Exploitation patterns of the multi species/gear hake (*Merluccius capensis and paradoxus*) fishery on South Africa's southeast coast.

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Abstract

The motivation for this study was to examine the exploitation patterns of the *M.capensis* and *M.paradoxus* hake fisheries on the Southeast Coast, and determine the size and species of hake caught in each of the hand-line, long-line, and trawl methods. The hand-line hake fishery has increased substantially over the last several years and concerns are beginning to emerge about the impact this will have on the inshore resource. collected on the South Coast between August 1998 and July 1999 was used to describe the hand-line method and estimate annual landings. Data on the size and species in long-line catches of hake caught during 1997 were already available for this study. Size distributions in trawl catches were determined from commercial category landing data reported by catch weight and depth. The species composition in these catches determined by comparison using *RV Afrikana* survey data collected in the same depth regions. Location plays a significant role in determining the sizes and species of hake caught by each gear. Hand-lines catch smaller sizes on average than do long-lines, inshore trawls target mainly *M.capensis* while offshore trawls catch both hake species. A substantial amount of the hand-line hake caught on the South Coast is not reported. Examination of the exploitation patterns reveal that intense trawling pressure is directed at the smaller sized *M.paradoxus* inhabiting the depth region between 160-400-meters. Inshore trawls discard a large amount of small sized *M.capensis* within the 100-meter isobath. A preliminary stock assessment on the status of each hake species found that *M.paradoxus* appears to be over-exploited while *M.capensis* was in better shape. However, length-based pseudo-cohort analysis, used in this assessment, is critically

reliant on having length frequency data from a steady state population in equilibrium. This limits the application of this model for management purposes and this finding is purely theoretical at this stage. Results suggest that each hake species is under a different pattern and level of exploitation and the multi-species nature of hake stocks on the South Coast should be considered in developing optimum management policies. Future work should focus on developing appropriate age/length keys so that an age-based VPA, which is more powerful than the length-based approach, can be applied towards stock assessments on the South Coast. Alternatively, length-data covering a longer period should be compiled and the equilibrium assumption further investigated so that the results from length-based models can be used with more confidence.

Contents

Chapter 1

Hake Stock Assessments – An overview of Current Methodologies and Management Policies

The Cape Hakes have been assessed as a single stock exploited by one fleet when in fact they consist of two species *Merluccius capensis* and *Merluccius paradoxus* exploited by several fleets. Their complex interactions have until recently been left out of most hake stock assessments and management policies. Geromont and Butterworth (1999) initiated a preliminary analysis of these interactions on the South Coast using a fleet disaggregated age-structured production model, but defining appropriate catch-at-age data for these two species has remained something of an enigma. *M.capensis* described as shallow water hake inhabits the inshore waters to a depth of 380-meters, while *M.paradoxus* occurs offshore between depths of 150m-800-meters (Payne 1989). Mixing between their respective inshore and offshore distributions has long created problems for separate species stock assessments. This overlap area was found to be inhabited predominantly by 1-2 year old *M.paradoxus* and 5-6 year old *M.capensis* (Badenhorst and Smale 1991). Trawls operating in these areas have not been able to dissociate catches before reporting their landings.

The International Commission for the Southeast Atlantic Fisheries (ICSEAF) created a series of divisions along the Southern African coastline. Divisions 1.3 + 1.4 (85% *M.capensis*) + 1.5 (70% *M.capensis*) + 1.6 (90% *M.paradoxus*) on the West Coast and Divisions 2.1+2.2 (70 % *M.capensis*) on the South Coast. Scientists generally agreed that stocks formed integral units in each division (Payne 1989). For management purposes, the South and West Coast stocks have been assessed separately using the ICSEAF boundary formed between Divisions 1.6 and 2.1. This diagonal boundary running southwest of Cape Agulhas was used as a means of separating the predominantly *M.capensis* South Coast stocks from their West Coast *M.paradoxus* counterpart. Since then it has been proposed that a more appropriate boundary would follow the 20° E longitudinal precluding Browns bank an area inhabited mostly by *M.paradoxus* and distinct from the predominant *M.capensis* catches on Agulhas bank (Leslie 1998). A general agreement between the fishing industry and the Department of Marine and Coastal Management (MCM) has aimed at splitting the annual TAC by a 2:1 ratio between the West and South Coast respectively (Chief Director Sea Fisheries 1997). The consequences of erroneous placement of this boundary on current management strategies were negligible provided the desired ratio was maintained (Punt et al. 1995).

Biomass dynamic or surplus production models coupled with the $F_{0.2}$ harvest strategy for Cape hakes have undoubtedly been successful so far in assessing hake stocks since their collapse in the 1970's. These models have been applied in many different forms based on a given data set and alternative biological parameters. The observation-error estimator form of the Butterworth-Andrew (1984) model has been reviewed and established as best model-estimation procedure when compared to other methodologies (Punt 1992b). This model is based on the Shaefer (1954) surplus production model but instead of assuming equilibrium a dynamic biomass estimate from a time series of *cpue* data was used to fit model parameters. Butterworth et al. 1992 attributes the successes achieved in managing hake stocks to the replacement of equilibrium models by dynamic production models, evident in the increasing trend in *cpue* over the last 15 years. The $F_{0.2}$ harvest strategy was initially used to assist in rebuilding dilapidated stocks. This strategy aimed at reducing the *total allowable catch* (TAC) to a level below the calculated *maximum* *sustainable yield* (MSY), thus allowing part of the surplus production to go to rebuilding the stocks. The $F_{0.2}$ strategy was initially set to equal the value of F where the slope on the yield effort function is 0.2 times the initial slope passing through the origin. This harvesting strategy was recently reduced to $F_{0.075}$ by the Sea Fisheries Advisory Council in August 1998 (Geromont 1999). Historically, these methods have assessed the combined hake biomass rather than the individual populations of the constituent species *M.capensis and M. paradoxus*.

The recent expansion of long-lining and hand-lining fisheries has raised new questions about current assessment methods and the individual status of each species. These fisheries target the *M.capensis* population almost exclusively and concerns have been mounting about disproportionate amounts of effort collapsing the inshore component. Japp and Wissema (1999) provided an overview of long-lining in South Africa that covered both the West and South Coast hake grounds. These studies concluded that any expansion of longlining should give priority to separate species management policies; *M.capensis* is the predominant target species on the South Coast while *M.paradoxus* is caught predominantly on the West Coast. It was further suggested that any increase above 10% of the TAC would begin to impact substantially on spawning stock biomass and should proceed cautiously to allow time for testing the effects on recruitment. The hand-line fishery has developed rapidly over the last several years, but it has never been assessed and the impact on the inshore hake resource is unknown. Hand-line quota was set at 2500-tons in 1998 and 1999.

Surplus production and ad hoc tuned Virtual Population Analysis (VPA) models have been applied to hake assessments on the South Coast with different appraisals of status and productivity (Punt 1994); conflicts between catch-at-age information and the *cpue* and biomass data were cited as causing this discrepancy. Large areas of unsuitable bottom topography have hampered biomass estimates on the South Coast using the swept area method and commercial trawl data separated by species has not been available (Leslie 1998). Aggregation of data was considered to not seriously compromise assessment results using these methods (Punt 1992a), but comparisons between surplus production and VPA models using disaggregated data sets have not yet been conducted.

Age-structured production models have been used to assess hake stocks on the South Coast. Geromont and Butterworth (1997) estimated the number of recruits entering the fishery each year by fitting *cpue*, survey biomass and commercial and survey catch-at-age data to stock-recruitment models. Difficulties were encountered in having to rely on unrefined catch-at-age data that included combined landings data of both species. Since then, these models have been further developed into fleet-disaggregated age-structured production models for separate species *M.capensis* and *M.paradoxus* (Geromont and Butterworth 1999). A TAC recommendation for the South Coast (E of 20°E) *M.capensis* stock was concluded using this method, but assessments for the *M.paradoxus* stocks were inadequate. Non-representivity of historic *cpue* data and inappropriate boundary assumptions were given as possible causes for the poor fits of this model to *M.paradoxus* data.

Establishing accurate catch-at-age data and applying age-based models towards hake stock assessments have been plagued with problems. The growth rates of Cape Hakes on the Agulhas bank (*Merluccius capensis and paradoxus*) although similar were found to differ considerably between the sexes (Kono 1980). The ability to determine age from otolith readings has not yet been refined because of an inability to ascertain timing in the first ring formation. The first distinct annual ring in hake otoliths has been described as proceeding a demersal ring laid down in the transitional life stage from pelagic to demersal existence (ICSEAF 1983). This has created problems in determining the correct age of smaller specimens and errors are frequently made, especially in differentiating between one and two year old specimens. Botha (1970) concluded that a large proportion of one-year-old hake in the Luderitz area had two distinct rings in their otoliths and therefore were incorrectly read as two-year–olds. Although these studies have shown that the demersal ring disappears in older specimens, a non-subjective means of determining apart these initial otolith rings in the smaller sizes still needs to be developed. Wysokinski (1982) applied an analysis to modal lengths in determining the growth of young hake and concluded that the first clearly visible ring should be interpreted as a secondary ring rather than the first annual ring. Appropriate and accurate sex /species based age-length keys are needed before VPA and other age based models can be applied to historic catch data.

The South African Network for Coastal and Oceanic Resources (SANCOR) launched a program in 1995 aimed at preliminary assessments of discarding in the South African trawl fisheries. The effects of hake discarding on the South Coast have not yet been fully analyzed, but are in the process of being assessed (Hart 1999). This problem is especially severe close inshore where trawls targeting sole (*Austroglossus pectoralis*) aggregate in close proximity to the inshore nursery grounds of *M.capensis*. The major concern so far has been the exclusion of discarded hake biomass in the determined annual TAC quota, but *growth over-fishing* is an equally important consideration that has not received a great deal of attention.

This study has aimed at establishing the exploitation patterns of the hand-line, long-line, and trawl fisheries and assessing the individual status of *M.capensis* and *M.paradoxus* on the Southeast Coast. Establishing the spatial distribution patterns and catch-at-length data for each hake species has formed an important part of this analysis: the size and species of hake caught changes with depth, location and gear type. The use of length-based models to analyze the effects of *growth over-fishing* on each species have been implemented in order to determine their relative status as it relates to fishing pressure. This study has focused on establishing catch-at-length data for all gears operating between longitudes (20° E and 27° E) on the Southeast Coast in 1997.

Chapter 2

The hand-line hake fishery off the Southeast Coast

Introduction

Targeting hake with hand-line has increased rapidly on the South Coast and now forms an integral part of the inshore hake (*Merluccius capensis*) fishery. The extent of ski-boat activity has been difficult to quantify because of the difficulties faced in monitoring this fishery. Some vessels are seasonal and others operate without permits. The requirement that monthly reports be submitted to the National Marine Line-Fish System (NMLS), a catch report database administrated by the Marine and Coastal Management agency (MCM), has not been adhered to by all participants and landing reports are considered dubious (Sauer et al. 1997). Catches have not been monitored and the exact amount of hake being landed remains unknown. Until now this component of the inshore hake fishery has never been assessed and the impact on the resource is unknown.

The first attempts at managing the line-fishery in South Africa were made by the National Marine Line-Fish Committee appointed in 1985 after reports of dwindling catch rates and reduced sizes in target line-fish species (Sauer et al. 1997). Management measures introduced included licensing of commercial and recreational fishermen, bag limits, minimum size limits and special protection for species whose status was becoming critical. A two-tiered licensing system consisting of commercial (A-category) and semi-commercial (B-category) permits was introduced. A-category permits allow full commercial exploitation of all line-fish species and B-category permits limit the number of species to be caught. The objective of having a two tiered system was to reduce A-category permits and issue B-licences in their place in order to steer effort off vulnerable reef fish (C.G. Wilke, Marine & Coastal Management, [MCM] pers. comm.). However, due to the existence of strong lobby groups and a lack of biological data little progress has been made and critical line-fish species continue to be over exploited. A new set of management measures for the South African line-fishery is currently under review.

The Sea Fisheries Act of 1988 hake had initially placed hake on the "*exploitable*" list allowing unlimited harvest by both A and B type permit holders. This ruling has effectively remained in force even though the new Marine Living Resources Act of 1998 had placed hake on the restricted list (Japp 1999). There has been a considerable amount of uncertainty surrounding legislation and control of new regulations and with the lack of proper enforcement the situation has been exasperated.

At least 120 licensed vessels, either full-time (A) or part-time (B), consisting of 26 deck-boats and 94 ski-boats were estimated to be operating on the Southeast Coast during 1997-1999 (MCM, Unpublished data). A similar estimate of 27 deck-boats and 105 ski-boats was recorded in an industry-compiled report (Japp 1999). These estimates did not include the many unlicensed recreational fishers that target and sell hake illegally, estimated at 25% of the total ski-boat effort.

The latest management initiative to be proposed has called for the establishment of three commercial licensing categories, a line-fish (L-F) permit, a Hake (H) permit and a Tuna (T) permit (C.G. Wilke, [MCM]). It was suggested that catches within these categories would be mutually exclusive with the exception of snoek (*Thyrsites atun*), which would be available for targeting by all permit holders. It was envisioned that the line-fish (L-F) permit would be subject to special constraints and conditions depending on the status of exploitable line-fish species at the time of issue.

Clarification on aspects of the hand-line hake fishery has been initiated in this chapter in support of this proposed management plan. The major aims have been to describe the hand-line method and establish biological indicators with a view of determining appropriate management procedures for this component of the inshore hake (*M.capensis*) fishery. These objectives have been determined as follows:

- Describe vessel type and usage
- Determine size distributions in hand-line catches
- Estimate annual hake landings
- Develop a standardized measure of *cpue*
- Examine the relationship between bottom water temperature and catch rates
- Determine sex ratios in hand-line catches

Methods

Monthly length measurements were randomly taken from ski-boat landings in Mossel Bay and Plettenberg Bay between August 1998 and June 1999. Statistics describing these measurements were compiled for each month (Table 1). A prolonged sampling protocol was adapted, sampling methodically over a prolonged period removes bias incurred from instantaneous cohort structure or seasonal migration of large specimens close inshore. All combined length frequency measurements were combined to determine size distributions in hand-line catches. Collecting biological information such as sex determination was only possible from sampling catches at sea when space was available and boat owners granted permission to board. Due to constraints in this regard these data set only exist for the period between August 1998 and February 1999.

Size distributions in the hand-line catches were assumed to remain constant over the last several years and length frequency data collected during the above sampling period was compared to catch data from other gears made available for 1997. Estimating total catch-at-length frequencies required the sample distribution to be raised by a factor of total hand-line catch weight / sample weight. The reports submitted to the National Marine Linefish system (NMLS) were not used to determine the total hand-line catch weights and a separate estimate was obtained.

Hake landings reported to the National Marine Linefish System (NMLS) were checked against the invoicing records of two private processing companies in Mossel Bay. Four hundred and forty seven invoices sale records from 40 ski-boat vessels were taken over a seven-month period. These catches, amounting to 75640-kg in total, were sold between August 1998 and February 1999. Each record provided the boat name, amount of hake bought and the date of sale. These were compared to the records submitted to the NMLS as a means of verifying their accuracy. Catches were documented as having been either submitted or not submitted. If an operator had not submitted any catch returns for the month sales were made then these catches were tallied as unreported catch. Catches were considered to have been reported if catch returns were submitted during the months when sales were made. The next determination to be made was checking the accuracy of those catch-returns that had been submitted. In making this determination, only those vessels with consistent sales records for the entire month were used. It was assumed that these vessels had not sold their catch to other buyers and their sales monthly totals were a true reflection of what had been landed. An amount totaling 19773-kg of summed monthly sale figures was available for this comparison and these were checked against the monthly catch-returns submitted to the NMLS. Boat licenses were noted to determine if they were operating as registered license holders, a pertinent factor in determining the magnitude of unreported hake catches.

A standardised *cpue* index requires the relationship between increasing fishing effort and fishing mortality to be additive. Catch per man-day describes this relationship more accurately than catch per boat-day because crew sizes differ so widely between boats. It is important to identify which fish species is being targeted when determining the amount of hake caught. Ski-boats target a variety of species based on availability. Clearly then an erroneous result would occur if hake catches per fisherman were taken from a crew that had been targeting other exploitable species. Landing records provided by local wholesalers in Mossel Bay show a distinct trend in alternate catches of either hake or other target species like Kob (*Argyrosomus* spp.) and/or reef fish (*Sparidae* spp.). Therefore *cpue* estimates were derived using only those ski-boat landings with hake catches > 10 kg per boat-day. These boats had low catches of Kob / reef fish and it was assumed that they were targeting hake. The average catch per man-day indices calculated from these records were compared to the hake catch returns sent to the National Marine Line-fish system (NMLS).

Bottom water temperatures off Mossel Bay were made available by technical staff working at the MOSSGAS drilling station located approximately 45 nautical miles due south of Mossel Bay. This data created an ideal opportunity to make some interesting comparisons of catch rates versus water temperature. Catch rates were correlated to these temperature data using catch per man-day indices formulated from the NMFS data base file for the two major fishing regions, Plettenberg Bay and Mossel Bay. It was assumed in defining the correlation that the bottom temperature trends off Mossel Bay would influence the average inshore temperatures for both regions.

Determining sex selectivity in hand-line catches required sampling at sea because catches were always gutted before being landed. Monthly observations were pooled into seasonal components; sex ratios for Spring used data taken from August until the end of October and ratios in Summer used data taken between November and the end of January (Table 3). The Chi-square statistic was used to test the hypothesis that sex ratios are independent of changing seasons. Gonad staging was recorded in six stages:

0)	Absent	Gonads are indiscernible because of “frill on gill”
1)	Immature	Immature no visible signs of eggs
2)	Active	Tiny eggs beginning to form in ovaries.
3)	Ripe	Ovaries large and distended, filled with eggs.
4)	Ripe and Running	Eggs readily extruded through cloaca.
5)	Spent	Ovaries visibly empty but large.

Results

Vessel descriptions

Hand-line vessels were categorized as being powered either by inboard or outboard engines. Inboards were observed to run on diesel, have bunks for overnight accommodation and be equipped with large ice compartments for storing fish. The smaller outboards or ski-boats were found in almost all cases to be gasoline powered and restricted to single day trips. Twin-hulls or catamarans are preferred over mono-hulls because of the initial stability factor attributed to this type of hull design. These reduce the rocking motion from swells making it easier to fish.

Although catamarans were in most cases fitted with inboard engines, some were equipped with outboards; inboards with twin hulls are usually referred to as deck-boats. Deck-boats usually carry between 12-15 crew and ski-boats carry between 2-8 crew. The exact number of boats operating in each region is unknown. Estimates for the three main regions in 1997 were 104 ski-boats and 26 deck-boats (Table 1).

Size distributions

The overall size distribution containing all length measurements taken in 1998 is symmetrical around a mean of 54 -cm (Figure 1). Measures of central tendency in monthly length distributions are void of any distinct trends between months and the mean and mode are closely matched for all months indicating symmetry in the monthly size distributions (Figure 2).

Size distribution curves were found to differ between gears; the average sized *M.capensis* caught by hand-lines was larger than inshore trawlers 0-160-meters ($P<0.001$) and smaller than long-line and offshore trawlers 160-400-meters ($P < 0.001$) (Figure 3). Larger sizes were caught by long-lines, which would be expected considering the different depths frequented by each gear. Hand-line effort was concentrated close inshore between 70-meters and 80-meters, while the majority of long-line fishing occurred in deeper water at around 200m.

Hake Landings

The majority of hand-line catches in 1997 were made off Mossel Bay and Plettenberg Bay and to a lesser extent Port Elizabeth, Knysna and Jeffrey's Bay (Figure 4). Hand-line hake catches have grown rapidly over the last 5 years. Catches reported to the National Marine Line-Fish System (NMLS) increased from 362-tons in 1995 to 1962-tons in 1998.

A substantial amount of hand-line caught hake was found not reported to the National Marine Linefish System (NMLS). From the invoicing records taken in Mossel Bay at least, 44844-kg out of the 75640-kg sold or (59.4%) had not been reported and no catch returns existed for those sale months. Of the unreported catches 34482-kg or (45.5%) could be attributed to licensed operators who had simply failed to submit catch-returns and 10362-kg or (13%) was landed by unlicensed operators (Figure 5). Approximately 27% or 11 out of the 40 ski-boats in this analysis were not licensed.

In this analysis, catch-returns from operators that had been submitted to the National Marine Linefish System (NMLS) were deemed reasonably accurate, although there was a slight tendency to under report catches. Licensed operators with consistent monthly sales reported 18,532-kg of the 19,733-kg sold to private companies in Mossel Bay. Catch returns in this scenario were under reported by a factor of 0.94. This was considered negligible compared to the unsubmitted data and was not included in calculating total landings.

