

**AN ANALYSIS OF THE TRAWL AND LONGLINE FISHERIES
FOR *MERLUCCIUS CAPENSIS*
OFF THE WEST COAST OF SOUTH AFRICA.**

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“Sometimes, the best answer is a more interesting question.”

Terry Pratchett

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ABSTRACT

The South African hake resource faces divergent fishing pressures and management issues. Although the resource consists of two species, management was simplified because the resource was only subject to trawl effort and because of the similarity in population parameters, single species assessment models could be adopted. The impact of trawling on the stock is considered to be well understood and the resource has shown recovery since exclusion of foreign vessels. The 1990s were punctuated by major political change and the need for transformation has resulted in an expansion of the number of fishing rights holders. Longlining has been reintroduced and there is no clear understanding of how the combined fishing pressures will affect the population structure of either *Merluccius capensis* or *M. paradoxus*.

Information is vital to successful management. Fisheries are complex and intricate, and at times appear impossible to control or monitor. An integrated information system provides easily understood graphical explanations of complex issues. This thesis assessed the dynamics of the trawl and longline fisheries between 1994 and 1999 using a geographical information system (GIS). The accessibility of a GIS incorporates the needs of scientists, managers and fishing communities. The simple GIS developed in this study revealed shifts in effort, facilitated the calculation of spatially precise catches and biomasses and highlighted the inadequacy of current sampling coverage.

Trawlers were shown to fish the same areas consistently during the years investigated, with highest fishing intensity and average CPUE achieved at depths between 300 and 500m. Analysis of the longline sector revealed several similarities to the trawl sector, fishing intensity was highest between 301 and 500m, suggesting that both sectors face a “friction of distance” dilemma. The distribution and abundance of hake, in particular the exploitable proportion of the population, was determined by a combination of depth and substrate type.

The selectivity patterns of trawlers and longliners were briefly investigated with the results illustrating that gear selectivity of the *M. capensis* stock was depth dependent. The deeper fishing occurred, the larger the length-at-selection. As a result, the *M. capensis* parental stock faces unprecedented fishing pressure. In the absence of reliable species-specific catch data, logistic and linear regression models were developed to split the hake catch into its respective species components. Large discrepancies between the predicted *M. capensis* catch for the two models were noted. Regression estimates constructed at a finer spatial scale may provide a better fit than the current depth logistic employed by Marine and Coastal Management.

A first attempt at assessing the *M. capensis* resource on the West Coast using an age-structured production model was presented. It was found that a lengthy and accurate *M. capensis* catch series is required before it is possible to successfully model the dynamics of the stock. It is necessary to incorporate finer spatial detail in the collation of catch data and collection of sampling data. It would be unadvisable to assume that the stock is stable or recovering. The implications of a size/sex relationship must be investigated and properly appraised.

ACKNOWLEDGEMENTS

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The stalwarts at M&CM were tireless in their aid. Dr Rob Leslie explained the intricacies of the data and the context in which the fishery stands and Jean Glazer was always available to furnish and discuss data. Sharon du Plessis and her counterparts in the Demersal section taught me about the nitty-gritty of catching hake and gathering research information.

Sediment data was generously given by David Sinclair at the Council for Geoscience and the Deep-Sea Trawling Association allowed use of their reported catch data. Sarah Radloff, Horst Kaiser and Jeremy Baxter extracted me from a mire of statistics. Frank Holzforster at Rhodes' Geography illuminated the processes of sediment transport. Tom Shipton is thanked for his editorial comments and compliments.

My family have been my foundation, providing me with emotional and financial support. They, together with my close friends, listened to many a night of ranting and dried many a frustrated tear. Mom and Dad, your confidence in me almost put me to shame. I cherish you all.

CHAPTER 1

GENERAL INTRODUCTION

South African hake - perspective & history

World catches of gadiform (cods, hakes and haddocks) resources are second only to those of clupeiformes (herrings, sardines and anchovy), with catches steadily increasing from less than 3.3 million tons in 1950 to almost 14 million tons in 1987 (Figure 1.1). Catches have subsequently decreased and stabilised in the early 1990s at approximately 10 million tons (Figure 1.1). Catches in the Atlantic Ocean peaked at 6 million tons in 1987 but have shown a continuous decline into the 1990's (Figure 1.2). African countries contributed only 200 000 tons but catches have stabilised since Atlantic Ocean catches peaked in 1987, with South Africa as the dominant harvester.

The two major species in South Africa's demersal fishery are: shallow-water *Merluccius capensis* Castelnau and deep-water hake *M. paradoxus* Franca. In 1997, the landed value of hake approached US\$200 million (Geromont *et. al.* 1999). The majority of the catch is harvested off the West Coast, an area falling within the productive southern Benguela upwelling system (Roel 1987, Roel and Macpherson 1988, Ware 1992). It is in this area that this study will focus.

The South African demersal trawling industry was initiated in 1904 with four trawlers. By 1922 the two largest stake-holders had merged to form a registered company, Irvin and Johnson (I&J) with 27 vessels. Despite open access to the hake resource during the industry's formative years, success in the industry required considerable capital. This ensured that I&J dominated the industry (Bross 1999). The fishery expanded rapidly and reached an annual catch of over 100 000 tons by 1954 (Leslie 1998).

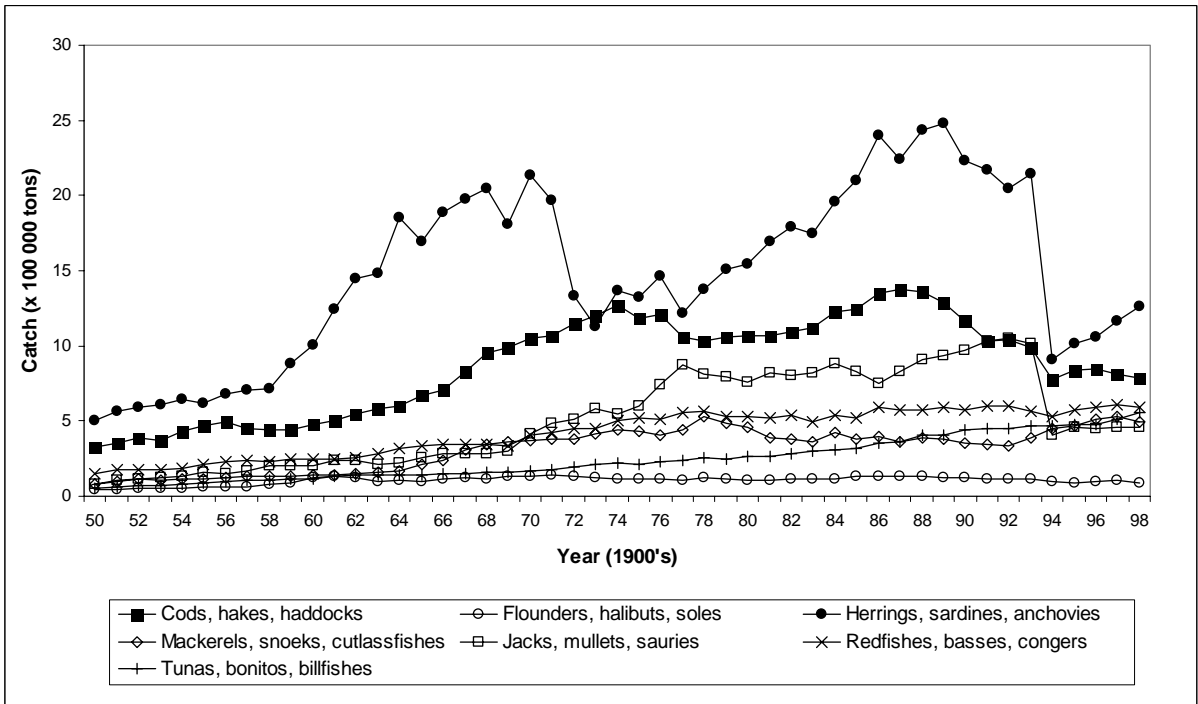


Figure 1.1 World Catch of the seven top producing species groups (FAO 1995a).

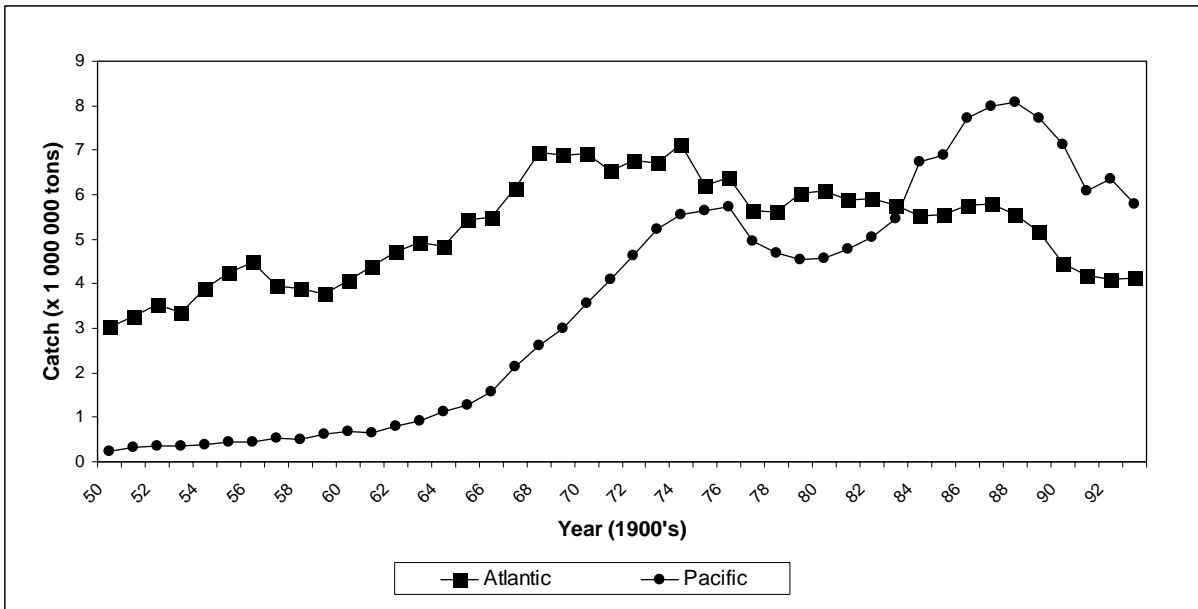


Figure 1.2 Catches of cods, hakes and haddocks in the Atlantic and Pacific Oceans (FAO 1995a)

Prior to 1950 trawlers had fished no further than 65km offshore between Cape Point and Saldanha Bay (Figure 1.3) with catches possibly dominated by *M. capensis* (Scott 1950 cited in Punt 1991). A massive increase in fishing effort occurred in the 1960s when foreign vessels entered the fishery, this resulted in domestic destabilisation. Within ten years of the foreign vessels entering the fishery, the South African contribution to the South East Atlantic hake landings dropped from 95% to 15% (Bross 1999). New fishing grounds were explored, with the entire continental shelf from East London to the northern border of Namibia becoming fished. By the mid 1970s the hake resources were considered biologically overexploited (Punt 1991).

The International Commission for South East Atlantic Fisheries (ICSEAF) was established in 1972 to investigate and control the exploitation of fish stocks in the southern African region (Punt 1991). The commission divided the area under its control into eight sub areas, two of which were further subdivided into divisions. Division 1.5 and 1.4 encompassed Namibian waters and 1.6 the South African West Coast. The South African Department of Trade and Industry appointed a Committee of Inquiry in 1975 which concluded that the foreigners (Spain and the USSR) should be expelled from the fishery and that the domestic industry required regulation (Bross 1999, Punt 1991). South Africa promulgated an Exclusive Fishing Zone on 1 November 1977, extending 200 nautical miles (nm) offshore. The domestic triopoly (I&J, Sea Harvest and Atlantic Trawling) of trawling companies that dominated the sector in 1978 provided sufficient effort to achieve maximum sustainable yield, with little possibility for industry expansion. Individual company quotas were introduced a year later (Bross 1999). ICSEAF was dissolved in 1990 with the independence of Namibia (Punt 1991).



Figure 1.3 Map of South Africa and Namibia showing ICSEAF Divisions.

Fishing methods

The present day South African deep-sea trawl fleet on the West Coast is composed of stern trawlers (wetfish/ice and freezer vessels) that operate offshore in water deeper than 110m. Shallow-water trawling is negligible. For the most part the deep-sea fishery deploys otter trawl gear and fishes on “hard ground”, as skippers avoid net losses and low catches. Despite the minimum mesh size (110mm) gear restriction introduced in 1977 it is known that skippers can, to a certain extent, target a particular size category of hake. Hence, catch composition is determined by species abundance and market requirements. Most fishing happens in daylight hours. Trawling is weather-dependent, with three to four trawls of one to four hours in duration completed within a day. Hake trawling grounds are well established and few pristine trawl areas exist (Japp *et. al.* 1995).

Hake longlining, where thousands of baited hooks are set along the length of a support line that is deployed in midwater, was introduced in 1983 in response to increased domestic demand. Nine experimental permits were granted in 1983, and for two years effort was mostly directed at the West Coast. Kingklip *Genypterus capensis* quickly became the target species of this small fishery, as the fish were abundant and the prices received were more lucrative than for hake. The *demersal bottom double longline* was designed for fishing on hard grounds and in rough waters, ensuring gear retrieval. These longlines could be weighted to target bottom-feeding kingklip or floated to target hake feeding in the water column. For the remainder of the 1980s the kingklip was increasingly targeted by a growing fishery, and by 1990 stock assessments indicated overexploitation of the kingklip resource. Permits to longline were withdrawn in 1990. Hand-line fisheries, particularly off the South-East coast, also caught hake which was on the open species list. No restrictions were placed on these catches. Ultimately, legislation was passed that defined a longline, limited the number of hooks, removed hake from the open species list for line fisheries, and limited hake bycatch (Japp *et. al.* 1995).

Current concerns

The 1990s were punctuated by major political change. A new government was formed, and transformation and redistribution were anticipated. Prior to the 1994 elections hake longlining was re-investigated. As trawling is capital intensive, longlining was seen as a method that fulfilled social objectives while achieving economic productivity. A three-phase strategy to investigate the biological and economic components of a demersal longline fishery was initiated in 1994 (Japp *et. al.* 1995). Longlining requires less capital than trawling and was therefore regarded as an ideal sector for development. Longline gear, however, is more versatile than trawl gear, and it is possible to change gear configurations significantly by altering hook size, bait and hook spacing.

Results of the one year pilot study (1994/95) revealed that longlining would result in a smaller reduction of the spawning stock than trawling. Reduction in the spawning stock equal to that of the trawl sector would allow a greater catch using longlines (Japp *et. al.* 1995). A phased increase in the proportion of the hake TAC allocated to longlining was recommended for the remainder of the experimental fishery (Japp 1996). The first fishing rights were issued in 1998, with 43 vessels being licenced (Leslie *pers. comm.* 2001). There are currently 100 active vessels fishing the initial allocation of 4000 tons. Quota allocation may be increased to the maximum recommended amount of 10 000 tons, but this is dependent upon the results of a pending appeals process following litigation over access rights (Leslie *pers. comm.* 2001).

The South African hake resource now faces divergent fishing pressures and management issues. Although the resource consists of two species, management was simplified because the resource was only subject to trawl effort. The impact of trawling on the stock is considered to be well understood (Butterworth *et. al.* 1992, Punt 1992) and the resource has shown recovery (Geromont and Butterworth 1997). The need for transformation has, however, resulted in an expansion of the fishing industry. Longlining has been re-introduced and there is no clear understanding of how the combined fishing pressures will affect the population structure of *M. capensis* and *M. paradoxus*.

The need to investigate the implications of increased *M. capensis* exploitation was recognised by Marine and Coastal Management. Japp *et. al.* (1995) suggest that monitoring and controlling a longline fishing fleet, policing fishing activities and landing points will prove a difficult, if not impossible task. In addition, frequent interactions (conflicts and gear loss) between trawlers and longliners have been recorded (Japp and Wissema 1999). These key issues all have strong spatial factors. The distribution and concentration of fishing effort with respect to the distribution and abundance of the two hake species is a decidedly spatial issue.

A spatial perspective

Several authors suggest that geographical information systems could play a large role in improving fisheries management (Caddy and Garcia 1986, Meaden and Kapetsky 1991, Giles and Nielsen 1992, Li and Saxena 1993, Booth 2000) as they are powerful tools, integrating spatially referenced data that provide a basis for management decisions, both technological and biological. Whilst Worrall (1991) contends that spatial analysis and spatial policy are of 'fundamental importance to government', Meaden and Do Chi (1996) assert that more efficient decision making is facilitated by the output from various analytical GIS functions. Nonetheless, marine GIS applications are still in the formative stages of development (Meaden 1996).

There have been two documented cases of attempts to develop comprehensive GISs for the management of marine resources. Firstly, Australia developed a 'national' marine GIS (Bradbury 1994) and secondly Libya established a marine fisheries GIS to manage a complete fishing industry in the future, on its underutilised coastline (Meaden and Reynolds 1994). More recently, GISs have been used to map the spatio-temporal exploration of fishing fleets, incorporating factors such as vessel specifications, gear type and the fishers themselves (Taconet *et. al.* 1997). GIS based decision support systems and numerical models of fisheries have been established for management purposes (Rodgers and Rouse 1997, Maury and Gascuel 1999). Spatial trends relating to key population parameters were incorporated into a stock assessment model by Booth (2000).

There are complex issues involved in the use of spatial analysis and geographical information systems. Martin (1991) suggests that the socio-economic applications should be considered when conceptualising a GIS, allowing a broader understanding of the entities involved in the analysis. Hearnshaw and Unwin (1994) discussed the term “scientific visualisation” with reference to geographical information systems. They proposed that the exploration of data and information in a spatial perspective facilitated understanding and insight into a study. Medyckyj-Scott and Hearnshaw (1993) debate the human factors in designing and developing effective geographical information systems.

The advantages of using GIS as a tool for resource management have become apparent. Catch data can now be analysed and represented within a spatial context providing an interactive platform for displaying temporal and spatial distribution maps, development and testing of distribution hypotheses and the integration of different survey type data within one system. This facilitates qualitative and quantitative comparisons (Northridge and Smith 1994). The use of real time data facilitates well-informed decisions regarding resource management. Trends or abrupt changes in resource status are highlighted by using comparative analysis (Meaden 1993, Ault and Patrick 1994, Boyd *et. al.* 1996, May *et. al.* 1997).

Thesis structure

This study presents a spatially referenced investigation of the fishing activities directed at the West Coast hake resources of South Africa. The objective of the study is to reassess the current assumptions regarding the hake stock and the fishery sectors using a single-species, rather than a combined species, approach. The thesis is divided into five chapters. Chapter 2 covers the general methodology, construction of a database for spatial analysis, data consolidation and capture for a geographical information system (GIS), definition of sampling areas and a description of coverages constructed for analysis. Chapter 3 presents a spatial analysis of fishing activity, trawling and longlining, with respect to depth, sediment type and logistics. In Chapter 4, the species dynamics of hake and the selectivity patterns of trawlers and longliners are briefly investigated. A method to determine the proportion of each species in commercial catches is compared to that used by Marine and Coastal Management. A first attempt at modeling the *Merluccius capensis* West Coast resource is also presented. Chapter 5 presents a general discussion and suggests management options for the West Coast *M. capensis* stock, with particular reference to the Northern Cape province. This study presents an arguable case towards considering the use of single-species management of the South Africa's hake resource.

CHAPTER 2

GENERAL METHODOLOGY

Introduction

Geographical Information Systems (GIS) have been identified as a suitable tool for managing spatial data and facilitating its analysis (Isaak and Hubert 1997, Meaden 1994, 1996, Rogers and Bergersen 1996, Korte 1994, Li and Saxena 1993, Bernhardsen 1992, Giles and Nielsen 1992, Meaden and Kapetsky 1991). Korte (1994) and Bernhardsen (1992), however, asserted that the construction of a GIS is a complex task that requires major commitments of time, money and organisational energy. As present day realities are constantly changing with hindsight and a perception of the “real” world is highly subjective, it is necessary to translate real world observations into delineated concepts and models.

The foundation of any functional GIS is a database containing spatially referenced information. As discrepancies are often highlighted during data manipulation, a suitable database includes data conversion and verification facilities, both to form the initial data set and throughout the development of the GIS. Outliers, when referenced to real world geographical concepts, can be easily identified and analytical errors corrected.

The construction of a comprehensive database is arguably an infinite process. Data can be interpreted and analysed from a number of perspectives *inter alia* biological, social and economic with even more possible applications. A spatial database must be rigorously normalised using unique codes for each data table. If possible the spatial references should be comparable between each data set. This study has focused on the fisheries related data. Two types of data were available relating to *M. capensis*: fisheries dependent (catch records) and fisheries independent information (abundance estimates and length frequency data).

A relational database was designed in this study: all information was attached to spatial co-ordinates, which would facilitate queries arising during analysis. The GIS package used was *TNTmips*[®] (version 6.2)¹. All spatial data was imported using latitude and longitude co-ordinates in Clarke 1880 (Africa) ellipsoid projection.

This chapter discusses data consolidation and capture, creation of coverages, data extraction and final database structure. In particular, it outlines many of the problems associated with the various data sources. Data consolidation and capture involved defining and delineating the sampling areas utilised, construction of an electronic commercial grid map and input of fisheries independent and dependent data. Creation of coverages entailed manipulation of fisheries independent data to develop depth contours because digitisations of existent bathymetry were subject to greater error. In addition, fishing zones were delineated for finer spatial analysis. Depths fished by longline vessels were extracted from the georeferenced depth contours. Furthermore, the substrate type on which all types of fishing occurred for the length of the west coast and within three fishing zones was also extracted. A description of each data set and flow charts of the final database structure are presented.

Data Consolidation and Capture

Sampling areas

The West Coast dynamics are determined by the southern Benguela upwelling system, which extends from Cape Agulhas to the Orange River mouth. It is a highly productive system. Although 83% of the primary production is exported out of the system, low seasonal variability in upwelling ensures continued yield “efficiency”. The West Coast continental shelf extends 86km at its widest point (Ware 1992). A continental shelf is defined by the United Nations Law of the Sea as the submerged prolongation of a coastal State’s land territory to a distance of 200nm which does not include deep ocean floor or oceanic

¹ Trademark of Microimages Inc. (www.microimages.com)

ridges; it is understood to be that part of the continental margin which is between the shoreline and the shelf break (UNLCOS 1994).

The continental shelf is widest north of Doringbaai, and the continental slope is steepest at the Namibian border. The shelf narrows and drops off steeply to the south of Doringbaai before widening again to form the Agulhas Bank (Payne 1989, Roel 1987). Roel (1987) found that while biomass was highest on the shelf, species diversity was highest in deeper waters with a boundary between the two defined at 385 ± 45 m.

Despite being a highly productive system, the coastline is uniquely open with few protected inlets and only one natural harbour. From a fishery perspective, the West Coast is therefore considered to be hostile and high energy environment (Bross 1999).

For the purposes of this study the South African West Coast has been defined as that area between where the 20°E line of longitude intersects with the coastline in the south and the Orange River mouth on the Namibian border in the north, extending beyond the continental shelf (Figure 2.1). The West Coast was defined by Marine and Coastal Management (M&CM) as ICSEAF Division 1.6 from 1978 to 1999. The division was defined by a diagonal line extending through the Agulhas Bank from Cape Agulhas (Figure 2.1) which defined ICSEAF Division 1.6. The vertical delimitation of 20°E was used as it simplified analyses and has been accepted as the standard at M&CM in 2000. A geo-referenced map of the South African coastline was obtained from Gibbs Engineering (Cape Town).

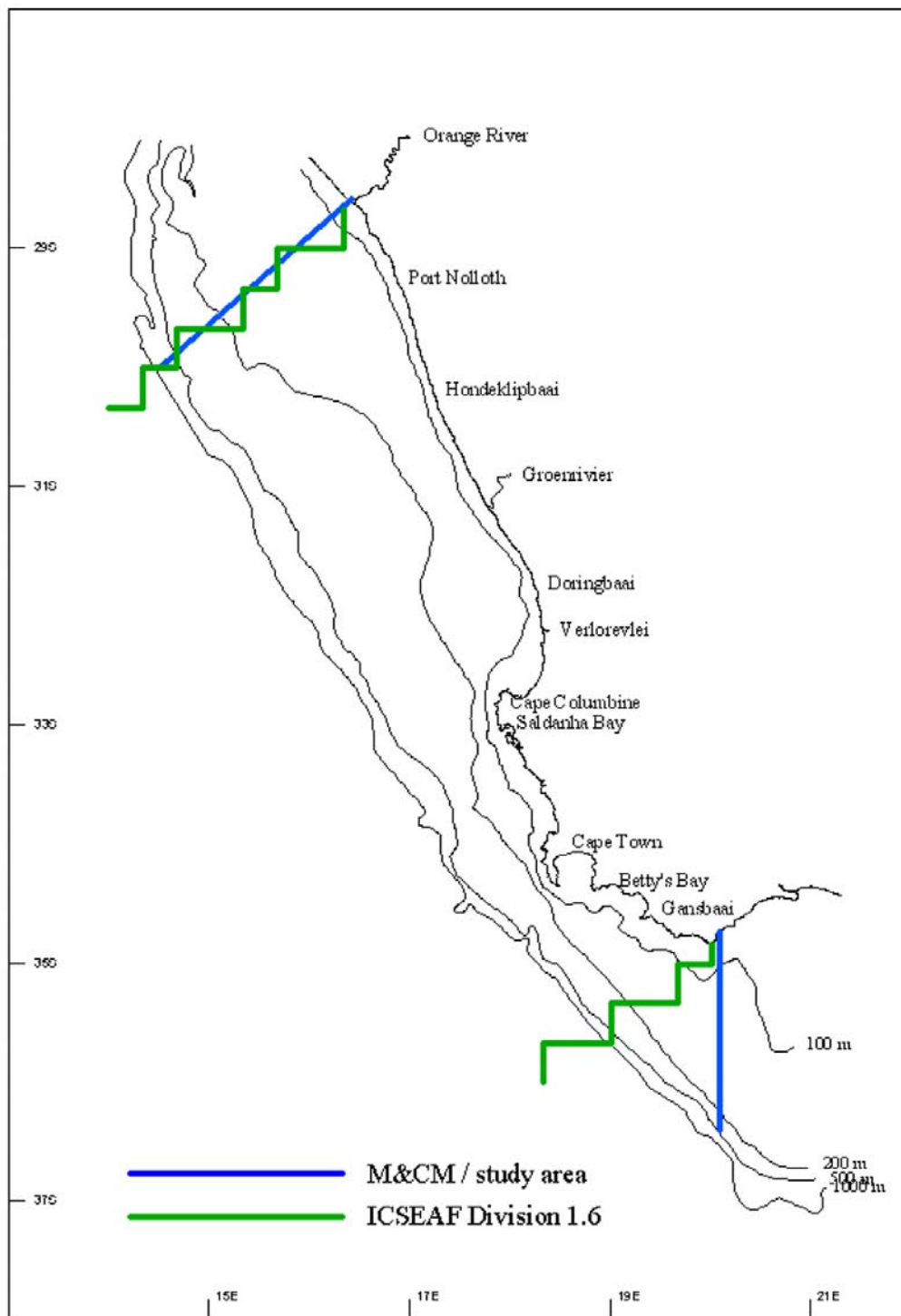


Figure 2.1 Delimitation of the South African West Coast using two methods: ICSEAF Division 1.6 (1978 to 2000) and that currently accepted by Marine and Coastal Management used in this study.

Commercial grid map

All catch records reported to M&CM are referenced to a commercial grid system (Figure 2.2) that is composed of 20' x 20' blocks² extending to the boundary of the EEZ. All licenced vessels are required to report each fishing incident (i.e. each trawl made or longline set) with data being collected and collated by M&CM personnel. For the purpose of this study fishing intensity is defined by the number of fishing incidents.

An electronic geo-referenced commercial grid map was constructed by creating a new vector object, entering the co-ordinates of the perimeter of the West Coast section of the grid map in latitude and longitude format (Figure 2.2). The perimeter was then merged with the West Coast section of the South African coastline to form a polygon. The polygon was then edited to remove all dangling lines, sliver polygons and excess nodes. A polygon grid was then computed within the polygon, producing rectangles (16.85 x 20 nm) which were numbered sequentially. The ellipsoid projection of the polygon grid accounts for the earth's curvature and the resultant "narrowing" of the area between the lines of longitude towards the south pole. As a result, the grids are only theoretically square on a flat piece of paper but, as the grid map construction has shown, are in fact quadrangles of varying width.

The final step was to create and relate a table of the assigned numbers of each grid block to its corresponding grid number according to the M&CM commercial grid map. All commercial catch information could then be related to the electronic grid map. The centre point of each grid block was calculated when the polygon grid was computed. These points were also related to their matching commercial grid block numbers.

² 20' denotes 20 minutes in terms of spatial co-ordinates. One nautical mile \approx one minute.

