MODELLING THE RELATIVE IMPACTS OF TRAWLING AND LONGLINING ON CAPE HAKE *MERLUCCIUS CAPENSIS* ON THE INSHORE AGULHAS BANK

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TABLE OF CONTENTS

DECLARATION

This dissertation reports the results of research that I carried out in the Marine Biology Research Institute, Zoology Department, at the University of Cape Town. It has not been submitted for any other degree or examination at any other university. Unless indicated otherwise, most of the data that are presented were obtained from Marine and Coastal Management Co-ordination, Department of Environmental Affairs and Tourism. All opinions expressed, unless otherwise acknowledged, are my own.

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Terence Phinda Jayiya

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Date

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During the time of the analysis and the write up of this project, numerous people and organisations gave me the benefit of their interest. But perhaps I should start by thanking my parents for making sure that I got to the level of doing a masters degree. To you I say *enkosi kakhulu*.

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ABSTRACT

A Geographic Information System (GIS) is used to elucidate vertical and horizontal patterns of distribution of *Merluccius capensis* on the inshore south coast (20°-27° E) of South Africa. Catch data are used to compare the size distributions in catches made by commercial trawls and longlines off the South Coast (20° E). Results show that *M. capensis* size increases with depth and that the distribution of fish < 30 cm is mostly west of 23° E with isolated pockets east of that region. No seasonal differences were found in the distribution of this species. Spatial mapping of survey trawl and longline data shows that these two operate on two distinct areas. Trawls fish on the softer grounds of the Agulhas bank whereas longlines operate over rocky areas. Size comparisons of the catches of the two fishing methods reveal that longlines catch very few fish that are < 60 cm whereas trawl catches are dominated by *M. capensis* of length < 60 cm. Analyses also revealed sex composition in longline catches to be different to that of trawls. All these results are discussed in relation to the ecology of *M. capensis* and the areas where data come from. Using size selectivity properties, the potential impacts of longlining and commercial trawling on the South Coast *M. capensis* (east of 20° E) are modelled with a yield per recruit and spawner biomass per recruit model. First, the age-specific selectivity vectors of the two fleets are estimated from catch data (length frequencies). A comparison of these shows that longlines select for larger and older individuals (from age four) whereas trawls select for a wide range of sizes (from age one) with catches being dominated by fish younger than five years of age. A yield per recruit and spawner biomass per recruit analysis is then applied using the fleet specific selectivity at age vectors. The analysis is done for three harvesting scenarios (longline only, trawl only and longline + trawl). Results show that at a natural mortality of 0.3 y^{-1} longlines provide a maximum yield of 352 g per recruit, which is greater than that of 193 g per recruit for trawls. At greater natural mortality values (e.g. 0.5 y^{-1}), trawls give a better yield than longlines. A maximum yield of 240 g per recruit is obtained when the two fishing methods are operating at the same time. The effects of longline and trawl fishing on spawner biomass are compared by expressing spawner biomass per recruit as percentage of its pristine level. After trawl fishing the percentage is 3.1% and after longline it is reduced to 38%. This comparison is further taken up by using an age-structured production model (ASPM), which is considered to be more dynamic than yield per recruit. The history of the fishery is re-created from 1967 by using the reported annual landings. From 1997 (the last available year of reported catches) the potential impacts are assessed by changing future catch limits ("what - if?" approach). The impacts of the fleets are assessed by looking at the spawner biomass responses to the catch limits. Finally an attempt is made to model sex-specific populations and to project egg production by the females under different longline and trawl catch limits. Using sex specific and egg production modelling, the resource collapsed after 10 years and this could probably be a result of the sensitivity of the model to sex-specific data. If the assumptions are valid, results suggest that an increase in the longline catch proportion of the TAC would increase the yield and help conserve the spawner biomass whereas an increase in the trawl proportion of the TAC would reduce the spawner biomass. Thus it seems part of the trawl catch should be reduced and the difference be allocated to the longlines without an increase in the TAC.

List of Figures

List of Tables

CHAPTER ONE

GENERAL INTRODUCTION

1.1 *Overview*

Species of the genus *Merluccius* are commonly referred to as hake around the world. The genus contains 14 currently recognised species, and is distributed in waters on both sides of the Atlantic Ocean, the eastern Pacific Ocean and off southern New Zealand (FAO species catalogue 1990). There are ten major hake fisheries, the most economically important being in Argentina, Uruguay, southern Africa, northern Peru and the West Coast of the USA (Pitcher and Alheit 1995). Elsewhere, hake are important demersal fish, such as in western Europe (Casey and Pereiro 1995) and South Africa (Crawford *et al.* 1987). Hake can be caught solely for human consumption (e.g. European and Cape hake) or used for fishmeal (Pitcher and Alheit 1995). The products and global markets of hake have been discussed by Sylvia (1995), whereas Pitcher and Alheit (1995) illustrated catch trends and fishery developments.

Distribution and habitat studies have shown that hake mainly inhabit the continental shelf and the upper slope region, but some species in certain seasons enter estuarine regions or deep waters of the lower continental slope (Dark 1975). Pitcher and Alheit (1995) noted that hakes may live in a range of different habitats, but are characteristically found in highly productive upwelling regions of the world. Ten of the 14 species of hake occur as sympatric species pairs (Pitcher and Alheit 1995) one in shallow waters and one in deep waters. This is particularly true of the Atlantic Ocean, which is where hake are believed to have evolved (Inada 1981).

The centre of evolution for *Merluccius* is generally accepted to be the proto-North Atlantic (Svedovitov, 1948). Grant and Leslie (2001) propose a combination of vicariance and dispersal events to explain the current, primarily Atlantic, distribution of hakes. They explain the common occurrence of sympatric species pairs in four regions in the Atlantic through a series of migrations and return migrations associated with periodic cooling of the equatorial waters. In some regions where there is this overlapping of species, little commercial distinction is made between the species and they are normally targeted and managed as a single resource.

There are three species of hake found in southern Africa: two species of Cape hakes (*Merluccius capensis* and *M. paradoxus*), and the Benguela hake (*M. polli*) which is found in Angolan and Namibian waters, but does not penetrate as far south as South Africa (Payne and Punt 1995). As in other regions where two species of hake co-occur, the Cape hakes overlap considerably in intermediate depths on the fishing grounds off South Africa (Botha 1970) and, are thus managed as a single species.

1.2. *Cape hakes: distribution and biology*

Cape hakes are found over the continental shelf and slope from Namibia (for *M. paradoxus*) and Angola (for *M. capensis*) to KwaZulu-Natal on the east coast of South Africa (Punt *et al.* 1992a). *M. paradoxus* has also been found on the Madagascar ridge in the Indian Ocean (FAO species catalogue 1990). Botha (1980) documented the biology of the two species and reported differences in growth rates between the species and sexes (Punt and Leslie 1991). Inada (1981) provided the distribution and taxonomic history of the Cape hakes and also gave a comprehensive description of the

distinct depth separation of mature adults of the two species (FAO species catalogue 1990). The distribution of the two species is shown in Figure 1.1.

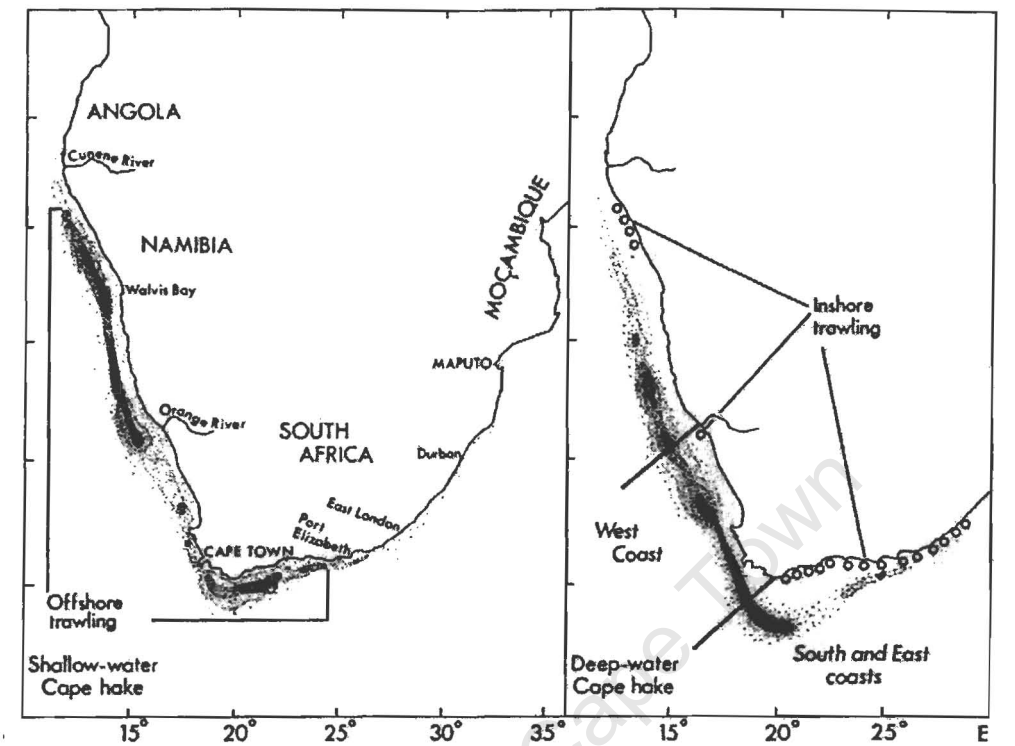

Fig. 1.1: Map of the South African coast showing the distribution of the two Cape Hake species (after Payne 1989).

Initially the Atlantic hakes were treated as a single species, *Merluccius merluccius*, with numerous sub species. The Cape hakes were regarded as a single subspecies, *M. m. capensis*. It was Franca (1962) who first recognised a second form of Cape hake, *M. m. paradoxus*. In the 1980s the two forms of Cape hakes were recognised as valid species (Inada 1981). Today the two species are distinguished morphologically according to the nature of their gill tubercles, the mean number of vertebrae, or by the form of the otolith (Badenhorst 1994). The full species status was confirmed by molecular genetic techniques including both allozymes and DNA (Grant *et al.* 1988).

The combined distribution of the Cape hakes extends from close inshore to a depth of almost 900 m (Punt *et al.* 1995a). However this distribution is strongly depth-dependent (Botha 1980), with both species displaying a similar increase in size with depth (Badenhorst 1984). *M. capensis* is a shallow-water species and is generally caught on the South and West coast in waters shallower than 440 m (Botha 1980). From about 150 m depth and deeper, *M. capensis* overlaps with deep-water Cape hake or *M. paradoxus*, a species whose distribution extends offshore to depths of at least 850 m (FAO species catalogue 1990). Because both species display a similar increase in size with depth (Badenhorst 1984), the adults of the two species do not generally overlap. When adults of both species have been found together, the actual stage of maturation is different for each species (Badenhorst and Smale 1991).

In addition to the influence of depth on the distribution of Cape hakes, there are geographical differences in the relative abundance of the two species. This has been attributed to the nature of the continental slope and shelf (Payne and Punt 1995). They also noted that shallow-water Cape hake are common in wide shelf areas (Agulhas Bank) whereas *M. paradoxus* favours the south-western Cape, where the shelf is particularly narrow and the slope less steep.

Another important factor to note in hake distribution is that juveniles are found closer inshore than adults. However there is a degree of overlap between juveniles and adults, which is reflected in the high incidence of inter-species "cannibalism", especially on the West Coast (Pillar and Wilkinson 1995). Juvenile *M. paradoxus* is an important food for adult *M. capensis*. Thus this is probably one case where

reduction of large hake by the fishery may promote the survival of the juveniles (Branch and Branch 1981).

If *M. capensis* adults prey on juvenile *M. paradoxus*, this is then not true cannibalism. People have tended to apply the term cannibalism to inter-specific predation in the Cape hakes. This is probably a result of the fact that they were regarded as single species until recently, and that they are harvested as a single species.

Despite their substantial commercial importance and long-established prominence in the local bottom trawl fishery, work done on hake up to the mid 1940s was of a purely descriptive and taxonomic nature with very little reference to biology (Botha 1985). Experts from various countries started working on the distribution, life history and feeding biology of hakes inhabiting the Benguela upwelling area in the late 1940s (Konchina 1987). During the last two decades there has been considerable work on the biology of hake aimed at improving management and assessment methods. This work has largely been on growth (Botha 1970, 1971; Punt and Leslie 1991) and feeding (Pillar and Barange 1993; Payne *et al.* 1987; Punt *et al.* 1992a, Roel and Macpherson 1988), with Botha (1980) and Inada (1981) covering some other biological aspects in more detail whereas Gordoa and Hightower (1991) investigated hake catchability.

Cape hakes are serial spawners that spawn year round (Osborne *et al.* 1999), with greatest spawning intensity in spring and early summer (Payne 1986). Age and length at onset of sexual maturity are different for the two Cape hakes (Botha 1971, Konchina 1987). Payne and Punt (1995) noted that *M. paradoxus* spawn at a younger

age than *M. capensis,* and males spawn at a smaller size than females in both species. Both species release eggs, which are fertilised in the water. The eggs and the larvae have a long pelagic existence and the juveniles probably settle to the bottom early in their second year of life (R.W. Leslie, Marine and Coastal Management, pers. comm.). Studies on hake growth have shown that young hake grow approximately 10 cm per annum (Botha 1970), with strong evidence that the growth rate changes with age (Botha 1971, Payne and Punt 1995).

The two species are long-lived, living for over 10 years, but only contributing substantially to the fishery up to about 9 years. Data from Botha (1971) showed clearly that in both species females grow somewhat faster than males, but males reach maturity earlier than females (Punt and Leslie 1991).

1.3. *The fishery*

The South African demersal fishery commenced around the turn of the century, initially targeting Agulhas sole (Cochrane *et al.* 1997), with hake making up a small proportion of the catch (Payne 1989). Chalmers (1976) reported hake catches of some 1000 tons annually between 1919 and 1927. As a result of improved catching methods and increased market demand, hake catches rose to 50 000 tons by 1950 (Lees 1969) and 115 000 tons by 1955 (Payne and Punt 1995). This catch probably included some Namibian landings. Cape hakes continued to be a local fishery until the early 1960s when they became a sought-after target of distant-water trawlers from several foreign countries (Badenhorst 1984). Between 1961 and 1965 the catches of Cape hake almost trebled with the increase in foreign trawlers and the catch rates of local trawlers dropped dramatically, prompting them to search outside South African

waters (e.g. Namibia) for the resource (Payne and Punt 1995). The catch by foreign vessels peaked in 1972, when, after two years of strong recruitment, 1 115 000 tons of hake were taken from the waters of the South-East Atlantic (Newman *et al.* 1980, Payne 1989). This catch established the Cape hake fishery as being the largest hake fishery in the world (Botha 1985). Soon after the 1972 catch, it became clear that the resource was being overfished and the catch decreased to 316 000 tons in 1980 (Crawford *et al.* 1987). The evidence of overfishing prompted the formation of the International Commission for the Southeast Atlantic Fisheries (ICSEAF). ICSEAF immediately introduced a number of management measures. The control measures resulted in the removal of some foreign effort and reduction in catches (Payne 1989).

The declining catch rates of hake prompted South Africa to introduce management measures to protect and rebuild the stock. These included the introduction of a 200 nautical mile exclusive economic zone (EEZ) in 1977 (Botha 1985) and a minimum mesh size of 110 mm (from a mesh size of 102 mm) in 1978 (Newman *et al.* 1980, Payne 1989). Badenhorst (1984) noted that, since the introduction of a 200 nautical mile EEZ off the Republic of South Africa, the hake fishery at the Cape of Good Hope reverted to an almost exclusively local one. Since the bulk of the catch was taken by foreign vessels prior to the introduction of the EEZ, the exclusion of foreign effort resulted in a massive reduction in catches, setting the scene for recovery. Such a rapid and massive drop in effort would not have been possible if the fishery was based on local fleets. The increased mesh size afforded some measure of protection to juvenile hake (Payne 1989). Thus these measures can be credited for sustaining and bringing the South African hake fishery to its current healthy status, with catches similar to those made before foreign intervention in the hake fishery, but only half of

the peak catch of 1972 (Payne and Punt 1995). Off South West Africa (Namibia), the hake resource was managed by ICSEAF and thus South Africa could not declare an Exclusive Economic Zone (EEZ) on their behalf. When Namibia gained independence in 1990, a 200 nautical mile EEZ was declared and ICSEAF was disbanded.

The South African hake resource is currently managed as two "stocks", West and South coast, each consisting of two Cape hake species. Initially the fishery was based on the West Coast but later moved eastwards in pursuit of the Agulhas sole *Austroglossus pectoralis* (Japp *et al.* 1994). It was only in the late 1960's that the South Coast started to yield large catches of Cape hake (Payne 1986). The division has no real biological basis (Payne and Punt 1995) and is entirely for management purposes (Punt 1994). The two stocks jointly account for about 70 % of South Africa's annual demersal catch, totalling about 145 000 tons (Stuttaford 1998). The bulk of the catch is from the West Coast, where *M. paradoxus* contributes up to 90 % of the commercial demersal landings (Payne 1989). It is this preponderance in catches that has led to the fishery in that area being regarded as a single-species fishery, with *M. capensis* and other demersal species contributing a small percentage to the catch (Crawford *et al.* 1987). *M. capensis* dominates catches of hake made over the Agulhas Bank, by as much as 70 %, with catches there always smaller than those on the West Coast (Payne and Punt 1995). Because no distinction is made between the two species in the commercial catches, for assessment and management purposes the two species have been considered as a single species (Crawford *et al.* 1987, Payne and Punt 1995).

In addition to the 200 nautical mile EEZ and minimum mesh size, the hake resource is regulated by an annual global total allowable catch (TAC). Although a "global" TAC is set for hake in the South African waters, TAC recommendations are formulated for each area separately, under the assumption that the populations of hake off the West and South Coasts are closed, or at least that the rates of immigration and emigration are small compared to the rates of mortality and recruitment (Punt 1994). As catches are always larger on the West Coast, a TAC split is determined by the management authority and the fishing industry (Punt *et al.* 1995a). As these regulations have helped improve South Africa's hake catches (Payne and Punt 1995) it is hoped that the catches will continue to improve. It is worth mentioning that even though hake catches have fluctuated very little compared to other fisheries, hakes nevertheless continue to form the backbone of the South African demersal fishery (Punt and Butterworth 1995, Punt 1994).

1.4. *Longlining and trawling for hake*

Globally, hake fisheries are dominated by one gear type – bottom otter trawls (FAO species catalogue 1995). Since trawls are towed on soft bottom grounds, hake in rocky and reef areas have been unavailable to this gear. Consequently, longlines, which can be deployed on the rocky grounds, have recently been used to target hake. Thus, in a fishery where hake are targeted by both gears, the two are normally not deployed on the same grounds. In areas where the catches of the two gears have been compared, longlines have been found to catch larger fish than trawls (O'Boyle *et al.* 1991, Bjordal and Lokkerborg 1996, Japp and Wissema 1999). Longlining is generally regarded as more "environmentally friendly" than trawling since it causes no damage to the substratum and also tends to be more species selective (Olsen 1997).

Research has however shown that large numbers of whitechinned petrels are being killed by longline vessels in South Africa despite the fact that fishing operations are performed at night. (Barnes 1994).

Demersal longlining is well established in the northern hemisphere, as well as in South American, Australian and New Zealand waters (Badenhorst 1988). The most important hake fishery in which a significant proportion of the catch is taken by longlines is in the northeastern Atlantic, with Spanish and Portuguese catches dominating (Bjordal and Lokkeborg 1996). Based on the performance of these vessels, the application for the first demersal longlining permit was made in South Africa in 1982 (Japp 1989). The first experimental longline permits were subsequently issued in 1983, and were given to established hake trawling companies, which already had hake quotas. These companies began longlining that same year, inviting Spanish and Portuguese skippers for their expertise (Japp 1988).

1.5. *Development of demersal longlining in South Africa*

As stated in the initial proposal for demersal longlining in South Africa, the intention was to longline for hake (Japp 1993). However, longliners found the kingklip *Genypterus capensis* resource abundant and lucrative and thus longlining quickly developed with kingklip as the target species (Japp 1995). The longline effort on kingklip was further increased in 1985 when additional permits were given to "independent operators[1]" (Japp 1988). The kingklip catch increased sharply and a record high of 8539 tons was reported in 1986 (Badenhorst 1988). By the end of 1987, trawl by-catches of kingklip were showing signs of decline (Japp 1993), and the

[1] Called "independent operators" as they did not form part of the established hake trawling companies.

kingklip longline catch rates had also decreased to 5340 tons by 1988, and to 3816 tons in 1989 (Punt and Japp 1994). There was concern that the longline fleet had severely depleted or negatively impacted the kingklip resource and recommendations were made to salvage the situation (Japp and Punt 1989, Japp 1989). As a consequence, the kingklip-directed longline fishery was closed at the end of 1990 (Punt and Japp 1994, Bjordal and Lokkeborg 1996).