The estimated amount of hake landed in Mossel Bay was calculated by raising reported landings by the estimated 59.4% that goes unreported. Hake landings were estimated as being 2.1739 times higher than that reported to the NMLS. These findings were extrapolated to reflect ski-boat activity for the South Coast region and hake landings reported to the NMLS over the last five years (Figure 6). Hand-line landings in 1997 using this scenario were estimated at 3955-tons.

Hand-line hake catches formed a substantial portion of the annual hake yield on the South Coast east of 20° E, totaling 44,095-tons in 1997. Of the total hake catch, offshore trawls harvested 34, 147- tons (75%), inshore trawls harvested 5,346-tons (12%), long-lines caught 1,715-tons (4%) and hand-line catch was estimated at 3,955-tons (9%) (Figure 7). In the inshore hake (*M.capensis*) fishery, total catches by all gears combined were estimated at approximately 25,684-tons. Hand-line and long-line catches in this sense form a substantially greater portion of the overall *M.capensis* yield with respective landings at 15 percent and 7 percent of the total harvest (Figure 8).

Standardized catch per unit effort

The relationship between catch-per-boat and crew size was found to be linear and boat catches increased with larger crews (Figure 9). Therefore, catch per man-day was chosen as the best means of describing the additive effects of increasing effort on catch rates. The average amount of time spent fishing per day (24-hour period) was approximately 14 hours.

The average hake catch per man-day calculated from factory landings in Mossel Bay was 29.87 kg; the distribution was positively skewed with a large variance around the mean (Figure 10).

Comparisons between catch-rates reported to the National Marine Line-Fish System (NMFS) and those derived from factory landing records were similar. The average catch per man-day that was reported to NMLS during the same period was 31.11 kg in Plettenberg Bay, 25.96 kg in Mossel Bay and 26.01 kg for the whole region.

Bottom temperature versus catch rates

Trends in the average catch-rates off Plettenberg Bay and Mossel Bay were strongly correlated and influenced by bottom water temperature (Figure 11). Catches declined in July and August during which time bottom temperatures were higher than normal. Temperatures recorded at the MOSSGAS platform rose from a low of 9.95 ° C in June to 11.16 ° C in July and 12.37 °C in August (Table 4). Monthly catch-rates were always slightly higher off Plettenberg Bay and appeared to be less effected by bottom temperatures at the MOSSGAS platform. The 100-meter isobath is only 15 miles off Plettenberg Bay whereas it is 45 miles off Mossel Bay; this allows ski-boat fishermen in Plettenberg Bay to reach cooler waters with relative ease when inshore water temperatures begin to climb.

Sex selectivity

Gonad staging techniques revealed no significant peak in spawning fish with ripe and running gonads, although the percentage of large females with ripe gonads was higher in December (Figure 12). Of all the females caught 23% had ripe gonads, 3% were ripe and running, the rest were immature. Reproductive cells suffer sever emancipation when infected with “frill on gill”, a parasite that attaches itself to the host’s gills. Gonads eventually disappear altogether making sex identification impossible in these cases. Approximately 8% of all hake caught in the inshore region were infected with this parasite.

A trend of changing sex ratios was evident in the monthly samples taken onboard inshore hand-line vessels. The ratio was higher for males in August and September, and equalized in October and November before increasing for females in December through until March (Figure 12). The ratio of males to females was significantly different between Spring and Summer (Table 3). The probability of obtaining these ratios from random effects, using the chi-squared statistic, was calculated at less than 0.1% ($p < 0.001$).

Discussion

The major aims of this study have been achieved, to describe and document aspects of the hand-line fishery on the South Coast with a view of offering some future direction for effective management. Until this study was conducted, no fieldwork had ever been done. As a first step, establishing the expected size distributions in hand-line catches was of paramount importance, as was an estimate of their annual landings. Without this data, any attempts to analyze this fishery would have been futile. However, a lot still needs to be done and this chapter should be viewed as a preliminary analysis of the hand-line fishery. Some suggestions and comments have been added to for future direction.

One of the major dangers of a burgeoning hand-line hake fishery is that increased fishing pressure will be redirected onto other line-fish species. These will be targeted when hake catches become scarce. Seasonal fluctuations in availability and the capacity for absorbing new entrants will exasperate this situation if trends continue. Line-fish species currently on the critical list are in danger of being decimating. The solution is to grant hake fishing licenses on condition of sole execution, a privilege that should be revoked automatically if permit conditions are ignored. This type of approach is provided for in Section 28 of the Marine Living resources Act of 1998 (Anon. 1999): – If the holder of any permit fails to comply with the conditions imposed in the permit the minister may in the interests of protecting a particular marine resource cancel the permit.

The combined lack of proper management control and unmonitored landing points are the major difficulties in assessing hand-line catches of hake. The most obvious means of calculating annual hand-line hake catch is simply to multiply the average *cpue* by the total amount of effort. However establishing this relationship is fraught with difficulties. Estimating the number of boats operating on a particular day is almost impossible. Add to this the variability around the estimated number of man-days fished each month due to unfavourable weather conditions and the estimate becomes too broad to benefit any precise assessment. One solution would be to have observers at each landing point.

Catch returns that had been reported were deemed to be fairly accurate. This finding was strengthened by two separate accounts. Sales records matched submitted catch-returns and separately derived average catch per man-day estimates matched those compiled from catch-return data sent to the National Marine Linefish System. It would appear then that efforts to determine annual hand-line hake catches are being confounded by those license holders who fail to submit returns and/or unlicensed or “illegal” operators.

Effort-control is recommended as the most appropriate management tool for the hand-line hake fishery. For a set number of hand-line hake permits the boat owners would have a vested interest in protecting their stake in the fishery and would assist in deterring illegal operators. With much at stake the licence holder would be highly foolish to contravene the conditions. The need for area bound permits must be stressed in implementing this type of control. This would prevent a particular region from becoming inundated with migrant fishers during certain seasons making management controls a lot more difficult to implement. Spot checks for compliance would be easy to conduct and verification of catch-reports made simpler by monitoring a set number of randomly selected vessels. The fishery would be easier to manage and the effects on the resource could be analysed with a high degree of certainty allowing new entrants opportunities as conditions unfold.

A managed hand-line fishery has the potential of becoming a valuable component of the hake fishery and a benefit to the local communities in the form of jobs and infrastructure. The value to the South Coast economy was reported as supplying 1000 jobs and R51-million in infrastructure (Japp 1999). An unmanaged hand-line fishery will become a nightmare for conservationists, fishermen and management agencies alike. Research should focus on establishing the line-hake fishery as a more precise target fishery with reduced by-catch. This would have to be administered by stringent landing controls and spatial zoning of catch areas. Creating a target hake fishery would aim at substantially reducing by-catch of other line-fish species and monitoring the inshore hake catches with a view of maintaining a sustainable yield in the future. There would be a mutual benefit for both fishermen and management agencies if co-operation were to succeed. Operating costs would be reduced and monitoring a target specific fishery offers a high degree of control.

The changing ratio of males to females between spring and summer could be attributed to spawning behavior. In this study a significantly higher number of males to females were caught by hand-line during spring. The sex ratios in spawning schools of Pacific hake were thought to favor males (Grinols and Tillman 1970). Larkins et al. (1967) found similar sex ratios in spawning Pacific hakes and offered the explanation that males concentrate on the spawning grounds prior to the females arrival, the latter are considered to arrive, ripen, spawn and then move offshore. Payne (1998), using information on gonad development, postulated that spring and early summer are the preferred hake spawning seasons, but continuous spawning is considered to occur throughout the year. It may be possible that the high ratios of male

M.capensis found in the shallow fishing grounds during spring are a prelude to an early summer spawning. In terms of these migrations effecting catch rates and size distributions, no significant trends were evident from the data at hand. The reasons for this are uncertain, as the average size would be expected to increase after December when the percentage of females was higher. From observations on the hand-line fishery, these factors have little effect on operations. Fishermen do not follow any migration patterns or trends with the exception of bottom temperature. Factors influencing catch rates and movement in and offshore remain something of a puzzle for most fishermen who rely on trial and error. The major importance in estimating the exact time of spawning would be to validate the frequency of annual spawnings thus assisting efforts to accurately interpret otolith readings. A longer time series of data is needed to examine these trends more closely.

Figures

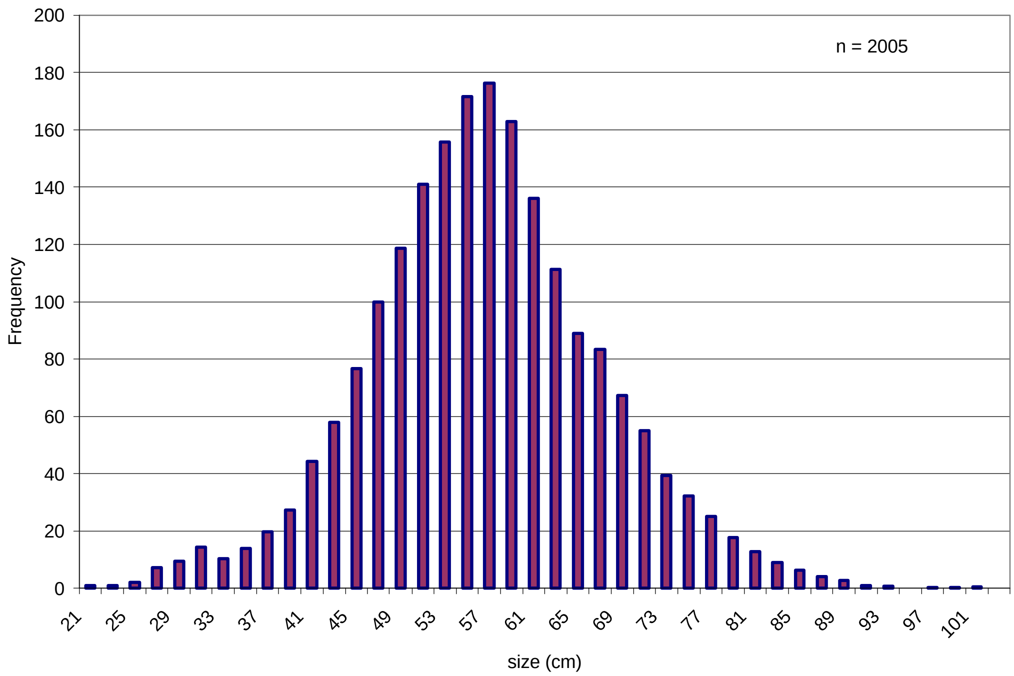


Figure 1. Hake length frequencies in sampled hand-line catches between Mossel Bay and Plettenberg Bay in 1998.

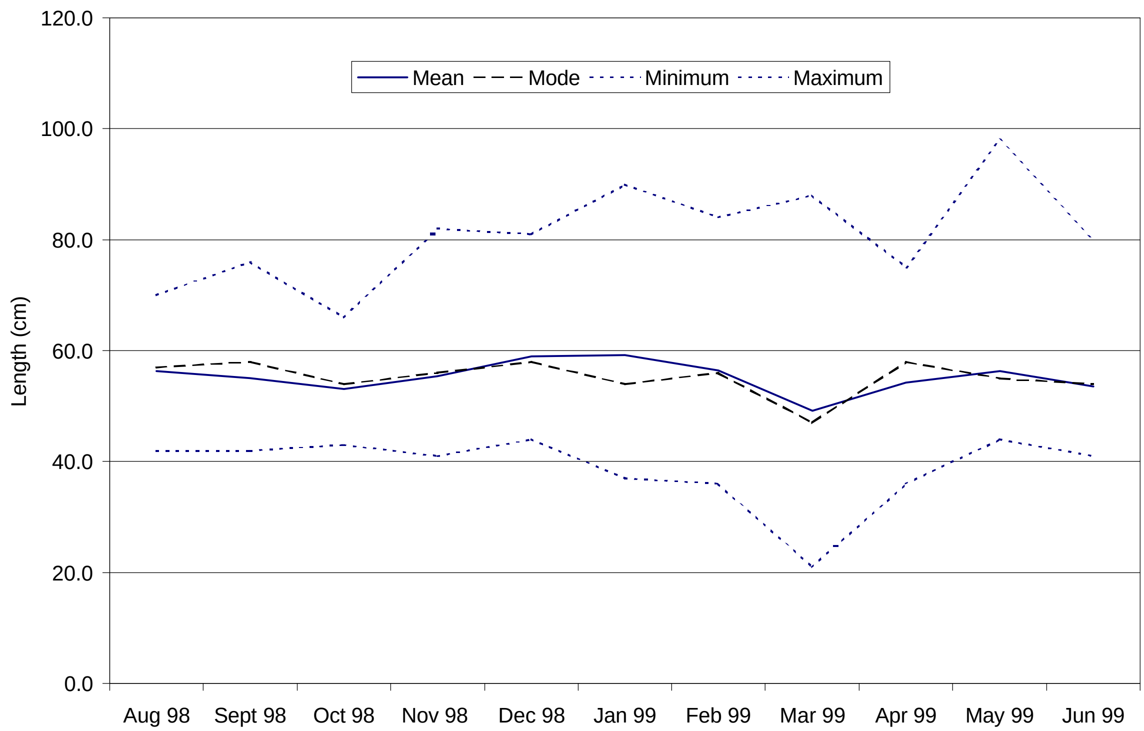


Figure 2. Average size trends in monthly hand-line hake catches.

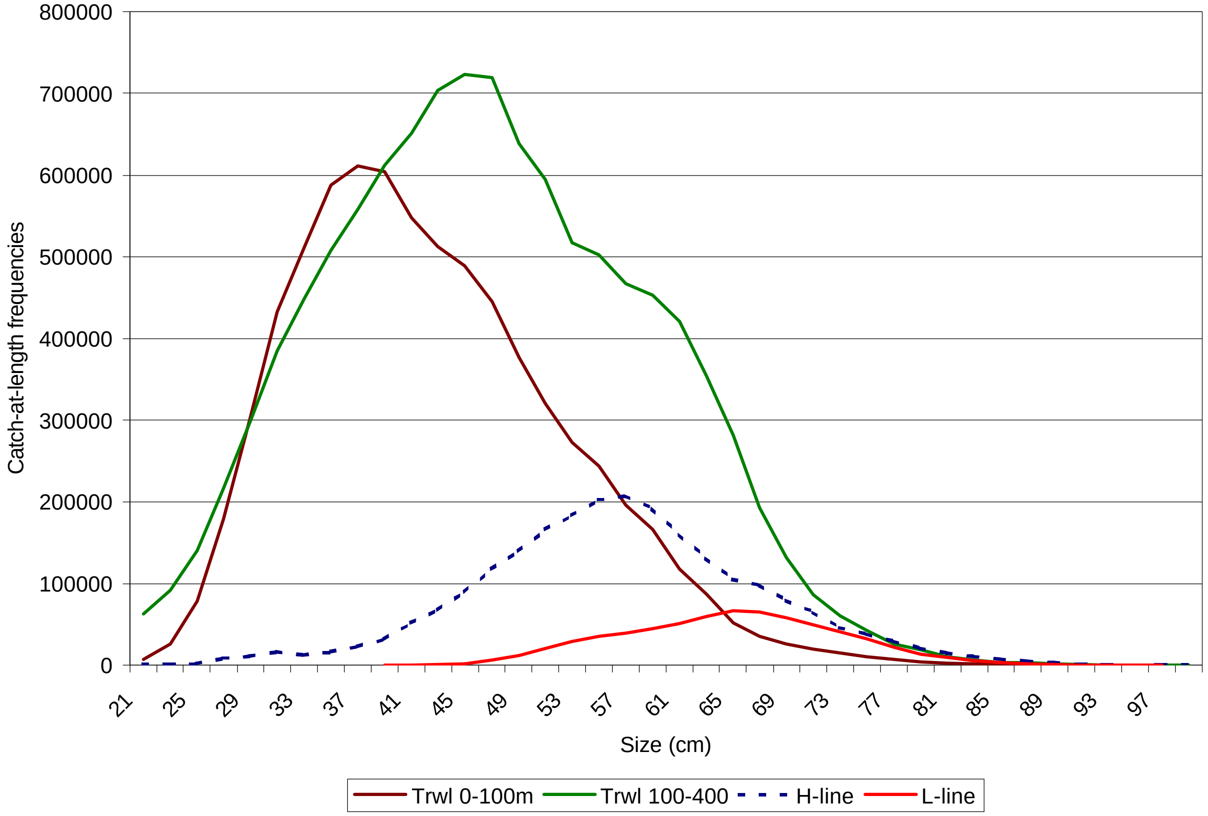


Figure 3. A comparison of size distributions by gear from inshore hake (*M.capensis*) catches.

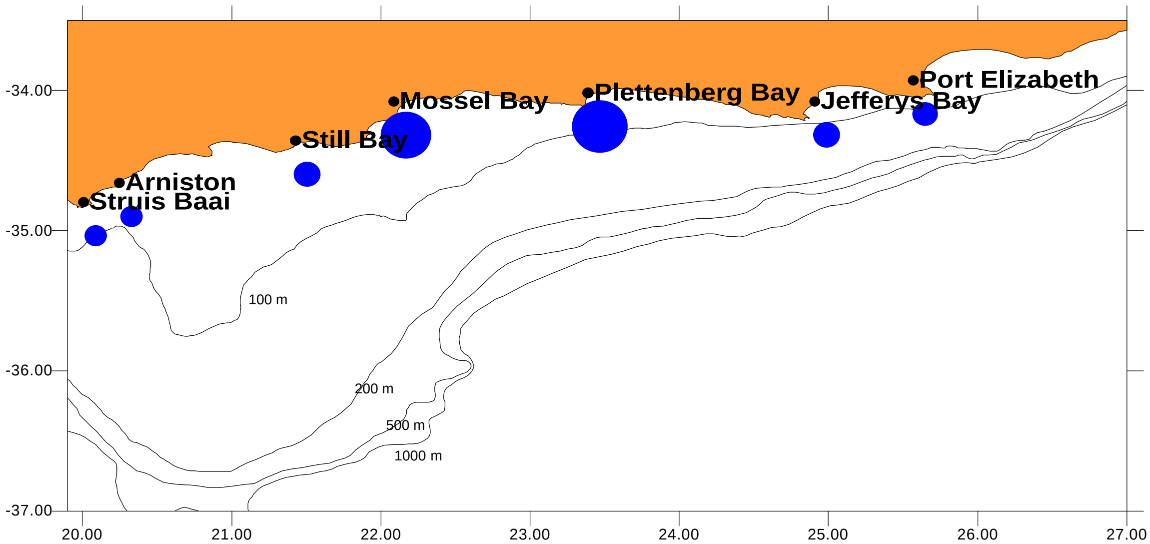


Figure 4. The relative proportions of hand-line hake catch reported to the National Marine Linefish System on the South Coast (Landings in Knysna are reported in the Plett. Bay).

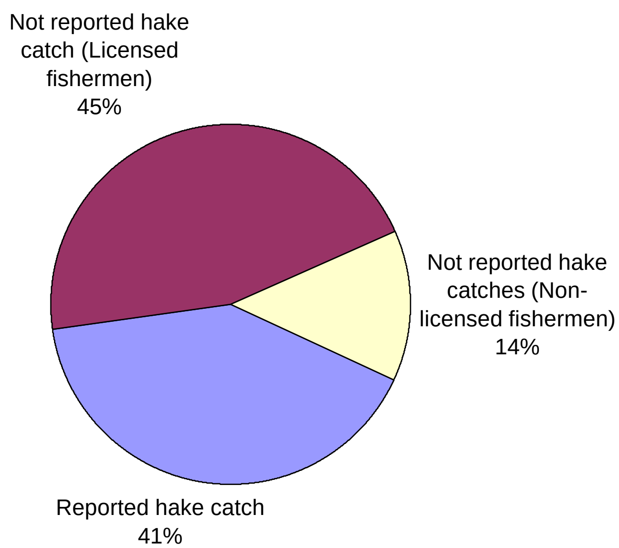


Figure 5. Reported hand-line hake catches in Mossel Bay.

