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Chapter 3

Biology and fisheries of the shallow-water hake (*Merluccius capensis*) and the deep-water hake (*M. paradoxus*) in Namibia

Wilhelm, M. R.^{1,6}, Kirchner, C. H.², Roux, J.-P.^{3,4}, Jarre, A.¹, Iitembu, J. A.^{2,5}, Kathena, J. N.² and Kainge, P.²

¹*MA-RE Institute and Department of Biological Sciences, University of Cape Town, Rondebosch 7701, South Africa*

²*National Marine Information and Research Centre (NatMIRC), Ministry of Fisheries and Marine Resources, Swakopmund, Namibia*

³*Lüderitz Marine Research, Ministry of Fisheries and Marine Resources, Lüderitz, Namibia*

⁴*Animal Demography Unit, Department of Biological Sciences, University of Cape Town, Rondebosch 7701, South Africa*

⁵*Department of Fisheries and Aquatic Sciences, University of Namibia, Private Bag 462, Henties Bay, Namibia*

⁶*University of Texas at Austin, Marine Science Institute, Port Aransas, Texas, 78373, USA. Email: margit.wilhelm@utexas.edu*

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3.1 Introduction

The Benguela upwelling system is one of the four major eastern boundary upwelling systems in the world, a cold-water regime bounded by two warm-water regimes, which has been well described by several authors (e.g. Shannon, 1985). Off Namibia, mid-shelf waters (180–350 m bottom depth) are defined by a wind-driven upwelling cycle with high inter-annual and seasonal variability (Bartholomae and van der Plas, 2007), hypoxic conditions, as well as a poleward undercurrent associated with the advection of anoxic and hypoxic water on the shelf (Mohrholz *et al.*, 2008).

The two sympatric hake species in the Benguela region are the shallow-water hake *Merluccius capensis* (Castelnau, 1861) and deep-water hake *M. paradoxus* (Franca, 1960). This review aims to summarise some features of these two species such as distribution, history, current management and characteristics of the hake-directed fishery in Namibia, abundance indices, life history, migration, spawning locations and behaviour, updates on age and growth, and progress towards ecosystem approach to fisheries (EAF) management, updating the previous review by Gordo *et al.* (1995).

3.2 Biology and life history

3.2.1 Stock structure

M. capensis and *M. paradoxus* (Figures 3.1a and b, respectively) have distinct genetic profiles (Grant *et al.*, 1987; 1988). Morphologically, they differ in the number of vertebrae (Franca, 1960), pigmentation of the gill rakers (van Eck, 1969), gill arch morphology (Bentz, 1976), otolith structure and morphology (Mombeck, 1969; Botha, 1971), length

of the pectoral fins (Inada, 1981), retinal structure (Mas-Riera, 1991) and sometimes colour of the anal fin (Gordoa *et al.*, 1995). Because these morphological features are not readily determined at sea and because the species overlap at certain depths, commercial landings have not been separated by species (Gordoa *et al.*, 2000). *M. paradoxus* was only recognised as a separate species a decade after exploitation began, from the previously known *Merluccius merluccius paradoxus* [Franca, 1971] to *Merluccius paradoxus* [Quéro, 1973]) (Lloris *et al.*, 2005): with *M. capensis* initially dominating commercial catches. For these reasons, the two species were assessed and managed as a single stock in both South Africa and Namibia since fisheries management started in the early 1980s (Botha, 1985). Species-specific stock assessments have been conducted in South Africa since 2006 (Rademeyer *et al.*, 2008), but not yet in Namibia (Kirchner *et al.*, 2012).

3.2.2 Distribution

Distribution of the two species of hake in the Benguela covers the area from Baía de Farto in Angola, at about 12°S and 14°E, to Port Elizabeth on the east coast of South Africa, at about 35°S and 25°E, with a virtually continuous distribution. *M. capensis* is more abundant north of 27°S and *M. paradoxus* is more abundant south of 27°S (Botha, 1985; Burmeister, 2001; Johnsen and Kathena, 2012).

Offshore distribution is depth-dependent. *M. capensis* occurs from shallower than 100 m to about 450 m bottom depth (see Figure 3.2 for latitudes and depth contours). *M. paradoxus* extends from 300 to 1000 m bottom depth, but most are caught at 300–500 m bottom depth (Gordoa and Duarte, 1991; Burmeister, 2001). This is reflected in their retinal structure with *M. paradoxus* showing a more developed scotopic system than *M. capensis*, with higher sensitivity and visual acuity adapted to dim light of their deep-water environment (Mas-Riera, 1991). South of 25°S the distribution of *M. paradoxus* can also extend to areas shallower than 200 m bottom depth, and both species usually occur deeper in northern Namibia (Johnsen and Kathena, 2012).

It is assumed that individuals of *M. capensis* ‘settle to the oceanic bottom’ at about 45 days (± 3 cm total length, TL), according with the mean duration of primordia in their otoliths (Gordoa *et al.*, 2001). However, they still show extensive vertical migration, and changes in diet occur long after that (see Sections 3.2.6.1 and 3.2.6.2), and are not fully available to the bottom trawls until they reach about 20 cm (Iilende *et al.*, 2001). Both *M. capensis* and *M. paradoxus* generally move

offshore as they grow older. From this, it follows that large *M. capensis* overlap in distribution with small *M. paradoxus* and that there is little inter-species overlap of large adult fish (Gordoa and Duarte, 1991; Burmeister, 2001).

The water masses found on the Namibian continental shelf and slope consist of surface water ≤ 200 m ($\geq 16^{\circ}\text{C}$, $\geq 35.5\text{‰}$ salinity), central water 200–500 m, mostly consisting of High-Salinity Central water, HSCW ($5\text{--}15^{\circ}\text{C}$ and $34.5\text{--}35.5\text{‰}$ salinity) and Antarctic intermediate water 500–1200m, ($4\text{--}5^{\circ}\text{C}$, minimum 34.25‰ salinity and $4.5\text{--}5.0$ ml/l dissolved oxygen [DO] content) (Duncombe Rae, 2005). Both hake species occur over all three principal water masses (depth range from 70 m to at least 920 m), but mainly at 220–440 m within the HSCW as well as the mixing areas above and below (Botha, 1980).

The latitudinal and depth distribution differences between *M. capensis* and *M. paradoxus* may therefore depend on their preferred temperature ranges (Macpherson and Duarte, 1991), estimated at a slightly warmer range for *M. capensis* (Inada, 1981). Species-specific distribution differences (and within-species juveniles and adults) could also result from differences in low-oxygen tolerance levels. *M. paradoxus* prefer more oxygenated water. DO levels increase from north to south in Namibia. Adults require higher oxygen concentrations than juveniles, and DO levels generally increase with bottom depth (Roel and Bailey, 1987; Mas-Riera et al., 1990). However, Botha (1980) showed that the distribution of hake was directly related to depth rather than to any of the temperature, DO or salinity variables. He argued that both species undergo daily vertical migration over wide ranges of values for each variable, and listed their optimum values as follows:
Temperature: *M. capensis* 8.8°C , *M. paradoxus* 8.1°C (tolerance range $.1\text{--}10.3^{\circ}\text{C}$); DO: *M. capensis* 3.6 ml/l, *M. paradoxus* 4.0 ml l⁻¹ ($1.1\text{--}6.4$ ml/l) and salinity: *M. capensis* 34.6 , *M. paradoxus* 34.6 ‰ ($34.2\text{--}34.9$ ‰).

3.2.3 Age and growth

The whole otolith method is used for estimating ages of both *M. capensis* and *M. paradoxus* in Namibia. This method has been described in photographic guides (ICSEAF, 1983; Wysokiński, 1983; Morales and Payne, 1985). It is recognised that interpreting zonation patterns on hake otoliths can be difficult and problematic (e.g. ICSEAF 1983; Morales and Payne 1985; Morales-Nin *et al.*, 1998; de Pontual *et al.*, 2006; Goicochea *et al.*, 2010). Age determination criteria have been reviewed during several workshops in the region (e.g. BENEFIT, 2005) and have been applied to acquire routine annual age data for current use in hake stock assessments in Namibia (Table 3.1A and B; Kirchner *et al.*, 2012).

Direct validation of the annual occurrence of otolith growth zones has been done only for the first growth zone of *M. capensis* (Gordoa *et al.*, 2001), showing that the first translucent zone occurs earlier than 1 year of age in *M. capensis*. Recently, otoliths collected regularly from fur seal scat samples since 1994 have been used to describe growth rates of young *M. capensis* and to calculate their birth dates independent of otolith zonation (Wilhelm *et al.*, 2013). Results show that *M. capensis* grow at about 1 cm/month, 12 cm/year and then growth reduces to about 9–10 cm/year for adult fish (Table 3.1C; Wilhelm, 2012). This information was used for age validation on *M. capensis* otoliths showing that they form a translucent and opaque zone pair at least twice per year. This indicated that the previously estimated ages and longevity of *M. capensis* had been over-estimated and growth rates/length-at-age, weight-at-age and maturity-at-age under-estimated (Wilhelm, 2012). This affected the assessment of both species as they are assessed together in Namibia using *M. capensis* weight-at-age and maturity-at-age information, Table 3.1B).

M. capensis usually grow faster and mature younger than *M. paradoxus* (Chlapowski, 1974; Botha, 1986; Table 3.1; Figures 3.3a and b) and females usually grow faster than males for both (Macpherson, 1976; Pozo Arteaga, 1976; Preński, 1978; Morales-Nin, 1991). *M. paradoxus* usually show a higher weight-at-length and lower proportion maturity at length than *M. capensis* (Table 3.1; Figure 3.3a).

3.2.4 Year-class strength

Roux (2007) presented a method of estimating *M. capensis* year-class strength (relative recruitment index, in numbers) from the proportion of their otoliths retrieved in winter samples of fur seal scats in southern Namibia between March and September, scaled by the survey estimate of recruitment. The strongest year classes described to date were from (the winter of) 2002, 1996, 2012, 2008 and 2007 cohorts, in that order. Roux (2007) showed that *M. capensis* year-class strength is strongly correlated with the strength of the previous year's cohort, suggesting that cannibalism of young *M. capensis* by 1 year older conspecifics is the primary driver of *M. capensis* recruitment.

Past hake diet records have shown increased cannibalism at increased water temperatures (Crawford *et al.*, 1987). Thus it was suggested that warm water temperature may have an indirect effect only on recruitment (Shannon *et al.*, 1988; Voges *et al.*, 2002).

3.2.5 Reproductive biology

3.2.5.1 Age- and length-at-maturity

The age and length at 50 % maturity indices (a_{50} and L_{50}) used for the current spawning stock biomass calculation for *M. capensis* and *M. paradoxus* in Namibia are indicated in Table 3.1. *M. capensis* usually matured younger than *M. paradoxus* (Botha, 1986; Figure 3.3). However, L_{50} were recently observed, using microscopic rather than macroscopic samples, for South African West coast *M. capensis* and *M. paradoxus* to be 57 and 41 cm, respectively (Singh *et al.*, 2011). This is likely to be the case for both hake species in Namibia as well, because maturity is currently assessed only macroscopically, and this analysis often over-estimates the maturity stages (Kainge *et al.*, 2007).