This closure was, however, not before some fishers had shown that hake could be caught effectively by longlines (Cochrane *et al.* 1997). Pressure was then brought on management authorities to allow longlining for hake in South Africa (Japp and Wissema 1999), and a hake-directed longline experimental fishery was initiated in 1994. When this was compared to the long-existing hake trawling fishery, longlines were shown to catch larger hake than trawls with longlines also catching a greater proportion of females (Badenhorst 1994, Geromont *et al.* 1995a and b, Japp 1995).

1.6. *Comparison between longlining and trawling*

The idea of using longlines, very much like the idea of trawling, is to optimise the economic benefits of resource exploitation. This has caused concern and debate as to which fleet has a more competitive advantage (more efficient) over the other (O'Boyle *et al.* 1991). Besides economic efficiency, other factors (e.g. fishing effects) are often considered by ecologists when comparisons between the two methods are made (Duhamel *et al.* 1997). Thus the introduction of experimental longlines for the Cape hakes has resulted in a comparison of the two gears in the hake fishery.

Primary factors that have been considered between the two gears include:

- Seal predation: Fish losses to seals by longlines are substantially higher than in trawls (Japp 1995). Longlines are particularly attractive to marine mammals because they provide an easy accessible source of food, and the fish caught on them are large (Capdeville 1997).
- Bird mortality: Longline–sea bird interactions in the Cape hake fishery have been assessed by Barnes (1994). He reported a large degree of bird mortality in the longlines but also concluded that some mitigating measures could be implemented to reduce this.
- Spawner-biomass-per-recruit: Recent assessments (Geromont *et al.* 1995) suggest that longlining is clearly superior to trawling on a spawner-biomass-per-recruit basis, because it targets larger fish (Cochrane *et al.* 1997). This is sensitive to the value of the natural mortality (*M*). With a low *M*, yield-per-recruit is higher when fish are caught at a larger size. However, if *M* is high then losses through natural mortality balance gains through somatic growth at a smaller size.
- Substratum damage: Bottom trawling with heavy gears and high engine power increases the potential for damaging seabed habitats and causing irreversible changes to seabed biodiversity (Olsen 1997). No seabed effects by longlines have been reported.

Other factors such as seal mortality, "ghost fishing", by-catch and discards are considered to be less severe in longlines than in trawls (Japp 1995). What these parameters suggest is that longlining is a more conservation-oriented technique (Japp and Wissema 1999), although much work still needs to be done in order to quantify

this, and the seabird mortality problems have yet to be satisfactorily addressed in practice.

1.7 Aims of this study

The first aim is to investigate the size distribution of *M. capensis* on the Agulhas Bank (east of 20°E). The second aim is to compare the size distribution of this species in catches made by commercial trawls and longlines. I then model the relative impacts of longlining and trawling on the *M. capensis* population, particularly on yield and spawner biomass.

1.8. *Thesis outline*

There are four other chapters in this thesis, in addition to the general introduction. In chapter two of this thesis I investigate the size distribution of *M. capensis*. This is done using GIS Arc View 3.2, which allows for fish size distribution to be mapped spatially along the coast. Further, size distribution of *M.capensis* in catches made by longlines and commercial trawls is examined with the aim of comparing the size selectivity of the two fishing methods.

In chapter three, I compare the relative impacts of longlining and commercial trawling on *M. capensis*. Using the selectivity of the two fishing methods, I apply a yield per recruit model to compare the impacts on yield and spawner biomass. In chapter four, I model the impacts of the two fishing methods on spawner biomass by making use of an age structured production model. Each of these two chapters is discussed separately. In chapter five, I present the conclusions of my study.

CHAPTER TWO

SIZE AND AGE DISTRIBUTION OF SHALLOW - WATER CAPE HAKE *M. CAPENSIS* BASED ON TRAWLS AND LONGLINES OFF THE SOUTH COAST OF SOUTH AFRICA

Abstract

The main aims of this chapter are to: (a) elucidate vertical and horizontal patterns of distribution of *M. capensis*, (b) compare the size distribution in catches made by commercial trawls and longlines off the South Coast (east of 20° E). The first aim is achieved by making use of trawl survey data and the GIS Arc view 3.2 programme. Results show that *M. capensis* size increases with depth and that the distribution of fish < 30 cm is mostly west of 23° E with isolated pockets east of that region. Spatial mapping of commercial trawl and longline data shows that these two operate on two distinct areas. Size comparisons of the catches of the two fishing methods reveal that longlines catch very few fish that are < 60 cm whereas trawl catches are dominated by *M. capensis* of length < 60 cm. Analyses also show sex composition in longline catches to be different to that of trawls. All these results are discussed in relation to the ecology of *M. capensis* and the areas where data comes from.

Key words: distribution, South Coast, longitude, commercial trawl, longline, age, and sex

2.1. INTRODUCTION

Establishing the size (length) and age composition of fish in catches made by both commercial fishing and research surveys is fundamental to stock assessment models and to fishery management. Assessment models use length and age data from catches in order to understand a fishery or to make predictions about it (Sparre and Venema 1997). For fishery management, size and age information from catches is often used to derive management regulations (e.g. Attwood and Bennett 1990). Fish size and age distributions are also important for gear selectivity studies, particularly in multi-gear fisheries where the selectivity and efficiency of gears need to be compared (Kasatkina 1997). Thus, for a rational assessment and management of a commercially harvested species, the size and age distribution of fish from both commercial and research catches should be clearly understood.

Cape hakes were initially (until 1994) harvested by bottom trawlers only. In 1994, an experimental longline fishery, which is still operating, was initiated for hake (Japp and Wissema 1999). Because of the small size of the vessels and the strong currents of the shelf which make it difficult to deploy longlines (R. Leslie, Marine and Coastal Management, pers comm.), this fishery tended to operate mainly inshore and thus targeted mostly *M. capensis* (J. Wissema, Marine and Coastal Management, pers. comm.). Japp (1995) documents the aims and objectives of the longline experiment together with its initial results.

This chapter aims to address two sources of data distribution of *M. capensis* on the Agulhas Bank. Firstly, the size distribution of this population is described from research survey data collected from 1992 to 1997. Secondly, this chapter describes the size and age distribution of *M. capensis* in catches made by longlines and commercial trawls off the South Coast using data collected from inshore catches of the two fleets during 1994 - 1996.

2.2. MATERIALS AND METHODS

2.2.1. *Demersal trawl survey data*

Length frequency information extracted from research survey databases of Marine and Coastal Management was used to investigate the distribution of *M. capensis*. Total length of each fish was recorded to the nearest centimetre. These data were collected during biannual hake biomass surveys conducted from inshore to a depth of 500 m (April/May) or 200 m (Sept/Oct) between 1992 and 1997 aboard the F. R. S. *Africana* (Fig. 2.1). Spring cruises were restricted to the 0-200 m depth range as they were mainly designed to assess the abundance of the Agulhas sole *Austroglossus pectoralis* and Chokka squid *Loligo vulgaris reynaudii* (R. L. Tilney, Marine and Coastal Management, pers. comm.). In 1996 and 1997, for logistical reasons, the spring surveys were not conducted. For both seasons and for all the years, the survey area was from Cape Agulhas (20° E) to Port Alfred (27° E). Badenhorst and Smale (1991) explain the characteristics of this area as well as the stratification for the cruises. The gear used for the sampling is the same as that described by Payne *et al.* (1984). For this chapter, the data were separated by depth stratum and analysed per season of collection. Depth ranges were 0-100 m, 101-200 m and 201-500 m.

2.2.2. *Commercial trawl catch data*

Commercial trawl data used in this chapter were the reported annual landings (in numbers) of the South Coast hake inshore demersal fishery. This fishery operates to depths of about 200 m and nearly all the hake caught are the shallow water *M. capensis* (Japp *et al.* 1994). These data were used to describe the size and age composition of the catches for the period 1994-1996. Sex and age classes contributing to the commercial catch were estimated using sex and age-keys obtained in research

surveys for the same years. Data from 1997 were not included, as there were no sex and age-length keys available at the time of this analysis. 1994 was chosen as the initial year because longlining only started in this year. No comparison between the two gears is possible for earlier years.

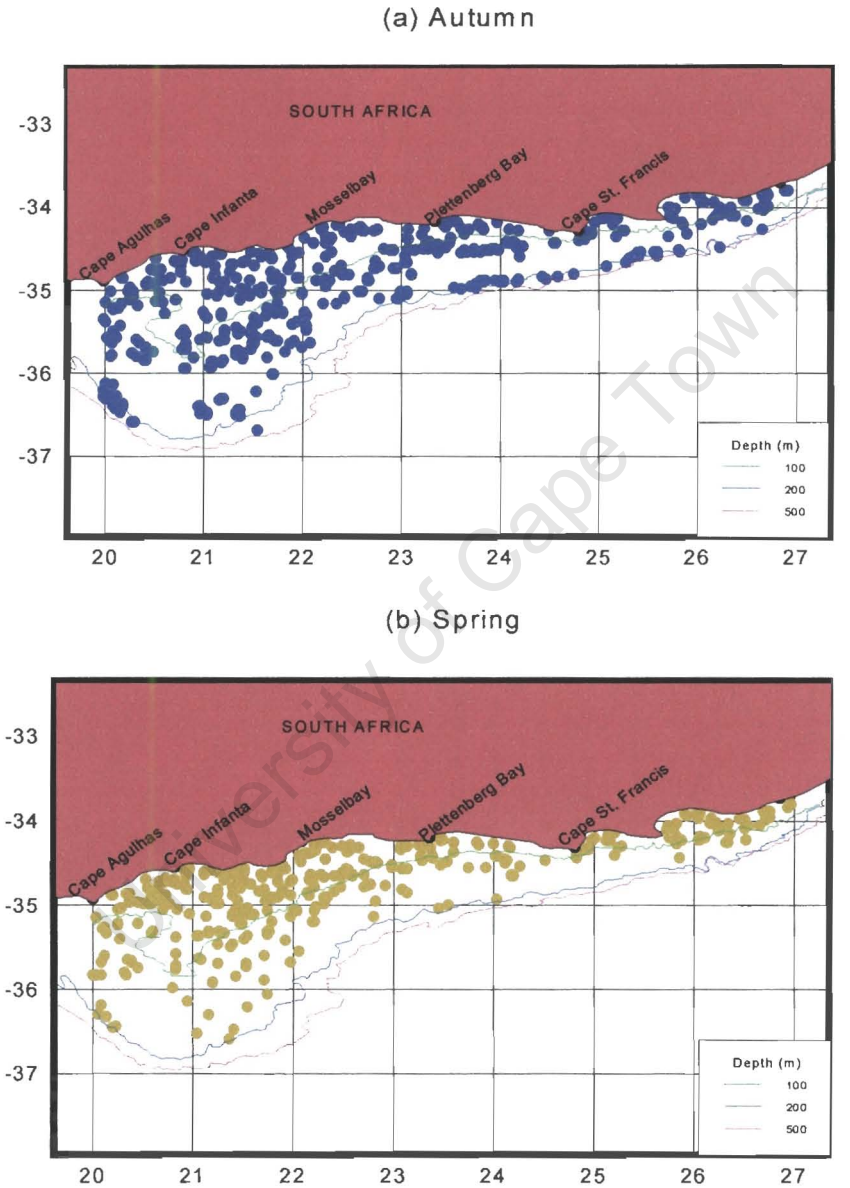

Fig. 2.1: South Coast survey grounds showing positions of research trawling stations for (a) Autumn and (b) Spring for the period 1992-1997.

2.2.3. *Longline catch data*

Longline data presented in this chapter were collected between 1994 and 1996 as part of the longline experimental fishery. This fishery was conducted on the Agulhas Bank at a mean depth of 138 m (Japp 1995) with commercial vessels that had scientific observers aboard for data collection (Fig. 2.2). Japp (1995) outlines the fishing method for the experiment. Briefly, observers obtained specific data on species and sex composition of the catches as well reporting on fishing technique, gear deployed seal/gear interactions and bird mortality. Specific log-books were designed for the collection of data at sea. These data were then captured on Excel spreadsheets and converted into a database.

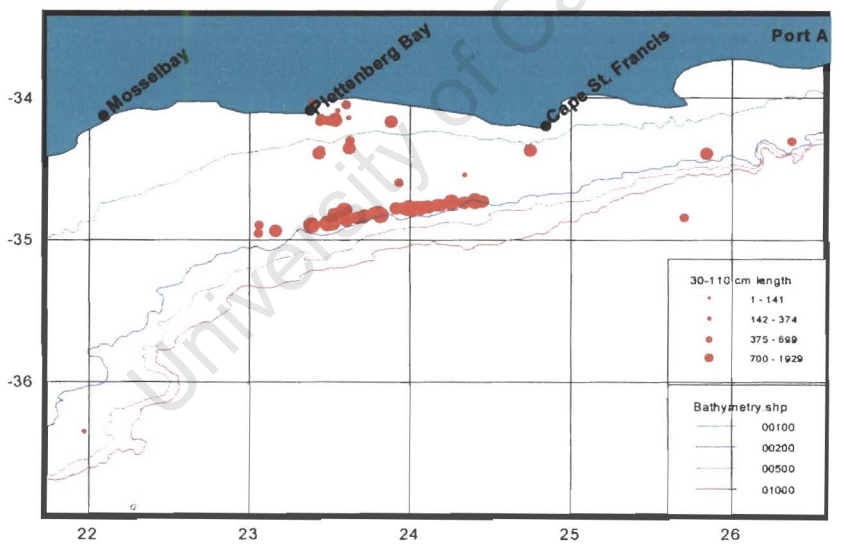

Fig. 2.2: South Coast longline catches (*M. capensis*) for the period 1994-1996. Port Alfred is shown as Port A, depth (m) is indicated by Bathymetry. Shp. Catches are in numbers.

As the longline catch data were not sex - specific, inferences about sex and age were made from research survey data for those years (noting that longlines operate on rocky grounds where research trawl surveys are not conducted). From these data, the size and age composition of the longline catches were assessed and compared to those made by commercial trawls.

2.2.4. *Statistical analyses*

M. capensis length frequency distribution in catches made by longlines and commercial trawls were statistically compared using the Kolmogorov–Smirnov (Zar 1999) two sample test. Kolmogorov-Smirnov two sample tests were also performed in order to compare size distribution of males and females within the longline catch and also within the trawl catch. Differences between data were considered significant at the 5% significance level. All statistical analyses were computed using the ©STATISTICA statistical package.

2.2.5. *Conversion of length to age*

MCM data from commercial catches are stored in length frequency form in the MCM databases. For this thesis these data are converted to age for histograms using age length keys (Appendix A3-A5): Hake otoliths used for the age length keys were collected during the survey trawls. Botha (1971) and Badenhorst and Smale (1991) describes in detail the methods used for otolith collection and reading. Briefly, otoliths were collected from a number of randomly selected fish. The length and sex of each specimen were recorded. Each otolith was then examined at least twice with the number of opaque band taken to represent the age of fish in years.

$$Catch\ at\ length \times Age\ length\ key = Catch\ at\ age$$

Unsexed length frequency data are converted to sex specific catch at length data by making use of sex length keys (Appendix A2):

$$Catch\ at\ length \times Sex\ length\ key = Sex\ specific\ catch\ at\ length$$

2.3. RESULTS

2.3.1. *Size distribution of M. capensis in demersal trawl surveys*

The length frequency data for the combined 1992-1997 South Coast demersal cruises show that the mean size of *M. capensis* increases with depth. The data reveal marked differences in mean size of the species east and west of 24° E. These differences in fish size, together with the distribution of this species by depth and longitude, are illustrated spatially on a seasonal basis on Figures 2.3 to 2.4 and in Table 2.1. Distributions are shown for two seasons and five density levels for four length classes.

Autumn (April/May) demersal surveys (Fig. 2.3) indicate that *M. capensis* is most concentrated in depths of 0-200 m. Spring surveys (Fig. 2.4) were not conducted beyond the 200 m depth stratum. Consequently, beyond this depth range it is not possible to compare size distribution and density of *M. capensis* between the two seasons. In depths shallower than 200 m, the distribution of this species is similar in autumn and in spring for all sizes classes.

For both seasons, *M. capensis* was found mainly on the outer shelf between Cape Agulhas (20° E) and west of Plettenberg Bay (23° E), with densities varying by size class east of this region. Recruits (< 10 cm) were generally limited to the area between 20° and 23° E, with small isolated pockets east of 23° E, whereas adults (> 30 cm) were widespread over the whole South Coast shelf. *M. capensis* of 10-30 cm length were also present over the whole shelf, but with greater densities found west of 23° E.

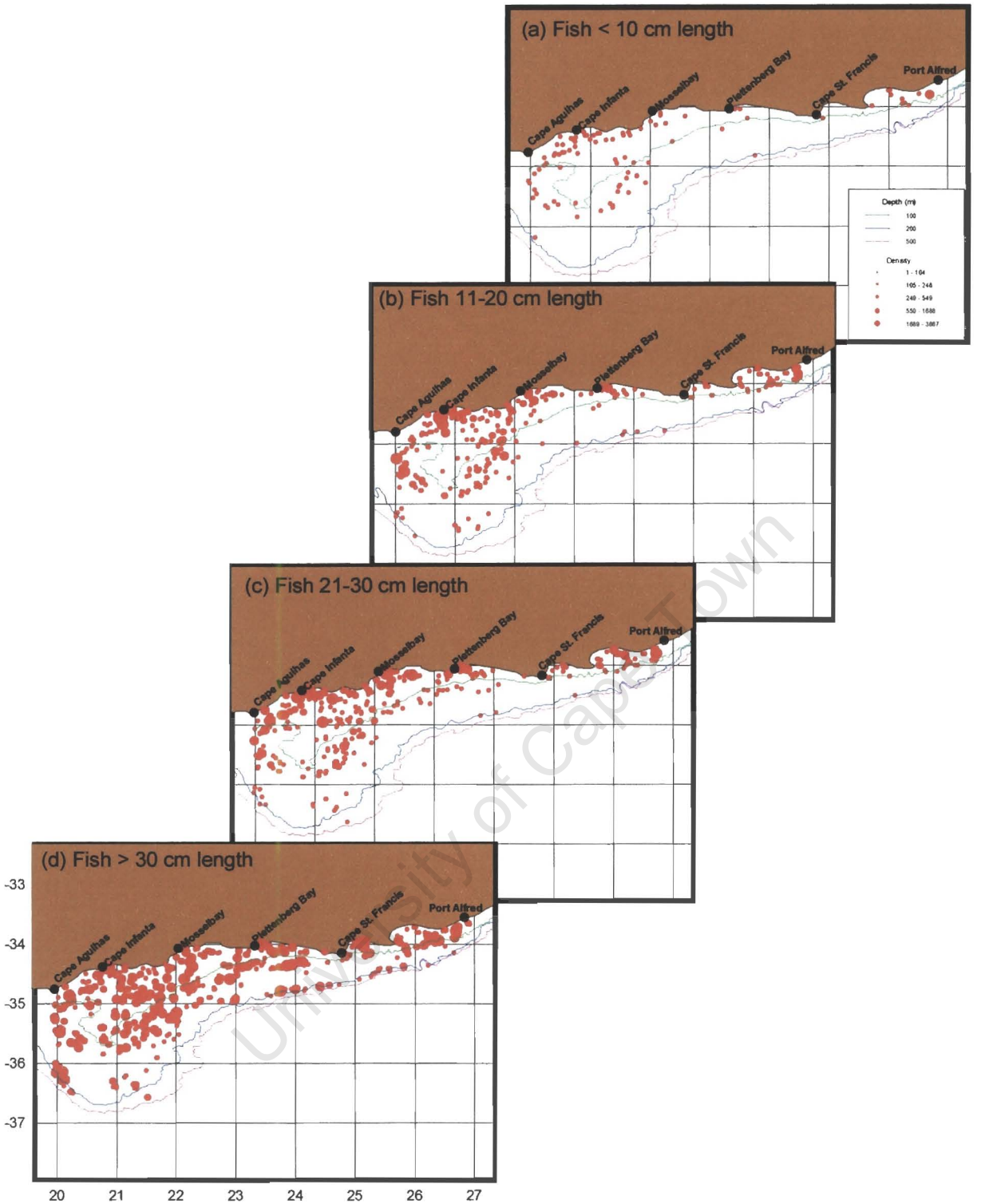

Fig. 2.3: Distribution of *M. capensis* by size class (a-d) derived from South Coast demersal surveys conducted during April and May. Total length is in cm and density in numbers