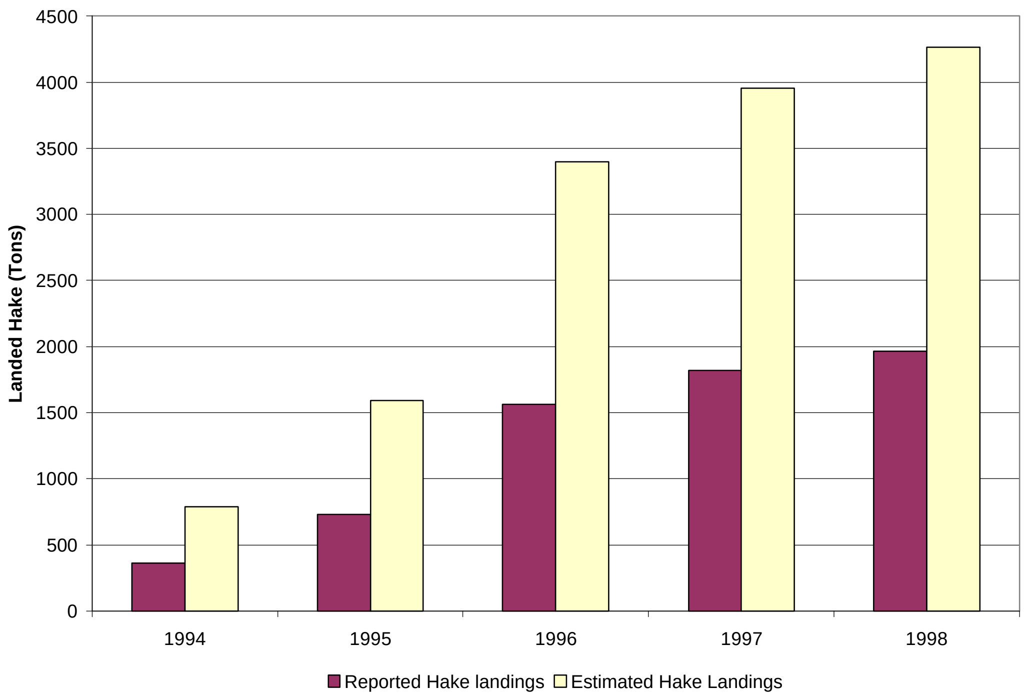


Figure 6. Reported versus estimated hand-line hake landings on the South Coast (1994-1998).

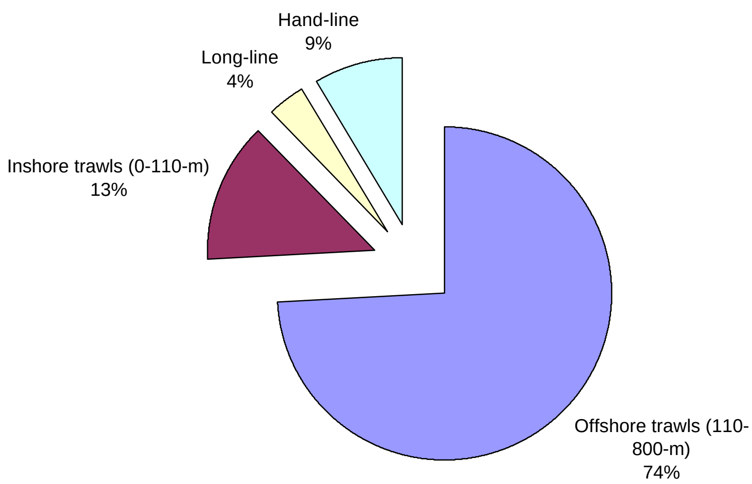


Figure 7. The estimated percentage of hake biomass (both species) caught by all gears on the South Coast in 1997.

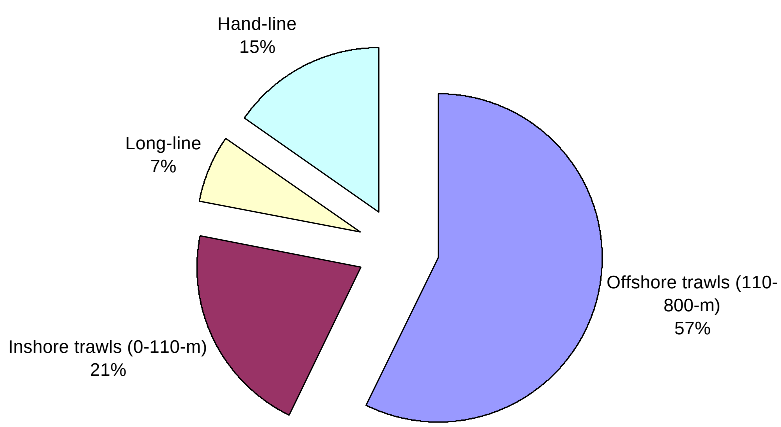


Figure 8. The estimated percentage of *M.capensis* biomass caught by all gears on the South Coast in 1997.

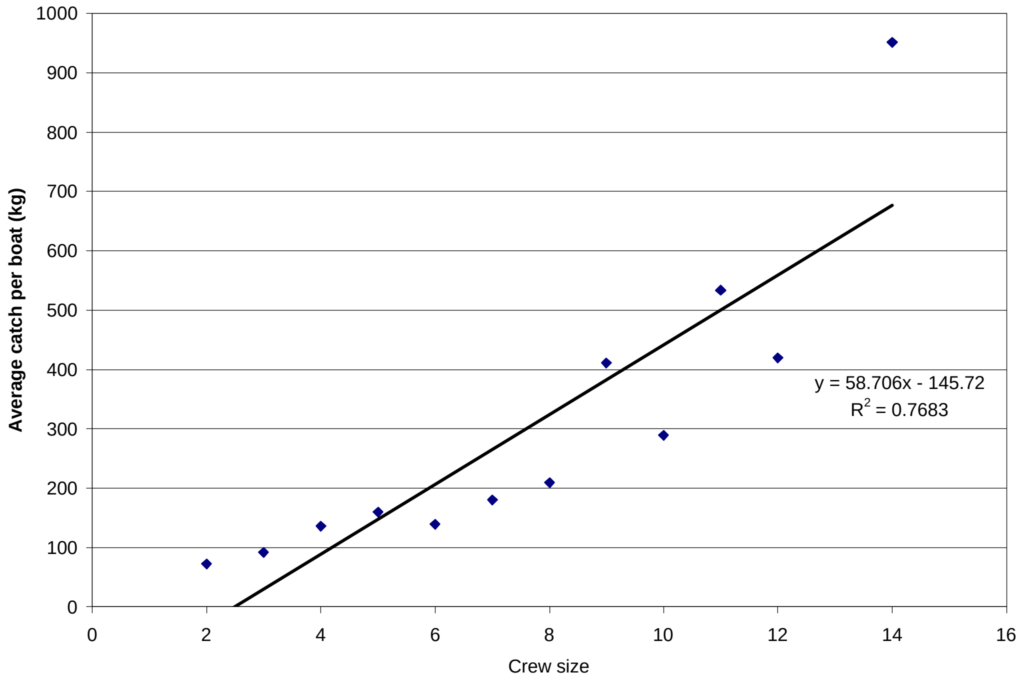


Figure 9. The relationship between average catch per boat-day and crew size.

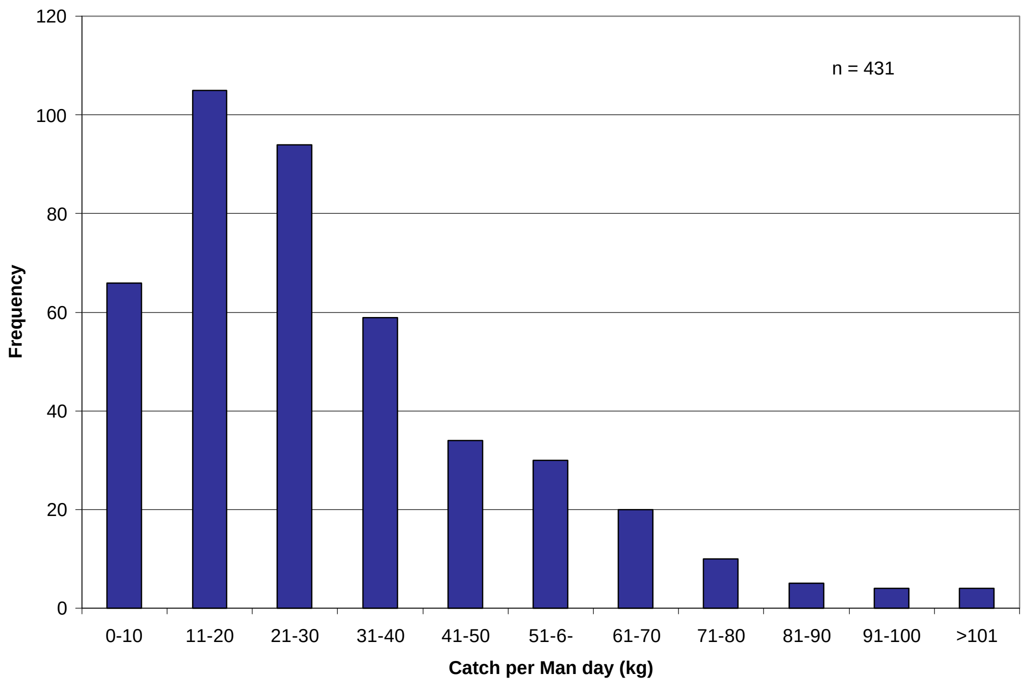


Figure 10. Frequency distribution of average catches per man-day in Mossel Bay taken between January and December 1998.

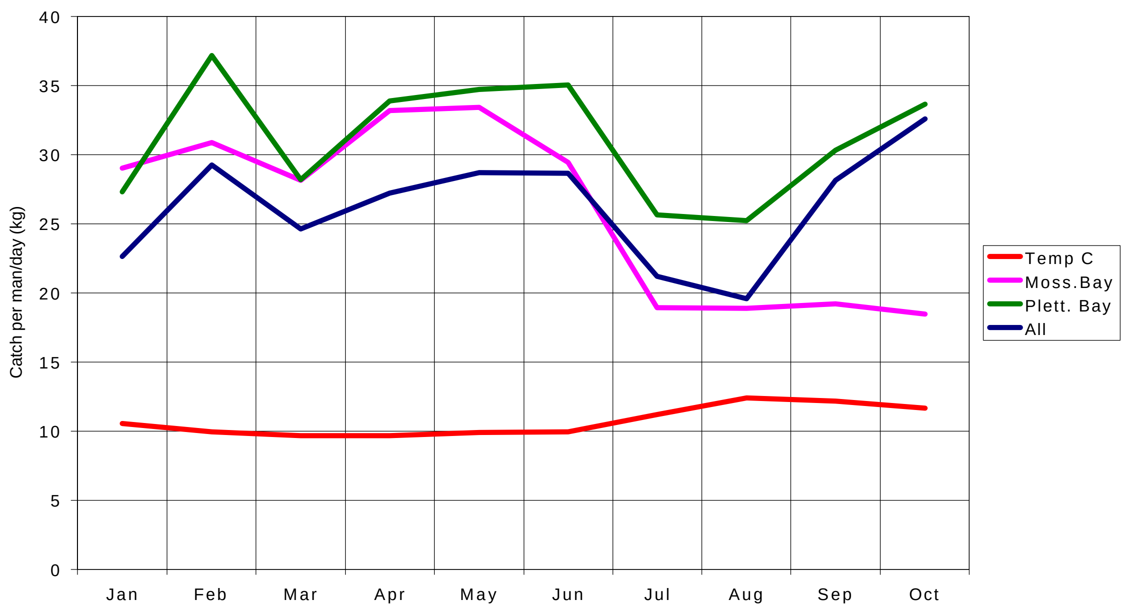


Figure 11. Monthly catch per man-day rates versus bottom water temperature off Mossel Bay.

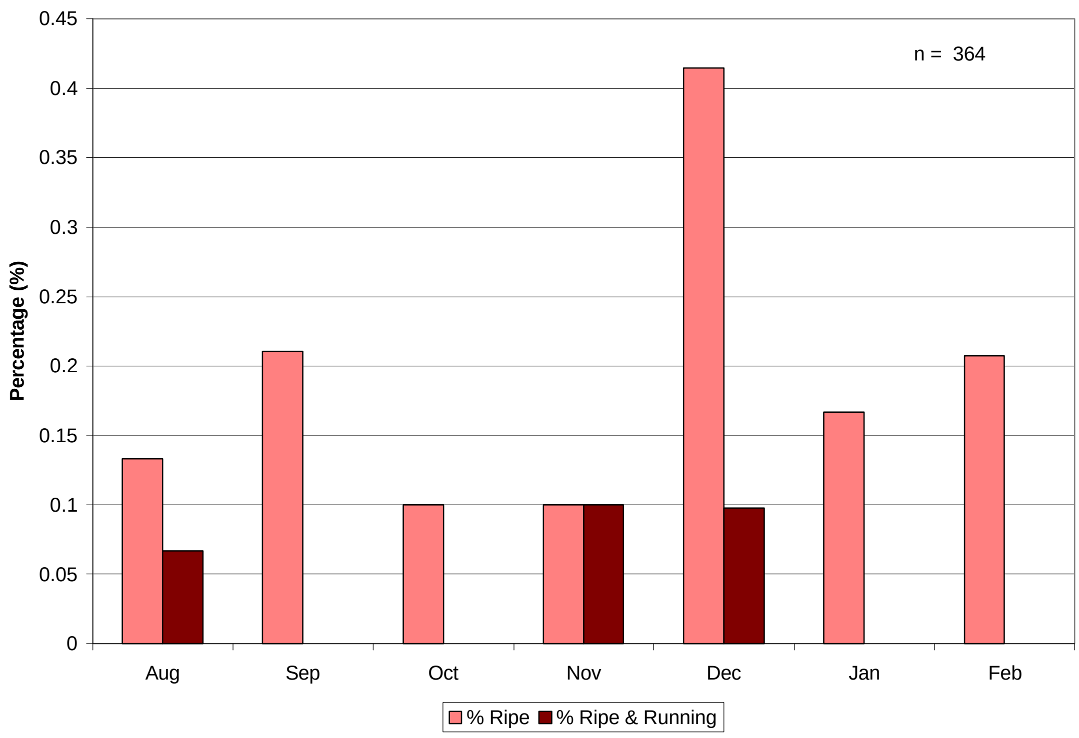
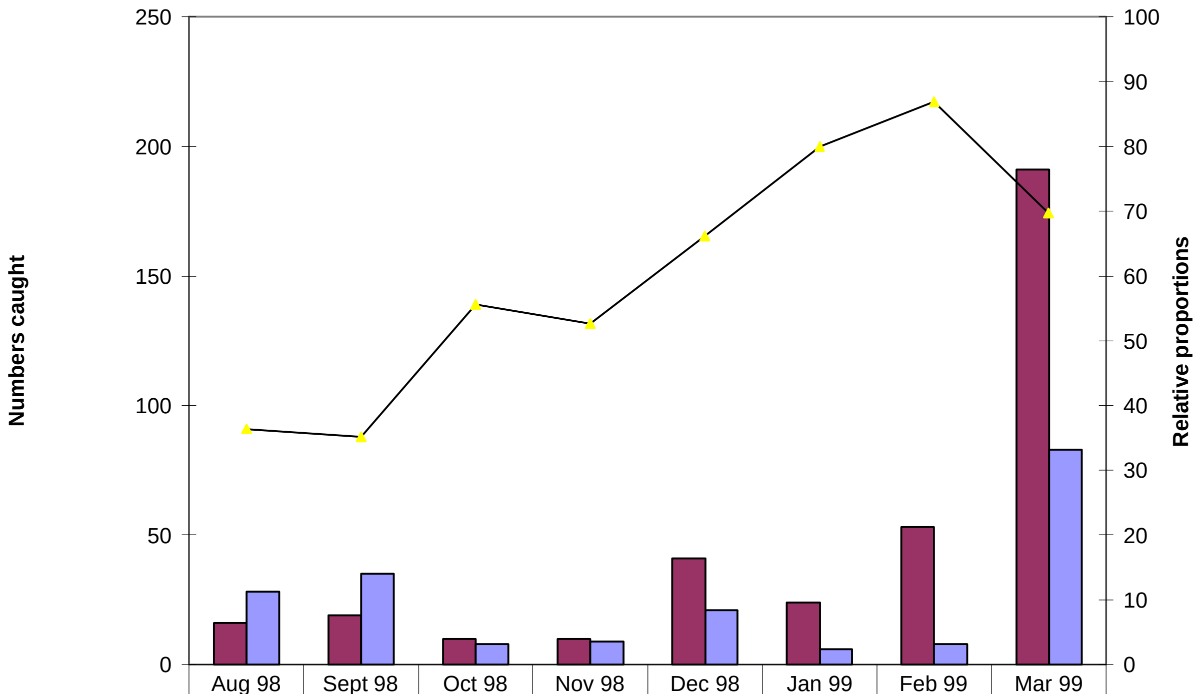


Figure 12. The percentage of females containing “ripe” or “ripe and running” gonads.



	Aug 98	Sept 98	Oct 98	Nov 98	Dec 98	Jan 99	Feb 99	Mar 99
Female	16	19	10	10	41	24	53	191
Male	28	35	8	9	21	6	8	83
% female	36	35	56	53	66	80	87	70

Figure 13. Sex ratios in monthly hand-line catches between August 1998 and March 1999.

Tables

Table 1. Monthly hand-line catch-at-length statistics from sampled landings between Mossel Bay and Plettenberg Bay.

Month	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Year	‘98	‘98	‘98	‘98	‘98	‘99	‘99	‘99	‘99	‘99	‘99	‘98-‘99
Mean	56.3	55.0	53.1	55.4	58.9	59.3	56.4	49.1	54.2	56.3	53.5	54.7
Std. Error	1.2	1.1	1.5	2.0	0.6	0.5	0.5	0.5	1.0	0.6	0.5	0.2
Median	57.0	54.0	52.5	56.0	58.0	58.0	56.0	47.0	54.5	55.0	53.0	54.0
Mode	57.0	58.0	54.0	56.0	58.0	54.0	56.0	47.0	58.0	55.0	54.0	58.0
Std.Dev	7.9	8.2	6.6	9.3	7.6	9.6	9.3	12.1	8.7	7.3	6.8	10.4
Kurtosis	-1.1	0.1	-0.4	2.0	-0.1	0.0	-0.1	-0.1	-0.5	7.5	2.5	0.5
Skewness	0.0	0.6	0.4	0.9	0.4	0.5	0.4	0.4	0.2	1.8	1.2	0.1
Min	42	42	43	41	44	37	36	21	36	34	41	21
Max	70	76	66	82	81	90	84	88	75	98	80	98
Count	47	55	20	21	169	366	381	547	80	136	183	2005
C.I.(95%)	2.3	2.2	3.1	4.2	1.1	1.0	0.9	1.0	1.9	1.2	1.0	0.5

Table 2. The estimated number of hake-directed commercial hand-line vessels operating out of the three major catch areas on the South Coast in 1997.

	Ski-boats	Deck-boats
Plettenberg Bay	21	15
Mossel Bay	60	11
Knysna	23	0
Total	104	26

Table 3. Numbers of males and females collected onboard hand-line vessels off Mossel Bay and Plettenberg Bay between Spring (August -October) and Summer (November-January).

	Spring	Summer	Total
Females	45	75	120
Males	71	36	107
Total	116	111	227

Table 4. Bottom water temperatures versus hake catch rates (kg /man-day) for inshore fishing areas along the South Coast. (Note bottom temperatures were taken from the Moss Gas platform off Mossel Bay).

	Jan ‘98	Feb ‘98	Mar ‘98	Apr ‘98	May ‘98	Jun ‘98	Jul ‘98	Aug ‘98	Sep ‘98	Oct ‘98
Temp (°C) at the MossGas Platform	10.53	9.93	9.64	9.69	9.92	9.95	11.16	12.38	12.16	11.65
Moss. Bay (kg)	29.03	30.88	28.14	33.18	33.42	29.46	18.94	18.90	19.21	18.44
Plett. Bay (kg)	27.28	37.17	28.17	33.89	34.72	35.08	25.65	25.21	30.33	33.66
All Areas (kg)	22.61	29.24	24.63	27.23	28.68	28.65	21.2	19.57	28.15	32.57

Chapter 3

Size and Species Selectivity in Trawled Hake Catches off the Southeast Coast in 1997

Introduction

Disaggregated catch-at-length data is an essential requirement needed for yield per recruit modeling and in this analysis establishing the individual status of *M.capensis* and *M.paradoxus* stocks on the South Coast. However commercial trawl landings are not separated by species; the two hake species are similar in appearance and landed together in combined trawl catches. Considerable mixing between their respective inshore and offshore distributions creates further difficulties in separating the two species, which cannot be done simply by assuming an arbitrary depth boundary. The extent of mixing at any given point is not yet fully understood, however proportions of *M.capensis* are assumed to decline linearly between depths of 160m and 400m, mixing outside this depth interval is considered minimal (Geromont et al. 1995). Depth related size preferences for this depth interval exist for both hake species; 5-6 year old *M.capensis* and 2-3 year old *M. paradoxus* form the principle components in the 200-500-meter depth range (Badenhorst and Smale 1991).