3.2.5.2 Spawning areas and alongshore migration

Spawning of *M. capensis* in the northern Benguela has been located in the areas listed in Table 3.2. In general, it appears that the northern (20–21°30'S) spawning area and central (22°S–25°S) spawning area in the 1970s and 1980s (O'Toole, 1976; 1978; Assorov and Berenbeim, 1983; Olivar *et al.*, 1988) have shifted southwards to 22–24°S (Centre) and 26–28°S (South), respectively, in the late 1990s (Kainge *et al.*, 2007) with a shift in gravity even further southwards as well as a shift to earlier in the year (Table 3.2; Wilhelm *et al.*, 2015). The reason for this apparent shift is unknown.

From both of the central and southern spawning aggregations (Table 3.2; Figure 2), *M. capensis* generally move northwards and offshore first between TLs of 25 and 30 cm (2.0–2.5 years old), and southwards and inshore again at greater than 55 cm TL (>3.5 years old) to spawn. Spawning generally occurs in winter and autumn in the central and southern spawning aggregation, but has been observed throughout the year (Figure 3.4; Wilhelm *et al.*, 2015).

No recent north-south temporal shifts in catchability by the fishing fleet have been observed off Namibia, indicating that these north-south migrations, recently described for *M. capensis*, occur throughout the year (Gordoa *et al.*, 2000). These alongshore migrations, however, occasionally coincide with the southward movement of warm Angolan tropical water or occasional Benguela Niño events, associated with the

intrusion of warm water and poleward migration of the Angola-Benguela front (Shannon *et al.*, 1986).

Some authors stated that *M. paradoxus* spawn in the same latitudes in Namibia but in deeper water than *M. capensis* (Porebski, 1976), or at about 23°S during a warmer season than *M. capensis* (Assorov and Berenbeim, 1983). Others found no indication that *M. paradoxus* spawn in Namibia (Gordoa *et al.*, 1995; Kainge *et al.*, 2007). Burmeister (2005) hypothesised that *M. paradoxus* is shared between Namibia and South Africa, with only one spawning area on the Agulhas Bank (35–36°S, 18–20°E) and nursery areas off the South African west coast (29–34°S) and southern Namibia. However, the extent of and reason for this hypothesised extensive long-shore migration of adult *M. paradoxus* are not clear. In addition, recently genetic differentiation between Namibian and South African *M. capensis* stocks has been identified but no stock differentiation was detected for *M. paradoxus* (von der Heyden *et al.*, 2007a; 2007b).

3.2.5.3 Spawning behaviour and inshore-offshore migration

For a recent conceptual model of *M. capensis* inshore-offshore migration throughout their life history see Figure 3.4. *M. capensis* adults usually move into shallow waters (<200 m bottom depth) to spawn, but deep offshore spawning also occurs. Historically, peak spawning occurred in shallowest waters in spring, from September to November (O'Toole, 1978; Olivar *et al.*, 1988; Olivar, 1990; Sundby *et al.*, 2001; Table 3.2). Further evidence for inshore and off-the-bottom movement of hake for spawning has been the decrease in catchability of *M. capensis* in the hake-directed fishery from April to September, with a peak in October. Moreover, the peak in *M. capensis* by-catch of the horse mackerel mid-water trawl catches shallower than 200 m bottom depths occurred in October (years 1999 to 2004) (Gordoa *et al.*, 2006).

Apart from moving inshore to spawn, *M. capensis* are also thought to be mesopelagic spawners, moving upwards above the low-oxygen layer in the water column to spawn. Their eggs have been found over a range of 100–400 m bottom depths, and at 30–150 m depth in the water column in the northern Benguela. Eggs and larvae are transported southward and shoreward by a sub-surface upwelling current (Olivar, 1990; Olivar and Shelton, 1993; Sundby *et al.*, 2001).

3.2.6 Feeding ecology

3.2.6.1 Diet and trophic relationships

Hakes constitute a large part of the diet of monkfish (Gordoa and Macpherson, 1990) and of other demersal finfish, sharks, seabirds, whales, dolphins, fur seals, snoek and other large pelagic predatory fish (Heymans *et al.*, 2004; Roux and Shannon, 2004; Mecenero *et al.*, 2006). *M. capensis* are also consumed by larger conspecifics, often as the main food source and as a dietary preference (Roel and Macpherson, 1988; Macpherson and Gordoa, 1994; Figure 3.5a).

Both Namibian hake species also feed on *M. paradoxus*, krill, crustaceans, cephalopods, Myctophidae (primarily *Lampanyctodes hectoris*), horse mackerel *Trachurus capensis*, bearded goby *Sufflogobius bibarbatatus* and other demersal and pelagic fish species (Macpherson and Roel, 1987; Traut, 1996) (Figure 5). They are opportunistic feeders so their diet changes seasonally (Roel and Macpherson, 1988), but during the life history of *M. capensis* their diet gradually changes from a crustacean and other fish-dominated diet to a mainly hake-dominated diet (Figure 3.5a); 40% of the diet of *M. paradoxus* consists of krill and crustaceans throughout their life history (Figure 3.5b).

Hake trophic levels were estimated from food web models at 4.0 for small and 4.5 for large *M. capensis*, and 4.1 for large *M. paradoxus* (Roux and Shannon, 2004; Watermeyer *et al.*, 2008). This puts them at a relatively high trophic level, similar to large pelagic fish, seals and seabirds (Shannon and Jarre-Teichmann, 1999). However, stable isotope-based results 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 (Iitembu *et al.*, 2012).

3.2.6.2 Feeding behaviour and vertical migration

The feeding activity of *M. capensis* is highest during the day (07:00–13:00), while *M. paradoxus* feed mainly at night (01:00–7:00). This difference could be an adaptation to enable their coexistence in the same area (Gordoa and Macpherson, 1991) and be related to their visual systems (Mas-Riera, 1991).

Both hake species tend to move upwards in the water column at night (Gordoa and Macpherson, 1991; Pillar and Barange, 1995; Iilende *et al.*, 2001). Even juvenile *M. paradoxus* (6–20 cm TL) showed the diel feeding behaviour of moving up into mid-water at night. The smaller juveniles (6–10 cm TL) performed the most extensive vertical migrations, lifting from the bottom (200 m deep) in the day to the upper 40 m of the water column at night (Stenevik *et al.*, 2009).

3.3 Fisheries

Hakes have constituted the most valuable demersal fishing resource in the region since 1965 (Crawford *et al.*, 1987). Currently, the hake fishery is the major source of employment in the fisheries sector in Namibia (70% in 2009/2010), employing 8956 people (8777 Namibians, 0.4% of the total population) in 2009/2010. The sector's overall contribution to the GDP was worth US\$ 306 million in 2006, increasing to US\$400 million in 2008/2009 and again US\$ 341 million in 2010, with added value to US\$ 462 million in export earnings. The fisheries sector overall contributes around 5.0% to the total GDP, fluctuating between 3.7 and 5.3% since 2006. It is Namibia's second largest earner of foreign currency after the mining sector, and the hake fishery contributes about a third of the total catch of the fisheries sector and half of all fishery products in value in Namibia (Weidlich, 2006; MFMR & NPC, 2011).

Fishing takes place over the entire coast, between 19 and 25°S at 200–400 m bottom depth, and between 25 and 29°S at 300–500 m bottom depth (Figure 3.6). A negligible proportion of the area has untrawlable grounds (Johnsen and Kathena, 2012).

Hakes are also caught as by-catch in other fisheries in Namibia, such as the mid-water trawl fishery (targeting horse mackerel), the monk and sole trawl fishery (*Lophius spp.* and *Austroglossus capensis*, respectively), and large pelagic hook and line fishery (Figure 3.7a).

By-catch of the hake-directed longline fishery includes seabirds such as 13 species of albatrosses and petrels and the Cape gannet *Morus capensis* (vulnerable; IUCN, 2012). The white-chinned petrel *Procellaria aequinoctialis* (vulnerable; IUCN, 2012) accounts for greater than 80% of the bird by-catch in the longline fishery. The most commonly caught albatross is the Atlantic yellow-nosed albatross *Thalassarche chlororhynchos* (endangered; IUCN, 2012). Black-browed albatrosses *Thalassarche melanophris* and white-capped albatrosses *Thalassarche steady* (near threatened; IUCN, 2012) are also commonly killed by longline vessels. By-catch of the longline fishery also includes shark species such as blue shark *Prionace glauca* (near threatened; IUCN, 2012) and mako shark *Isurus oxyrinchus* (vulnerable, IUCN; 2012), puffadder shyshark *Haploblepharus edwardsii* (near threatened; IUCN, 2012), St. Joseph's shark *Callorhinchus capensis*, whitespotted smooth-hound shark *Mustelus palumbes* and skates such as *Raja spp.* By-catch of the hake-directed trawl fishery mainly includes kingklip *Genypterus capensis*, monk, horse mackerel, many grenadier species belonging to the family Macrouridae, and to a lesser extent causes incidental mortality of marine mammals such as dolphins and the albatross and petrel species mentioned previously (Figure 3.7b).

3.3.1 Development of the fishery and management measures

Exploitation of hakes in Namibia started with about 100 trawlers in 1964 with open access fishing on hake and horse mackerel by fleets mainly from Cuba, Israel, Italy, Japan, Poland, Portugal, South Africa, Spain and the USSR. Between 1968 and 1972, Soviet and Spanish fleets caught about 90% of the hake of all foreign fleets off the Namibian coast (Paterson *et al.*, 2013). Catches peaked at 800,000 t in 1972 (Figure 3.8), resulting in an initial drastic decline in the stock biomass (Gordoa *et al.*, 1995; Kirchner *et al.*, 2012).

From 1976, the fishery was managed following advice by the International Commission for Southeast Atlantic Fisheries (ICSEAF), implementing a minimum mesh size of 110 mm (1976) and member country quotas or total allowable catch (TAC) (1977–1989). However, the overall TAC was never reached, probably because it was set too high. Later, the stock continued to decline, and by 1980, the catch had declined to only 170,000 t (Figure 3.8). The population size of hake had been reduced to less than 50% of the unfished spawning stock biomass (B_0), and the catch per unit effort had decreased by 60%. Between 1981 and 1989, catches ranged between 300,000 and 400,000 t. In addition, Namibia's waters remained an open access area until 1990 when the Exclusive Economic Zone (EEZ) was proclaimed by the newly independent Namibia (Paterson *et al.*, 2013).

3.3.2 Current management regime

In 1990, Namibia became independent and the new Ministry of Fisheries and Marine Resources (MFMR) took over management of the fishery on a heavily depleted resource (Payne and Punt, 1995). Immediate measures were taken to protect the hake stocks including a ban on foreign fishing fleets and the proclamation of a 200-mile-EEZ, according to international law. The White Paper of December 1991 (MFMR, 1991) was enacted in the Sea Fisheries Act by 1992 (MFMR, 1992), replaced with the Marine Resources Act in 2000 (MFMR, 2000), the Marine Fisheries Regulations of 2001 (MFMR, 2001) and a new White Paper, Namibia's Marine Resources Policy, in 2004 (MFMR, 2004).

