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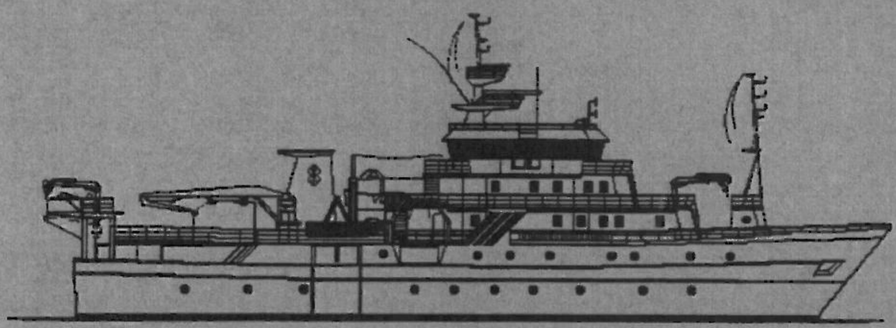

BENEFIT SURVEYS

Cruise Report No 3/98

Survey of the investigation on spawning hake and their eggs and larvae

23 September 1998 - 6 October 1998

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Investigation on spawning hake and their eggs and larvae

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by

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Institute of Marine Research
Bergen, 1998

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CHAPTER 1 INTRODUCTION

1.1 Objectives

An overall goal of BENEFIT is to improve the knowledge and understanding of the important commercial stocks, their environmental condition and the linkage between environmental processes and growth, distribution and abundance of the fish stocks.

The present survey is the third investigation of a BENEFIT project with the specific objective to investigate the spatial distribution of spawning hake in the Benguela ecosystem and to explore the mechanisms which contributed to retain the eggs and larvae within the upwelling ecosystem. This includes the physical environment with the current pattern and the physical properties of the eggs and early larval stages.

1.2 History of the project and specific objectives of the third survey.

The first investigation was carried out 27 September - 7 October 1995 with R/V "Dr. Fridtjof Nansen" (Sundby and O´Toole 1995) and was limited to a pilot study in the central Namibian region from Cape Cross to Hollam´s Bird Island. The pilot study gave a first measure of the buoyancy of artificially fertilised hake eggs which showed relatively heavy eggs. In addition, plankton samples gave a first indication that the hake eggs in Namibian waters are deeply distributed in the water column which correspond well with the buoyancy measurements and the vertical distribution of the spawning fish.

The second investigation was carried 2 - 20 October 1997 and covered three separate regions, the two first in South Africa, 1) from the western Agulhas Bank to Saldanha Bay, 2) over the Childs Bank, and the third region in Namibian waters from Lüderitz to Walvis Bay (Sundby *et al.* in prep). A Multinet® plankton sampler was purchased in order to obtain improved recordings on the vertical distribution of eggs, larvae and zooplankton. The survey showed that the hake eggs were somewhat more shallowly distributed in South African waters than in Namibian waters although the buoyancy of the eggs were not substantially different for the two regions. Buoyancy of eggs was also measured for a number of other fish species. An extensive zooplankton sampling was conducted. The technique of the artificial fertilisation of hake eggs was further developed, and hake gonads were sampled for subsequent detailed analysis. The current pattern was mapped in detail with the ADCP onboard the vessel in order to interpret the transport of the hake eggs. The ADCP analysis showed strong topographical steering of the subsurface currents in the Childs Bank region. Genetic studies were undertaken by using electrophoresis.

The present investigation was the last one of the project. The survey covered the Namibian waters from Hollam´s Bird Island to Cunene River. In addition to the general objectives of the project, this last investigation aimed at mapping all of the spawning areas of *Merluccius capensis* in Namibian waters, and to further investigate the spawning behaviour in relation to the low oxygen layer. The survey was also the start of a new project to investigate the maturation of Namibian hakes and seasonal cycles of spawning, and attention was particularly paid to potential spawning of *Merluccius paradoxus* in Namibian waters.

1.3 Participation

The scientific staff during the cruise was:

From Namibia:

Johnny Gamatham, Paul Kainge, Malaki Shimanda and Konrad Thorisson

From Norway:

Berit Endresen, Olav Kjesbu (to 27 September), Jarle Kristiansen, Magnar Mjanger, Svein Sundby (from 27 September) and Anders Thorsen.

From South Africa:

Alan Boyd (from 27 September) and René Osborne.

1.4 Narrative

The vessel left Cape Town on 23 September, two days after schedule. The first day of delay was due to technical problems; the second day was due to storm conditions. The vessel arrived in the Lüderitz region on 25 September but the weather conditions were still too rough to start the field work. The field investigations therefore started off Hollam´s Bird Island later on 25 September with a section westwards where CTD, ADCP, Multinet®

plankton sampler and trawl were used. The second section was made off Sandwich Harbour after which the vessel headed for Walvis Bay where Alan Boyd and Svein Sundby came onboard and Olav Kjesbu left the vessel to stay at NatMIRC in Swakopmund. The survey continued with east-west sections and cross sections to Orange River. The station work continued with CTD, Multinet plankton sampler, and trawling. From Walvis Bay the speed of the ship was reduced down to 7 - 8 knots in order to keep optimal conditions for underway current recording from the Acoustic Doppler Current Meter (ADCP).The field work was terminated with trawl stations off Sandwich Harbour on the evening of 4 October. The vessel then headed for Walvis Bay where it arrived in the morning of 5 October. Experimental work and report writing continued during 5 October.

CHAPTER 2 MATERIAL AND METHODS

2.1 Physical measurements

The work started 25 September 1998 off Hollams Bird Island and terminated off Sandwich Harbour 5 October 1998 after having surveyed the shelf region north to Cunene River. Cruise tracks with CTD stations are shown in Figure 2.1.

2.1.1 Wind data

Wind speed and direction were measured continuously whilst the vessel was underway and entered manually whilst the ship was on station. There were problems with the manually-entered station data and the entries during the first CTD stations (924 - 939) are incorrect, because wind direction was manually entered from the bridge in 10ths of degrees while the programme interpreted the entry as degrees. From CTD station 940 the wind direction was entered manually from the bridge in degrees. The continuous recordings stored by the weather station are, however, correct and wind speed for the duration of the cruise north of Lüderitz is shown in Figure 3.1.

2.1.2 Current data

Data collection and calibration

The ADCP was set up in Cape Town and the heading adjusted to the ships gyro-compass. The offset for transducer misalignment was maintained at minus 3 degrees. This compensation is actually for various electronic factors, but as they have appeared to be relatively constant over a number of cruises, the are compensated in the misalignment field. The bias between ADCP and gyro heading and the GPS course was checked after leaving Walvis Bay and found to be between zero and one degree. Given that data were mainly bottom-referenced and collected at survey speeds of less than 8 knots or on station, errors due to heading bias can be regarded as minimal. The velocity smoothing interval used for the Navigation data was 150 seconds, which yielded a more erratic velocity field than the previously used 300 seconds, but reduced the number of outliers which result from a long smoothing interval and ships movement on station. Navigation-referenced velocities were only used on 3 deep stations and twice whilst underway for approximately an hour on the outer margin of the grid. Bottom-referenced currents were usually very accurate, but on several occasions noisy data resulted from dense distributions of fish, plankton and jellyfish. The latter in particular caused trouble resulting from the fact that they were invisible to the ship's main 38 kHz echo sounder, but were strongly registered by the 150 kHz ADCP (and also the ship's 120 kHz sounder). Whilst this matter was being investigated the ADCP was switched off and set up with a new heading offset. Therefore two basic cfg files were used: 1998410a and 1998410b. The original cfg file, 1998410 was updated to 1998410a early on in the cruise as it only searched for a lost bottom track after 10 pings.

South of Walvis Bay, data were collected on station only, but thereafter data were also collected continuously underway. All the data are stored in the directory c:\hena on the ADCP PC, and on the "ADCP processing PC" in the directory c:\ADCP\hena.