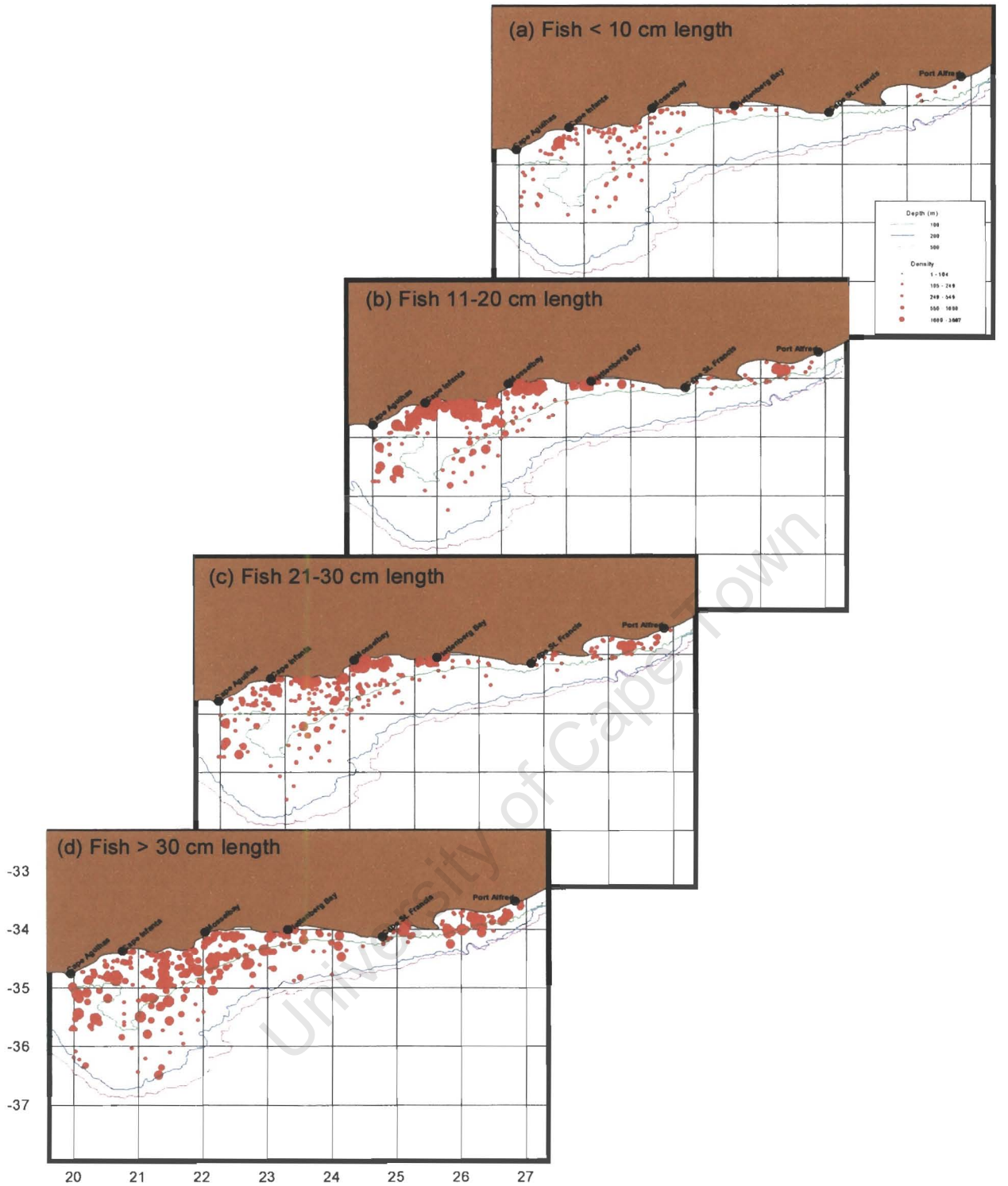

Fig. 2.4: Distribution of *M. capensis* by size class (a-d) derived from South Coast demersal surveys conducted during September and October. Total length is in cm and density in numbers

As depth has an important influence on size distribution, the data are stratified by depth when investigating the influence of longitude on fish size. Data shows different trends in distribution by longitude of this species for different depth ranges (Table 2.1). In the 0-100 m depth stratum, fish east of 23° E have mean lengths > 30 cm, whereas west of 23° E the mean lengths are < 30 cm. This indicates that, in that depth stratum, the species tends to be larger east of Plettenberg Bay (23° E), where the shelf narrows and the 100 m isobath is closest to the coast. For the 101-200 m depth interval, the data indicate an increasing trend in size as one moves east to about 25° E (Table 2.1). From Cape Agulhas (20° E) the mean length successively increases with longitude until it reaches a maximum at 25° E and generally decreases from there (Table 2.1). There is no obvious trend in size of *M.capensis* with longitude in the 201-500 m depth stratum. Table 2.1 clearly indicates an increase in mean size with depth.

2.3.2. *Size distribution of M. capensis in catches made by commercial trawls and longlines*

There is a clear difference in length distributions of *M. capensis* in the catches made by longlines and commercial trawls (Fig. 2.5) during the study period (1994-1996). For longlines, 20% (by number) of the fish caught are < 60 cm, whereas 94% of the trawl catch is composed of fish < 60 cm. The length at first capture for longlines is 39 cm, whereas that for trawls is 21 cm. The reported maximum lengths are 101 cm and 87 cm, respectively for longlines and commercial trawls. A difference of 25.2 cm is observed between the mean lengths of catches made by the two gears.

The differences between *M. capensis* length distribution in catches made by the two types of gear are verified using a Kolmogorov-Smirnov test. The test demonstrates

statistically significant differences ($p<0.001$) in the size composition of *M. capensis* in catches made by longlines and commercial trawls. The significance of difference in frequency distribution is estimated at a probability $P=0.05$. When considering these differences it should be noted that the two fishing methods fish on different areas.

Table 2.1. Statistics of *M. capensis* trawl samples from demersal surveys conducted between 1992-1997 on the South Coast of South Africa.

a. 0-100 m depth

Longitude (° E)	No. of Trawls	No. caught (n)	Mean Lt (cm)	SD (cm)	SE (cm)
20-21	100	56033	25.2	11.3	0.048
21-22	134	57908	28.4	14.0	0.058
22-23	81	54680	26.0	11.8	0.050
23-24	51	20121	32.0	14.7	0.104
24-25	16	1647	42.5	12.8	0.316
25-26	34	7252	42.6	11.3	0.133
26-27	46	16762	32.0	14.0	0.108
27-28	1	78	43.5	8.5	0.965

b. 101-200 m depth

Longitude (° E)	No. of Trawls	No. caught (n)	Mean Lt (cm)	SD (cm)	SE (cm)
20-21	79	23743	33.5	14.1	0.091
21-22	104	24453	38.0	15.7	0.101
22-23	59	10217	46.1	13.4	0.133
23-24	54	7470	50.6	12.1	0.141
24-25	34	4203	51.4	8.9	0.137
25-26	16	3328	46.0	11.0	0.191
26-27	22	6878	39.8	12.7	0.154
27-28					

c. 201-500 m depth

Longitude (° E)	No. of Trawls	No. caught (n)	Mean Lt (cm)	SD (cm)	SE (cm)
20-21	10	1133	55.9	10.2	0.304
21-22	2	119	68.7	10.7	0.985
22-23	2	151	57.4	7.5	0.613
23-24	7	691	62.0	8.8	0.333
24-25	8	505	69.9	9.5	0.423
25-26	11	380	67.4	10.8	0.553
26-27	2	18	45.4	5.3	1.258
27-28					

Given that the longline catch consists of large fish (Fig. 2.5), and given that the females dominate the older ages (Botha 1986), it is likely that the longline catches will contain a higher percentage of females than males. Since the catches were not sex specific, sex specific age length-keys are applied to the catch data in order to test this assumption and the results presented in Figure 2.6. Based on the sex specific age length-keys, longlines reveal larger mean lengths than commercial trawls for both sexes (Fig. 2.6). Also, the longlines show a higher percentage (56%) of females compared to that of commercial trawls (43%). Bearing in mind that sexes were not directly counted, it is deduced from the sex-length key analysis that the longlines tends to catch more females. This is in accordance with the findings of Japp (1995), who separated the catches by sex.

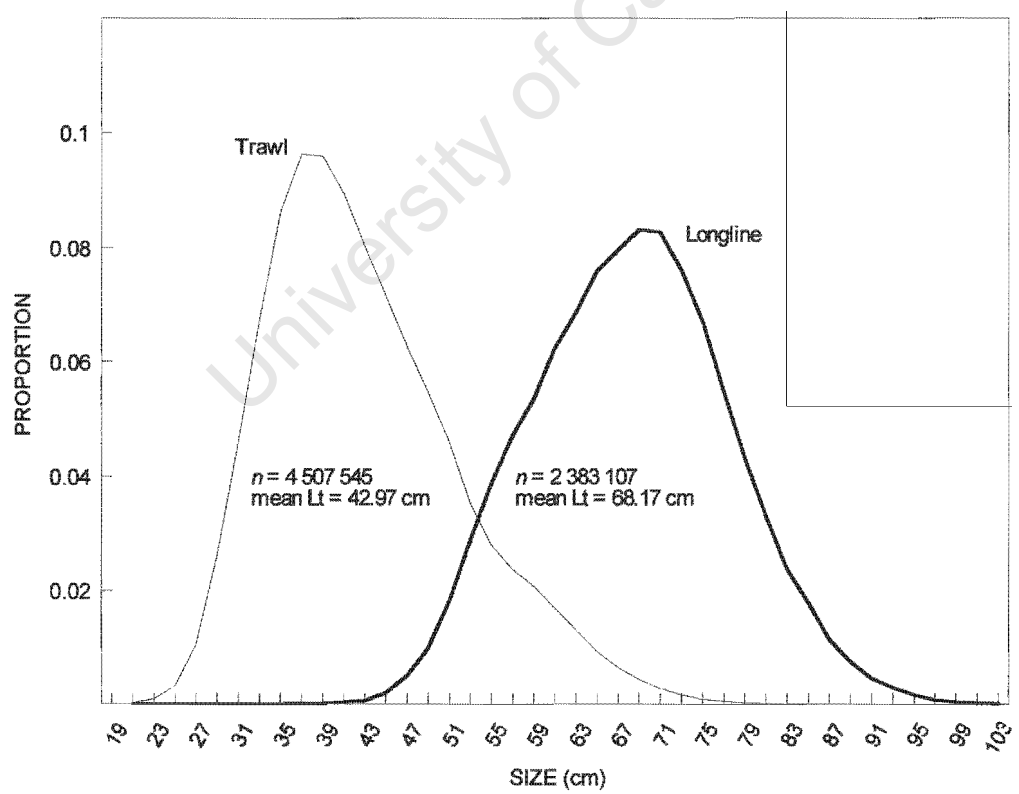

Fig. 2.5: Size distribution of *M. capensis* in catches made by commercial trawls and longlines on the South Coast between 1994-1996. (n = numbers sampled)

Sex specific size differences (inferred from sex length-keys) are more evident in longline catches than in commercial trawls. Figure 2.6 shows that there is a difference of 5.4 cm between the mean lengths of males and females in catches made by longlines. For commercial trawls, the mean lengths are 43.36 cm for males and 42.46 cm for females. For longlines, larger size classes are mostly composed of females.

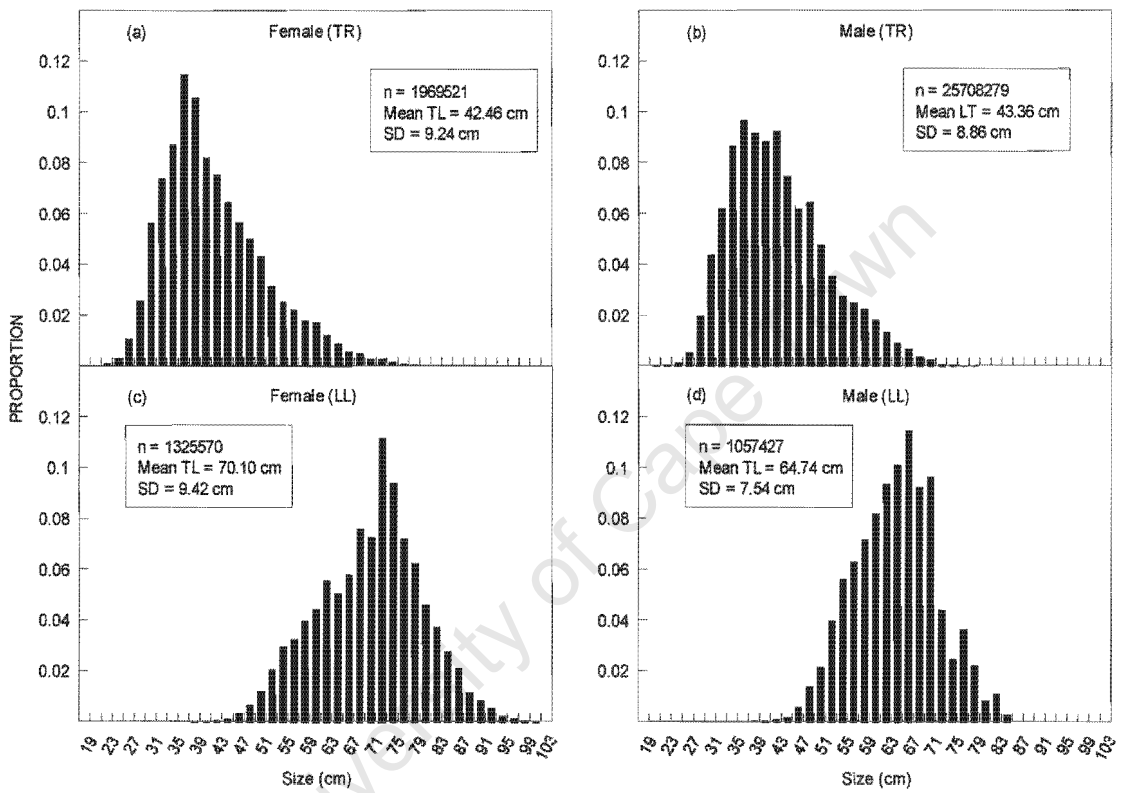

Fig. 2.6: Size frequency distribution of *M. capensis* in commercial catches made by longlines (LL) and trawl (TR) between 1994-1996. (n = numbers sampled). Length at 50% maturity is 36 cm for males and 48 cm for females (Punt and Leslie 1991).

2.3.3. *Age distribution of M. capensis in catches made by commercial trawls and longlines.*

Between gears – Histograms of the age distribution of *M. capensis* in catches made by longlines and commercial trawls are shown in Figure 2.7. It is clear that longlines

catch mainly fish that are older than five years whereas commercial trawls catch fish that are mostly younger than five years of age. These results also show the age at first capture. It must be pointed out however, that sex and age data for fish for both longlines and commercial trawls catches are derived from age-length keys.

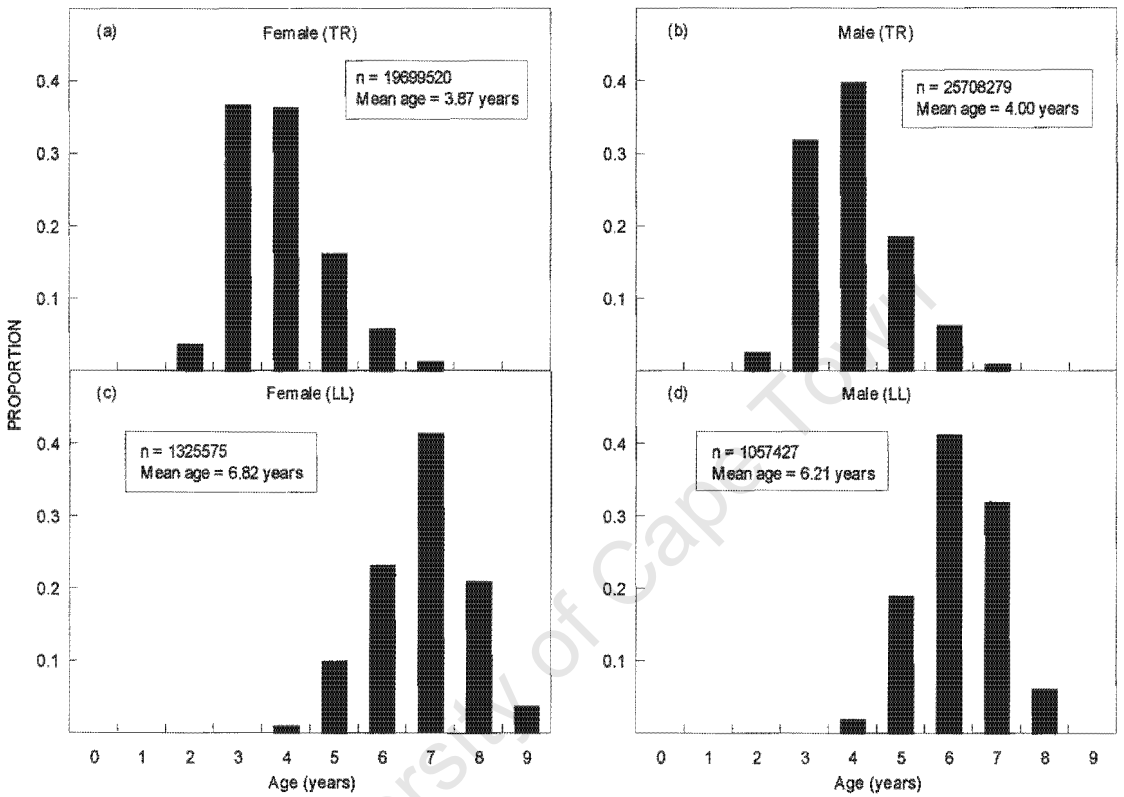

Fig. 2.7: Age-frequency distribution of *M. capensis* in catches made by longlines (LL) and commercial trawls (TR) on the South Coast between 1994-1996. (n = numbers sampled).

Within gears – The sex composition and age distribution of the longline catch from the age-length key analysis can be divided into two groups. Firstly, there are those fish that are less than seven years of age. In this category, the longline catch comprises of more males in all the respective ages (Fig. 2.8a). The second group consists of *M. capensis* that are older than six years. Here, the longline catch has more

females than males in all the ages, with no males recorded at age nine years. Most males in the longline catch are at age six, whereas most females are of seven years. Since females grow faster than males (Botha 1986), the older ages are likely to be dominated by females. The age distribution of males and females for *M. capensis* in commercial trawls shows little difference. Both sexes are caught in all the ages recorded. The mode was at age three for females and age four for males. Kolmogorov-Smirnov two-sample tests shows that the distribution of males is significantly different ($p<0.001$) from that of females in catches made by both longlines and by commercial trawls. This test tests for differences in the whole cumulative frequency distributions, not just the means.

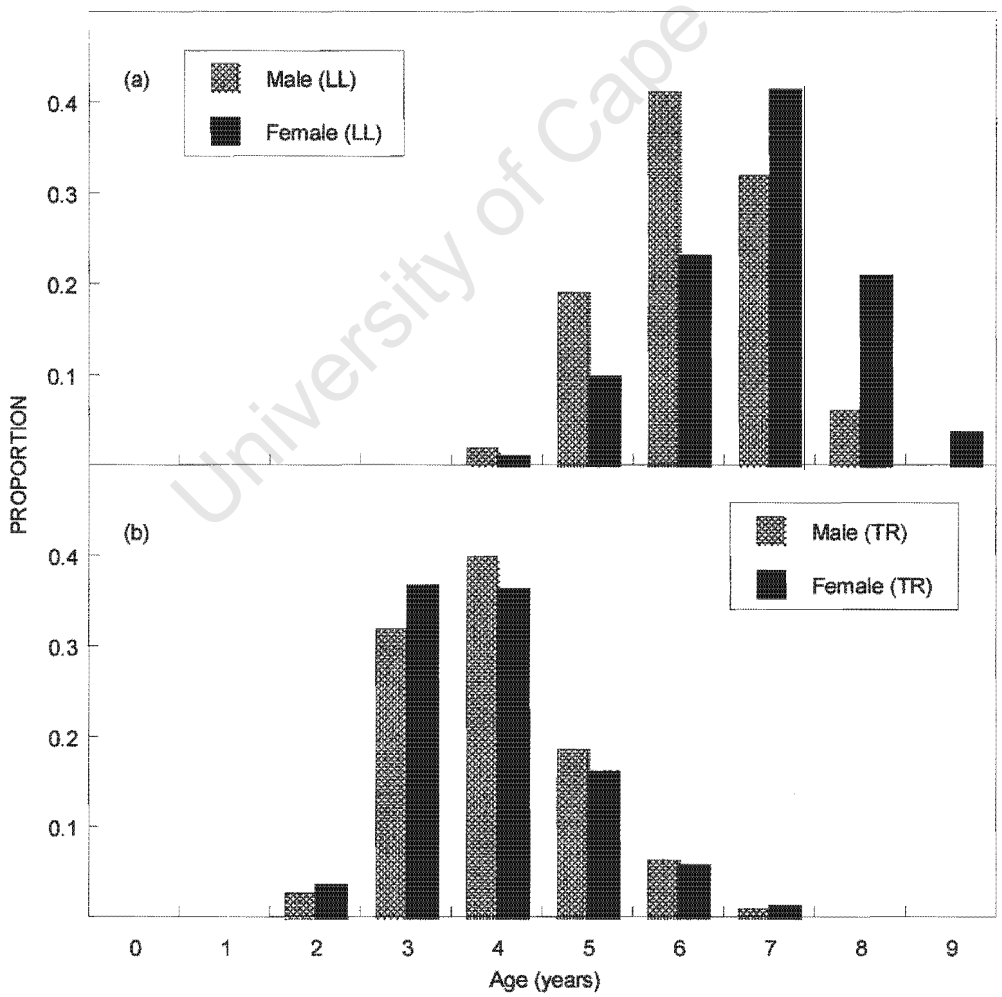

Fig. 2.8: Age distribution for *M. capensis* in catches made by longlines (LL) and commercial trawls (TR) on the South Coast between 1994-1996.