Theoretically, it should be possible to dissociate combined species catch-at-length data given an estimate of their individual size distributions and expected weight proportions in a certain depth interval. The proportion of each species per size class would then be a function of these two estimates. The weight proportion of each species as it relates to depth can be calculated using the aforementioned depth/proportion algorithm (Geromont et al. 1995). Size distributions for each species at a given depth are available from the *RV Africana* demersal trawl surveys data taken on the South Coast in these mixing areas. Adjusting the size distributions of each species to fit their relative proportion by depth is presented as one method available to separate trawl catches into their estimated numbers per size class.

The size of *M.capensis* and *M.paradoxus* caught by trawls on the South Coast depends largely on depth and location. Smaller sizes are concentrated near the shallower ranges of their respective distributions. Badenhorst and Smale (1991) described the inshore waters (< 50 m) as being the nursery area for *M.capensis* after which size/age increases with depth. The same pattern emerges for *M.paradoxus* suggesting a preference for deeper water in the adult population (>400m) and smaller sizes inhabit their innermost depth range (160-400m). Total trawl landings on the South Coast in 1997 amounted to 40 345 tons, approximately 55% of this was taken between 160-400-meters.

Mesh size restrictions outlined in the Marine Living Resources Act of 1998 limits the size of trawl nets to 110mm on the west coast, however no recommendations have been set for the South Coast (Anon 1998). Current restrictions applied to the South Coast allow trawls to use either a 110mm or 75mm mesh; offshore trawls are not permitted to trawl inside the 110-m depth contour (Chief Director Sea Fisheries 1997). Inshore trawls on the other hand are permitted to operate at any depth including the region inside the 110 meters isobath. Inshore trawls (0-110m) target *M.capensis* while offshore trawls (110-800m) catch both *M.capensis* and *M.paradoxus*.

This main objective of this chapter is to estimate the numbers by length of each hake species caught by trawls (E of 20°E) on the South Coast in 1997. Identifying areas with intensive fishing effort and determining the species composition in these areas forms an important part of this analysis. Steps in reaching these determinations are as follows:

- Identify target areas
- Estimate catch-at-length frequencies for commercial trawls by depth zone (0-160m, 160-400m, 400-800m)
- Estimate *M.capensis* discard-at-length frequencies in the inshore region (0-100m, 100-160m)
- Determine the relationships between average size and depth for species distributions between depths of 160-400m
- Calculate the landed weights of *M.capensis* and *M.paradoxus* as per 20-meter depth interval between depths of 160m-400m
- Determine the expected catch-at-length distributions for *M.capensis* and *M.paradoxus* between depths of 160-400m using survey trawl data raised to reflect commercial trawl catches in the area.
- Dissociate commercial trawl catch-at-length frequencies into their constituent species (*M.capensis* and *M.paradoxus*) composition using the expected catch-at-length distributions from survey trawl data.

Methods

Hake landings reported as per 20 x 20 nautical mile grids were projected onto a map of the South Coast using the midpoint of each grid as the geographic co-ordinate. Intensive fishing areas were easily identified using this illustration. These areas superimposed onto the expected distribution patterns provided some insight into what species were being targeted most heavily. The expected distribution patterns of each hake species were described using survey data taken between 1986-1998. Survey trawl catch weights of each hake species were summed over 5 x 5 nautical mile survey grids and the calculated proportions in each grid extrapolated onto similar depth gradients.

Catch-at-length data was estimated by converting a collection of length frequency samples taken from each of six commercial grading categories to match their reported weight landings by depth. Length distributions for each category were assumed independent of location trawled. Lengths in each distribution were converted to weight using the average length weight relationships from previous studies on Cape hakes; conversion formula for *M.capensis* weight = 0.008445 * L^3 and *M.paradoxus* weight = 0.007936 * L^3 (Kono 1980). Length frequency distributions in each category were then raised sequentially by two factors. The first factor was calculated as: landed category weight per depth zone / category length distribution weight. The second factor was calculated as: total hake landings per depth interval (All fleets) / individual company's hake landings per depth zone. Category length distributions raised to reflect total hake landings were summed together over all size classes providing a single catch-at-length distribution estimate for all trawling in a given depth zone. Depth zones were selected according to their species composition and relative bearing on the analysis. Catches within depths of 160-meters were considered to be predominantly *M.capensis*, those between depths of 160-400-meters a mixture of *M.capensis* & *M.paradoxus* and catches made in water deeper than 400-meters predominantly *M.paradoxus*.

Discarded hake data pertaining to the inshore region (0-200-meters) off the South Coast was made available for this analysis (Hart, Unpublished data). The majority of these discards were considered to represent *M.capensis* catches by their being caught close inshore. Data had been collected between 1997-1998 and provided information on the size and amount of hake discarded per trawl haul at a given depth and location. These were collectively attributed to the inshore depth zones used in parts of this analysis, namely 0-100m, 100-160m. The estimated proportion of discarded catch in each zone was calculated by dividing the summed discard weights by the summed retained weights. This multiplied by total trawl landings in each zone gave the estimated amount discarded. Discarded hake length frequency distributions for each depth zone were raised to reflect these amounts. Discard length frequency estimates were added to the separately derived catch-at-length estimates for the inshore (0-160-meters) region. Discard length frequencies were not estimated for the 160-400-meter depth zone because samples covering this range did not extend beyond a depth of 225-meters.

Length distributions for each hake species between 160-400m were assumed to remain stable over time and depth. Length data collected from all research surveys (1986 – 1998) taken between 160-400m on the South Coast was pooled and stratified according to depth. This was done for both hake species *M.capensis* and *M.paradoxus* using 20-meter depth stratum. *M.capensis* measurements collected between 320-400m were combined to increase sample size in this depth range. Statistics associated with each length frequency distribution were calculated from random length samples generated in each depth interval (Tables 5&6). The mode and mean of each size distribution was used to test size dependence on depth using normal linear regression techniques. A slope of zero would imply an insignificant trend in increasing size with depth across the 160-400m-depth range would. An analysis of variance procedure tested the preceding hypothesis using critical F-values of $F_{0.05, (1), 8}$ for *M.capensis* and $F_{0.05, (1), 11}$ for *M.paradoxus.*

The expected weight of each species landed between 160-400-meters in 20-meter depth intervals was calculated using the previously described depth/proportion algorithm (Geromont et al. 1995). This formula for calculating the proportion of *M.capensis* at a given depth (*df*) using the midpoints from each depth interval is given as

$$Pcap = m * df + c$$

Where the slope $m = -1/(d2 - d1)$, $c = -m*d2$, $d1 = 160$m and $d2 = 401$m

The expected weight of *M.capensis* (*Wcap*) landed in each depth interval (*df*) is calculated as

Wcap at *df* = *Pcap* * total hake landed in depth interval

The expected length distributions of *M.capensis* and *M.paradoxus* for each 20-meter depth interval between 160-400-meters were calculated using *RV Africana* survey data. These were raised by a factor of (expected weight / length distribution weight). The expected weight having been calculated as the amount of each species landed by commercial trawlers in a given depth zone. Raising factors applied to *M.capensis* length distributions were calculated separately for each depth interval. This was unnecessary for *M.paradoxus* distributions where no significant size changes occurred between depths of 160m-400m and all length measurements were combined into one distribution before being raised. Once raised to match their expected weight proportions by depth, length distributions for each depth interval were summed over all size classes.

Commercial trawl catch-at-length frequencies for the 160-400-meter depth zone were split into their respective species distributions using the expected proportions of *M.capensis* from survey distributions as per 2-cm size interval. Once separated, length frequency distributions for each species (*M.capensis* and *M.paradoxus*) between 160-400m were added to their respective inshore (0-160m) and offshore (400-700m) length frequency estimates.

Results

Target Areas

In examining the exploitation patterns of hake caught on the South Coast (East of 20°E) it was noted that massive fishing pressure is directed between 160-400-meters in areas with a high abundance of small *M.paradoxus*. Certain areas were found to be heavily exploited because they are favorable to trawling and produce high returns whereas other areas like the sole fishing grounds are inadvertently more heavily trawled for hake than catch-rates would dictate. The most heavily exploited target areas are between 160-meters and 400-meters near latitudinal co-ordinates 36° 40 ′ S and 35° 05 ′ S (Figure 1). The level of intensity in these areas has a significant impact on separate species stock assessment occurring as it does in the region where hake species overlap. Trawl landings on the South Coast in 1997 reveal that 24,347 tons or (55%) of the total hake catch was taken between 160-400m (Table 1). A graphical illustration of species distributions using survey catch weights demonstrates the declining proportion of *M.capensis* as it relates to depth (Figure 2). This mixing area falls directly onto the most heavily exploited regions.

Landed catch-at-length frequencies by depth zone (0-160m, 160-400m, 400-800m)

The length frequency distributions in each commercial grading category were normally distributed around the mean of their respective size groupings (Figure 3). Catch-at-length estimates derived from these categories were attributed to three depth zones based on their respective species composition. The derived *M.capensis* length frequency distribution inside the 160-meter isobath had a mean, median and mode of 42.8-cm, 41-cm and 35-cm; sizes ranged between 21-cm and 81-cm (Figure 4). The derived length frequency distribution for hake caught in the intermediate zone between depths of 160m-400m contained a high proportion of small individuals (Figure 5). This length distribution had a mean, median and mode of 41-cm, 37-cm and 29-cm, sizes ranged between 21-cm and 89-cm. The derived *M.paradoxus* length frequency distribution outside the 400-meters isobath had a high proportion of large specimens above 45-cm (Figure 6). This distribution had a mean, median and mode of 42.3-cm, 39-cm and 35-cm respectively; sizes ranged between 21-cm and 95-cm.

Discard length frequencies in the inshore region (0-100m, 100-160m)

The amount of hake discarded between 0-100-meters was estimated at 32.6% of the total trawled hake catch, the amount discarded between 100-160-meters was estimated at less than 2.9% (Table 2). Discarding was still apparent at greater depths and was estimated at 7.8% of the amount landed between 160-200-meters. However, no inferences could be made for the 160-400-meter depth zone because collected data did not fully cover this range.

The numbers of discarded hake in the small size classes (13cm-39cm) was high in the inshore hake grounds between 0-100-meters because of the high proportion of discarded weight in this region (Figure 7). The number of discards per size class for the 100-160-meter depth range was far less by comparison (Figure 8).

The estimated numbers per size class were totaled for 0-160-meter depth zone and added to the separately derived catch-at-length data for this region to provide a full complement of trawled catch data for inshore *M.capensis*.

The relationships between average size and depth for species distributions between 160-400m

The statistics associated with *M.capensis* and *M.paradoxus* length distributions across the 160-400-meter depth interval reflect the difference in average size for each 20-meter interval, with *M.capensis*, on average, being larger than *M.paradoxus* (Tables 4 & 5). The mean and mode in *M.capensis* length distributions were found to increase with depth between 160 and 400-meters while the opposite was true for *M.paradoxus* (Figures 9&10). No significant trends were found in the *M.paradoxus* length distributions (Table 3).

Landed weights of *M.capensis* and *M.paradoxus* as per 20-meter depth interval between 160-400m

The proportion of *M.capensis* in trawl catches was calculated at 0.963 in the 160-180-meter depth interval and declined linearly to 0.046 in the 380-400-meter depth interval. These were used to calculate the landed weight of each hake species from hake landing reports in each depth interval (Table 4). A total of 11557-tons of *M.capensis* and 12788-tons of *M.paradoxus* was calculated as have being caught between 160-400m.

Expected length frequency distributions for *M.capensis* and *M.paradoxus* between 160-400m using survey data

The *M.capensis* and *M.paradoxus* length distributions derived from survey trawls were raised to reflect the amount landed by commercial trawls in each 20-meter depth interval (Table 4). The combined length frequency distributions for each species closely resembled the shape of the separately derived catch-at-length distributions for both species combined (Figure 11). The expected number of *M.paradoxus* between 30cm-41cm using survey trawl data was slightly greater than the number determined for combined species in the commercial trawl catch-at-length estimates. However, this discrepancy had little effect on the estimated proportions of *M.capensis* per size class. Few small *M.capensis* (21cm-41cm) were caught by survey trawls in the 160m-400m-depth interval. The total proportion of *M.capensis* per 2-cm size class derived from the expected length distribution of each species increases with ascending size class (Figure 12).

Trawl landing length frequencies dissociated into their constituent species composition

Commercial length frequencies split into their respective components using the expected proportions in each 2-cm size class do not deviate radically from the expected length distributions from survey data (Figures 13&14). The estimated amount of *M.capensis* calculated by converting lengths to weight equaled 11,418 tons compared to the expected amount of 11,605 tons. The *M.paradoxus* distribution using the same comparison was 12,739 tons and 12,927 respectively. Cumulative frequency curves of each distribution demonstrate the slight differences between the two estimates; derived *M.pardoxus* length frequency estimates between 33cm and 49cm are less than expected *M.paradoxus* distributions from surveys. This opposite is true for derived *M.capensis* length frequency estimates between 49cm and 77cm, which were more than the expected size classes from survey distributions (Figure 15).

Commercial length frequencies estimates for *M.capensis* (<160m) and *M.paradoxus* (>400m) were added to split species catches between 160-400-meters. Discard length frequencies were added providing total catch-at-length estimates for each species on the South Coast in 1997 (Figures 16&17).

Discussion

The conventional method used to derive length composition data is to randomly select a representative sample and raise it by a factor of total catch in the region divided by the weight of the sample. Estimating length frequencies from size category data is essentially an imitation of this provided measurements are taken randomly from each category and category size distributions do not change over time. This method can be used for any region where landed weights are reported as per commercial category. These distributions were assumed to remain constant for all depths and regions trawled. Any deviations from this assumption would likely occur from varying size selectivity in the trawls.

Accuracy in reported category landings by depth is an important consideration because category length frequencies are raised by a factor of landed weight / category sample weight. However the fishing industry uses category-landing information on a regular basis as part of their fishing strategy and it is unlikely that they would be inaccurate.

The benefit of using category length distributions to establish catch-at-length data is that they can be applied retrospectively. Category landings on the South Coast data exist in raw data format from 1986. Catch-at-length composition data, once converted to age classes, can be applied to a VPA and used to extract valuable biological indicators. This historic perspective would otherwise be lost. This may be the only method available for establishing historic commercial catch-at-length data and in this sense, future research might refine some of these estimates. This would aid current stock assessment methods by providing an alternative biomass index on which to model the population dynamics of this resource.

Survey trawls use a smaller mesh size than commercial trawls, but size selectivity appears to be more dependent on location than mesh size in the 160-400-meter depth zone. The slightly less than expected numbers of smaller sized hake in the commercial trawl catches may well be reflecting the unreported and in this analysis unaccounted for discard length frequencies in this depth interval.

Catch-at-length composition data for each species in the 160m-400m-depth interval is essential for a separate species length based analysis. Insofar as a visual inspection is concerned the derived estimates of catch-at-length data for the two species resemble the shape of expected length frequency distributions using survey data, but confidence intervals around these estimates are difficult to provide. These discrepancies between expected length frequencies from survey data and estimated commercial length frequencies from separating proportions in each size classes could be due to any number of factors including randomness. A comparison of survey trawls versus commercial trawls in the 160m-400m-depth interval needs to be conducted in order to strengthen results. If differences were found to be slight, it would be worthwhile to simply substitute survey data and not attempt to split commercial estimates.

Figures

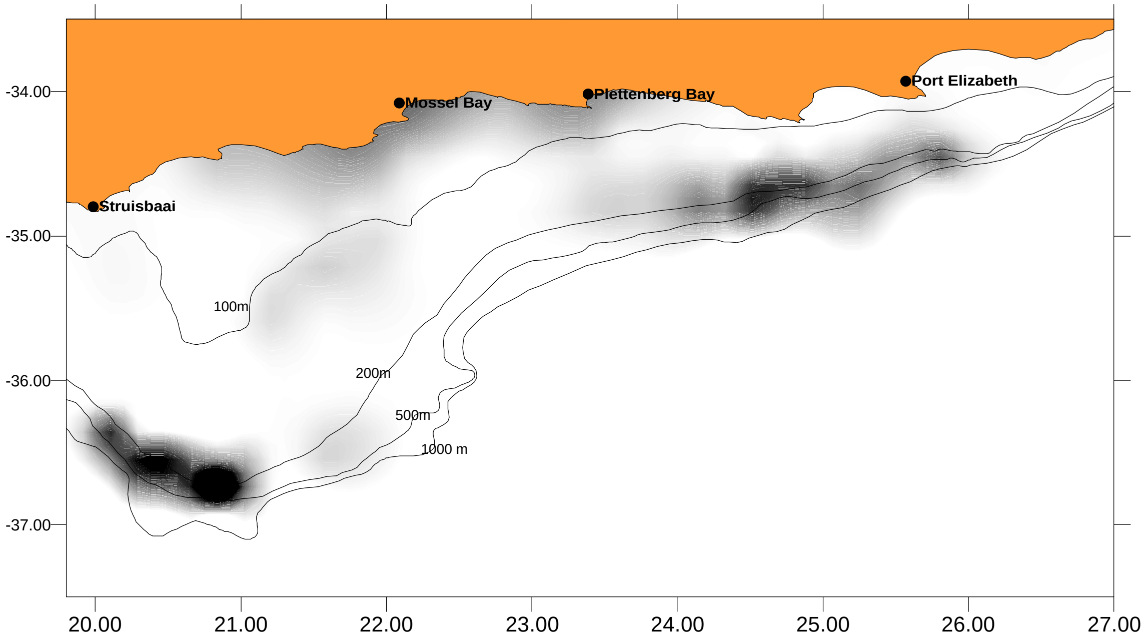


Figure 1. Hake target areas with intensive fishing effort on the south coast in 1997.

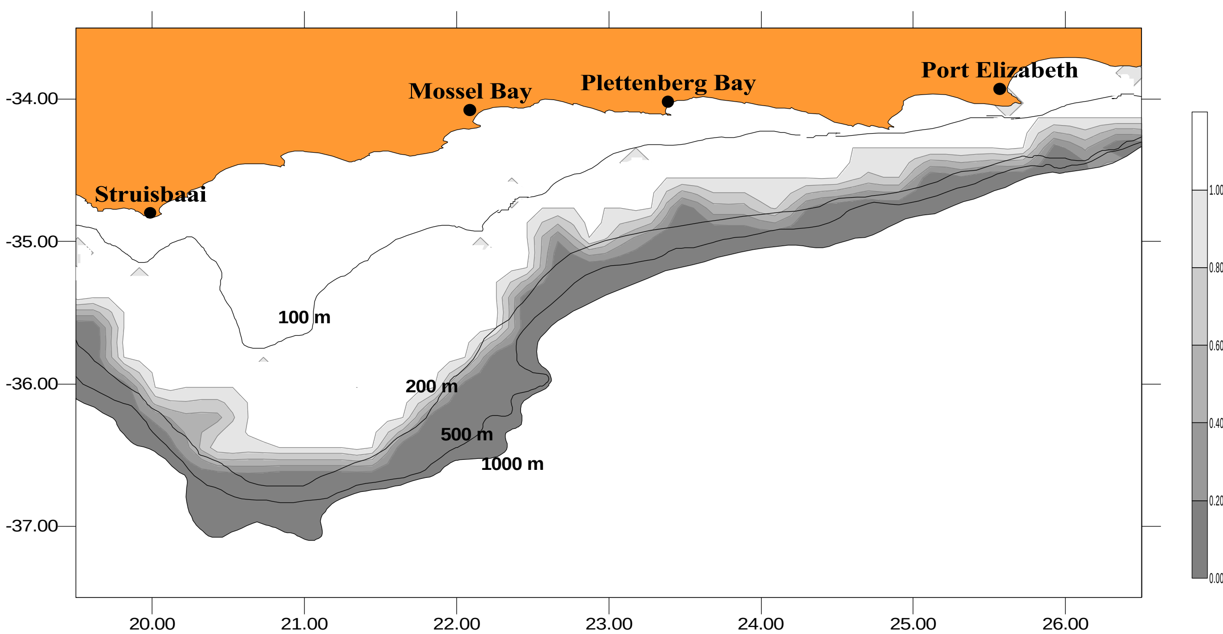


Figure 2. Proportions of M.capensis decline with depth

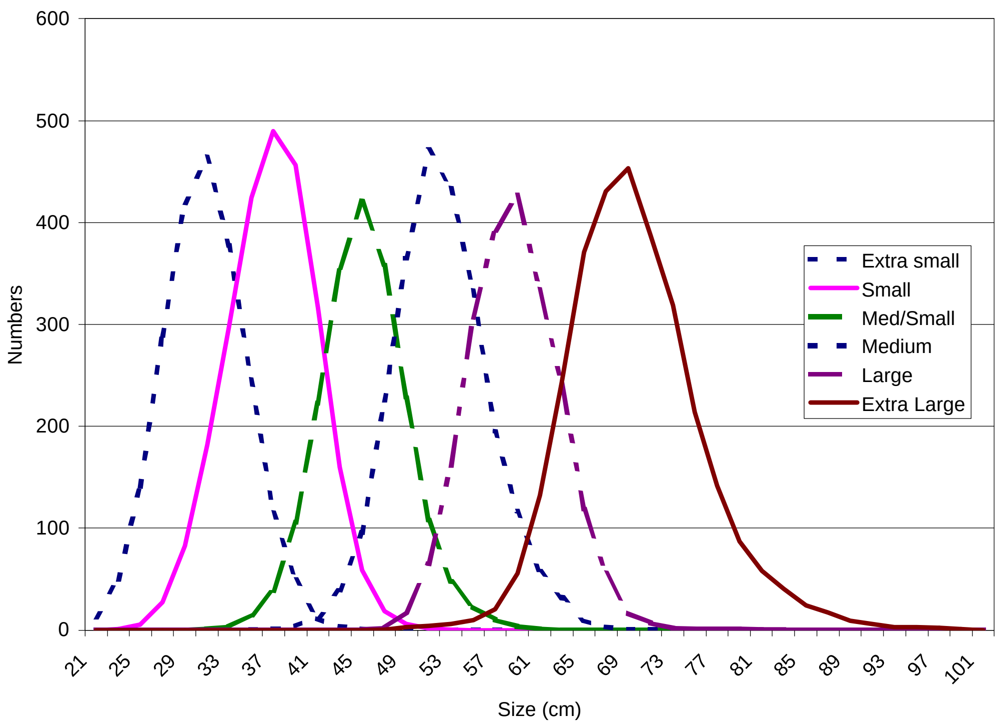


Figure 3. Length frequency samples taken from commercial grading system.