Processing

The ADCP data were processed by converting the data to ASCII files using the playback menu in the ADCP Transect program. Separate conversions were made for data collected on station and for data collected underway. Thereafter, velocities at selected depths were extracted into UMS "external files" from the ASCII files using Martin Dahl's program, ADCPUMS, which was recently updated. The station data were extracted for depths of 35, 50, 100, 150 and 200 m; where deep enough. The underway data were only processed for depths of 35 and 50 m. Basically whole periods of good data, as long as 13 hours and including stations, were processed as one. This could only be done if the whole data did not contain data contaminated by the bottom. There is a Norwegian Help menu for the program ADCPUMS.

The ADCP external files were plotted using the SFRI 's UMS software. This allows both individual vectors to be plotted in a geographic frame of reference as well as all enabling averaging to take place on any spatial scale. Both the station and underway data were generally averaged in blocks of 2.3 minutes of latitude and longitude. The reason for the fraction (0.3) was to minimise the likelihood of data from the same station being split into different blocks because of the cruise track following set lines of half degrees of latitude, and the ship alternated from being either a little south or north of this line. This procedure largely preserved the integrity of stations and was also suitable for underway data, generally combining 4 to 5 five-minute vectors into one. Both and un-averaged underway currents at 50 m depth (Figure 3.2) and averaged underway currents at 35 -50 m depth (Figure 3.3) are displayed to show the features of the water circulation. However, the pattern for 35-50 m depth is interpreted in detail also using the information from the hydrographic measurements (Figure 3.4). In addition, large-scale averaging was carried out on the station data to highlight latitudinal changes (Figures 3.6 and 3.7). Finally, currents at all stations, at depths from 35-200 m, were combined to estimate (roughly) the net flow of the Benguela current on the shelf.

2.1.3 Hydrography

A Seabird 911 CTD was deployed to collect data on temperature, salinity and oxygen between the surface and 10 m off the bottom. This was done at the positions shown in the station grid in Figure 2.1. CTDs were done at all plankton stations. CTDs were also done at most of the trawl stations, but not on pelagic trawl stations PT 183 and PT 197 and not on demersal trawl station BT 198. Bottle samples for calibration of the oxygen and salinity sensors were taken at most CTD stations. The oxygen samples were titrated within 12 hours of sampling, using the standard Winkler technique. Three sets of standards were undertaken ensuring that all titration calculations were based on a recent standard, as well as interpolating for the small changes in standard which did occur. The results yielded a very tight regression line (Figure 2.2) with a slope and offset very similar to the October 1997 cruise, but significantly different from the August 1998 cruise. The concentration of the bi-iodate standard was checked after the cruise by Magnar Hagebø at Institute of Marine Research, Bergen. The normality of the bi-iodate solution was measured to 0.0398818 +/- 0.000077 which is very close to the standard of 0.04. The salinity samples were not analysed during the cruise, but stored onboard for later analysis.

2.2 Plankton sampling

2.2.1 Multinet plankton sampler

Eggs, larvae and zooplankton were sampled with a Multinet® plankton sampler from Hydrobios. The plankton sampler had 5 nets with a mesh size of 405 micrometers. A Scanmar depth recorder with acoustic transmission to the vessel was mounted on top of the Multinet. The sampler was towed in an oblique haul from 10 m above sea floor to the sea level. The five nets covered the depth intervals:

10 m above the sea floor - 200 m
200 - 150 m
150 - 100 m
100 - 50 m
50 - 0 m.

At stations were sampling depth was less than 200 m the upper depth intervals were kept the same, and the lowest net was then towed from 10 m above the sea floor to the nearest 50 m interval. The plankton sampler was retrieved at a speed of 0.5 m/sec while the vessel maintained a speed of 2 knots. 42 plankton samples were made from Hollam's Bird Island to Cunene River (Figure 2.3).

2.2.2 Processing of samples

Large jellyfish were removed from the samples and their diameters measured. Then the contents of each net were kept separately at about 5° C until analysed. The analysis of the whole series of samples from one station was finished within 3-12 hours from sampling. Fish eggs, fish larvae and zooplankton were identified using 6-50 × magnification. Ichthyoplankton was identified to species if possible, the eggs counted and staged and the length of the larvae measured.

Hake egg were stage determined using the description of Mattews and de Jager (1951) who described 15 stages from the blastodisc (stage 1) to egg with embryo shortly before hatching (stage 15). In the figures in the present report the hake eggs were grouped in three stages:

- Stage I is equal to Mattews and de Jagers (1951) stages 1 - 11, and is approximately the egg less than 1 days old.
- Stage II is equal to stages 12 - 14, and is approximately eggs of age from 1 to 3.5 days.
- Stage III is equal to stage 15, and is the eggs shortly before hatching. In Namibian coastal water temperatures of 11 °C, this occurs about 4 days after fertilisation.

Hake eggs and pilchard eggs from some of the stations were picked out of the fresh samples and put into the density gradient column for buoyancy measurements. The zooplankton was separated into large groups only (order, or higher). The 0 - 50 m sample at each station was preserved in 5 % formalin and stored. Total zooplankton volume was measured. Numbers of fish eggs and larvae per 10 m^2 surface were calculated for each depth interval.

2.3 Trawl sampling

The main purpose of the trawl hauls was to catch mature fish with running eggs and milt in order to conduct artificial fertilisation and subsequently measure the buoyancy of the eggs and larvae. There were made 20 trawl hauls during the cruise, 3 of them were pelagic trawl hauls and 17 were demersal hauls (Figure 2.4). The bottom depths at the trawl stations ranged from 156 m to 509 m. The mean trawling depth was 330 m. Half of the trawl hauls were made at bottom depths between 300m and 360 m. The trawling time for the pelagic hauls ranged from 14 to 31 min. The trawling time of the demersal hauls ranged from 18 to 34 min.

The catch was sampled according to standard procedure. In addition, most of the hakes caught on each station were opened for determination of sex and maturity status. The fish with running eggs and milt were kept aside for artificial fertilisation.

Sub samples were also taken for further studies on the newly established project «Spawning time and reproductive investment of Namibian hakes, *Merluccius capensis* and *Merluccius paradoxus*». For this project about 60 individuals, 30 females and 30 males, of each of the two species were randomly sampled from the trawl catches. For each individual total length in cm and whole weight in kilograms was measured. Then liver, gonads and *viscera* were removed and weighted. A total of 597 fishes were samples during the survey. In addition, for each trawl sample 10 ovaries were fixed on formaldehyde for further studies on land. A total of 104 selected ovaries, 74 *M. capensis* and 30 *M. paradoxus*, were fixed on formaldehyde.

2.4 Artificial fertilisation of hake eggs

From earlier experience (Sundby and O´Toole 1995), only a small fraction of the mature hakes have running eggs. At most trawl stations all fish were inspected for sex determination and maturation stage within about 2 hours after the fish were caught. Often the expanded swimbladder obstructed the oviduct so that ovulated eggs were not running. Therefore the fish were always opened and the ovary scrutinised too look for mature eggs. Several times running eggs could be obtained when the gonad was cut open. Mature males were normally easier to strip for milt without cutting the gonad open. Running eggs were mixed with milt in a 1 liter beaker and was filled up with fresh sea water taken from the surface layer. If fertilisation was successful, eggs floating at the surface could be observed after about 2-4 hours. The live eggs were then gently skimmed off the surface by a spoon and transferred to clean sea water. Subsequently, the eggs were ready to be introduced into the salinity gradient column for buoyancy measurements.