2.4. DISCUSSION

In this chapter, two data sets of length frequencies from the South Coast *M. capensis* population were investigated. First, research survey data collected from 1992-1997 were analysed and presented with the assumption that the effects of gear selectivity by the research trawl is at sizes far smaller than the minimum size caught by commercial gear. Therefore the research catch can be treated as a true reflection of the population in the size-range selected by commercial gear. Second, commercial data (from trawls and longlines) were examined in order to determine the size distribution of *M. capensis* in catches made by both gears. These gears have been shown (Geromont *et al.* 1995a and b) to have different selectivity properties, which are confirmed in this analysis by the different size compositions, in catches made by the two fleets (Fig. 2.5).

2.4.1. *M. capensis* survey data 1992-1997

This analysis from six biannual demersal surveys supports the findings of Badenhorst and Smale (1991), who utilised five biannual datasets and showed that *M. capensis* size increases with depth. This depth-size relationship was also observed by Smale (1984), Botha (1985) and Payne (1986), who utilised more limited datasets. The size increase with depth revealed juveniles (<10 cm) to be recruiting to between 0-100 m depth with small concentrations beyond this depth stratum. Roel and Bailey (1991) also observed this inshore distribution of juveniles and suggested that by actively locating themselves at that depth, they would be adopting an effective survival strategy. The inshore area is relatively free of competitors such as juvenile *M. paradoxus* and predators such as "cannibalistic" adult hake. As they grow larger (11-20 cm) juvenile *M. capensis* densities increase beyond the 0-100 m depth interval as

they move further offshore. Fish of > 30 cm are distributed further offshore than the two previous size classes and are also found on all the surveyed grounds (Figs 2.3-2.4). The suggestion that *M. capensis* tends to move into shallower waters during May/June (Badenhorst and Smale 1991) is not apparent in this study. Rather, the data here reveal no seasonal differences in the offshore increase with size, but seem to indicate a near absence of fish < 30 cm on the central Agulhas Bank, particularly during the spring cruises (figs 2.3-2.4) Whether this is caused by some environmental factor or by fish actively seeking out favourable grounds is not yet clear.

Off the South Coast, longitude is the second most important parameter influencing size distribution of *M. capensis*. Juveniles (<10 cm) are mainly distributed west of 24° E and as they grew bigger, they move further to the east (Figs 2.3-2.4). It is not apparent why there is a greater mean length to the east. This eastward migration is apparent from both spring and autumn surveys. Although there is no evidence of this, one possible reason for larger mean lengths to the east could be the availability of preferred temperatures. Juveniles may move more to the west in order to protect themselves from cannibalistic adult hake. It is also worth noting here that this eastwards movement with increase in size has been observed by Barange *et al.* (1998) in the study of the distribution patterns of horse mackerel, another demersal species on the South Coast. Also the size classes in the present study are similar to those derived by Barange *et al.* (1998) for horse mackerel.

The length frequency analysis described above provides some useful insight into the distribution of *M. capensis* on the South Coast. However, these data are from trawl

research surveys, which are limited to areas of suitable trawl grounds, thereby representing only part of the population of this species. Also, it is unlikely that the gear used was equally efficient in representing all sizes. In fact, Badenhorst and Smale (1984) noted that fish of certain sizes were poorly represented in their research samples. Thus, from a fisheries assessment and management viewpoint, effort needs to be directed at sampling the untrawlable grounds. However, this may be very difficult if not impossible and thus Badenhorst and Smale (1991) suggest that if a chosen block is untrawlable, the nearest trawlable ground should be used as a sampling station. The use of underwater cameras could also lead to some idea of the population structure of hake on the rough grounds. This in turn would be very useful for the assessment and management of the longline fishery, which operates on these grounds, and also for comparative studies of longline and trawl.

2.4.2. *Commercial trawls and longline data*

Size and age distributions are examined in catches of *M. capensis* made on the Agulhas Bank by two different gears. The longline catch is only a small fraction of the commercial trawl catch and is obtained from untrawlable grounds of the South Coast. Since the bottom trawls are towed on the bottom, the presence of reefs at the edge of the continental shelf prevents trawls from being made over much of the shelf edge and upper slope of the South Coast (Badenhorst and Smale 1991). Any attempts to anchor longlines on the soft grounds is likely to lead to a conflict between trawlers and longliners and thus longlining is restricted to the rough grounds. Consequently the longline and trawl fishing grounds are spatially distinct with trawls (research and commercial) covering most of the South Coast (Figs 2.1-2.2). Bearing these

differences in mind, this study compared the size and age distribution of catches made by the two fishing methods.

Differences in size and age distribution are deduced from catches made by longlines and commercial trawls. The longlines catch larger *M. capensis*. The commercial trawls, by contrast, catch a large proportion of small fish but also catch large individuals. Also, longlines are catching more females than commercial trawls. This finding was also reported by Geromont *et al.* (1995), who commented that on the West Coast longlines and trawls were catching similar proportions of the sexes. Thus, this study confirms the findings by Japp (1995) that longlines exploit mostly large hake, whereas commercial trawls catch a much broader size spectrum of fish. What should be noted is that the findings by Japp (1995) were for both species of hake, whereas this study is based only on *M. capensis*.

Age comparisons based on the catches of the two fleets merely served to further confirm the findings on length. This is hardly suprising since the age structure is deduced from the observed size structure. Therefore the age data are very well correlated to those of size.

The results in this study show that the sizes of fish caught by the two gears are markedly different. Part of this difference might be explained by the fact that the geographical distribution of hakes is not homogeneous. These results should prove useful when the potential expansion of the longline fishery into a more permanent fishery is considered. Also, the results presented here could be useful when estimating the selectivity values to be used in simulating the potential impacts of the two fisheries on *M. capensis* populations on the South Coast.

CHAPTER THREE

A COMPARISON OF LONGLINING AND TRAWLING ON THE INSHORE SOUTH COAST STOCK OF *MERLUCCIUS CAPENSIS* USING A YIELD PER RECRUIT MODEL

Abstract

The potential impacts of longlining and trawling on the South Coast *M. capensis* resource (east of 20° E) are modelled using a yield per recruit and spawner biomass per recruit model. First, the age-specific selectivity vectors of the two fleets are estimated from catch data (length frequencies). A comparison of these shows that longlines select for larger and older individuals whereas trawls select for a wide range of sizes. A yield per recruit and spawner biomass per recruit analysis is then applied using the fleet specific selectivity at age vectors. The analysis is done for three harvesting scenarios (longline only, trawl only and longline + trawl). Results show that at a natural mortality of 0.3 y^{-1} longlines provide a maximum yield of 352 g per recruit, which is greater than that of 193 g per recruit for trawls. At greater (assumed) natural mortality values, trawls give a better yield than longlines. A maximum yield of 240 g per recruit is obtained when the two fishing methods are operating at the same time. Expressing spawner biomass after fishing as a percentage of its pristine level compares longline and trawl fishing effects on spawner biomass. After trawl fishing the percentage is 3.1% and after longline it is reduced to 38%.

Keywords: Age-specific selectivity; yield per recruit and spawner biomass model; longlining and trawling

3.1. INTRODUCTION

That commercial fisheries have an impact on fish populations is generally accepted. Several authors (O'Boyle *et al.* 1991, Stevens *et al.* 2000, Koslow *et al.* 2000, Zwanenburg 2000) have reviewed population effects of fishing. Overall, their analyses revealed that fishing can impact on populations in two different ways. First, fishing brings about changes (mostly decreases) in stock abundance as a result of overfishing or of reducing the spawner stock. Second, fishing can alter the size spectrum of a population, in most cases towards smaller individuals (Bianchi *et al.* 2000). These effects occur as a result of the size selectivity properties (Kasatkina 1997) of the fishing method concerned. In this chapter, an attempt is made to model the impacts of longlining and trawling using a yield per recruit (YPR) and a spawner

biomass per recruit (SBPR) model (Beverton and Holt 1957, Beverton 1994) for *M. capensis* off the South Coast (east of 20° E).

Fishing gear is designed to remove some kinds of individuals in preference to others, usually individuals that are larger and therefore older (Law 2000, King 1995). A major concern to fisheries scientists is to be able to predict the potential impacts of this size-selection before a new fishing method is adopted. One way of doing this is to compare the size selectivity properties of various fishing methods that are used to harvest a particular stock. In this chapter, age specific selectivity vectors from longlines and trawls are estimated using catch data and are subsequently used as parameters in the YPR and SBPR analyses that compares potential impacts of the two fishing methods on *M. capensis*. The aims of the YPR and SBPR analyses are to: (a) investigate the maximum yield for longlining, trawling and the two methods combined and (b) to examine the impacts of the two fishing gear on the spawning biomass of the population.

3.2. MATERIALS AND METHODS

3.2.1. Data

Three sources of data for the *M. capensis* stock off the South Coast have been used to estimate the age-specific selectivity values. The first is the annual commercial trawl catches (length frequencies). The second data source is the annual longline catch data also in the form of length frequencies (Appendix A1). The third is the trawl survey data that includes length frequencies and age-length keys (Appendix A5). All these data were obtained from the databases of Marine and Coastal Management (MCM) and are for the surveys of 1996. From the databases the length frequency data (survey) were recorded by cruise number. For this study the cruise specific data were lumped in terms of year (all the cruises for one year were pooled together). Population growth parameters of *M. capensis* that were used in the model were those estimated by Punt and Leslie (1991).

M. capensis discard data collected in 1997 for the South African Network for Coastal and Oceanic Research (SANCOR) discard project were incorporated into the commercial trawl data. These were simply added as additional length frequency data onto the catch data. Since discard data are not available for fishing seasons before 1997, an assumption was made that commercial trawls discarded the same lengths in both 1996 and 1997. This assumption was made because there is no other discard data available for other years. Thus 1997 discard data were simply added to the 1996 commercial trawl data. The impact of the discards was to increase the number of small fish when compared to the landed data. Since the aim was to construct an age-based YPR and SBPR model, the length frequency data were converted to age data. This was achieved by multiplying the catch data (length frequency) by the age-length

key of the same year (Sparre and Venema 1997). The products of this were catch-at-age data (Table 3.1) for both fishing methods and survey estimates of the numbers-at-age. The maximum age group (plus-group) considered was eight years, as there were very few fish that were older than eight years when the lengths were converted to age.

3.2.2. *Fishing Gear Selectivity*

A method of estimating selectivity vectors that is similar to that used by Armstrong and Japp (1992) and Geromont *et al.* (1995b) was then employed for the estimation of both longline and trawl selectivity values. The catch-at-age estimates for each fishing method are divided by the survey estimates of the population numbers-at-age, which were obtained by means of the age-length keys described above. For the inshore fishery, the survey trawl mesh net is 35 mm and that for commercial is 75 mm and thus comparing the two is thought to be a suitable method of estimating selectivity. The main assumption being, that which is caught by the survey mesh is a true reflection of the population structure. However, when looking at the survey estimates of numbers at age (Table 3.1 and 3.2) data show that the numbers of fish greater than 4 years of age start to decrease whereas ages 0 to 4 years numbers increase. This is possibly caused by the lack of availability of older fish to the mesh size (R. W. Leslie, Marine and Coastal Management, pers. Comm.) and thus in making the abovementioned assumption this possibility has to be noted.

Tables 3.1 & 3.2 illustrate the method and the estimated selectivity vectors. These vectors are based on the 1996 data but can be used for all the years if one assumes that there are no major changes in the age composition of the stock. Since survey data is not available for all the years, selectivity values won't be available for some. Also, the

model is set up in a way that makes it difficult to have selectivity values for each year during the modelling.

Table 3.1. Longline *M. capensis* catches at age, research survey estimates of numbers at age and the estimated selectivity values. Estimated selectivities are expressed as proportions of the maximum value in column four.

AGE (years)	Relative Catch numbers	Survey estimates of numbers at age	Catch numbers/ survey estimates ($*10^{-6}$)	Estimated selectivity
0	0.000	0	0	0.000
1	0.000	87	0	0.000
2	0.000	710	0	0.000
3	0.000	1681	0	0.000
4	0.010	2281	4	0.002
5	0.113	1389	84	0.039
6	0.296	737	401	0.194
7	0.426	312	1366	0.660
8+	0.155	75	2069	1.000

Table 3.2. Commercial trawl *M. capensis* catches at age, research survey estimates of numbers at age and the estimated selectivity values. Estimated selectivities are expressed as proportions of the maximum value in column four. (NB: Discard data have been included).

AGE (years)	Relative Catch numbers	Survey estimates of numbers at age	Catch numbers/ survey estimates ($*10^{-6}$)	Estimated selectivity
0	0.000	0	0	0.000
1	0.019	87	216	0.765
2	0.203	710	286	1.000
3	0.404	1681	241	0.841
4	0.247	2281	108	0.378
5	0.091	1389	65	0.228
6	0.031	737	42	0.147
7	0.005	312	17	0.058
8+	0.000	75	2	0.007

3.2.3. The yield and spawner biomass per recruit model

A fleet specific YPR model was applied to the resource from age zero to a maximum lumped age group (8+) under natural and fishing mortality. The classical Beverton and Holt (1957) YPR model considers gear selection to be "knife-edge". For this analysis the selectivity was computed not assumed. The model assumes a steady-state stock structure; that is, the total yield in any one year from all the age classes is the same as that from a single cohort over its whole life span (King 1995). Recruitment is a quantity that the model treats as a constant, but does not specify. Natural mortality is assumed to be constant for all the age-classes and fishing mortality is independent of age but affected by the selectivity at age. The dynamics of the population are governed by the following Beverton and Holt (1957) equation:

$$N_a = R \qquad \text{if } a = 0 \qquad (3.1)$$

$$N_a = N_{a-1} e^{-Z_{a-1}} \qquad \text{if } 1 \le a < \max \qquad (3.2)$$

$$N_a = N_{a-1} e^{-Z_{a-1}} / (1 - e^{-Z_a}) \qquad \text{if } a = \max \qquad (3.3)$$

where

N_a is the number of fish of age a (in years)

R is the number of 0-year-olds (R = 1 for these calculations)

max is the maximum age considered (taken to be a plus group).

Z_a is the instantaneous total mortality rate of fish of age a:

$$Z_a = M_a + S_a^{TR} F^{TR} + S_a^{LL} F^{LL} \qquad (3.4)$$

where

M_a is the instantaneous natural mortality rate of fish of age a

S_a^{TR} denotes the commercial trawl fishing selectivity at age a,

S_a^{LL} denotes the longline fishing selectivity at age a,

F^{TR} denotes the instantaneous fishing mortality caused by the trawl fleet and F^{LL} denotes the instantaneous fishing mortality caused by the longline fleet.

The numbers at age caught by the trawlers ($C_{N_a}^{TR}$) and by longliners ($C_{N_a}^{LL}$) are given by the Baranov (1918) catch equation.

$$C_{N_a}^{TR} = (S_a^{TR} F^{TR} / Z_a) N_a (1 - e^{-Z_a}) \quad (3.5)$$

$$C_{N_a}^{LL} = (S_a^{LL} F^{LL} / Z_a) N_a (1 - e^{-Z_a}) \quad (3.6)$$

Thus the catch in weight at age by trawlers ($C_{W_a}^{TR}$) and by longliners ($C_{W_a}^{LL}$) becomes:

$$C_{W_a}^{TR} = W_{a+1/2} C_{N_a}^{TR} \quad (3.7)$$

$$C_{W_a}^{LL} = W_{a+1/2} C_{N_a}^{LL} \quad (3.8)$$

where $W_{a+1/2}$ denotes the weight of fish age a in the middle of the year.

The yield-per-recruit associated with trawling (YPR_{TR}) and longlining (YPR_{LL}) respectively is given by Geromont *et al.* (1995a):

$$YPR_{TR}(F^{TR}) = \sum_{a=0}^{max} C_{w_a}^{TR} \quad (3.9)$$

$$YPR_{LL}(F^{LL}) = \sum_{a=0}^{max} C_{W_a}^{LL} \quad (3.10)$$

and the spawning biomass-per-recruit (SBPR) is given by:

$$SBPR_{TR} = \sum W_{pmat,a} N_a \quad (3.11)$$

$$SBPR_{LL} = \sum W_{pmat,a} N_a \quad (3.12)$$

where $W_{pmat,a}$ is the weight of the proportion of fish mature at age a

Length at age was calculated the von Bertalanfy growth equation:

$$L_a = \left[L_\infty (1 - e^{-k(a-t_0)})\right] \quad (3.13)$$

Where:

L_a is the length at age, L_∞ is the theoretical maximum length, K is a growth coefficient, t_0 is the theoretical age at zero length.

and mass at age from an weight-length relationship:

$$W_a = \alpha L_a^{\beta} \qquad (3.14)$$

Where W_a is the mass of a fish of L_a and α and β are constants. The mass of the 8 plus group was assumed to be equal to the mean mass of the 8 year olds.

3.2.4. *Values for the model parameters*

Values for population parameters for *M.capensis* are listed in Table 3.3. The value of natural mortality (M = 0.3 y^{-1}) was assumed for all age classes, though natural mortality is likely to decrease with age (Barnes 1994). It is the M value that is used in most cape hake stock assessments (e.g. Geromont *et al.* 1995a and b). A value of M = 0.5 y^{-1} was also used for sensitivity analysis. The proportions mature for each age were taken from Punt and Leslie (1991). The rationale for choosing a plus-group (8+) is that few animals older than 8 years are caught in the trawl fishery.

Table 3.3. *M. capensis* parameters used for the YPR and SBPR models.

Parameter	Estimate	Source
M	0.3 (y^{-1})	Geromont *et al.* (1995b)
$L\infty$	270.7 (cm)	Punt and Leslie (1991)
K	0.039 (y^{-1})	Punt and Leslie (1991)
t_0	-0.730 (y^{-1}.)'	Punt and Leslie (1991)
β	3.113	Punt and Leslie (1991)
α	0.0050 ($g.cm^{-\beta}$)	Punt and Leslie (1991)

Table 3.4: The proportion of *M. capensis* that are mature (Sexes combined) at different ages (Punt and Leslie 1991). The model assumes that population density is not different to that of 1991.

AGE	Proportion Mature
0	0
1	0.05
2	0.25
3	0.5
4	0.75
5	0.85
6	0.95
7	1
8+	1

3.2.5. Model calculations

The per recruit models (YPR and SBPR) are applied for three different scenarios: 1) catches by longliners only, 2) by trawlers only and 3) by both longliners and trawlers operating at the same time. For each of the fishing scenarios, the per-recruit models used a value of 0.3 y^{-1} for *M*. The values of fishing mortality were varied.

3.2.6. *Sensitivity Analysis*

The YPR and SBPR estimates are influenced to varying degrees by the input parameters of the model. Some of these model parameters are assumed or taken from the literature and thus the sensitivity of the results to altering these needs to be assessed. These sensitivity tests are performed here by altering fishing selectivity at age, natural mortality and age at maturity. Selectivity is changed to be knife-edged at age 4 years for the longline fleet and discards are incorporated for the trawl fleet.