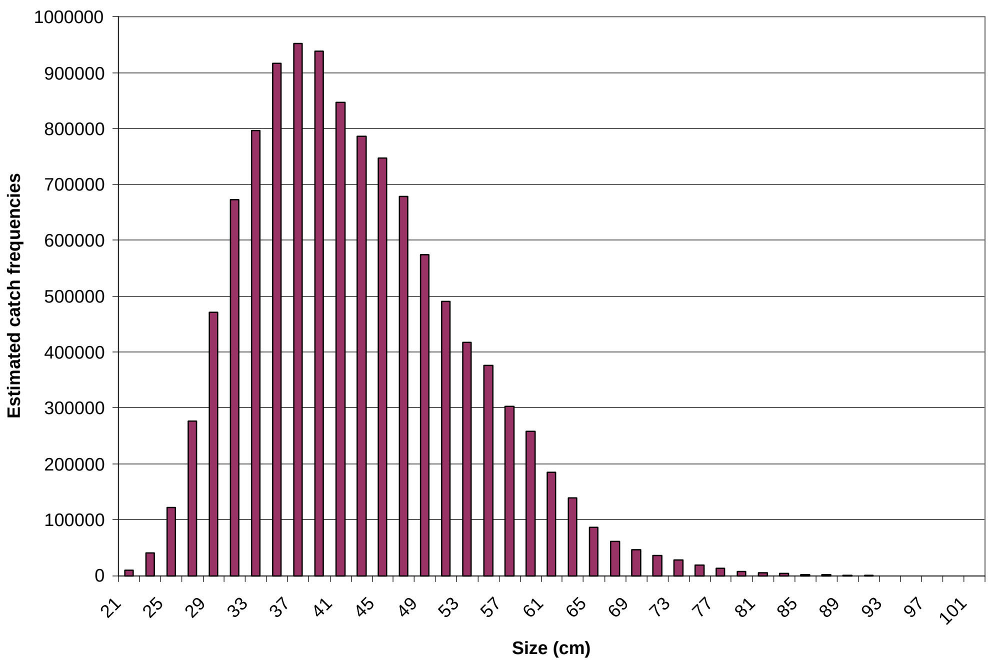


Figure 4. Catch-at-length estimates for *M.capensis* caught within 160m.

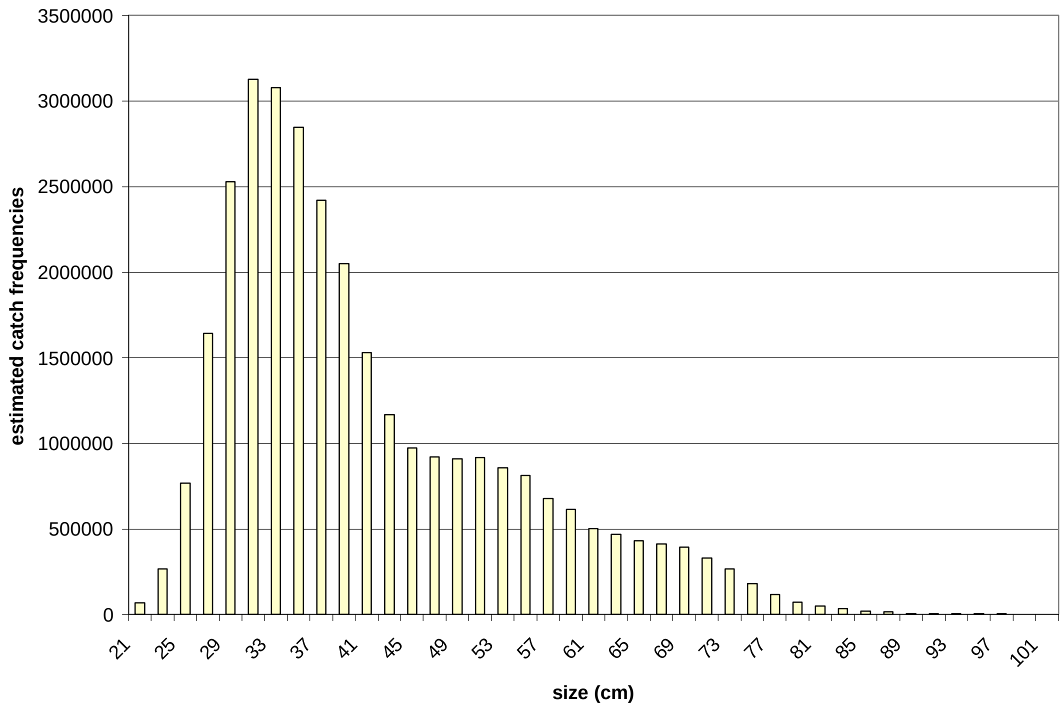


Figure 5. Catch at length estimates for *M.capensis* & *M.paradoxus* between 160-400m.

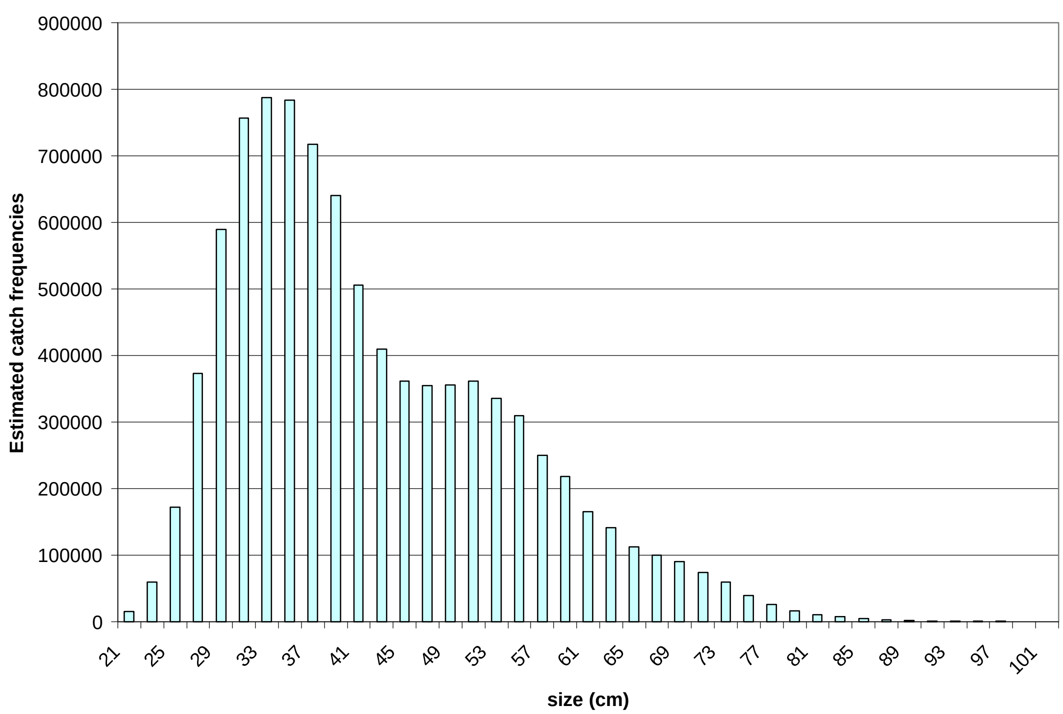


Figure 6. Catch at length estimates for *M.paradoxus* outside 400m.

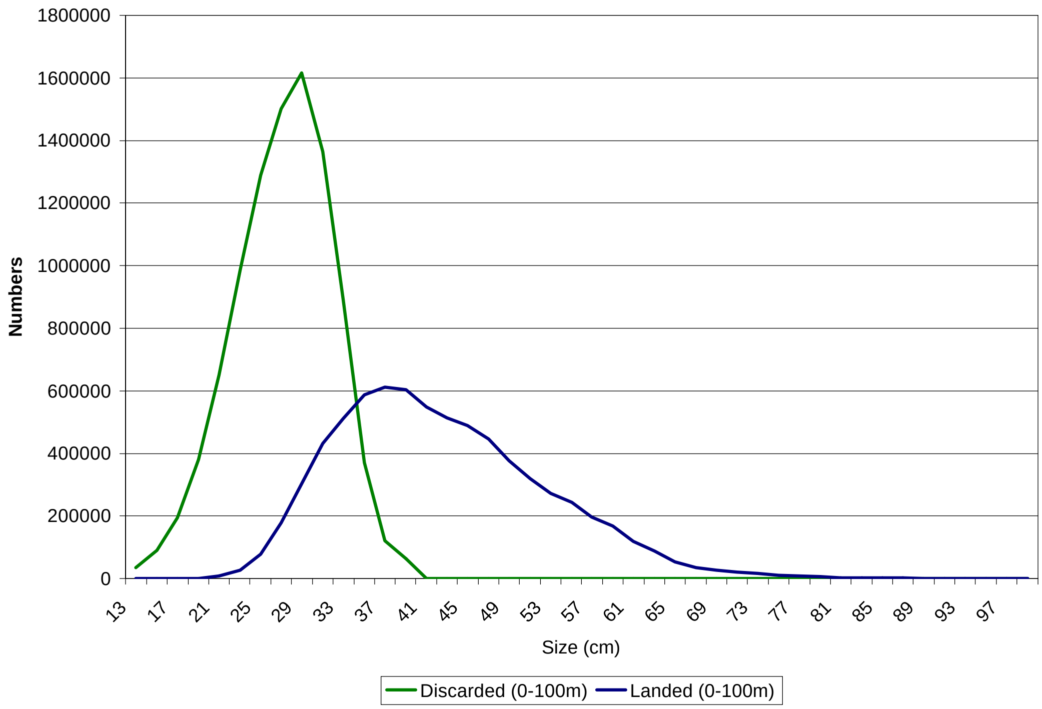


Figure 7. Estimated numbers per size class of hake discarded by trawls between (0-100m).

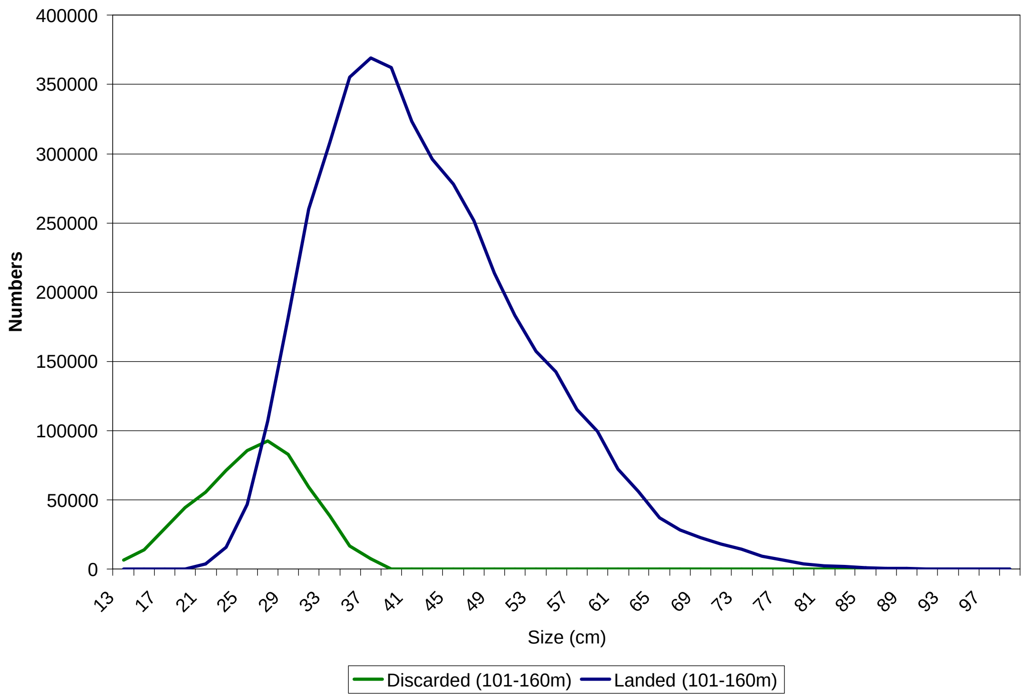


Figure 8. Estimated numbers per size class of hake discarded by trawls between (100-160m).

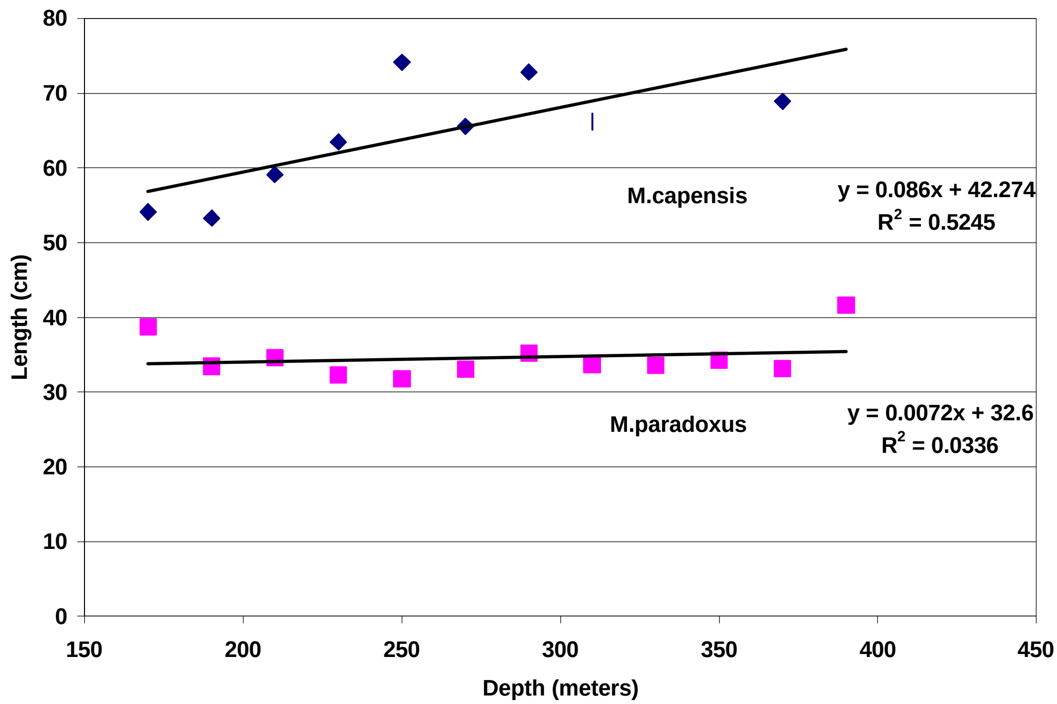


Figure 9: Mean length versus depth between 160m and 400m.

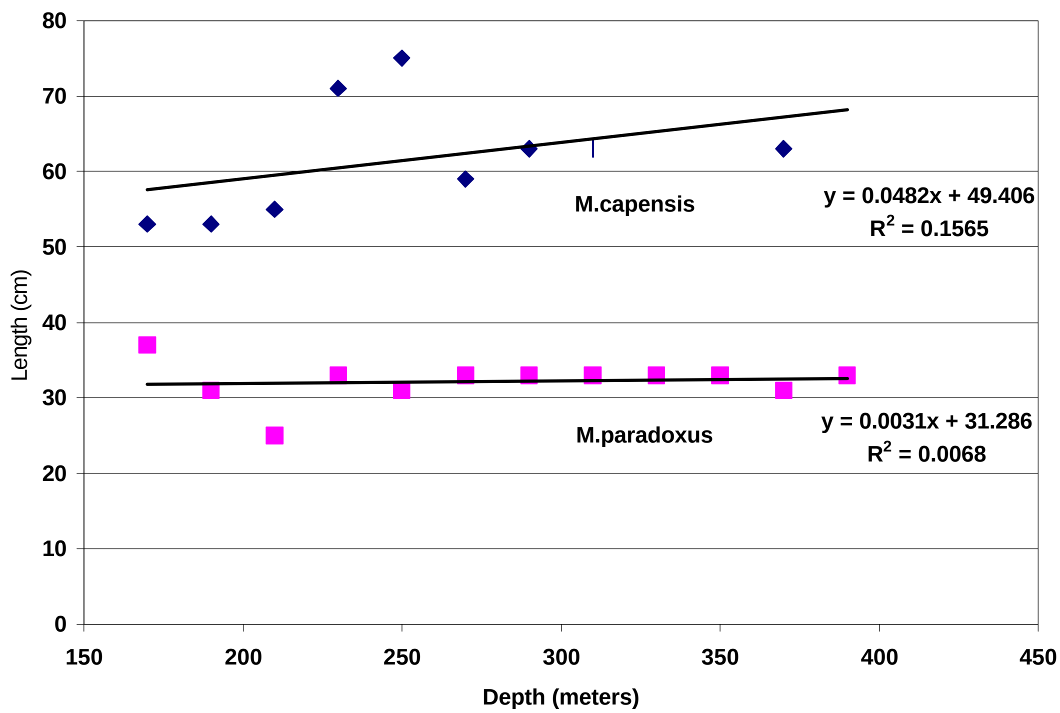


Figure 10: Length mode versus depth between 160m and 400m.

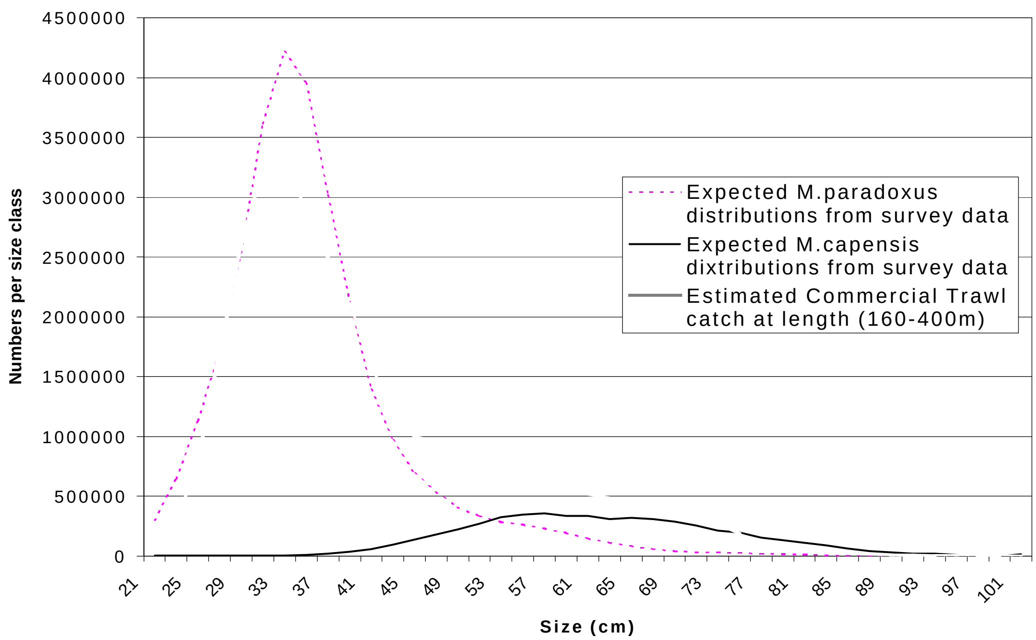


Figure 11. Expected length distributions from survey trawls versus estimated catch-at-length data from commercial trawl landings (160-400m).