2.5 Buoyancy measurements of fish eggs and larvae

Buoyancy of fish eggs and larvae were measured in a unit from Martin Instrument Co. Ltd. (MIC®) containing three salinity gradient columns submersed in a water bath consisting of a rectangular transparent container. The water in the container was temperature-controlled to 11.0 °C by a cooling engine permanently mounted in the laboratory. The salinity gradient was made from two stock solutions prepared from fresh water and natural ocean salt from Instant Ocean®. The earlier methods used in 1995 and 1997 (Sundby and O'Toole 1995; Sundby *et al.* in prep.) by preparing the two stock solutions from diluted natural sea water and salt-added natural sea water could not be used this time, because the quality of sea water in the harbour of Cape Town was not considered good enough. The high saline stock solution had a salinity of 55 ‰ and the low-saline stock had a salinity of 29 ‰. The filling of the columns were made by the standard filling device supplied by Martin Instrument Co. consisting of two conical flasks connected by a plastic tube at the bottom. The flask with the low salinity solution was equipped with a magnetic stirrer and an additional outlet to a peristaltic pump which provided the supply of the saline water into the columns. Even relatively small movements in ship will cause problems in making a linear salinity gradient with this kind of filling procedure. This is because the movement will cause the saline water solutions in the two flasks to intermix through the connecting tube during filling. Therefore the columns were filled at harbour in Cape Town before departure, and the salinity gradients in the columns kept constant during the cruise. The salinity gradients in the columns were calibrated with spherical glass floats; four floats were introduced in each column. The absolute density of the floats were given with an accuracy of +/- 0.0002 $g \cdot cm^{-3}$.

Buoyancy measurements were made on «wild» caught pilchard eggs and hake eggs by the Multinet sampler and on artificially fertilised hake eggs. The eggs were introduced with a pipette just below the surface of the columns, and the eggs were allowed to settle for 3-4 hours before first reading of the vertical position in the column. Neutral buoyancy of the eggs were expressed in salinity units by calculating the salinity gradient in the column from the absolute densities of the floats and the temperature in the columns.

CHAPTER 3 RESULTS

3.1 Physical measurements

3.1.1 Weather

Figure 3.1 shows wind speeds recorded during the cruise. The wind direction was steadily from south-east during the survey. Following a gale opposite Lüderitz, where the wind speed reached 42 knots, the wind in the southern survey region (Hollams Bird Island to Conception Bay) averaged a speed of 26 knots. From Walvis Bay and northwards the wind speed decreased from about 24 knots and reached a minimum average during the cruise of 15 knots in the mid region of the survey between Cape Cross and Palgrave Point. Wind speed then increased again in the northernmost part of the survey from Dune Point to Cunene River where it averaged 22 knots. The stronger winds were pulsed on a daily basis. The reduction in windspeed to approximately 15 knots midway through the cruise was accompanied by widespread southward flow on the shelf and shelf-edge north of 21°S, but this feature, which will be discussed later, is likely to primarily have had an oceanic cause because of its scale and depth.

3.1.2 Currents

Near-surface flow

A quasi-continuous record of the currents at 50 m depth along the ship track is shown in Figure 3.2. Major changes in current speed and direction occurred over relatively small distances and yet adjacent vectors are coherent. Therefore it appears that the figure is showing the signal and not measurement noise. The "banding" in the flow patterns noticed in the previous cruise of October 1997 are again apparent. On the line opposite Swakopmund (and a degree further north) three distinct regions of northward flow occurred, one relatively substantial which will be traced between lines and 2 very minor branches which appear to be localised. The 35-50 m average of the continuous measurements still picks up all except the smallest features (Figure 3.3). Figure 3.4 shows the same average flow field together with an interpretation of the main streams of flow. This figure suggests the continuity of a relatively narrow stream of northward flow, just inside the 200 m isobath, moving offshore between 19 and 20° S, and then moving even closer inshore north of Cape Frio. On the inner margin of this stream, small cyclonic eddies (clockwise in the southern hemisphere) develop at different sites leading to southward flow close to the coast. Some fairly major eddies are also present: anti-cyclonic examples at 22° S and at 19° S, and the main cyclonic eddy just north of 20° S which returns much of the shelf waters southward. On the outer margin of the station grid above the shelf, the flow is dominantly southward apart from between 19 and 20° S where it is offshore towards the northwest. The interesting, and puzzling, aspect of the pattern is the widespread occurrence of southward flow on the shelf between 20 and 22° S in particular. This flow may have a time-dependent aspect as suggested by the reduction in upwelling winds, but there is also evidence of it in the vertical structure of the temperature and salinity sections. The offshore flow in the vicinity of 19° S is consistent with the 50 m temperature and salinity plots (Figures 3.17 and 3.18).

Flow at different depths

This is shown by the data collected on station. Firstly, all good 5-minute recordings of currents measured on a station are presented as current roses at a particular depth, as is the standard format for many Nansen cruises (Figures 3.5a-3.5e). Alongside each rose is the map of averages for that depth. The presentation of currents at 35, 50, 100, 150 and 200 m also allows for comparison with biological data collected on each station or trawl. The 35 and 50 m maps (Figures 3.5a and 3.5b) show basically the same features as the continuous data and therefore will not be described again. However, the region south of Walvis Bay was not surveyed continuously and the northward leg and the near-surface station data show net northward movement, and also onshore at 50 m deep just inside the 200 m isobath. The northward flow would probably be continuous with the main northward stream shown in Figure 3.4. The 100 m maps (Figure 3.5c) show onshore south of Cape Frio and Rocky Point, and also opposite Swakopmund, with offshore or southerly flow at most other localities. Currents tended to be weaker south of Walvis Bay and inshore, and stronger further offshore. The same can be noted for the currents at 150 m depth (Figure 3.5d) - although the region of weaker currents has shifted offshore. The sites of onshore flow was also different apart from at Rocky Point; due the position of the major eddy there. The data at 200 m depth (Figure 3.5e) are more variable, due to measurement error resulting from the common occurrence of fish and also dense aggregations of jellyfish at these depths. Onshore flow can be noted at 21.5° S.

Average patterns

Currents were also averaged over whole degrees of latitude. All vectors within a specified depth range recorded on station were used for this purpose and the result is plotted at the mid-point. Mean vectors for the upper 35-50 m are shown in Figure 3.6 and for the lower layer (100-200 m) in Figure 3.7. The upper vectors show longshore southward flow between

19.5 and 21.5° S, and at 18° S, but offshore flow at Cape Frio and northward flow at Rocky Point.

In the 100-200 m layer, currents were more uniformly southward, apart from onshore flow at 21° S, and the offshore and onshore flow at Cape Frio and Rocky Point respectively. The latter feature reflects the same major eddy there as shown by the continuous near-surface (35-50 m) flow schematic shown in Figure 3.4. A 35-200 m depth average for all sections in the area of investigation showed a southeasterly (longshore) flow with a speed of 7 $cm \cdot s^{-1}$.

3.1.3 Hydrography

Horizontal sections

Horizontal distributions of temperature, salinity and oxygen at depths of 10 m and 50 m are shown in Figures 3.14 - 3.19. The 10 m distribution for temperature and oxygen (Figures 3.14 and 3.16) show a dominantly longshore distribution of isolines reflecting the upwelling process occurring along the whole coast although the coldest water clearly occurs south of Walvis Bay. However, the salinity (Figure 3.15) increases more markedly northwards (as well as offshore) in accordance with the shifts in the salinity of the source of upwelled water.

At 50 m depth, more meso-scale structure is present in the distributions (Figures 3.17 - 3.19) with an indication of onshore movement between Cape Cross and Ambrose Bay, and south of Cape Frio, with offshore movement at that site shown in the temperature, and to a lesser extent, the salinity and oxygen distributions. The low oxygen values (below 2ml/l at 50 m deep, between 19 and 21° S coincide with the cool band of less than 13 °C water where the isotherms move away from the coast in the same region.