3.3 RESULTS

3.3.1. *Age-specific selectivity*

A comparison of the selectivity curves for longlining and commercial trawling is shown in Fig. 3.1. Selectivity vectors calculated from point estimates (up to a plus group) are given in Table 3.5. Selectivity parameters were estimated by fitting the following selectivity curves to the observed values by minimising the sum of squares using a non-linear minimisation route (solver in excel).

$$S_a^{LL} = \frac{1}{(1+e^{-P2(a-P1)})} \tag{3.15}$$

$$S_a^{TR} = \frac{1}{(1+e^{-P4(a-P3)})} * \left(1-\left(\frac{1}{(1+e^{P6(a-P5)}}\right)\right. \tag{3.16}$$

where:

P1 (6.67) is the inflection age for the first curve

P2 (2.24) is the slope of the first curve

P3 (2.13) is the inflection age for the second curve (ascending side)

P4 (14) is the slope of the second curve (ascending side)

P5 (5.07) is the inflection age for the second curve (descending side)

P6 (-1.16) is the slope of the second curve (descending side)

a is age

S_a^{LL} and S_a^{TR} are the estimated age-specific selectivities for longline and trawl.

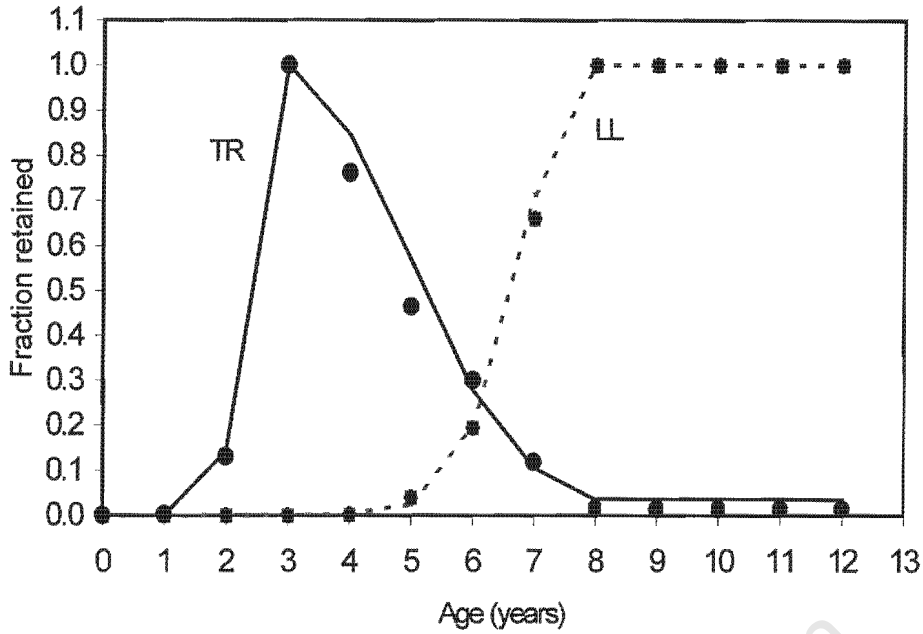

Fig. 3.1: Fishing selectivity at age for *M. capensis* off the South Coast. Curves are fitted to observed data in Table 3.5, using equations 3.15 and 3.16. Data points are the observed and the lines the best fit to the observed selectivity.

The age-specific selectivity values (Table 3.5) indicate that *M. capensis* are most vulnerable to trawling at about 1-4 years of age, thereafter becoming less available to trawls. From Table 3.6 it is clear that most of the commercial trawl catches come from age 3 years and very little from fish > 5 years and older, with full selection at approximately 3 years of age. When the discard data are included, the estimated age at full selection decreases to 2 years. In contrast, the longline catches contain progressively more individuals as age increases. Full selection by longlines occurs from 7 years of age. Most of the longline catch comes from fish 6-7 years old with the smallest contribution from fish 4 years old (Table 3.6).

Table 3.5. Selectivity-at-age values for the South Coast *M. capensis* estimated from longline and trawl catches at age.

Age	Longline	Trawl Landed	Trawl + Discards
0	0.000	0.000	0.000
1	0.000	0.002	0.765
2	0.000	0.131	1.000
3	0.000	1.000	0.841
4	0.002	0.763	0.378
5	0.039	0.465	0.228
6	0.194	0.299	0.147
7	0.660	0.118	0.058
8+	1.000	0.014	0.007

Table 3.6. South coast (inshore) commercial trawl and longline catches-at-age of *M. capensis* expressed as a proportion of the numbers caught for each year.

	Trawl			Longline		
Age (years)	1994	1995	1996	1994	1995	1996
0	0.00	0.00	0.00	0.00	0.00	0.00
1	0.02	0.02	0.02	0.00	0.00	0.00
2	0.25	0.23	0.20	0.00	0.00	0.00
3	0.37	0.35	0.40	0.00	0.00	0.00
4	0.18	0.23	0.25	0.01	0.01	0.01
5	0.12	0.12	0.09	0.20	0.10	0.14
6	0.06	0.05	0.03	0.38	0.26	0.30
7	0.01	0.01	0.01	0.31	0.37	0.42
8+	0.00	0.00	0.00	0.10	0.26	0.14

3.3.2. YPR and SBPR analyses

In order to compare potential impacts of the extreme scenarios of harvesting with longline or trawl only, YPR and SBPR analyses were performed. The results of these analyses are shown in Figures 3.2 and 3.3. Natural mortality was set at 0.3 y^{-1}.

Results of comparing the extreme harvesting strategies of longlining or trawling only at an M value of 0.3 y^{-1} (Fig. 3.2) clearly show that for any F value, longlines give a higher yield. This is hardly unexpected if one considers that the large fish caught by

the longlines would bring an increased catch in weight, so that even if the two caught the same numbers, longlines would still fare better. Even though the trawls catch a suite of sizes, the catch of the big fish by this fleet is a small proportion when looking at the selectivity estimates in Table 3.5. Further, by catching small fish the trawls result in fewer fish reaching large sizes and this impacts on the yield at large F values.

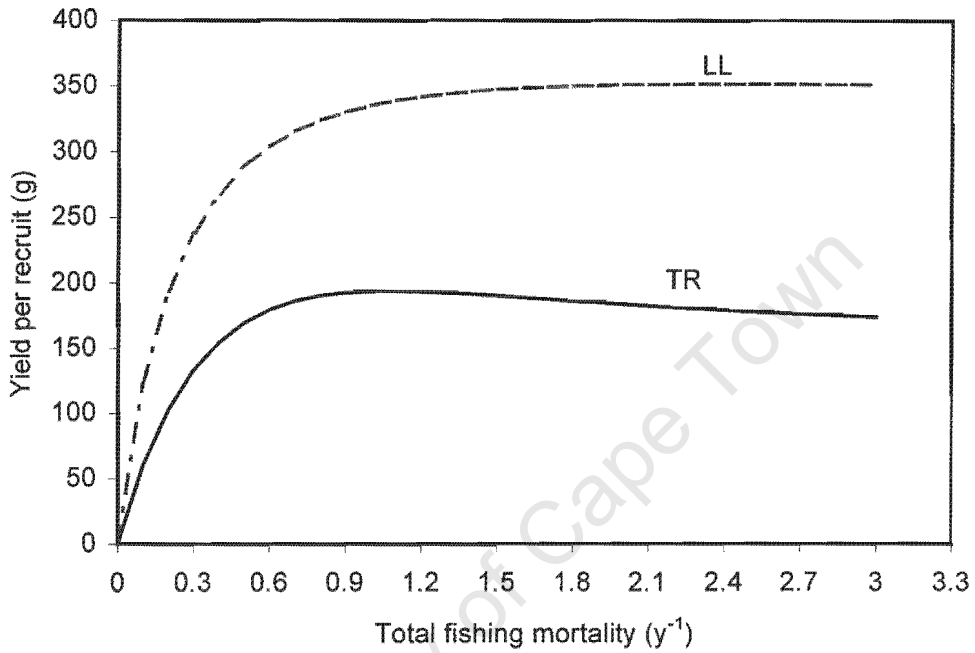

Fig. 3.2: Plot of yield per recruit against total fishing mortality for trawling (TR) only and for longlining only (LL).

It is possible that at a different natural mortality value the curve (Fig 3.2) would have different properties and hence fishing mortality should be discussed having a specific *M* in mind. This is because in theory a YPR increases with increasing mean age at first capture to a maximum value, then declines. The decline is because loss to *M* is greater than gain in biomass through somatic growth (King 1995) Therefore the age at which yield is maximum will depend on natural mortality.

Spawner biomass responses to the one-fleet scenarios are shown in Figure 3.3. When operating with longline only, the resulting spawner biomass is greater than with trawls only. This is an effect of the age at maturity and the selectivity of the two fleets. *M. capensis* become 50% mature at age 3 at which point the trawls are fully selective. Some fish are caught before they reach the 50 % maturity reference point, thus reducing the spawning stock. Longlines on the other hand catch fish of 4 years and older. This means the longlines create a form of "sanctuary" for fish younger than 4 years, allowing them to contribute to spawn prior to capture.

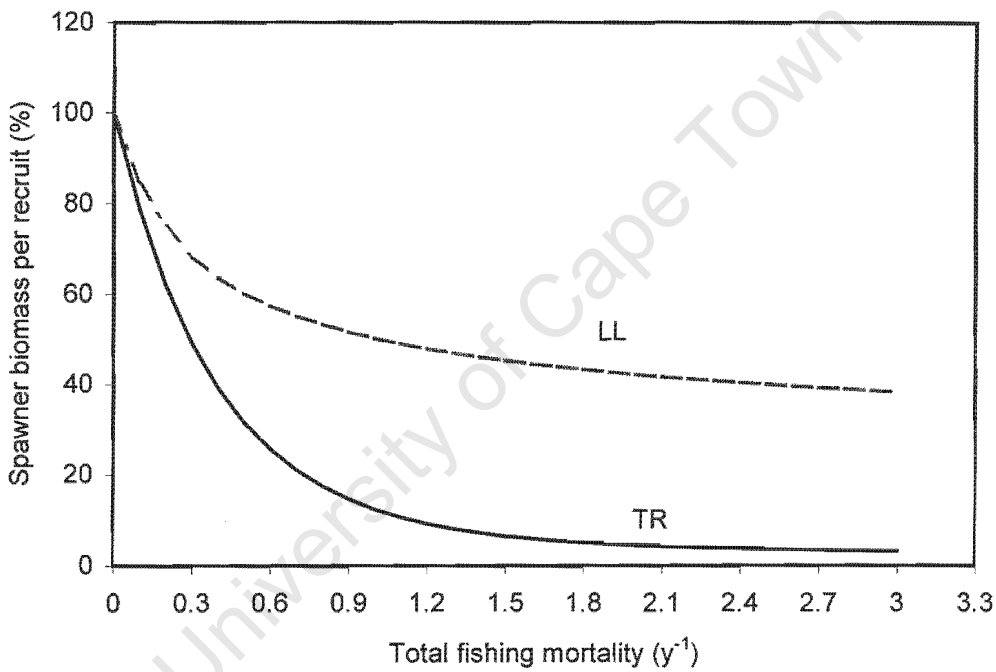

Fig. 3.3: Spawning biomass per recruit against fishing mortality of trawl (TR) or longline (LL) only. Spawning biomass is expressed as a proportion of the unexploited spawner biomass.

Figure 3.4 shows results of the YPR and SBPR analyses performed for the choice of natural mortality (M) of 0.3 y^{-1}. This figure is for the assessment of the combined effect of longlining and trawling (i.e. the two are harvested at the same time). Two

output values can be compared for longlining and trawling. The maximum yield (MY) and the fishing mortality at MY (F_{MY}). The combined MY is obtained by adding the catches of the two fleets.

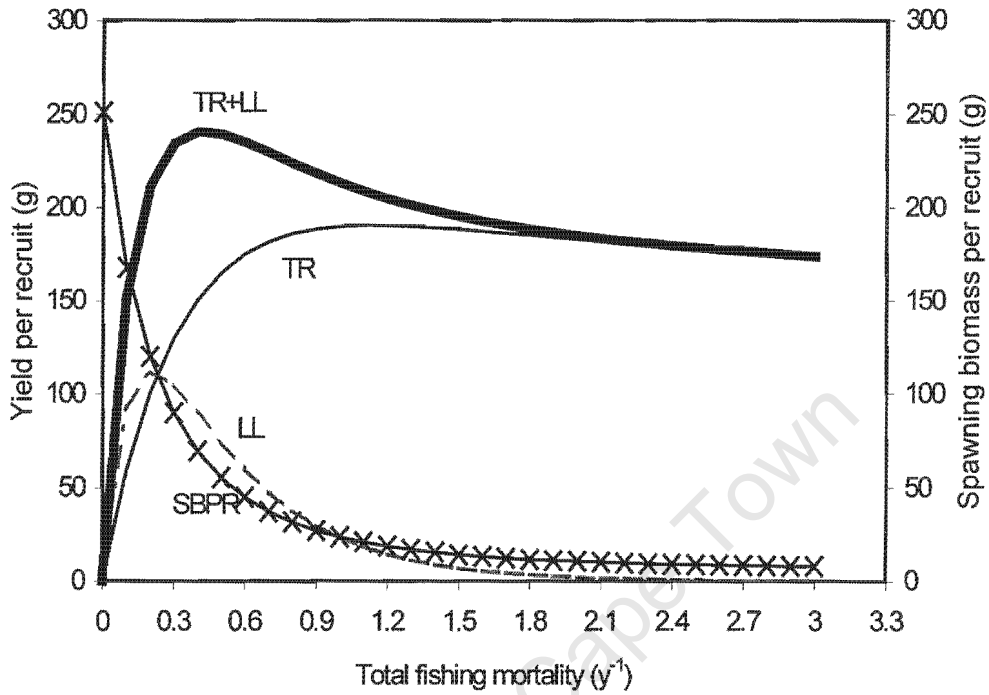

Fig. 3.4: Plot of yield per recruit against total fishing mortality for trawling (TR) and longlining (LL) operating at the same time (TR+LL is combined yield). Natural mortality (*M*) is set at 0.3 y^{-1}. Spawning biomass is on the secondary Y-axis. At the same fishing mortality for both methods, catch levels are different (Table 3.7).

Figure 3.4 shows that F_{MY} for longline is 0.21 y^{-1}, much smaller than for the trawl. This can be attributed to the fact that longlines catch a large proportion of large individuals. As *F* increases the trawl yield increases and reaches a maximum at an *F* value of 1.1 y^{-1}. This increased trawl catch starts impacting negatively on the longline yield. This is to be expected when considering that longlines start catching at age 4 whereas trawls catch from age 1. Thus at high *F* values the trawls start reducing the number of fish that reach the age selected by the longlines and this reduces the

longline catch. At the combined maximum yield (LL+TR) F for each is 0.4 y^{-1} with the trawls contributing about 63 % of the catch (Table 3.7). Results also revealed that from F values of 0.3 y^{-1} the trawls start exceeding the longline catch proportion in the total catch whereas at F values less than that the longlines contribute more of the catch. Catch proportions for the two fishing methods (when they are operating together) at the same F values are summarised in Table 3.7.

Table 3.7. Trawl (Tr) and Longline (LL) catch proportions when the two fleets are operating at the same time for the same fishing mortality (y^{-1}).

F	Tr	LL
0	0	0
0.1	0.39	0.61
0.2	0.47	0.53
0.3	0.55	0.45
0.4	0.63	0.37
0.5	0.69	0.31
0.6	0.75	0.25
0.7	0.79	0.21
0.8	0.83	0.17
0.9	0.86	0.14
1.0	0.89	0.11
1.1	0.91	0.09
1.2	0.93	0.07
1.3	0.94	0.06
1.4	0.96	0.04
1.5	0.96	0.03

Figure 3.4 also shows the combined effect of longlining and trawling on the spawning stock of the population. Clearly an increase in the yield results in the reduction of the spawning stock. The yield increase is the consequence of the increased *Fs* and hence the spawning stock is plotted against F values. It would seem from the Figure 3.4 that the spawning biomass reaches small values at high fishing mortality rates. At high

fishing mortality rates, the yield is largely to the trawl method, which selects fully at age 3 (the age at 50% maturity), thereby greatly reducing the spawner biomass.

3.3.3. *Sensitivity analyses*

Figure 3.5 shows the results of the YPR and SBPR under a natural mortality rate of 0.5 y^{-1} for the extreme scenarios of trawling or longlining only. All other parameters have remained unchanged.

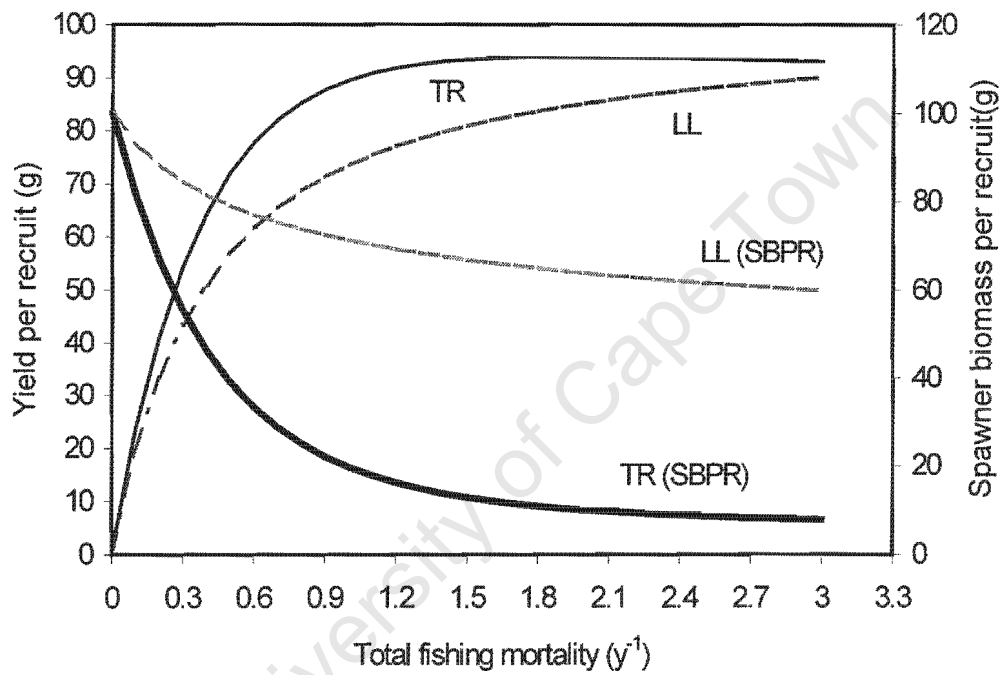

Fig. 3.5: Plot of YPR and SBPR against total fishing mortality for the extreme choices of longline (LL) or trawl (TR) only. Spawner biomass is expressed as a percentage of the unexploited level.

In this example, the YPR results favour trawling (Fig. 3.5). The resource is depleted by the effect of natural mortality (at a high M the rate of attrition is high) before it reaches the ages that are caught by the longlines and as a consequence the longline catch is reduced. In terms of spawning biomass the longline only scenario leaves the

resource with a greater spawner stock, a similar result when M = 0.3. This is a consequence of the combination of longline and age at maturity selectivity.

Results of the sensitivity analyses together with those of the base case are summarised in Tables 3.8 and 3.9. Table 3.8 shows sensitivity results from the two fleets operating at the same time whereas those in Table 3.9 are for the longline or trawl only. The degree of sensitivity of the model is indicated by the difference in the results of the base case to those of the perturbed case where a model parameter has been changed.

Table 3.8. Results of base case analyses compared to the sensitivity analyses for maximum yield (MY), spawner biomass at MY (SSB_{MSY}) in grams, and trawl and longline catch proportions at MY. Results are shown for fishing mortality of 0.4 y^{-1}. a_m is age at maturity, for the base case age at maturity is 1 and is changed to 4 for sensitivity analyses. Knife-edge selection (at age 4) is for longlines and discards for trawls. $SBPR_{MY}$ is also expressed as a percentage of the pristine level at a particular M.

	Combined effort				
Parameter	MY (g)	$SBPR_{MY}$ (g)	SBPR(%)	TR_{MY}	LL_{MY}
Base case					
M=0.3	241	695	28%	0.626	0.374
M=0.5	81	231	40%	0.786	0.214
Knife-edged (LL)					
M=0.3	243	408	16%	0.498	0.502
M=0.5	94	161	27%	0.579	0.421
a_m =4					
M=0.3	243	315	13%	0.498	0.502
M=0.5	94	107	21%	0.579	0.421
Discard-inclusive (TR)					
M=0.3	165	473	19%	0.582	0.418
M=0.5	64	151	26%	0.793	0.207
a_m =4					
M=0.3	165	420	17%	0.582	0.418
M=0.5	64	119	23%	0.793	0.207

Results in Tables 3.8 and 3.9 show that an increase in the rate of natural mortality reduces both the SBPR and YPR. This is a result of a decrease in survivors in the populations, which is a consequence of the greater natural mortality (0.5 y^{-1}). Decreasing the selectivity of the longlines by making it knife-edged at age 4 increases the YPR and decreases the SBPR. By making longline less selective and knife-edged increases the numbers caught and thus improves MY, whereas the increased catch reduces the SBPR. Knife-edged selection has the impact of increasing the probability of capture for all the selected ages and thus reduces the SBPR. As the model assumes constant recruitment it is not possible to assess the impact of reduced SBPR on recruitment and the subsequent catch. This would be possible in a dynamic model. Compared to the base cases, the discard-inclusive trawl selectivity decreases the YPR and SBPR. Changing the age at maturity from one to four reduces the SBPR for both the knife-edged and discard selectivities but has no effect on YPR. Maturity at age four years, results in entry of fish to the spawning stock being delayed and many fish probably get caught (largely by the trawl gear) before they reach that age. Increasing the age at first capture also results in the spawning stock being no longer being protected by an age at first capture that is older than the age at maturity.

