9.2% (from 813 000 to 888 000 tonnes) between January/February 2021 survey and February/March 2022 survey, mostly in the non fishable biomass (by 19.8% from 519 000 to 622 000 tonnes) ((Fig. 3.5). However, the total fishable biomass decreased by 9.6% from the 293 000 to 265 000.

It can be seen from Figure 3.5 (a) that the combined survey biomass estimates in the Namibian waters since 1990 have been dominated by *M. capensis* (more than 80%). On the contrary, the hake catches by the fishery consist of about 70% *M. paradoxus* (see Section 3.4). A study by Kathena *et. al.* (2016) also estimated the fishing mortality of *M. paradoxus* to be higher than that of *M. capensis (Fig.3.5 (b)).*



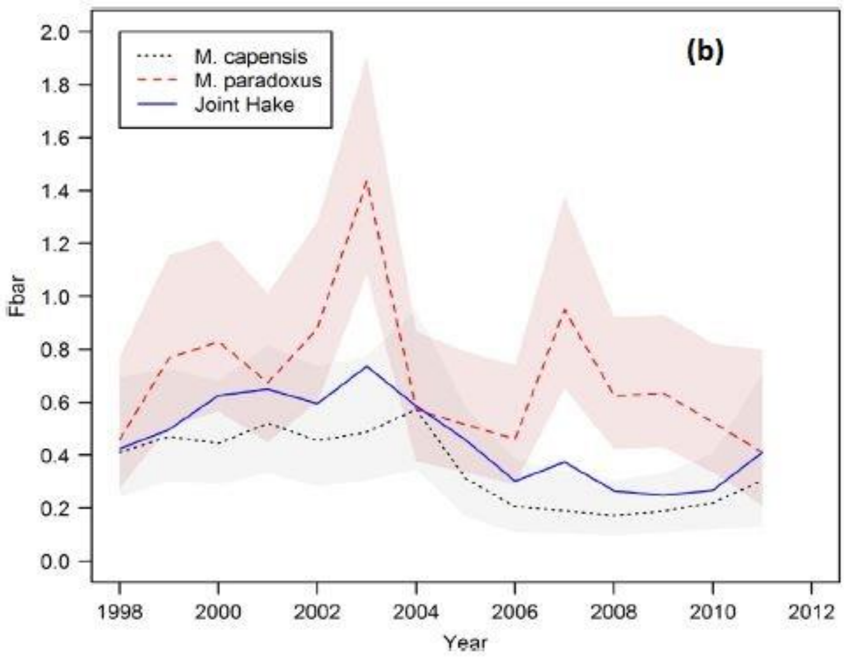


***Figure 3.5: (a)** Survey biomass estimates of hake, from a swept-area survey in 2021, combined (solid blue line), M. capensis (dotted green line) and M. paradoxus (dotted red line). **(b)** Estimated F-bar (fishing mortality) with 95% confidence intervals (Kathena et al 2016).*

3.3.3 The biomass of *M. capensis*

For *M. capensis*, the total biomass increased by 6.1% from 694 000 to 736 000 tonnes (coefficient of variation, CV = 10%) between the 2021 and the 2022 surveys (Fig. 3.6). The non-fishable biomass increased by a 13.3% (473 000 to 536 000 tonnes) and the fishable biomass decreased by 9.5% (221 000 to 200 000 tonnes). The non-fishable biomass still makes up the largest component of M.capensis, accounting for anything between 60-80%.

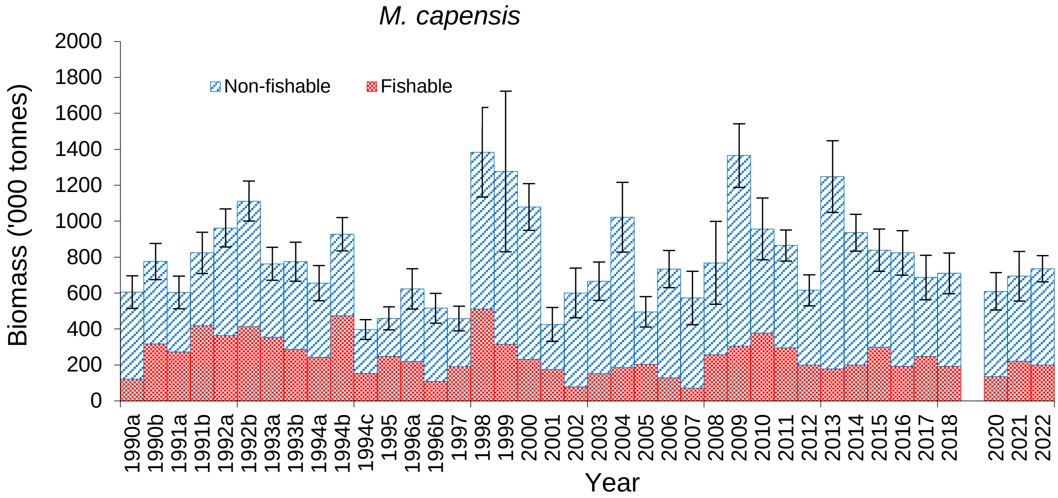


***Figure 3.6**: Estimated fishable and non-fishable biomass of M. capensis from swept-area surveys in 2022.*

3.3.4 The biomass of *M. paradoxus*

For *M. paradoxus*, the total biomass has increased by 27.7% (from 119 000 to 152 000 tonnes, CV = 11%). The fishable component decreased by 9.7% (from 72 000 to 65 000 tonnes) while the non-fishable increased by 87% (from 46 000 to 86 000 tonnes) (Fig. 3.7). As opposed to *M. capensis*, the fishable component makes up a larger component of the *M. paradoxus* stock, though the non-fishable biomass has been increasing since 2003, meaning younger *M. paradoxus* fish are recruiting into Namibian waters.

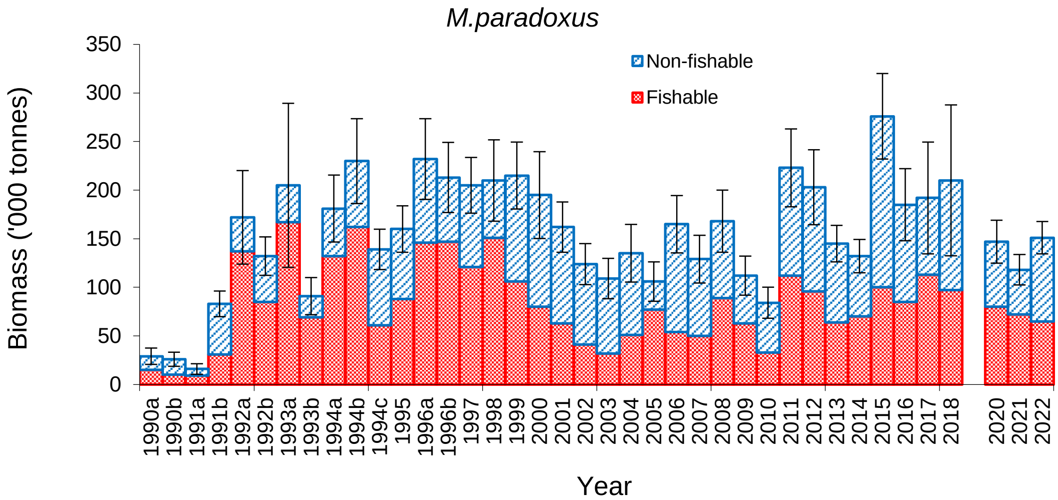


***Figure 3.7**: Estimated fishable and non-fishable biomass of M. paradoxus from swept-area surveys in 2022.*

3.3.5 Spatial density distribution

The two species of hake occur on the shelf and upper slope in the Namibian waters, with *M. capensis* at depths from about 100 m to 350 m and overlapping with the shallow end of the distribution range of *M. paradoxus*, which occurs mainly at depths of 300 m to 600 m (Burmeister, 2001). Catches of *M. paradoxus* have also been recorded at depths exceeding 600 m albeit in low quantities. A depth-related size distribution, with the smaller fish occurring shallower than the larger fish, has been recorded in both hake species (Burmeister, 2001; Kainge *et al*., 2015).

During the 2022 survey, high densities of *M. capensis* (>80 t/nm²) were found primarily between 17° S and 19° S, 23°S and between 26° S and 29° S mainly along the 200m isobaths. Medium densities (40-80 t/nm²) were found mainly along the central coast between 200 and 500 m depths (Fig. 3.8).