The distribution of temperature and salinity close to the bottom follow very similar trends (Figures 3.24 and 3.25) with minimum values offshore and south of Walvis Bay. This relation is expected because of the tight relationships between temperature and salinity in South Atlantic Central Water, which upwells in the Benguela System. However, the increasing salinity north of Cape Frio can be related to the typical subsurface flow of water from Angola onto the narrow northern shelf. The bottom oxygen values (Figure 3.22) were lowest (less than 0.1 ml/l) in an elongated band between the 150 m and 300 m isobaths stretching from 19°30' S to 21°30' S. Smaller regions of oxygen concentration less than 0.1 ml/l also occurred inshore south of Henties Bay (as is typical) and further offshore at the same locality in a bathymetric hollow.

Three other horizontal sections of physical/chemical parameters were drawn specifically to highlight certain features. There are the depth of the 13 and 14°C isotherms (Figures 3.20 and 3.21) and the distribution of dissolved oxygen at a depth 50 m above the seabed (Figure 3.19). The depth of the 14°C isotherm suggests the onshore flow opposite Ambrose Bay (at 50 depth) referred to earlier, as well as onshore flow at 19° S, moving offshore opposite at Cape Frio in general agreement with the position of the major northernmost gyre shown in Figure 3.4.

The deeper lying 13°C isotherm suggest some recirculation of water below 120 m at 20° S (suggesting the near-surface feature shown at 19,5°S) may lie further southward than indicated nearer the surface.

The eddy opposite Cape Frio is not shown directly by the depth of the 13 °C isotherm due to its depth structure (or insufficient data points), but there is a «gap» in the cross-shelf isolines at its position. The distribution of oxygen at 50 m above the bottom has the same elongated nature of the oxygen minimum at the bottom, but its inner margin is located further offshore and it also extends further southward past Walvis Bay (< 0.3 ml/l). The coincidence of its inner margin with southward flowing water column (shown in Fig. 3.4 for the surface and in the station data for deeper levels) is clear, and it is suggested that the currents prevailing during the cruise were causing or enhancing its elongated nature.

Vertical sections

Vertical sections of temperature, salinity and oxygen are presented for each line positioned along a half degree of latitude, from 23°30'- 19°30' S (Figures 3.8 - 3.13).

The southernmost line at 24°30' S, off Hollams Bird Island, (Figure 3.8) indicates active upwelling on the inner shelf in the temperature section. The oxygen section could be interpreted as also showing upwelling inshore of CTD station 926 - but northward advection of relatively high oxygen and fresher water at 150 - 200 m seems the better explanation.

The line at 23°30' S, off Sandwich Harbour, (Figure 3.9) shows a typical upwelling on the inner portion of the shelf. The uplift of the isolines of temperature and oxygen, is less than 80 m. The low salinity water (< 35.0) near the surface also suggests upwelling, but it could have been advected from further south according to the currents at 35 m depth on station, enhancing the signal (of an isoline moving from below 200 m to the surface). Oxygen is low near the bottom, but moderate-to-high near the surface.

At the 22°30' S line, off Swakopmund, (Figure 3.10) a similar situation prevailed on the inner shelf, although with lower oxygen values inshore. At the shelf break, both the lower isotherms and isohalines slope downward towards the coast, consistent with the southward flow measured. Some uplift of the isotherms occurs on the steeper part separating the inner and outer-shelf, where northward flow was observed.

The temperature section for 21°30' S, off Cape Cross, (Figure 3.11) shows an elevation at CTD 947 and a dip at CTD 948, consistent with the inner rim and mid points of the eddy centred at 22° S drawn in Figure 3.4. The low oxygen water occurs offshore of the 200 m isobath, down to 300 m. Currents show this water body moving southwards and onshore.

At 20°30' S, off Palgrave Point, (Figure 3.12) strongly downward sloping isohalines and isotherms below 200 m are consistent with the broad band of southward flow measured on the outer shelf. There is upwelling occurring above this depth and also closer to the coast. This appears to be moving low oxygen water onto the inner shelf (consistent with currents at 150 m closest to the coast). Maximum upwelling appears to occur above the 150 m isobath. This could assist in formation of localised northward flow just further offshore, closer to the 200 m isobath, as shown in the current schematic.

At 19°30' S, off Möwe Point, (Figure 3.13) there is strong upwelling on the outer shelf, some downwelling in the midshelf region (particularly evident in the isohalines) and upwelling again inshore. The dome of the upwelling coincides with centre of the cyclonic eddy shown in the current schematic, with northward flow on its outer limb and southward flow in the region of the 200 m isobath (i.e. the region of northward flow has shifted). Inshore the flow continues southward despite the uplift in the isotherms. The belt of low oxygen water has less vertical extent than on the previous line, but is still marked.

3.2 Distributions of ichtyoplankton and zooplankton

3.2.1 Zooplankton distribution.

Horisontal distribution of the zooplankton volume is presented in Figure 3.26. From Hollams Bird Island (24° 30' S) to Cape Cross (22° S) the highest zooplankton volumes were found at the inshore stations. To the north of Cape Cross the highest zooplankton volumes were found at the offshore stations. As a group, various copepod species were very common and at most stations dominating at all depths. Onshore, medium sized species (*Calanoides*, *Metridia*, *Centropages*) were more common, whereas large species (*Rhincalanus*, *Eucalanus*) were more common at the offshore stations.

Euphausiids were common at all stations, except at some shallow stations in the north. This group dominated the zooplankton at the intermediate stations between about 100 m and 300 m bottom depth. The amphipods had a very similar distribution pattern in the southern area, but north of Palgrave Point the distribution pattern was more irregular (probably other species).

The chaetognaths group was very common at all stations and most depths, north of Henties Bay. Furthermore, there was also a southward tongue of chaetognaths over the shelf break, extending south to 23° 30' S. South of Ambrose Bay, decapoda (pelagic shrimps and crab larvae) were only found offshore and not in great numbers. North of 21° S, these groups were more common, but the spatial distribution was more complex, probably due to the eddy off Cape Frio (see chapter on currents). Mysids were only important at one zooplankton station, ca 50 km off Sandwich. Polychaetes were an important part of the zooplankton at most stations north of Henties bay, more offshore in the southern part but more onshore north of 21° S (probably different species).

Thaliaceans were important in the offshore samples between Swakopmund and Dune Point. The large cnidaria (jellyfish) found were mainly of two kinds, Aequorea ("mags") and Crysaora ("reds"). The Crysaora were found at a few stations of intermediate depth, but usually in low numbers (Figure 3.27). The Aequorea, on the other hand (Figure 3.28), were abundant between 18° S and 24° S. Both species were mainly abundant in a strip parallel to the shore with the highest concentrations about 70 - 80 km from the shore, except in the Cape Frio region where they were closer to the shore.

3.2.2 Eggs and larvae from hake.

3.2.2.1 Hake eggs.

Horisontal distribution

Hake eggs were found along the entire coast of sampling, mainly offshore above bottom depths from 150 m to 350 m. Figure 3.29 shows the concentration of hake eggs per 10 m^2 surface, all stages. Egg concentrations were increasing towards north. Four centres of high concentrations were found. From south, one patch of moderate concentration (peak value about 450 eggs/10m^2) was found between Conception Bay and Walvis Bay. This was in the same area as found in the last years cruise (October 1997). A higher concentration centre (peak value about 1300 eggs/10m^2) was found off Cape Cross (22° S) and coincided with the anticyclonic eddy described in paragraphs 3.1.2 Currents and 3.1.3 Hydrography. The two major patches of egg concentration were found off Dune point (20° S) (peak value 2700 eggs/10 m^2) and off Rocky Point/Cape Frio (18° 50' S) (peak value 4000 eggs/10 m^2) and coincided with the cyclonic eddy and the anticyclonic eddy, respectively, described in paragraphs 3.1.2 Currents and 3.1.3 Hydrography. More than 70 % of the hake eggs in the area of investigation were found within these to northernmost located gyres between Palgrave Point and Cape Frio. In the northernmost gyre newly spawned (Stage I) eggs dominated (Figure 3.30) In the gyre off Palgrave Point stage II eggs were most abundant (Figure 3.31). The southernmost egg centre, off Sandwich Harbour, had the largest proportion of stage III eggs (Figure 3.32)

Vertical distribution

The vertical distribution of hake eggs, all stages, differed for the four different centres of concentration(Figures 3.33 - 3.37). For the southernmost centre, off Conception Bay/Walvis Bay, only a minor fraction was found in the upper 50 m (Figure 3.33). The highest egg concentrations were found in the depth layer from 100 - 150 m depth (Figure 3.35). Relatively large concentrations were also found below 200 m depth (Figure 3.37). Oxygen concentration was most probably not a limiting factor in this region. The concentration at about 250 m depth was above 0.7 ml/l (Figure 3.23). Newly spawned (stage I) eggs were found at highest concentrations at 100 - 150 m depth and below 200 m depth (Figures 3.38 - 3.42). The major concentrations of eggs just prior to hatching (stage III) eggs were found in highest concentration from 50 to 150 m depth (Figures 3.48-3.52). No stage III eggs were found below 200 m depth and above 50 m depth.