The main aims of the management plan of MFMR were first to rebuild the hake stocks and to 'Namibianize' the fishing industry (MFMR, 1992). Regulations implemented to achieve this were an immediate reduction of the TAC from 411,000 to 60,000 t in 1990 and 1991, respectively, but increasing again in subsequent years (Figure 3.8), limitation of entry licences, enforcement of a minimum mesh size of 110 mm, enforced catch and discard monitoring, and establishment of an observer programme, which has conducted at-sea sampling of the trawl fishery's catch since 1997 (van der Westhuizen, 2001).

A further regulation put into place was a 200-m depth restriction (no hake-directed fishing allowed shallower than the 200-m-isobath). In the 2006/2007 season, this was extended to a 300-m depth restriction for wetfish vessels from 25°S to the Orange River, a 350 m depth restriction (rationale unknown) for freezer vessels from 25°S to the Orange River and closure of the hake-directed fishery in October to reduce the impact of the fishing during the hake spawning season and enhance spawning success. Freezer vessels process at sea, returning filleted frozen product ready for the market, while wetfish vessels return the fish to onshore processing facilities in Walvis Bay and Lüderitz. Since 1992, between 87,000 and 189,000 t of hake has been caught annually (mean: 138,000 t) (Figure 3.8). *M. paradoxus* usually makes up between 52% and 71% of the annual catches (Johnsen and Kathena, 2012).

At present, the hake fishery is managed as a species-aggregated single stock in Namibia, at the national level, though the *M. paradoxus* stock is thought to be shared between South Africa and Namibia. However, within the Benguela Current Large Marine Ecosystem programme (BCLME), progress has been made towards cooperative management,

including the recent establishment of the inter-governmental Benguela Current Commission (BCC), facilitating trans-boundary research.

The setting of the annual TAC is based on a species-aggregated fleet-disaggregated statistical catch-at-age analysis (SCAA), used in Namibia since 1998. The TAC is set to account for an approximate 20% rebuilding strategy of the estimated replacement yield. Furthermore, to provide security for the fishing industry, in theory, inter-annual fluctuations of the TAC are limited to 10% (Kirchner *et al.*, 2012).

3.3.3 The decision-making process

Section 38 of Namibia's Marine Resources Act (MFMR, 2000) provides for the Minister of the MFMR to determine the total allowable catch (TAC) after consultation with the Marine Resources Advisory Council (MRAC) (Sections 24-31 of the Marine Resources Act). MRAC is composed of two MFMR representatives, five representatives of the fishing industry, and six representatives of other economic sectors. In practice, the procedure (recommendation process) has been as follows:

1. A working group including industry members, MFMR scientists and consultants meets to discuss the available data and the stock assessment. This was initiated in 1997 and has continued since.
2. MFMR scientists prepare a report for TAC recommendations and related issues.
3. The report is presented to the Minister and other senior officials of the MFMR.
4. Recommendations are put to the MRAC. MRAC takes cognisance of socio-economic considerations and formulate their own recommendations for the Minister.
5. The Minister makes recommendations to Cabinet, taking into account the recommendations of the scientists, the MRAC and any other relevant factors and Cabinet sets the TAC.

3.3.4 Recent fishing history

In 2010, the hake fleet consisted mainly of bottom trawlers (62 licensed vessels) as well as 13 licensed longline vessels. Longline vessels caught an average of 5.2% of the total catch for the period 2007 to 2011 (Figure 3.7a). The bottom trawl component consists of freezer vessels (10 licensed vessels), and wetfish trawlers (52 licensed vessels). However, usually only about 60% of all licensed vessels actually fish (Kirchner and Leiman, 2014). These have caught between 170,000 and 180,000 t in recent years (Figure 3.8).

3.3.5 Products and markets

The Namibian hake fishery is almost entirely export-based. In 2010, about 97% by final (processed) value, which is 108% of the landed value of fish and fish products, was exported. About 61% of all exported products (by value) was to Spain. If not marketed in Spain, they are distributed further to other EU countries such as Italy, Portugal, France, Germany and Netherlands ($\pm 3\%$ each of the total Namibian exported hake products). Non-EU exports are to South Africa (16%), Australia (2%), Malaysia (1%), the Democratic Republic of Congo (2%) and the USA (2%). Namibian hake products face competition from South Africa, Argentina, Chile and Australia, but Namibia is the leading frozen hake supplier, in terms of volume and value, to the Spanish market. Hake is mainly exported in the form of frozen fillets (skin on and skinless); as well as in other product forms such as headed and gutted (fresh), baby hake (fresh), cutlets, tails, minced, blocks, sausages and roe (MFMR & NPC, 2011).

The average price of hake from freezer vessels is US\$ 1639 per t and that from wetfish vessels is US\$ 2037 per tonne. The current proportion of wetfish to freezer vessel gives revenue of about US\$ 35.3 million (Kirchner, 2014).

3.3.6 Stock assessment

3.3.6.1 Resource surveys

The survey index is taken from bottom trawl swept-area abundance surveys that have been conducted along the Namibian coast since 1990, initially 2–3 times per year, and since 1997 once per year in austral summer (January–February) (Burmeister, 2001). According to the survey abundance index, *M. paradoxus* has been 3 to 11 times lower in biomass than *M. capensis* in Namibia and up to 40-fold less in the first few surveys (Figure 3.9). *M. capensis* biomass estimates fluctuated between very low in the mid-1990s and early 2000s, and very high in the late 1990s, while the *M. paradoxus* biomass appeared to decrease steadily in that period. *M. capensis* biomass estimates appear to be more sensitive to environmental fluctuations and their availability to the bottom trawls because of their extensive vertical migration (see Sections 3.2.6.2 and 3.3.6.2). There is no apparent correlation or lagged correlation between the total biomass estimates of the two species.

3.3.6.2 Catch per unit effort analyses

The Namibian catch per unit of effort (CPUE) series for the commercial trawl fishery was standardised for month, vessel gross tonnage, latitude and depth of fishing and interaction between year and month, using generalised linear modelling (GLM), explaining about 40% of the variability (Brandão and Butterworth, 2004; extended to 2011, MFMR, unpublished data). The CPUE has drastically declined since 1992, with slight increases in the late 1990s and mid-2000s. Recently, it has increased again to close to the 1992-level while the catches have remained relatively constant (Figure 3.10).

Despite the CPUE being at an all-time minimum in 2005 (Figure 3.10), the Namibian hake industry further invested in vessels and factories in the period 2007/2008 and has the capacity to catch and process about 205,000 t (fishing season 2008/2009), 137,000 t for wetfish, and 68,000 t for freezer vessels per year (Kirchner and Leiman, 2014). It is therefore a significantly over-capacitated fishery (Kirchner and Leiman, 2014; Paterson *et al.*, 2013).

Hake move off the bottom and offshore during periods of cold water temperatures, strong surface winds, and low DO concentrations, reducing their availability to bottom trawls, and thus reducing their catch rates (Macpherson *et al.*, 1991; Hamukuaya *et al.*, 1998; Gordoa *et al.*, 2000). A positive correlation between SST and CPUE was observed of

age groups 4 years and older, the main component of the fishery, but a negative correlation with SST and CPUE of age groups 0 and 1 (Roel and Bailey, 1987; Gordo and Hightower, 1991; Gordo *et al.*, 2000). The highest CPUE is usually observed in the middle of the day (Johnsen and Lilende, 2007). During warm-water periods or years, 4+ hake shoal closer to the bottom, making them more susceptible to bottom trawling and increasing their CPUE (Shannon *et al.*, 1988). This could result in poor recruitment in warm years (Macpherson *et al.*, 1991).

3.3.6.3 Stock assessment modelling

SCAA essentially is an age-structured production model, which is designed to combine various data and information in a meaningful way; including catch data and catch-at-age information from both survey and commercial catches (e.g. Deriso *et al.*, 1985; Butterworth and Rademeyer, 2005), weight-at-age and maturity-at-age calculated from survey measurements (Table 3.1; Figure 3.3). Age-specific natural mortality parameters (M) are currently set externally. Several abundance indices, including the current commercial CPUE series (Figure 3.10), a recent summer survey biomass index, as well as winter surveys (Figure 3.9) and information of some historic Spanish surveys that were conducted in Namibian waters are used to tune the model. The steepness parameter (h) on which the stock-recruitment relationship is based, annual recruitment fluctuations, and the age-specific gear selectivity functions are estimated within the model. On the basis of these values, the Namibian hake stock is currently (year 2012) assessed at between 14 and 26% of B_0 , at 95–120% of SSB values of 1990 (used as B_{\min} reference point in Namibia), and at about 33% of the maximum sustainable yield level (B_{MSY} , the limit reference point) (Kirchner *et al.*, 2012).

3.4 Advances in Ecosystem Approach to Fisheries management (EAF)

The three countries bordering the Benguela Current – Angola, Namibia and South Africa – are committed to implementing an EAF, as advised by the BCC, which was established in the mid-2000s between the governments of these three countries. Namibia was praised for a high potential for implementation of an EAF (Mora *et al.*, 2009). Some progress has been made towards implementation, as described in the following section.

An Ecosystem Risk Assessment (ERA) was carried out for the Namibian hake fisheries in 2005 (Nel, 2007) and reviewed in 2008 (Cochrane *et al.*, 2009; Petersen *et al.*, 2010). Concerning the ecological dimension, issues of extreme risk included incidental by-catch of seabirds and technical interactions with the monk fishery. Major concerns related to general changes in trophic structure of the ecosystem as a whole, particularly persistently low abundance of small pelagic fish (sardine and anchovy), which also constitute food for hake. Research into the impact of demersal trawling on demersal fish communities off Namibia showed moderate to high impact, and no improvement since fishery management measures were put in place following Namibian independence (Mafwila, 2011). Impacts of fishing have also been shown to have altered the structure and functioning of the ecosystem (Jarre-Teichmann *et al.*, 1998; Watermeyer *et al.*, 2008; Roux *et al.*, 2013).

By-catch by the hake fishery in Namibia is managed through corrective levies on kingklip *G. capensis*. A small TAC of monkfish *Lophius vomerinus* is implemented in the hake sector, beyond which a levy is required for monkfish (Petersen *et al.*, 2010). In order to address the issue of incidental bird mortality, experiments of using tori lines (bird-scaring lines) on longliners and trawlers were conducted. Tori lines reduce bird mortality in the trawl fishery by 99% and in the longline fishery by at least 80%. Combining tori lines, shooting before sunrise and better weighting of the lines brought the by-catch down by at least 90% in the longline fishery (J. Paterson, Albatross Task Force, unpublished data). A National Plan of Action (NPOA) for seabirds and sharks, in which compliance with mitigation measures, such as tori lines and offal management, is part of the permit conditions for both the longliners and trawl fishery, has been drafted and reviewed over the period 2003–2007, but has not yet been implemented in Namibia.