Similar effects of changing age at maturity, natural mortality, knife-edged longline selectivity and discard-inclusive trawl selectivities are observed when considering the extreme cases of longline and trawl only harvesting strategies (Table 3.9). What is most obvious here is that the longline fleet alone will give a greater YPR and SBPR when compared to the trawl only scenario. The increased yield is due to the catch of large, older fish by longlines as compared to trawl. Non-selection of fish that are younger than four (5 % of the fish maturing at age one) by the longlines contributes to

the improved spawner biomass, whereas catching these fish at age one by the trawl fish (discard inclusive) leads to reduction in spawner biomass.

Table 3.9. Sensitivity analyses for two extreme cases of "trawl only" or "longline only". Changes are made for age at maturity (a_m) from 1 to 4 years, longline and trawl selectivities. Fishing mortality is set at 0.4 y^{-1}. a_m is age at maturity. Knife-edged selection is at age 4. Spawner biomass at MY (SSB_{MSY}) is in grams but also shown as percentage of the pristine level at a particular M.

	LL only		TR only	
Base case	M= 0.3	M= 0.5	M= 0.3	M= 0.5
MY (g)	268	51	154	64
$SBPR_{my}$ (g)	1604	469	989	266
$SBPR_{my}$ (%)	64%	81%	39%	46%
	Knife-edged (LL)		Discard-inclusive (TR)	
MY (g)	285	87	98	51
$SBPR_{my}$ (g)	804	280	703	178
SBPR(%)	32%	49%	28%	31%
a_m =4				
MY (g)	285	87	98	51
$SBPR_{my}$ (g)	707	224	649	146
$SBPR_{my}$ (%)	29%	43%	26%	28%

3.4. DISCUSSION

3.4.1. *Fishing selectivity*

The patterns in the fishing selectivity of longlines and trawls were similar to those of the results from the "hake - directed longline pilot study" presented by Japp (1995). In that study Japp (1995) compared length selectivity whereas in the present study the comparison was age-based. The results of Japp (1995) were based on data collected in 1994 whereas for this study the data were from 1996 and also included discard data from commercial trawlers. Other authors who have compared the selectivity properties of longlines and trawls include O'Boyle *et al.* (1991) and Geromont *et al.* (1995 a, b). In all these studies (including the present) it has been shown that the longline gear tends to catch larger and thus older fish than compared to the trawl catch.

In the *M. capensis* data presented here, two factors may be responsible for the difference in the age specific selectivity (and thus the size composition in the catches) of the two fishing methods. The first is that the longline and trawl fishing grounds are spatially distinct (see chapter two). Trawls are towed on the soft bottom areas of the South Coast whereas longlines are anchored on the rough ground areas. Therefore it may be probable that the rough grounds have more large *M. capenis* than the trawlable areas and thus there is a greater availability of older *M. capensis* to longline than to the trawl gear. In trying to show this point, Japp (1995) conducted two comparative trawl/longline surveys. The purpose was to obtain data that could be used to compare longline and trawl under prescribed conditions while fishing in the same areas and depths on the same day. Results of this survey showed longlines to be catching large fish and trawls mostly small fish (indeed trawls do catch large fish but

the large ones are mixed with the small fish ones). This then leads to the second possible reason as to why the two have different selectivity properties and thus different size composition in their catches. Larger fish probably have can swim faster than small fish. This may enable them to avoid the trawl net. In mesh selectivity experiments which use the alternative haul method, the larger meshed net often catches relatively more large fish than small meshed net (Beverton and Holt 1957). These authors attribute this to the larger fish avoiding the smaller meshed net. This factor is, however, behavioural and difficult to assess fully. Also, the presence of large hake at the bottom during trawling may affect the size distribution in catches made by the fleet. Pillar and Barange (1995) have shown that *M. capensis* migrate vertically as individuals and not as a population, returning to the bottom when satiated. Hook size has also been mentioned in other gear studies as a factor that affects the size of fish caught (Punt *et al.* 1996). It is also possible that larger, more aggressive fish chase the smaller fish away from the bait.

3.4.2. *Per recruit analyses*

The difference in selectivity raises a number of questions. Which of the two fishing methods provides a better yield and spawner biomass? Since trawling is not likely to be phased out (Japp 1995), how is the introduction of longlining going to affect the yield and spawner biomass? By selecting for larger and more fecund fish (see Osborne *et al.* 1999), what is the potential impact on *M. capensis* egg production and subsequent recruitment? Apart from the question of recruitment, this chapter has attempted to give answers to these questions by making use of YPR and SBPR models (Beverton and Holt 1957). The recruitment question cannot be addressed here since per recruit analyses assume constant recruitment (Beverton 1994).

The per recruit and sensitivity analyses have shown that variation in *M* has a marked effect on YPR and SBPR. Per recruit analyses of Bennett (1989) also showed this effect of *M*. As shown in the results here, both YPR and SBPR reveal a decline with a natural mortality increase. This is to be expected when considering that natural mortality is the intrinsic rate of death due to natural causes (e.g. the rate of attrition of a cohort). At an *M* of 0.5 y^{-1} the attrition is greater and a smaller proportion of the cohort survives each year so that less fish are available to the fishery. In turn reduced numbers mean a small spawning stock. It should however be remembered that natural mortality values used here were assumed. This perhaps suggests a need to obtain more accurate estimates of *M* values for *M. capensis*. Research surveys on unexploited stocks may be one possible way of estimating natural mortality (Barnes 1995). If an unexploited stock does not exist, estimates from species with similar life patters could also be used to estimate natural mortality values.

When the two fleets are operating at the same time, longlines give a better yield and spawning biomass at values of *F* less than 0.3 y^{-1}. This can be attributed to the fact that longlines catch a greater proportion of large individuals, which then contribute a substantial weight to the catch of the fishery. This increase in spawning biomass with a decrease in trawl fishing mortality was attributed by Armstrong and Japp (1992) to the fact that not many hake are caught by the longlines until six or seven years of age, allowing hake to survive through several reproductive years before being caught. The model shows this increase in SBPR for all the *M* values used. The same phenomenon was observed by Fennessy (1994) in a YPR and SBPR comparison of skiboats and trawls on *Argyrosomus thorpei*. Fennessy (1994) also considered the combined effects

of skiboats +trawls and the extreme case of either one of the two at a particular time and found that trawlers reduced the YPR and SBPR values for the *A. thorpei* fishery.

In line with previous per recruit analyses on longlining and trawling (Geromont *et al.* 1995b), the model seems to favour longlining in terms of yield and spawner biomass. However, as shown here, this conclusion is sensitive to the value of *M*. Thus in considering these results it should be noted that improved estimates of input parameters to the model are required, but for the same fishing mortality the model favours an increase in the proportion of longline catch as this would act to improve the spawner biomass and improve the yield. It is clear from the results here that impacts of the two fishing methods on the spawning biomass are different. For the same fishing mortality, longlining results in a larger spawner biomass while fishing with trawls reduces the spawner biomass to levels less than those left behind by longlines. The model has also answered the question of maximum yield and shows that trawls obtain a maximum yield of 193 g per recruit whereas longlines attained a much greater value of 352 g per recruit.

3.4.3. *Possible management options*

Per-recruit results have shown that a reduction in the trawl catch would result in improved spawning biomass and yield per-recruit (see also Geromont *et al.* 1995a and b). Reducing the trawl catch may not be easy if one considers the amount of investment that is already in this particular sector. One way to avoid this may be to increase the mesh size of the net but keep the trawl total allowable catch the same. Sutton (2000) has also suggested this in his research work focussing on the exploitation patters of longlines, handlines and trawls. Also square mesh panels could

be used to improve escapement of small fish ((R. W. Leslie, Marine and Coastal Management, pers. Comm.). This would reduce the pressure on the immature individuals and possibly improve the spawner stock. Another option may be to take some of the trawl catch and allocate it to longlines. In doing this the trawl companies whose catch has been reduced could be allocated the new longline catch and thus removing any fear of loss. This addresses the investment issue and also the biomass aspect. These comments are made on the basis of the YPR results and need further testing in a more dynamic model. Also, it is good to have management regulation but it all depends on the compliance levels in that particular fishery. So some regulations are good but are bypassed during fishing.

CHAPTER FOUR

MODELLING THE RELATIVE IMPACTS OF LONGLINING AND TRAWLING ON *MERLUCIUS CAPENSIS* OFF THE SOUTH COAST USING AN AGE-STRUCTURED PRODUCTION MODEL

Abstract

Using an age-structured production model (ASPM) based on that of Punt *et al.* (1992b), an attempt is made to compare the relative impacts of longlining and trawling on *M. capensis* on the Agulhas bank. First the history of the fishery is re-created from 1967 by using the reported annual landings. From 1997 (the last year of reported catches considered in this study) the potential impacts are assessed by changing future catch limits ("what - if? approach"). The impacts of the fleets are assessed by looking at the spawner biomass responses to the catch limits. Finally an attempt is made to re-model sex-specific populations and to project egg production by the females under different longline and trawl catches. Results suggest that an increase in the longline proportion of the TAC would increase the yield and help conserve the spawner biomass whereas an increase in the trawl proportion of the TAC would reduce the spawner biomass. Sex specific and egg production modelling collapsed the resource after 10 years and this could probably be a result of the sensitivity of the model to sex-specific data.

4.1. INTRODUCTION

Prior to the development of the age-structured production model (ASPM) used by Punt *et al.* (1992b), the assessment methods used by various workers (e.g. Punt and Butterworth 1989) for South African hake stocks were based on static surplus production models (Fox 1975, Schaefer 1954), virtual population analysis (VPA) and dynamic surplus production model (Butterworth and Andrew 1984). The production model utilised catch, *cpue* and biomass survey data whereas the VPA made use of catch-at-age and effort data (Punt 1994, Butterworth *et al.* 1990). The ASPM was then developed for instances when the above data were not available, and to supplement the other two methods. Its use has since gained momentum, both locally and internationally in the assessments of multi-fleet fisheries of hake and other species (e.g. Punt and Japp 1994, Punt *et al.* 1995b, Restrepo 1997) and where there is a lack of catch-at-age data (Booth and Punt 1998).

The major advantage of the ASPM is that it takes into consideration the underlying age-structure of a population, which it then projects forwards. Consideration of the age structure is very important when it comes to multi-fleet fisheries where different gears may target different age classes. By incorporating fleet-specific selectivity, the ASPM can link changes in the age-structure of the population to the activities of a specific fleet. Besides the age-specific selectivity, the ASPM requires that a stock recruitment relationship be established and thus allows for the estimation of recruitment. The ASPM in this chapter differs from the YPR model (chapter 3) in that it uses catch information to reconstruct the history of the resource.

Using an ASPM, this chapter investigates the effects of different harvesting levels by longlines and trawls on the spawner biomass of the South Coast *M. capensis* population. The approach is different to that of YPR in that a catch is allocated and the effects of that on the spawner biomass are linked to the catch level. The population and the spawner biomass are projected forward over a 30-year period. Impacts of catch limits are then reflected by spawner biomass levels. A sex-specific ASPM is then constructed with the objective of comparing the effects of fishing on both the spawner males and females. This is made possible by the availability of sex-specific parameters. The main objective of using the ASPM after the YPR is that the dynamic model allows one to set recruitment from the beginning of the fishery whereas the YPR assumes constant recruitment.

4.2 MATERIALS AND METHODS

The age-structured production model analysis involves constructing a deterministic age-structured model of the population dynamics.

4.2.1. *Initial condition*

For the purposes of this study, the resource is assumed to have been at its unexploited equilibrium level at the start of 1966 (reported catches start in 1967) with an age structure determined by the formula $N_{1966,a} = R_0 n_a$ where:

$$n_a = 1 \qquad \text{if } a = 0 \qquad (4.1)$$

$$n_a = n_{a-1} e^{-M_a} \qquad \text{if } 1 \le a < \max \qquad (4.2)$$

$$n_a = n_{a-1} e^{-M_{a-1}} / (1 - \exp^{-M_a}) \qquad \text{if } a = \max \qquad (4.3)$$

where:

a = age in years

n_a is assumed resource number at its unexploited level,

$N_{y,a}$ is the number of fish of age a at the start of year y,

M_a is the rate of instantaneous natural mortality

max is the maximum age (considered to be a plus group).

R_o is the number of 0-year olds in millions of fish at the deterministic equilibrium that corresponds to an absence of harvesting. R_0 is calculated from the value for K^{sp} (the spawner biomass of the resource in the absence of harvesting).

$$R_0 = K^{sp} / \sum_{a=0}^{\max} f_a w_a n_a \qquad (4.4)$$

where f_a is the proportion of fish at age a that are sexually mature, and w_a is mean weight at age

4.2.2. *Resource dynamics*

From 1966 the population numbers are governed by:

$$N_{y+1,a} = R_{y+1} \qquad \text{if } a = 0 \qquad (4.5)$$

$$N_{y+1,a} = N_{y,a-1} e^{-Z_{y,a-1}} \qquad \text{if } 1 \le a < \max \qquad (4.6)$$

$$N_{y+1,a} = N_{y,a-1} e^{-Z_{y,a-1}} + N_{y,a} e^{-Z_{y,a}} \qquad \text{if } a = \max \qquad (4.7)$$

where R_y is the number of 0 year olds at the start of year y, $Z_{y,a}$ is the total mortality of fish of age a during year y, with

$$Z_{y,a} = M_a + S_a^{TR} F_y^{TR} + S_a^{LL} F_y^{LL} \qquad (4.8)$$

where S_a^{TR} denotes the commercial trawl fishing selectivity for age a,

S_a^{LL} denotes the longline fishing selectivity for age a,

F_y^{TR} and F_y^{LL} denote the trawl fishing and the longline fishing mortality during year y for these fleets.

4.2.3. *Recruitment*

This is assumed to be related to spawner biomass by means of the Beverton-Holt relationship:

$$R_y = \Psi \frac{\alpha SB_{y-1}}{\beta + SB_{y-1}} \tag{4.9}$$

where α and β are the parameters defining the curve and Ψ is the recruitment multiplier. In a deterministic framework where there is no recruitment variability $\Psi = 1$. Spawner biomass is calculated from:

$$SB_y = \sum_{a=0}^{\max} N_{y,a} w_a f_a \tag{4.10}$$

The values for the stock-recruitment relationship parameters α and β are calculated from R_0 and the steepness of the stock recruitment relationship h. Steepness is defined as the fraction of the number of recruits at unexploited equilibrium expected when the spawning biomass is reduced to 20 % of its unexploited level (Francis 1992), so that:

$$\alpha = \frac{4hR_0}{(5h-1)} \tag{4.11}$$

$$\beta = \frac{SB_0(1-h)}{(5h-1)} \tag{4.12}$$

4.2.4. *Catches and the estimate of* F_y

Annual trawl catches are described by the catch equation as follows:

$$C_y^{TR} = \sum_{a=0}^{\max} w_{a+\frac{1}{2}} N_a \frac{S_{y,a}^{TR} F_y^{TR}}{Z_{y,a}} (1 - e^{-z_{y,a}}) \tag{4.13}$$

and similarly for longline:

$$C_y^{LL} = \sum_{a=0}^{\max} w_{a+\frac{1}{2}} N_a \frac{S_{y,a}^{LL} F_y^{LL}}{Z_{y,a}} (1 - e^{-Z_{y,a}}) \tag{4.14}$$

where $w_{a+\frac{1}{2}}$ is the weight-at-age of fish in the middle of the year. The estimates of F_y^{LL} and F_y^{TR} are obtained by solving equation 4.13 and 4.14 given C_y the observed annual catch. This is conducted by minimising the sum of squares.

4.2.5. *Model parameters*

Parameter values are taken from previous *M. capensis* studies. The virgin spawner biomass (K^{sp}) and the steepness of the stock-recruitment curve (h) are those used by Geromont and Butterworth (2000). The number of 0-year olds corresponding to the

absence of fishing is estimated using K^{sp}. Expected selectivity at age is assumed to be time invariant and is estimated for the longline fleet using a two parameter logistic function, and for the trawl fleet using a four-parameter double logistic function.

$$S_a^{LL} = \frac{1}{(1+e^{-P2(a-P1)})} \tag{4.15}$$

$$S_a^{TR} = \frac{1}{(1+e^{-P4(a-P3)})} * \left((1-(\frac{1}{(1+e^{P6(a-P5)}} \right) \tag{4.16}$$

where:

P1 (6.67) is the inflection age for the first curve

P2 (2.24) is the slope of the first curve

P3 (2.13) is the inflection age for the second curve (ascending side)

P4 (13.97) is the slope of the second curve (ascending side)

P5 (5.07) is the inflection age for the second curve (descending side)

P6 (-1.16) is the slope of the second curve (descending side)

Natural mortality M_a is assumed to be the same for all the ages and equal to 0.3 y^{-1}. This value is chosen as it is the most widely used for cape hake stock assessments (e.g. Geromont *et al.* 1995 a and b, Punt 1994 and Punt and Butterworth 1989). The mass in g of a fish of age a in years is calculated from the growth equation: $w_a = a\left[L_\infty(1-e^{-K(a-t_0)})\right]^b$. The growth parameters are given in Table 4.1.

Table 4.1: *M. capensis* growth parameters used for the age-structured production model.

Parameter	Estimate	Source
$L\infty$	270.7 (cm)	Punt and Leslie (1991)
K	-0.039 (y^{-1})	Punt and Leslie (1991)
t_0	0.730 (y^{-1}.)'	Punt and Leslie (1991)
b	3.113	Punt and Leslie (1991)
a	0.0050 ($g.cm^{-\beta}$)	Punt and Leslie (1991)

In order to calculate the spawner stock the model had to incorporate maturity estimates. The numbers of mature individuals (Table 3.4, Chapter 3) are assumed to increase with age and the proportion mature at age was taken from Punt and Leslie (1991). Parameter estimates used for the modelling exercise are given in Table 4.2

Table 4.2: *M. capensis* parameters used for the age-structured production model.

Parameter	Estimate	Source
K^{SP}	180000 tons	assumed
R_0	71 million	estimated
h	0.949	Geromont and Butterworth (2000)
β	2451	estimated
α	72	estimated

4.2.6. *Sex-split ASPM*

In a separate analysis, the ASPM described above was split into male and female sub-populations. The objective of this was to assess the impacts of the two fishing methods on the egg production by the females. For this, fecundity estimates were as

detailed in Osborne *et al.* (1999). Sex ratio was assumed to be equal for all ages (0.5) when setting up the pre-exploitation population. This is done bearing in mind that females grow faster than males (Botha 1980) and attain bigger lengths than males on average. Thus the age based sex ratio will be 1:1 but the length based sex ratios will be 1:1 for small fish, and skewed towards females at large sizes. If unequal age proportions were assumed, the model would need sex specific mortality at age values.

The total population was split into sexes by multiplying the total population prior to fishing (1966) by the assumed sex proportions. Thus the relative numbers (n) for females (f) in year are given by:

$$n^{f}_{1966,a} = n_{1966,a} f_{proportion} \tag{4.17}$$

and for males $$n^{m}_{1966,a} = n_{1966,a} m_{proportion} \tag{4.18}$$

From 1967 the female (f) numbers are governed by:

$$N^{f}_{y+1,a} = 0.5R_{y+1} \qquad \text{if } a = 0 \tag{4.19}$$

$$N^{f}_{y+1,a} = N^{f}_{y,a-1} e^{-Z^{f}_{y,a-1}} \qquad \text{if } 1 \le a < \max \tag{4.20}$$

$$N^{f}_{y+1,a} = N^{f}_{y,a-1} e^{-Z^{f}_{y,a-1}} + N^{f}_{y,a} e^{-Z^{f}_{y,a}} \qquad \text{if } a = \max \tag{4.21}$$

and for males (m):

$$N^m_{y+1,a} = 0.5R_{y+1} \qquad \text{if } a = 0 \qquad (4.22)$$

$$N^m_{y+1,a} = N^m_{y,a-1} e^{-Z^m_{y,a-1}} \qquad \text{if } 1 \le a. < \max \qquad (4.23)$$

$$N^m_{y+1,a} = N^m_{y,a-1} e^{-Z^m_{y,a-1}} + N^m_{y,a} e^{-Z^m_{y,a}} \qquad \text{if } a = \max \qquad (4.22)$$

The total mortality (Z) for a female fish of age a during year y is:

$$Z^f_{y,a} = M_a + S^{TR,f}_a F^{TR} + S^{LL,f}_a F^{LL} \qquad (4.23)$$

and for males (Z)

$$Z^m_{y,a} = M_a + S^{TR,m}_a F^{TR} + S^{LL,m}_a F^{LL} \qquad (4.24)$$

4.2.7. *Sex-specific model parameters*

The sex-specific selectivity-at-age (Table 4.3) values for both longline and trawl were obtained by dividing the (sex-specific) catch-at-age estimates with the sex-specific survey estimates of the numbers at age. Growth parameters used for the sex-specific analysis were obtained from Punt and Leslie (1991) and are given in Table 4.4.