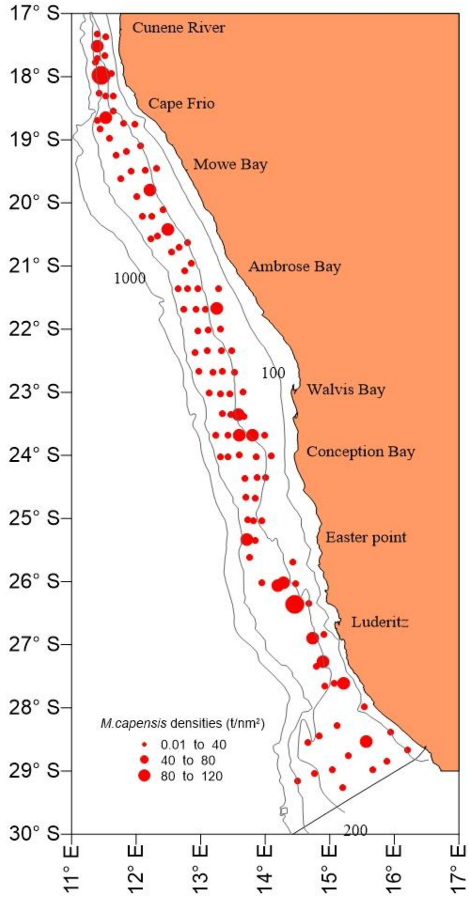


Figure 3.8: *Density distributions (t/nmi²) of M. capensis (left) and M. paradoxus (right) from the Feb/Mar 2022 swept-area survey. Depth contours represent 100, 200, 500 and 1000 m depths.*

M. paradoxus were concentrated in high-density in the area between 26° S and 28° S between 300 and 400 m depths. Medium densities were found around 19° S at 500 m depth and in the south around 29° S, as well along the coast and around 500 m depth. In the far south these densities were well spread across the shelf (Fig. 3.8). The link between the density distribution, temperature and oxygen are described and shown in Part 2.6 of this report.

3.3.6 Depth-stratified biomass distribution

Figure 3.9 shows the biomass of both species of hake in the five-depth strata. In general, the abundance of both species decreases with an increase in depth. Compared to 2021 the biomass of *M. capensis* decreased in the 100-200 and 301-400 strata but increased in the 200-300m stratum, whilst none were found beyond 400 m depth in both years.

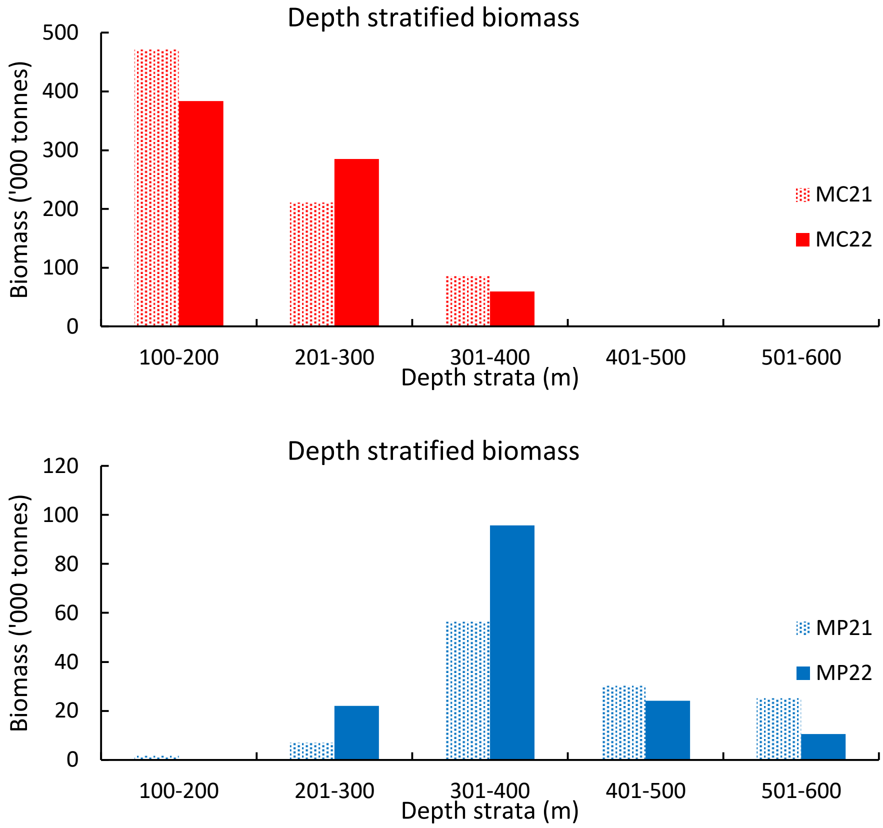


Figure 3.9: *Depth-stratified biomass distributions of the two species of hake: M. capensis (top) and M. paradoxus (bottom) from the 2021 and 2022 swept-area surveys.*

M. paradoxus biomass decreased in the 400 to 600m strata while an increase was observed in the shallower strata. Proportion wise, *M. capensis* dominated the two shallower depth zones (100- 300 m) while *M. paradoxus* dominated from 400 and deeper. The two species occur almost on an equal basis in the intermediate depths of 301-400 m.

During the 2022 survey, the *M. paradoxus* medium-sized group (20-35 cm) was abundant in the 201 to 400 m depth zones. Equal proportions of the 20-35 cm and >35 cm were found in the 401-500 stratum after which the >35 cm were predominant. with a smaller sized group (<20cm) being most abundant in the 101-200 m depth zone (Figure 3.10). According to Jansen *et. al.* (2016) and Burmeister (2001), the depth distribution of hake may change in relation to their age and size. Kainge *et. al.* (2015) also showed that in survey catch rates the medium-sized *M. paradoxus* dominates the 301-500 m depth zone.

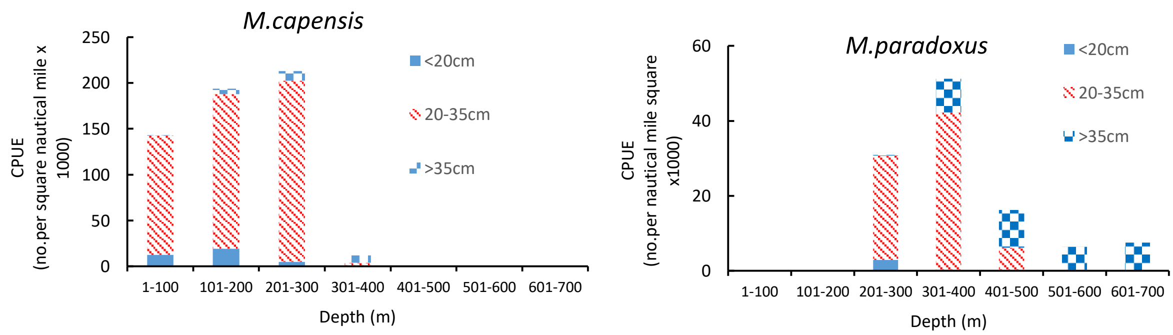


Figure 3.10 *Average catch rates of the two hake species by size groups in relation to depth during the 2022 survey.*

In *M. capensis* the 20-35 cm size group was more abundant in the first three depth zones and significantly declined as you go deeper.

3.3.7 Size composition

The overall size composition of *M. capensis* shows an increase in the biomass of fish between 20-25 cm, most probably due to the growth of the cohort observed at 13 cm last year. A sligh increase in fish greater than 55 cm is also observed during the 2022 survey (Fig. 3.11). However, the abundance estimates show significantly lower recruitment in 2022 (Fig 3.12).

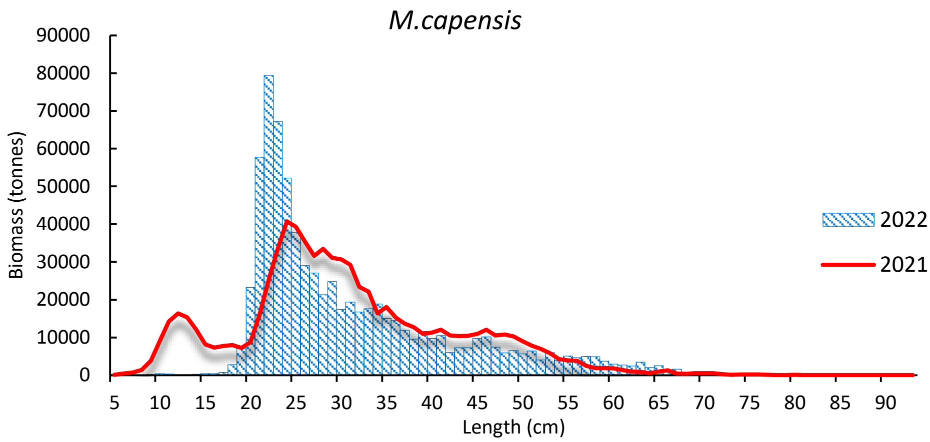


Figure 3.11*: Comparison between the biomass (in tonnes) per 1-cm length class of M. capensis from surveys in 2021 and 2022.*

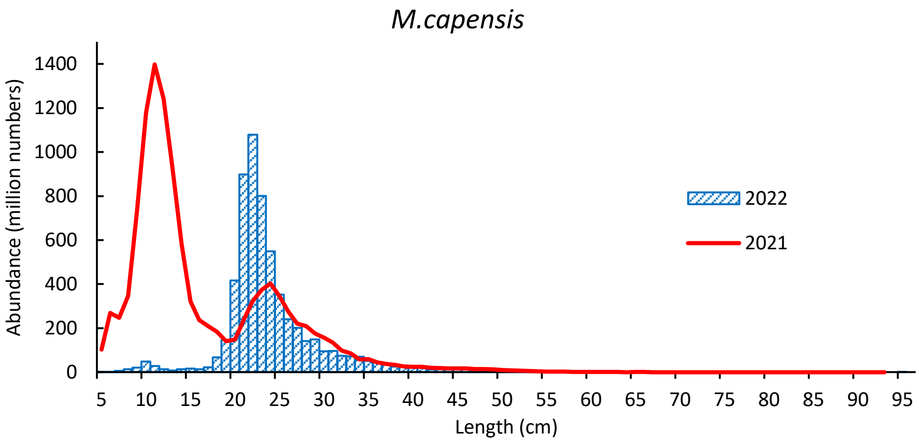


Figure 3.12: *Comparison between the abundance (in numbers) per 1-cm length class of M. capensis during the surveys in 2021 and 2022.*

It is evident that a large part of the biomass of *M. capensis* is made up of smaller fish, less than 36 cm, while that of *M. paradoxus* is more spread, with fish between 20 and 50 cm fish dominating. The *M. paradoxus* biomass increased, especially in the size classes between 19 to 40 cm and very few fish bigger than 60cm were found (Fig. 3.14).