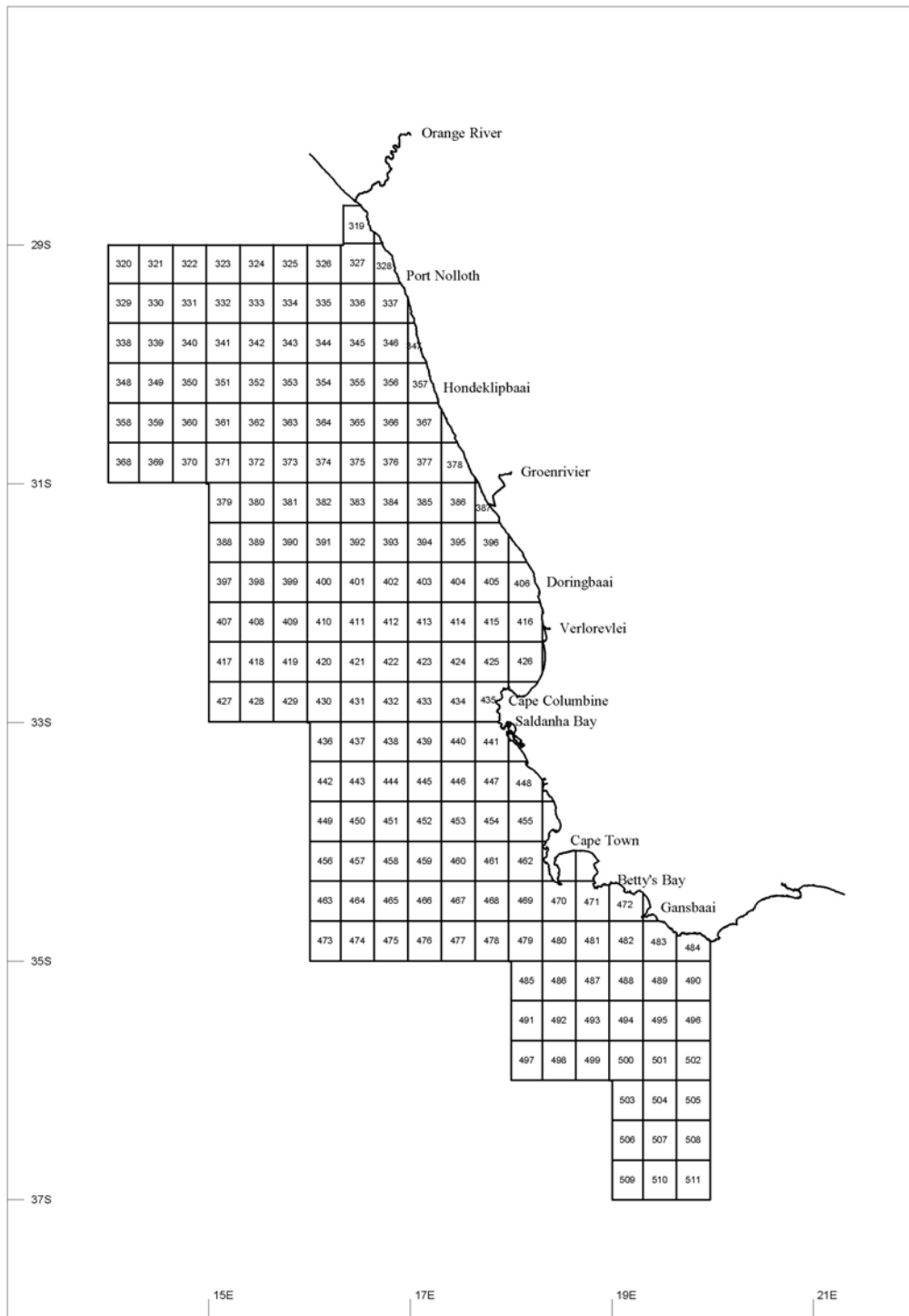


Figure 2.2 Commercial grid map used by fishing vessels for reporting catches. Each block is 20'x20'.

Fisheries dependent data

Trawl Data

West Coast catch and effort data from commercial vessels was obtained from M&CM with the permission of the South African Deep-Sea Trawling Association. A flow chart of the construction of the trawl database is described by Figure 2.3. These data consisted of reports by both wetfish and freezer trawlers, the majority of which operate out of Cape Town or Saldanha Bay. It was decided that the data would be assessed in depth intervals of 100m, for example a reported depth of 255m would be classed in 300m strata (i.e. 201m to 300m). Data for the period 1994 to 1999 was extensive (Appendix A), although the differing reporting methods posed some analytical difficulties.

Each catch record had two components, key and a catch. The key contains information pertaining to the trawl position, date, duration and effort statistics. The second component includes the estimated nominal landed weight per species recorded at that position. Most wetfish trawler vessels declare their catches as *drag tallies*, reporting the catch and effort for each trawl completed. All freezer trawler vessels and the remaining wetfish trawlers, in contrast, declare their catches as *daily tallies*, attributing the total catch for the day to one trawl position. Position and effort data were recorded for all trawls. The effort and catch over a day by a vessel was summed and the average catch allocated to each position fished during that day. Drag CPUE was thus calculated as $\frac{Catch}{1000} \bullet \frac{60}{Effort} = tons.hr^{-1}$.

The position bias was considered to be small, as trawlers tend to remain within the same area for the day. The catch was thus mapped and interpreted with reference to the M&CM commercial grid map. It is worth noting that during this process, discrepancies between landing date and trawl date were observed.

TRAWL DATA

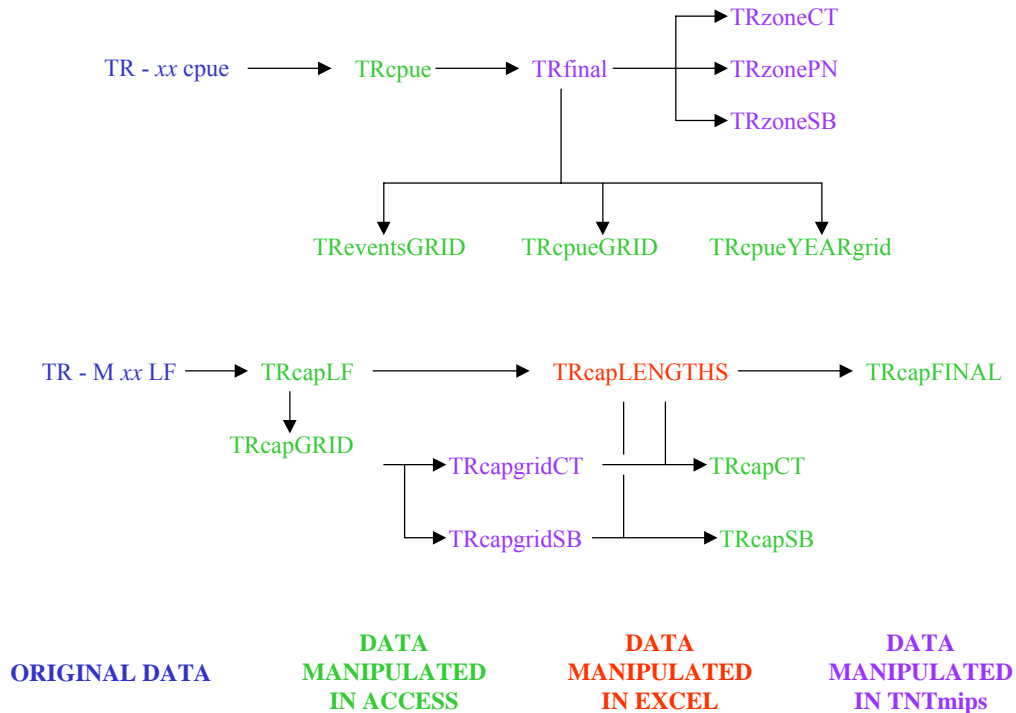


Figure 2.3 Database construction of trawl catch information. Abbreviations are explained in Appendix B.

Observer Data

An average of four observer trips per year on board commercial trawler vessels have been undertaken by M&CM staff since 1994. The data collected includes species composition of the catch, hake biological information and length frequencies. The reports submitted by the oceanographic research assistants (ORAs) were captured into *MS Excel*[®]. The spreadsheets consisted of a sample summary, length frequencies and biologicals collected (Appendix C).

Longline Data

Data collected during the Hake Longlining Fishing Experiment was collated into a *MS Access*® database by M&CM. The data included catch, effort, depth, and in certain cases species-specific length frequencies, catch per unit effort was calculated as *tons per thousand hooks*. Longliner vessels reported the latitude and longitude of their start position for each longline set, however, start depth was only reported in 1999. Queries were used to extract all catch and position information (Appendix D). A flow diagram of the database construction is described by Figure 2.4. The Fishing Experiment extended beyond the West Coast, however, only those catches made off the West Coast were considered in this study. The simplest method of limiting the data to the West Coast was to import the data into *TNTmips*®, plot the catch sites; delete all points outside the West Coast and save the layer as a separate coverage. Length frequencies of *M. capensis* were queried from the database and West Coast specific data extracted.

LONGLINE DATA

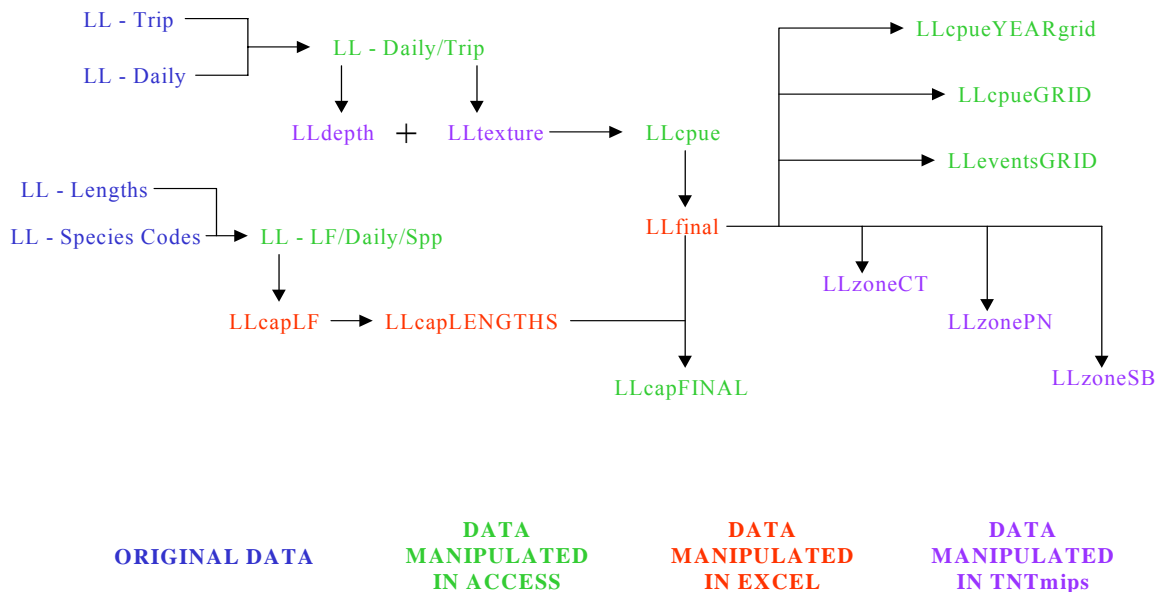


Figure 2.4 Database construction of longline catch information. Abbreviations are explained in Appendix B.

Fisheries independent data

A subset (1986 to 1999) of the research trawl data collected by the *FRS Africana* along the West Coast, was obtained from M&CM. The data consisted of summer (January/February) and winter (July/August) surveys until 1989 and only summer surveys for the remaining years. The *M. capensis* length frequency data for each cruise was extracted in depth strata of 100m intervals. A flow chart of the research database structure is given in Figure 2.5.

In order to have a spatially referenced data set, trawl data were cross-referenced to the catch data with station positional information. In addition, the data set was limited to catches of both *Merluccius* species (Appendix E). The complete data set was imported into *TNTmips*® as a vector object and points were created using the decimalised latitude and longitude co-ordinates. The research catch data was best represented in vector format as the catch information was related to a specific latitude and longitude. Where outlier points were apparent, attributed to incorrect data entry in the original data, they were deleted.

Catches were standardised to tons.nm⁻². The area (nm²) covered by each trawl was calculated as:

$$A = \frac{\left(\frac{duration}{60} \cdot speed \right) \cdot mwidth}{1852},$$

where one nautical mile is equivalent to 1852 metres, trawl *duration* was recorded in minutes, trawl *speed* in knots and *mwidth* is the mouth width (m) of the trawl gear used. Catch was calculated by:

$$C = \frac{kg/1000}{A}.$$

RESEARCH DATA

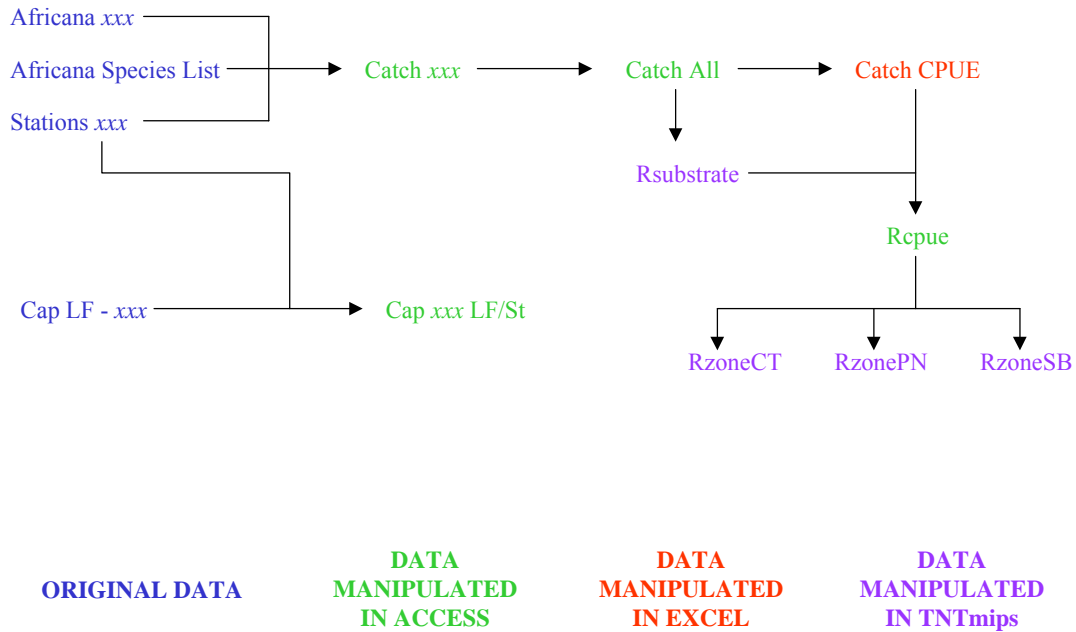


Figure 2.5 Database construction of research survey information. Abbreviations are explained in Appendix B.

Substrate type

The Council for Geoscience, Cape Town, provided a sediment texture coverage of the South African continental shelf. Texture classes were: mud, sand and gravel. Eight further combinations of classes can be defined by the proportion of mud, sand or gravel contained in the sediment. Definitions of these substrate types are provided by Pidwirny (2000):

Mud - silt and clay-sized sediment particles less than 63 microns in diameter.

Sand - mineral particles with a size between 0.6 and 2.0 millimeters in diameter.

Gravel - unconsolidated sediments composed of rock fragments greater than 2mm.

Rock - compact and consolidated mass of mineral matter, three types are recognised: igneous, sedimentary and metamorphic.

Minerals - naturally occurring inorganic solids with a crystalline structure and specific chemical composition.

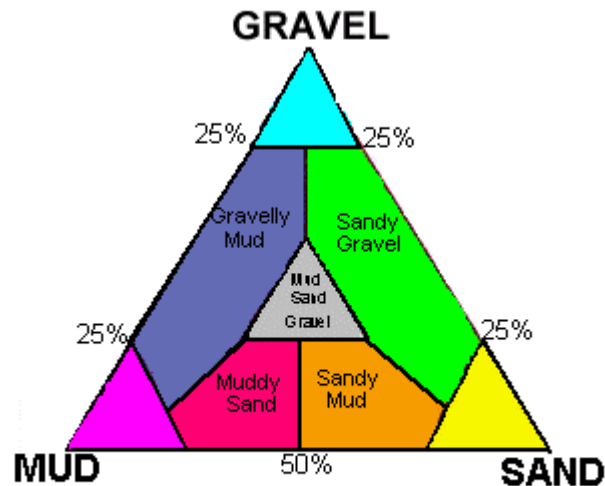


Figure 2.6 Diagrammatic representation of the mud, sand and gravel component of the eight sediment texture classes.

The data used by the Council for Geoscience to collate a map of sediment texture was collected using a Van Veen grab, thus the sediment types are surficial as the sampling process cannot sample bedrock. M&CM have recorded “untrawlable” areas encountered since research trawls were started in 1986. These areas were noted with reference to their research grid map, in which blocks are 5'x 5'. A coverage of untrawlable grounds was created (Figure 2.7) and overlaid onto the sediment texture map. The data associated with each coverage could not, however, be combined.

Depth

Despite an extensive sampling process, the isobaths on the South African Navy Charts used by M&CM were considered inaccurate, as they had been constructed by hand (Figure 2.8). Therefore, it was necessary to create a geo-referenced bathymetric coverage. The intention was to extract the depth corresponding to longline catches made from 1994 to 1998, as depth was not reported in these years. The data provided by M&CM included the bottom depth recorded at the start point of each research trawl at a specific latitude and longitude - a total of 1951 data points (Figure 2.9). The distribution of sample points was constrained by where the *RS Africana* could successfully complete trawls, therefore features such as islands and underwater canyons were not accounted for. However, the reported depths were considered accurate enough to use in the construction of a surface model representing the depth structure of “trawlable” grounds off the West Coast.

Creation of coverages and data extraction

Depth

Surface modeling has different levels of complexity and relies on the density of data points within an area for its accuracy when creating an approximation of a functional surface. Several possibilities are available: surface fitting, contouring and triangulation. Surface fitting constructs a surface that includes trends and patterns in a direct representation of the input data. An inverse distance algorithm was not considered feasible as it utilises a weighting factor to interpolate a surface value based on a set of nearby points. Nonsensical depth values were generated, as increased weight was placed on the centre of the study area. The output surface using a polynomial did not match the original value of the input points, and there was insufficient data coverage to warrant the use of triangulation. Kriging was considered unsuitable as the points were not evenly spaced. The minimum curvature interpolation was considered the most suitable as it applies a 2D cubic spline function to the input data and fits a smooth surface to the elevation values during initialisation. Further iterations adjust the output raster cell values so that a smooth uniformly representative surface is produced (Cressie 1993).

A table consisting only of the longitude, latitude and corresponding depth was imported into *TNTmips*[®] and used as the *input* for a minimum curvature surface fitting process. The output cell size was defined as 1852m x 1852m (1852m \approx 1 nautical mile) producing a 16 bit signed integer with 442 lines and 287 columns. The cell size was set as 1 nm² and duplicate points averaged. The parameters of the model were as follows: curvature was linear, the search area a circle, weighting power = 2.00, coarse grid ratio = 8, maximum iterations =10, tension = 1, matching tolerance = 0.1 and allowed variation from the original = 0. The search distance of 35 cells was calculated by dividing the largest distance between the data points (64km) by the width of the output cell size.

The raster surface corresponding to the continental shelf was extracted from the surface model, to be used in the contouring process (Figure 2.9). This ensured that the contours would be generated only for the offshore region, between the coast and the continental shelf edge. Linear contours were generated at 100m intervals, starting at 0m on the coast and ending at 900m on the continental shelf. As contour lines did not extend the length of the coast at depths greater than 500m, the surface was considered valid up to the 500m depth contour (Figure 2.10). Features such as the Cape Canyon were not generated in this process as the data used was only collected from trawlable grounds. Although this coverage does not include such features it is considered more accurate in describing the trawl grounds of the West Coast which are of particular interest in this study (Figure 2.11).

It was not possible to extract the depth value of the raster cells corresponding to the vector points representing each longline catch. Rather the contour lines were joined to form polygons of depth strata. The vector points of all longline catch sites within each polygon were extracted separately using the vector combination process and the tables exported for statistical analysis.

Substrate

The sediment texture shapefile was imported into *TNTmips*[®] and geo-referenced. Although eight different sediment texture permutations exist off the South African coast, only four are found on the West Coast: Muddy Sand, Sand, Mud and Sandy Mud. Substrate type for all catch records (commercial and research) was later extracted. Untrawlable areas occurred across all sediment types. Typically an untrawlable area will have a surficial layer of sediment under which lies bedrock and several rock outcrops. The longline events occurring on “rocky sediment” were extracted. Although the untrawlable areas overlap commercial grid blocks that have been fished it should be recognised that fishing occurs on the outskirts of these areas.

Fishing zones

The West Coast extends 1478km between Cape Agulhas and the Orange River mouth. When both trawl and longline fishing over the last five years was mapped, two distinct patterns were noted (Figure 2.12). The highest frequency of trawls occurred in a narrow band parallel to the coastline, whereas the longliner catch sites formed two distinct nodes of fishing intensity. The fishing zones have been defined by lines of latitude and, for simplicity, named sequentially after the largest ports found on the West Coast. The data sets for trawlers and longliners, containing depth strata and substrate information were re-imported to *TNTmips*[®], and the points contained in each fishing zone were extracted using the vector combination process. The data tables were exported for analysis.

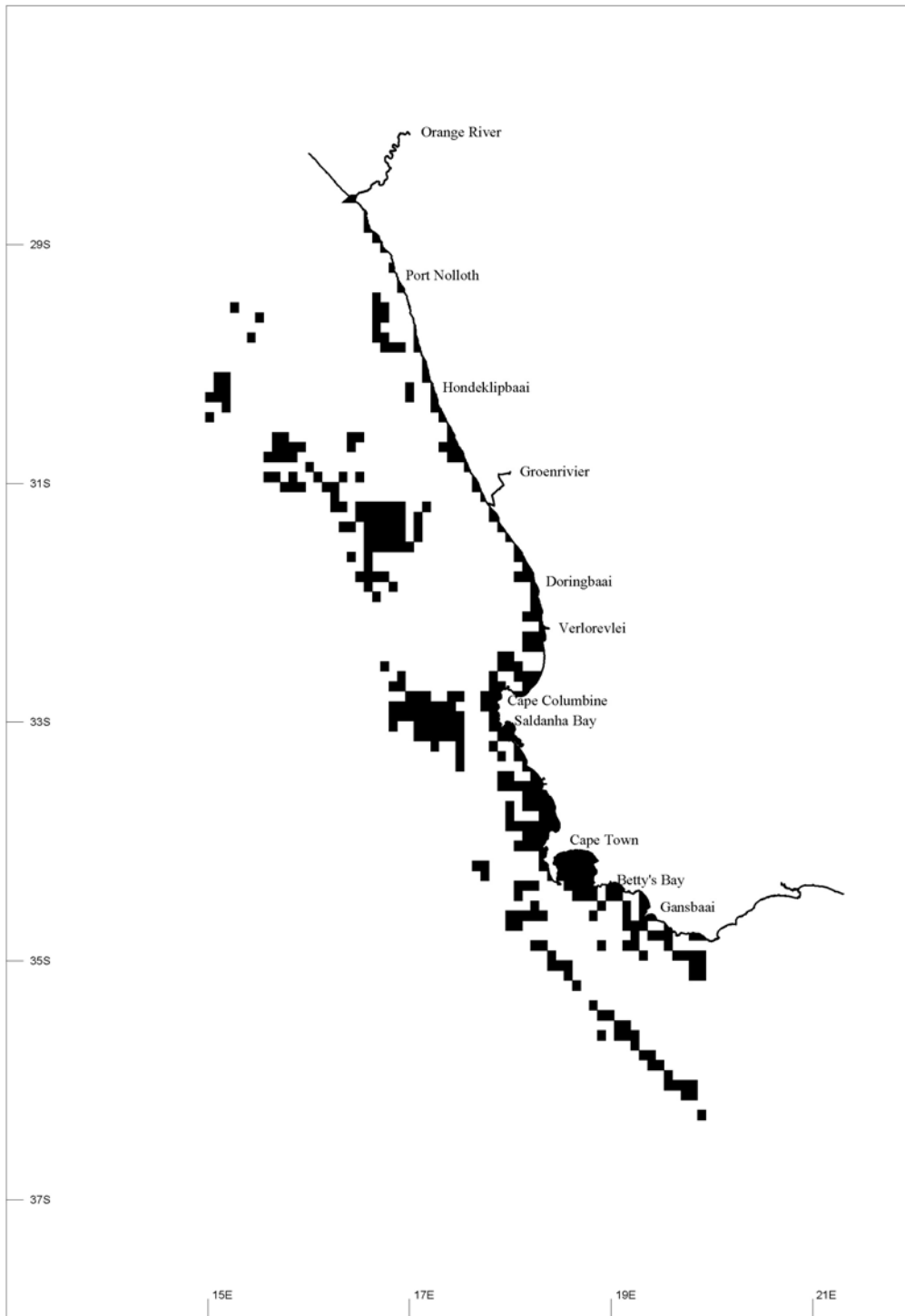


Figure 2.7 Areas off West Coast declared untrawlable by Marine and Coastal Management during research surveys (Leslie *pers. comm.* 2001).

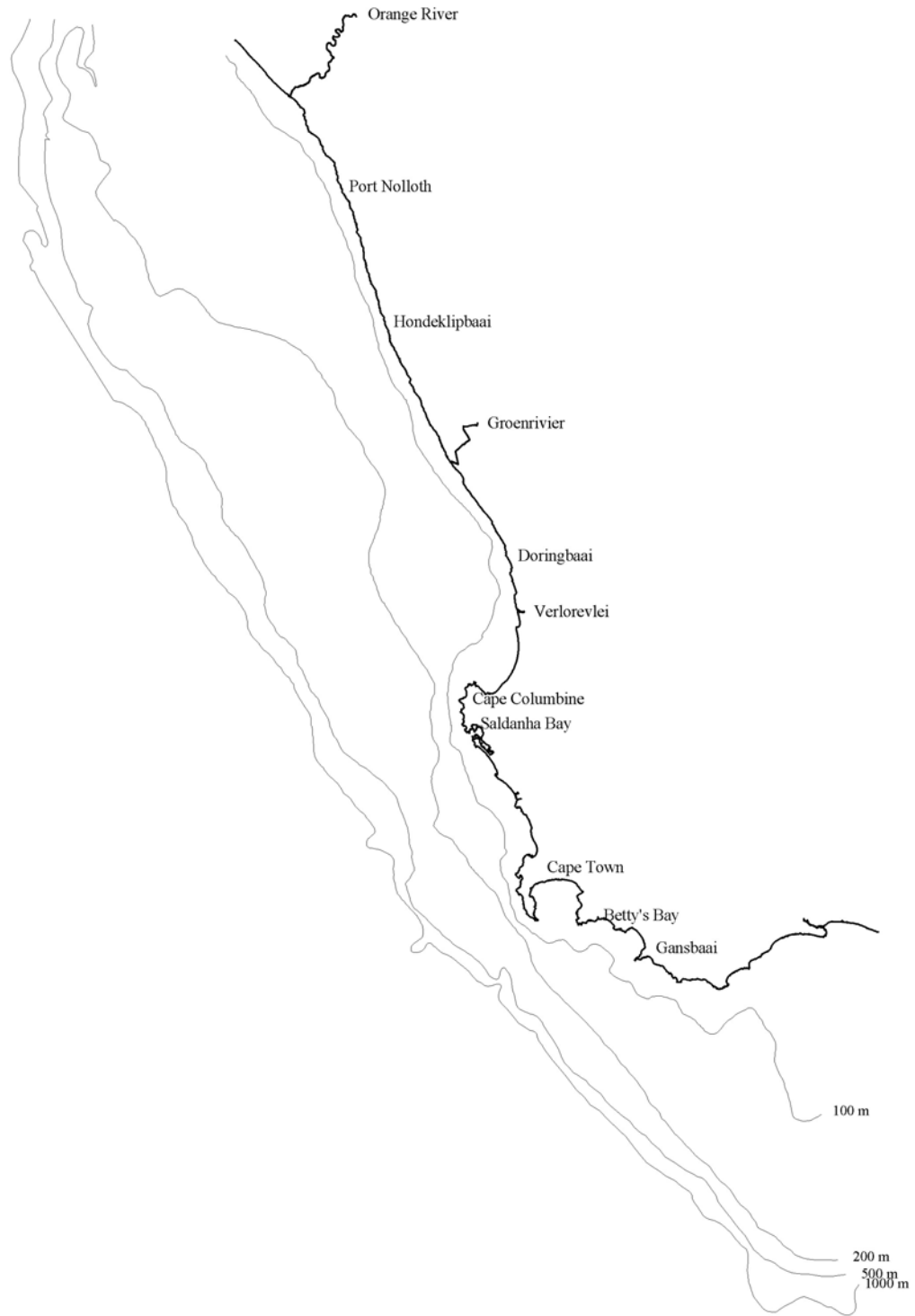


Figure 2.8 Admiralty chart of isobaths (from the South African Navy) as used by Marine and Coastal Management (Leslie *pers. comm.* 2001).