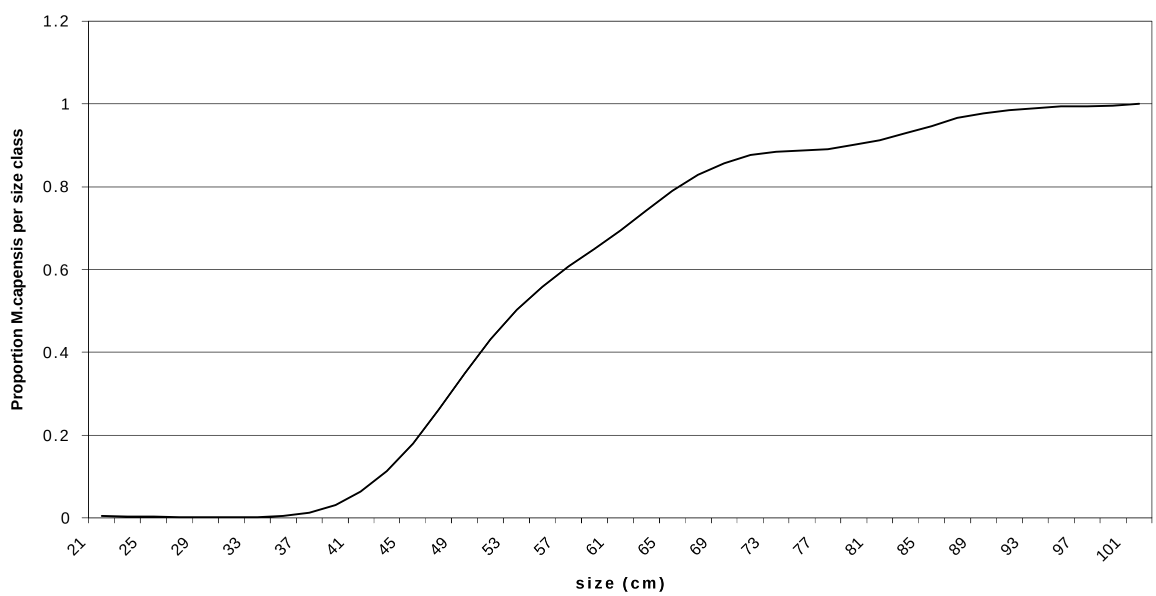


Figure 12. Proportions of *M.capensis* per 2-cm size class from survey trawls between (160m - 400m).

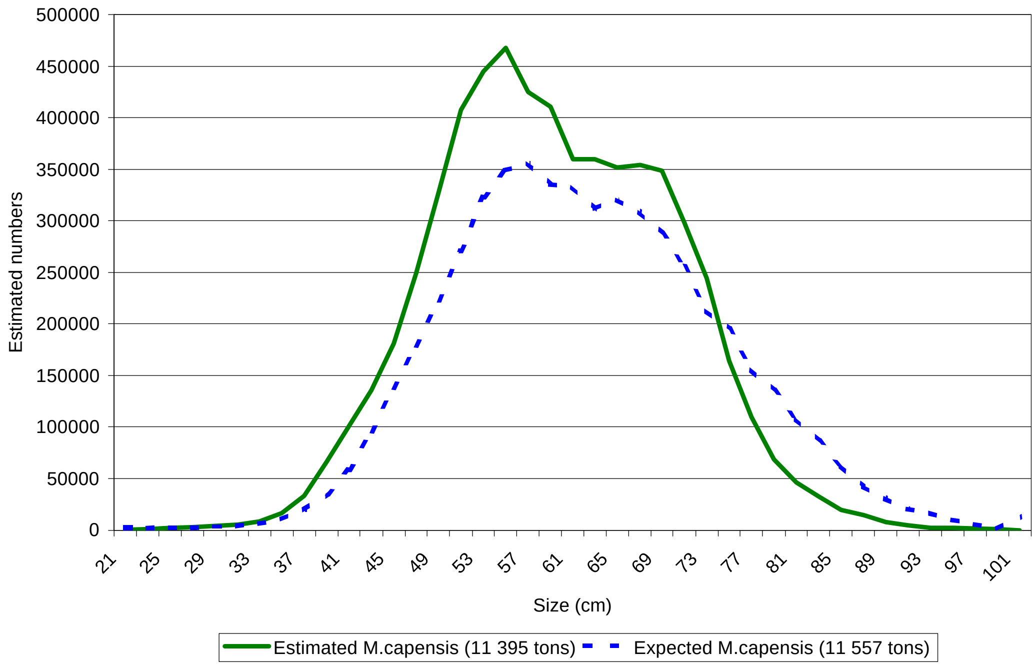


Figure 13. Estimated versus expected *M.capensis* catch-at-length frequencies (160-400m).

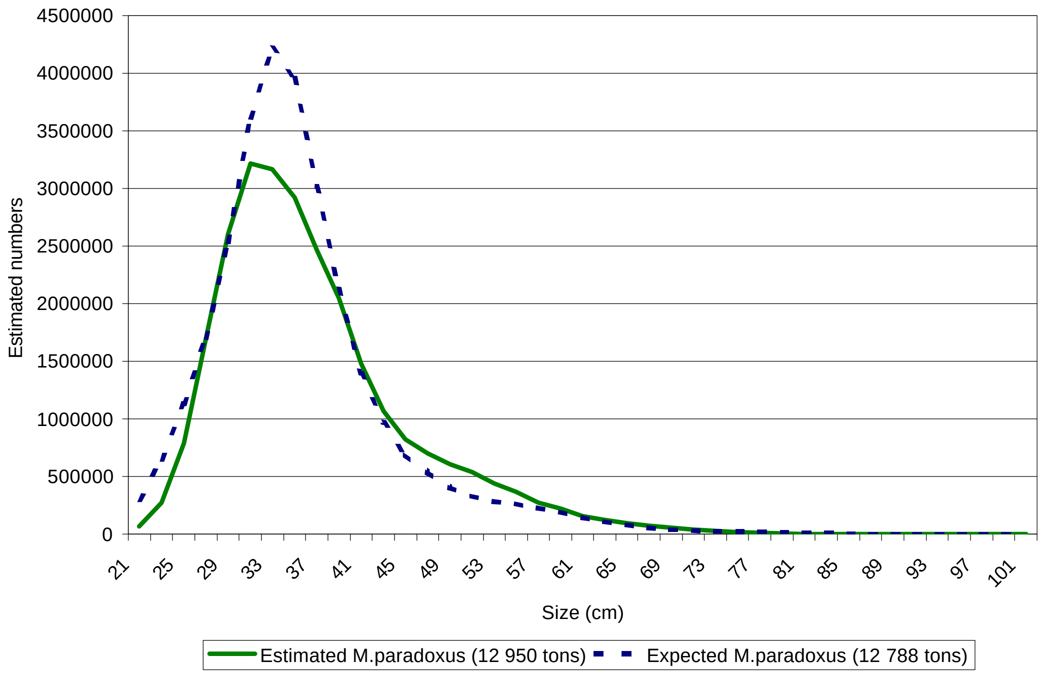


Figure 14. Estimated versus expected *M.paradoxus* catch-at-length frequencies (160-400m).

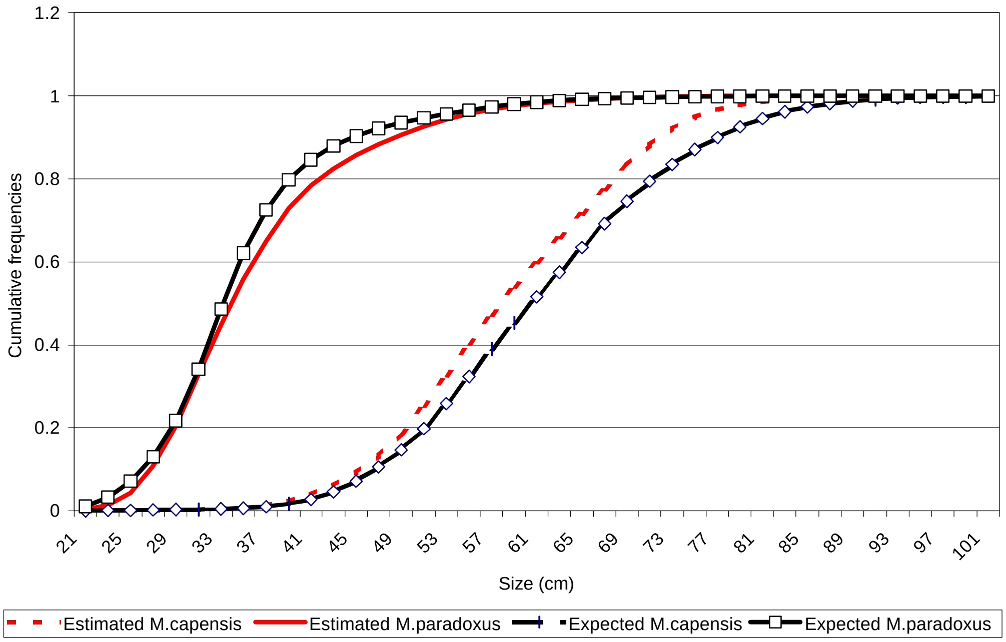


Figure 15. Cumulative frequency curves for expected and derived *M.paradoxus* and *M.capensis* curves between 160-400 meters.

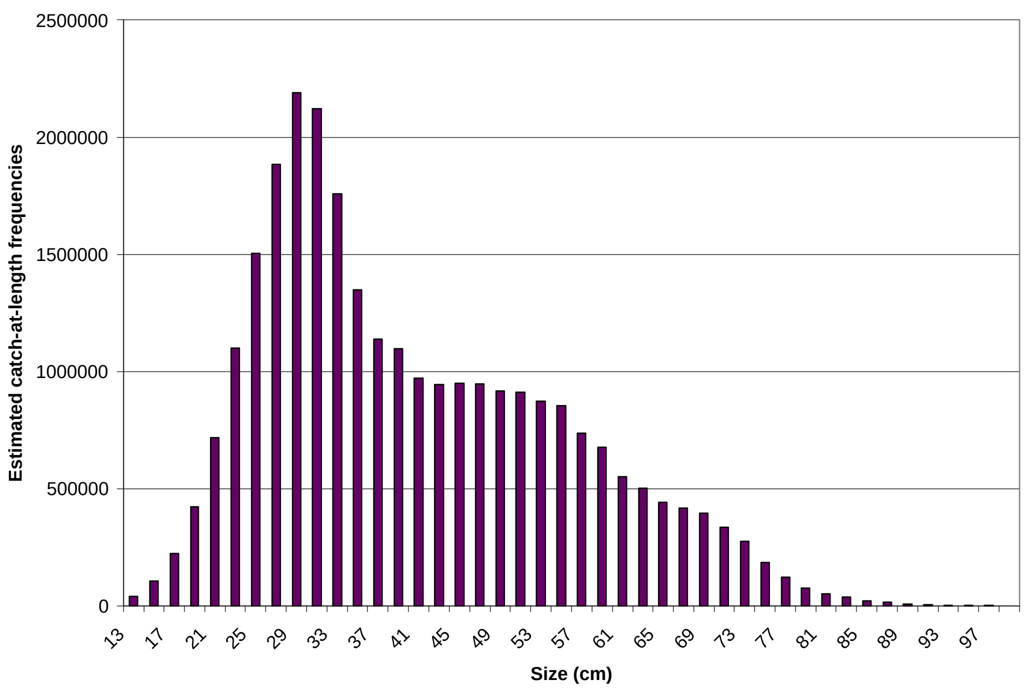


Figure 16. Catch-at-length estimates for trawled *M.capensis* landings on the South Coast in 1997.

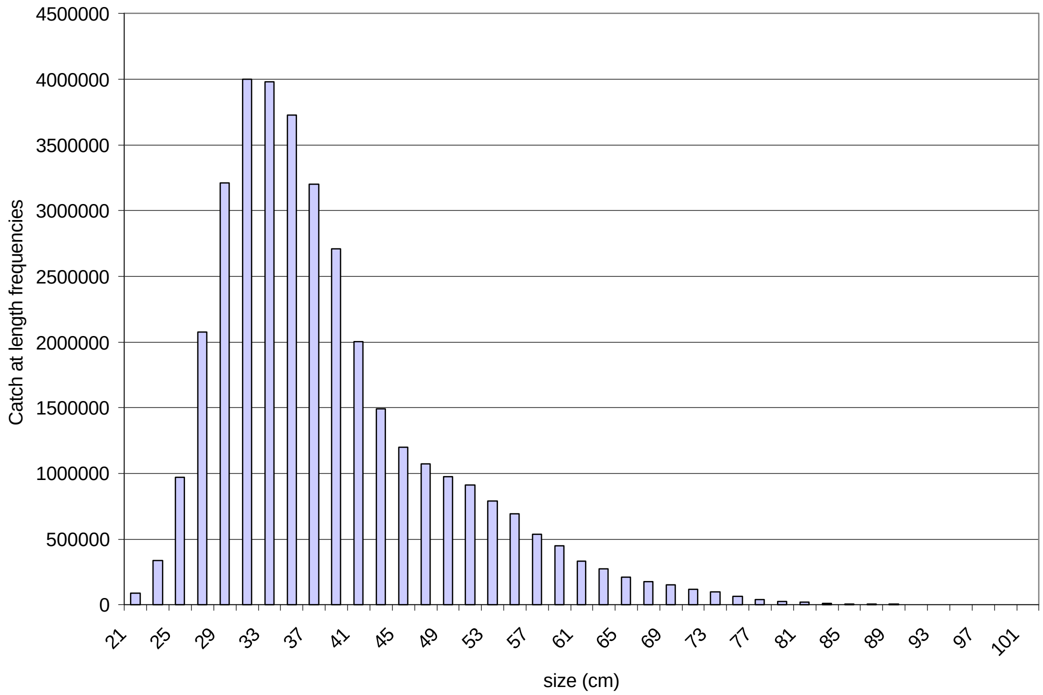


Figure 17. Catch-at-length estimates for trawled *M.paradoxus* landings on the South Coast in 1997.

Tables

Chapter 4

A Preliminary Assessment of the Current Stock Status of (*Merluccius capensis and paradoxus*) on the Southeast Coast of South Africa.

Introduction

Jones's (1984) pseudo-cohort analysis, or length-based VPA as it is otherwise known, was developed for use in instances where age-based stock assessment methods cannot be applied. This and other length-based assessment techniques have received a great deal of attention in tropical fish stock assessments, where seasonal ring formations in otoliths are not readily observable (Pauly 1979, 1984). Sparre (1985) compiled a comprehensive manual on tropical stock assessments and most of its pages are devoted to methods used for analyzing length data. Hilborn and Walters (1992) wrote the following about length-based VPA "This method is critically dependent on having a length frequency distribution that is either from a population at equilibrium, or represents an average distribution over some period of time for which recruitment and exploitation rates have been stable on average (no significant trends in either)".

The F.A.O. (1996), in assessing problems facing fisheries management in the Mediterranean, described the use of length-based models as having achieved some success in determining basic biological parameters. This report added that these methods had not established the necessary linkage between scientific advice and management action, but attributed this to a variety of problems including an absence of co-operative institutional framework. Aldebert et al. (1993) used length-based VPA and yield-per-recruit models to analyze gear interactions and determine the status of hake stocks in the Gulf of Lions hake fishery, in the NW Mediterranean; conclusions were that the NW Mediterranean hake fishery was certainly over-exploited. Since then, the length-based pseudo-cohort approach was compared to an age-based VPA for the same NW Mediterranean hake stocks with results being quite similar, confirming the previous length-based studies (Aldebert and Recasens 1996).

This chapter has aimed at providing a preliminary analysis of South Coast hake stocks using a length-based pseudo cohort analysis. However, due to the paucity of data the analysis is strictly theoretical at this stage and cannot be applied for management purposes. Two major objectives have been outlined. The first has been to examine the status of each hake species in relation to the combined levels of effort exerted on their individual stock structures. The second has been to analyze the inter-specific gear interactions caused by simultaneously increasing long-line and hand-line effort while keeping trawl effort constant.

Methods

To complete this analysis two basic assumptions were necessary: 1) It was assumed that catch-at-length data collected off the South Coast in 1997 came from a steady state population at equilibrium. 2) That migration of hake stocks off the South Coast fishing grounds does not occur. Then declining numbers per size class must have occurred as a direct result of fishing and natural mortality. These assumptions have not been justified and therefore results can only be treated as theoretical at this stage.

Catch-at-length data for each hake species (*M.capensis* and *M.paradoxus*) was compiled separately for all gears operating off the South Coast in 1997 for use in this analysis (Tables 1 & 2). Long-line length frequency samples collected during the course of 1997 were made available for this analysis (MCM, Unpublished data). These were raised up by a factor of landed catch weight / sample weight. Long-line landings east of 20°E were reported as 1750 tons in 1997, approximately 50% of the annual long-line allocation (4400 tons). Hand-line catch-at-length data was established in the same manner using a landed hake estimate of 3955 tons. Long-line and hand-line catches are predominantly *M.capensis*. Trawl catches inside the 160-meter isobath were assumed to comprise predominantly of *M.capensis*, while those outside the 400-meter isobath were treated as *M.paradoxus*. This separation by depth is in line with the depth/proportion algorithms developed for the South Coast (Geromont et al. 1995). Methods for deriving trawl data disaggregated into species composition have been covered in the preceding chapter and catch-at-length data for the respective inshore and offshore components was divided into the relevant depth intervals. Discard length frequency estimates between 0-100-meters and 101-160-meters were added to the total trawl *M.capensis* catch-at-length data. As explained in Chapter 3, discard length frequency estimates for depths outside 160-meters were not available for this analysis.

Jones's length-based pseudo-cohort analysis (1984) was used to calculate instantaneous fishing mortality (F) and abundance-at-length for both species caught on the South Coast during the course of 1997. Input catch-at-length data for each hake species was attributed to 2-cm size class groupings. All calculations were made using the processing capabilities of Microsoft EXCEL - spreadsheets and the Microsoft ACCESS – relational database package. The calculation procedure is analogous to Pope's (1972) cohort analysis and proceeds recursively by calculating the number of fish that attain length $L1$ from the number of fish that attain length $L2$. Sparre (1997) has written this calculation procedure using length-based symbols as

$$N(L1) = [N(L2) * H(L1, L2) + C(L1, L2)] * H(L1, L2)$$

N ($L1$) is the number of fish that attain $L1$ and N ($L2$) is the number that attain $L2$, $C(L1, L2)$ is the amount caught between $L1$ and $L2$ and $H(L1, L2)$ is the fraction that survive natural deaths between $L1$ and $L2$ given as

$$H(L1, L2) = [L1 - L\infty / L\infty - L2] \wedge (M / 2k)$$

The numbers alive in the largest or plus size group *N (L97)* are calculated using the length-based version of the catch equation written as

$$C(L97, L\infty) = N(L97) * F / Z * [1 - \exp(-Z * \Delta\mathrm{t})]$$

Theoretically the age corresponding to *L¥ is* infinite and *N (97)* is approximated as

$$N(97) = C(97,\infty)/F/Z$$

An initial guess of *F/Z* is required to calculate numbers in the plus group *N* (97cm, ∞). An input value of *F/Z* = 0.5 was used in this analysis.

The F-mortality rate between *L*1 and *L*2 is given as

$$F = M * (F/Z)/(1 - F/Z)$$

where F/Z is calculated using the catch equation.

Biological growth parameters for the two hake species were taken from an age and growth study on the eastern Agulhas bank (Kono 1980). Growth parameters derived for both sexes combined were used for each of the hake species: L_∞ = 129.1cm, k = 0.0989, t_o = -0.0059 for *M.paradoxus* and L_∞ = 118.8cm, k = 0.1106, t_o = 0.0955 for *M.capensis*.