Whilst *M. paradoxus* larger than 60 cm are not available in the Namibian waters they occur in the South African waters (Stromme *et al.* 2016).

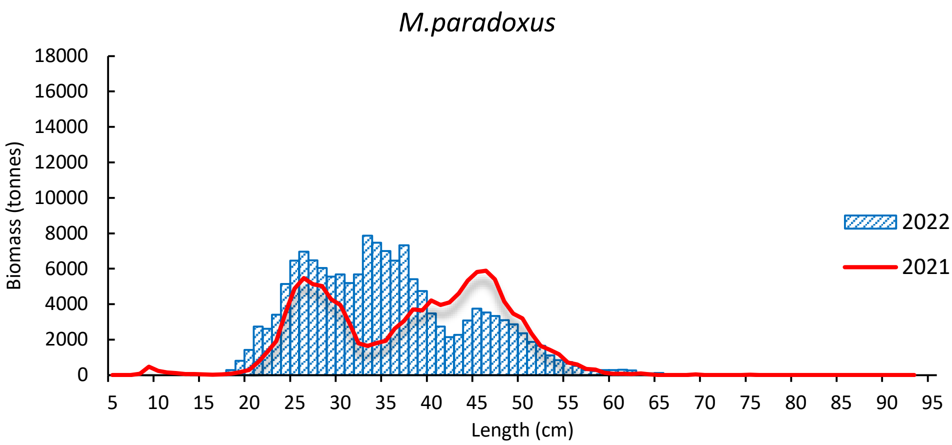


***Figure 3.13**: Comparison between the biomass (in tonnes) per 1-cm length class of M. paradoxus during the surveys in 2021 and 2022.*

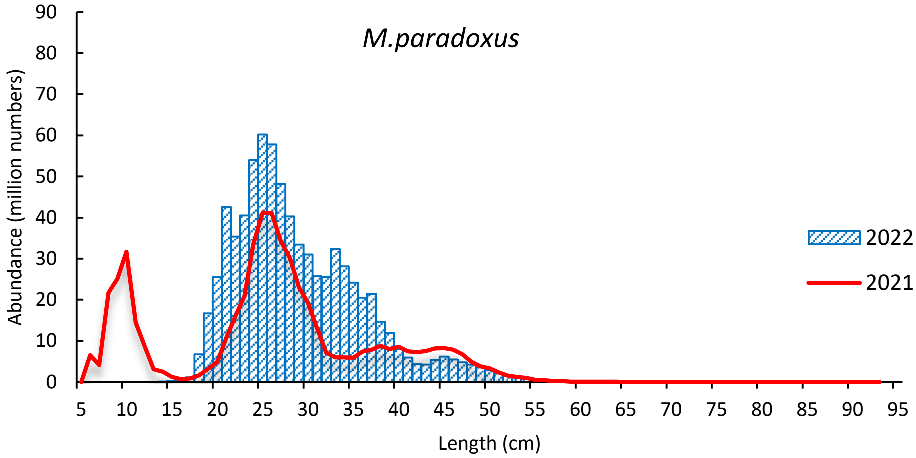


***Figure 3.14:** Comparison between the abundance (in numbers) per 1-cm length class of M. paradoxus during the surveys in 2021 and 2022.*

3.3.8 The recruitment of *M. capensis*

Recruits to the *M. capensis* stock are estimated from the numerical abundance of the cohort of fish with a modal length of about 22 cm (between 17 and 27 cm), assumed to be about 1.5-2 years old when caught during the surveys.

The recruitment of *M. capensis* of 4.7 billion fish detected during the 2022 survey (the 2020 cohort) was stronger than that in 2021 (the 2019 cohort) of 2.6 billion fish and is also higher than the long term average (Fig. 3.15). These fish are expected to be fully recruited into the fishery by the second half of 2022, although some of these may occasionally be available to the bottom trawl gear. Although no direct link exists between the spawning stock biomass (Bsp) and recruitment, Kainge *et. al.* (2013) reported that the abundance of Bsp only resulted in high recruitment during optimal upwelling periods.

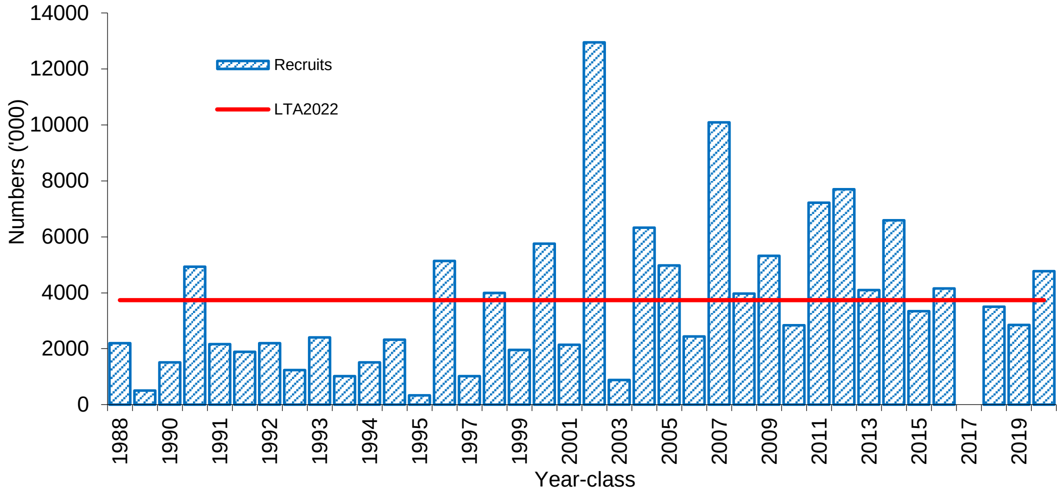


Figure 3.15: *Estimates of the strength of year classes of M. capensis (detected at age 1.5-2 during the hake surveys).*

The strength of the *M. paradoxus* cohort cannot easily be estimated, as the species does not appear to spawn in the Namibian waters (Burmeister 2005, Kainge *et. al.* 2007), but is confirmed to spawn on the west coast of South Africa (Jansen *et. al.* 2015).

3.4 The Fishery

Figure 3.16 shows the fishing effort distribution of hake trawlers (Freezers (A), Wet-fishers (B) and long-liners (C) for 2021. Wet-fishers operated along the entire coastline while the Freezers mainly concentrated south of Walvis Bay and the Hake long-liners in the central region (between 21 and 25°S) with some patchy fishing effort south of Luderitz.

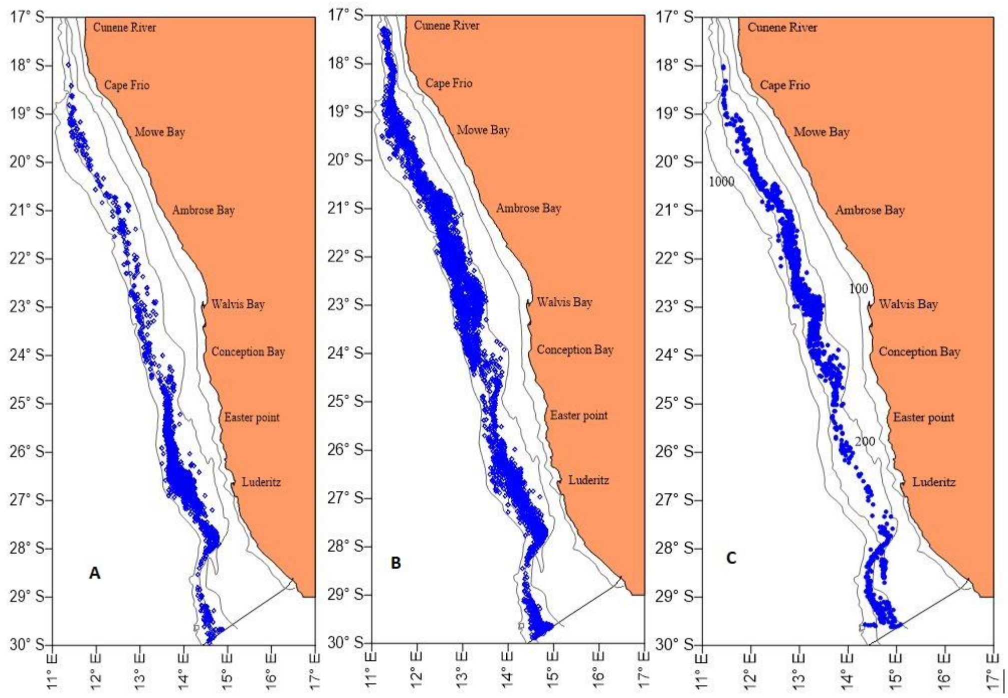


Figure 3.16: *Spatial distribution of fishing positions for hake trawlers* (*Freezers (a), Wet fishers (b) and Long-liners (c) during 2021. Depth contours represent 100, 200, 500 and 1000 m.*