Within the dimension of ‘ability to achieve’, the ERA highlighted the lack of an approved EAF management plan for the hake fisheries,

comprising a suitable set of indicators. Lack of transparency in the hake fisheries sector was found hindering the implementation of fisheries management. Research into the human dimension of the fishery has received increased attention since the mid-2000s. First results highlight the ecological understanding of skippers. Examples are their understanding of spawning seasons or size distribution in different areas, diurnal migration and differences between the species (Paterson, in press; Paterson and Kainge, 2014), which currently is not used in the management process (Draper, 2011; Paterson, in press; Paterson *et al.*, 2014) as well as the failure of the current management to achieve stated ecological or social objectives (Paterson and Petersen, 2010; Paterson *et al.*, 2013). Some concerns on social issues within the fishery have been addressed in the National Development Plan as well as poverty alleviation being incorporated in a management strategy (Petersen *et al.*, 2010). The management plan of the Namibian hake fishery has been reviewed since 2011 (MFMR, 2012). It was finally launched in November 2014 and is implemented for the period November 2014 to April 2018, when it is to be reviewed and amended.

3.5 Discussion

Although *M. capensis* has always been more abundant than *M. paradoxus* off Namibia (Figure 3.9), *M. paradoxus* makes up the bulk of the Namibian commercial catches (Johnsen and Kathena, 2012). Yet, in general the Namibian *M. capensis* stock is recovering very slowly, if at all (Kirchner *et al.*, 2012). Causes for this could include ecosystem degradation due to the very low abundance of small pelagic fish present in the northern Benguela ecosystem since the mid-1970s (Ludynia *et al.*, 2010, Roux *et al.*, 2013). It has been estimated that since the collapse of small pelagic fish, mainly sardine *Sardinops* in the northern Benguela ecosystem in the early 1970s, cannibalism of age-1 *M. capensis* on age-0 conspecifics has increased almost 10-fold, through comparison with the southern Benguela, and that overall diet energy density of young *M. capensis* has declined by 20–25% (Roux *et al.*, 2013). Both of these effects have probably undermined the recovery potential of this species.

Further explanation could be the skew target of the fishery towards large *M. capensis*. As the fishery has been restricted to beyond 200-m bottom depth since 1990 and now 350 m in southern Namibia, and because of the species' depth distribution ranges, the target has been only large *M. capensis*, and *M. paradoxus* of all sizes. This has left a younger *M. capensis* stock causing proportionately greater reduction in

recruitment of *M. capensis*, according to the *BOFFFF* hypothesis, which states that big old fat fecund female fish produce exponentially more offspring than young ones (Mullon *et al.*, 2012).

The socioeconomic reasons weigh heavily in the decision-making process towards the final TAC (Section 3.3.3). The over-capacity of the fishery and the large number of people employed by the fisheries sector overall, and the hake industry in particular, are often used as leverage and so TACs have often been set much higher than advised by MFMR scientists (Garcia Rey and Grobler, 2011; Paterson *et al.*, 2013). In addition, it is believed that catch reporting during the pre-independence (ICSEAF) period was deliberately biased (Roux and Shannon, 2004; MRAG, 2005).

Finding support for the different hypotheses of why *M. capensis* is not recovering despite the bulk of the catches coming from the *M. paradoxus* fishing resource is confounded by the fact that stocks are not separated in the assessment model, and so species-specific abundance and productivity are poorly understood.

In addition, a large contributing factor is that the age data used in the current stock assessment is based on slow growth *M. capensis* (Table 3.1B). A stock that is more reactive to variability in the catches and environmental fluctuations is expected for a faster-growing species with an expected higher natural mortality (more resilient but also more at risk). *M. paradoxus* should be fished according to more conservative fishing strategies applied to less productive species. At present in Namibia, management does not reflect this, as *M. paradoxus* is fished at higher catch rates than *M. capensis*, and young *M. capensis* are protected by the 200/300-m depth restriction. Adjustments to the management strategies that will follow a split-species management approach should take these results and hypotheses into consideration.

In order to assess the stocks separately and to achieve more specific recommendations, age validation and age determination research on *M. paradoxus* needs to be carried out as currently this is only based on indirect validation not covering all months of the year and all age groups (Wilhelm, 2012).

Although there is a great need for further research (e.g. species-disaggregated stock assessments and management strategies, *M. paradoxus* age validation and the maturity parameters), a lot of progress has been made and the Namibian hake-directed fishery is

continued to be managed towards recovery to B_{MSY} in the northern Benguela

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References

- Assorov, V. V., and Berenbeim, D. Y. 1983. Spawning grounds and cycles of Cape hakes in the southeast Atlantic. Collection of Scientific Papers of the International Commission for Southeast Atlantic Fisheries, 10 (i): 27–30.
- Bartholomae, C. H., and van der Plas, A. K. 2007. Towards the development of environmental indices for the Namibian shelf, with particular reference to fisheries management. African Journal of Marine Science, 29 (1): 25–35.
- BENEFIT. 2005. Report of the 2005 BENEFIT hake otolith reading workshop. National Marine Information and Research Centre, Swakopmund, Namibia, 19–30 September 2005: 20 pp.
- Bentz, K. L. M. 1976. Gill arch morphology of the Cape hakes *Merluccius capensis* Cast. and *M. paradoxus* Franca. Fisheries Bulletin of South Africa, 8: 17–22.
- Botha, L. 1971. Growth and otolith morphology of the Cape hakes *Merluccius capensis* Cast. and *M. paradoxus* Franca. Investigational Report of the Division of Sea Fisheries Research of South Africa, 97: 1–32.
- Botha, L. 1980. The biology of the Cape hake *Merluccius capensis* Cast. and *M. paradoxus* Franca. PhD thesis, Stellenbosch University, South Africa: 182 pp.

- Botha, L. 1985. Occurrence and distribution of Cape hakes *Merluccius capensis* Cast. and *M. paradoxus* Franca in the Cape of Good hope area. South African Journal of Marine Science, 3: 179–190.
- Botha, L. 1986. Reproduction, sex ratio and rate of natural mortality of Cape hakes *Merluccius capensis* Cast. and *M. paradoxus* Franca in the Cape of Good Hope area. South African Journal of Marine Science, 4: 23–35.
- Brandão, A., and Butterworth D. S. 2004. Standardisation of commercial catch per unit effort data of Namibian hake for the period 1992 to 2003. HWG/WKShop/2004/doc2.
- Burmeister, L.-M. 2001. Depth-stratified density estimates and distribution of the Cape hake *Merluccius capensis* and *M. paradoxus* off Namibia, deduced from survey data, 1990–1999. South African Journal of Marine Science, 23: 347–356.
- Burmeister, L.-M. 2005. Is there a single stock of *Merluccius paradoxus* in the Benguela ecosystem? African Journal of Marine Science, 27: 23–32.
- Butterworth, D. S., and Rademeyer, R. A. 2005. Sustainable management initiatives for the southern African hake fisheries over recent years. Bulletin of Marine Science, 76 (2): 287–319.
- Chlapowski, K. 1974. Length composition and maturity of hakes *Merluccius capensis* and *M. paradoxus* caught in the ICSEAF area during the period from November 1972 to January 1973. Collection of Scientific Papers of the International Commission for Southeast Atlantic Fisheries, 1: 182–192.
- Cochrane, K. L., Augustyn, C. J., Fairweather, T., Japp, D., Kilongo, K., Iitembu, J., Moroff, N., Roux, J.-P., Shannon, L., Van Zyl, B., and Vaz Velho, F. 2009. Benguela Current Large Marine Ecosystem—Governance and management for an Ecosystem Approach to Fisheries in the region. Coastal Management, 37: 235–254.
- Crawford, R. J. M., Shannon, L. V., and Pollock, D. E. 1987. The Benguela ecosystem. Part IV. The major fish and invertebrate resources. Oceanography and Marine Biology: An Annual Review, 25: 353–505.
- de Pontual, H., Groison, A.-L., Piñeiro, C., and Bertignac, M. 2006. Evidence of underestimation of European hake growth in the Bay of Biscay, and its relationship with bias in the agreed method of age estimation. ICES Journal of Marine Science, 63: 1674–1681.
- Deriso, R. B., Quinn, T. J., and Neal, P. R. 1985. Catch-age analysis with auxiliary information. Canadian Journal of Fisheries and Aquatic Sciences, 42: 815–824.
- Draper, K. 2011. Technologies, knowledges, and capital: Towards a political ecology of the hake trawl fishery, Walvis Bay, Namibia. MA thesis, University of Cape Town, South Africa.

- Duncombe Rae, C. M. 2005. A demonstration of the hydrographic partition of the Benguela upwelling ecosystem at 26°40'S. *African Journal of Marine Science*, 27 (3): 617–628.
- Franca, P. 1960. Nova contribuição para o conhecimento do género *Merluccius* no Atlântico oriental ao sul do Equador. *Memoria Junta Investigaciones Ultramarina Serié*s, 2 (18): 57–101.
- Garcia Rey, M., and Grobler, J. 2011. Spain's hake appetite threatens Namibia's most valuable fish. *The Namibian*, 07 October. <http://www.namibian.com.na/news/full-story/archive/2011/october/article/spains-hake-appetite-threatens-namibias-most-valuable-fish-1/>
- Goicochea, C., Wosnitza-Mendo, C., Mostacero, J., and Moquillaza, P. 2010. Periodicidad de formación de anillos de crecimiento en otolitos de la merluza peruana *Merluccius gayi peruanus* Ginsburg [Periodicity of growth ring formation in otoliths of Peruvian hake *Merluccius gayi peruanus* Ginsburg]. *Informes del Instituto del Mar del Perú*, 37 (3–4): 79–83.
- Gordoa, A., and Duarte, C. M. 1991. Size-dependent spatial distribution of hake (*Merluccius capensis* and *Merluccius paradoxus*) in Namibian waters. *Canadian Journal of Fisheries and Aquatic Sciences*, 48: 2095–2099.
- Gordoa, A., and Hightower, J. E. 1991. Changes in catchability in a bottom trawl fishery for Cape hake (*Merluccius capensis*). *Canadian Journal of Fisheries and Aquatic Sciences*, 48: 1887–1895.
- Gordoa, A., Lesch, H., and Rodergas, S. 2006. By-catch: complementary information for understanding fish behaviour. Namibian Cape hake (*M. capensis* and *M. paradoxus*) as a case study. *ICES Journal of Marine Science*, 63 (8): 1513–1519.
- Gordoa, A., and Macpherson, E. 1990. Food selection by a sit-and-wait predator, the monkfish, *Lophius upsicephalus*, off Namibia (South West Africa). *Environmental Biology of Fishes*, 27 (1): 71–76.
- Gordoa, A., and Macpherson, E. 1991. Diurnal variation in the feeding activity and catch rate of Cape hake (*Merluccius capensis* and *M. paradoxus*) off Namibia. *Fisheries Research*, 12 (4): 299–305.
- Gordoa, A., Macpherson, E., and Olivar, M. P. 1995. Biology and fisheries of Namibian hakes (*M. capensis* and *M. paradoxus*). In *Hake fisheries ecology and markets*, pp. 49–79. Ed. by J. Alheit, and T. J. Pitcher. Chapman & Hall, London.
- Gordoa, A., Masó, M., and Voges, E. 2000. Monthly variability in the catchability of Namibian hake and its relationship with environmental seasonality. *Fisheries Research*, 48: 185–195.