Table 4.3. Fleet and sex-specific selectivity-at-age vectors for the South Coast *M. capensis* population.

Age	Male (LL)	Female (LL)	Male (TR)	Female (TR)
0	0.000	0.000	0.000	0.000
1	0.000	0.000	0.001	0.000
2	0.000	0.000	0.239	0.085
3	0.000	0.000	1.000	1.000
4	0.002	0.001	0.765	0.793
5	0.030	0.037	0.457	0.484
6	0.142	0.195	0.290	0.316
7	0.437	0.738	0.139	0.106
8+	1.000	1.000	0.037	0.012

Table 4.4: Sex-specific growth parameters for *M. capensis* (Punt and Leslie 1991).

Parameter	Male	Female
k (y^{-1})	0.086	0.041
t_0 (years)	-0.449	-0.707
Linf (cm)	144.6	260.9
s	3.105	3.116
y (in gm)	0.005	0.005

4.2.8. *Catches-at-age*

Annual catches for each fleet are given by:

$$C_y^{TR} = \sum_{a=0}^{\max} W^f_{a+\frac{1}{2}} N_a^f \frac{S^{TR,f}_{y,a} F_y^{TR}}{Z^f_{y,a}} (1 - e^{-Z^f_{y,a}}) + \sum_{a=0}^{\max} W^m_{a+\frac{1}{2}} N_a^m \frac{S^{TR,m}_{y,a} F_y^{TR}}{Z^m_{y,a}} (1 - e^{-Z^m_{y,a}}) \quad (4.25)$$

$$C_y^{LL} = \sum_{a=0}^{\max} W^f_{a+\frac{1}{2}} N_a^f \frac{S^{LL,f}_{y,a} F_y^{LL}}{Z^f_{y,a}} (1 - e^{-Z^f_{y,a}}) + \sum_{a=0}^{\max} W^m_{a+\frac{1}{2}} N_a^m \frac{S^{LL,m}_{y,a} F_y^{LL}}{Z^m_a} (1 - e^{-Z^m_{y,a}}) \quad (4.26)$$

4.2.9. *Catch data utilized*

The catch-by-mass data for the entire South Coast *M. capensis* inshore fishery are given in Appendix A6. The first reported catches are in 1967 and 1983 for the trawl gear and the longline fisheries respectively. For the purposes of this study, the last year of reported catches considered is 1997 for both sectors. These catch data were used to estimate the fleet specific fishing mortality for each year.

4.2.10. *Evaluation of impacts of alternative future harvesting strategies*

Projections are performed in terms of two management scenarios. Scenario 1 assesses the impacts of keeping the annual TAC the same as the terminal year (1997) but allocated different catch proportions to longlines and commercial trawls. For scenario 2 the annual TAC is increased and decreased by different percentages while keeping the fleet proportions equal to those of the terminal year. Each scenario has different harvesting strategies that are summarised in Table 4.5 and Table 4.6.

Table 4.5: TAC and catch proportions for harvesting strategies considered for scenario 1.

Harvesting Strategy	TAC	Trawl	Longline
1.A	12813	69%	31%
1.B	12813	100%	0%
1.C	12813	80%	20%
1.D	12813	50%	50%
1.E	12813	20%	80%
1.F	12813	0%	100%

Table 4.6: TAC restrictions for five of the harvesting strategies of scenario 2.

Harvesting Strategies	Trawl	LL	TAC	TAC relative to 1997
2A	31%	69%	12813	same as 1997
2B	31%	69%	19219	5% increase
2C	31%	69%	14094	10% increase
2D	31%	69%	16657	30% increase
2E	31%	69%	8969	30% decrease

4.3. RESULTS

4.3.1. *Sex combined projections*

As can be seen in Figure 4.1 (1A), a continuation of the 1997 TAC restrictions for both longlines and trawls causes no changes in the spawner biomass. If the 1997 TAC was set to harvest the resource at a sustainable level then this result should hardly be surprising. Harvesting strategies 1D-1F (Table 4.5) result in an increase of the spawner biomass (Fig. 4.1). For these three strategies the longline proportion of the TAC is increased from that of 1997 whereas the total TAC is unchanged. It would seem from these results that increasing the longline catch proportion (within the 1997 TAC) would be best for the spawning biomass whereas the opposite is true for an increase in the trawl catch proportion (1B & 1C). This is a consequence of the different selectivity estimates of the two fleets, which tend to select for different ages, and is dependant on the assumed selectivity patterns being maintained.

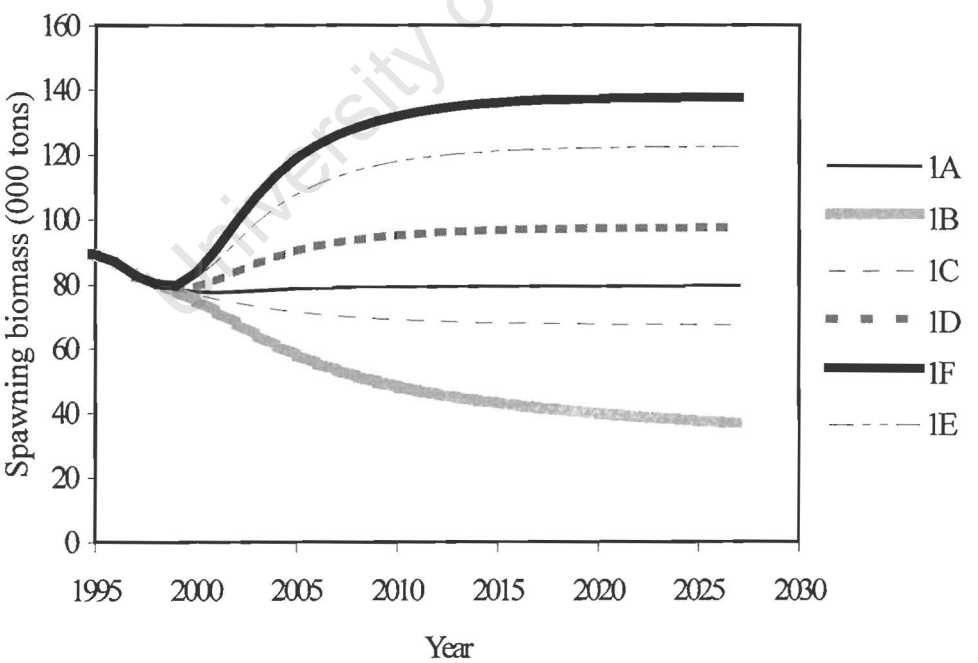

Fig. 4.1: Projected spawning biomass under five different TAC restrictions (1A-F).

Figure 4.2 illustrates the potential impacts of increasing the catch by 5 % (2B), 10% (2C) and 30% (2D) whereas 2E shows that of a 30 % reduction from the TAC of 1997. Strategies 2B-2D clearly lead to a reduction of the spawning biomass with strategy 2D offering the lowest spawner biomass. A reduction of the TAC by 30% (2E) reflects an increase of the spawner biomass, which is hardly unexpected. It would seem from Figure 4.2 that the TAC should not be increased if properties of longlining and trawling remain the same but needs to be maintained at the level of 1997.

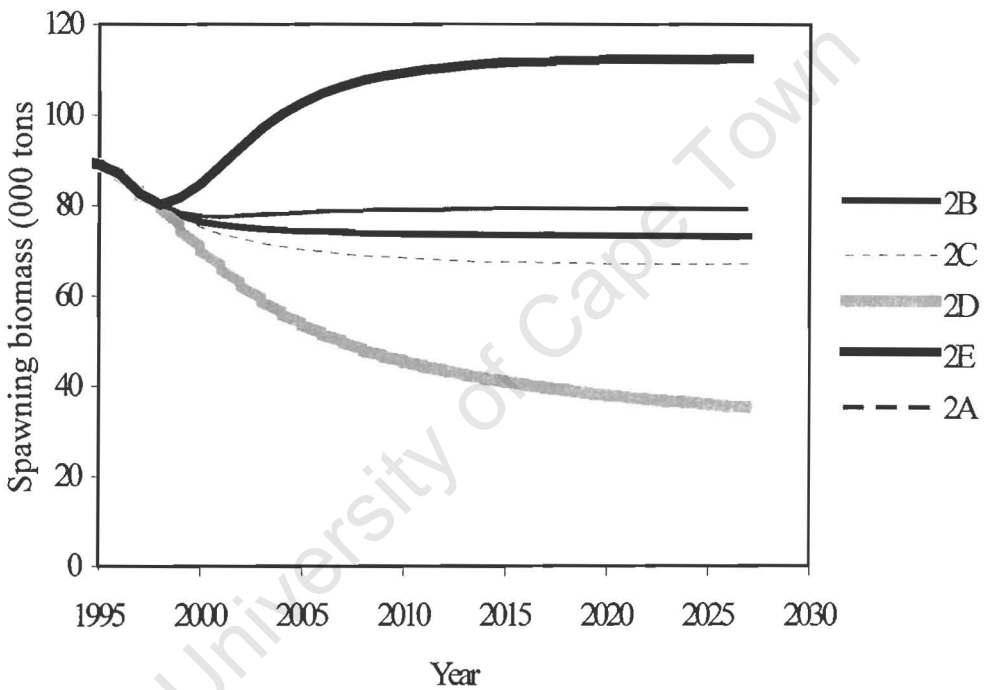

Fig. 4.2: Projected spawning biomass under 5 different TAC levels (2A-E), with the proportions of longlining and trawling similar to those of 1997. Also see Table 4.6

Different catch levels have been shown to either cause an increase or decrease in the numbers of spawners (Fig. 4.2). Since the spawners are the part of the population that produces new recruits, it becomes important to assess the impacts of an increase or decrease on recruitment. This is done using a stock recruitment relationship. Figure

4.3 shows the curve used in this chapter to relate the numbers of recruits to spawning biomass for an *h* (steepness of the stock-recruitment curve) value of 0.949. This curve shows that even at low values of spawning biomass (caused by heavy fishing), recruitment is not reduced to low levels. This was evident during the ASPM modelling (data not shown). It is suggested here that this is a result of the *h* value chosen for the modelling.

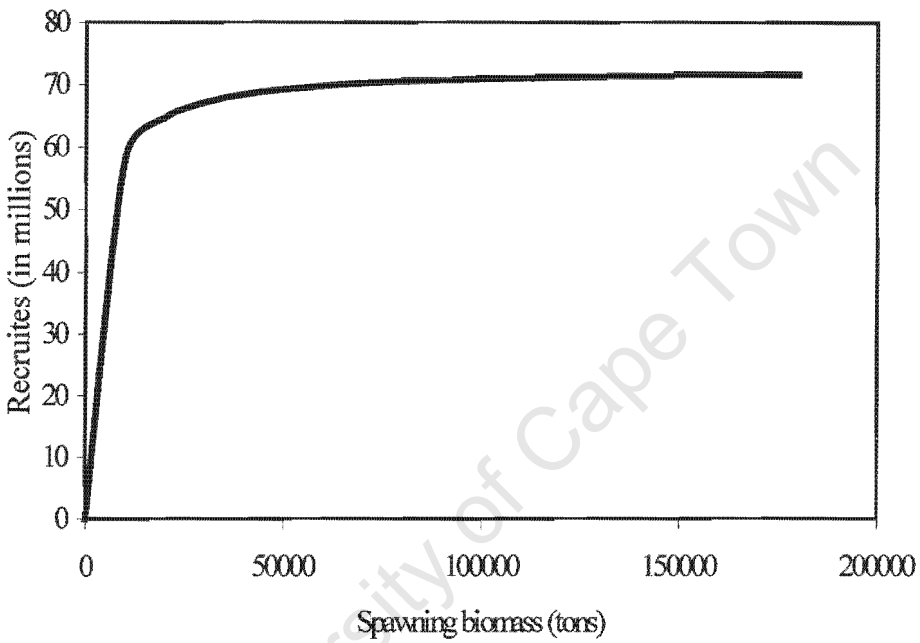

Fig. 4.3: Stock-recruitment relationship for the ASPM used to model catch levels of longlining and trawling for *M. capensis*.

4.3.2. Sex-specific projections

Sex-specific data were used to model the possible impacts of fishing on both male and female populations separately. This is made possible by the availability of sex specific data (derived from sex specific length data and age length keys). The sex-structured ASPM examines the impacts of fishing on each sex within the population. Fishing impacts are compared for the spawner biomass and effects on egg production.

Both male and female spawner biomass and population numbers were projected forward from 1997 under the terminal year catch proportions of longlines and trawls. ASPM predictions of spawner biomass show that the continuation of the 1997 catch proportions (with sex-specific selectivity) leads to an extinction of the resource by the year 2007 (Fig. 4.4). Though the population extinction happens a decade later, by the year 2004 the model is unable to attain the catch proportions of 1997. This is true for both sexes and the model also shows no differences in the trend of decline. Spawner biomass extinction within such a period could be caused by high catch rates. If this is not true, the extinction may be a consequence of the sensitivity of the initial conditions and, to the sex-specific selectivity.

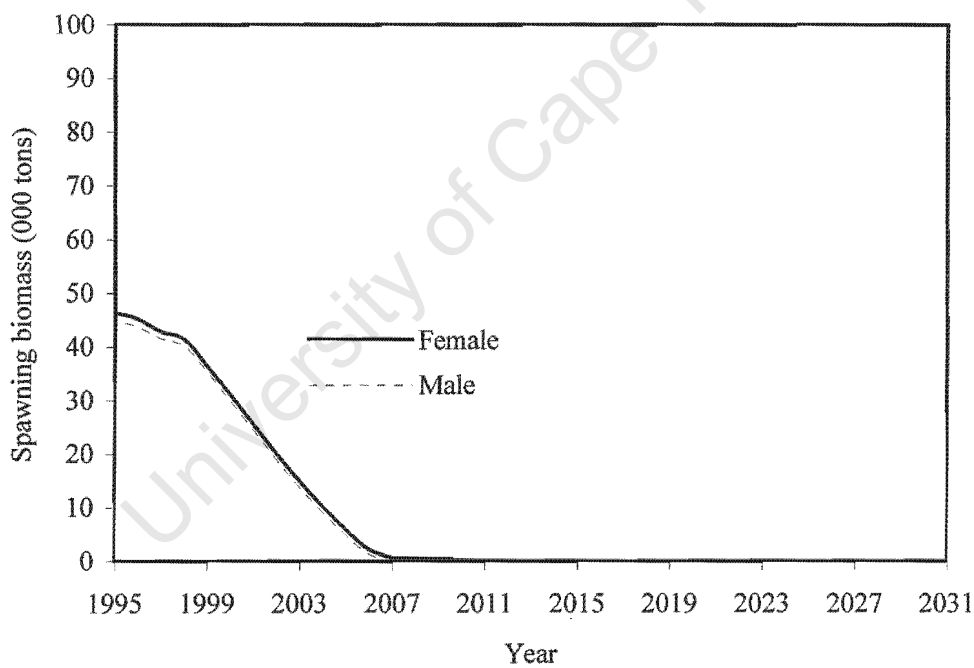

Fig. 4.4: Projected sex-specific spawner biomass. Projections are under the 1997 longline and trawl catch proportions.

Results of egg production projection are shown in Figure 4.5. These were obtained by projecting the female population only. As expected, the results did not deviate from those of the spawner biomass projections. This confirms that a decrease in the

spawner biomass will ultimately reduce egg output. It should be noted here that when performing the egg projections it was assumed that it is only the spawner biomass that affects the egg output.

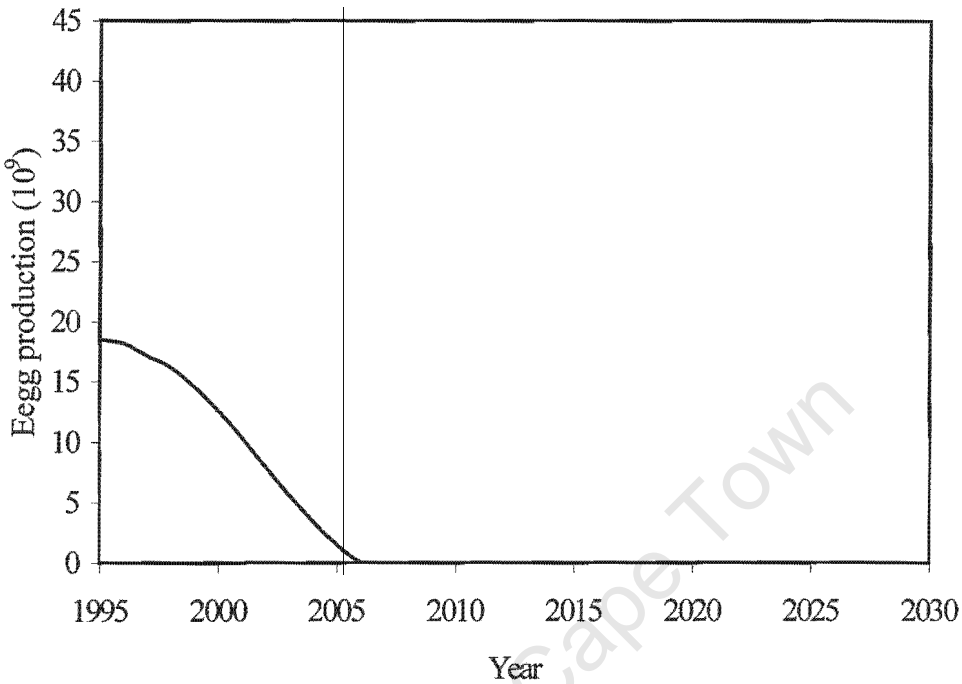

Fig. 4.5: Projected egg production. The projections are performed under the 1997 longline and trawl catch proportions.

4.4. DISCUSSION

Spawner biomass projections obtained by making use of the ASPM (Punt *et al.* 1992) gave results that are qualitatively similar to those of the YPR model used in Chapter 3 of this thesis. For both models, an increase in the proportion of the catch taken by longline gives results in which the spawner biomass responses are positive. It should be noted that the YPR model makes an important assumption (YPR assumes constant recruitment, yet not specified) that is absent in the ASPM analysis and thus this qualitative similarity should give confidence in the approach that has been used here. It is also worth noting that when longlining and trawling were compared in the Scotian Shelf groundfish fishery (O'Boyle *et al.* 1991) its was concluded that longlines would give a higher yield and better spawner biomass. This conclusion was drawn after O'Boyle *et al.* 1991 used a bioeconomic model to compare the two fleets.

During the ASPM projections performed for this chapter, the model seemed quite sensitive to the perturbation of some parameters (e.g. selectivity). The probable cause of this was the choice of parameter values (e.g. K^{SP} or h). Since the model was not fitted to any data, the parameter values were chosen from a range of values used by Geromont *et al.* (2000). Changing one of these would require a change in the others. This puts some limitations on the model and hence no sensitivity analysis is reported here. It should also be noted that the main objective was to use the model to help understand the potential impacts future catch limits would have on the resource.

4.4.2. *Sex-combined analyses*

Figure 4.1 examines the impact on the spawning stock of implementing different trawl and longline proportions under a constant TAC. Results showed that all (except

harvesting strategy 1B) the different catch proportions considered under the 1997 TAC are sustainable but at different spawner biomass levels. Increasing the trawl proportion of the catch from that of 1997 clearly leads to reduction of spawning biomass. This trend is more evident when access to the resource is restricted to trawlers only (harvesting strategy 1B). The advice would be to avoid this and consider the option of reducing the trawl catch proportions (1D, 1F). This may, however, not be simple if one considers the amount of investment already made in the trawl industry. What would be plausible though would be continuation of the 1997 catch levels (1A) which brings no changes to the levels of the spawning biomass. Any change to the 1997 catch levels should depend on what effect that level would ultimately have on recruitment and thus this analysis needs to be taken further.

Figure 4.2 shows what happens if the total TAC is increased or decreased while maintaining the trawl and longline catch proportions similar to those of 1997. The model indicates that any increase (even as small as 5%) in the total TAC clearly reduces the spawning biomass. This is probably a consequence of the increased trawl catch associated with the higher TAC. It is unlikely to be due to the longlines as the model has shown that maintaining the 1997 TAC with a longline only harvesting strategy increases the spawning biomass.