3.4.1 Size structure of commercial catches

3.4.1.1 Hake Trawlers

The analysis of the catches by size in the hake fleet was made according to four regions as explained in Table 3.2 below and Figure 3.17

Table 3.2: *Defined raising strata for the Namibian coast.*

Degree South	Depth zones (gear depth)	Depth region
<24°	<350	North shallow
<24°	>=350	North deep
>=24°	<350	South shallow
>=24°	>=350	South deep

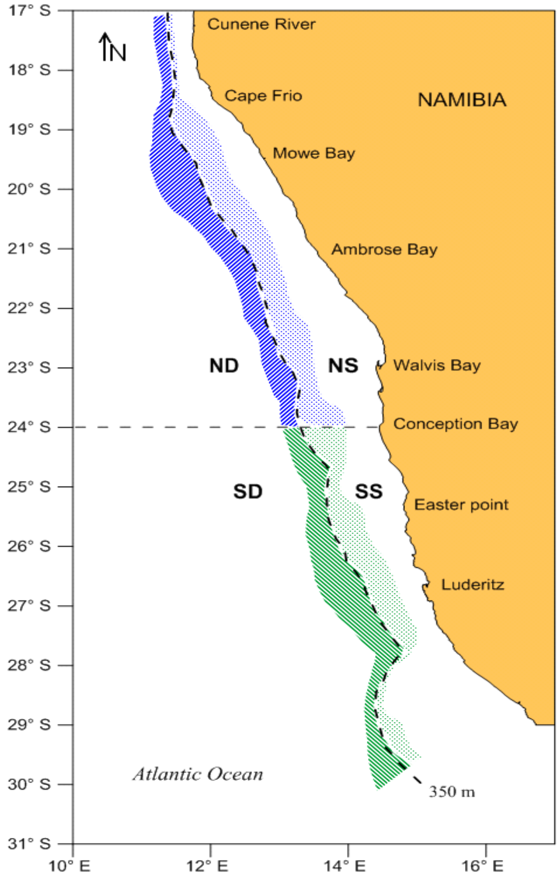


Figure 3.17 Schematic representation of *regions by depth (<350, >=350m) and latitude (Northern of 24°S, 24°S or Southern of 24°S) Shadowed areas represent possible areas for hake fisheries (between 200 and 1000m)*

For 2020 and 2021, the commercial catch data shows similar size distributions for both species (Figs.3.18 and 3.19).

There is an increase in the frequency of *Merluccius capensis* between 35 cm – 60 cm length during 2021 compared to 2020 (Fig. 3.18), whereas there were slightly more *Merluccius paradoxus* in the length class of 20 cm to 30 cm (Fig. 3.19).

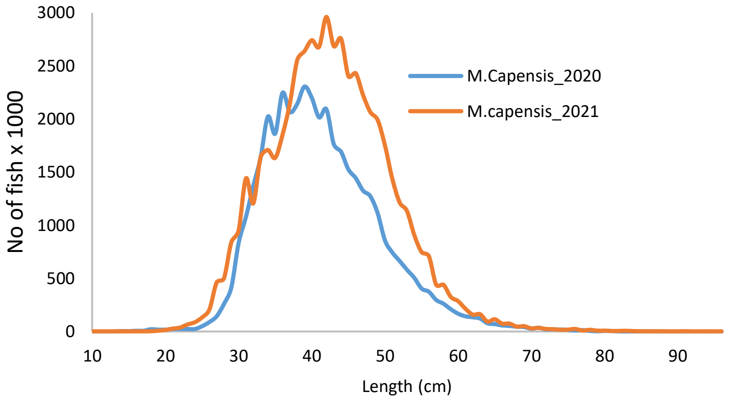


Figure 3.18: *Number of M. capensis by size caught in Namibian waters in 2020 and 2021.*

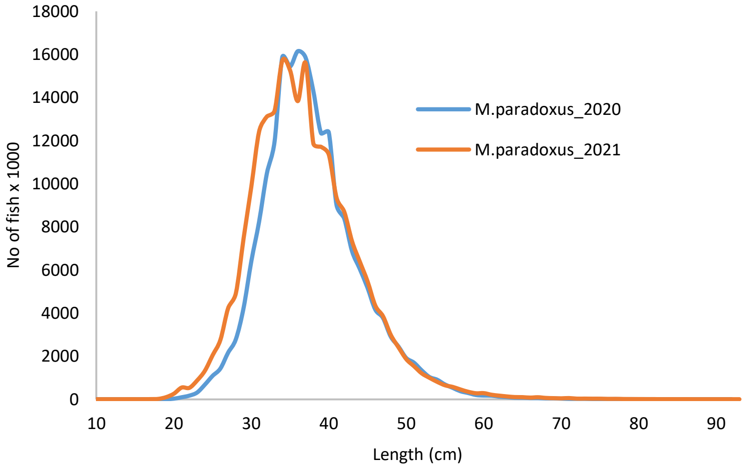


Figure 3.19: *Number of M. paradoxus by size caught in Namibian waters in 2020 and 2021.*

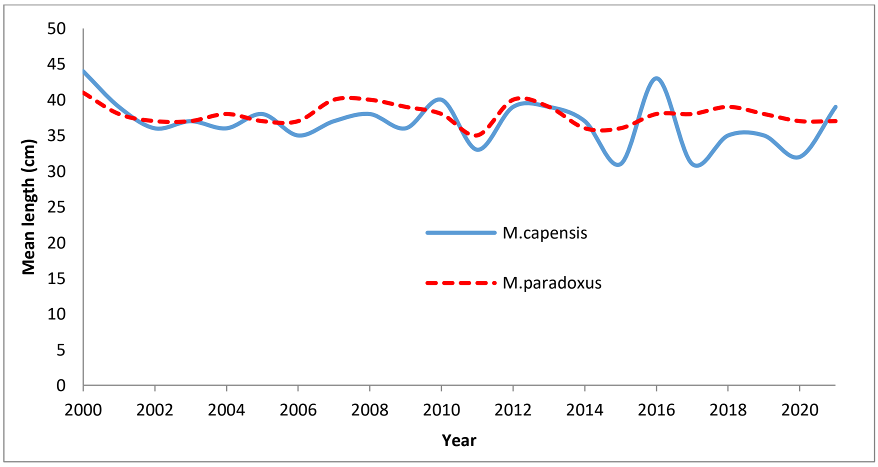


Figure 3.20*: Mean length of M. capensis (blue) and M. paradoxus(red) in catches made from 2000 -2021*

The mean length of *Merluccius capensis* has increased from 32 cm to 39 cm whereas for *Merluccius paradoxus* it remained at 37 cm in 2020 and 2021 receptively (Fig. 3.20). The increase in the mean length of *M.capensis* could be attributed to the growth in the number frequency of fish between 35 cm to 60 cm.

Table 3.3 Percentage of total catches of M.capensis and M.paradoxus caught by the hake bottom trawlers during 2020 and 2021

Specie	2020		2021	
	Weight (%)	Numbers (%)	Weight (%)	Numbers (%)
Merluccius capensis	20	16	26	19
Merluccius paradoxus	80	84	74	81

The percentage contribution of *M.capensis* caught by trawlers has increased in weight and numbers between 2020 and 2021, whereas for *M.paradoxus* it has decreased, (Table 3.3). The observed increase in weight in the catches of *M.capensis* could be explained by the increase in frequency of fish between 35 cm and 60 cm (Fig. 3.18). *M.paradoxus* continue to dominate the hake commercial catches, probably due to the fact that more sampling activities take place on freezer vessels in deeper waters in the south where the species is in more abundance (Kathena *et al* 2018).

3.4.2 Commercial catch per unit effort (CPUE)

3.4.2.1 Trawler fleet

Although the CPUE (catch rates) can be used as an index of fish abundance in fisheries assessment, it should be interpreted with caution (Maunder *et al.* 2006), as it could also be a reflection of improvements in fishing gear and changes in fishing strategies (Johnsen & Iilende, 2007) or variations in migration pattern of fish stocks (Salthaung & Aanes 2003). Experience with the codfish has shown that as the abundance decreases, the stock tends to aggregate making it easier for fishers to target, which results in high CPUEs which is not reflective of increase in abundance.

Annual standardized CPUEs (kg/h) were determined by averaging monthly catch rates in order to remove fluctuations due to seasonality and fleet strategy (Gordoa *et al.* 2006, Salthaug & Godø 2001) (Fig. 3.21).

The lowest catch rates were recorded between 2002 and 2008 when the CPUE fluctuated around 600 kilograms indicating that the stock was in bad condition. However, thereafter until 2011 the CPUE increased remarkably but was followed by a sharp decrease in 2012, to slightly below 1000 kg/hr. The decline in 2012 may have been a result of a decline in the stock due to two years of unsustainably high TACs. Hake trawlers annual standardized CPUE has slightly decreased in 2021 currently standing at 1583.65 kg/h compared to the 2020 level (1644.22 kg/h).