- Gordoa, A., Raventós, N., and Dealie, F. F. 2001. Comparison between micro- and macro-structure readings in the age estimations of Cape hake. *Journal of Fish Biology*, 59: 1153–1163.
- Grant, W. S., Becker, I. I., and Leslie, R. W. 1988. Evolutionary divergence between sympatric species of southern African hakes *Merluccius capensis* and *M. paradoxus*. I. Electrophoretic analysis of proteins. *Heredity*, 61: 13–20.
- Grant, W. S., Leslie, R. W., and Becker, I. I. 1987. Genetic stock structure of the southern African hakes *Merluccius capensis* and *M. paradoxus*. *Marine Ecology Progress Series*, 41: 9–20.
- Hamukuaya, H., O’Toole, M. J., and Woodhead, P. M. J. 1998. Observations of severe hypoxia and offshore displacement of Cape hake over the Namibian shelf. *South African Journal of Marine Science*, 19: 57–59.
- Heymans, J. J., Shannon, L. J., and Jarre, A. 2004. Changes in the northern Benguela ecosystem over three decades: 1970s, 1980s, and 1990s. *Ecological Modelling*, 172 (2–4): 175–195.
- ICSEAF. 1983. Otolith interpretation guide, Hake. International Commission for Southeast Atlantic Fisheries, 1: 70 pp.
- Iilende, T., Strømme, T., and Johnsen, E. 2001. Dynamics of the pelagic component of the Namibian hake stocks. *South African Journal of Marine Science*, 23: 337–346.
- Iitembu, J. A., Miller, T. W., Ohmori, K., Kanime, A., and Wells, S. 2012. Comparison of ontogenetic trophic shift in two hake species, *Merluccius capensis* and *Merluccius paradoxus*, from the Northern Benguela Current ecosystem (Namibia) using stable isotope analysis. *Fisheries Oceanography*, 21: 215–225.
- Inada, T. 1981. Studies on the merluccid fishes. *Bulletin of Far Seas Fisheries Research Laboratory (Shimizu)*, 18: 172 pp.
- IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 05 March 2013.
- Jarre-Teichmann, A., Shannon, L. J., Moloney, C. L., and Wickens, P. A. 1998. Comparing trophic flows in the southern Benguela to those in other upwelling ecosystems. *South African Journal of Marine Science*, 19: 391–414.
- Johnsen, E., and Iilende, T. 2007. Factors affecting the diel variation in commercial CPUE of Namibian hake – Can new information improve standard survey estimates? *Fisheries Research*, 88: 70–79.
- Johnsen, E., and Kathena, J. N. 2012. A robust method to separate Namibian commercial hake catches by species – a necessary step towards a biologically realistic hake stock assessment. *African Journal of Marine Science*, 43 (1): 43–53.

- Kainge, P., Kjesbu, O. S., Thorsen, A., and Salvanes, A. G. 2007. *Merluccius capensis* spawn in Namibian waters, but do *M. paradoxus*? African Journal of Marine Science, 29 (3): 379–392.
- Kirchner, C. H., Kainge, P., and Kathena, J. N. 2012. Evaluation of the status of the Namibian hake resource (*Merluccius* spp.) using statistical catch-at-age analysis. Environment for Development Discussion Paper Series, 12-12: 1–52.
- Kirchner, C. H. 2014. Estimating present and future profits within the Namibian hake industry: a bio-economic analysis. African Journal of Marine Science, 36(3): 283-292.
- Kirchner, C. H. and Leiman, A. 2014. Resource rents and resource management policies in Namibia's post-Independence hake fishery. Maritime Studies, 13(7): 1-23.
- Lloris, D., Matallanas, J., and Oliver, P. 2005. Hakes of the world (Family Merlucciidae). An annotated and illustrated catalogue of hake species known to date. FAO Species Catalogue for Fishery Purposes, 2: 57 pp.
- Ludynia, K., Roux J.-P., Jones, R., Kemper, J., and Underhill, L. G. 2010. Surviving off junk: Low-energy prey dominates the diet of African penguins *Spheniscus demersus* at Mercury Island, Namibia, between 1996 and 2009. African Journal of Marine Science, 32: 562–572.
- Macpherson, E. 1976. Relative growth of *Merluccius capensis*. Collection of Scientific Papers of the International Commission for Southeast Atlantic Fisheries, 3: 115–118.
- Macpherson, E., and Duarte, C. M. 1991. Bathymetric trends in demersal fish size: is there a general relationship? Marine Ecology Progress Series, 71: 103–112.
- Macpherson, E., and Gordoia, A. 1994. Effect of prey densities on cannibalism in Cape hake (*Merluccius capensis*) off Namibia. Marine Biology, 119 (1): 145–149.
- Macpherson, E., Masó, M., Barange, M., and Gordoia, A. 1991. Relationship between measurements of hake biomass and sea surface temperature off southern Namibia. South African Journal of Marine Science, 10: 213–217.
- Macpherson, E., and Roel, B. A. 1987. Trophic relationships in the demersal fish community off Namibia. South African Journal of Marine Science, 5: 585–596.
- Mafwila, S. K. 2011. Ecosystem effects of bottom trawling in Namibia. PhD thesis, University of Cape Town, South Africa: 326 pp.
- Mas-Riera, J. 1991. Changes during growth in the retinal structure of three hake species, *Merluccius* spp. (Teleostei: Gadiformes), in

- relation to their depth distribution and feeding. *Journal of Experimental Marine Biology and Ecology*, 152 (1): 91–104.
- Mas-Riera, J., Lombarte, A., Gordo, A., and Macpherson, E. 1990. Influence of Benguela upwelling on the structure of demersal fish populations off Namibia. *Marine Biology*, 104 (2): 175–182.
- Mecenero, S., Roux, J.-P., Underhill, L. G., and Bester, M. N. 2006. Diet of Cape fur seals *Arctocephalus pusillus pusillus* at three mainland breeding colonies in Namibia. 1. Spatial variation. *African Journal of Marine Science*, 28 (1): 57–71.
- MFMR. 1991. Towards responsible development of the Fisheries Sector. White paper of the Ministry of Fisheries and Marine Resources, Republic of Namibia: 65 pp.
- MFMR. 1992. Sea Fisheries Act (Act no. 29 of 1992). *Government Gazette of the Republic of Namibia*, 493: 57 pp.
- MFMR. 2000. Marine Resources Act 2000 (Act no. 27 of 2000). *Government Gazette of the Republic of Namibia*, 2458: 40 pp.
http://209.88.21.36/opencms/opencms/grnnet/MFMR/Laws_and_Policies/marineAct.html
- MFMR. 2001. Regulations relating to the exploitation of marine resources. The Marine Fisheries Regulations (Government notice no. 241). *Government Gazette of the Republic of Namibia*, 2657: 50 pp.
http://209.88.21.36/opencms/opencms/grnnet/MFMR/Laws_and_Policies/marineregulation.html
- MFMR. 2004. Namibia's Marine Resources Policy. Towards responsible development and management of the Marine Resources Sector. Ministry of Fisheries and Marine Resources, Republic of Namibia: 23 pp.
http://209.88.21.36/opencms/opencms/grnnet/MFMR/Laws_and_Policies/whitepaper.html
- MFMR. 2012. Management Plan for the Namibian hake fishery. Ministry of Fisheries and Marine Resources, Republic of Namibia: 36 pp.
- MFMR & NPC. 2011. Ministry of Fisheries and Marine Resources. Statistics.
http://209.88.21.36/opencms/opencms/grnnet/MFMR/Fishing_Industry/statistics.html
- Mohrholz, V., Bartholomae, C. H., van der Plas, A. K., and Lass, H. U. 2008. The seasonal variability of the northern Benguela undercurrent and its relation to the oxygen budget on the shelf. *Continental Shelf Research*, 28: 424–441.
- Mombeck, F. 1969. Vorläufiger Bericht über Seehecht-Untersuchungen im SO Atlantik Institut für Seefischerei der Bundesforschungsanstalt für Fischerei, Aussenstelle, Bremerhaven. *Archiv für Fischereiwissenschaft*, 21: 45–61.

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- Mora, C., Myers, R. A., Coll, M., Libralato, S., Pitcher, T. J., Sumaila, R. U., Zeller, D., Watson, R., Gaston, K. J., and Worm, B. 2009. Management Effectiveness of the World's Marine Fisheries. *PLoS Biology*, 7(6): e1000131.
- Morales, B. Y. O., and Payne, A. I. L. 1985. A note on the interpretation of hake otoliths. *Collection of Scientific Papers of the International Commission for Southeast Atlantic Fisheries*, 12 (ii): 69–79.
- Morales-Nin, B. Y. O. 1991. Growth of Cape hake *Merluccius capensis* off Namibia determined by means of length frequency analysis and age/length data. *South African Journal of Marine Science*, 10: 53–60.
- Morales-Nin, B. Y. O., Torres, G. J., Lombarte, A., and Recasens, L. 1998. Otolith growth and age estimation in the European hake. *Journal of Fish Biology*, 53: 1155–1168.
- MRAG. 2005. Review of impacts of Illegal, Unreported and Unregulated fishing on developing countries. Final Report, July 2005: 176 pp.
<http://webarchive.nationalarchives.gov.uk/+/http://www.dfid.gov.uk/pubs/files/illegal-fishing-mrag-report.pdf>
- Mullon, C., Field, J. G., Thébaud, O., Cury, P. M., and Chaboud, C. 2012. Keeping the big fish: Economic and ecological tradeoffs in size-based fisheries management. *Journal of Bioeconomics*, 14: 267–285.
- Nel, D. C. 2007. Ecological Risk Assessment (ERA) for the Namibian Demersal Hake Fishery. In *Ecological Risk Assessment: A Tool for Implementing an Ecosystem Approach for Southern African Fisheries*, pp. 125–144. Ed. by D. C. Nel, K. L. Cochrane, S. L. Petersen, L. J. Shannon, B. J. van Zyl, and M. B. Honig. WWF South Africa Report Series, 2007/Marine/002. WWF, Cape Town, South Africa.
- O'Toole, M. J. 1976. Distribution and abundance of the hake *Merluccius* spp. off South West Africa 1972–1974. *Collection of Scientific Papers of the International Commission for Southeast Atlantic Fisheries*, 2: 151–158.
- O'Toole, M. J. 1978. Aspects of the early life history of the hake, *Merluccius capensis* Castelnau, off South West Africa. *Fisheries Bulletin of South Africa*, 10: 20–36.
- Olivar, M.-P. 1990. Spatial patterns of ichthyoplankton distribution in relation to hydrographic features in the northern Benguela region. *Marine Biology*, 106: 39–48.
- Olivar, M.-P., Rubiés, P., and Salat, J. 1988. Early life history and spawning of *Merluccius capensis* Castelnau in the northern Benguela current. *South African Journal of Marine Science*, 6: 245–254.