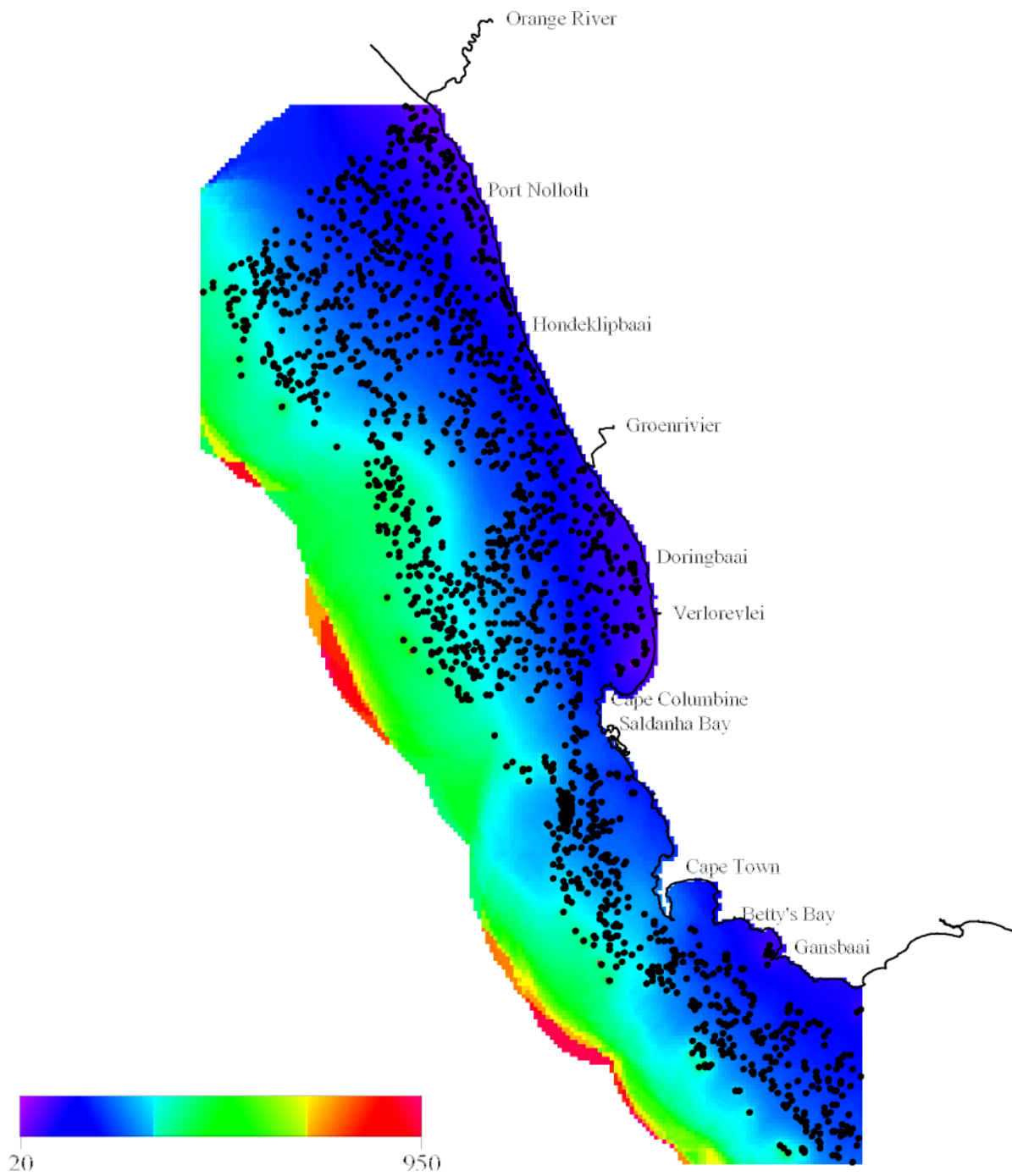


Figure 2.9 Minimum curvature surface model of depth (m) constructed using research survey data represented by black vector points.

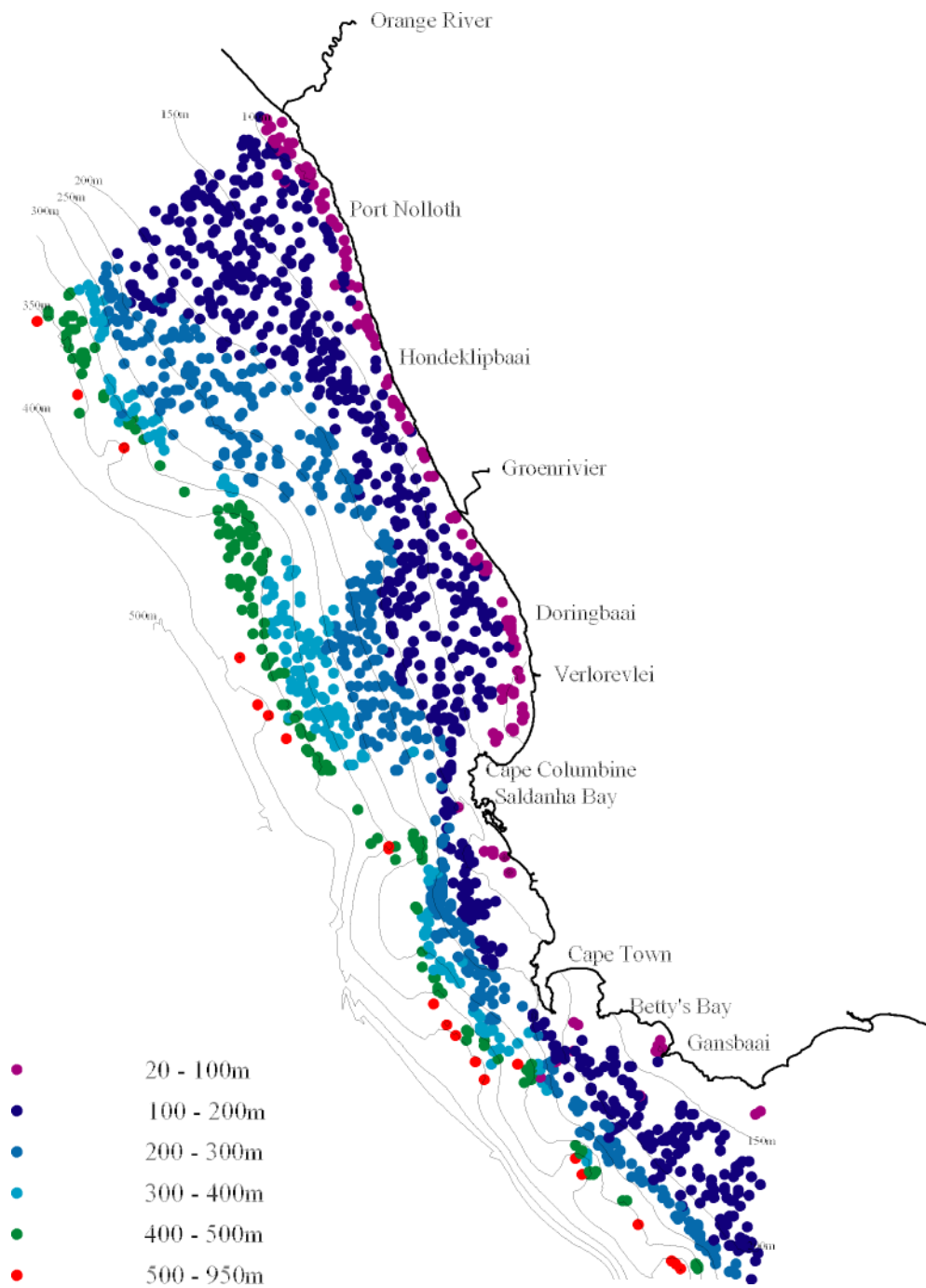


Figure 2.10 Depth contours constructed from surface model using research survey data (represented as vector points).

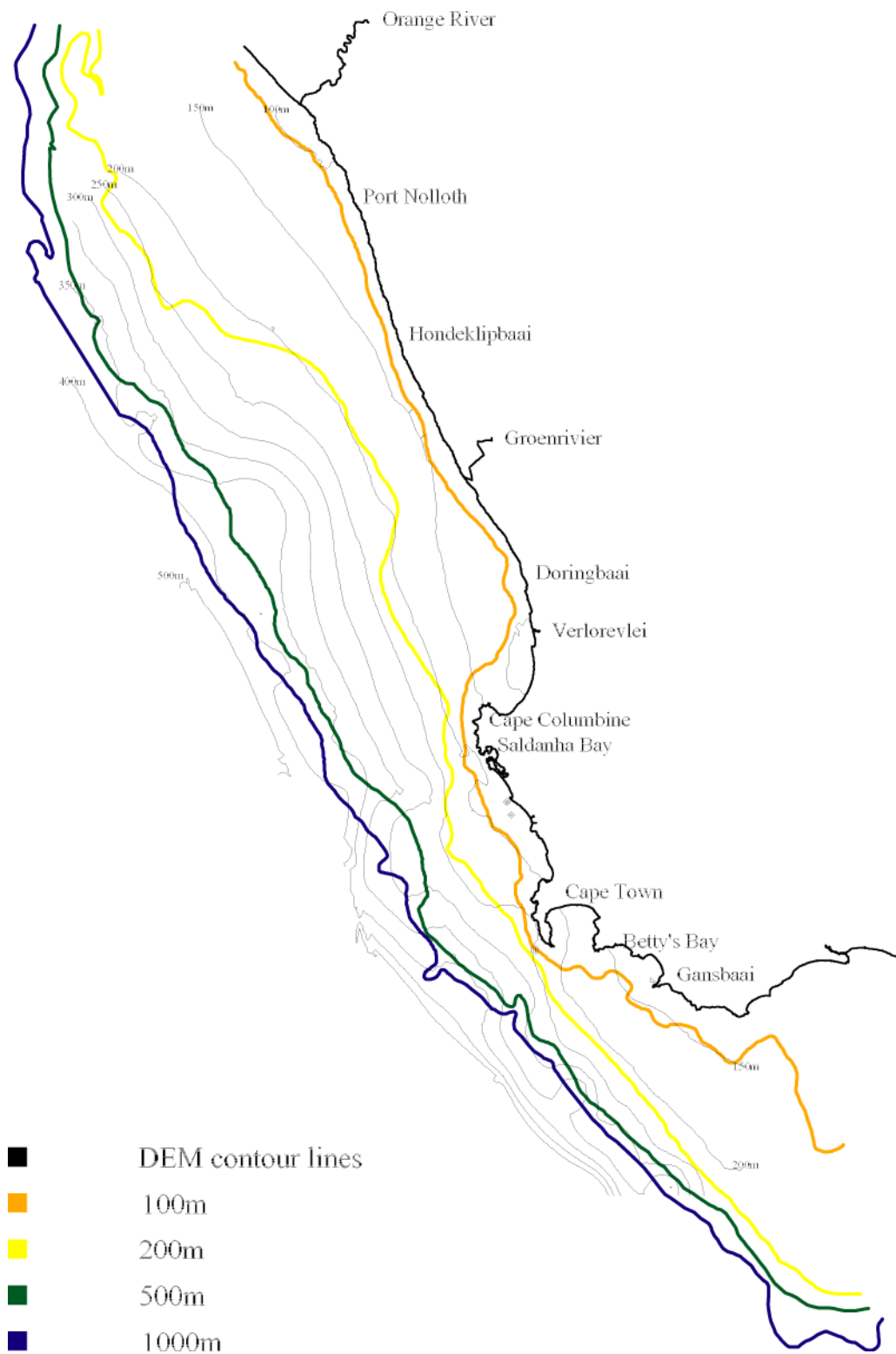


Figure 2.11 Depth contours developed in this study compared with isobaths from the South African Navy's Admiralty Charts (Leslie *pers. comm.* 2001).

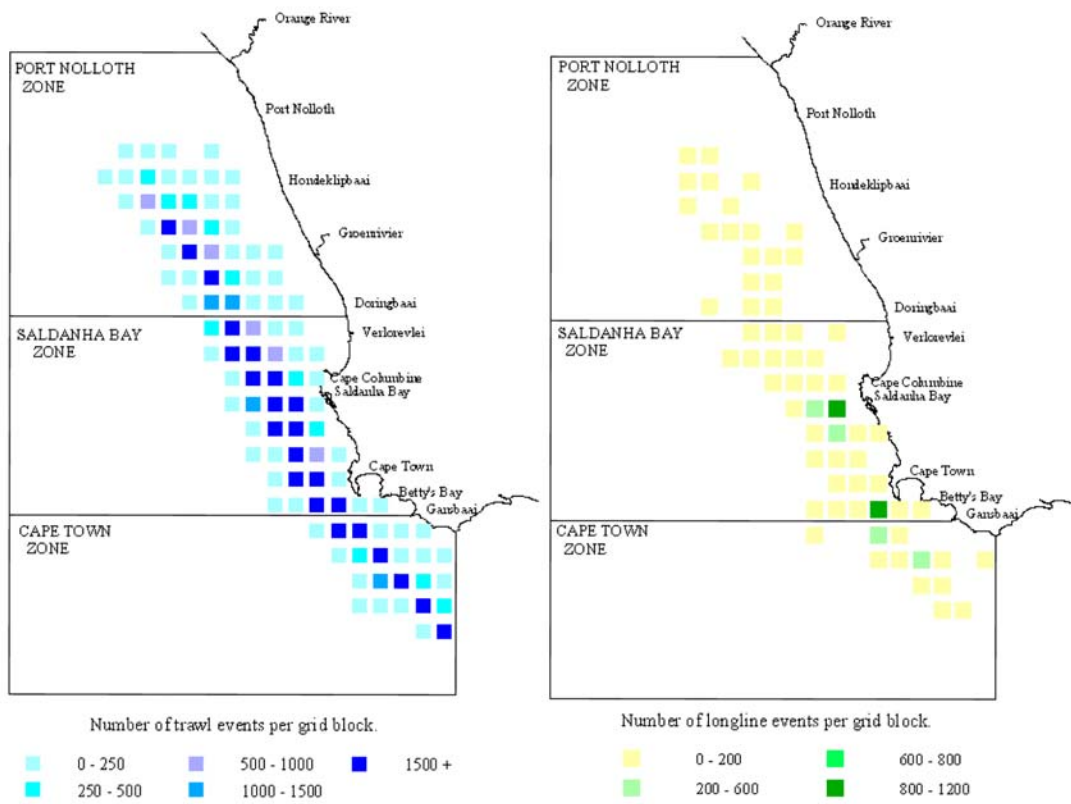


Figure 2.12 Trawl and longline fishing intensity for the period 1994 to 1999. Intensity is graded by colour.

CHAPTER 3

SPATIAL ANALYSIS OF FISHING ACTIVITY

Introduction

Historically, the majority of the South African hake resource has been subject to trawling effort. As such, the fishery dynamics were simplified facilitating a stronger understanding of the dynamics of the fishery and its effect on the resource. In light of the introduction of hake-directed longlining, which differs from trawling with respect to *inter alia* vessel size, areas fished and sex and size of fish caught, a re-investigation of Cape hake resource management is necessary. An improved understanding of fishing intensity (number of fishing events) and effort distribution is therefore required to determine possible impacts on the resource. Garcia (1997) and Mace (1997) have presented current debates over the philosophy and structure of fisheries management. The emerging trend is to adopt a “holistic” approach based on sound scientific information, incorporation of socio-economic factors, strategic planning, use of sustainability indicators, promotion of community participation and effective enforcement. Several of these factors can be understood from a spatial perspective. GISs have been presented as a suitable tool for natural resource management (Hearnshaw and Unwin 1994, Koeln and Giles 1982).

A literature review revealed that little has been published with regard to the substrate on which hakes are found. Similarly, little has been documented on commercial fishing preference however several studies regarding depth have been completed. It is known that both species of Cape hakes have a depth-related distribution. Roel (1987) reported a boundary between *Merluccius capensis* and *M. paradoxus* communities at $380 \pm 45\text{m}$, Galaktionov (1993) sampled fingerling *M. capensis* in a depth range of 50 to 200m and Pillar and Barange (1995) affirmed that while juvenile *M. capensis* are abundant inshore (less than 150m), a significant overlap occurred between larger *M. capensis* and smaller *M. paradoxus* between 150 and 400m.

Considering that good management decisions need information on fishing patterns, a GIS was used to investigate spatial trends of both sectors (trawling and longlining), and at what depths and substrate types they fish. Possible correlations between fishing intensity (the number of trawls completed or longlines set), catch per unit effort (CPUE), substrate type and depth would provide a better spatial understanding of the fishery and possible predictive abilities with regard to fleet structure off the West Coast.

Materials and methods

Bottom depth was recorded for all commercial hake-directed trawls reported during the study period (1994 to 1999), bottom depths were reported only for the final year (1999) of the longline experiment. Distribution of fishing intensity and CPUE were assessed in depth strata of one hundred meters (e.g. 200m = 101 to 200m). As trawlers do not report spatial co-ordinates only the grid block fished, spatial analysis of the trawl sector was limited to a resolution of 20' x 20' commercial grid blocks.

Sediment texture off the South African coastline was obtained from the Council for Geoscience (Cape Town, Geological Survey 1986) with the primary components of sediment texture classified in Chapter 2. The sediment was considered surficial *i.e.* non-lithified and unconsolidated. Areas considered untrawlable by M&CM were designated as rock with a surficial sediment covering. These data were considered to be sufficient for the purposes of this investigation as they could be considered representative of current day sediment deposits (Dyer 1986, Holzförster *pers. comm.* 2000).

The lumped trawl and longline data sets (*TRfinal* and *LLfinal*) were separated into annual data sets. Descriptive statistics were determined for each data set with Kolmogorov-Smirnov tests applied to assess the assumption of normality in the depth, catch per unit effort and length frequency data. The data were not normally distributed (all p-values < 0.001), in particular CPUE was found to be

highly right skewed and could not be normalised using either natural logarithm or square root transformations.

A Kruskal-Wallis rank sum test was therefore applied to test the following hypotheses:

H_0^1 : the number of fishing events are equal across all depths.

H_0^2 : catch per unit effort is random across all depths.

H_0^3 : the number of fishing events are equal across all substrates.

H_0^4 : catch per unit effort is equal for all substrates.

Tests for individual contrasts were conducted using a Bonferroni pair-wise procedure. The Bonferroni procedure compares n -permutations of the data with a Mann-Whitney U test (non-parametric z-test equivalent) with the rejection criteria for each combination at:

$$\text{Kruskal - Wallis } p\text{-value} / n\text{-combinations}$$

Possible interactions between year and depth and year and substrate were assessed with a two-way ANOVA as there was no non-parametric equivalent. A contingency table analysis was used to test the independence of fishing intensity from substrate type for each of the fishing sectors (Appendix F). This test accounts for differences in area covered by the four sediment classes. This was achieved by calculating the expected number of fishing events within each sediment class from the percentage cover in each sediment class.

Results

Depth

Trawl fishery

The majority of trawls were conducted between 300 and 500m (Figure 3.1) with average fishing depths of 350 ± 114 m, 408 ± 84 m and 411 ± 76 m in the Cape Town, Saldanha Bay and Port Nolloth fishing zones respectively (Table 3.1). Overall, annual fishing intensity (number of trawls) and effort (minutes) was fairly constant throughout the study period (Table 3.1).

Average CPUE for the study period was highest in the same depth range (300 to 500m) as highest fishing intensity, although the average CPUE per grid block was lower in the Port Nolloth zone (Figure 3.2). CPUE was significantly higher in the 400m and 500m strata (Figure 3.3). Maps of average annual CPUE per grid block revealed differences in the spatial distribution between years (Figure 3.4). The incidents of $5+$ tons.hour⁻¹ average CPUE for 1994 may be considered outliers.

Average CPUE per grid block for the study period was 1.5 to 2 tons.hour⁻¹ (Figure 3.2), while several grid blocks had an annual average CPUE ranging between 2.5 and 5 tons.hour⁻¹ (Figure 3.4). Fishing intensity was highest in the Cape Town zone at 300m but mean CPUE was highest at 500m. The Saldanha Bay zone showed a similar trend with higher CPUE at 400m but with greater fishing intensity in the 500m stratum (Table 3.2). For most years, CPUE was significantly higher between 301m to 500m (Figure 3.5). A two-way ANOVA established an interaction between year and depth (p-values $\ll 0.001$), i.e. the trends in CPUE by depth strata were not consistent over the years investigated, corroborating results presented in Figure 3.2.

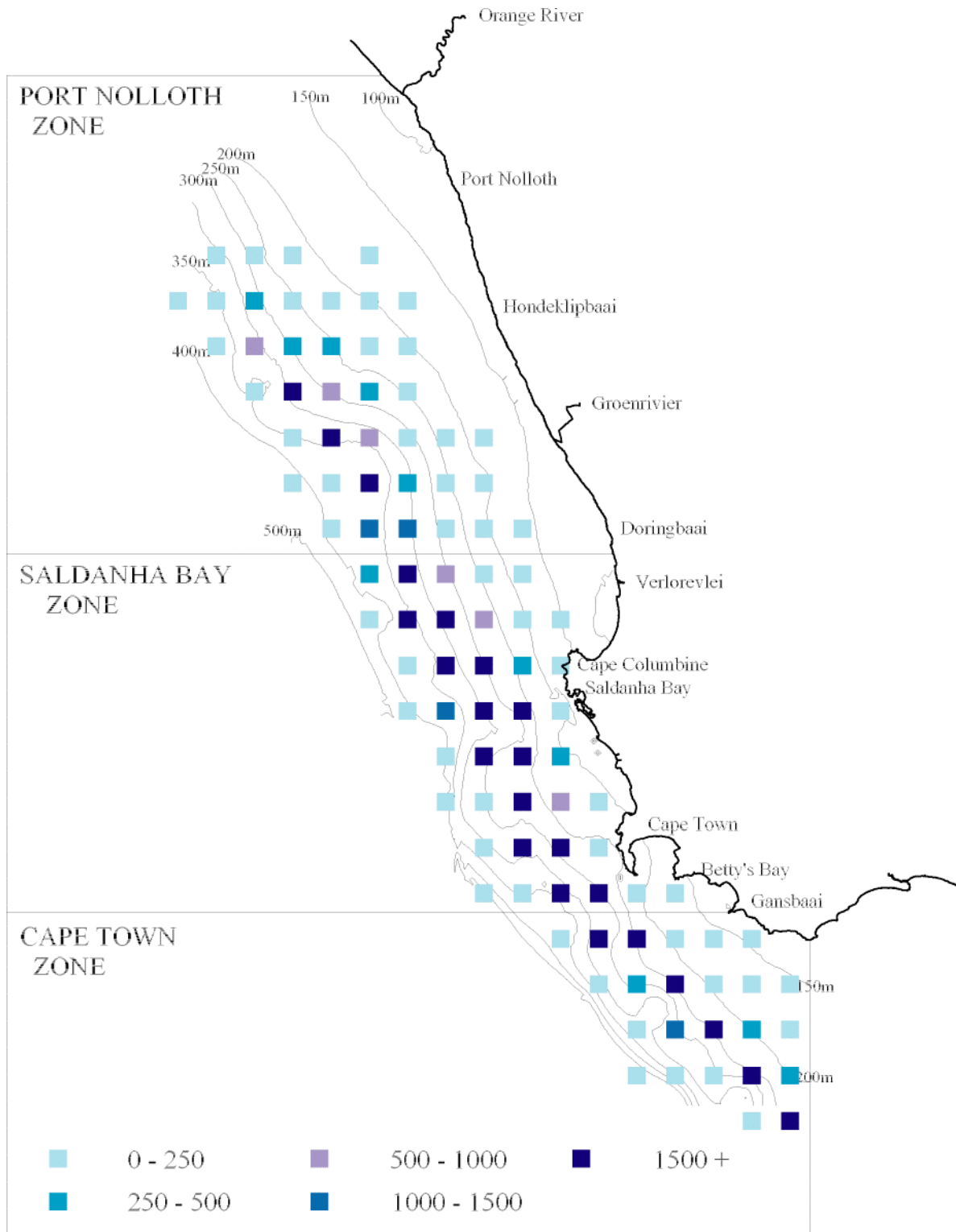


Figure 3.1 Total number of commercial trawls completed in each grid block for all years (1994 to 1999).

Intensity is graded by colour.

Table 3.1 Depth fished (m) by trawlers off the West Coast and fishing zones for all years (1994 to 1999).

Zone	Year	Mean \pm Std Dev	Median	Range	n	Effort (min)
Entire West Coast	all	393.42 \pm 95.68	400	20 - 999	185393	27165239
	1994	385.59 \pm 93.90	398	50 - 900	30718	3882337
	1995	386.76 \pm 92.58	390	112 - 710	32745	4388600
	1996	390.67 \pm 97.64	395	20 - 999	29557	4266436
	1997	402.45 \pm 97.12	412	95 - 997	32865	4985148
	1998	398.96 \pm 96.31	412	109 - 999	32100	5055947
	1999	396.13 \pm 95.21	409	110 - 684	26924	4526006
Port Nolloth zone	all	410.82 \pm 76.32	440	95 - 550	14228	2943616
	1994	384.36 \pm 82.82	420	193 - 549	2397	444443
	1995	392.13 \pm 80.77	435	199 - 520	1380	247276
	1996	426.53 \pm 69.87	450	190 - 550	2595	493850
	1997	413.29 \pm 79.79	44	95 - 550	3042	639997
	1998	405.63 \pm 77.87	437	128 - 534	2247	516563
	1999	431.29 \pm 55.35	442	147 - 547	2554	599882
Saldanha Bay zone	all	407.70 \pm 84.45	411	20 - 999	124373	17898210
	1994	408.43 \pm 81.63	411	110 - 682	22537	2742171
	1995	410.87 \pm 81.65	413	112 - 710	23124	3120905
	1996	411.11 \pm 83.04	415	20 - 900	16887	2472548
	1997	408.91 \pm 82.96	413	108 - 997	21137	3128093
	1998	404.95 \pm 89.05	414	110 - 999	22956	3507322
	1999	401.25 \pm 88.09	403	115 - 682	17451	2888299
Cape Town zone	all	350.17 \pm 114.19	320	50 - 999	46792	6323413
	1994	297.13 \pm 90.36	260	50 - 900	5784	695723
	1995	318.22 \pm 89.02	295	115 - 665	8241	1020419
	1996	347.16 \pm 110.59	320	100 - 999	10075	1300038
	1997	382.93 \pm 127.25	389	135 - 995	8686	1217058
	1998	376.88 \pm 119.07	385	109 - 851	6897	1032062
	1999	370.23 \pm 115.65	380	110 - 684	6919	1037825

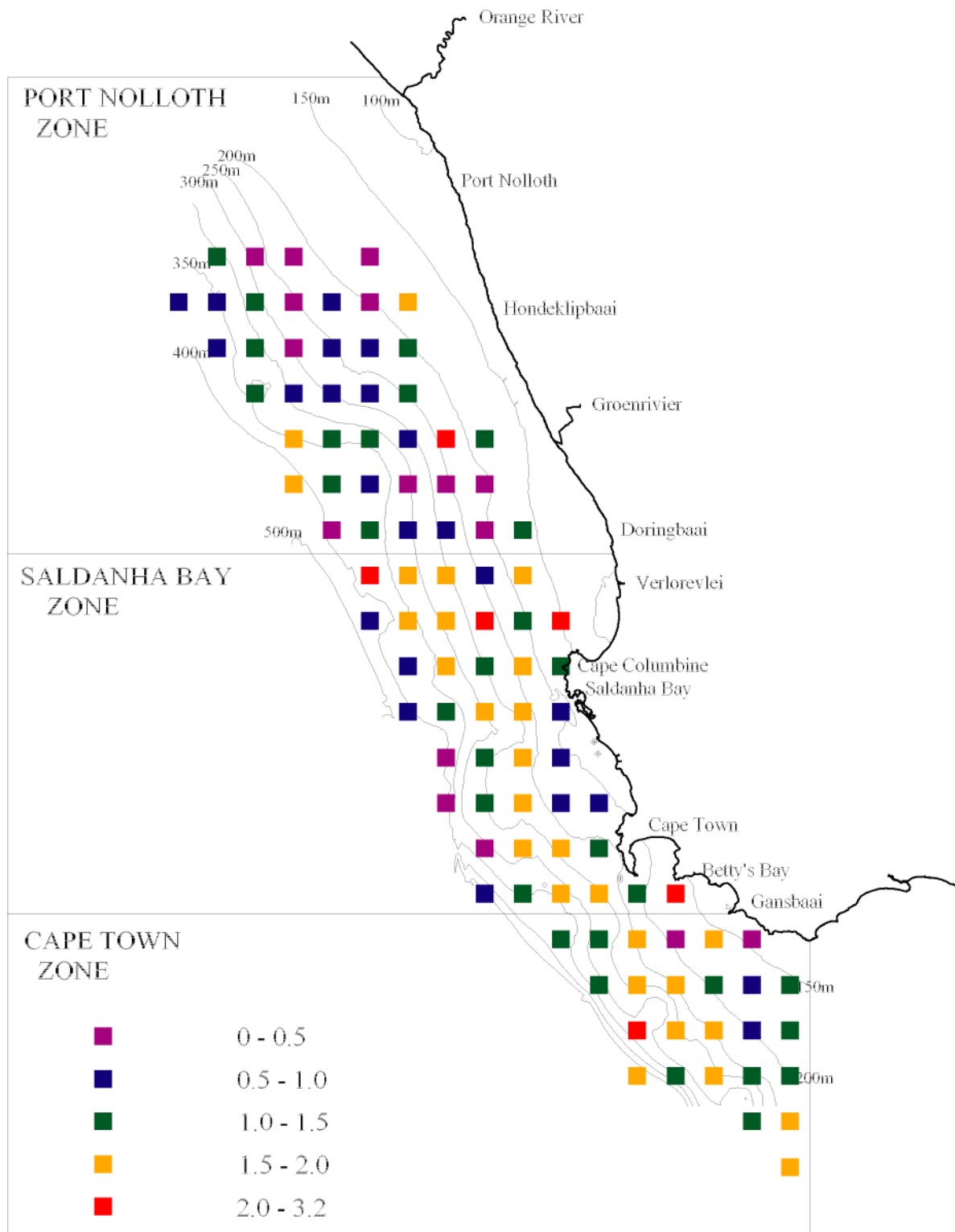


Figure 3.2 Average trawl CPUE (tons.hour⁻¹) per grid block fished between 1994 and 1999.