A "length-based Thompson and Bell" model was used to analyze derived F-mortality values. The principle behind this model is the same as the age-based Thompson and Bell model (1934) model, only the formulas are slightly different. The formulas used in this model were taken from the tropical fish stock assessment manuals by Sparre (1997) and the data inputs needed for this model were derived from the aforementioned Jones's pseudo-cohort analysis procedure. Data inputs by length group included fishing mortalities, the natural mortality factor *H(L1,L2)* and an initial estimate of the number of recruits entering the smallest size class. The calculations proceed as a forward version of the length-based VPA

$$N(L2) = N(L1) * [\ 1/H(L1,L2) - F(L1,L2)/Z(L1,L2)\ ] * 1/[H(L1,L2) - F(L1,L2)/Z(L1,L2)\ ]$$

The yield in each length group is given as

$$Y(L1,L2) = C(L1,L2) * \overline{W}(L1,L2)$$

where the mean weight is calculated as

$$\overline{W}(L1,L2) = q * [(L1 + L2)/2]^{b}$$

and q and b are parameters in the length-weight relationships.

The mean number of survivors of each length group is given as

$$\overline{N}(L1,L2) * \Delta t(L1,L2) = [N(L1) - N(L2)]/Z(L1,L2)$$

The corresponding mean biomass in each length group is

$$\overline{B}(L1, L2) * \Delta t(L1, L2) = \overline{N}(L1, L2) * \Delta t(L1, L2) * \overline{W}(L1, L2)$$

The average biomass during the life span of a cohort is estimated as

$$\overline{B} = \sum \overline{B}i * \Delta ti$$

It was possible to determine optimum fishing levels and examine gear interaction by multiplying the determined F-mortality values in each length group by an adjusted F-at-length-array. Values in the F-at-length–array were set to proceed in increments of 0.1 between 0 and 3. The effects of increasing and decreasing the total F-value on the yields of each species were used to predict the relationship between current effort levels of exploitation and the maximum sustainable yield. Effort levels in excess of the amount needed to achieve a maximum sustainable yield (MSY) were considered as a clear indication that the stock was over-exploited. In addition, the effects of increasing long-line and hand-line effort on the inshore *M.capensis* resource were examined. This particular scenario was developed to examine the effects of simultaneously increasing long-line and hand-line F-mortality values while keeping trawl (inshore and offshore) F-mortality values constant. The F-mortality exerted by each gear as per 2-cm size interval was calculated as

$$F(i) = F(total) * C(i) / C(total)$$

where *C (i)* is the number of hake caught by gear no.i and *F(total)* and *C(total)* are the fishing mortalities and numbers caught by all gears.

Botha (1986) calculated the rate of instantaneous natural mortality (M) for Cape Hakes in the Cape of Good Hope area using the Rikhter and Efanov (1977) age at maturity method (*M.paradoxus* ♀ = 0.34, ♂ = 0.44 and *M.capensis* ♀ = 0.33, ♂ = 0.42). The average value between the sexes of each species was used in this analysis; *M.paradoxus* = 0.39 and *M.capensis* = 0.375. Natural mortality (M) was assumed to remain constant over exploitable size classes (21cm-99cm). To test model sensitivity to the derived and uncertain natural mortality estimate, the optimum F-value needed to maximize yields for each species was determined under an array of varying M-values. The initial M-values chosen for *M.capensis* and *M.paradoxus* were adjusted by 20% to provide a lower and upper value. The predicted yield under each optimum F-value was compared to the predicted yield under the current F-value (F = 1.0) for each different M-value. The difference between these two predicted yields was used to determine the magnitude of these changes under each scenario.

Results

The main global results of the length-based VPA have been summarized in Table 3. *M.capensis* biomass was calculated at 106,116 tons and *M.paradoxus* biomass at 47,408 tons; initial recruitment numbers at 21-cm were estimated at 98,391,182 for *M.capensis* and 88,359,911 for

M.paradoxus. The total F-mortality rate on *M.paradoxus* as per 2-cm size class increased rapidly in the small size classes (21cm-39cm) after which values gradually increased to reach a peak value of F = 0.8 near 81-cm (Figure 1). The pattern is different for *M.capensis,* after some increase in F-mortality rates between 27cm-37cm, mortality declined and then rose gradually to reach the highest levels of F = 0.58 near 77-cm. (Figure 2). The calculated proportions of fishing mortality (F) exerted by each gear on the size class structures of each hake species have been summarized in Table 4.

The status of each species was evident in their predicted yield curves under an array of adjusted F-mortality values. The *M.capensis* yield under current effort levels (F = 1) was slightly below the asymptotic value and had reached the desired balance between achieving an optimum yield without impacting adversely on stock biomass (Figure 3). The opposite was true for the *M.paradoxus* stocks and the current level of fishing mortality (F = 1) had exceeded the level needed to achieve an optimum yield (Figure 4). Reducing effort under the current exploitation patterns by 50% was predicted to have little effect on yield, while greatly increasing standing stock biomass. The model predicted an increase of 34,610 tons in biomass under this scenario, emphasizing the effects of induced *growth over-fishing* on *M.paradoxus* stocks.

Inter-specific gear interactions and their effects on *M.capensis* yields were all compared under the same scenario of simultaneously increasing long-line and hand-line effort while keeping trawling effort constant. The predicted effects of increasing long-line and hand-line effort under this scenario were predicted to have the largest impact on trawls operating between 100-400-

meters; inshore trawl (0-100-meters) yields were not noticeably reduced (Figure 5). Hand-line yields were predicted to surpass long-line yields under this scenario with long-line yields not being able to grow far beyond 2000 tons. Doubling long-line and hand-line effort was predicted to increase overall *M.capensis* yield from 22 441 tons to 23 202 tons, a meager increase amounting to approximately 750 tons (Figure 6).

The length-based models used in this analysis were highly sensitive to a varying natural mortality estimate. The effects of adjusting natural mortality by 20% to equal an upper value of 0.45 and a lower value of 0.3 was used to test the *M.capensis* model (Table 5). The upper and lower M-values calculated at 0.468 and 0.312 respectively were used to test the *M.paradoxus* model (Table 6). Both of these tests show considerable variation around the derived optimum F-values. Given the general trend of these results, *M.paradoxus* appears to be over-exploited while *M.capensis* appears to be moderately exploited. The upper M-value of 0.468 used in the *M.paradoxus* analysis calculated the optimum F-value at F = 1.2, a 20 % increase in effort was predicted to increase yield by 86 tons. The upper level M-value of M =0.45 used in the *M.capensis* analysis calculated the optimum F-value at F= 2.6, this would mean that effort increased by 160 % would increase yields by 3281 tons.

Discussion

There is strong evidence from the results of this study that while *M.capensis* stocks are in line with optimum fishing levels *M.paradoxus* stocks are over subscribed. With the bulk of current fishing pressure directed at small sized *M.paradoxus* the differences in the status of each species comes as no surprise. Total hake landings in 1997 between 160m-400-m were reported at 24,346 tons, approximately 50% of this amount comprised *M.paradoxus* of which the majority were under 40-cm in total length. This will produce unproductive yields due to *growth over-fishing* unless natural mortality is so high that it warrants this level of exploitation.

The length-based VPA and Thompson and Bell models describing hake population dynamics on the South Coast need to be viewed in light of their limitations and constraints. Assuming a constant parameter system and a population in equilibrium are probably far from reality. This limits their application in terms of setting quotas or effort controls. It should be noted that given the recent increase in long-line and hand-line effort, the fishery is expanding and in the process of development. The numbers caught in the larger size groups are temporarily increasing due to the increased effort and the relative decline between successive groupings does not accurately measure mortality. F-mortality in this case would be underestimated. However, the accuracy in establishing the separately derived catch-at-length data for each hake species, used as input into these models, has not yet been proven. The veracity of this data needs to be checked against empirical data sets before further conclusions can be made. Methods used to split mixed hake trawl catches have been covered in Chapter 3. The biological parameters used to describe growth and length-weight relationships are equally important and determine the general trends in these models. For this reason, biological parameters derived for Cape hakes on the Agulhas Bank (Kono 1980) were favored over other estimates.

Natural Mortality (M) is an important parameter and has a large influence on the final analysis. Most of the derived natural mortality estimates for Cape Hakes use the Rikhter and Efanov (1977) formula. This method relies on the determined age at 50% maturity. However, both growth and age at 50% maturity differ considerably between the sexes (Kono 1970, Botha 1986). This particular aspect may have led to the high degree of variation surrounding natural mortality estimates, because both growth and species/sex composition are strongly influence by location. Mombeck (1970) estimated the length at 50 % maturity to be some 100-mm lower in the Northern fishing grounds than around the Cape of Good Hope area. Past natural mortality estimates for the Cape Hakes (both species combined) range from 0.2 – 0.25 (Prenski 1980). Assorov and Shcherbitch (1979) calculated M to be 0.5 for *M.paradoxus* and 0.42 for *M.capensis*, but the location of the survey area was not given in this analysis. Natural mortality estimates used in this analysis need to be put into perspective. If natural mortality is less than that used in this analysis (M= 0.39 for *M.capensis* and M= 0.375 for *M.paradoxus*), the effects of *growth over-fishing* will be more severe than determined in this analysis. The opposite holds true for a natural mortality estimate that is larger than that used in this analysis. The latter suggests that an increase in fishing effort would be warranted - an unrealistic scenario given the history of hake stocks collapsing due to excess effort in the 1970's. From an overview of the hake stocks, worldwide natural mortality was estimated at M = 0.4 and it was established that the status of the majority of hake stocks was one of moderate over-exploitation (Pitcher and Alheit 1995). Any claim to suggest that fishing effort should be increased because natural mortality is high should be met with skepticism. In all likelihood, natural mortality in Cape hakes is a dynamic parameter that fluctuates with population density and fishing pressure. Accepting a higher natural mortality value and disregarding the effects of *growth over-fishing* on small sized hake needs to be weighed against the potential loss in future yields.

There is considerable scope for altering unproductive fishing practice and inducing better overall yields with an optimum management policy that considers the benefits of spatially based controls. It is already known that size and species composition is dependent on depth (Badenhurst and Smale 1991). In this sense, effort could be directed towards areas where the larger sizes could be harvested reducing the adverse effects of *growth over-fishing*. Furthermore, induced F-mortality rates on the separate species can be controlled by implementing spatially determined fishing zones.

Migration from the South Coast fishing grounds is an important consideration. Assuming declining numbers per age/size class to be a result of fishing and natural mortality would be a misperception if stocks do indeed migrate away from the fishing grounds. Cape hakes are thought to generally migrate shoreward for spawning (Payne 1989). This theory is supported in other hake stocks of the world (Grinols et al. 1970). Fortunately, this does not present a major problem for the models used in this analysis. On the other hand, a lateral migration would seriously bias results. The eventuality of this occurring is difficult to ascertain and no formal studies have yet been conducted. If lateral migration away from the fishing grounds does occur, VPA models would have to incorporate an additional parameter to account for the decline in successive size structure. In terms of offering management advice, understanding the patterns of migration would enable sensible decisions to be made about the most productive harvesting strategies. An example would be to avoid areas inhabited with small sizes during certain periods and attempt to track the larger fish, barring of course aggregated spawning assemblies.

With long-line and hand-line effort increasing rapidly management policies will need to consider how gear interactions are going to affect inter-specific catch rates and overall yields. Modeling the effectiveness of one gear over another cannot be done in isolation (Djama and Pitcher 1997) and multiple gear interactions need to be considered. Management will need to focus on examining these interactions in conjunction with developments in the fishery.

The swept-area trawl survey method estimated 163,283 tons of Cape hake between 0-500-meters on the South Coast in 1997 (Leslie 1998). This is considered a relative index of biomass rather than an absolute measurement. Combined hake biomass estimates in this study are 153,524 tons, but this includes the entire population in the depth range between 0-700m. Either the swept-area method provides an over estimate of hake biomass or length based VPA tends to under estimate. *M.capensis* was estimated at 106,116 tons and *M.paradoxus* was estimated at 46,073 tons.

Future research should focus on several issues in order assist future management considerations. 1) Determine the validity of assuming equilibrium in the hake fishery on the South Coast. In making this determination, recruitment and exploitation rates would be required to have been constant over *n* number of years, *n* being the life span of hake. Data for the last *n* number of years would have to be compiled to determine the average length frequencies for this period. 2) Develop appropriate length/age based keys for each hake species and sex. One set of keys would have to be developed for each year because growth rates may vary between years. 3) Improve the methods used to dissociate mixed species landing data. A Global Information System (GIS) database could be developed for this purpose by determining more precise estimates based on specific location. Variation in derived estimates of species proportion by depth between these areas would be reduced.

Figures

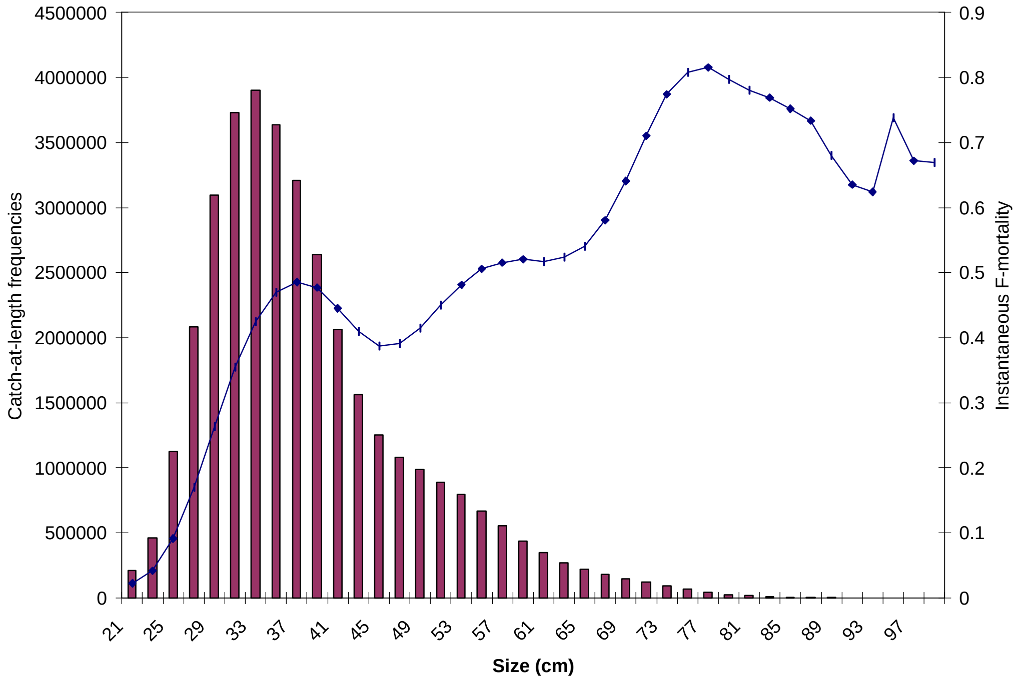


Figure 1. F-mortality on *M.paradoxus* as per 2-cm length interval

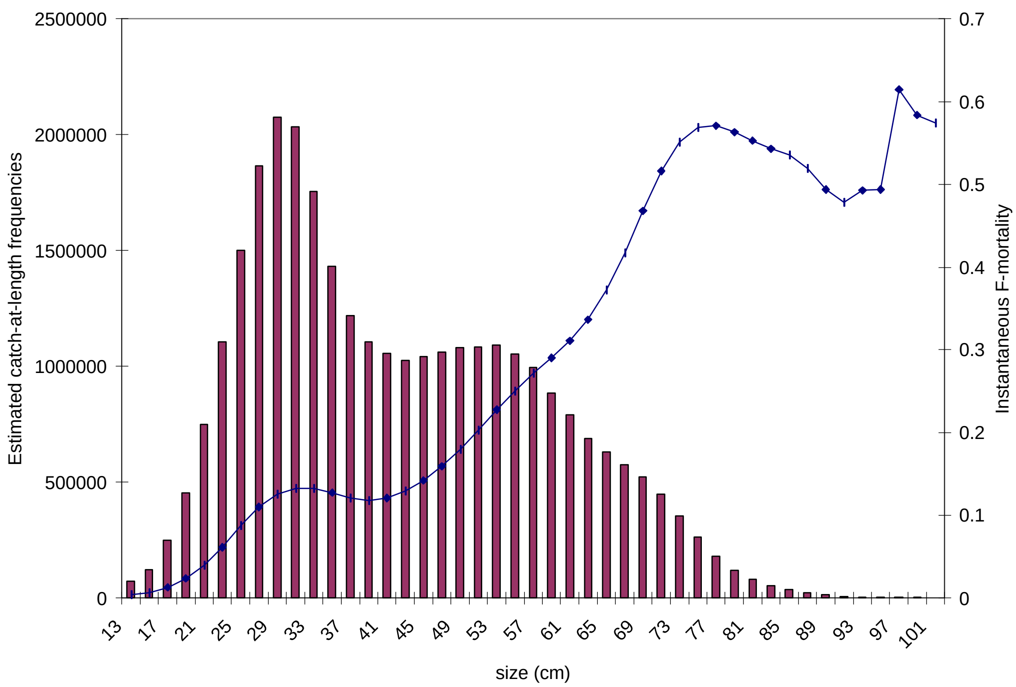


Figure 2. F-mortality on *M.capensis* as per 2-cm length interval.