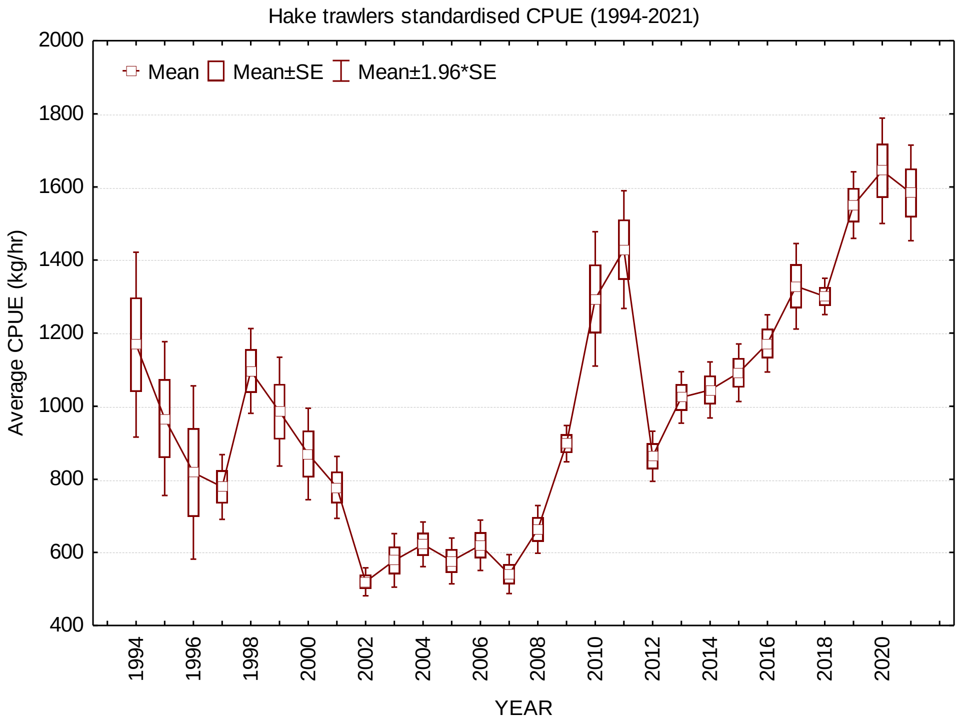
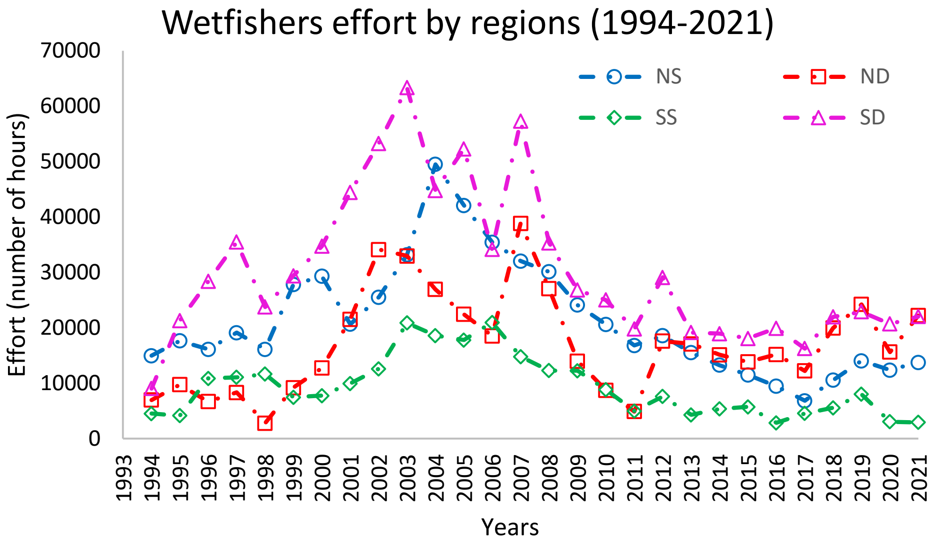


Figure 3.21: *Standardized annual CPUE for hake trawlers.*

3.4.3 Fishing Effort and CPUE per Region

The total effort for both fleet types has been decreasing in all regions since 2007 (Figures 3.22 (a) 3.23 (a)), resulting in an increase in CPUE from 2008-2011 (Fig. 3.22 (b) & 3.23 (b)). The wetfish trawlers spent more hours in SD and NS (Fig. 3.22 (a)), while freezer trawlers invested most effort in the South Deep (SD) region where *M. paradoxus* occurs (Fig. 3.23 (a)).

In 2021 wetfisher's effort increased in all four regions (Fig. 3.22a) resulting in increases in CPUE in the ND and NS regions and a decrease in SS and SD regions (Fig.3.22b). The CPUE for freezers displays a sharp increase in NS, a slight increase in SD and ND while in the SS region has decreased in 2021 (Fig. 3.23a, b).



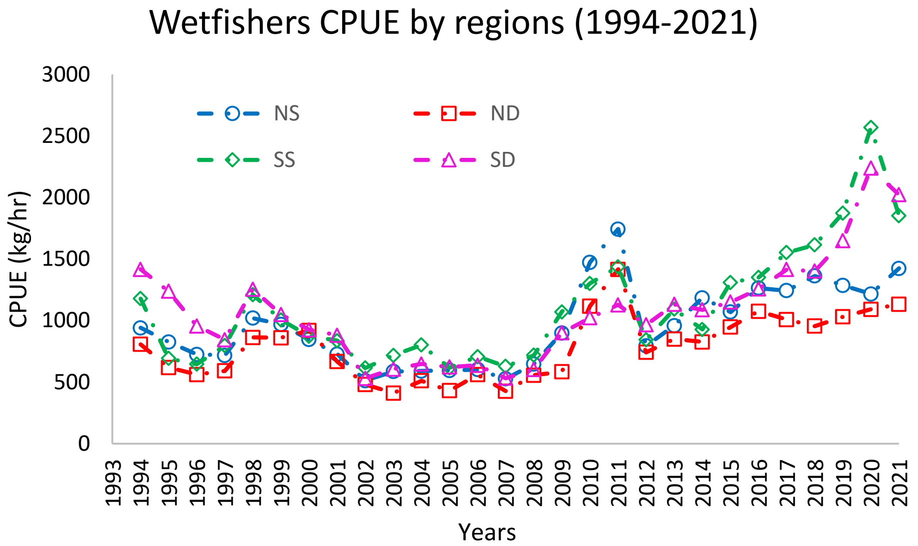
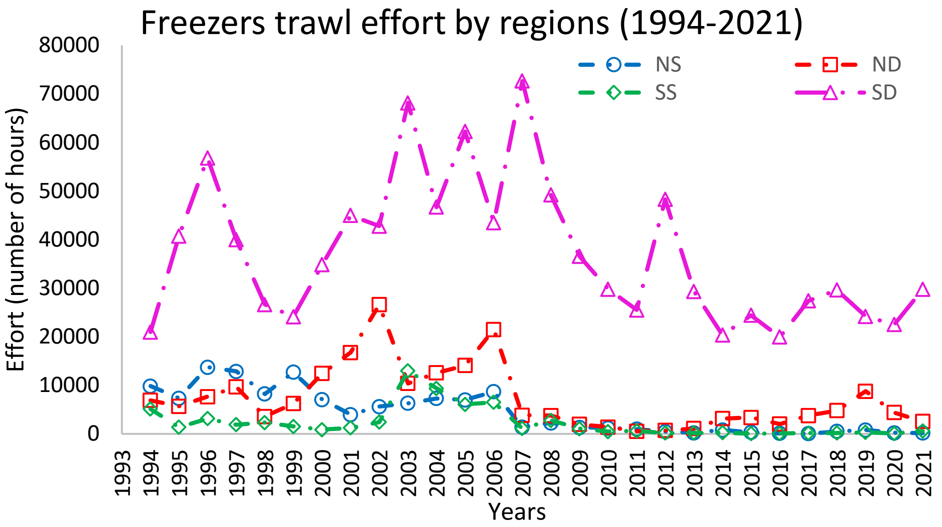


Figure 3.22: *(a) Standard fishing hours (top) and (b) CPUE (bottom) by region per year for wetfish trawlers*



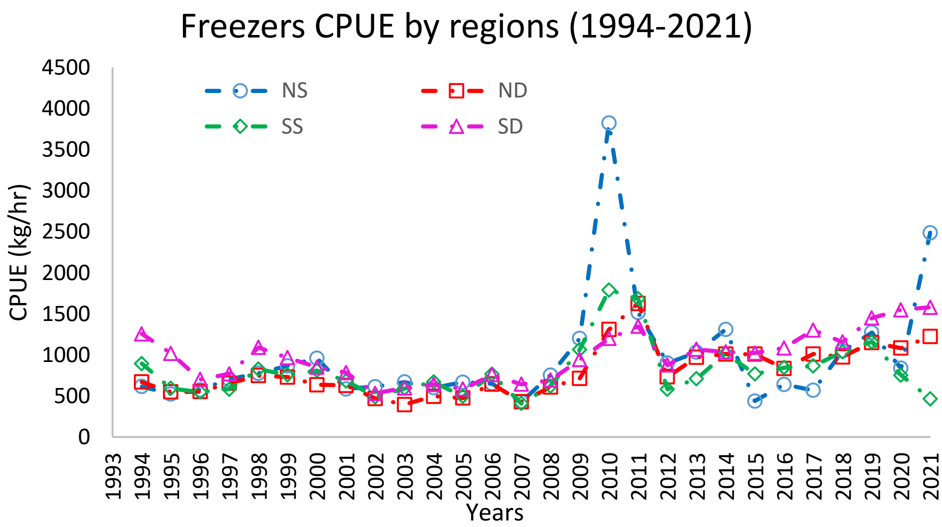


Figure 3.23: *(a) Standard fishing hours (top) and (b) CPUE (bottom) by region per year for freezers trawlers*

3.4.4 Long liner fleet

Hake long-liners' CPUE (Catch/Hook-hour) has been decreasing from 1999 to 2001, followed by consistently low levels between 2001 and 2007, after which it has been increasing, except for a dip in 2013. From 2015 a downward trend in the effort is evident with a slight increase in 2017. There is an observed decrease in CPUE from 0.043 kg/Hooks*hours in 2020 to 0.034 kg/Hook*hours in 2021 (Fig. 3.24).