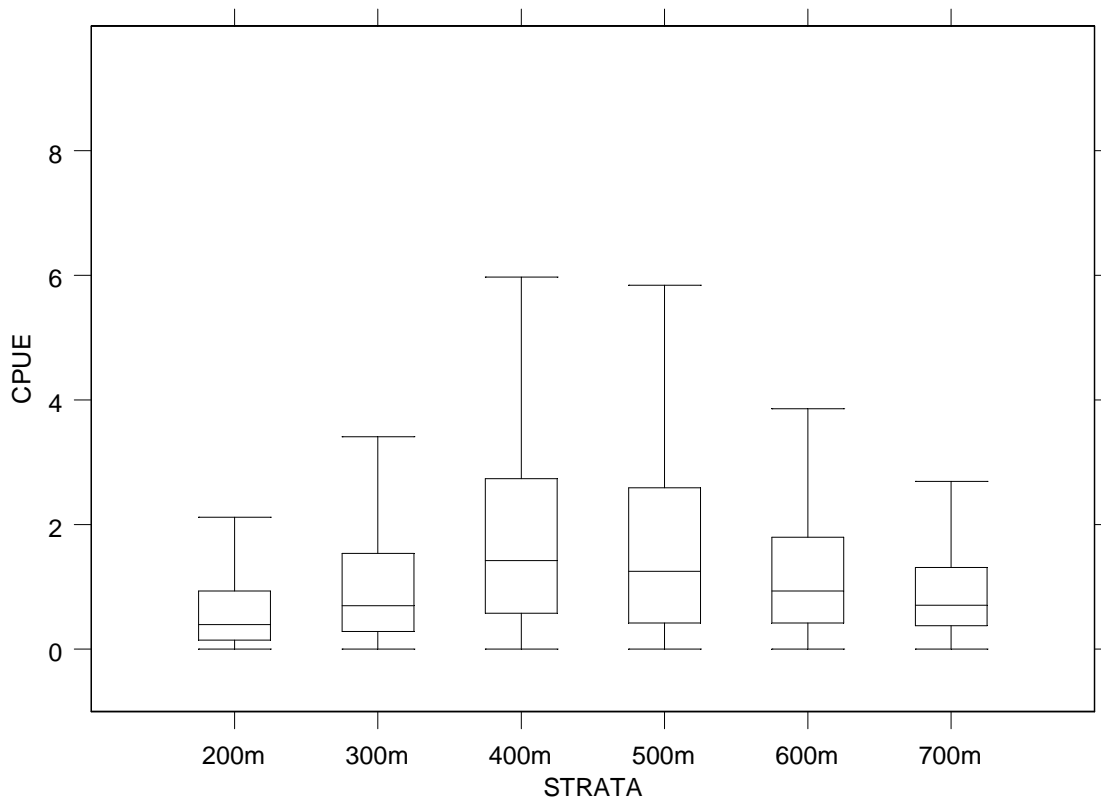


Figure 3.3 Box and whisker plot of trawl CPUE (tons.hour⁻¹) distributed across different depth strata for all years (1994 to 1999). Strata sharing a common letter were not significantly different from one another. Number of trawl events in each depth strata are given in parentheses.



Figure 3.4 Average annual trawl CPUE (tons.hour⁻¹) per grid block fished between 1994 and 1999.

Table 3.2 Trawler CPUE (tons.hour⁻¹) for all years (1994 to 1999) with reference to depth strata.

Depth Strata	Port Nolloth		Saldanha Bay		Cape Town	
	mean	n	mean	n	mean	n
100m	0.03 ± 0.02	3	0.18 ± 0.26	9	0.67 ± 0.81	2
200m	0.51 ± 0.73	137	0.86 ± 1.72	753	0.73 ± 1.00	1178
300m	0.62 ± 0.78	1706	1.25 ± 1.57	14298	1.17 ± 1.44	19731
400m	0.67 ± 0.94	1599	2.00 ± 2.18	42441	2.19 ± 2.82	10979
500m	1.09 ± 1.49	10541	1.95 ± 2.25	50487	2.43 ± 4.00	9960
600m	0.98 ± 1.29	242	1.36 ± 1.64	15736	1.53 ± 2.04	4233
700m			0.96 ± 0.97	573	1.14 ± 1.25	351
800m			0.17 ± 0.25	47	0.36 ± 1.00	94
900m			0.11 ± 0.16	27	0.27 ± 1.43	203
999m			2.70 ± 3.81	2	0.11 ± 0.38	61
All	0.98 ± 1.38	14228	1.80 ± 2.10	124373	1.69 ± 2.63	46792

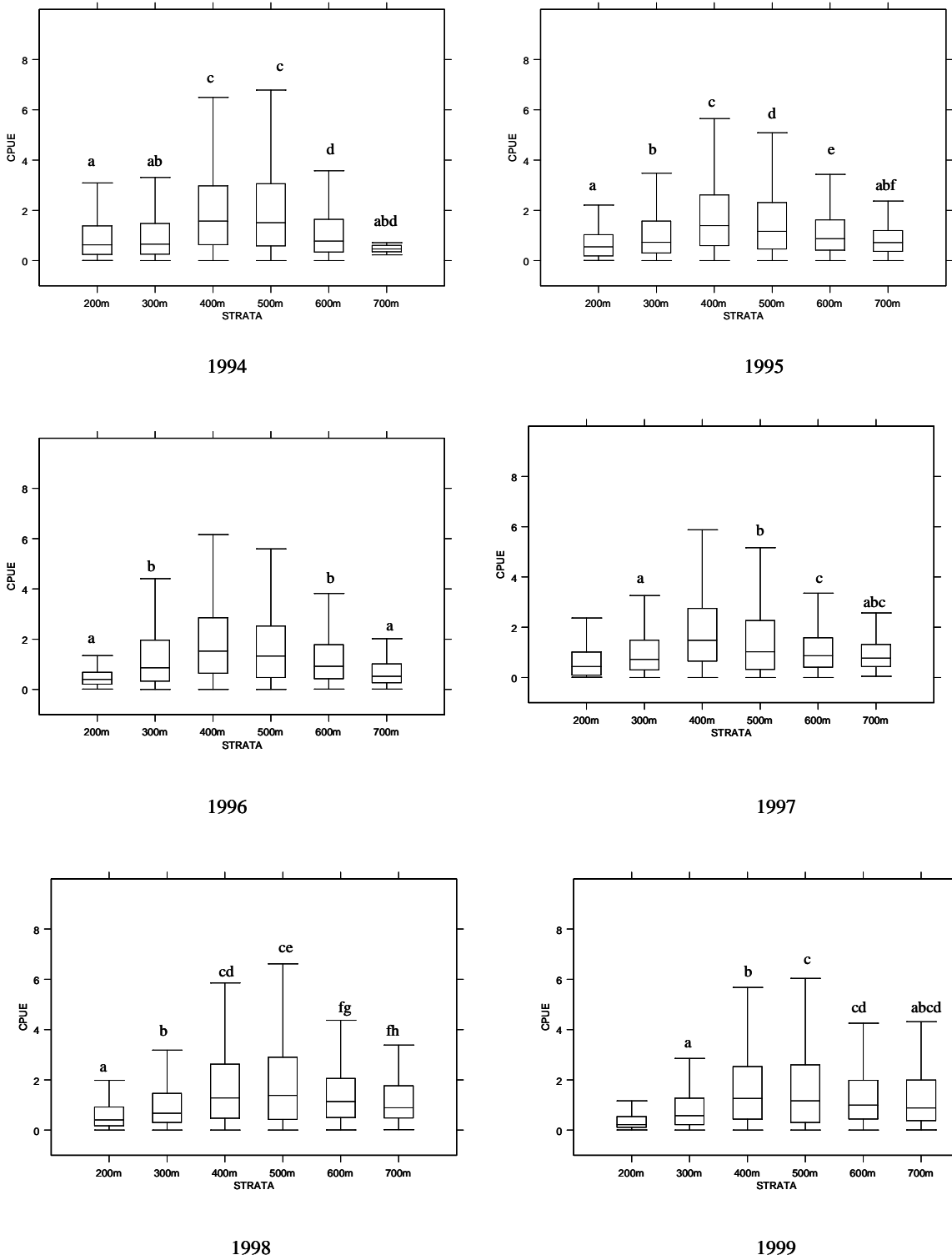


Figure 3.5 Box and whisker plot of trawler CPUE (tons.hour⁻¹) distributed across different depth strata for each year (1994 to 1999). Strata sharing a common letter were not significantly different.

Longline fishery

Fishing events were assigned to a depth stratum using the vector combination process discussed in Chapter 2. Longline fishing intensity (number of lines set) on the West Coast is illustrated in Figure 3.6 and shows no discernable pattern in depth strata fished. Figure 3.6 does, however, illustrate that fishing is concentrated around the two largest ports on the West Coast: namely Cape Town and Saldanha Bay with some fishing excursions into northern waters. Overall, fishing intensity was highest between 301 and 500m, with a shift from the 300m stratum to the 400m stratum in 1998 (Figure 3.7). The mean and median fishing depths for 1999 are summarised in Table 3.3. Figure 3.8 illustrates that fishing intensity has increased over the past six years with the area fished expanding annually. Fishing intensity was highest in 1997 with CPUE reaching almost 0.5 tons.1000 hooks⁻¹ in 1999 (Table 3.4).

Table 3.3 Depth fished (m) by longliners off the West Coast and fishing zones in 1999.

Zone	Year	Mean ± Std Dev	Median	Range	n
West Coast	1999	341.46 ± 71.26	330	152 - 549	331
Port Nolloth	1999	319.45 ± 35.31	300	300 - 415	40
Saldanha Bay	1999	346.17 ± 72.88	377	215 - 494	115
Cape Town	1999	342.42 ± 74.26	336	152 - 500	176

Table 3.4 Longliner CPUE (tons.1000 hooks⁻¹) for all years (1994 to 1999).

Year	Mean ± Std Dev	Median	Range	n
1994	0.25 ± 0.30	0.13	0 - 1.30	475
1995	0.25 ± 0.33	0.05	0 - 1.68	208
1996	0.35 ± 0.27	0.30	0 - 1.50	968
1997	0.30 ± 0.33	0.24	0 - 7.45	1384
1998	0.38 ± 0.40	0.32	0 - 4.00	259
1999	0.48 ± 0.34	0.45	0 - 3.55	920

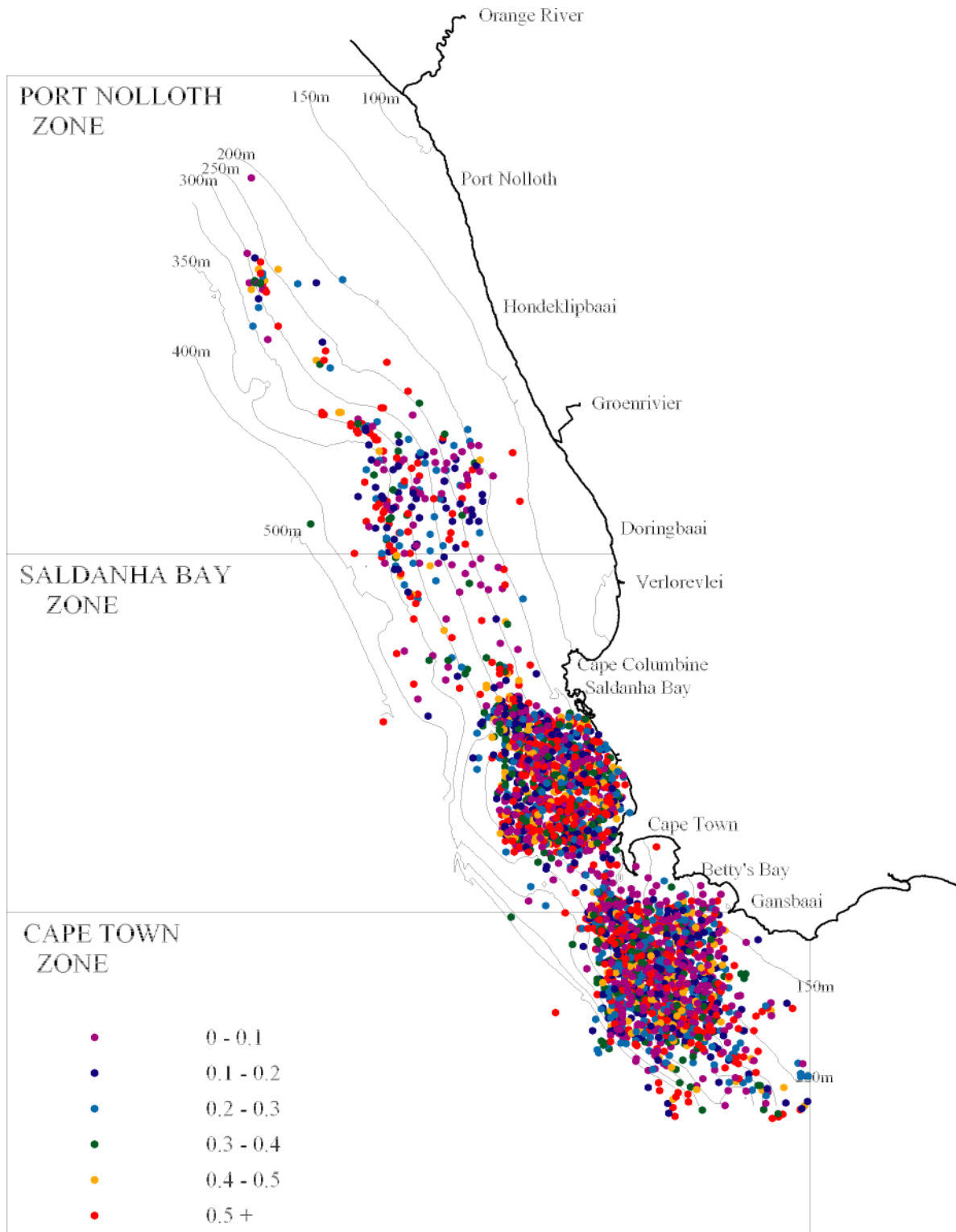
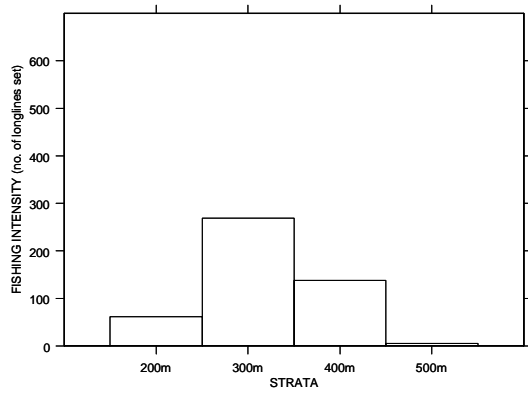
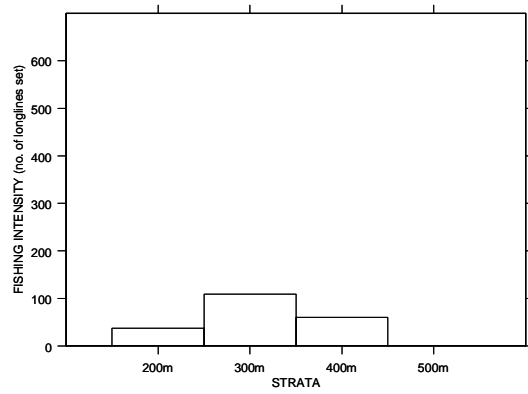


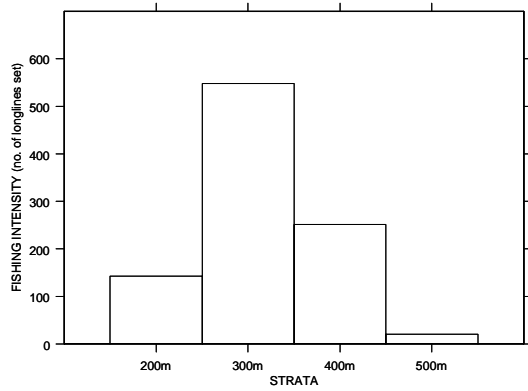
Figure 3.6 Average longline CPUE (tons.1000 hooks⁻¹) of lines set between 1994 and 1999.



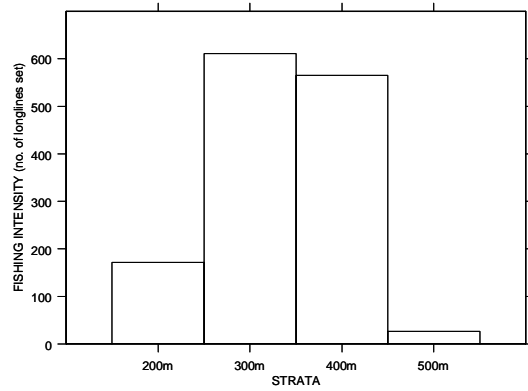
1994



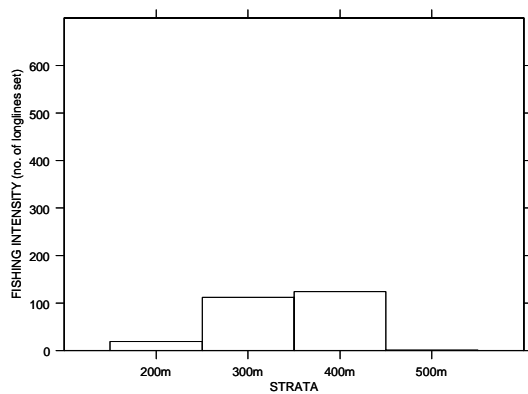
1995



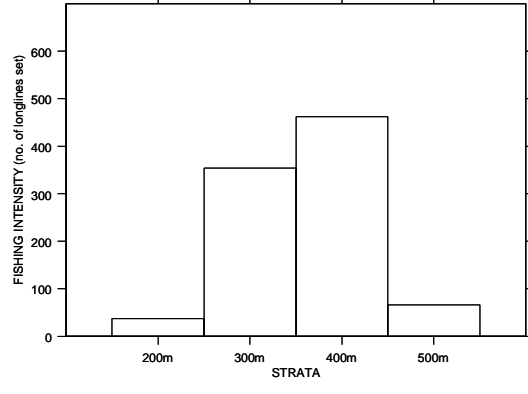
1996



1997



1998



1999

Figure 3.7 Distribution of annual longline fishing intensity (number of longlines set) across depth strata for all years (1994 to 1999).

Fishing effort increased offshore between 1994 and 1999, as shown by the spatial distribution of average longline CPUE (tons.1000 hooks⁻¹) per grid block (Figure 3.8). It is interesting to note that although the CPUE for the Saldanha Bay and Cape Town fishing zones were highest in the 500m depth strata, fishing intensity was highest in the 300m and 400m strata respectively (Table 3.5). There were also significant differences between CPUE across depth strata for each year (p-value = 0.0027), however a significant interaction (p-value = 0.005) was only noted for the Cape Town zone.

Table 3.5 Longliner CPUE (tons.1000 hooks⁻¹) for all years (1994 to 1999) with reference to depth strata.

Depth Strata	West Coast		Port Nolloth		Saldanha Bay		Cape Town	
	mean	n	mean	n	mean	n	mean	n
100m	0.40 ± 0.56	2			0.40 ± 0.56	2		
200m	0.28 ± 0.25	469	0.39 ± 0.45	9	0.31 ± 0.25	144	0.26 ± 0.24	316
300m	0.34 ± 0.33	2003	0.39 ± 0.35	124	0.34 ± 0.34	1017	0.33 ± 0.30	862
400m	0.38 ± 0.35	1600	0.43 ± 0.39	103	0.38 ± 0.30	560	0.36 ± 0.38	937
500m	0.42 ± 0.36	138	0.42 ± 0.38	22	0.52 ± 0.49	42	0.39 ± 0.25	54
All	0.35 ± 0.33	4214	0.41 ± 0.37	258	0.36 ± 0.33	1765	0.34 ± 0.33	2169

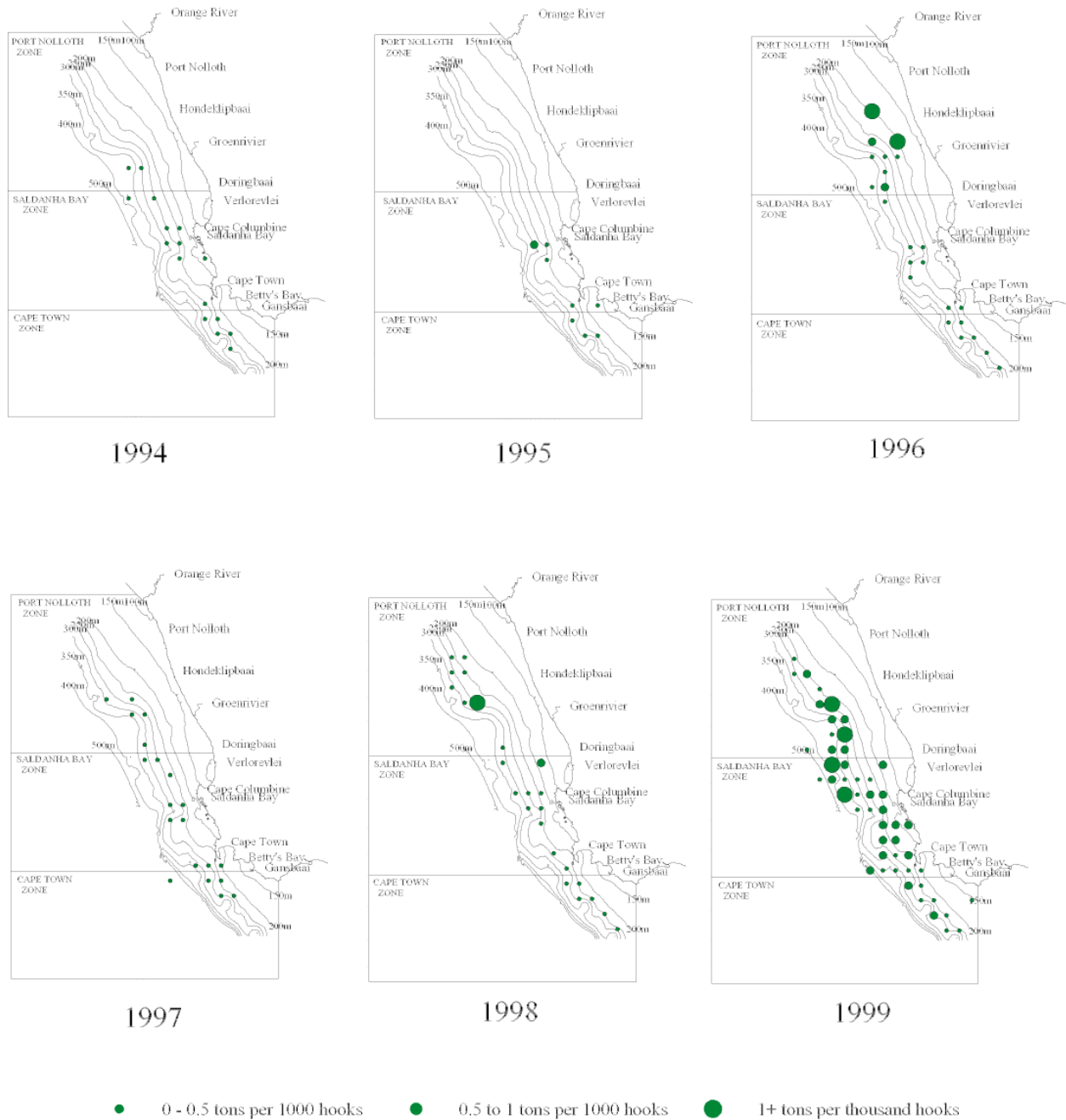


Figure 3.8 Average annual longline CPUE (tons.1000 hooks⁻¹) per grid block fished between 1994 and 1999.

Substrate

The distribution of surficial sediment on the West Coast is presented in Figure 3.9. The inshore region (<300m) is characterised by large areas of sand interspersed with patches of sandy mud and muddy sand. A thin strip of mud extends the length of the coast from Verlorevlei to the Orange River mouth, the majority of mud sediment is found deeper than 500m. Only 10% of the West Coast has been found to be untrawlable by M&CM (Table 3.6), the majority of this untrawlable ground is encompassed within sand sediment where a surficial amount of sand is found between bedrock outcrops. The large untrawlable area off Groenrivier mouth is known as Child's Bank, and the area off Saldanha Bay encompasses Dassen Island and a feature known as the 'rocky horrors' (Leslie *pers. comm.* 2001).

Table 3.6 The area of the West Coast covered by different surficial sediment texture classes.

Percentages of sediment area class to the total area are shown in parentheses.

Sediment class	Area covered (km ²)	Untrawlable area (km ²)
Muddy Sand	71 904 (31.7%)	3 520
Sand	66 708 (29.4%)	17 973
Mud	54 113 (23.9%)	1 094
Sandy Mud	33 685 (14.9%)	1 484

The results of the contingency tables that tested for the independence of fishing intensity and substrate type were highly significant (Table 3.7) with 69% of trawling events and 72% of longlining events having occurred on sand in the last six years despite the lower proportion of this sediment type in the study area.

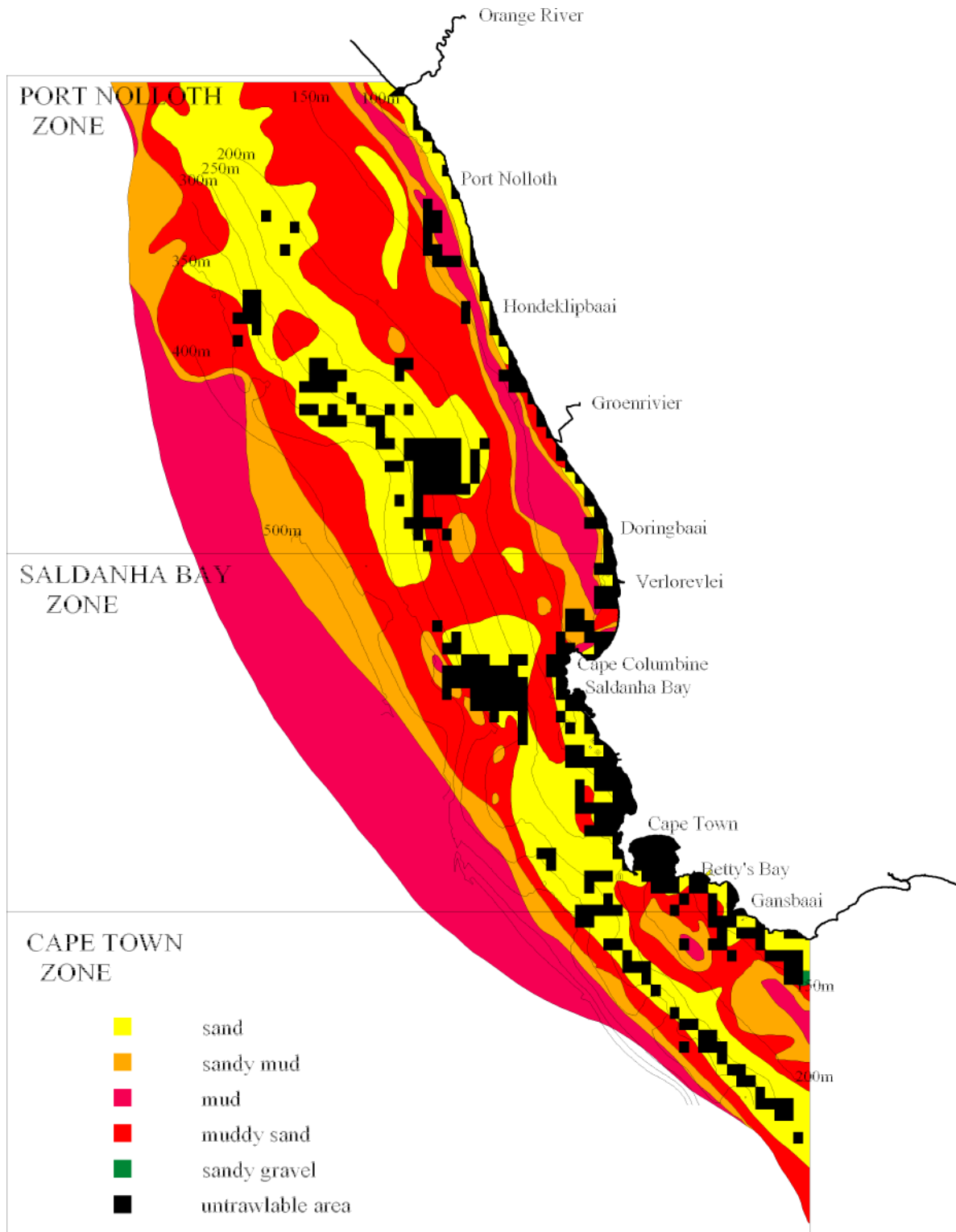


Figure 3.9 Distribution of surficial sediments off the West Coast (Council for Geoscience, Cape Town) and untrawlable (rocky) areas as recorded by Marine and Coastal Management (Leslie *pers. comm.* 2001).