For the second centre of egg concentration off Cape Cross, the major concentrations were found above 150 m depth with peak concentration in the depth layer from 100 -150 m (Figures 3.33-3.37). Also relatively high concentrations were found in the upper 50 m. Newly spawned (stage I) eggs dominated, and they were mainly found at 50 - 100 m depth and even above 50 m depth (Figures 3.38-3.42). Stage II eggs dominated at 100 - 150 m depth (Figures 3.43-3.47). Stage III eggs were found only above 150 m and in very small concentrations (Figures 3.48-3.52). Below 200 m depth the oxygen concentration was quite low, largely below 0.3 ml/l, and consequently it was probably too low for hake eggs to survive.

The third centre of egg concentration, off Palgrave Point, was located above the extensive water mass with very low oxygen concentration. The concentration was 0 ml/l at the bottom at the section off Palgrave Point (Figure 3.22), and concentrations of less than 0.3 ml/l extended up to between 200 and 100 m below the surface. Very high egg concentrations were found in the upper 50 m, and this was mainly stage II eggs (Figure 3.43). Strangely enough, eggs were also found at moderate concentration even down below 200 m depth, and mainly stage II eggs (Figures 3.37 and 3.47).

The forth and northernmost centre of hake eggs, off Cape Frio, was located to the north of the water mass of low oxygen (Figures 3.22 and 3.23). Oxygen concentration at the bottom was higher than 0.3 ml/l, and thus oxygen was probably not a limiting factor. Peak egg concentrations were at the 100 - 150 m depth layer (Figures 3.33-3.37) and newly spawned (stage I) eggs dominated here (Figures 3.38-3.42). Stage II eggs were found in highest concentrations in the upper 50 m (Figures 3.43-3.47). Only low eggs concentrations were found below 150 m depth. Stage III eggs were only present in the upper 50 m, and then in low concentrations (Figures 3.48-3.52).

3.2.2.2 Hake larvae.

The hake larvae were differently distributed from the hake eggs (Figure 3.53). Larvae were not at all present in the two northernmost egg centres where extensive amounts of newly spawned eggs were found. The hake larvae were mainly concentrated around three centres. The southernmost off Conception Bay which was very close to the southernmost egg centre. Another was located off Swakopmund, and the third and most extensive was located off the coast to the north of Cape Cross. Generally, the larvae were found closer to the coast, and there were also larvae distributed inshore from Walvis Bay to Palgrave Point.

Figure 3.54 shows the average length distribution of hake larvae at each positive station. Practically all the older (longer) larvae are found inshore, to the east of the main concentrations of hake larvae, indicating onshore movement in the depth layers where eggs and larvae are found. This is largely consistent with the observed current pattern of the area as indicated in Figure 3.4.

3.2.3 Eggs and larvae of other fish species.

Besides hake, eggs of seven fish species were recorded, and larvae of at least 13 species were caught. Some of these species had only one or few records but others should be mentioned, because of their importance to the fisheries or because of their ecological importance.

Pilchard eggs were caught at five stations, between 19°30 S and 21° S (Figure 3.55). The highest concentration was at 20°30 S, indicating an early spawning close to the shore at Palgrave Point. Small numbers of horse mackerel larvae were caught at 11 stations, mainly at offshore stations between Swakopmund and Möwe Point (Figure 3.56). The larvae were small (3-8 mm), suggesting an age of less than two weeks from hatching. The size distribution points to an early spawning, more towards the northern part of the larval distribution. Goby larvae were quite common in the onshore area from Hollams Bird Island to Cape Cross (Figure 3.57). The highest concentration was found off Sandwich Harbour. As the goby larvae grow slowly, the observed length distribution (4-14mm), indicates ages from just hatched up to several weeks old. The onshore transport of larvae hinted at by the size distribution should be treated with caution due to the relatively long time period involved (1-2 months?).

3.3 Fish distribution

3.3.1 Fish species in the trawl catches.

Figure 3.58 shows the total trawl catches in kg/trawl hour together with the catch of the five most abundant species and the sum of the remaining species. *Merluccius capensis* or

Merluccius paradoxus dominated in 18 of the 20 trawl stations. At the northern most and deepest trawl station off Cape Frio (trawl station 196) *Trachyrincus scabrus* species was the most abundant, and at trawl station 199 off Cape Cross *Pterothrissus belloci* was most abundant. The *Trachyrincus scabrus* species was in general found at the deepest trawl stations, while *Trachurus capensis* was abundant at the trawl stations between 200 and 350 m depth to the north and to the south of the large water mass of low oxygen (< 0.1 ml/l) located from Cape Cross to Möwe Point.

3.3.2 Distribution of hake species

Both *Merluccius capensis* and *M. paradoxus* were present in the trawl catches all along the investigated coast from Hollams Bird Island to Cunene River, but the two species were separated by vertical distribution. Figure 3.60 shows the ratio in weight of *M. capensis* to weight of all hakes caught at the trawl stations. Generally, only *M. paradoxus* were caught in the bottom trawl at depths below 400 m. The exception was the northernmost trawl station (BT 196) at 489 m depth off Cape Frio. Here 26 % of the weight of the hakes were *M. capensis*. Above 400 m depth *M. capensis* dominated except at one of the southernmost stations (BT 185) off Hollams Bird Island. Here 52 % were *M. paradoxus* of the trawl catch taken at 361 m depth. Figure 3.59 shows the distribution of *M. capensis*. As for the egg distributions the fish has the highest abundance in the offshore regions where bottom depths are between 200 and 400 m. The highest abundances where found at oxygen concentration of about 0.3 ml/l and very close to the regions where oxygen concentrations were less than 0.1 ml/l.

Merluccius polli were caught at four of the northernmost trawl stations. One spent female was caught at trawl station BT 194 off Möwe Point at 470 m depth, and one large maturing female was caught at station BT 196 off Cape Frio at 489 m depth. At the two other trawl stations only fry and juvenile *M. polli* were caught, and they were both more inshore at shallower depths. One juvenile was caught in a pelagic trawl haul (PT 197) taken at 200 m depth, 50 m above the bottom off Cape Frio. Eighteen *M. polli* fry were caught in a bottom trawl haul (BT 195) off Cape Frio at 205 m depth.

3.3.3 Maturity and sex ratio of hakes

Only immature *M. paradoxus* were caught, and the females dominated the catches. The few fishes of *M. polli* indicated that spawning occurred, and that this probably took place at relatively great depths. No *M. polli* males, however, were caught. The major part of *M.*

capensis was immature, and at the shallowest trawl stations all hakes were immature and generally smaller. Mature *M. capensis* were caught at stations with trawling depths from 300 to 360 m. Only at four stations, however, mature fish with running eggs were caught. Three of these stations (BT 186, BT 201 and PT 202) were located at the centre of egg distribution off Sandwich Harbour described in paragraph «3.2.2.1 Hake eggs». The fourth trawl station (BT 190) having females with running eggs was located near the second centre of egg distribution off Cape Cross. At both of these two locations a high fraction of males occurred (Figure 3.61). No females with running eggs were caught at the two northernmost centres of egg concentration, even though these two centres contained the major part of the hake eggs. However, near the centre off Cape Frio a relatively high fraction of males occurred.