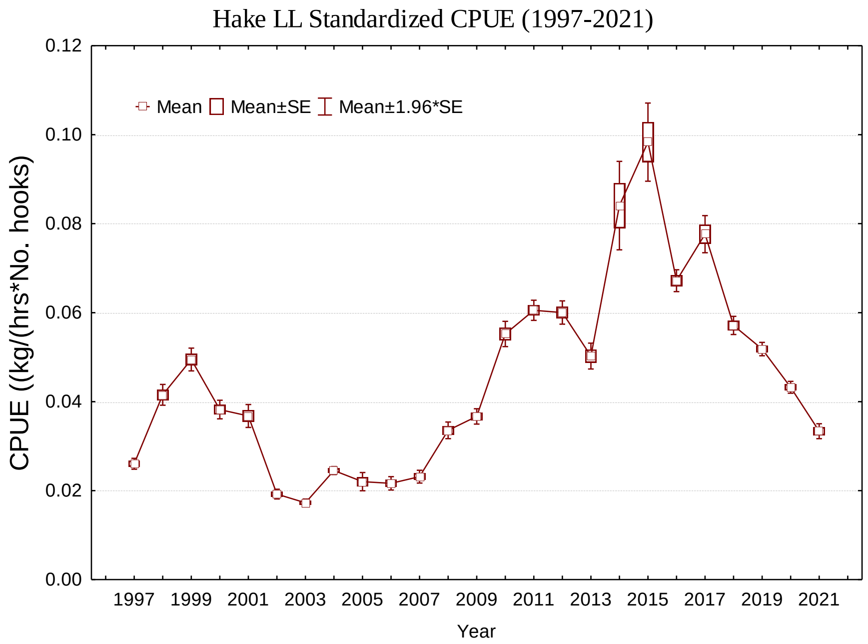


Figure 3.24: *Mean annual CPUE (kg/hr*hook) for the longline fleet since 1997.*

3.5 Stock Assessment

3.5.1 Background

A Statistical catch-at-age Analysis (SCAA) model is used to assess the status of the hake stocks and provide management advice (Butterworth *et al* 2001; Rademeyer and Butterworth 2003; Kirchner *et al* 2012; Kathena *et al* 2015). This model treats the two species of hake, *Merluccius capensis* and *M. paradoxus*, as a single species (Butterworth *et al* 2001; Rademeyer and Butterworth 2003). Input data to the model are total catches, survey and commercial catch-at-age and the CPUE from commercial vessels and survey biomass indices. Age data from successfully read otoliths were converted to age-length keys (ALK) and these are applied to both survey and commercial length frequencies to produce catch at age (CAA) data which are subsequently fed into the model.

3.5.2 The Resource Assessment of September 2022

The SCAA uses the observed catch-at-age and the assumed natural mortality to update the abundance of each cohort from one year to the next deterministically (Kathena *et al* 2015). Each cohort is initialized via a Beverton-Holt stock-recruitment relationship, where each recruitment is allowed to deviate according to a log-normal distribution with an externally specified standard deviation (Butterworth *et al* 2001, Kathena *et al* 2015). The first year is treated as a special case; since there is insufficient information to estimate the size of every cohort present reliably, the assumption is made of a steady age-distribution (Butterworth *et al* 2001), under total mortality at age given by the natural mortality at age and commercial selectivity-adjusted fishing mortality, where that fishing mortality is an estimated parameter of the fitting process. The fishing and survey selectivity are assumed to follow parametric functions (Kathena *et al* 2015). Model parameters (stock-recruitment function parameters together with annual deviations from this relationship, selectivity and multiplicative bias parameters, and yearly fishing mortalities) are estimated by penalized maximum likelihood (Kirchner *et al* 2012).

3.5.3 Input data

Historic catches, indices of abundance (CPUE and combined survey biomass), and catch-at-age data, collected from the commercial fishery and the research biomass surveys are used in the operating model. The data used in the assessment are listed as follows:

- Catches (1964-present)
- Abundance Indices.
  - Fishery-dependent:
  - ✓ 1965-1980. ICSEAF CPUEs series.
  - ✓ 1972-1995. the seven vessels CPUE.
  - ✓ 1992-2021. Namibian standardized CPUE.
  - Fishery-independent:
  - ✓ 1983-1990. Spanish Surveys.
  - ✓ 1990-2022. Namibian summer surveys.
  - ✓ 1990, 1992-1996. Namibian winter surveys.

- Catch at Age.
  - Commercial:
  - ✓ 1968-1988. ICSEAF fisheries.
  - ✓ 1997-2021. Namibian fisheries.
  - Surveys:
  - ✓ 1990-2022. Namibian summer.
  - ✓ 1990, 1992-1996. Namibian winter.

3.5.4 Hake Stock Status

Twelve (12) model specifications as indicated in Table 3.5 were run to determine the state of the stock. The state of the resource relative to the 1990 level and to the Spawning stock biomass that would produce a maximum sustainable yield (Bsp_{msy}) are represented in (Fig. 3.25 (a-b)). The 1990 reference point was selected as the year where the hake stocks were at their lowest, while the Bsp_{msy} is the target biological reference point as per the FAO guidelines of responsible fishing.

Table 3.5: *Model specification with associated parameters, some are fixed others are estimated, the red text highlights the changes in specifications for each model.*

	Specifications which has been subject of modifications						
Model name	Data exclusion	Recruitment St.dev	Natural mortality (M)	Catchability	CPUEs St.dev	Productivity	Selectivity
Base case	none	0.5	change with age (set)	estimated	estimated	constant	decrease for big sizes
Mod2	CPUE 1990 onwards	0.5	change with age (set)	estimated	estimated	constant	decrease for big sizes
Mod3	none	0.25	change with age (set)	estimated	estimated	constant	decrease for big sizes
Mod4	none	0.5	equal for all ages (est)	estimated	estimated	constant	decrease for big sizes
Mod5	none	0.5	estimating at infinity	estimated	estimated	constant	decrease for big sizes
Mod6	none	0.5	change with age (set)	q=0.4	estimated	constant	decrease for big sizes
Mod7	none	0.5	change with age (set)	q=0.6	estimated	constant	decrease for big sizes
Mod8	none	0.5	change with age (set)	q=0.8	estimated	constant	decrease for big sizes
Mod9	none	0.5	change with age (set)	q=1	estimated	constant	decrease for big sizes
Mod10	none	0.5	change with age (set)	estimated	GLM, ICSEAF=0.2, 7 Vessels =0.4	constant	decrease for big sizes
Mod11	none	0.5	change with age (set)	estimated	estimated	Shift mid-80s	decrease for big sizes
Mod12	none	0.5	change with age (set)	estimated	estimated	constant	increase for big sizes

Figure 3.25, depicts the total biomass for the 2022 assessment year, as estimated by the different model specifications relative to the 1990 reference point (Fig 3.25 (a)), and the spawning stock biomass relative to the Bsp_{msy} (Fig 3.25 (b)).

The model fitness is assessed through the Akaike Information Criterion (AIC), where the smallest AIC indicate the best fit. The model fit decreases from left to right for the different model specifications, indicating that the base case is the 4th best fit model. Given that the Akaike value for the base case is within the best five it was selected for further analysis, as it is based on the most plausible biological assumptions (the rule is that if it is within the best 5 then it is selected for further analysis). The Best Case model, estimated the total biomass to be above the 1990 reference point, and the spawning stock biomass to be below the Bsp_{msy}.