Table 3.7 Contingency table analysis where the independence of fishing intensity was tested against substrate type for the trawl and longline fishing sectors.

Fishing effort x substrate type (3x4)	χ^2	<i>df</i>	<i>p-value</i>
Trawlers	167402.4	6	<< 0.001
Longliners	4172.85	6	<< 0.001

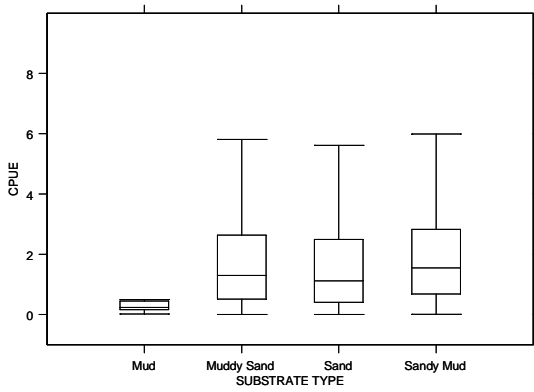
Although 27% of the area covered by sand is untrawlable (Table 3.6), less than a third of longlining has occurred on untrawlable ground since 1994 (Table 3.8). Which implies that the significance of surficial sand sediment should not be underestimated.

Trawl fishery

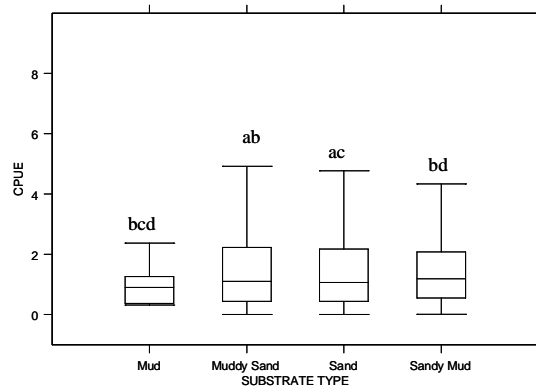
CPUE was significantly higher over surficial sediment with a sand component (Figure 3.10). This trend was evident in both the Port Nolloth and Saldanha Bay zones, however, mean CPUE in the Cape Town zone was highest on mud (Figure 3.11). Fishing was concentrated around untrawlable areas in deeper water to a large degree (Figure 3.12).

Longline fishery

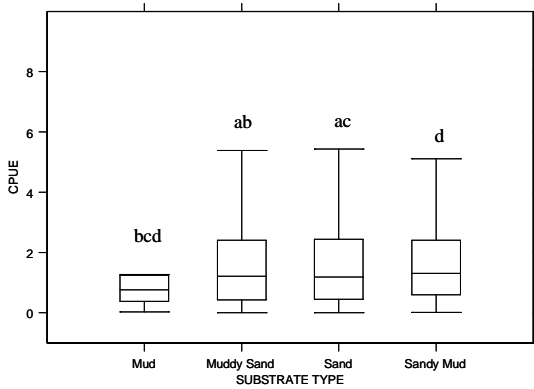
Similar to the trawl fishery, longline CPUE was significantly higher on surficial sediment with a sand component (Figure 3.13). A two-way ANOVA established an interaction between year and substrate types over the full study period (p -value = 0.0007) and within the Cape Town fishing zone (p -value = 0.005). Trends in CPUE by substrate type were, however, not consistent over the years investigated. Although areas of highest longlining intensity coincided with untrawlable areas, relatively little longlining occurs on or near untrawlable ground (Figure 3.14).



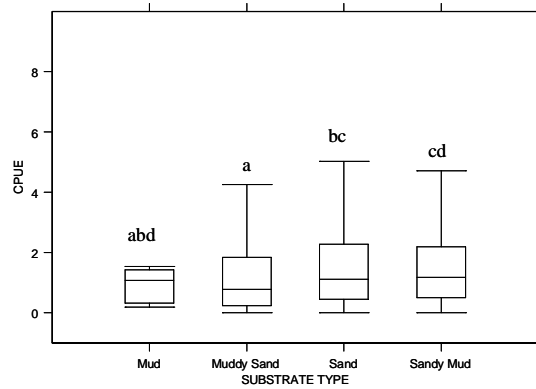
1994



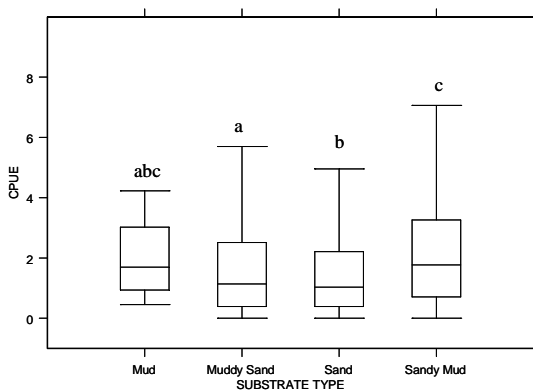
1995



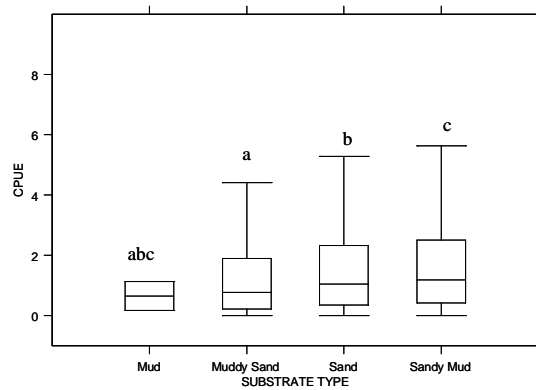
1996



1997

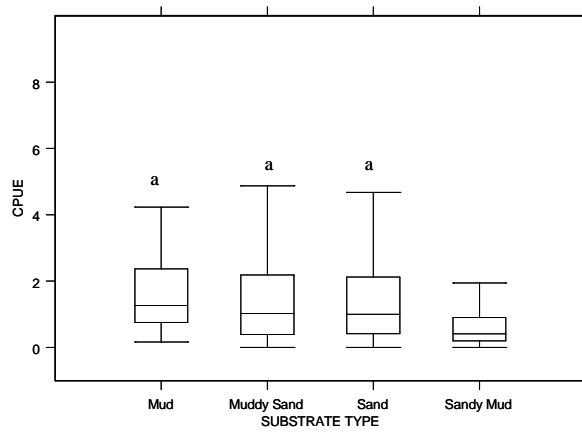


1998

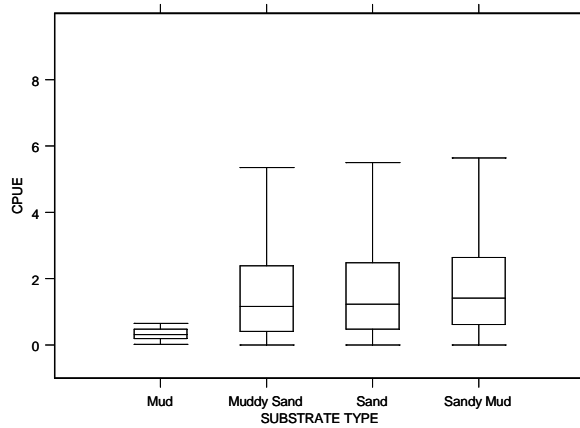


1999

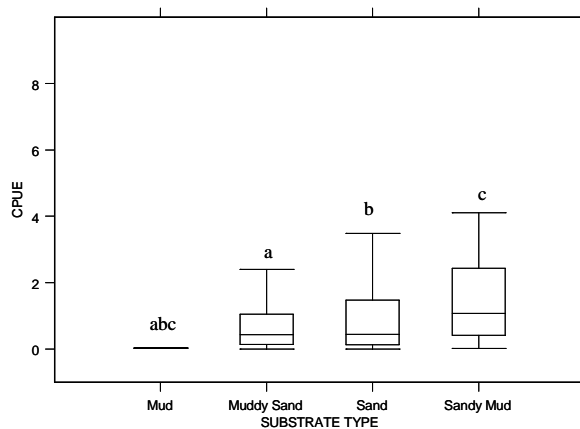
Figure 3.10 Box and whisker plot of trawl CPUE (tons.hour⁻¹) distributed across different substrate types for each year (1994 to 1999). Strata sharing a common letter were not significantly different.



Cape Town



Saldanha Bay



Port Nolloth

Figure 3.11 Box and whisker plot of trawl CPUE (tons.hour-1) distributed across different substrate types for each fishing zone. Strata sharing a common letter were not significantly different.

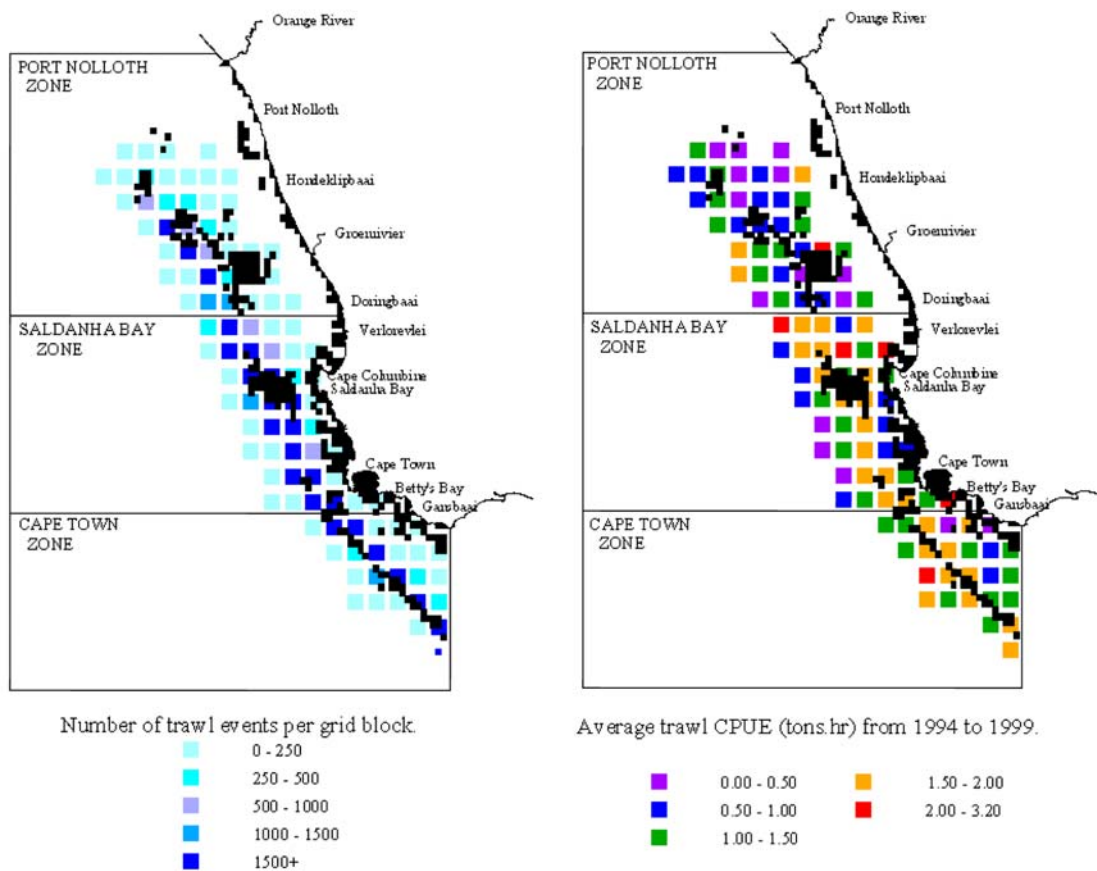


Figure 3.12 Fishing intensity (number of trawls) and average trawl CPUE (tons.hr⁻¹) per grid block considered against the distribution of untrawled grounds (depicted in black).

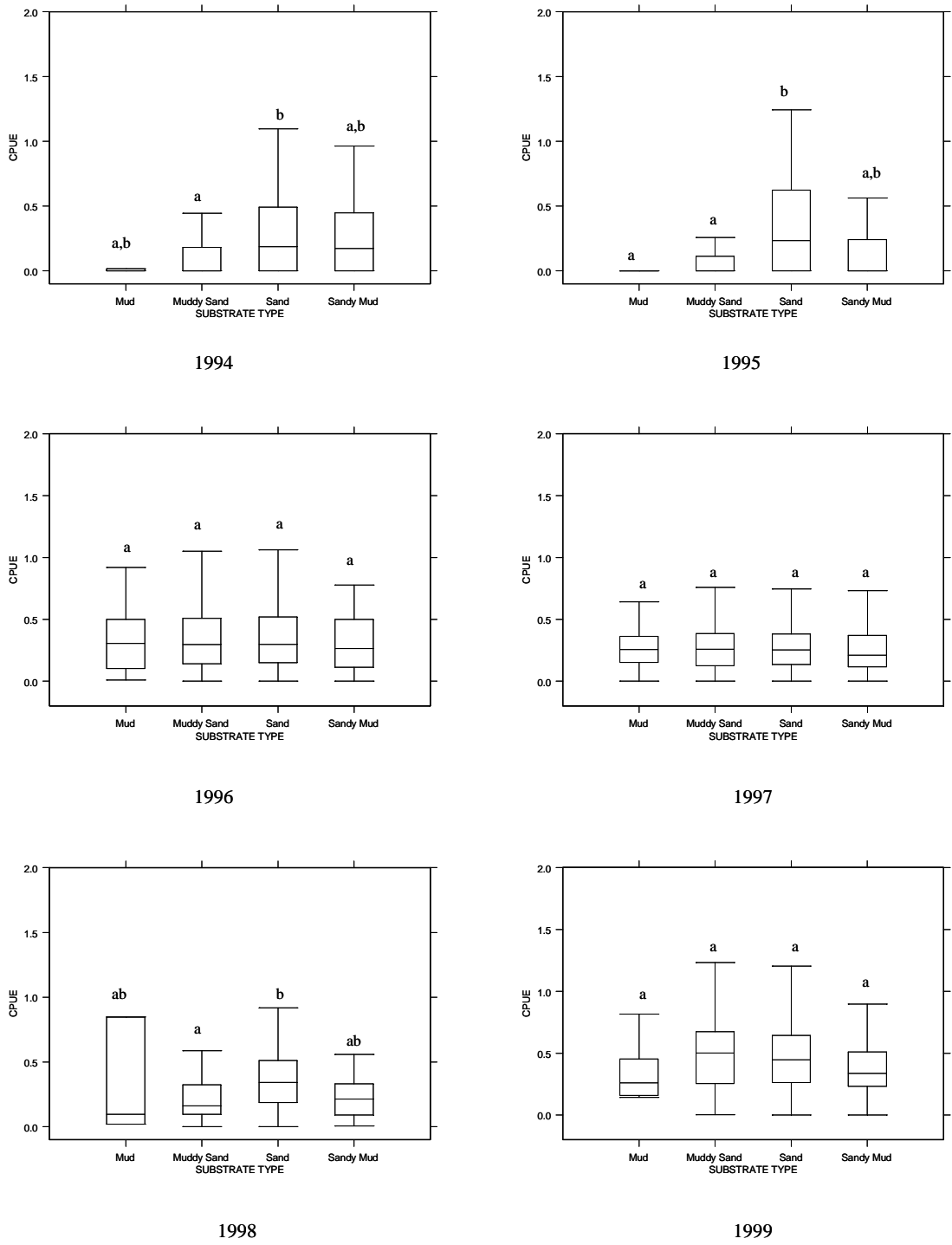


Figure 3.13 Box and whisker plot of longline CPUE (tons.1000 hooks-1) distributed across different substrate types for each year (1994 to 1999). Strata sharing a common letter were not significantly different.

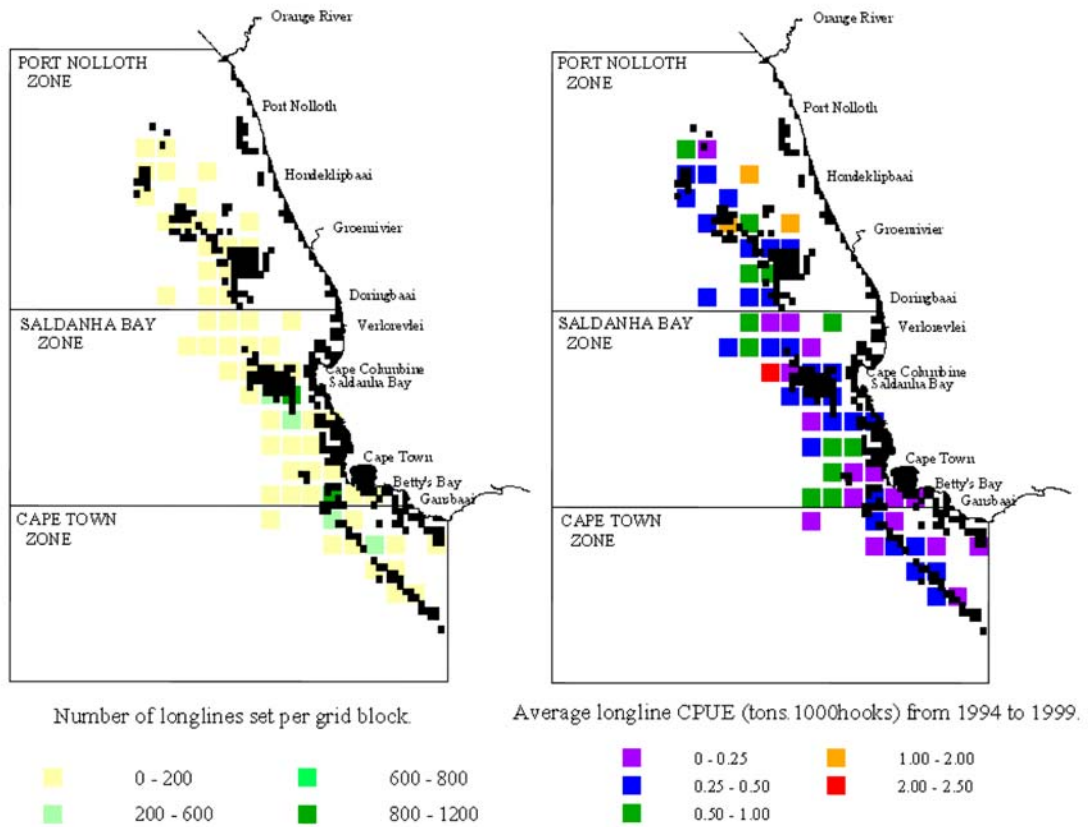


Figure 3.14 Fishing intensity (number of longlines set) and average longline CPUE (tons.1000 hooks⁻¹) per grid block considered against the distribution of untrawlable grounds (depicted in black).

There was no conspicuous trend in either annual longline intensity or mean CPUE that occurred on untrawlable ground (Table 3.8). Although mean CPUE increased dramatically in 1998 and continued to increase in 1999, there was a notable increase in fishing intensity.

Table 3.8 Mean annual longline CPUE (tons.1000 hooks⁻¹) in untrawlable areas. Number of longlines set each year is given in parentheses and the number set on each surficial sediment is given in brackets.

Surficial Sediment	1994	1995	1996	1997	1998	1999
Muddy Sand [72]	0.225 (8)	0.056 (5)	0.320 (28)	0.247(27)	0.062 (2)	(2)
Sand [1072]	0.282 (126)	0.177 (44)	0.374 (227)	0.268 (275)	0.414 (55)	0.472 (345)
Mud [10]	(0)	(0)	0.225 (2)	0.270 (6)	0.097 (1)	(1)
Sandy Mud [10]	0.000 (1)	0.000 (1)	0.476 (4)	0.045 (1)	0.240 (1)	(2)

Comparison with findings in longline experiment

Japp et. al. (1995) recorded that the grid blocks 439, 440 and 469 were subject to the highest fishing intensities during the longline fishing pilot study. They expressed concern as to the impact of fishing intensively on one ground for a continued period and noted that the issue warranted further investigation. The results in Figure 3.15 showed a similar trend with the grid blocks with the highest fishing intensity across the entire period (1994 to 1999) being 439, 440, 469 and 479 (Figure 3.15). Catch rates have increased slightly over the study period (Figure 3.16), despite fluctuations in the fishing intensity (Figure 3.17).

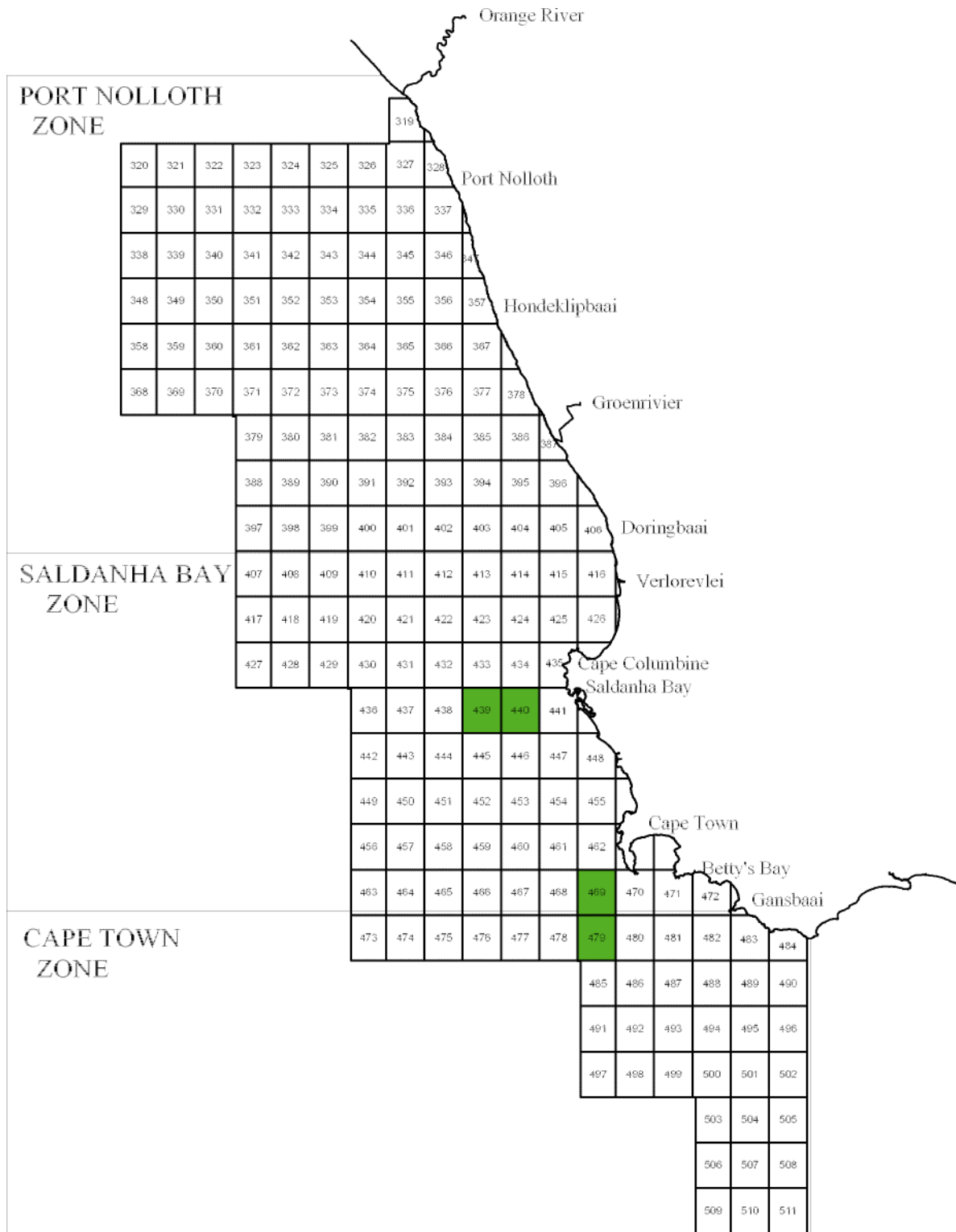


Figure 3.15 Commercial grid blocks in which longline intensity was highest for study period (1994 to 1999).

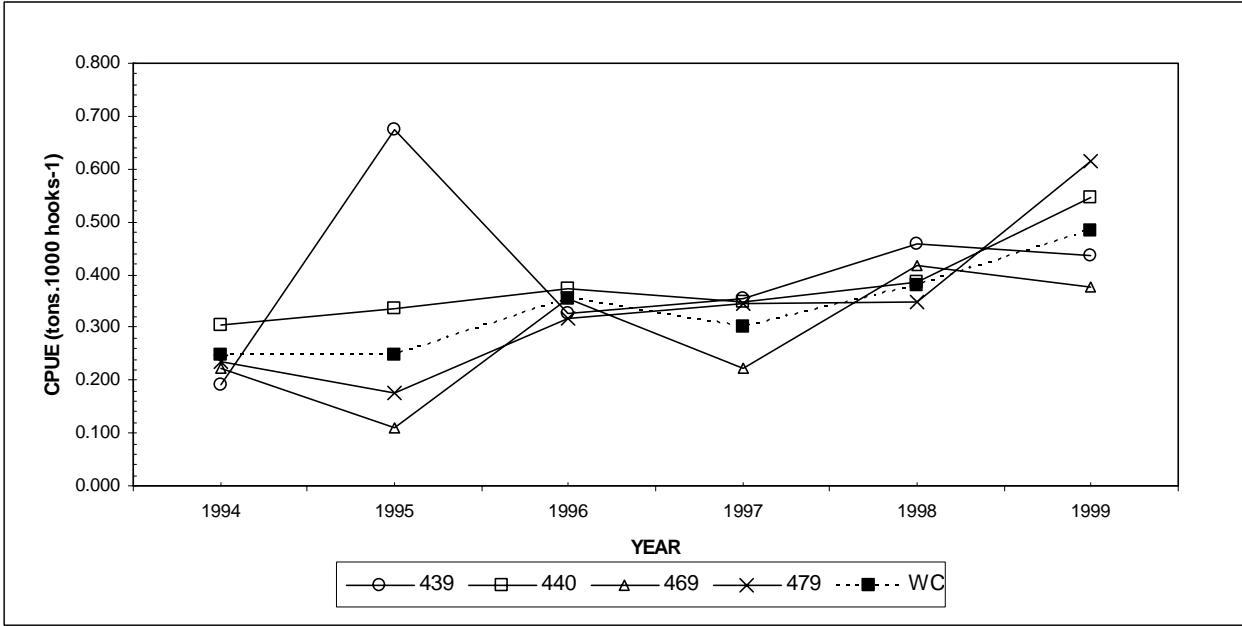


Figure 3.16 Annual average CPUE (tons.1000 hooks⁻¹) for the four most intensely longlined grid blocks for all years (1994 to 1999). WC represents the average for the entire West Coast.

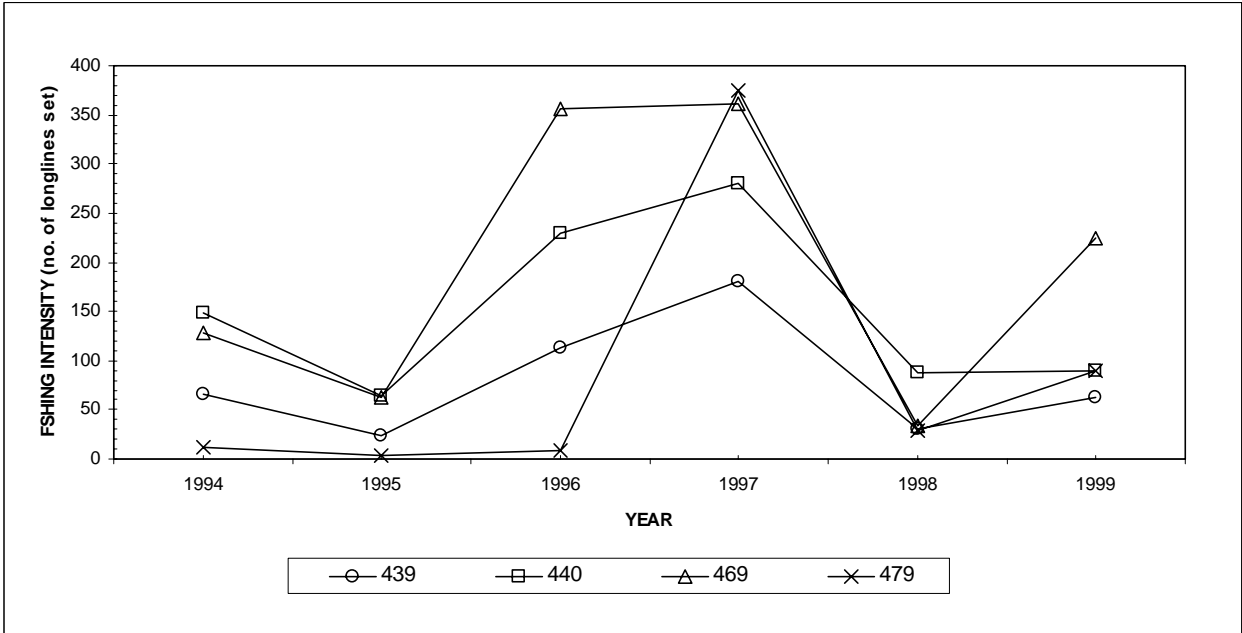


Figure 3.17 Trends in longline fishing intensity (number of longlines set) for four specific grid blocks for all years (1994 to 1999).