- Olivar, M.-P., and Shelton, P. A. 1993. Larval fish assemblages of the Benguela current. *Bulletin of Marine Science*, 53(2): 450–474.
- Paterson, B. in press. Tracks, trawls and lines—Knowledge practices of skippers in the Namibian hake fisheries. *Marine Policy*, DOI: 10.1016/j.marpol.2014.07.017.
- Paterson, B. and Kainge, P. 2014. Rebuilding the Namibian hake fishery: a case for collaboration between scientists and fishermen. *Ecology and Society*, 19(2): 49-59.
- Paterson, B., Kirchner, C. H., and Ommer, R. 2013. A short history of the Namibian hake fishery – A social-ecological analysis. *Ecology and Society*, 18(4): 66.
- Paterson, B., Norton, M, Jarre, A, and Green, L. F. 2014. Science, Fishers' knowledge and Namibia's fishing industry. *In Africa-centred Knowledges: Crossing Fields and Worlds*, pp. 111–125. Ed. by B. Cooper, and R. Morrell. James Currey, Suffolk.
- Paterson, B., and Petersen, S. L. 2010. EAF implementation in Southern Africa: Lessons learnt. *Marine Policy*, 34: 276–292.
- Payne, A. I. L., and Punt, A. E. 1995. Biology and fisheries of South African hakes (*M. capensis* and *M. paradoxus*). *In Hake fisheries ecology and markets*, pp. 15–47. Ed. by J. Alheit, and T. J. Pitcher. Chapman & Hall, London.
- Petersen, S. L., Paterson, B., Basson, J., Moroff, N., Roux, J.-P., Augustyn, C. J., and D'Almeida, G. (Eds) 2010. Tracking the implementation of an Ecosystem Approach to Fisheries in southern Africa. WWF South Africa Report Series, 2010/Marine/001, Volume 2: 163 pp. WWF, Cape Town, South Africa.
- Pillar, S. C., and Barange, M. 1995. Diel feeding periodicity, daily ration and vertical migration of juvenile Cape hake off the west coast of South Africa. *Journal of Fish Biology*, 47: 753–768.
- Porebski, J. 1976. The morphology and distribution of hake *Merluccius* spp. in early stages of development, as a basis for determination of regions and periods of concentration of the species. *Collection of Scientific Papers of the International Commission for Southeast Atlantic Fisheries*, 3: 165–173.
- Pozo Arteaga, E. 1976. Some data on the biology of the Cape hake (*Merluccius capensis*) inhabiting the Cunene and Cape Cross divisions of the ICSEAF area. *Collection of Scientific Papers of the International Commission for Southeast Atlantic Fisheries*, 3: 179–185.
- Preňski, L. 1978. Studies on hake, *Merluccius capensis*, in ICSEAF Divisions 1.4 and 1.5 in 1977. *Collection of Scientific Papers of the International Commission for Southeast Atlantic Fisheries*, 5: 89–94.
- Rademeyer, R. A., Butterworth, D. S., and Plagányi, E. E. 2008. A history of recent bases for management and the development of a

- species-combined Operational Management Procedure for the South African hake resource. *African Journal of Marine Science*, 30(2): 291-310.
- Roel, B. A., and Bailey, G. W. 1987. Preliminary investigations of the relationship between hake abundance and hydrological parameters in the Benguela system. *Collection of Scientific Papers of the International Commission for Southeast Atlantic Fisheries*, 14 (ii): 193–201.
- Roel, B. A., and Macpherson, E. 1988. Feeding of *Merluccius capensis* and *M. paradoxus* off Namibia. *South African Journal of Marine Science*, 6: 227–243.
- Roux J.-P. 2007. Simulations of Cape hake recruitment variability and implications for EAF management in Namibia. Appendix 4c. In *Report of the third regional workshop, Cape Town, South Africa (30 October–3 November 2006)*, pp. 73–82. Ecosystem approaches for fisheries (EAF) management in the BCLME (Project LMR/EAF/03/01), Report No 4, UNTS/RAF/011/GEF. FAO, Rome.
- Roux, J.-P., and Shannon, L. J. 2004. Ecosystem approach to fisheries management in the northern Benguela: the Namibian experience. *African Journal of Marine Science*, 26: 79–93.
- Roux, J.-P., van der Lingen, C. D., Gibbons, M. J., Moroff, N. E., Shannon, L. J., Smith, A. D. M., and Cury, P. M. 2013. Jellyfication of marine ecosystems as a likely consequence of overfishing small pelagic fish: lessons from the Benguela. *Bulletin of Marine Science*, 89 (1): 249–284
- Shannon, L. J., and Jarre-Teichmann, A. 1999. A model of trophic flows in the northern Benguela upwelling system during the 1980s. *South African Journal of Marine Science*, 21: 349–366.
- Shannon, L. V. 1985. The Benguela ecosystem. Part I. Evolution of the Benguela, physical features and processes. *Oceanography and Marine Biology Annual Review*, 23: 105–182.
- Shannon, L. V., Boyd, A. J., Brundrit, G. B., and Tauton-Clark, J. 1986. On the existence of an El Niño-type phenomenon in the Benguela System. *Journal of Marine Research*, 44 (3): 495–520.
- Shannon, L. V., Crawford, R. J. M., Brundrit, G. B., and Underhill, L. G. 1988. Responses of fish populations in the Benguela ecosystem to environmental change. *Journal du Conseil International pour l'Exploration de la Mer*, 45: 5–12.
- Singh, L., Melo, Y. C., and Glazer, J. P. 2011. *Merluccius capensis* and *M. paradoxus* length at 50% maturity based on histological analyses of gonads from surveys. Demersal working group document, Department of Agriculture, Forestry and Fisheries, Cape Town, South Africa, FISHERIES/2011/JUL/SWG-DEM/33: 6 pp.

- Stenevik, E. K., Lipinski, M. R., and Zaera, D. 2009. 2009 BCC survey No. 2. Transboundary survey between Namibia and South Africa with focus on the juvenile stage of deep water hake, 21 February – 5 March 2009. Cruise report No 2/2009. FAO PROJECT: CCP/INT/003/NOR. Cruise reports *Dr. Fridtjof Nansen* EAF-N2009/2, Bergen, Norway: 62 pp. <http://www.eaf-nansen.org/nansen/topic/18011/en#2009>
- Sundby, S., Boyd, A. J., Hutchings, L., O'Toole, M. J., Thorisson, K., and Thorsen, A. 2001. Interaction between Cape hake spawning and the circulation in the northern Benguela upwelling ecosystem. *South African Journal of Marine Science*, 23: 317–336.
- Traut, P. J. 1996. Diet and annual consumption for the Cape hakes on the Namibian shelf, with special reference to cannibalism. MPhil thesis, University of Bergen, Norway: 66 pp.
- van der Westhuizen, A. 2001. A decade of exploitation and management of the Namibian hake stocks. *South African Journal of Marine Science*, 23: 307–315.
- van Eck, T. H. 1969. The South African hake, *Merluccius capensis* or *Merluccius paradoxus*? *South African Shipping News and Fishing Industry Review*, 24: 95–97.
- Voges, E., Gordo, A., Bartholomae, C. H., and Field, J. G. 2002. Estimating the probability of different levels of recruitment for Cape hakes *Merluccius capensis* off Namibia using environmental indices. *Fisheries Research*, 58: 333–340.
- von der Heyden, S., Lipinski, M. R., and Matthee, C. A. 2007a. Mitochondrial DNA analyses of the Cape hakes reveal an expanding, panmictic population for *Merluccius capensis* and population structuring for mature fish in *Merluccius paradoxus*. *Molecular Phylogenetics and Evolution*, 42: 517–527.
- von der Heyden, S., Lipinski, M. R., and Matthee, C. A. 2007b. Species-specific genetic markers for identification of early life-history stages of Cape hakes, *Merluccius capensis* and *Merluccius paradoxus* in the southern Benguela Current. *Journal of Fish Biology*, 70 (Suppl. B): 262–268.
- Watermeyer, K. E., Shannon, L. J., Roux, J.-P., and Griffiths, C. L. 2008. Changes in the trophic structure of the northern Benguela before and after the onset of industrial fishing. *African Journal of Marine Science*, 30 (2): 383–403.
- Weidlich, B. 2006. Hake needs protection: Minister. *The Namibian*, 3 November. [http://www.namibian.com.na/index.php?id=28&tx_ttnews\[tt_news\]=28055&no_cache=1](http://www.namibian.com.na/index.php?id=28&tx_ttnews[tt_news]=28055&no_cache=1)

- Wilhelm, M. R. 2012. Growth and otolith zone formation of Namibian hake *Merluccius capensis*. PhD thesis, University of Cape Town, South Africa: 236 pp.
- Wilhelm, M. R., Roux, J.-P., Moloney, C. L., and Jarre, A. 2013. Data from fur seal scats reveal when Namibian *Merluccius capensis* are hatched and how fast they grow. *ICES Journal of Marine Science*, 70:1429–1438.
- Wilhelm, M. R., Jarre, A., and Moloney, C. L. 2015. Spawning and nursery areas, longitudinal and cross-shelf migrations of the *Merluccius capensis* stock in the northern Benguela. *Fisheries Oceanography*, 24(S1): 31-45.
- Wysokiński, A. 1983. Photographic guide for determination from otoliths of the age of young hake *Merluccius capensis* from South West Africa (Namibia). *South African Journal of Marine Science*, 1: 19–55.

Table 3.1 Length and weight for the beginning and middle of the year and the proportion mature (Prop. mature) at each age for (A) *M. paradoxus*, (B) *M. capensis* assuming slow growth rates used in the current Namibian hake assessment and C. *M. capensis* assuming fast growth rates using new age information available (Wilhelm, 2012). Also shown are the parameters used to calculate each of the values for each age (years)*

Parameters	(A) <i>M. paradoxus</i>				(B) <i>M. capensis</i> - slow growth				(C) <i>M. capensis</i> - fast growth			
	Length (cm)	Begin-year weight (g)	Mid-year weight (g)	Prop. mature	Length (cm)	Begin-year weight (g)	Mid-year weight (g)	Prop. mature	Length (cm)	Begin-year weight (g)	Mid-year weight (g)	Prop. mature
L_{∞} (cm)	127				149				134			
K (per year)	0.0731				0.0609				0.127			
t_0 (years)	-1.60				-1.28				-0.049			
a		0.0063	0.0063			0.0051	0.0051			0.0051	0.0051	
b		3.04	3.04			3.08	3.08			3.08	3.08	
L_{50} (cm)				30.5				24.8				24.8
δ (cm)				7.43				5.21				5.21
Age (years)												
0	14.1	19.6		0.10	11.2	8.8		0.07	0.8	0.0		0.01
0.5	18.2		42.4	0.16	15.4		23.1	0.14	9.0		4.5	0.05
1.0	22.1	76.8		0.24	19.4	47.2		0.26	16.7	29.8		0.17
1.5	25.9		124.2	0.35	23.3		83.0	0.43	23.9		90.1	0.46
2.0	29.5	185.5		0.47	27.1	131.9		0.61	30.7	194.1		0.76
2.5	33.0		261.1	0.58	30.8		195.0	0.76	37.1		346.5	0.91
3.0	36.4	351.4		0.69	34.3	273.3		0.86	43.0	548.7		0.97
3.5	39.7		456.3	0.77	37.8		367.1	0.92	48.6		799.7	0.99
4.0	42.8	575.5		0.84	41.1	476.8		0.96	53.9	1096.9		1.00
4.5	45.9		708.8	0.89	44.4		602.6	0.98	58.8		1436.5	1.00
5.0	48.8	855.4		0.92	47.5	744.4		0.99	63.4	1813.9		1.00
5.5	51.6		1014.9	0.94	50.6		902.0	0.99	67.8		2224.3	1.00
6.0	54.3	1186.5		0.96	53.5	1074.9		1.00				
6.5	57.0		1369.3	0.97	56.4		1262.8	1.00				
7.0	59.5	1562.6		0.98	59.2	1465.2		1.00				
7.5	61.9		1765.6	0.99	61.9		1681.3	1.00				

*The expected length (L_t) (cm) at age group t was calculated using the von Bertalanffy growth function (VBGF): $L_t = L_{\infty} * (1 - \exp(-K * (t - t_0)))$, where t is the age (years), L_{∞} is the asymptotic length (cm), K is the growth coefficient (per year) and t_0 is the theoretical age (years) at length zero. Weight (W_t) (g) at age t was calculated from L_t using the weight-length equation: $W_t = a * (L_t)^b$, where a and b are constants calculated from research survey data. Proportion mature at length L_t (PL_t) was calculated using the logistic ogive: $PL_t = 1 / (1 + \exp(-(L_t - L_{50}) / \delta))$, where L_{50} (cm) is the length at which 50% of the fish are mature and δ is the width of the maturity ogive (cm).