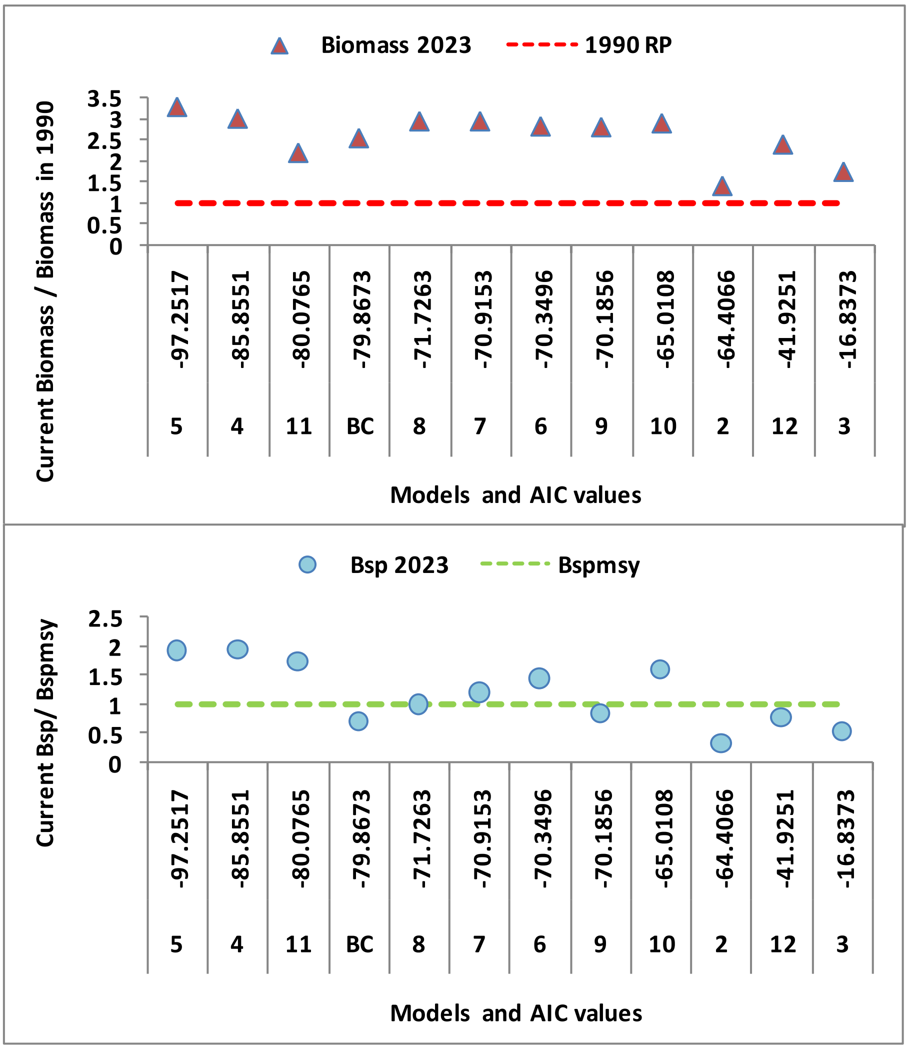


Figure 3.25 (a-b) *Total biomass relative to the biomass in 1990 (a) and spawning stock biomass relative to Bsp_{msy} (b) for all model specifications.*

Figure 3.26 presents the estimated spawning stock biomass with their respective 95% confidence intervals, for the best five model specifications since 1964. The figure also shows the estimated Bsp_{msy} value for the base case model. In the base case model, mod8 and mod11 estimated the spawning stock biomass very closely and their 95% confidence intervals are very similar, while mod5 and mod4 estimates are higher with wider 95% confidence intervals. The median for the base case, mod8 and mod11 are all shown to be below the estimated Bsp_{msy} for the base case.

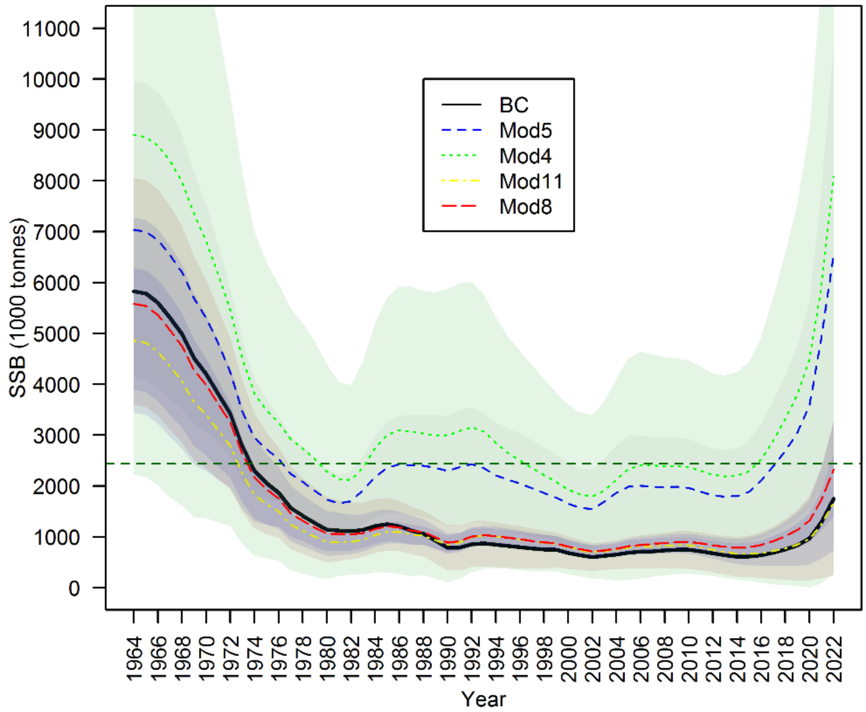


Figure 3.26*: Estimated spawning stock biomass for the best five model specifications. The shaded area represents the 95% confidence interval. The horizontal dotted line represents the Bsp_{msy} level for the base case model.*

Figure 3.27 (a-b) presents the base case model fit to the GLM standardized CPUE (GLM_CPUE) and the combined survey biomass estimate time series. The model fits some of the data very well and others not. In the last 7 years, the observed GLM standardized CPUE time series and the survey biomass estimates are showing opposing trends, while the model estimates are showing similar trends for both data series. Overall, the current assessment overestimates both the GLM standardized abundance and the survey biomass estimates.

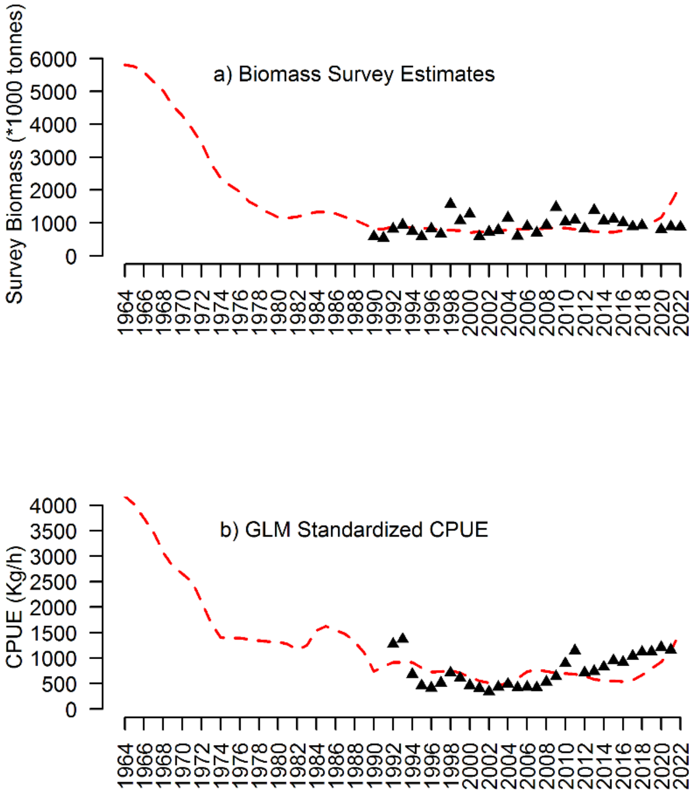


Figure 3.27 (a-b): *Model fit (red dashed line) to the observed GLM standardized CPUE and summer surveys*

Figure 3.28, depicts the residuals of the observed and estimated commercial and survey catch-at-age data. Comparing the residual plots from the two indices it is evident that both have some systematic patterns. As these are standardized residuals it is to be expected that their sizes are about the same for all age classes. Before 1990 catches from age 7 are overestimated by the model. In the last five years, the commercial catch the model overestimated from age 4-7 while underestimating the age 2-3. In the most recent biomass survey, the model overestimated all age groups except age 2. Overall it seems that there are more systematic patterns in the biomass surveys than in the commercial catch-at-age. These patterns could be a result of assuming a constant catchability for all ages.