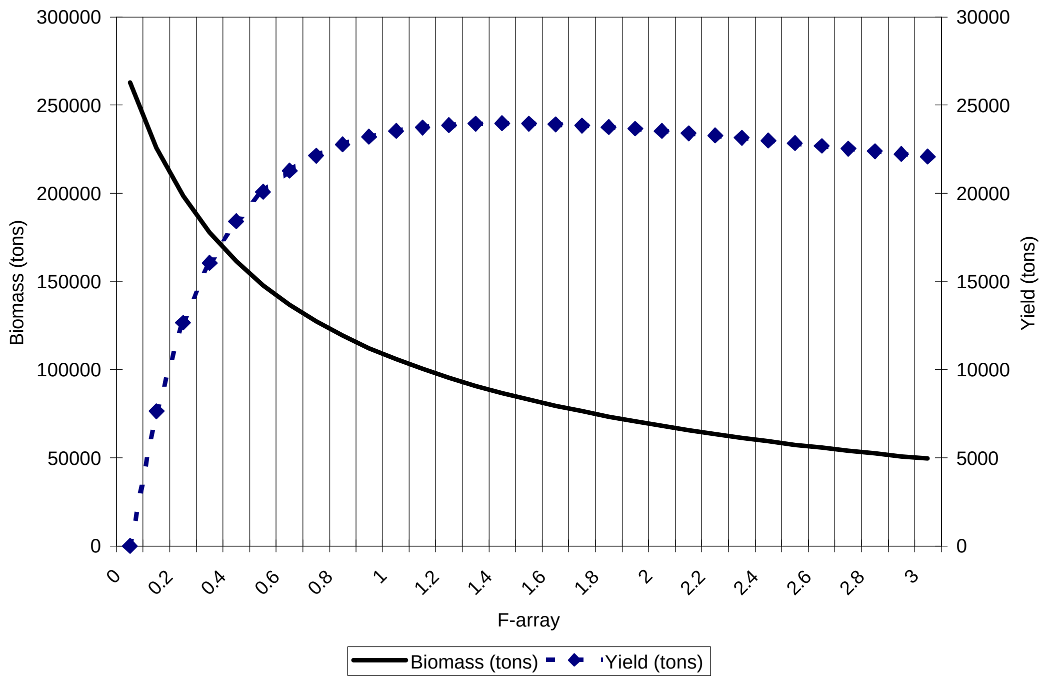


Figure 3. Thompson & Bell length-based analysis of *M.capensis.*

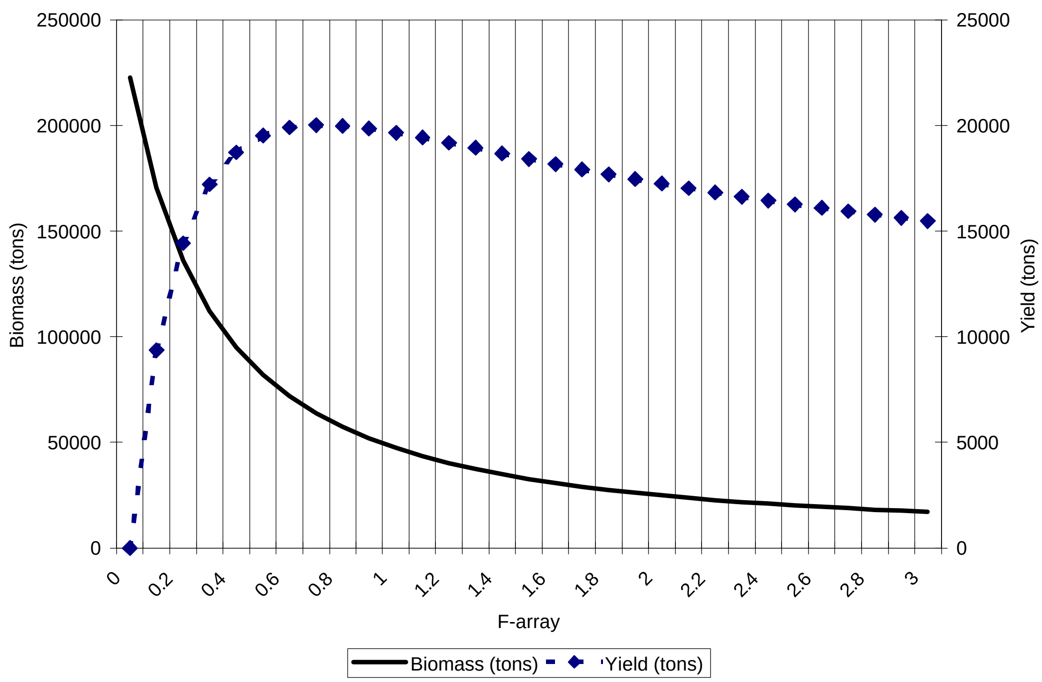


Figure 4. Thompson & Bell length-based analysis of *M.paradoxus.*

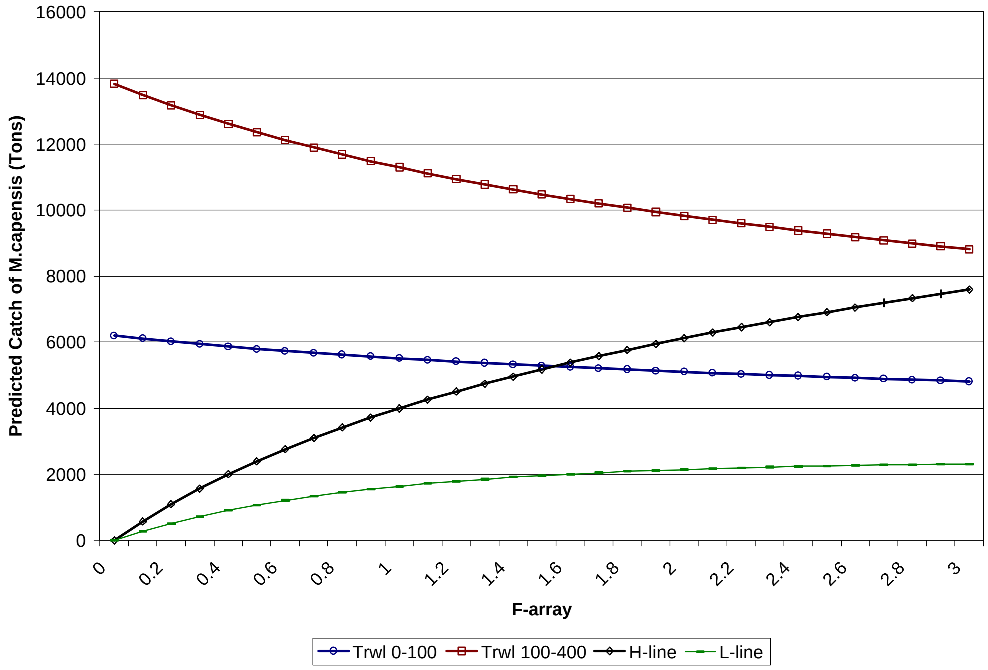


Figure 5. Predicted catches of *M.capensis* for each gear when increasing long-line and hand-line effort simultaneously and keeping trawling effort constant.

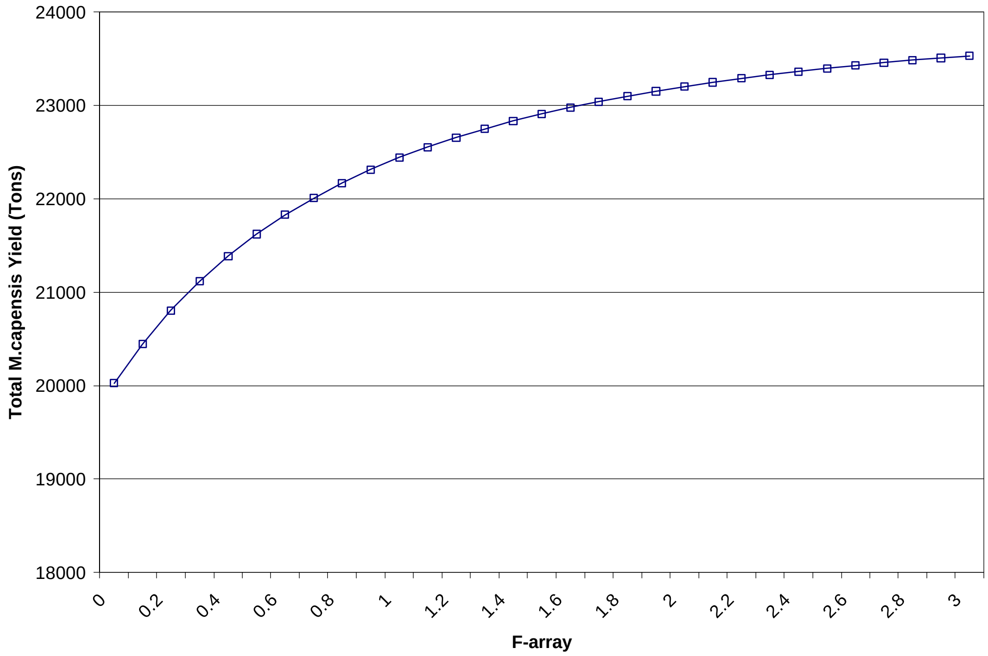


Figure 6. Predicted *M.capensis* yields by all gears when simultaneously increasing long-line and hand-line effort and keeping trawling effort constant.

Tables

Table 1. *M.capensis* catch and discards in numbers split by gear type and depth.

Size cm	Trawl 0-100m	Discards 0-100m	Trawl 101-160m	Discards 101-160m	Trawl 160-400m	Hand-line 0-100m	Long-line 0-200m	Total Catch
13	0	35179	0	6638	0	0	0	41817
15	0	90017	0	14207	0	0	0	104224
17	0	192617	0	29197	0	0	0	221814
19	0	379826	0	44665	0	0	0	424491
21	6728	651028	4006	55527	361	1179	0	718829
23	26406	985010	15731	71364	1126	1179	0	1100816
25	78237	1289683	46648	85520	2365	2358	0	1504810
27	178512	1502403	106647	92858	3039	8645	0	1892104
29	303509	1617056	181797	83222	3855	11002	0	2200442
31	432616	1364474	259954	59176	5091	16896	0	2138208
33	511381	890028	308331	38714	8292	12181	0	1768928
35	588301	370825	355404	16732	16458	16503	0	1364224
37	611097	118977	369103	7747	33498	23183	0	1163605
39	604159	64403	362399	341	65775	32221	74	1129373
41	547849	0	323270	0	101152	52260	370	1024901
43	512657	0	295840	0	135681	68371	1134	1013683
45	489426	0	278119	0	180989	90375	2391	1041301
47	445037	0	251919	0	249064	117881	6632	1070531
49	376419	0	213769	0	327932	139885	12006	1070010
51	320409	0	183245	0	407682	166212	20585	1098132
53	272469	0	157115	0	445221	183501	28721	1087027
55	244365	0	142367	0	467759	202362	35205	1092058
57	195725	0	115408	0	425292	207863	39297	983586
59	166254	0	99433	0	411028	192146	45140	914000
61	118112	0	72505	0	359854	160318	51451	762239
63	87246	0	56077	0	359592	131241	60252	694407
65	51882	0	37153	0	351610	104914	67106	612664
67	35551	0	28386	0	354192	98234	64764	581127
69	25554	0	22758	0	348400	79373	58403	534489
71	19871	0	18271	0	298352	64834	49898	451226
73	15201	0	14356	0	244299	46366	40727	360950
75	10157	0	9603	0	164294	38115	32419	254587
77	6811	0	6409	0	109365	29470	22138	174194
79	4283	0	3996	0	68352	20826	13781	111238
81	2871	0	2679	0	46385	14932	9713	76579
83	1952	0	1832	0	32572	10609	6065	53030
85	1125	0	1074	0	19822	7466	3402	32890
87	817	0	780	0	14694	4715	2243	23249
89	432	0	412	0	7850	3143	1282	13119
91	262	0	250	0	4806	1179	444	6941
93	123	0	118	0	2271	786	493	3791
95	123	0	118	0	2282	0	222	2745
97	108	0	103	0	1997	393	229	2830
99+	31	0	29	0	571	393	0	1024

Table 2. *M.paradoxus* catch in numbers by offshore trawls split by depth.

Size cm	Trawl 160-400m	Trawl 400-700m	Total Catch
21	71151	15843	86993
23	274540	61311	335851
25	791659	177715	969373
27	1689101	384764	2073865
29	2603870	607505	3211375
31	3218272	780206	3998478
33	3167501	812056	3979557
35	2920577	808177	3728754
37	2461304	739707	3201012
39	2047877	660194	2708071
41	1478974	522022	2000995
43	1069806	421970	1491776
45	824050	372481	1196531
47	702482	366306	1068788
49	607947	366539	974486
51	538591	372882	911472
53	441031	345874	786904
55	369406	319138	688543
57	274190	258205	532395
59	222086	224622	446707
61	157984	171212	329195
63	125298	145614	270911
65	93835	116151	209986
67	73629	102937	176566
69	58214	92951	151165
71	42097	76934	119030
73	32079	61902	93981
75	20809	41445	62254
77	13493	27548	41041
79	7462	17045	24507
81	4445	11428	15873
83	2453	7859	10312
85	1117	4675	5792
87	509	3394	3903
89	182	1793	1975
91	70	1089	1159
93	23	512	536
95	12	512	525
97	11	448	459
99+	3	128	131

Table 3. The estimated biomass and calculated abundance-at-length for *M.paradoxus* and *M.capensis* populations on the South Coast in 1997 using Length-based VPA.

Size	M.capensis			M.paradoxus		
(cm)	Est. Abundance	F-mortality	Biomass (Tons)	Est. Abundance	F-mortality	Biomass (Tons)
21	98391182	0.06	1171	88359911	0.02	1066
23	91056085	0.07	1469	81993767	0.04	1338
25	83915090	0.09	1789	75725313	0.11	1626
27	76834123	0.10	2121	69165780	0.18	1909
29	69909152	0.11	2457	62065381	0.26	2158
31	63290238	0.12	2794	54431392	0.34	2349
33	57123523	0.12	3129	46682993	0.41	2474
35	51492721	0.11	3463	39294082	0.45	2536
37	46423244	0.10	3796	32678000	0.47	2547
39	41876275	0.10	4126	26944297	0.46	2522
41	37744653	0.10	4441	22184704	0.44	2481
43	33916447	0.10	4728	18327874	0.42	2435
45	30328951	0.12	4977	15247260	0.41	2385
47	26962892	0.13	5176	12701989	0.41	2319
49	23787524	0.15	5312	10521986	0.42	2223
51	20798225	0.18	5375	8608715	0.45	2094
53	17995045	0.20	5359	6944111	0.48	1935
55	15398770	0.22	5264	5512901	0.50	1757
57	13018860	0.25	5094	4328243	0.51	1572
59	10880490	0.27	4857	3358864	0.52	1391
61	8982955	0.29	4564	2593613	0.52	1218
63	7327329	0.32	4223	1984259	0.53	1056
65	5886396	0.35	3835	1509586	0.56	905
67	4643191	0.39	3405	1131061	0.60	760
69	3574978	0.44	2942	829779	0.65	621
71	2675529	0.48	2465	589676	0.71	489
73	1938616	0.52	1998	402448	0.76	370
75	1360093	0.55	1571	264892	0.79	270
77	928052	0.56	1203	168346	0.81	192
79	618274	0.57	902	105556	0.81	134
81	404851	0.57	665	65334	0.80	93
83	260761	0.56	482	40044	0.78	64
85	164590	0.57	341	24067	0.77	42
87	100591	0.57	234	14094	0.75	28
89	59276	0.59	155	8187	0.72	18
91	33700	0.60	99	4626	0.72	11
93	18064	0.56	59	2675	0.65	7
95	9015	0.55	33	1497	0.62	4
97	4233	0.51	42	743	0.59	7
Total			**106116**			**47408**

Table 4. F-mortality rates by species and gear type.

M. capensis						*M.paradoxus*		
Size cm	Trawl 0-100m	Trawl 101-400m	H-line	L-line	Total F	Trawl 160-400m	Trawl 400-700m	Total F
13	0.004	0.001	0.000	0.000	0.004			
15	0.006	0.001	0.000	0.000	0.007			
17	0.011	0.002	0.000	0.000	0.013			
19	0.021	0.003	0.000	0.000	0.024			
21	0.037	0.003	0.000	0.000	0.040	0.018	0.004	0.022
23	0.057	0.005	0.000	0.000	0.062	0.034	0.008	0.042
25	0.080	0.008	0.000	0.000	0.088	0.075	0.017	0.091
27	0.098	0.012	0.001	0.000	0.110	0.138	0.031	0.170
29	0.110	0.015	0.001	0.000	0.126	0.213	0.050	0.263
31	0.112	0.020	0.001	0.000	0.133	0.285	0.069	0.355
33	0.105	0.027	0.001	0.000	0.133	0.338	0.087	0.425
35	0.089	0.036	0.002	0.000	0.127	0.368	0.102	0.470
37	0.076	0.043	0.002	0.000	0.121	0.373	0.112	0.486
39	0.070	0.045	0.003	0.000	0.118	0.361	0.116	0.477
41	0.065	0.050	0.006	0.000	0.121	0.329	0.116	0.445
43	0.066	0.055	0.009	0.000	0.130	0.294	0.116	0.410
45	0.067	0.063	0.012	0.000	0.142	0.267	0.121	0.387
47	0.066	0.074	0.018	0.001	0.159	0.257	0.134	0.391
49	0.063	0.091	0.024	0.002	0.180	0.259	0.156	0.415
51	0.059	0.109	0.031	0.004	0.203	0.266	0.184	0.450
53	0.057	0.126	0.038	0.006	0.227	0.270	0.211	0.481
55	0.056	0.140	0.046	0.008	0.250	0.271	0.234	0.506
57	0.054	0.149	0.057	0.011	0.272	0.265	0.250	0.515
59	0.053	0.162	0.061	0.014	0.290	0.259	0.262	0.521
61	0.048	0.176	0.065	0.021	0.311	0.248	0.269	0.517
63	0.042	0.201	0.064	0.029	0.337	0.242	0.282	0.524
65	0.032	0.236	0.064	0.041	0.372	0.241	0.299	0.540
67	0.026	0.275	0.071	0.047	0.417	0.242	0.339	0.581
69	0.022	0.325	0.070	0.051	0.468	0.247	0.394	0.641
71	0.023	0.362	0.074	0.057	0.516	0.251	0.459	0.710
73	0.023	0.395	0.071	0.062	0.551	0.264	0.510	0.775
75	0.023	0.389	0.085	0.072	0.569	0.270	0.538	0.808
77	0.022	0.379	0.097	0.073	0.571	0.268	0.547	0.815
79	0.022	0.366	0.105	0.070	0.563	0.243	0.555	0.797
81	0.021	0.354	0.108	0.070	0.553	0.219	0.562	0.781
83	0.020	0.352	0.109	0.062	0.543	0.183	0.586	0.769
85	0.018	0.340	0.122	0.055	0.536	0.145	0.607	0.752
87	0.018	0.345	0.105	0.050	0.519	0.096	0.638	0.734
89	0.016	0.311	0.118	0.048	0.494	0.063	0.617	0.680
91	0.018	0.349	0.081	0.031	0.478	0.039	0.597	0.636
93	0.016	0.310	0.102	0.064	0.493	0.027	0.597	0.624
95	0.022	0.432	0.000	0.040	0.494	0.018	0.721	0.738
97	0.023	0.456	0.085	0.050	0.615	0.016	0.656	0.672
99+	0.018	0.342	0.224	0.000	0.584	0.013	0.656	0.669

Table 5. *M.capensis* - sensitivity tests of yield curve to natural mortality using adjusted M-value at 20% above and below base case value.

Fraction	M-value	Optimum F-value for maximum yield	Yield increase from F = 1
0.8	0.3	0.8	212 tons
1	0.375	1.4	445 tons
1.2	0.45	2.6	3281 tons

Table 6. *M.paradoxus* - sensitivity tests of yield curve to natural mortality using adjusted M-value at 20% above and below base case value.

Fraction	M-value	Optimum F-value for maximum yield	Yield increase from F = 1
0.8	0.312	0.5	2425 tons
1	0.39	0.7	365 tons
1.2	0.468	1.2	86 tons

Chapter 5

Conclusions

Age-structured models are the norm for analyzing effort levels and their relation to optimum yields. However, length-based cohort analysis (Jones 1984) was used in this study due to a lack of historical landing data and unreliable aging data. Length-based VPA is critically dependent on having length frequency distributions from a population at equilibrium. This is often considered a poor reflection of reality, which limits the application of this model in terms of advising long term management policy. Results from a length-based VPA must be viewed in light of their limitations. However, in spite of the equilibrium assumption there is strong support for the overall conclusion. *M.paradoxus* stocks may be over-subscribed due to intense pressure directed at small sized recruitment and line-effort directed at *M.capensis* stocks should proceed slowly to allow time for recruitment patterns to be monitored.

Yield-per-recruit models essentially aim at establishing the level of effort necessary to achieve optimum yield. Levels of fishing effort that are in excess of the amount needed to sustain optimum yields are said to induce *growth over-fishing*. Often fishing pressure is simply too high on the smaller individuals which are harvested before they have reached a reasonable weight. The remedy when only trawls are used is to either decrease effort or increase mesh size, but with a multiple gear fishery the mix of varying size selectivity requires a more complex analysis. There is still considerable scope for improving yields by analyzing the most productive mix of fishing gear. With long-line and hand-line effort increasing rapidly management policies will need to consider gear interactions more closely. From results in this analysis, it appears that increasing long-line and hand-line effort will impact most strongly on trawl catches of *M.capensis* between 100-400-meters. Trawl catches of *M.capensis* in this depth range are larger than those close inshore. For this reason, inshore trawling will remain less affected by changes in the line fishery provided recruitment does not decline.

Separating mixed trawl data by species for the Cape hakes was attempted for the first time in this analysis and it is too early at this stage to predict exactly how accurately this derived data conforms to the real situation. Accurate catch-at-age data for each hake species is the key to resolving many of the issues currently hampering hake stock assessments. As already mentioned in the introduction, surplus production and ad hoc tuned VPA models applied to stock assessments on the South Coast have produced different appraisals of status and productivity (Punt 1994). The author suggests that these discrepancies are due to conflicts between catch-at-age information and biomass data. A starting point in resolving this issue is to first establish accurate catch-at-length data and then progress towards producing accurate length/age keys. The methods used in this analysis to separate mixed species in trawl landings could shed some light on this issue. A separate species age-based VPA could be reconstructed were it possible to refine these techniques and apply them retrospectively. Refining these methods would require an extensive analysis of previous landing data by commercial grading category and depth for the last several years. The species composition in the mixing area would have to be reviewed and empirical models developed to dissociate the species based on location and depth. Real landing data could be checked against the predicted outcome to test the veracity of this form of spatial analysis. Adjusting survey trawl catch data to reflect commercial trawl selectivity curves could be used as an addition method for determining separate species catch-at-length data.

It is suggested that surplus production models include in their assessments a spatial extension that acknowledges the boundaries and general exploitation patterns of each species. Defining integral stock units and finding their boundaries is a topic not yet fully understood. Little is known about the migratory patterns of hake. The degree to which stocks exhibit sedentary behavior will determine the practicality of forming any separate species management structures for the South and West coasts. Nearly all commercially exploited hake exhibit an inshore-offshore movement (Grinols and Tillman 1970), but the extent of lateral movement still needs to be established. It would be feasible to manage ICSEAF Divisions 2.1 and 2.2 separately for example, should the hake stocks once settled exhibit little movement. One possible scenario may be that *M.paradoxus* display large migration patterns while *M.capensis* remain sedentary. In this case, having a separate management policy for each species would be a more beneficial arrangement. Tracing their movements would help steer effort off areas where small sizes congregate and redirect it onto the areas where the large fish invariably end up. Understanding the migration patterns of hake will contribute significantly towards establishing the best harvesting strategy and it is strongly urged that such a study receive priority in the near future.

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