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Table 3.2 Summary of spawning areas and spawning season of *M. capensis* in the northern Benguela reported by different authors

Reference	Area	Months	Evidence
O'Toole (1976; 1978)	19°20'S & Walvis Bay (23–24°30'S) 22–24°40'S	January–March January–March November–December	Presence of larvae
Assorov and Berenbeim (1983)	Cape Frio (20°S–21°30'S) Walvis Bay (22°S–25°S)	All seasons, peak in winter–spring (July–October) Spring (October–December)	Presence of mature fish stages IV–V
Olivar <i>et al.</i> (1988)	18–23°S 20–21°S 22–23°S	August November November	Presence of eggs
Olivar and Shelton (1993)	Most of the Namibian coast 18°S–27°S		Presence of larvae
Kainge <i>et al.</i> (2007)	20°S, 22°S–24°S and around 28°S	Peak in September (not matched with areas)	High densities of adults with gonadosomatic index greater than 1.3%
Wilhelm <i>et al.</i> (2015)	Central (22–24°S) area Southern (26–28°S) area	Both areas: peaks in winter (June–August) and summer/autumn (February–May)	High density of <18 cm fish and >50 cm adults. Back-calculating hatch dates from <18 cm fish in each area

Figures



Figure 3.1 Images of (A) *Merluccius capensis* and (B) *M. paradoxus* (Photographs by Rob Leslie).

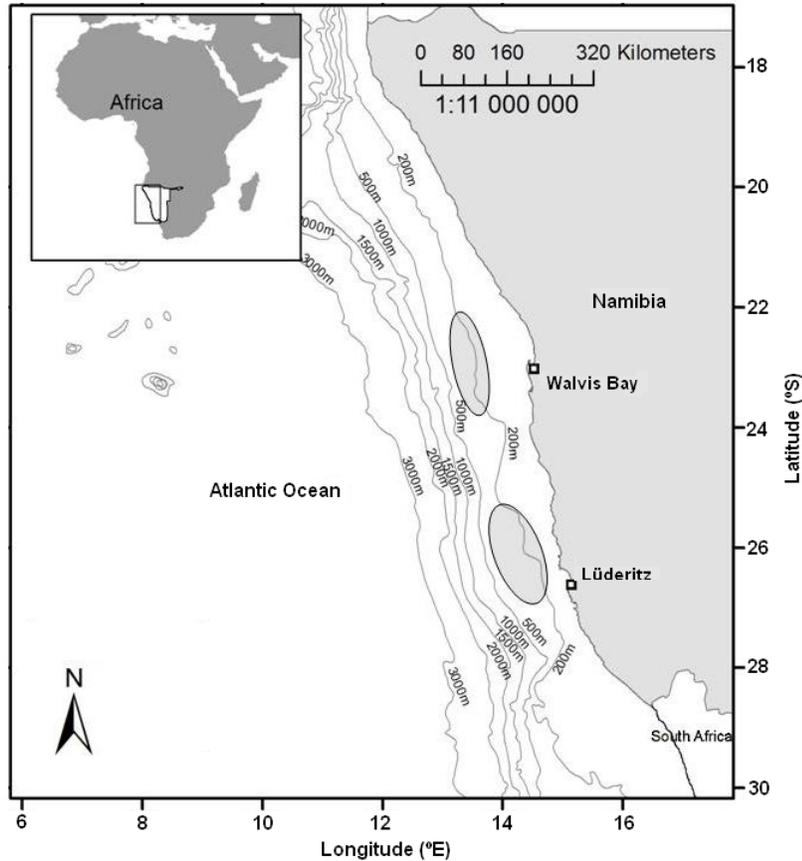


Figure 3.2 Map outlining the Namibian coastline with depth contours. Circles indicate the spawning centres of *M. capensis* – derived from (i) high densities of females with high GSI (from Kainge *et al.*, 2007) and (ii) aggregations of spawning adults and juveniles (Wilhelm *et al.*, 2015).

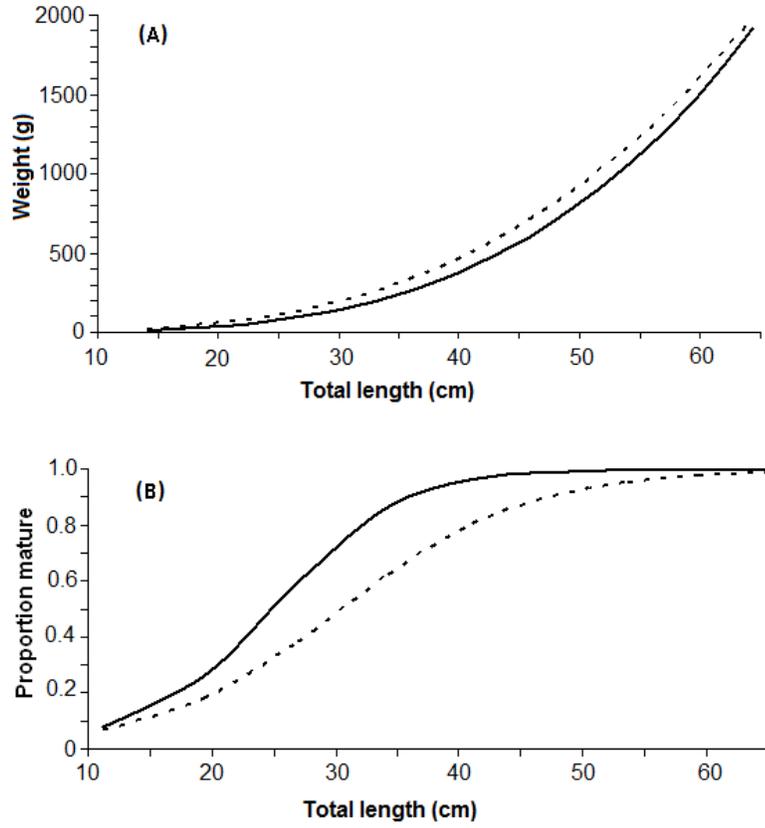


Figure 3.3 Weight-length relationships (A) and maturity-length ogives (B) of Namibian *M. paradoxus* (dashed line) and *M. capensis* (solid line).

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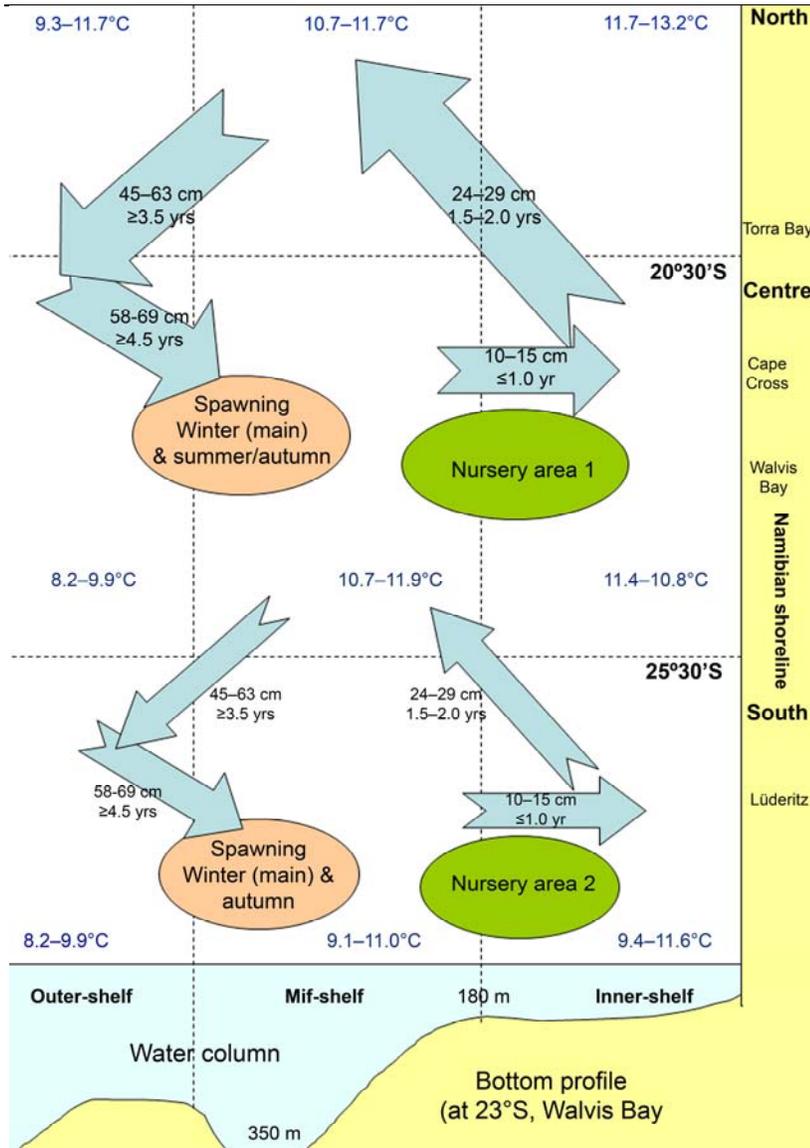


Figure 3.4 Namibian *M. capensis* proposed spawning centres and migration patterns from nursery (0 years old and 3 cm TL) to 4+ years old spawning fish (>50 cm TL). Ellipses indicate spawning and nursery areas. Arrows show inshore-offshore and alongshore migration. Temperatures refer to the range of the means of the coldest and warmest months at specific depths and areas (from Wilhelm *et al.*, 2015). (Source: Wilhelm *et al.* 2015. Reproduced with permission of John Wiley & Sons.)