3.4 Artificial fertilisation

From macroscopic inspection the mature gonads were divided in two categories. The first category was purplish in colour and had fully hydrated oocytes. The eggs were, however, usually not fully running and artificial fertilisation of eggs from such gonads were never successful. The second category of mature gonads looked more like maturing gonads than fully mature. They were yellow-orange in colour and consisted mainly of non-hydrated oocytes. In the central part of the gonad there was, however, at some occasions a thin core of fully mature running eggs, and these eggs were easily fertilised. Because of the immature appearance of these gonads each one off them had to be squeezed or cut open to find out if there were mature eggs. The mature fish were often surprisingly small. During the present cruise artificial fertilisation was only successful with fish from trawl stations BT 201 and PT 202 off Sandwich Harbour by the end of the cruise.

After mixing the running eggs with milt, sea water taken from the surface layer (salinity of about 35.0 and temperature about 16°C) was added and the mix was allowed to stand for some hours on the trawl deck. After a couple of hours the first fertilised and live eggs appeared at the surface. Because of the special hydrofobic surface of live eggs they float on top of the surface. After about 4 hours the live eggs were skimmed off the surface and transferred to a jar of clean sea water to separate them from milt and dead eggs at the bottom. The viability of the eggs that were transferred to clean sea water was very high. First cell division was observed after about 4 hours.

3.5 Buoyancy of eggs and larvae

Buoyancy measurements were made on pilchard eggs and hake eggs caught in the Multinet and artificially fertilised hake eggs from mature fish caught in bottom trawl station 201 and pelagic trawl station 202. Figure 3.62 shows the neutral buoyancy in salinity units for wild caught hake eggs from the two plankton stations 29 and 37. The upper panel shows the buoyancy of the egg from plankton station 29, sampled from the egg patch above the oxygen minimum layer off Palgrave Point. The median neutral buoyancy of these eggs was very high, 36.14 expressed in salinity units, which would imply that these eggs would sink in nature. The mid panel shows partly the same eggs at a later stage as hatched larvae. As they have lost the chorion, which is the heavy fraction of the eggs, they have become considerably lighter, and would have a positive buoyancy under natural conditions. The lower panel shows the buoyancy distribution of late stages of hake eggs sampled from the northernmost egg patch at station 37. These eggs were lighter (except for the smaller heavy fraction which was probably poor quality eggs) than those from the former station and more similar in buoyancy to those eggs investigated during the 1995 and 1997 cruises.

Figure 3.63 shows the neutral buoyancy of pilchard eggs sampled in the Multinet at plankton station 37. They were lighter than the hake eggs. This was also observed during the 1997 cruise where pilchard eggs were sampled in South African waters. The eggs became heavier through development; the lower panel shows the buoyancy distribution 22 hours later compared to the upper panel.

The artificially fertilised eggs showed a much more narrow buoyancy distribution and they were lighter than the wild caught eggs. Figures 3.64, 3.65 and 3.66 shows the buoyancy distribution of eggs from female no 1, female no. 2 and females no. 3/4/5, respectively. 18 hours after fertilisation the mean neutral buoyancy in salinity units were between 33 and 34. After 31 hours the eggs from female no 2 (Figure 3.65) and females no. 3/4/5 (Figure 3.66) had all become heavier, while the eggs from female no. 1 (Figure 3.64) was not significantly heavier. The buoyancy measurement were terminated after 31 hours because the cruise was ended.

CHAPTER 4 DISCUSSION

We expect that hydrographic features and the circulation pattern which we have displayed above represent a fully developed upwelling situation because of the steadily blowing strong wind from south-southeast, both prior to and during the survey period. In addition to the well-known large-scale pattern of upwelling with inshore low temperatures, three areas of gyres were identified which appeared both in the ADCP recordings and in the hydrographic data. These gyres were located off Cape Cross, off Palgrave Point and off Cape Frio. Closer inspection of the distributions of hake eggs revealed that three centres of high egg concentration coincided with the areas of the three gyres. As there was a high concentration of stage-I eggs (less than 1-days-old eggs) within these gyres, it indicates that eggs have not been captured by the circulation features into the gyres from outside and concentrated, but rather that spawning has taken place within the gyres and that the gyres have retained the eggs as also the highest concentrations of the older eggs are found here.

In the area of the fourth centre of egg concentration, off Sandwich Harbour, the ADCP recordings were more sparse than in the other areas. In the ADCP depth layers of 50, 100 and 150 m depth (Figures 3.5b, 3.5c and 3.5d) there are, however, some indications of a cyclonic circulation, and the horizontal distribution of salinity at 50 m depth (Figure 3.18) and at the bottom (Figure 3.25) do show an eddy-like feature. In contrast to the other three centres of egg concentration, the area off Sandwich Harbour was dominated by older egg stages. This does not necessarily indicate that these eggs are carried into the gyre from outside, since spawning hakes were taken in trawl catches here. The same area was also visited during the similar cruise in October 1997 (Sundby *et al.* in prep), and also then spawning hake were caught here. During the pilot cruise of the project in September/October 1995 (Sundby and O'Toole 1995) eggs were also found in higher concentrations off Sandwich Harbour and within one of the other centres of egg concentration, off Cape Cross. However, the ADCP data could not be relied upon during that cruise and the hydrographic data did not have a spatial resolution good enough to reveal eddies in 1995.

Another major feature of the circulation pattern during the present 1998 cruise was the dominating onshore and southward flow below 35 m depth. As the major part of the eggs are below 50 m depth, eggs are carried onshore and southward from the spawning areas unless they are retained within the gyres. This view is also supported by the fact that larvae are slightly more onshore distributed (Figure 3.53) than the eggs and that the longest (and oldest larvae) are distributed closest to the shore (Figure 3.54).

The total number of hake eggs occur mainly close to the coast only in the region between Cape Frio and Rocky Point, where the water is being «funelled» onshore between a pair of cyclonic and anticyclonic eddies. Between 20 and 22° S the 0-50 m hake eggs in particular follow the general sweep of southward flow, but with no eggs at 22°30' S at that depth. However, hake larvae were encountered on that line in abundance, in the same southward flow of approximately 12 cm/s (3 knot or 6 miles per day).The difference between the peak abundances of hake eggs and larvae show a southward shift, and onshore shift (south of 20° S) with most inshore stations containing larvae but not eggs.

In conclusion, it seem to be a typical feature that hake are spawning within gyres along the shelf of Namibia, and that the combined effect of the gyres and the onshore/southward transport of eggs below the upper layer may provide effective mechanisms to retain the eggs and larvae within the Benguela upwelling system, and are thus prevented from being swept out in the South Atlantic and possibly becoming lost for recruitment. It should be pointed out that even though the wind was stronger than normal prior to and during the survey there was no sign of offshore loss of eggs. In fact, with this deep distribution of the eggs the onshore transport might be even enhanced in strong upwelling winds.

The extent of the offshore oxygen minimum has varied over the three surveys in 1995, 1997 and 1998, and the lowest values was recorded in 1998. This year a large oxygen minimum with less than 0.1 m/l extended more than 50 m above the bottom in a 30-70 km broad band from Walvis Bay to Möwe Point, a distance of about 450 km. Off Palgrave Point, at 20° 30' S, the low oxygen layer had its maximum extention. Here oxygen values of less than 0.3 ml/l extended over bottom depths from 100 m to 300 m, and its maximum height was 100 m above the bottom.