Discussion

A large number of factors may influence where a vessel fishes, including vessel size, gear type, weather condition, market requirements, and economic concerns. Vessel size will obviously limit the distance that can be safely traversed from the nearest port and the duration at sea. Gear type is more restrictive for the trawl sector, as hard ground and steep slopes must be avoided. Weather conditions will determine which fishing grounds are targeted, e.g. to avoid storms, northern waters are targeted during the winter season. Market requirements vary throughout the year; in particular the selling price of longline caught hake is subject to international demand. It is, however, the economic concerns of each fishing sector that may play the largest role in understanding the spatial distribution of fishing activity investigated in this chapter.

Over the past six years the trawl sector has fished the same areas consistently with highest fishing intensity and average CPUE achieved at depths between 300 and 500m. Lower average CPUE and less fishing occurred in northern waters (Port Nolloth fishing zone). Analysis of each fishing zone revealed that highest fishing intensity did not coincide with highest CPUE for either Cape Town or Saldanha Bay. Rough seas off Cape Point may explain higher fishing intensity closer to shore in the Cape Town zone. Higher CPUE in deeper water, where catches are “cleaner” because the bycatch component is reduced, is forfeited. In contrast, the more sheltered waters of the Saldanha Bay zone allow for more fishing in deeper water. Particularly clean catches are taken on grounds bordering untrawlable areas. CPUE is highest in the 400m strata, however this may be attributed to substrate type as mud dominates the waters deeper than 500m and CPUE was found to be highest on surficial sediments with a sand component. Mud is, however, found in shallower waters in the Cape Town zone, which explains the higher CPUE on mud for this zone.

The analysis of the longline sector revealed several similarities to the trawl sector. Although there is no obvious depth related distribution of fishing intensity, statistical analysis suggests that fishing intensity is highest between 301 and 500m. The highest catch rates observed in the pilot study were between 351 and 400m (Japp *et. al.* 1995). There has also been a shift in fishing intensity to deeper waters with a corresponding increase in CPUE during this study period. The rapid increase in average CPUE since 1994 indicates a steep learning curve. As fishermen are typically territorial, the increase in longliner entrants to the fishery (Japp and Wissema 1999) accounts for the larger area covered by the vessels. Only a third of longlining occurs on untrawlable grounds, this corroborates reports of increased vessel interactions.

As with the trawl sector, analysis of each fishing zone revealed that highest longlining intensities did not coincide with highest CPUE. In contrast, highest longline CPUE was achieved in 500m water for both the Cape Town and Saldanha Bay zones. Fishing intensity was highest in shallower water for both, confirming reports by Japp *et. al.* (1995) that “offshore” vessels had the highest catch rates. This may be the result of several factors. Vessel size would preclude high intensity fishing in deeper waters for the majority of the season, particularly off storm-swept Cape Point. Japp *et. al.* (1995) noted that catch rates were vessel specific, dependent on the skipper’s experience and the individual vessel operating efficiency. It is likely that the significant difference between years in CPUE is the result of market forces and the increased experience and success in using the longlining fishing technique. Alternatively, it may be more difficult to target a certain size or species in the other two zones because of the distances to be traversed as the continental shelf widens further north. In addition, there would be negative interaction with trawl vessels.

Trawl vessels do not face these travel constraints, which also showed significant differences between CPUE at depth over the years. It is interesting to note that CPUE averaged out over the six year period, despite the large CPUE average per grid block within each year. The position of these higher catches varied between years, indicating either areas of abundance that vary temporally or more likely the effect of market forces. De Blois and Rose (1995) found that shoals of cod *Gadus morhua* expand and contract in response to foraging activity. They also suggest these aggregation dynamics should be considered when interpreting trawl data. Trawl vessels, despite their gear limitations, are capable of targeting a certain size of fish by fishing in certain depth and at certain positions along the West Coast. This offers some explanation for areas of higher CPUE.

Why, for both fishing sectors, is CPUE highest in a different depth strata to that most intensely fished? It is suggested that both sectors face a “friction of distance” dilemma (Caddy and Carocci 1999). The dilemma is two-fold for the longline sector because the vessels are small and incapable of navigating high seas and are therefore restricted to the inshore regions. Despite higher CPUE achieved in deeper water, the costs of steaming further out from port would probably offset the subsequent increase in profit. Whilst remaining in the depth range where catch rates are reasonably high they reduce costs by not traveling large distances.

Trawlers also face cost increases in terms of distance from ports. There is a trade-off as “optimal” CPUE is achieved in deeper water but suitable soft grounds are abundant in the shallower regions. Although the Agulhas Bank is considered the main hake fishing ground, two thirds of the fishing that has occurred off the West Coast in the last six years has been in the Saldanha Bay fishing zone. The continental shelf is much wider in the Saldanha Bay fishing zone, with a shallower gradient than that of the Agulhas Bank. There are better opportunities for “easier” and therefore more economical trawling from Saldanha Bay.

Using spatial analysis, all four null hypotheses presented were rejected. This suggests that the distribution and abundance of hake, in particular the exploitable proportion of the population, is determined by a combination of depth and substrate type.

Several studies have confirmed the distribution of marine species is depth-related. The ontogenetic migration of fish into deeper water has been documented for many fish species, these include: Dover sole *Microstomus pacificus*, shortspine thornyheads *Sebastolobus alascanus*, sablefish *Anoplopoma fimbria* (Jacobson and Hunter 1993, Jacobson and Vetter 1996), panga *Pterogymnus laniarius* (Booth and Buxton 1997), juvenile sparids (Harmelin-Vivien *et. al.* 1995), alfonsio *Beryx splendens* (Lehodey *et. al.* 1994) and pollock *Theraga chalcogramma* (Swartzman *et. al.* 1994). Mariscal Romero *et. al.* (1998) confirmed a bathymetric/thermic gradient in the demersal fish assemblages off the continental shelf of Mexico. Cantabrian shelf fish communities also exhibit strong bathymetric influence (Sanchez 1993). Green (1996) found depth was of overriding importance in *Labroides dimidatus* habitat use. Depth-dependent distribution may be explained by the physiology of the animals. Claireaux *et. al.* (1995a, 1995b) found that Atlantic cod *Gadus morhua* favour colder bottom water layers diurnally and rise into warmer layers nocturnally. The distribution of three shrimp species in Kuwait waters was determined by a combination of depth and temperature, and depth and salinity, indicating depth as the most influential factor (Ye *et. al.* 1999). Payne (1989) proposed that temperature may contribute to the differing relative abundance of *M. capensis* and *M. paradoxus*, resulting in aggregations. The diet of both species varies geographically but hake can adapt to perturbations in the availability of their prey (Payne *et. al.* 1987).

Although this study shows a strong relationship between substrate type and fishing activity there are several mitigating factors which should be weighed when considering an abundance estimate relative to substrate type. The density and distribution of fish may be affected by turbidity and the concentration of prey items associated with substrate types (Le Clus *et. al.* 1994). This is particularly relevant with respect to soft suspendable sediments such as mud. The physical properties of the sediments themselves, currents and interaction with biological components may therefore play an important role (Seiderer and Newell 1999). Jennings *et. al.* (1996), in defining the importance of habitat variables, suggests substrate should not be used as a sole determinant of biomass.

Spatial analysis was fundamental to facilitating the conclusions reached in this chapter. To achieve a realistic understanding of fishing pressure, the distribution of effort must be visualised in the context of fishable areas and distances from viable harbours. When fishing effort is assessed as a single concept, for simplicity, for an area as large as the West Coast, several levels of interaction and limiting factors are overlooked. Identifying where sector clashes are likely to occur and the most economically effective way to harvest the West Coast hake resource is realistically possible only through a GIS. The database used in this study would need additional vessel information and economic variables to enable such predictions.

CHAPTER 4

AN ASSESSMENT OF THE *MERLUCCIOUS CAPENSIS* STOCK ON THE WEST COAST

Introduction

Since the declaration of the 200nm EEZ, the assessment and management of the South African hake resource has evolved from simple gear restrictions to increasingly complex and predictive models. Initially, the total allowable catch (TAC) set for hake between 1978 and 1982 was based on a combination of Gulland's (1961) effort-averaging procedure, and the Fox (1970) surplus production function. From 1983 to 1989 the TAC recommendation was based on the Schaefer-form of the Butterworth-Andrew (B-A) observation error estimator (Butterworth and Andrew 1984) with an $f_{0.1}$ harvesting strategy. During the 1990s an $f_{0.2}$ harvesting strategy was employed (Punt 1992).

The model used for the 1990s was considered to be adequate despite the use of species-aggregated catch data (Punt 1993). Disaggregated species data is still not available as commercial catches of hake are not separated into species before processing, and it is not possible to reliably distinguish between the species in a processed form. The B-A observation error estimator (surplus production model) was assumed adequate if the fishing strategy did not change. Given the recent changes in the fleet structure of the hake-directed fisheries and a shift to targeting larger fish of higher quality, such a simple model was no longer considered adequate (Geromont *et. al.* 1999).

The B-A $f_{0.2}$ model predicted CPUE trend diverged from the observed trend indicating model misspecification. Continued use of the Schaefer model would have necessitated a severe drop in the TAC which, in the socio-economic context, was considered unacceptable (Geromont *et. al.* 1999). As a result an in-depth revision of the operational management procedure (OMP) for the West Coast Cape hake resource started in 1992 with the development of a standardised general linear model (GLM) and a

species disaggregated Operating Model (Brown *et. al.* 1996). The selected management procedure (MP) incorporated a Fox-form dynamic production model with an $f_{0.075}$ harvesting strategy, historic standardised CPUE for 1955-1977, GLM standardised CPUE for two time periods (1978-1984 and 1993-current), direct survey biomass estimates and associated CV's (Geromont and Glazer 1998).

The Operating Model of West Coast hake is an age-structured production model (ASPM) (Geromont and Butterworth 1998). The Fox-form was chosen for its simplicity as Geromont *et. al.* (1999) reported that the Fox and ASPM estimators produced similar projections. Punt (1991) discussed that the data available for assessing the West Coast hake resource can readily be used in an age-structured model-estimation procedure, and proposed that more reliable estimates of management quantities could be generated. Booth and Punt (1998) added that models which explicitly account for age-structure are preferred by biologists and fisheries managers.

In the process of constructing an ASPM, *M. capensis* specific gear selectivities and catches of trawlers and longliners need to be determined. An ASPM of the form presented by Geromont and Butterworth (1998) was used for the purposes of comparison and application. The derivation and application of species specific catch data in the construction of an *M. capensis* ASPM is discussed. The feasibility of the ASPM and future data collection for *M. capensis* specific analysis is considered.

Materials and methods

General

In order to model the dynamics of *M. capensis* using an ASPM it is necessary to have estimates of total annual catch, relative abundance data and several age-specific model parameters: selectivity, maturity, natural mortality and mass.

The six year catch series calculated in this study was insufficient for the purposes of tuning the assessment model. Total annual catch and standardised catch-per-unit effort (CPUE) between 1978 to 1997 calculated by Glazer (1999) was therefore considered the most suitable data available (Table 4.1). Glazer (1999) used a GLM to account for interactions between year, fishing depth, latitude, seasonal variation, vessel and bycatch. In these calculations M&CM assume that no *M. capensis* occur at depths greater than 289m, and therefore exclude all records of fishing activity at these depths from their analysis. As a result, this data could be negatively biased. Biomass estimates for *M. capensis* (Table 4.2) calculated from research survey data were obtained from Leslie (1998), and growth parameters for *M. capensis* (Table 4.3) from Punt and Leslie (1991).

Table 4.1 Total annual hake (both species) landings (Geromont 1999) and *Merluccius capensis* catch and CPUE estimations (Glazer 1999). All catches and landings are reported in tons.

Year	Hake	<i>M. capensis</i>		<i>M. capensis</i>			
		catch	CPUE (kg.min ⁻¹)	WC logistic ¹	zone logistic ²	zone linear ³	WC linear ⁴
1978	101 140	6 068	1.83				
1979	92 704	8 343	2.00				
1980	101 538	8 123	1.92				
1981	100 678	9 061	2.19				
1982	85 970	7 737	2.08				
1983	73 677	4 407	2.31				
1984	88 410	7 044	2.32				
1985	99 590	4 921	3.05				
1986	109 091	4 309	2.81				
1987	104 010	4 018	1.65				
1988	90 131	3 398	1.31				
1989	84 896	3 384	1.47				
1990	78 918	2 356	1.84				
1991	85 521	855	2.54				
1992	86 280	1 726	2.98				
1993	98 110	981	1.99				
1994	102 770	911	1.51	7 040	4 956	13 237	14 879
1995	94 716	844	1.04	6 943	4 136	15 309	15 371
1996	91 364	889	1.10	6 854	3 771	16 926	14 785
1997	92 328	808	1.43	6 032	3 763	14.341	13 714
1998	107 248			7 053	4 764	14 411	14 708
1999	100 000			5 592	3 655	12 725	12 107

¹ Catch calculated using logistic depth model for the entire west coast.

² Catch calculated using logistic depth model for the each fishing zone.

³ Catch calculated using linear depth and latitude model for each fishing zone.

⁴ Catch calculated using linear depth and latitude model for the entire west coast.

Table 4.2 *Merluccius capensis* abundance estimates. Figures marked with an asterisk were omitted from the model because the value was unrealistic. Note that the summer survey of 1989 was aborted and thus no abundance estimate is available and winter surveys were discontinued in 1991. Estimates from Leslie (1998).

Year	Summer survey (tons)	Summer SE	Winter survey (tons)	Winter SE
1985	124 852	22 709	181 517	27 479
1986	117 829	23 639	119 609	18 492
1987	75 705	10 242	87 407	11 200
1988	66 737	10 767	47 129	9 569
1989			323 879	67 303
1990	*455 861	135 252	157 826	23 564
1991	77 369	14 996		
1992	95 568	11 752		
1993	108 983	19 048		
1994	120 206	35 834		
1995	198 173	26 815		
1996	83 347	9 288		
1997	257 332	46 062		

Table 4.3 *Merluccius capensis* growth parameters (Punt and Leslie 1991).

Parameter	Value
α	0.0050
β	3.113
L_{inf}	270.6
K	0.039
t_0	-0.730

Species Split

Although M&CM have constructed a species disaggregated operating model, further methods were investigated for comparison. A Syrjala (1996) test was used to assess whether the distributions of each species were random. This test is non-parametric and compares normalised densities of two populations at geographical locations. The significance of the results was determined using a randomisation test that compares n random pair-wise comparisons of the data against that which has been observed. A randomisation test was necessary because of the sample size ($n > 100$ for each year), 20 data points would require $2^{20} = 1\,048\,576$ permutations. If 10% of the randomised test statistics were greater than the point test statistic, then the hypothesis that the two populations are random can only be rejected 90% of the time, i.e. equivalent to a p-value of 0.1.

Research survey catch data (*Rcpue*) was used to map the distribution of *M. capensis* and *M. paradoxus* for each year investigated (1986 to 1999). The separation of the catch data for analysis within each fishing zone was achieved using vector combination processes described earlier. Catch was mapped as point pie-charts depicting the ratio of each hake species at each sampling point. The percentage of *M. capensis* at a particular survey catch point was calculated as the proportion of both hake species present. This value was only calculated for catch points where at least one of the species was sampled.

A logistic model relating the percentage of *M. capensis* to depth was constructed, similar to the method employed by M&CM (Glazer 1999). To account for latitudinal differences in hake abundance found by Millar (2000), a two-parameter linear model was constructed that relates the percentage of *M. capensis* to depth and latitude for the entire West Coast and within each fishing zone. The modified logistic model was of the form:

$$PC = 100 - \frac{100}{1 + e^{\left[-\left(\frac{d - d_{50}}{\delta} \right) \right]}}$$

where d_{50} is depth at 50% abundance and δ is the steepness of the ogive. Whereas the linear model was of the form:

$$PC = \beta_1 * depth + \beta_2 * latitude + \beta_0,$$

where PC is percentage *M. capensis* and β the vector of regression coefficients. The proportion of *M. capensis* caught during the study period were calculated using the estimated regressions where the latitude co-ordinate was at the centre point of the commercial grid block in which fishing occurred. The catch data used in this study does not include catches that were not spatially referenced, and outliers were removed using criteria developed by M&CM before the *M. capensis* total catch for that year was calculated (Table 4.1). The coefficient of determination was calculated as:

$$r^2 = 1 - \frac{\text{residual SS}}{\text{total SS}}.$$

Gear Selectivity

Selectivity patterns of the trawl and longline gears was estimated by comparing observed catches from the commercial fleets with a length-based prediction of catch. Length frequency data were obtained from sea-based observers. The model used (Punt *et. al.* 1996) differs from previously used methods which confound the observed catches with a combination of availability of fish to the fishing gear and the selective properties of the gear. Instead of fitting a selectivity distribution model to observed catches at length, the model used in this study therefore attempts to separate availability from selectivity.

Change in length and number over time were calculated using the following equations:

$$\frac{dL}{dt} = K(L_{\infty} - L) \text{ and } \frac{dN}{dt} = -ZN,$$

with change in numbers over length determined by division as:

$$\frac{dN}{dL} = \frac{-ZN}{K(L_{\infty} - L)},$$

where Z is total mortality ($Z=M+F$), M is natural mortality, F is fishing mortality, L_{∞} the theoretical maximum length, L is length and K Brody's growth coefficient. The number of fish at length is obtained by integration between two length intervals L and L_0 (which is the length of a fish at zero age). The above equation was integrated so that the number of fish surviving between lengths L and L_0 were independent of age-specific natural mortality (M) such that:

$$N(L) = \int_L^{L_0} \frac{dN}{dL} = N(L_0) \left[\frac{L_{\infty} - L}{L_{\infty} - L_0} \right]^{Z/K}.$$

By assuming that catch is proportional to the number of fish available to the fishing gear, the selectivity pattern of the fishing gear and length independent fishing mortality, then predicted catch ($\hat{C}(L)$) is calculated as:

$$\hat{C}(L) = S(L) \times N(L) \times F,$$

where $S(L)$ is selectivity at length L . As it can be reasonably assumed that all but the smaller size classes of fish are susceptible to being harvested, a logistic selectivity function was considered suitable for trawl gear. In contrast, the longline fishery follows a re-parameterised gamma (or normal) distribution because hook size would preclude both the largest and smallest size classes from being harvested (Punt *et. al.* 1996). The temporally invariant logistic used in this study is of the form:

$$S(L) = \left[1 + e^{\left[-\left(\frac{l_1 - l_2}{2} - L_{50} \right) / \delta \right]^{-1}} \right]^{-1},$$

where l_1 and l_2 are the lower and upper bin ranges, L_{50} is the length of a fish at 50% selectivity and δ is the width (steepness) of the ogive. The re-parameterised gamma form used was:

$$S(L) = \left[\frac{(l_1 + l_2)/2}{L_{50}} \right] \bullet e^{-\left[\frac{L_{50} - (l_1 + l_2)/2}{p} \right]} \text{ where } p = 0.5 \left[\sqrt{(L_{50})^2 + 4(\delta^2)} - L_{50} \right].$$

Length was converted to age by: $t = t_0 - \left[\frac{\ln\left(1 - L_t/L_\infty\right)}{K} \right]$.

As it was assumed that $\hat{C}_i = qC_i$, predicted catch was scaled to the magnitude of the observed catch (C_i) using a constant of proportionality calculated as:

$$q = \frac{1}{n} \sum_{i=1}^n \left[\frac{C_i}{\hat{C}_i} \right],$$

where n is the sample number of each year i . K and L_∞ were given in the von Bertalanffy growth equation from which L_0 was calculated. M was fixed at 0.3 year^{-1} . Parameter estimates were obtained from Punt and Leslie (1991) with length of a zero-aged fish calculated as:

$$L_0 = \left[L_\infty 1 - e^{-K(t_0)} \right].$$

As catches were assumed to be Poisson distributed, the likelihood to be maximised was therefore:

$$LL = \prod_{i=1}^n \frac{e^{-\hat{C}_i} \hat{C}_i^{C_i}}{C_i!}.$$

The selectivity model was constructed so as to make the value assigned to $N(L_0)$ arbitrary, while M (natural mortality) was fixed at a value of 0.3 year^{-1} . The negative logarithm of the likelihood function used to estimate F , L_{50} and δ , after dropping the constants was:

$$-\ln LL = \sum_{i=1}^n [C_i - C_i \ln \hat{C}_i].$$

Operating Model

The fixed model parameters required in the ASPM (Table 4.4) were as follows: start-year weight-at-age (w_a), midyear weight-at-age ($w_{a+1/2}$), commercial selectivity-at-age (S^{comm}), survey selectivity-at-age (S^{sur}), age-at-maturity (f_a) and natural mortality-at-age (M_a). Maximum age was defined at seven years ($m=7$) and for the purposes of the model is also considered as a lumped plus-group. Weight-at-age was calculated as $w_a = \alpha [L_\infty (1 - \exp^{-K(a-t_0)})]^\beta$ using the von Bertalanffy growth parameters for *M. capensis* calculated by Punt and Leslie (1991).

Table 4.4 Biological parameters calculated for *Merluccius capensis*. Maturity-at-age and commercial selectivity were calculated in this study. Natural mortality was fixed at 0.3 year^{-1} . Values for survey selectivity were calculated by Geromont and Butterworth (1997).

Parameter	Age							
	0	1	2	3	4	5	6	7
f	0.0190	0.0583	0.1648	0.3861	0.6672	0.8647	0.9532	0.9848
M	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
S^{comm}	0	0	0	0.019	0.445	0.970	0.999	1
S^{sur}	0	0	1	1	1	1	1	1

The number of recruits at the start of each year (R_y) was related deterministically to the spawner stock (B^{sp}) size in the previous year using the Beverton-Holt stock-recruit relationship:

$$R_y = \frac{\alpha B_{y-1}^{sp}}{\beta + B_{y-1}^{sp}}$$

where α and β are the spawner biomass recruit relationship parameters. The stock-recruit relationship was re-parameterised (Francis 1992) in terms of the pre-exploitation equilibrium spawning biomass (K^{sp}):

$$\alpha = \frac{4hR_1}{5h-1} \text{ and } \beta = \frac{K^{sp}(1-h)}{5h-1},$$

where h is the fraction of the recruits at equilibrium when spawner biomass is 20% of unexploited equilibrium. B_{y-1}^{sp} is the spawner biomass at the start of the previous year as,

$$B_{y-1}^{sp} = \sum_{a=0}^m f_a w_a N_{y,a} .$$

Resource dynamics in terms of numbers of fish-at-age, was modeled by the equations:

$$N_{y,0} = R_y$$

$$N_{y,a} = N_{y-1,a-1} e^{-(M_{a-1} + S_{y-1,a-1}^{com} F_{y-1})} \text{ for } 1 \leq a < m-1$$

$$N_{y,m} = N_{y-1,m-1} e^{-(M_{m-1} + S_{y-1,m-1}^{com} F_{y-1})} + N_{y-1,m} e^{-(M_m + S_{y-1,m}^{com} F_{y-1})}$$

where $N_{y,a}$ is the number of fish at age a at the start of year y and F_y is terminal fishing mortality in year y .

Total catch by mass in year y is therefore:

$$\hat{C}_y = \sum_{a=0}^m w_{a+1/2} N_{y,a} \frac{S_{y,a}^{com} F_y}{Z_{y,a}} (1 - e^{-Z_{y,a}}) \text{ where } Z_{y,a} = M_a + S_{y,a}^{com} F_y$$

Fishing mortality in year y was estimated using a bisection routine.

The model estimates of annual exploitable biomass are calculated as:

$$B_y^i = \sum_{a=0}^m w_a S_{y,a}^{sur} N_{y,a} \text{ (begin-year)}$$

$$B_{y+1/2}^i = \sum_{a=0}^m w_{a+1/2} S_{y,a}^{sur} N_{y,a} e^{-Z_{y,a}/2} \text{ (mid-year)}.$$

No deterministic equilibrium was assumed in the model as the catch series available for *M. capensis* began in 1978, after more than 50 years of documented exploitation. Initial “pristine” spawner biomass per recruit R_1 and spawner biomass per recruit for 1977 were calculated as:

$$R_1 = \frac{K}{SBR} \text{ and } R_{1977} = \alpha - \frac{\beta}{SBR},$$

$$\text{where } SBR = \sum_{a=1}^m \tilde{N}_a f_a w_a \text{ and } \tilde{N}_a = \begin{cases} 1 & a = 0 \\ N_{a-1} e^{-Z_a} & 0 > a > m-1. \\ \frac{N_{a-1} e^{-Z_a}}{(1 - e^{-Z_a})} & a = m \end{cases}$$

R_l is calculated assuming no fishing mortality, i.e. $Z_a = M_a$. Fishing mortality (F) was estimated for R_{1977} and the age-structure was assumed to be in deterministic equilibrium. Model parameters h , K^{sp} and F_{1977} were estimated by minimising a negative log-likelihood. The contribution of each abundance index i in year y to the negated log-likelihood was given by:

$$-\ln LL = \sum_i \left[\sum \ln \hat{\sigma}^i + \frac{(\ln I_y^i - \ln(\hat{q}^i B_y^i))^2}{2(\hat{\sigma}^i)^2} \right] = \sum_i n_i \ln \hat{\sigma}^i + \frac{n_i}{2}.$$

The maximum likelihood estimates of $\hat{\sigma}^i$ and \hat{q}^i were calculated as:

$$\hat{\sigma}^i = \sqrt{\frac{1}{n_i} \sum [\ln I_y^i - \ln(q^i B_y^i)]^2} \quad \text{and} \quad \hat{q}^i = \exp \left[\frac{1}{n} \sum_y (\ln I_y^i - \ln B_y^i) \right],$$

where I_y^i is the abundance index for year y and series i , the model estimate of biomass B_y^i and q^i is the constant of proportionality for abundance series i where n_i is the number of points for abundance series i . The standard errors from the research survey estimates were not considered in the analysis as variability ($\hat{\sigma}^i$) was assumed to be comprised of both sampling error and changes in resource abundance.

Results

Selectivity

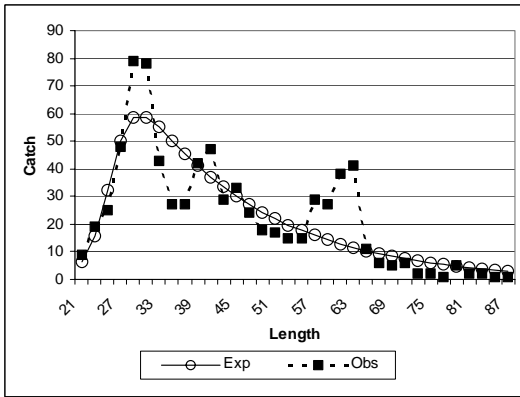
The sample structure of length frequency data collected from the trawl sector is represented in Table 4.5. Observed and expected catches at length are illustrated in Figures 4.1 and 4.2. The results obtained for the trawl fishery appear contradictory (Table 4.6). Not only does F vary between years, lengths at 50% selectivity (L_{50}) are disparate. In contrast to the trawl fishery, the results obtained for the longline fishery are similar between years (Table 4.6).

Table 4.5 Sample structure of *Merluccius capensis* length frequency data collected from the trawl sector.

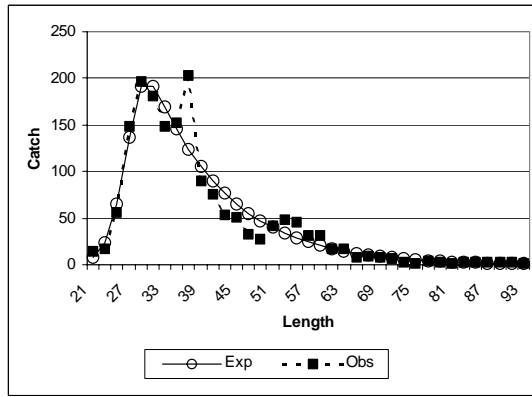
Year	Depth strata				Total no. of fish
	201-300m	301-400m	401-500m	501-600m	
1995	112	277	385		774
1996		728	1013		1 741
1997	357		139	261	757
1998	328				328
1999		728			728

Table 4.6 Results from selectivity model for *Merluccius capensis* in both fishing sectors, fishing mortality (F), length at 50% selectivity (L_{50}), age at 50% selectivity (a_{50}) and δ for length and age.