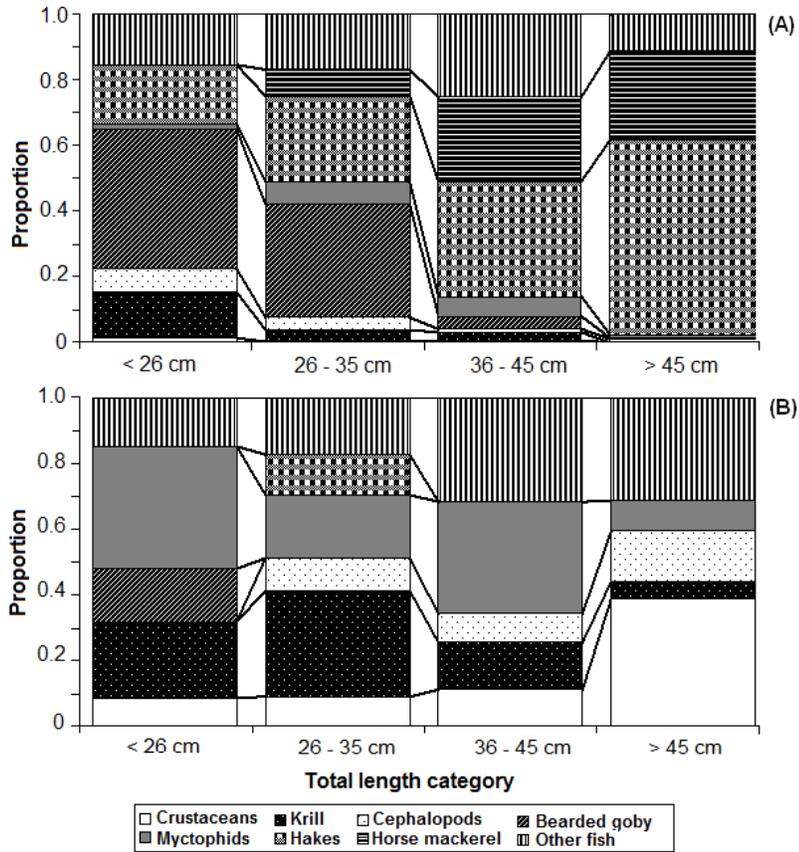


Figure 3.5 Diet composition (proportion wet mass) of stomach contents of fish collected during two surveys January–February 1999 of (A) *M. capensis* (n=859) and (B) *M. paradoxus* (n=297) (J.-P. Roux, MFMR, unpublished data).

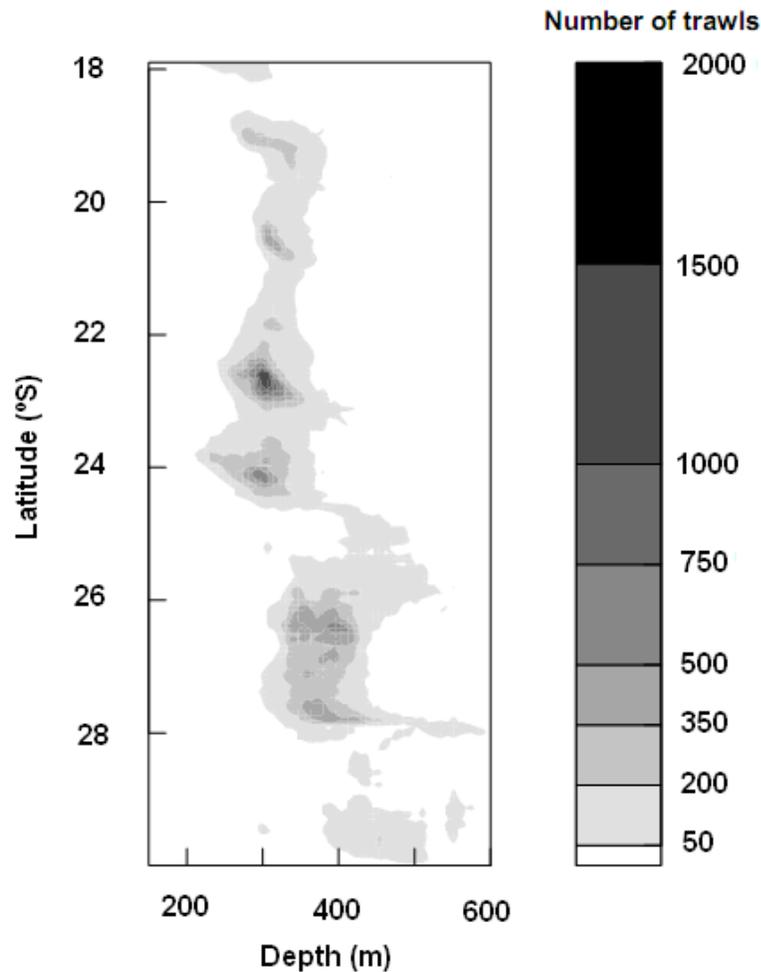


Figure 3.6 Number of commercial trawls conducted by grid cell 1998 to 2007 (5 nmi x 0.1° resolution) (from Johnsen and Kathena, 2012). (Source: Johnsen & Kathena 2012. Reproduced with permission of NISC (Pty) Ltd.)

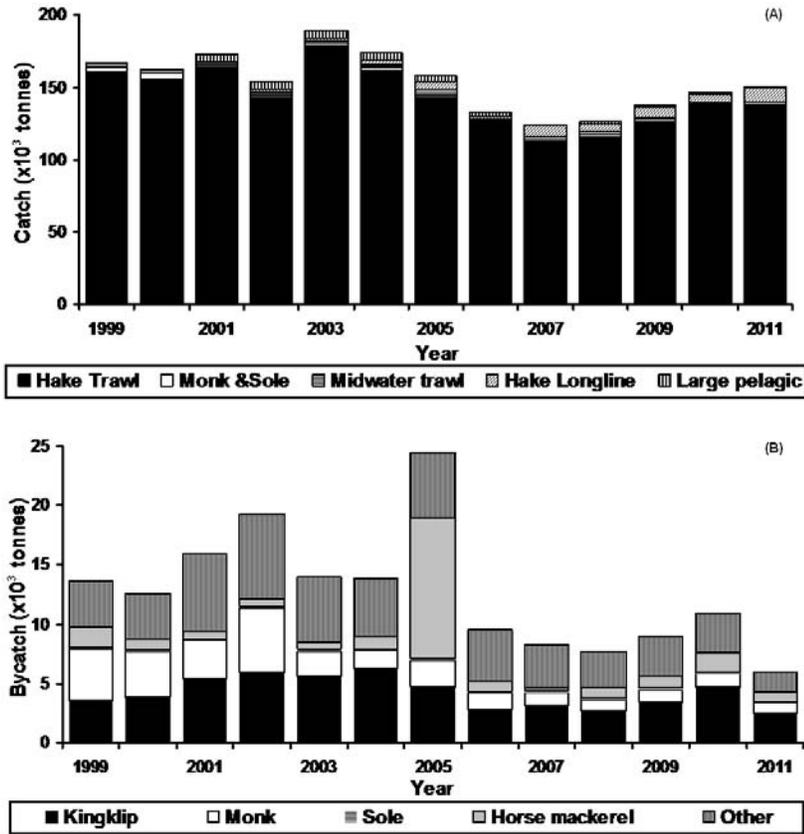


Figure 3.7 Annual total catch ($\times 10^3$ t) from 1999 to 2011 of (A) Namibian hake caught in the different fisheries (hake trawl and longline fisheries are hake-directed, mid-water trawl fishery targets horse mackerel) and (B) the main by-catch of the hake-directed trawl fishery.

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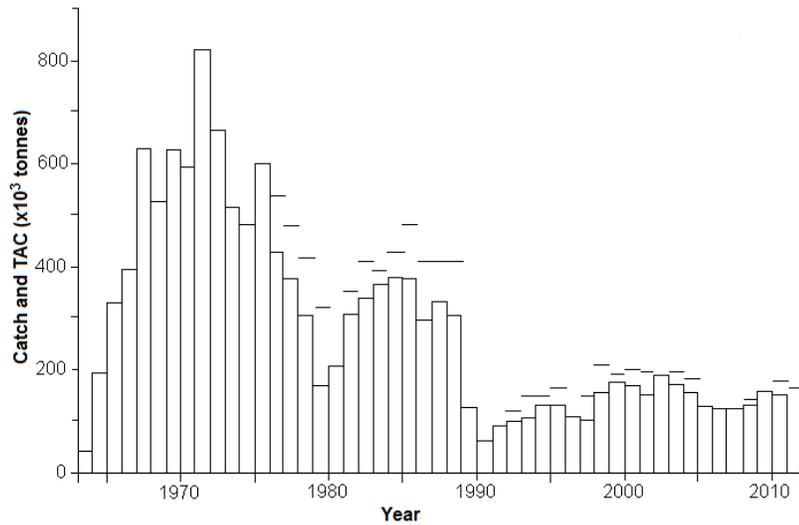


Figure 3.8 Annual total catch of the Namibian hake fishery ($\times 10^3$ t) from 1964 to 2011 (white bars), and total allowable catch (TAC) limits set in Namibia from 1976 to 2012 (black dashes).

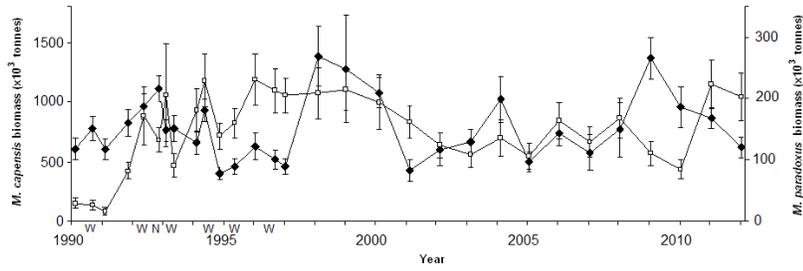


Figure 3.9 Swept-area biomass survey abundance indices (biomass in 10^3 t) and associated standard deviations for *M. capensis* (solid diamonds) and *M. paradoxus* (open squares) since the start of the Namibian Ministry of Fisheries and Marine Resources (MFMR) surveys in 1990. “W” indicates that that particular survey is used in the “winter survey” time series within the stock assessment model, while “N” indicates it is not used. All other surveys are used in the “summer survey” time series. The combined biomass estimate for both species is currently used in the assessment.

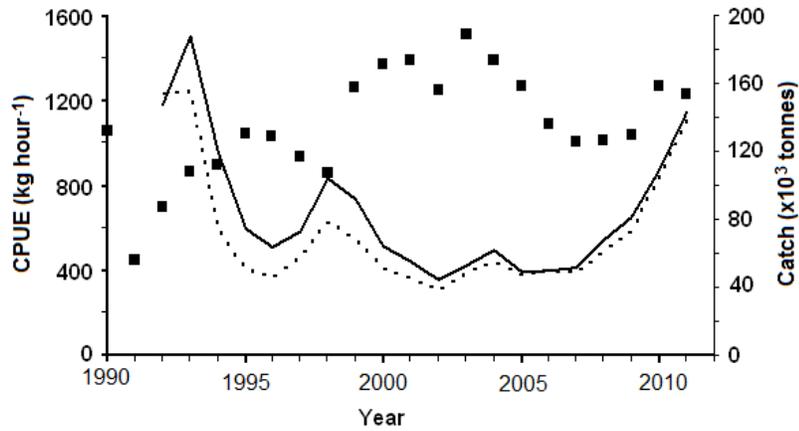


Figure 3.10 GLM standardised (solid line) and unstandardised (dashed line) catch per unit effort (CPUE) series for the Namibian hake fleet (both *M. capensis* and *M. paradoxus* combined) from 1990 to 2011. Annual total catch in (10^3 t, 1990 to 2011) is super-imposed as black squares.