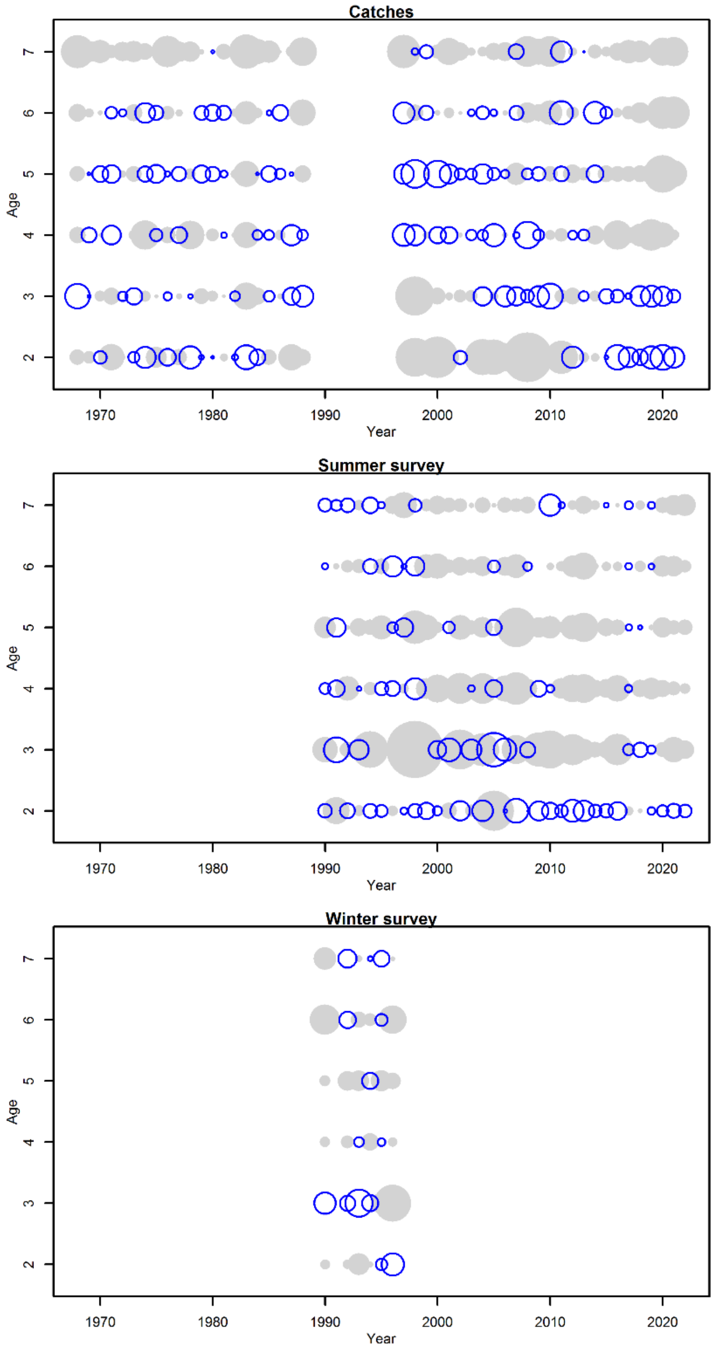


Figure 3.28: *Residuals of the catch-at-age data. The top panel is the commercial data, the middle the Namibian summer surveys and the bottom the Namibian winter surveys. The size of the bubbles shows the deviation from the estimated to the observed catch-at-age data. The grey solid bubbles are the ages that are overestimated and the open blue circles are underestimated.*

Figure 3.29 (a) presents model estimated recruitment from 1964-2022 (a) and a Beverton and Holt recruitment curve fit onto the estimated recruitment values (b). Recruitment was estimated to be lower since mid-80 to 2014, but it has increased in the subsequent years followed by a drop in the last two years.

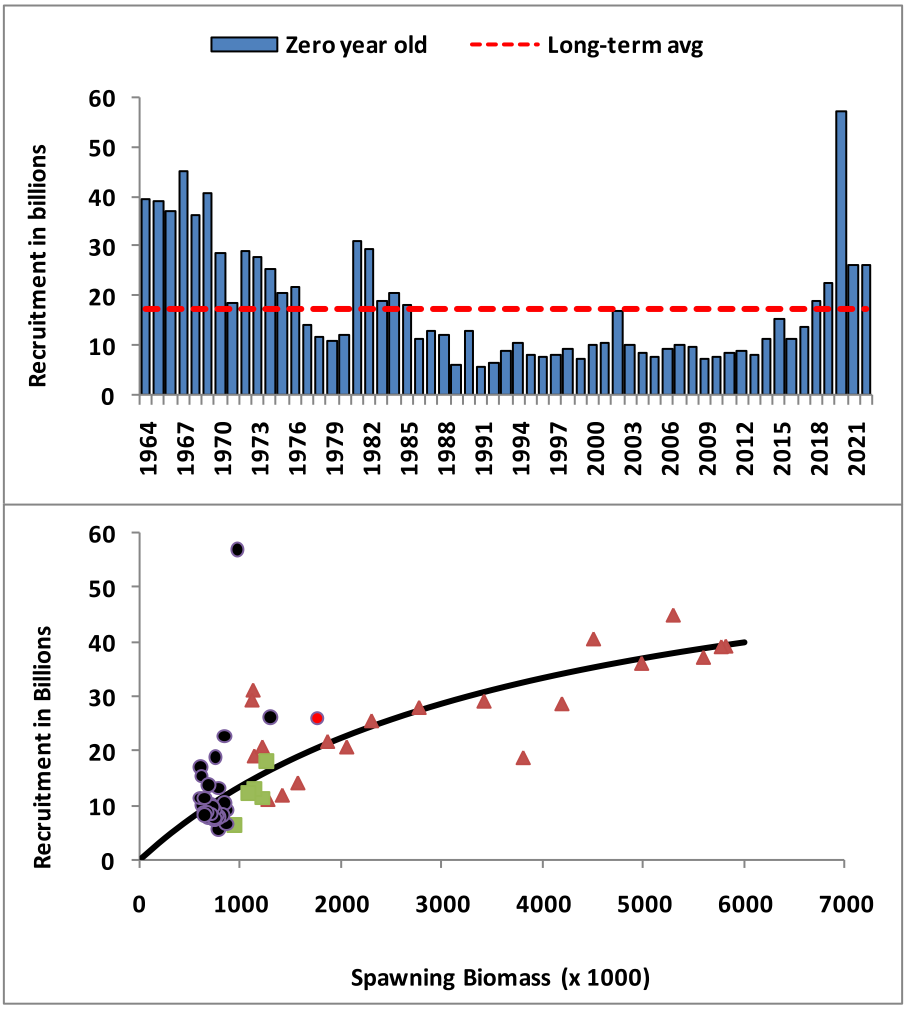


Figure 3.29: *Model estimated recruitment (numbers) from 1964-2022 (a), Beverton and Holt recruitment curve fit onto the estimated recruitment values (b). The red triangles are recruitment values from 1964-1984; green solid squares (1985-1990) and the purple solid circles (1990-2021), and the red solid circle (figure 3.30b) represents the estimated recruitment in 2022.*

3.5.5 Management

The vertical line in the Management Monitor Graph (MMG, Fig. 3.30) represents the Bsp_{msy} and the horizontal line ithe level of fishing relative to the replacement yield of the stock (i.e. it indicates 'sustainability'). This graph illustrates both, management (along the y-axis) and the status of resources (along the x-axis) and is, therefore, a useful tool to track past management and the subsequent increase or decrease in the resource. Above the horizontal line, the stock will decrease in the subsequent year as more catch is taken than the stock produced in that year (the catch is higher than the replacement yield). The left of the vertical line indicates that the state of the resource is below the Bsp_{msy}. This means that for the stock to be above the Bsp_{msy}, catches have to be lower than the replacement yield (below the horizontal line). Currently, the stock is slowly moving towards the Bsp_{msy} level.

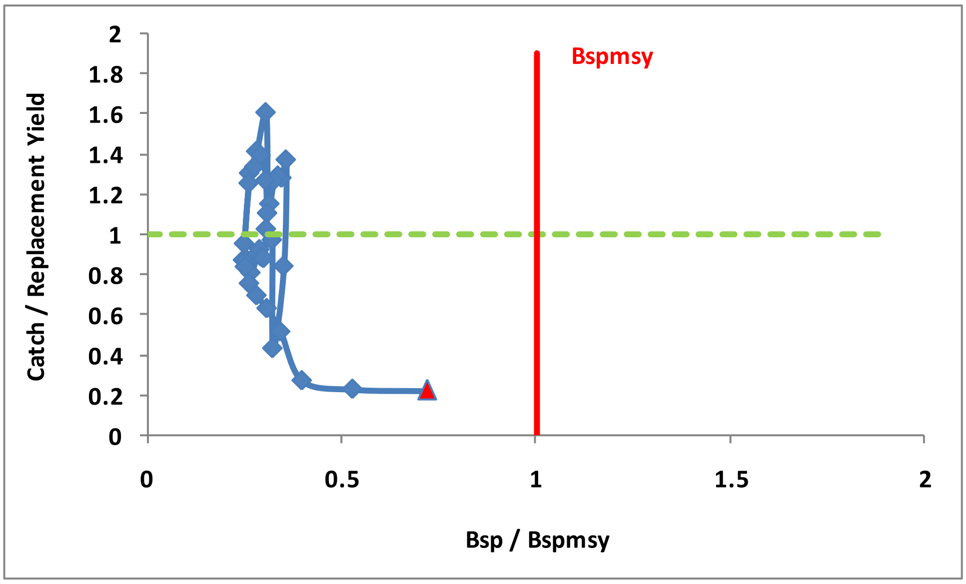


Figure 3.30: *"Management Monitor Graph". The horizontal line indicates the points at which catch is equal to replacement yield and the vertical line indicates spawning stock biomass equal to the spawning stock biomass leading to Bsp_{msy}.*

Currently, the hake resource is estimated to be below the maximum sustainable yield level (Bsp_{msy}), which means that rebuilding the resource is still a priority. To enable this, only part of the replacement yield (RY) can be harvested and the rest left to replenish the resource (Kirchner *et al* 2012). The total allowable catch (TAC) is therefore calculated by (Kirchner *et al* 2012):

$TAC_y = \beta * \left[\left(\sum_{y}^{y-4} RY_y \right) / 5 \right]$ where β is the proportion harvested of the 5-year average of RY, in this case 0.80.

3.6 Points of consideration

- The base case model estimates a growth (growth due to increase in weight of fish and not numbers) of 22% in the total biomass,
- The spawning stock biomass has increased by 36%,
- The recruits have remained the same since the last assessment.
- The stock has reached the 55% of the Bspmsy (Annex 1), a level that we promised to achieve by the year 2025, however
- The stock is still below the desired Bsp_{msy} level and needs further rebuilding to this level
- The CPUE for both trawlers and longliners decreased, and is more pronounced in the longline fleet.

3.7 Recommendations

- ➢ A TAC of **154 000** tonnes (status quo) is therefore recommended for the 2022/2023 fishing season to allow the resource to rebuild to the Bsp_{msy} level target.