From the vertical distribution of the eggs it seems obvious that the oxygen minimum influenced the depth of spawning at the two spawning centres off Cape Cross and particularly off Palgrave Point: Newly spawned (stage I) eggs were found in large concentrations in the upper 50 m of the water column (Figure 3.38) and between 50 and 100 m depth (Figure 3.39). These eggs are less than about 1 days old and with their estimated rising speed they would not have ascended more than maximum 50 m during 24 hours. At the two other spawning centres which were found outside the oxygen minimum, i.e. off Sandwich Harbour and off Cape Frio, the minimum oxygen concentrations at the bottom were above 0.7 ml/l and above 0.3 ml/l, respectively. Here, the concentration of newly spawned eggs peaked in deeper layers, between 100 and 150 m. During the 1995 and in 1997 cruises the oxygen concentrations were not as low and peak hake eggs concentrations were then below the 50 - 100 m depths.

The distribution of the newly spawned eggs seems in all three years to be mainly distributed along the slope where bottom depth are 200 - 400 m. Our working hypothesis was that spawning occurs near the bottom. When oxygen concentration becomes too low we have been speculating whether spawning might be displaced more offshore. This year, however, the spawning hakes were displaced higher up above the oxygen minimum and spawned pelagically rather than demersally and more offshore. The calculated ascending speeds of the eggs based on the buoyancy measurements is very low, from 20 to 40 m per day. This implies that the vertical distribution measured in the field is very dependent on the spawning depth the hakes select and, consequently, on the extent of the low oxygen layer.

The measurements of the buoyancy of the artificially fertilised hake eggs and the wild caught eggs hake are consistent all three years. They are neutrally buoyant in salinities ranging from 32.5 to 34.5 which is a rather narrow buoyancy distribution compared to pelagic eggs like eggs from Atlantic cod and North Sea mackerel (Sundby 1997). During the pilot study in 1995 the cumulative mortality of the artificially fertilised egg was about 50 % onto hatching. The high mortality will have the effect of biasing the neutral buoyancy toward higher values, as the osmoregulation do not function properly in eggs of poor condition and dying eggs. The poor osmoregulation results in salt intrusion and higher neutral buoyancy, and this condition may last for several hours before they actually die and drop rapidly out of the salinity gradient column. As the method of fertilisation improved during the subsequent two cruises in 1997 and 1998 egg mortality was substantially reduced. The wild caught eggs showed a considerable higher spreading in the buoyancy, and mortality was higher than for the artificially fertilised eggs. This was most probably due to that they undergo great stress during filtering in the plankton net and during the subsequent handling of the sample onboard. Consequently, artificially fertilised eggs will give more reliable data on neutral buoyancy.

The hake eggs become heavier through development until hatching. This is a general feature of many species of fish egg (e.g. Ådlandsvik *et al.* 1998). At hatching, however, they suddenly becomes lighter due to the loss of the heavy chorion material. The newly hatched hake larva is a rather undeveloped creature compared to other pelagic larvae which are most often ready to start feeding short after hatching. The hake larva has neither functional eyes nor a functional mouth at hatching. It floats with head and yolk sack up due to the extra buoyancy of the oil droplet in the yolk sac. In the salinity gradient column the hake larvae have been observed to swim in bursts downward for a 2 -3 seconds at regular intervals, and rests for about one minute. After several days of development the yolk is shrinking and the oil droplet is moved further back in the yolk. Hence, its centre of gravity moves back and larva is observed head down in the resting phase.

The lack of functional eyes and mouth at hatching is typical for eggs of many fish species where hatching occurs deep down in the water column. Atlantic halibut eggs in Norwegian waters (Haug *et al.* 1986) and blue whiting eggs to the west of the British Isles (Ådlandsvik *et al.* 1998) are spawned at several hundred metres depth and they hatch below 200 m depth. Like the hake eggs, Atlantic halibut and blue whiting eggs are very undeveloped at hatching. On one hand, it may be argued that functional eyes and mouth is not necessary properties of larvae that are found below the upper layer where food production, like copepods nauplii, is found. On the other hand, there are indications that early hatching may occur when oxygen supply to the embryo in the egg becomes a limiting factor. Both arguments could be valid for hake eggs.

The horizontal distribution of the larger *M. capensis* (Figure 3.59) are, like the distribution of the newly spawned eggs (less than 1 days old), concentrated offshore above bottom depths of 200-400 m. The smaller juvenile hakes seem to dominate in shallower areas and mainly inshore of the 200 m isobath. However, very small mature hakes of lengths less than 25 cm, both males and females, are often observed in the trawl catches at the spawning areas. Females of these hakes appear more often to have gonads with a portion of free running mature eggs than the bigger female hakes. Consequently, successful artificial fertilisation was more frequently with eggs from the small hakes with gonads which appeared to be rather immature, but had a portion of free running eggs in the core of the gonad. This observation confirms that macroscopic staging of gonad maturity is a difficult issues for batch spawning fishes, like the hakes. Microscopy studies of the development of the hake oocytes are therefore a needed study in order gain knowledge of the length of the spawning period.

CHAPTER 5 CONCLUSION

This was the third and last cruise in the project on the study of spawning behaviour of hake, physical properties of the eggs and larvae and transport mechanisms to the nursery areas (1995-1998). The cruises covered only Namibian waters during the first cruise in September/October 1995 and during this last cruise in September/October 1998. In October 1887 also two regions in South African waters was covered, the shelf region from western Agulhas Bank to Saldanha Bay and the Childs Bank.

During the three cruises different parts of Namibian waters were covered. The first cruise which was a short pilot investigation only covered the shelf from Hollams Bird Island to Cape Cross. The second cruise covered the shelf from Lüderitz to Walvis Bay and the third cruise covered the shelf from Hollams Bird Island to Cunene River. The major results of the three cruises are consistent. Geographically, five well defined centres of spawning. have been identified between Lüderitz and Cape Frio. The region to the west of Sandwich Harbour (between Conception Bay and Walvis Bay) was visited during all three cruises and all of them showed a higher concentration of hake eggs. The second centre of spawning was found off Cape Cross. It was visited two times, during the 1995 and the 1998 cruises. The three remaining spawning centres have only been visited once. In the southernmost area of investigation a region of higher concentration of eggs was identified downstream the Lüderitz upwelling cell, between Lüderitz and Hollams Bird Island, during the 1997 cruise. The two remaining spawning centres were observed in northern Namibia during the present cruise, one off Palgrave Point and the other off Cape Frio. It seems that the spawning centres coincide with areas of mesoscale gyres of the Benguela Current.

The extent of the low oxygen layer has varied from year to year and seems to influence the spawning depth. In regions where the oxygen concentration is not a limiting factor for the eggs, i.e. the oxygen concentration is above 0.5 ml/l, spawning seem to occur near the bottom. When the low oxygen layer is widely distributed spawning occurred pelagically high up in the water column above the low oxygen layer, as shown for the spawning centre off Palgrave Point during the 1998 cruise.

Measurements on the specific gravity of both artificially fertilised eggs and «wild» eggs caught in the plankton sampler show for all years that the buoyancy of the hake eggs in Namibian waters is relatively small and the specific gravity increase during development.

The calculated ascending speeds of the eggs is from 20 m to 40 m per day. This implies that most eggs spawned at 200 m and deeper will not reach the surface layers with offshore transport before hatching. A large proportion of the eggs will hatch at deeper layers. The buoyancy measurements are consistent with the vertical distribution of the hake eggs obtained from the plankton sampler: To the north and to the south of the extensive low oxygen layer observed in 1998 between Cape Cross and Möwe Point the highest concentration of hake eggs was found in the 100 - 150 m depth layer. In the region of the low oxygen layer, however, the maximum egg concentration was found above the oxygen minimum, in the upper 50 m. These eggs were mainly less than 1 day old showing that spawning had taken place pelagically high up in the water column.

During the 1998 cruise emphasis was put on mapping the detailed current pattern by ADCP. The results of the ADCP recordings, supported by the hydrographic data, show that the three northernmost centres of spawning are located within areas where gyres are formed. This will contribute to reduce advectional loss of the hake offspring. In addition there is a strong onshore and southerly current component below the offshore transport of upper layer. These environmental conditions, together with the low ascending speeds of the eggs, is here proposed to be mechanisms to concentrate the offspring in the nearshore regions and prevent them from being swept away from the region by the offshore upwelling transport.