No collapse in recruitment was shown at any of the catch levels and harvesting strategies used during the modelling. This is largely an effect of the stock recruitment relationship established by the h (steepness of the recruitment curve) value that was used (Fig. 4.3). To test for this, the value of h was reduced to 0.777, which flattens the stock recruitment curve (data not shown) and strengthens the recruitment relationship.

It was observed that the model is sensitive to the assumed *h* value. As the levels used here were taken from the literature, this indicates that more work is needed to determine the probable bounds for *h* in *M. capensis*.

4.4.3. *Sex-specific analysis*

When fecundity is age dependent it becomes important to assess the impact of age specific selectivity on egg production and sex-specific spawner biomass. The modified ASPM, which allows for separation of sexes, made this task possible. However, an assumption was made that it is only fishing that affects the production of eggs when in fact factors such as food availability and size of spawners (Lo *et al.* 1996) have been shown to have an affect. This potential limitation must be considered when discussing these results.

The model showed that fishing with the 1997 catch proportions leads to a virtual extinction of the resource after a decade. This was unexpected, considering that no extinction was occured when the sexes were pooled together and modelled as one population. A number of parameters were introduced that possibly made the sex-specific ASPM different to the non-sex specific. First, assumed sex proportions in the total population (0.5 for all ages) were used to recreate the history of the resources whereas the reported catches used were not sex-specific. The selectivity estimates were also assumed to be sex-specific when projecting the sex-specific populations. If the model is sensitive to certain parameters, as it became apparent during the analyses, the sex-specific results presented above could be misleading. It would seem that a much more extensive sex-specific data set is required for a sex-specific

framework. This would then bring more certainty to the model results, which in turn could provide some concrete management advice.

Assessing the impacts of future catches was the main objective of the present study and thus very little attempt was made to look at the degree to which the sex-specific scenario will be able to describe the essential features of the two fleets. Under this scenario (during forward projections) a catch was allocated to a specific fleet. The catch was not sexed but it was assumed that the model under sex-specific condition would generate the same catch by using sex-specific selectivity and therefore allocating the appropriate number of males and females to the total catch. The testing of such assumptions is beyond the scope of this work but it hoped that such aspects are considered in the future.

CHAPTER FIVE

CONCLUSIONS

Length frequency data collected during the bi-annual surveys of 1992 to 1997 show no seasonal differences in the distribution of *M. capensis* on the south coast of South Africa (Figs 2.3-2.4). This series of cruises shows that the mean length of *M. capensis* increases with depth during both seasons that were considered. Thus these results are in accord with those of Badenhorst and Smale (1991) who concluded that this species was always widespread over the continental shelf and that older individuals were more abundant offshore. These similarities are to be expected when considering that the same type of methods described in detail by Payne *et al.* (1984) were used to survey the current series of data and that which was utilised in the study of Badenhorst and Smale (1991). Apart from depth, this study found longitudinal distribution to be less distinctive for this species with fish less than 30 cm mostly distributed west of 23° E within the 0-100 m depth stratum. Seasonal density comparisons of *M. capensis* were complicated by the unequal number of trawls between autumn and spring. It is also possible that certain areas were trawled in one season and not in the other and thus if seasonal density is of importance these factors need to be considered in future studies.

Commercial trawls and longlines have different selectivity properties on *M. capensis*. Catch data showed that longlines are highly size selective when compared to commercial trawls. Commercial trawls catch a suite of sizes while longlines catch only the large fish. When considering these differences it should be noted that the two fishing methods operate on different grounds. However, there is no reason to believe that when they operate on the same grounds their selectivity properties would be

similar. This point was tested during the longline experimental study of Japp (1995) and results showed that on any ground, longlines were more size selective than commercial trawls.

The distribution of males was markedly different to that of females in the longline catch. This was not the case in the trawl aggregations (Fig. 2.8). If *M. capensis* females grow to be bigger than males and longlines select for large individuals, this should hardly be surprising. This comparative analysis of the selectivity properties is very important for modelling the impacts of the two methods and has been further used for that in this study. It is also becomes important when it comes to future allocation of catches between the two fishing methods.

The sex specific age structured production model (ASPM) analysis showed both sexes collapsing within a decade (Fig. 4.4). This is unlikely, considering all the other results and the general stability of the hake fishery over many years. Even if management measures were conservative (e.g. reduction of the TAC) the resource collapsed after a decade. The conclusion here is that this part of the results should be treated with great caution as the model was very sensitive to sex specific parameters and thus the sex specific analysis could be taken further with a better set of input parameters (e.g. sex ratios in the population).

Given that *M. capensis* has for many years been harvested by trawls only, potential impacts of introducing longlining for this resource need to be fully assessed before a final decision can be taken regarding the use of longlines. A question that is of most significance is that concerning the spawning biomass of the resource. This is because,

without a viable spawner biomass there would be no future catches. This means that the resource needs to be harvested in a way that allows sufficient young fish to mature to maintain a stable spawner biomass. A second consideration is the maximum yield expected for a particular fishing method. Good management seeks to maximise yield, while assessing long-term sustainability of the resource. Thus YPR analyses were carried with a view of addressing these questions when both or only one fishing method was allowed to operate.

Per-recruit analyses have shown that for the same catch levels, longlines leave a larger spawner biomass in the population when compared to trawls (Fig 3.3) which is similar to the results of Geromont *et al.* (1995a and b). Longlines also provide a better yield than trawls if the catch limit is the same when only one fishing method is operating at a time. These differences are a result of the different size selectivity properties of the two fishing methods. If these do not change, the conclusion is that permanent use of longlining should be given serious consideration because longlines would act to conserve the resource and improve yields. This conclusion is dependent on the assumptions made during the modelling, the data used and the degree to which the model was able to truly reflect the actual reality. It should be noted here that the results depend on the choice of natural mortality (M) and that the value of M can change with time. There is also very little evidence that the selectivity properties will stay constant for a long time. Thus more robust assessments will have to be carried out before this conclusion is take to fisheries managers. Socio-economic aspects, which are beyond the scope of the present work, will also need to be considered.

Comparing the impacts when the two are operating at the same time, yield per recruit (YPR) analyses suggests that a larger longline proportion would improve spawner biomass. Reduction of the trawl catch limit would also benefit the trawlers as the improved spawner biomass (due to longline selectivity) would act to improve the population numbers if there is a positive spawner – recruitment correlation.

The ASPM suggests that any increase in the TAC (from that of 1997) in the trawl catch would result in spawner biomass reduction (Fig 4.2). The ASPM analyses also suggest that increasing the proportion of the TAC allowed to longline would act to improve the spawner biomass without a reduction in the total TAC. When considering these model results it is worth noting that improved estimates of input parameters (e.g. natural mortality and the *h* parameter) to the models are required as most of these parameters were taken from the literature.

The per recruit models (YPR and SBPR) are different to the ASPM and this makes it difficult to quantitatively compare the results from the two. For example, per recruit models look at the impacts of a particular fishing mortality (Fig 5.1) whereas the ASPM would look at the impacts of allocating a specific TAC. Thus the ASPM can project over time (Fig. 5.2). These differences must be taken into consideration when looking at the results of per recruit models and ASPM. Having noted the differences between the two, it is worth mentioning that on the question of the potential impacts on spawning biomass, per recruit analysis results were qualitatively similar to those of the ASPM. Figure 5.1 is a YPR output and Figure 5.2 is from the ASPM. Figures 5.1 and 5.2 show the effects of longlining and trawling on the spawning biomass. Both models suggest that trawls reduce the spawner stocks far more than longlining. These

results are based on the 1996 size selectivity properties (Fig. 3.1) of the two fishing methods

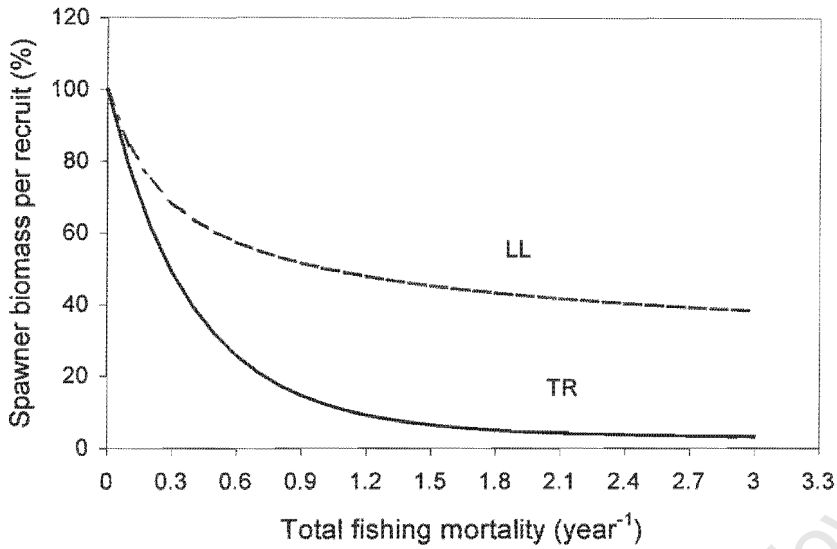

Fig. 5.1: Spawning biomass per recruit against fishing mortality of trawl (TR) or longline (LL) only. Spawning biomass is expressed as a proportion of the unexploited spawner biomass.

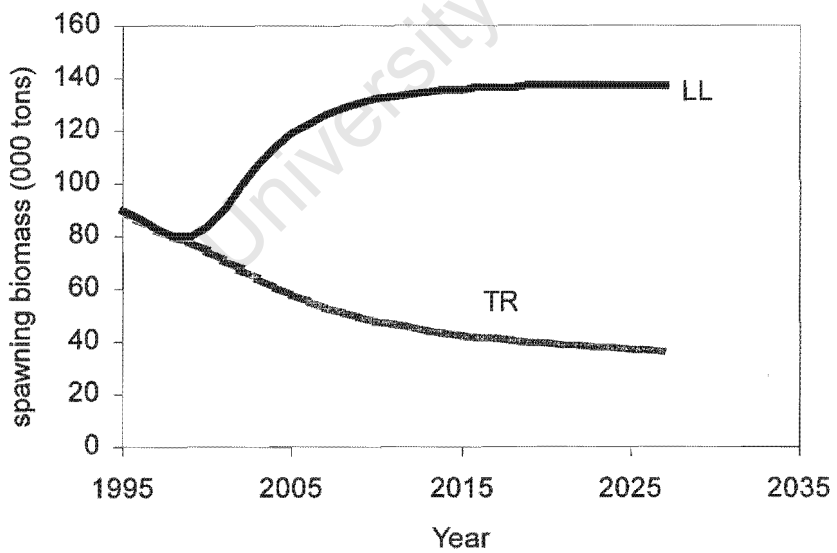

Fig. 5.2: ASPM Projected spawning biomass of trawl (TR) only and longline only (LL).

This study has attempted to adress a number of questions related to the longline and trawls fishery for hake and specifically *M. capensis*. The results presented here are largely depended on the selectivity values of the two fleets. A change in selectivity properties will most probably affect the impacts that the fleets have on the resource. If, for example, the longline age at first capture was to move towards smaller sizes, then the difference between trawls and longline is likely to be reduced. Since the present study made use of selectivity values estimated in 1996, it is suggested that new selectivity values be produced and compared to those used here. As mentioned earlier, a socoi-economic analysis is also needed before a permanent decision is taken regarding longlining and trawling for hake.

This study, depending on the degree to which the modelling was correct, offers two management options. Longlines should be restricted to the rough grounds and not be allowed to operate on the trawl areas. Any movement by the longlines to the soft bottom areas is likely to lead to a conflict. This particular point has also been stressed by Japp (1995). The second option would be to increase the longline proportion of the TAC provided that there is adequate recruitment and an increase in the hake biomass. Thus new entrants (the stated reason for introducing longlining) would be able benefit from the fishery without putting the trawlers in a position where they will have to reduce their catch.

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Appendices

Appendix A1: Length frequency data from longline and commercial trawls catches used to compare size distribution. (MCM unpublished data).

	Commercial Trawls			Longlines		
Size	1994	1995	1996	1994	1995	1996
19	0	0	0			
21	2491	0	2956			
23	11762	631	13335			
25	37210	12540	33519			
27	129081	66743	142764			
29	413794	220241	374605			
31	594437	511278	1123290	0	0	0
33	944667	678386	1416520	0	0	0
35	1084873	1122760	1730262	0	0	0
37	1082382	1301061	2365581	0	0	0
39	996667	1296101	2141195	219	206	0
41	937973	1328473	1615828	109	309	0
43	892030	1277670	1687300	1040	155	0
45	792275	1196409	1193531	1204	825	545
47	748711	1021539	929353	3394	1083	5447
49	848961	922307	868211	5858	2526	14434
51	676740	755210	635876	11278	4898	21788
53	502551	573541	445092	17902	9539	41397
55	458831	405267	342154	28139	11292	58827
57	452575	337883	284329	35201	22893	51473
59	401976	288524	242221	41497	21604	65091
61	326948	259274	212955	41661	27379	75712
63	220258	204248	156165	45822	33360	93142
65	135238	161207	108933	42373	29596	101313
67	79586	130930	67580	40402	38567	118471
69	53727	85152	53292	39472	36557	122011
71	24118	56309	31220	33340	39135	125552
73	19716	31249	14698	30329	42795	121194
75	11210	13535	6602	22719	32225	95594
77	5803	6201	3071	18723	35577	79525
79	3779	2512	2184	13413	30833	61550
81	1217	759	460	10402	25058	34043
83	1118	684	0	7117	21191	32409
85	665	214	0	5365	16396	17430
87	255	0	0	4161	14334	9260
89	0	0	0	3121	8611	3268
91	0	0	0	2245	4434	4085
93	0	0	0	1533	3300	1906
95	0	0	0	493	1341	1089
97	0	0	0	328	877	272
99	0	0	0	55	258	0
101	0	0	0	55	155	0
103	0	0	0	0	0	0

Appendix A2: *M. capensis* assumed sex proportion for the South Coast inshore population. These were used as sex length-keys to convert catch in length to sexed catch in length (MCM unpublished data).

	1994		1995		1996	
Size	Male	Female	Male	Female	Male	Female
19	0.85	0.15	0.00	1.00	0.02	0.98
21	0.83	0.17	0.04	0.96	0.03	0.97
23	0.66	0.34	0.07	0.93	0.03	0.97
25	0.60	0.40	0.16	0.84	0.14	0.86
27	0.53	0.47	0.31	0.69	0.31	0.69
29	0.54	0.46	0.51	0.49	0.46	0.54
31	0.52	0.48	0.57	0.43	0.46	0.54
33	0.53	0.47	0.57	0.43	0.49	0.51
35	0.58	0.42	0.56	0.44	0.56	0.44
37	0.54	0.46	0.53	0.47	0.52	0.48
39	0.55	0.45	0.48	0.52	0.55	0.45
41	0.51	0.49	0.54	0.46	0.66	0.34
43	0.54	0.46	0.59	0.41	0.68	0.32
45	0.57	0.43	0.58	0.42	0.64	0.36
47	0.61	0.39	0.56	0.44	0.60	0.40
49	0.66	0.34	0.60	0.40	0.63	0.37
51	0.58	0.42	0.59	0.41	0.60	0.40
53	0.57	0.43	0.59	0.41	0.63	0.37
55	0.59	0.41	0.57	0.43	0.61	0.39
57	0.59	0.41	0.57	0.43	0.63	0.37
59	0.69	0.31	0.60	0.40	0.52	0.48
61	0.54	0.46	0.59	0.41	0.63	0.37
63	0.58	0.42	0.63	0.37	0.55	0.45
65	0.44	0.56	0.60	0.40	0.69	0.31
67	0.55	0.45	0.65	0.35	0.62	0.38
69	0.43	0.57	0.53	0.47	0.50	0.50
71	0.60	0.40	0.54	0.46	0.48	0.52
73	0.22	0.78	0.31	0.69	0.22	0.78
75	0.23	0.77	0.33	0.67	0.11	0.89
77	0.10	0.90	0.22	0.78	0.36	0.64
79	0.35	0.65	0.14	0.86	0.23	0.77
81	0.00	1.00	0.00	1.00	0.25	0.75
83	0.00	1.00	0.43	0.57	0.08	0.92
85	0.14	0.86	0.11	0.89	0.00	1.00
87	0.00	1.00	0.00	1.00	0.00	1.00
89	0.00	1.00	0.00	1.00	0.00	1.00
91	0.00	1.00	0.00	1.00	0.00	1.00
93	0.00	1.00	0.00	1.00	0.00	1.00
95	0.00	1.00	0.00	1.00	0.00	1.00
97	0.00	1.00	0.00	1.00	0.00	1.00

Appendix A3: *M. capensis* age length-key for the South Coast inshore population for 1994. Key is used here to convert catch in length data to age (MCM unpublished data).

Size	0	1	2	3	4	5	6	7	8	9
7	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.83	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.17	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.30	0.70	0.00	0.00	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
35	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
41	0.00	0.00	0.00	0.23	0.77	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.18	0.82	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
47	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
49	0.00	0.00	0.00	0.00	0.92	0.08	0.00	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.15	0.85	0.00	0.00	0.00	0.00
53	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
55	0.00	0.00	0.00	0.00	0.08	0.92	0.00	0.00	0.00	0.00
57	0.00	0.00	0.00	0.00	0.00	0.93	0.07	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.75	0.25	0.00	0.00	0.00
61	0.00	0.00	0.00	0.00	0.00	0.21	0.79	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
65	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
67	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.14	0.00	0.00
69	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.17	0.00	0.00
71	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.88	0.00	0.00
73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.22	0.00
79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.57	0.00
81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.33
83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.71	0.00
89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50
91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.67
93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
101	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
103	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix A4: *M. capensis* age length-key for the South Coast inshore population for 1995. Key is used here to convert catch in length data to age (MCM unpublished data).

Size	0	1	2	3	4	5	6	7	8	9
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.33	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.09	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.75	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.30	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.18	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.65	0.35	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.39	0.61	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.15	0.85	0.00	0.00	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
35	0.00	0.00	0.00	0.96	0.04	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	0.57	0.43	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.33	0.67	0.00	0.00	0.00	0.00	0.00
41	0.00	0.00	0.00	0.04	0.96	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
47	0.00	0.00	0.00	0.00	0.75	0.25	0.00	0.00	0.00	0.00
49	0.00	0.00	0.00	0.00	0.33	0.67	0.00	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
53	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
55	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
57	0.00	0.00	0.00	0.00	0.00	0.79	0.21	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.27	0.73	0.00	0.00	0.00
61	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.04	0.00	0.00
65	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
67	0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.46	0.00	0.00
69	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.91	0.00	0.00
71	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.96	0.00	0.00
73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.05	0.00
77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.35	0.00
79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.80	0.00
81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.44
89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
101	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
103	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix A5: *M. capensis* age length-key for the South Coast inshore population for 1996. Key is used here to convert catch in length data to age (MCM unpublished data).

Size	0	1	2	3	4	5	6	7	8	9
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.86	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.25	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.22	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.75	0.25	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.33	0.67	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.09	0.91	0.00	0.00	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
35	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	0.75	0.25	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.33	0.67	0.00	0.00	0.00	0.00	0.00
41	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.92	0.08	0.00	0.00	0.00	0.00
47	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00
49	0.00	0.00	0.00	0.00	0.25	0.75	0.00	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.09	0.91	0.00	0.00	0.00	0.00
53	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
55	0.00	0.00	0.00	0.00	0.08	0.83	0.08	0.00	0.00	0.00
57	0.00	0.00	0.00	0.00	0.00	0.36	0.64	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.17	0.83	0.00	0.00	0.00
61	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
65	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
67	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.67	0.00	0.00
69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.67	0.00
79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.88	0.00
81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50
89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.67
95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
101	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
103	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
105	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix A6: *M. capensis* catch data for the South Coast inshore fishery for both longline and commercial trawl. Data are taken from R. W. Leslie pers. comm.

Year	Trawl catch in tons	Longline catch in tons
1967	10000	0
1968	10000	0
1969	10000	0
1970	10000	0
1971	10000	0
1972	10000	0
1973	10000	0
1974	10056	0
1975	6372	0
1976	5740	0
1977	3500	0
1978	4931	0
1979	4931	0
1980	4931	0
1981	9400	0
1982	8089	0
1983	7672	0
1984	9035	16
1985	9203	357
1986	8724	386
1987	8607	449
1988	8417	402
1989	10038	169
1990	10012	348
1991	8206	4270
1992	9252	2599
1993	8870	278
1994	9569	1129
1995	10630	1447
1996	11062	3354
1997	8834	3979