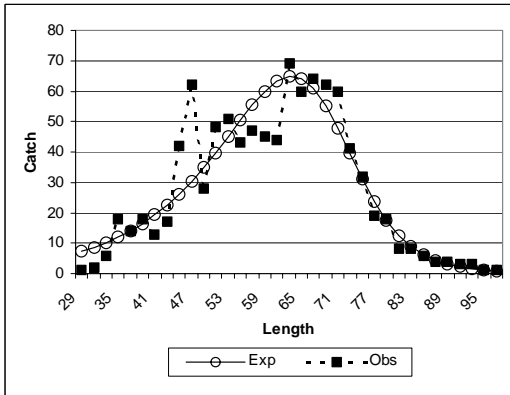
Fishing sector	Year	F	L_{50}	δ_L	a_{50}	δ_a
Trawl	1995	0.001	26.85	1.79	4.13	0.29
	1996	0.169	29.33	1.62	4.56	0.27
	1997	0.299	77.70	7.51	13.06	1.32
	1998	0.001	50.14	1.41	8.11	0.24
	1999	0.282	71.07	3.49	11.82	0.64
Longline	1994	0.001	80.51	22.39	13.79	4.2
	1996	0.002	79.50	11.21	12.91	1.87



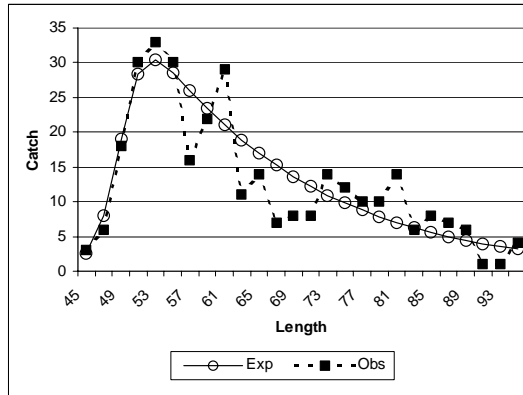
1995



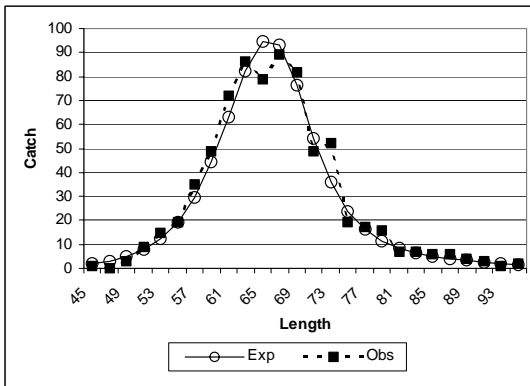
1996



1997

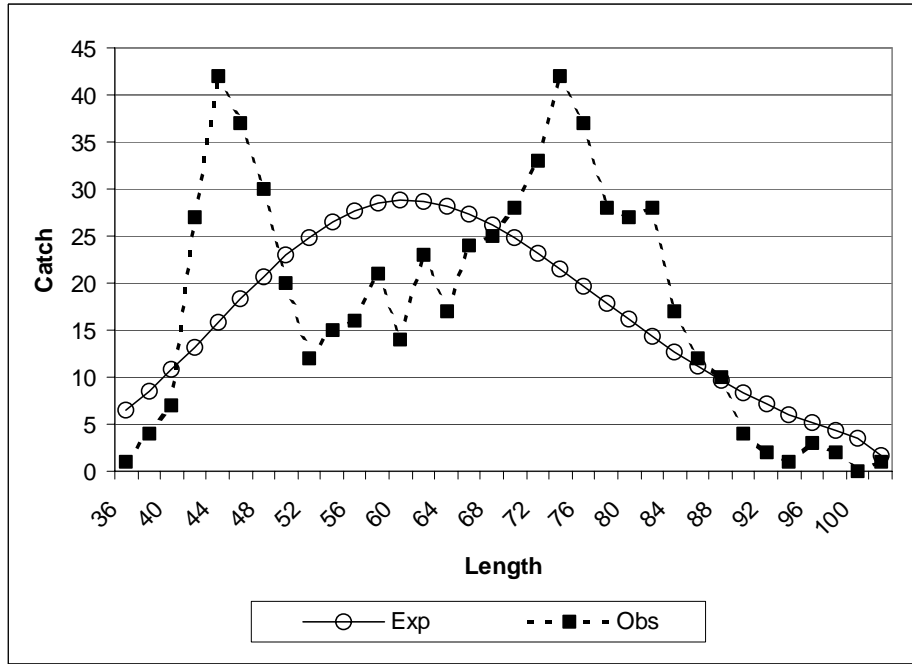


1998

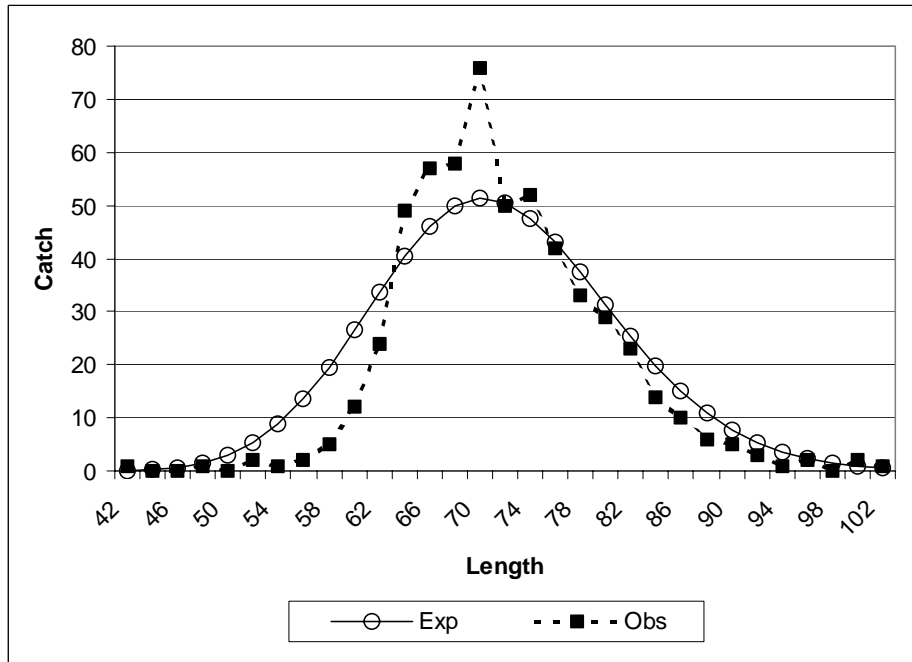


1999

Figure 4.1 Observed and expected catches (number of fish) of *Merluccius capensis* from commercial trawl samples.



1994



1996

Figure 4.2 Observed and expected catches (number of fish) of *Merluccius capensis* from longline samples.

Selectivity-at-age, for use in the ASPM, was constructed from the 1996 sea-based trawl data set. The 1996 data set was selected as it was the largest sample and the depths sampled were reflective of overall fishing trends discussed in Chapter 3.

Length frequency data collected on research surveys indicate that the average size of *M. capensis* found between 201 and 300m is 40cm, increasing to 51cm between 301 and 400m. Similar results are observed in Figure 4.1. Unfortunately, research trawls have not extended much beyond 500m (Table 4.7), in the last 14 years almost 90% of the trawls have been in water shallower than 401m.

Table 4.7 *Merluccius capensis* length frequencies measured during nine research surveys conducted over six years (1986, 1988, 1990, 1992, 1994 and 1999). No fish were measured at depths greater than 500m although trawls were completed.

Depth	100m	200m	300m	400m	500m	600m	700m	800m	900m	999m
10cm	43 430	634	10	0	0					
20cm	64 726	70 775	796	0	0					
30cm	136 547	118 597	7 380	1	0					
40cm	3 631	29 929	11 239	119	0					
50cm	121	5 361	8 741	869	0					
60cm	28	1 554	5 100	1 568	20					
70cm	7	476	2 256	932	24					
80cm	2	156	670	147	18					
90cm	2	24	138	48	5					
100cm	0	5	20	6	0					
110cm	0	0	2	1	0					
Trawls	153	760	571	231	179	4	0	12	7	6
	(8%)	(39.5%)	(29.7%)	(12%)	(9.3%)	(0.2%)	(0%)	(0.6%)	(0.4%)	(0.3%)

Species Split

The depth-dependent distribution of hake is clearly evident in Figure 4.3, with *M. capensis* and *M. paradoxus* non-randomly distributed across the West Coast (Table 4.8).

Table 4.8 Results of the Syrjala (1996) test for *Merluccius capensis* and *M. paradoxus* research CPUE (3000 random pair-wise permutations). Minimum possible p-value was 0.0003.

Year	<i>M. capensis</i>		<i>M. paradoxus</i>	
	xi	p-value	xi	p-value
1986	1.792	0.0003	2.842	0.0003
1987	1.609	0.0003	2.603	0.0003
1988	1.289	0.0017	1.809	0.0023
1989	0.990	0.0067	4.982	0.0003
1990	1.618	0.0550	4.445	0.0003
1991	1.504	0.0003	1.879	0.0010
1992	0.849	0.0040	0.726	0.1127
1993	0.363	0.1380	0.767	0.0693
1994	0.457	0.0030	0.833	0.0440
1995	0.811	0.0137	2.438	0.0003
1996	0.628	0.0003	2.947	0.0003
1997	1.465	0.0027	1.791	0.0007
1999	0.779	0.0003	1.256	0.0067

Commercial catches are reported by statistical 20' x 20' grid block. For the analysis, the latitudinal coordinate corresponding to the mid-point of the grid block was applied to all catches from that block.

Although this is not entirely accurate, the estimation faces a maximum error of only 10' for each trawl completed in the grid block where the gear was shot.

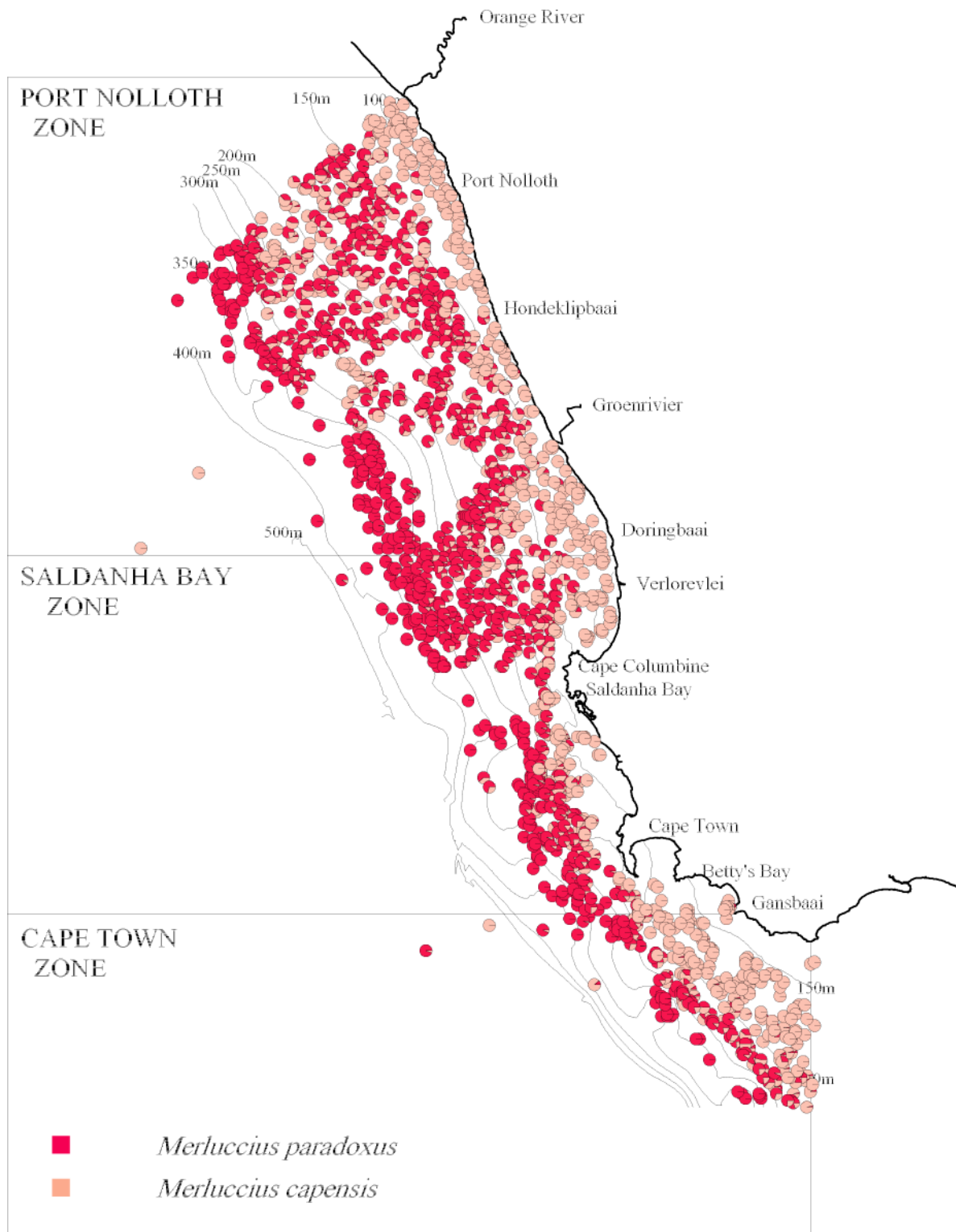


Figure 4.3 Relative proportion of *Merluccius capensis* and *M. paradoxus* caught in research surveys from 1986 to 1999.

The logistic model relating the percentage of *M. capensis* to depth provided a superior fit (Table 4.9) when compared to the linear model which incorporated both depth and latitude (Table 4.10). However, the specific models for each of the fishing zones provided a better fit than the models for the West Coast (Table 4.9 and 4.10). In contradiction to research trawl survey results (Table 4.11), catches predicted in this study were considerably higher than those calculated by M&CM. This is attributed, in part, to the assumption M&CM make regarding the absence of *M. capensis* deeper than 289m. The logistic models predict a minimum of 4% *M. capensis* at 289m (Table 4.9).

Table 4.9 Results of the logistic regression model relating the percentage of *M. capensis* to depth and latitude within each fishing zone and for the entire West Coast.

Coefficients	Cape Town	Saldanha Bay	Port Nolloth	West Coast
R ²	0.780	0.600	0.505	0.534
d ₅₀	220.088	201.115	192.121	209.331
σ	21.116	49.208	59.579	55.807
PC at 289m	3.7%	14.4%	16.4%	20.0%

Table 4.10 Results of the linear regression model relating the percentage of *M. capensis* to depth and latitude within each fishing zone and for the entire West Coast.

Coefficients	Cape Town	Saldanha Bay	Port Nolloth	West Coast
R ²	0.492	0.436	0.449	0.434
β ₀	5.678	117.495	70.725	80.445
β ₁	-0.196	-0.205	-0.236	-0.215
β ₂	3.019	-0.852	0.964	0.577
ANOVA				
Pr (depth)	0.000	0.000	0.000	0.000
Pr (latitude)	0.468	0.607	0.401	0.064
n	278	552	886	1919

Table 4.11 *Merluccius capensis* data collected on trawler vessels by M&CM staff from 1994 to 1999, number of fish measured and the depths at which catches were recorded.

Year	n	Depths (m)
1994	0	310, 340, 346, 415, 410, 330, 380, 353
1995	774	350, 345, 349, 417, 302, 420, 320, 370, 370, 240
1996	1 714	300, 310, 320
1997	962	130, 420, 440, 250, 265, 270, 370, 280, 350
1998	328	391, 300, 310, 350, 360, 400, 270, 420, 275, 380, 370, 430, 475
1999	728	330, 340, 355, 320, 342, 315, 266, 350, 264, 220, 400, 360, 345, 380

Assessment

Results from the ASPM did not adequately describe the dynamics of the *M. capensis* stock sufficiently (Figures 4.4 & 4.6 and Table 4.12). As a consequence no management quantities or variances were calculated.

Table 4.12 Results of *Merluccius capensis* age-structured production model.

Parameter	Value	Parameter	Value
K^{sp}	247	-ln(Summer)	-1.613
h	0.323	-ln(Winter)	1.508
F	0.188	-ln(LL)	-0.105
R_1	0.119		
α	0.249		
β	272.051		

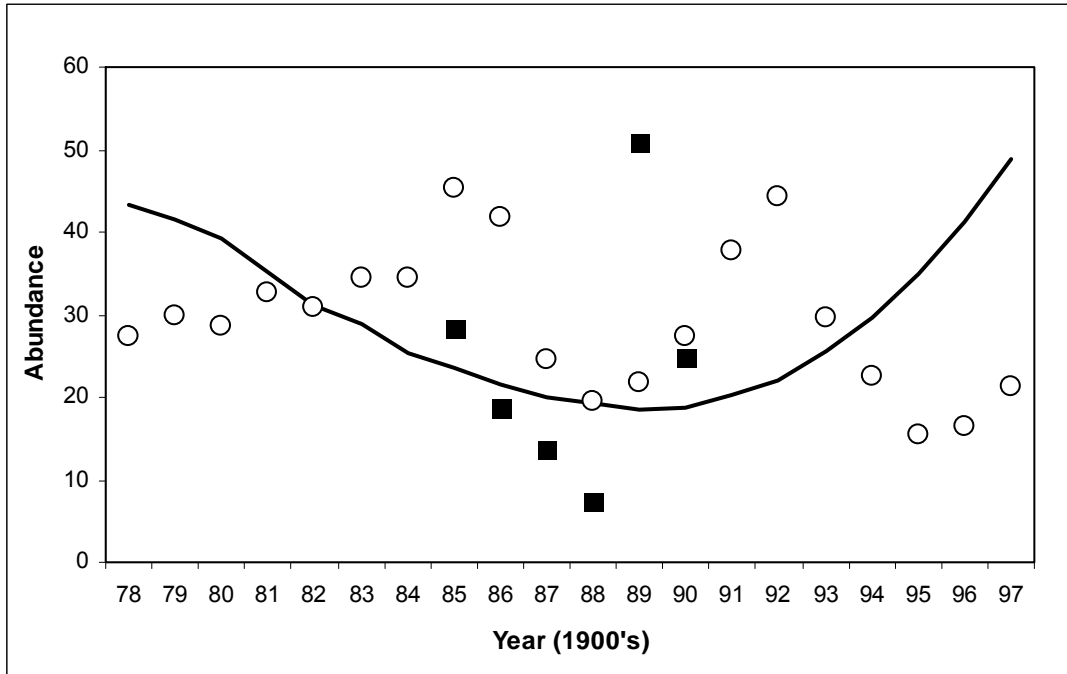


Figure 4.4 Estimated *Merluccius capensis* annual CPUE (○) (Glazer 1999), midyear biomass estimate from ASPM (○) and abundance estimates the winter surveys (■) (Leslie 1998).

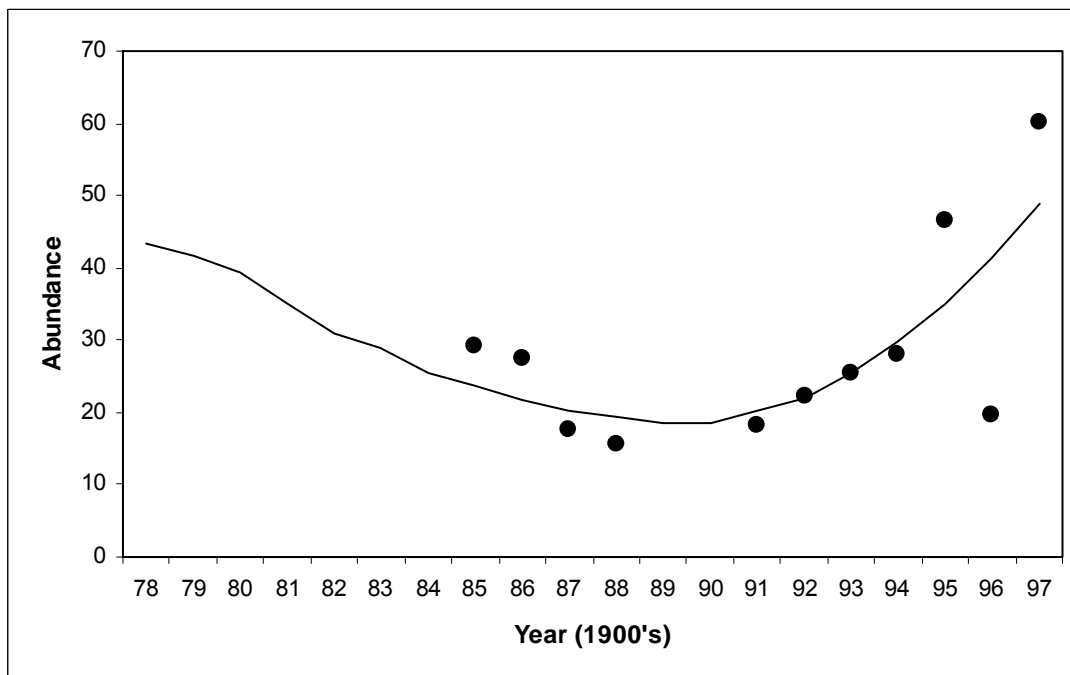


Figure 4.5 Midyear biomass estimate from ASPM (○) and abundance estimates for summer (●) surveys (Leslie 1998).

Discussion

South Africa has two sympatric species of hake and, until recently, the majority of its fishing effort was trawl-dominated, catching predominantly *M. paradoxus*. As such, it was possible to assess and manage the two species as a single stock. A diversification in fishing pressure will undoubtedly have an effect on the two species.

The implications of trawl and longline selectivity patterns were briefly investigated. The selectivity method used a standard per-recruit type approach to estimate the size structure of the population. The efficacy of this model is debated as the assumption of a randomly distributed population precludes accounting for the depth-dependent distribution of the stock with all size-classes not being equally available to the fishing gear. Essentially, the estimated selectivity of *M. capensis* could be a combination of size-specific gear selectivity and size-specific availability (Leslie *pers. comm.* 2001). However, the model is well-understood and was used for preliminary investigations.

The quality of sea-based commercial trawl length frequency data is debatable, only a few months are sampled each year and only one vessel per month. Should the vessel find a large aggregation of fish it will fish a small area for the duration of the voyage. Moreover, M&CM has little control as to which vessel is sampled and no control over its destination. If the vessel fishes with the fleet it is representative of the catch for its company for that month, but often vessels are sent out to look for specific products (Leslie *pers. comm.* 2001). Furthermore, space is at a premium when working on a freezer vessel, and as such the sampler must select fish off the conveyer belt and sort the fish in a separate work area. Each trawl hauls 8 to 10 tons of fish, so it is difficult to identify *M. capensis*, particularly the smaller specimens (Leslie *pers. comm.* 2001). The accuracy of the sample is also dependent on the speed and experience of the sampler.

The only other source of species separated length frequency data is from the *RV Africana*. The annual West Coast Demersal Survey occurs over a four week period in January/February. Although far more fish are measured over a far wider area, the fishing technique is vastly different to commercial trawls. The *Africana* trawls for a maximum of 30 minutes while the average commercial trawl duration is between 90 and 120 minutes. Moreover, the *RV Africana* lines the cod-end with 27.5mm pilchard mesh and the side panels are 38mm, the commercial vessels on the whole use 110mm mesh net and often fly the net when fishing harder ground. Consequently, it seems inappropriate to disregard the potential application of sea-based commercial data on sampling bias alone.

As it is not feasible to identify processed fish to species, it is necessary to collect more length frequency data at sea for the trawl sector in order to construct more accurate species-specific selectivity models. Although it is possible to identify landed longline hake, there was also a paucity of species specific data. During the entire period of the longline fishing experiment 58% of the length frequencies collected were of “unidentified hake”, although the proportion of identified hake increased throughout the experiment. Only 17% of the length frequencies collected from longline catches were *M. capensis*.

Despite sub-optimal sample sizes and potential sampling bias, the results provide useful information on the selective properties of the gear. With the exception of 1998 more than 700 fish were sampled in the trawl fishery in each year. All fish sampled in 1999 were, unfortunately, from the same grid block. Given that there is little difference in sample size and number of grid blocks sampled between 1995 and 1997, the difference in their L_{50} values could be attributed to the depth at which the samples were taken. In 1995 and 1996 all *M. capensis* were sampled in water 500m and shallower, whereas in 1997, 34% of the sample was deeper than 500m. It is implied that the impact of trawl catches on the *M. capensis* stock is depth dependent. The deeper fishing occurs, the higher L_{50} will become - for both sectors.

Japp *et al.* (1995) observed an increase in mean fish size with depth, and furthermore that males are dominant in shallow-water while females dominate the deeper waters. Longline *M. capensis* catch on the South Coast was skewed toward large fish (55-89cm) during the pilot study (Japp *et al.* 1995), but these results were attributed to the size selective nature of the gear (Japp and Wissema 1999). Between 1993 and 1997 Japp and Wissema (1999) found no significant changes in the size distribution of fish caught. Size/age at first capture was determined to be 41 cm (4+ years), and the proportion of females in the catch increased with fish size with little differences between the catches on either coast. Fisheries independent data confirms that the size of *M. capensis* increases with depth, the average size greater than 51cm in water 301 to 400m deep.

If this trend holds to further scrutiny there are several implications. Japp *et al.* (1995) concluded during the Longline Fishing Experiment that “all *M. capensis* fish greater than 100cm are expected to be females, compared to 83% for *M. paradoxus*”. They further suggested that the difference in mean length between the sexes reflects variations in stock structure and the possibility that each species is differentially available to the longline fishery. The *M. capensis* parental stock could face unprecedented fishing pressure as a result of trawlers fishing at depths that target larger fish (adults) and a potential increase the proportion of the TAC allocated to the longline sector, which also targets large fish.

The importance of depth in interpreting catch and effort data to gain an understanding of *M. capensis* population structure cannot be underrated. The proportion of hake catch which is *M. capensis* was therefore determined with reference to depth. Although the final results of fishing zone specific calculations were not vastly different to those for the entire West Coast, they provided a superior fit to the data. The large discrepancy between the results of the logistic model and the linear models warrants investigation. Differential latitudinal abundance of hake along the West Coast has been documented (Millar 2000), which suggests that *M. capensis* catch in previous years is likely to be different to that indicated by models based exclusively on depth. Regression estimates constructed at a finer spatial scale than three fishing zones may

provide a better fit than the current depth logistic employed, however the increase in precision must be balanced by an awareness of the potential increase in bias.

The annual catch figures calculated by M&CM for *M. capensis* were significantly different to those calculated in this study. The large difference can be attributed to two factors: the minimal depth range at which M&CM consider *M. capensis* to be found i.e. no deeper than 289m (Glazer 1999), and the assumption that *M. capensis* is uniformly distributed. The assumption of a cut-off depth is flawed as M&CM oceanographic research assistants (ORA's) have recorded several catches of *M. capensis* by trawler vessels in water deeper than 289m (Table 4.6). Although the data collected on commercial vessels is subject to sampling error it is doubtful that the ORA's collecting the data would grossly misidentify which species they were measuring. Over 1700 *M. capensis* were measured in 1996 alone.

Regardless of the various problems associated with the M&CM *M. capensis* specific model parameter estimates, a time series of six years was deemed insufficient to construct an age-structured production model. A 20 year time series proved to be of sub-optimal length and the CPUE series did not correlate with the total annual catches. The annual catch of *M. capensis* has decreased since 1978 with a small recovery in 1984; however, CPUE has oscillated over the years with no distinct pattern. Furthermore, the current assessment procedure does not incorporate the effect of longline selectivity on the *M. capensis* stock off the West Coast.

Considering that M&CM have precluded catches of *M. capensis* deeper than 289m, it seemed appropriate to compare the trend in their commercial CPUE with the abundance estimate for the 0 to 200m depth zone (Figure 4.4). These abundances were calculated from Leslie (1998). The abundance calculated for 1990 appeared unrealistic as 62% of the total hake biomass was reported as *M. capensis*. An interesting pattern was observed in that an increase in *M. capensis* abundance for both the summer and winter surveys predated an increase in commercial CPUE. This could be interpreted as an fluctuation in recruitment, possibly correlated

to environmental variables. Pennington and Strømme (1998) present a similar situation for the case of the Newfoundland northern cod resource in which more weight was given to the commercial CPUE. A consistent over-estimation of the stock resulted in the collapse and closure of the fishery.

It was not possible to model the dynamics of the *M. capensis* stock or sufficiently explain the effect of the two fisheries on the stock. This was possibly due to the small trawl catches calculated by M&CM which are insufficiently large to provide a model with sufficient signal for tuning purposes. It is necessary to incorporate finer spatial detail in the collation of catch data and collection of sampling data. The calculation of an accurate *M. capensis* CPUE time series is crucial. Improved understanding of the implications of a change in fishing strategy will only be possible when fisheries independent sampling takes place across the areas fished by all sectors. Research surveys should extend hake-directed trawls beyond the 500m depth range and the number of commercial vessels sampled by M&CM staff needs to be increased.

What is the status of *M. capensis* on the West Coast? Survey abundance estimates indicate that *M. capensis* biomass has fluctuated in the last twelve years. The annual catch presented by Glazer (1999) suggests that the stock is either being depleted or is not being targeted by the fishing industry. Alternatively, the stock is being depleted to the point that effort shifts or the population dynamics alter and *M. paradoxus* is caught. Trawl catch calculated on a spatial basis indicates a consistent *M. capensis* catch by the dominant trawl sector. Catches taken by the longline sector have varied, however this can largely be attributed to the disruptions between the different phases of the longline fishing experiment. However, the 1999 *M. capensis* catch was the highest yet and the development of the sector warrants careful attention.

It would be unadvisable to assume that the stock is stable or recovering. In light of increased fishing effort and shift in selectivity due to the entrance of the longline sector it is vital to determine how best to assess and manage the resource. In particular, the implications of a size/sex relationship must be investigated and

properly appraised. This investigation has shown that it is inadvisable to rely exclusively on stock assessment models as empirical observations can be invaluable in tracking the status of a stock. Several of the parameters used in the current assessment procedure were settled by discussion and “understanding” of the resource. A pertinent example is the assumption that no *M. capensis* are caught deeper than 289m by commercial vessels.

Although this study did not succeed in developing a model to adequately describe the West Coast *M. capensis* stock, it has shown that it is beneficial to assess a stock within a spatial context. The simple GIS used in this study revealed shifts in effort, facilitated the calculation of spatially precise catch prediction and highlighted the inadequacy of current sampling coverage. There is a need to incorporate spatial analysis into stock assessment procedures. Models including spatio-temporal variation would be highly complex and, as such, error prone. Model predictions can be compared to a spatial visualisation of what actually occurred e.g. parental stock (i.e. large fish) distribution and the distribution and associated effort of each vessel. This would facilitate model refinement and verification on an annual basis.

CHAPTER 5

GENERAL DISCUSSION

Capture fisheries provide ~90 million tons of fish annually, directly and indirectly affecting the livelihood of ~200 million people. Overcapacity and overexploitation are a problem worldwide, few species are underutilised and it is recognised that 70% of commercially fished stocks require drastic management intervention (Garcia and Grainger 1997). Fisheries management that has been founded solely on resource status has proved to be inefficient. Socio-economic realities, ignored in the past, are now considered important and therefore have to be incorporated into decisions regarding resource usage, catch allocation and user group participation (Garcia and Grainger 1997). The understanding of resource dynamics will always be fraught with uncertainty due to process and measurement error. Process error includes inherent variability in environmental conditions and life history responses to these conditions, while measurement error is the inability to accurately quantify catch, fishing effort and life-history parameters. Social dependency on fisheries resources further complicates issues placing management decisions in the political domain, particularly with regard to user rights and quota allocation.

Management procedures (MPs) are currently considered a suitable compromise, as they incorporate scientific, fisher and managerial perspectives. An MP is based on a set of decision rules which, in theory, should reduce political intervention from the management of a resource. Active inclusion of the fishing communities allows the resource users a sense of ownership, thereby fostering responsibility in resource utilisation, improving compliance and most importantly increasing trust between scientists and fishers (FAO 1995b).

Information regarding catch, effort, biological parameters and fishing areas is vital to making successful management decisions. Fisheries are complex and intricate, and at times appear impossible to control or monitor. Management decisions are principally based on scientific recommendations as the status of a

resource is considered to be of primary importance. Resource status and productivity are assessed by developing quantitative models that incorporate abundance trends from fisheries dependent and independent data, the suitability of the species' life-history for harvesting, and the effect of technological advances in the fishing gear used. Continued and improved collection of such data is, therefore, critical to improved scientific understanding and management efficiency.

It can be argued that the South African hake stock is one of the most reliably productive and well-managed demersal resources in the world (Butterworth and Punt 1999). Catches have increased steadily since 1978 and a stable trawl industry has developed along with the resource. The introduction of a longline hake fishery in 1998 has diversified fishing pressure and, renewed international interest in South African hake may jeopardise the fragile status of the Cape hake resource. An understanding of fishing patterns and new harvesting methods would contribute to improving management recommendations.

Overview of Findings

This thesis has investigated certain aspects relating to the fishing patterns of the hake-directed fleet together with the distribution and abundance of the hake resource using a Geographical Information System (GIS).

It is clear that new insight was gained into this fishery using a GIS (Chapter 2) as a tool (Wright *et. al.* 1997), which was employed throughout the thesis. Certain key aspects should be noted for the GIS to be maintained and possibly extended. The time and planning involved in developing any spatial database cannot be overestimated. It is therefore necessary to carefully plan the exact structure of a spatial database, how data sets are related, field names of the data that will be used, the fields that need to be calculated, data verification and validation are vital. The usefulness of this tool is illustrated in assessment of fishing activity off Port Nolloth.

It has been shown that many factors may affect where a vessel fishes (Chapter 3). Although both the trawl and longline sector fish in water between 300 and 500m, there are separate trends within each sector. Trawlers fish predominantly in deeper water (>400m), skirting the edges of untrawlable grounds to achieve high CPUE returns. Longliners, on the other hand, fish shallower water (300-350m) and there is a strong relationship between surficial sand sediment and longlining activity. These separate trends are attributed, in part, to friction of distance issues: safety and economic viability, both trawlers and longliners must consider the distance travelled from port. A third of the longlining effort was on untrawlable grounds, thus the remaining two-thirds occurs on trawl grounds. This has two significant implications: it creates a large potential for conflict between the sectors and places the hake stock under increased pressure because untrawlable areas may have served as refugia.

The diversification of hake-directed fishing has implications in terms of which portions of the hake population will be targeted. Chapter 4 included an investigation into the selectivity patterns of the two sectors. Results confirm that the size of *M. capensis* caught was not only determined by the gear but also the depth at which fishing occurred. Length at 50% selectivity increases with depth with longliners catching larger fish than trawlers, despite trawlers fishing in deeper waters. Although *M. capensis* are generally not found in waters deeper than 450m, longliners extended their fishing range to deeper waters. Reports that longliners are moving into trawl grounds and lower catches of *M. capensis* on the South Coast (Ball *pers. comm.* 2001) suggest that it is vital to include the selectivity effects of both sectors in an assessment of the West Coast *M. capensis* resource.

The age-structured production model (ASPM) assessment of the *M. capensis* West Coast stock required species-specific catch and effort data that was constructed from combined species catch data. *M. capensis* aggregations vary temporally but they may also be subject to temperature, seasonal fluctuations and any number of other oceanographic factors. Two models were used to estimate the proportion of *M. capensis*

(Chapter 4) using depth and latitude. Both models displayed a strong fit to the data but the resultant annual *M. capensis* catches were varied between the models. Although variation in *M. capensis* abundance is not only subject to depth and latitudinal variation, these estimates have been shown to be reliable indicators.

The ASPM was not successful in reliably portraying the status of the *M. capensis* West Coast stock, and this was attributed to data insufficiency. It is doubtful that commercial catches of hake will ever be reported on a species specific basis. A method of determining the proportion of *M. capensis* caught by the commercial vessels must be refined, in order to use the historical catch data. It would be ideal to use all possible historical data to produce as robust an assessment for *M. capensis* as possible. It appears that the ASPM developed for *M. capensis* would be viable if a longer catch series was available, facilitating the estimation of several fixed parameters.

A comparison of trawling intensity and relative abundance of the two hake species shows the fishing grounds north of Groen Rivier mouth were subjected to minimal fishing effort despite the presence of both species (Figure 5.1) and suitable trawl grounds (Figure 5.2). Length frequency data collected during research surveys indicates that these waters were dominated by *M. capensis* of harvestable size: fish between 20 and 40cm total length (Figure 5.3), with a smaller proportion of 50-60cm fish. The implication of this scenario is that viable fishing operations could be based in Port Nolloth, an area where there is considerable “community” interest and impetus to join the hake-fishing industry (Japp *et. al.* 1995). The success had by the longline fishing vessel *Oosterdam* on the northern section of West Coast, landing her catch in Port Nolloth was documented by Japp *et. al.* (1995) but this *M. capensis* dominated fishery is potentially subject to the horizontal and vertical movement of hake in the waters bordering Namibia. The status of the *M. capensis* resource requires additional research before effort is further shifted toward single species fisheries.

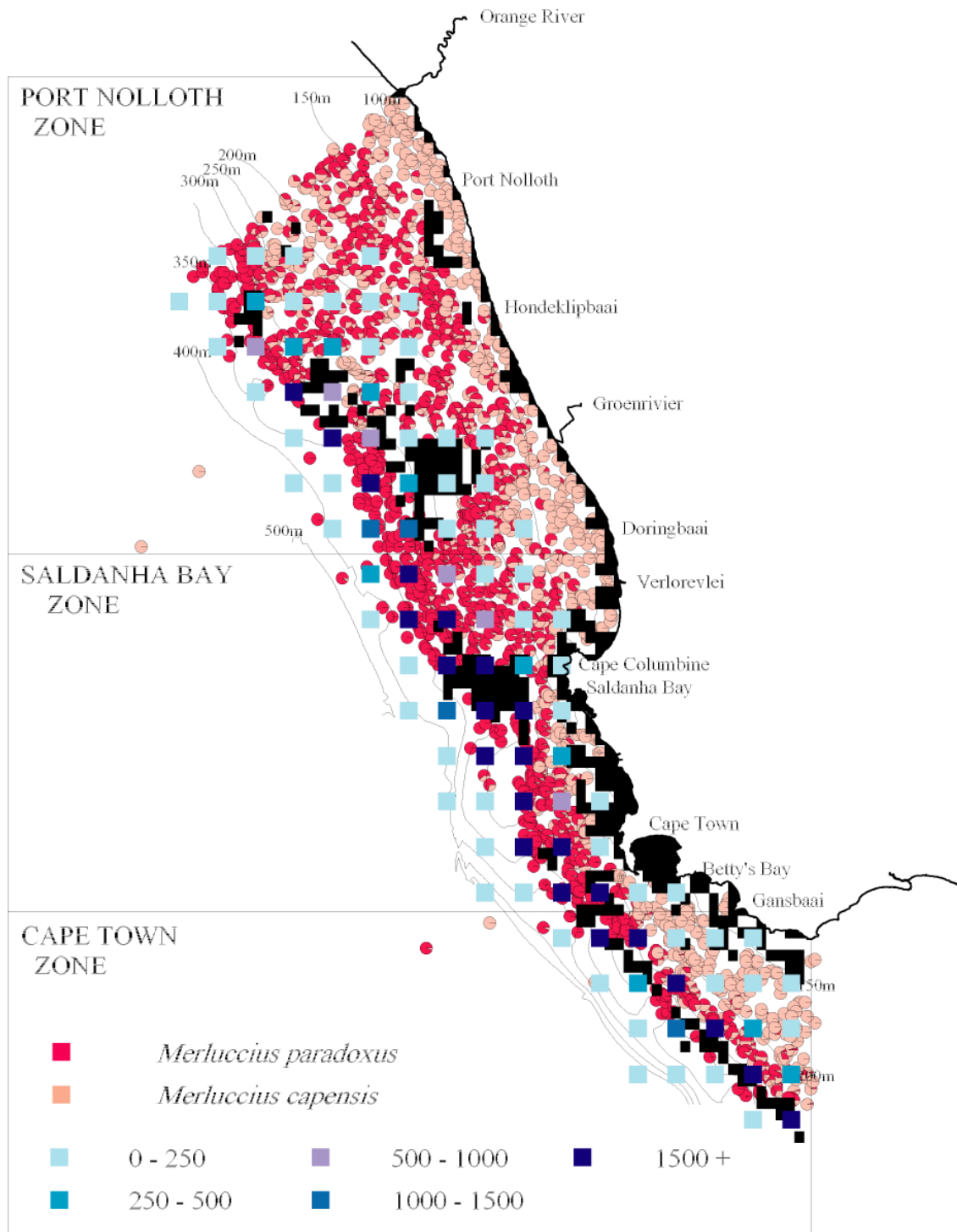


Figure 5.1 Total number of commercial trawls completed in each grid block for all years (1994 to 1999), compared to the distribution of *Merluccius capensis* and *M. paradoxus* (1986 to 1999), untrawlable areas are depicted in black.

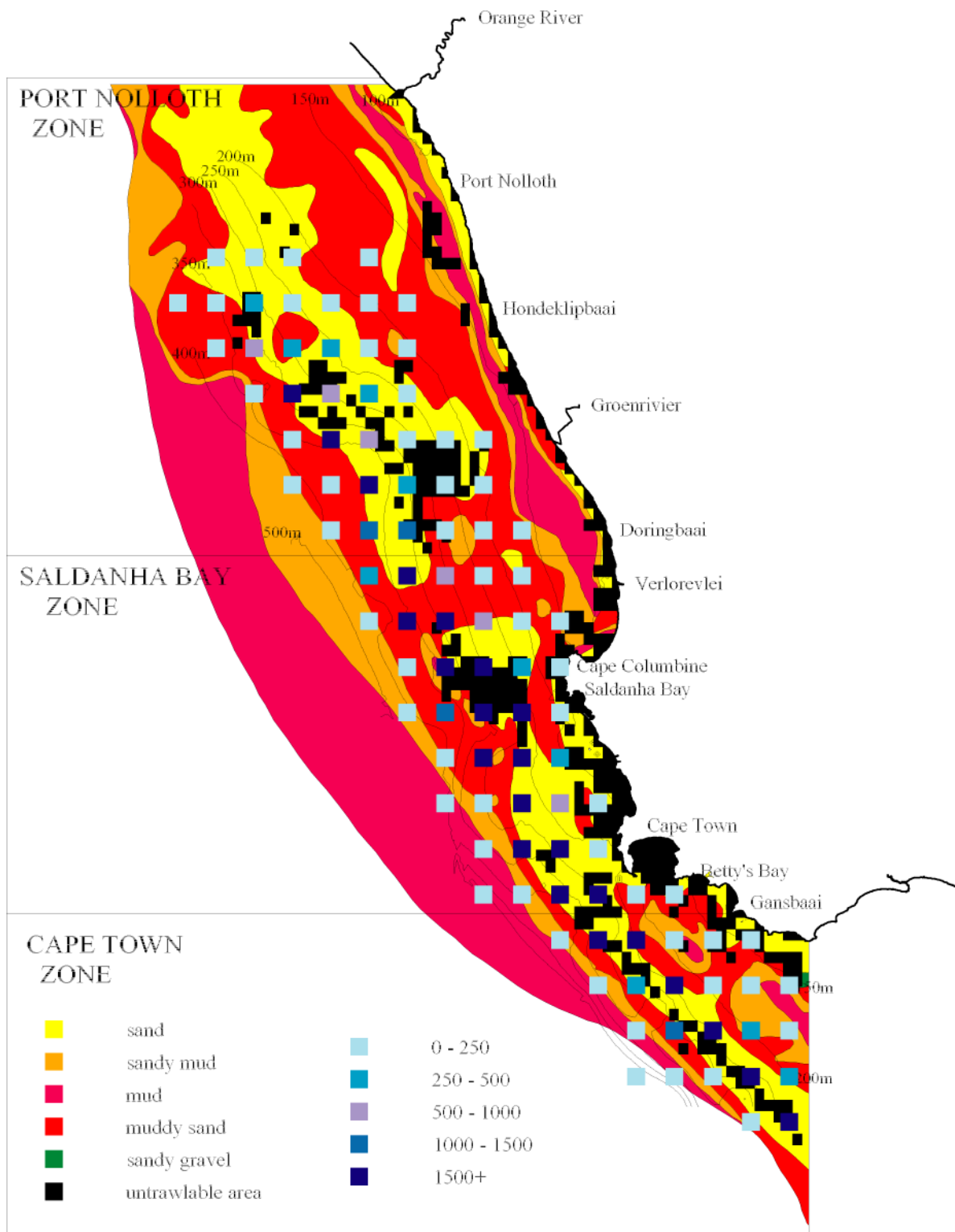


Figure 5.2 Total number of commercial trawls completed in each grid block for all years (1994-1999), compared to the distribution of surficial sediments and untrawlable grounds.

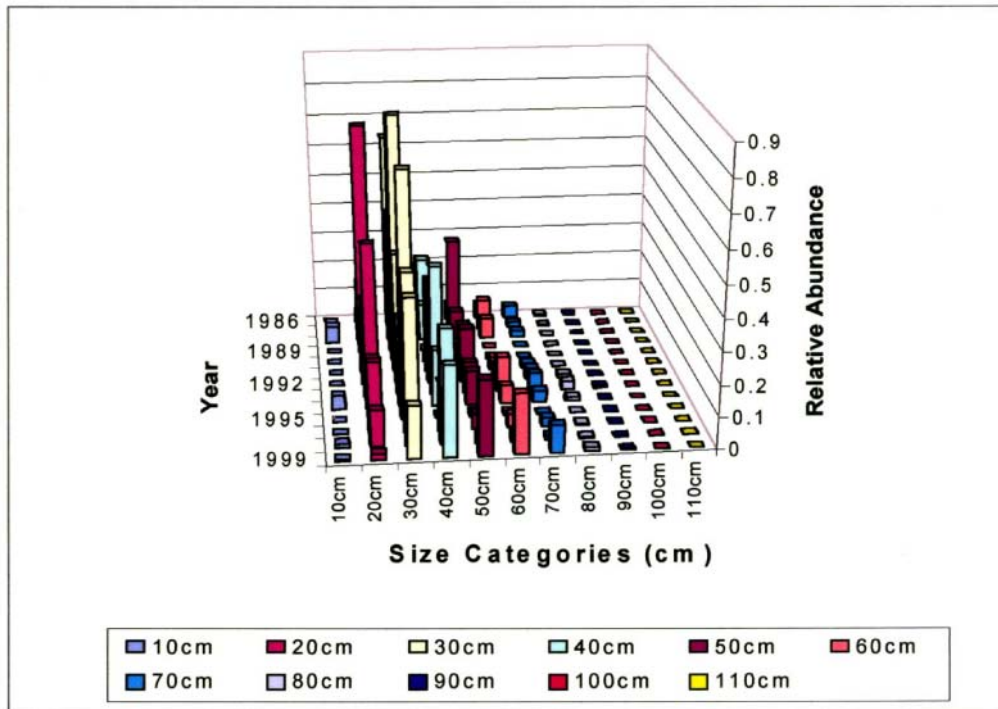


Figure 5.3 Relative abundance of *Merluccius capensis* size categories measured during research trawls (1986 to 1999) north of the Groen Rivier mouth

Management Considerations

Devising a management procedure for two species which are morphologically indistinct and whose distributions overlap is difficult and species-specific TACs are unrealistic until there is a better understanding of how much *M. capensis* is caught. Although the longline fishery lands catches an order of magnitude smaller than the trawlers, longline gear selectivity produces catches of larger fish and by deduction older fish. Changes in the population structure would be most obvious in these upper age groups, the spawner biomass, of *M. capensis*.

Although there is plenty of opportunity to land a catch, it is the speed with which it is packed and shipped to an airport for export that determines its value. Thus, a successful small hake-directed longline operation would be constrained by its proximity to an airport. The key in using the longline sector to monitor the health

of the *M. capensis* resource is to make it beneficial to report species-specific landings. Namibia utilise a rebate on levies to encourage hake to be landed and processed in Namibia (Oelofsen 1999). Such an incentive scheme could be introduced to ensure longline vessels land their catch at points where sampling takes place, providing an opportunity to vest responsibility in those who have fishing rights (Mace 1997). Implementation may prove painful at first but would provide crucial information for separate species assessment and viable management (Hemming and Pierce 1997).

The data that is currently used to monitor the status of *M. capensis* is insufficient. Commercial trawlers extend their greatest effort in waters deeper than 400m. Research surveys have not sampled adequately to predict the size range of *M. capensis* in these waters and the observer data collection procedures of the oceanographic research assistants (ORAs) of Marine and Coastal Management (M&CM) need revision. These opportunities could be better utilised by ensuring that a greater variety of boats are sampled within a year and that all possible *M. capensis* measurements are taken.

Conclusion

In South Africa, the restructuring process that addresses previously disadvantaged fishing communities, mirrors the overcapacity problem facing the rest of the world (Mace 1997). Existing vessels, facing reduced TACs are placed in a precarious economic situation. Hutton *et. al.* (1997) discuss why South Africa's living marine resources are a highly sensitive issue with political ramifications. This "complicated and emotional process" is now being addressed in a transparent manner by the Department of Environmental Affairs Rights Allocation Unit (RAU 2000). No definite conclusions regarding the status of *M. capensis* can be reached, but it is almost certain that the stock will face increased pressure in the future.

Continued research surveys are essential (Geromont *et. al.* 1999) to detect the impact of changes in selectivity and increased fishing efficiency. Without an independent estimate of abundance an upward bias in CPUE

might not be detected. Pennington and Strømme (1998) present an apt analogy of the importance of survey data to stock assessment procedures, equating the exclusive use of catch data to using the quantity of lumber produced from a forest - “production may stay high until the last tree is gone”. Although it is unlikely that a fishery would succeed in removing every single fish, the numbers available to the gear will become so low that fishing would no longer be economically viable.

The relationship between depth and species size has been noted in past studies and latitudinal effects have recently been identified (Millar 2000). These observations could be used to construct species-split models at a finer spatial resolution, and the resulting models tested to determine accuracy. In addition, the characteristics of the pre-1978 fishery must be incorporated into calculations of historical *M. capensis* catch, i.e. gear changes and accounting for the shallower depths fished in the early part of the century. The early trawl and line fisheries that existed at the turn of the century would have caught predominantly *M. capensis*. Furthermore, the effect of the new longline fishery must be incorporated and the implications of a size-sex relationship must be investigated to accurately assess the effect of changes in selectivity on the parental stock.

As noted in this thesis, it is the interaction of several factors and in some situations the interaction itself that needs to be understood when assessing the status of a resource. These interactions are perhaps best investigated within an integrated information system, such as GIS, where graphical explanations of complex issues are easily understood. This accessibility suggests there is a need to incorporate GIS into stock assessment procedures, using the tool for scientific purposes. In addition, GIS can benefit managers, allowing the prediction of conflict, effort distribution and contextualising socio-economic realities. It is these realities that concern fishing communities and industry most, and only once recognised, the maintenance of the resource will come a close second.

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APPENDIX A: Catch information reported by trawl vessels.

<u>TRfinal</u>	East Coast Sole (kg)
Company code	West Coast Sole (kg)
Vessel code	Snoek (kg)
Power factor (calculated by M&CM - particular to each vessel)	Mackerel (kg)
Year of landing	White Squid (kg)
Month of landing	Red Squid (kg)
Day of landing	Large Hake (kg)
Year of trawl	Medium Hake (kg)
Month of trawl	Small Hake (kg)
Day of trawl	Hake fillets (kg)
Start time (of trawl)	Ribbonfish (kg)
Effort (minutes)	
ICSEAF code (division in which fishing occurred)	
Commercial Grid Number	
Fishing depth (m)	
Mesh size (mm)	
Alpha code (target species: H=hake)	
Total Hake catch (kg)	
Total specified species (kg)	
Total others (kg)	
Latitude (co-ordinates of upper left corner of grid block in which fishing occurred)	
Longitude (co-ordinates of upper left corner of grid block in which fishing occurred)	
Horse Mackerel (kg)	
Monk (kg)	
Kingklip (kg)	

APPENDIX B: Database flowchart - data table descriptions for Figures 2.3, 2.4 and 2.5.

TRAWL DATA

TR - M xx LF - length frequency data collected by technicians in xx year

TR - xx cpue - catch records for xx year with cpue calculated

TRcpue - combined TR - xx cpue tables with no ID field

TRfinal - catch information with ID field and extracted sediment texture classes

TRfinal xx - QUERY extraction of catch in each year (xx) TRfinal (used TRAWL date not landing date)

TRzoneCT - *TRfinal* catch records in Cape Town zone

TRzonePN - *TRfinal* catch records in Port Nolloth zone

TRzoneSB - *TRfinal* catch records in Saldanha Bay zone

TRcapLF - *Merluccius capensis* length frequency data combined from *TR - M xx LF*

TRcapLENGTHS - length data extrapolated from *TRcapLF*

TRcapFINAL - QUERY of *TRcapLENGTHS* and *TRfinal*

TRcapGRID - ID, grid, day, month, year & depth data from *TRcapLF* exported to TNTmips

TRcapgridCT - *TRcapGRID* records in the Cape Town zone

TRcapgridSB - *TRcapGRID* records in the Saldanha Bay zone

TRcapCT - QUERY of *TRgridCT* and *TRfinal*

TRcapSB - QUERY of *TRgridSB* and *TRfinal*

LONGLINE DATA

LL - Daily / Landings / Lengths / Species Codes / Trips - original M&CM data

LL - Daily/Trip - QUERY to match catch and position records

LL - LF/Daily/Spp - QUERY extracting all hake (both species) length frequencies measured

LLdepth - catch information of all species and extracted depth strata

LLtexture - catch information of all species and extracted sediment texture classes

LLcpue - hake catch information including depth strata and sediment texture class

LLfinal - duplicate records removed from *LLcpue*

LLzoneCT - Cape Town zone data subset of *LLfinal*

LLzonePN - Port Nolloth zone data subset of *LLfinal*

LLzoneSB - Saldanha Bay zone data subset of *LLfinal*

LLcapLF - *Merluccius capensis* length frequency data extracted from *LL – LF/Daily/Spp*

LLcapLENGTHS - length data extrapolated from *LLcapLF*

LLcapFINAL - QUERY of length data for *M. capensis* (*LLcapLENGTHS*) and corresponding catch info
(*LLfinal*)

RESEARCH DATA

(*xxx* - represents the cruise number of the data collected and saved as separate data sets)

Africana xxx - catch data collected on *xxx* West Coast sampling survey cruise (19 in total)

Africana Species List – species codes and scientific nomenclature of all species caught in Research surveys

Stations xxx - positional data for *xxx* cruise

Cap LF xxx - length frequency data for *M. capensis* on *xxx* cruise

Catch xxx - QUERY *Africana*, *Stations* & *Species* codes to extract hake catch data with positions

Cap xxx LF/St - QUERY *Cap LF* & *Stations*

Catch All - All *Catch xxx* data to be sorted into species for MIPS use.

Catch CPUE - removed duplicate sample sites, calculated cpue and % component of each hake spp. for *Catch*

All

Rsubstrate - *Catch All* data exported from TNTmips and combined in Excel with relevant sediment texture data

Rcpue - QUERY *Catch CPUE* & *Rsubstrate* data

RzoneCT - Cape Town zone data subset of *Rcpue*

RzonePN - Port Nolloth zone data subset of *Rcpue*

RzoneSB - Saldanha Bay zone data subset of *Rcpue*

APPENDIX C: Sampling information collected by Marine and Coastal Management staff on trawl

vessels.

Sample summary

Length frequencies

Date

Date

Day

Species

Month

Time

Year

Position

Vessel

Mesh Size (mm)

Drag (a trawl event)

20 to 100 (1cm Intervals)

Time (trawl started)

Total Count

Position (Commercial Grid Block Number)

Depth (m)

Biological information

Merluccius capensis (number of bins)

Date

M. paradoxus (number of bins)

Time

Number of *M. capensis* measured.

Position

Number of *M. paradoxus* measured.

Species

Number of *Trachurus trachurus capensis* measured.

Total Length (mm)

Number of *other species* measured.

Wet Weight - Gutted Mass (g)

Biological information of *M. capensis* (collected or not)

Sex

Biological information of *M. paradoxus* (collected or not)

Maturity Stage (1 to 6)

Number of seals present around vessel

Gonad Mass (g)

Bins of H&G hake (headed and gutted)

Stomach Mass (g)

Bins of PQ hake (head on - guts out)

State

Notes

Stomach Contents

Otolith Reference Number

APPENDIX D: Catch information reported by longline vessels.

<u>LLfinal</u>	Common name (used to select for shallow-water hake in query process)
Daily ID	
Trip ID	Length frequencies from 30cm to 132cm (2cm intervals)
Vessel ID	
Day	<u>LLcapFINAL</u>
Month	LL ID
Year	Trip ID
Commercial Grid Number	Vessel ID
Latitude (decimal degrees)	Day
Longitude (decimal degrees)	Month
Depth (m)	Year
Strata	Commercial Grid Number
Hake (kg)	Latitude
CPUE (kg per thousand hooks)	Longitude
Texture Class	Length
Texture Description	Depth
	Strata
<u>LLcapLF</u>	Texture
LL ID	
Day	
Month	
Year	
Latitude degrees	
Latitude minutes	
Latitude (decimal degrees)	
Longitude degrees	
Longitude minutes	
Longitude (decimal degrees)	

APPENDIX E: Survey data collected by Marine and Coastal Management.

Rcpue

Cruise

Station

Trawl

Research Grid Number

Latitude

Longitude

Depth (m)

Strata

Time

Day

Month

Year

Duration (minutes)

Speed (knots)

nm distance (= knots / (duration/60))

nm squared (= nm distance*nm squared)

MWidth (width of net opening)

M. capensis Catch Weight (kg)

M. capensis cpue (tons/nm²)

Percentage of hake catch that was *M. capensis*

M. paradoxus Catch Weight (kg)

M. paradoxus cpue (tons/nm²)

Percentage of hake catch that was *M. paradoxus*

APPENDIX F: Summary tables of the observed frequencies of fishing intensity for substrate type.

Table 1: The 3x4 summary tables for the observed frequencies in each category. Fishing intensity (number of fishing events) was considered against the substrate types present on the West Coast. Comparison was drawn between the trawl and longline data separately.

Variable (substrate type)	Observed frequency			Row total
	PN	SB	CT	
<u>Trawlers</u>				
Muddy Sand	3976	32621	8505	45102
Sand	10194	80793	37775	128762
Mud	1	20	475	496
Sandy Mud	57	10939	37	11033
Total:	14228	124373	46792	185393
<u>Longliners</u>				
Muddy Sand	30	296	436	762
Sand	218	1444	1375	3037
Mud	1	0	116	117
Sandy Mud	9	25	242	276
Total:	258	1765	2169	4192