Often quite small hakes, less than 25 cm length, were observed with running eggs which were successfully artificially fertilised. Maturity staging of female hake by macroscopic inspection of the gonad is connected with great uncertainties. Females with running eggs are often misjudged as maturing, i.e. not fully mature, while mature fish with fully hydrated oocytes over the entire gonad had usually not running eggs and artificial fertilisation was consequently unsuccessful. This demands for closer microscopic studies on the maturation processes of hake

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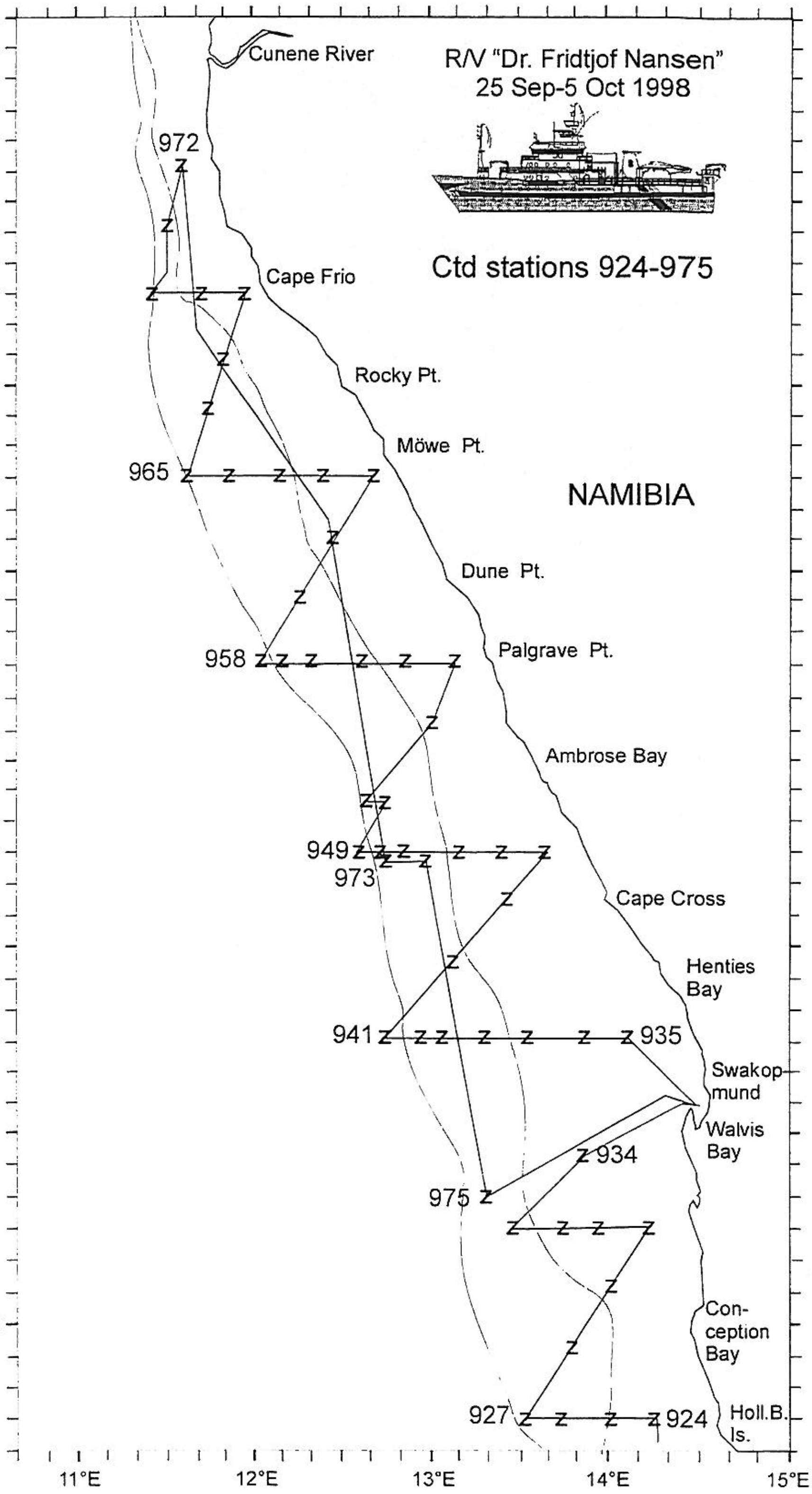


Fig. 2.1 Cruise tracks and CTD stations of
R/V "Dr. Fridtjof Nansen" 25 September - 5 October 1998

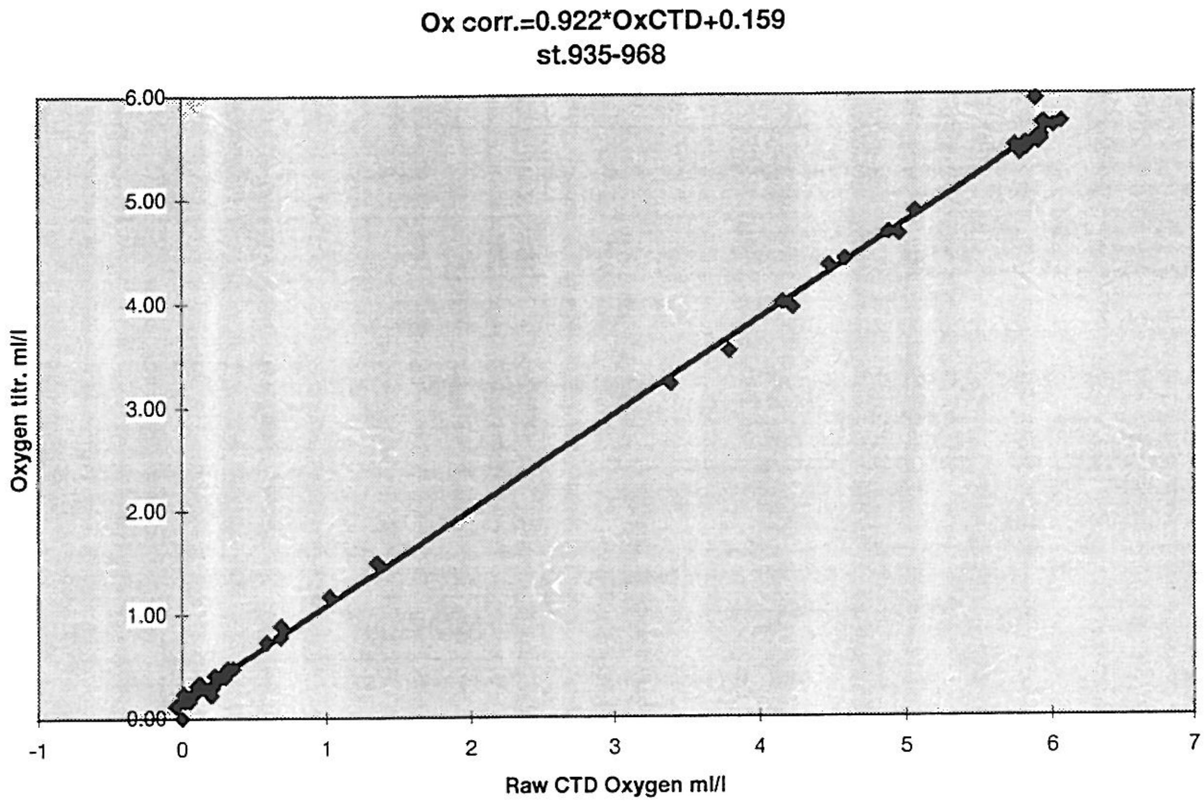


Figure 2.2 Correlation between oxygen concentrations measured by the polarographic CTD oxygen sensor and titrated water samples.

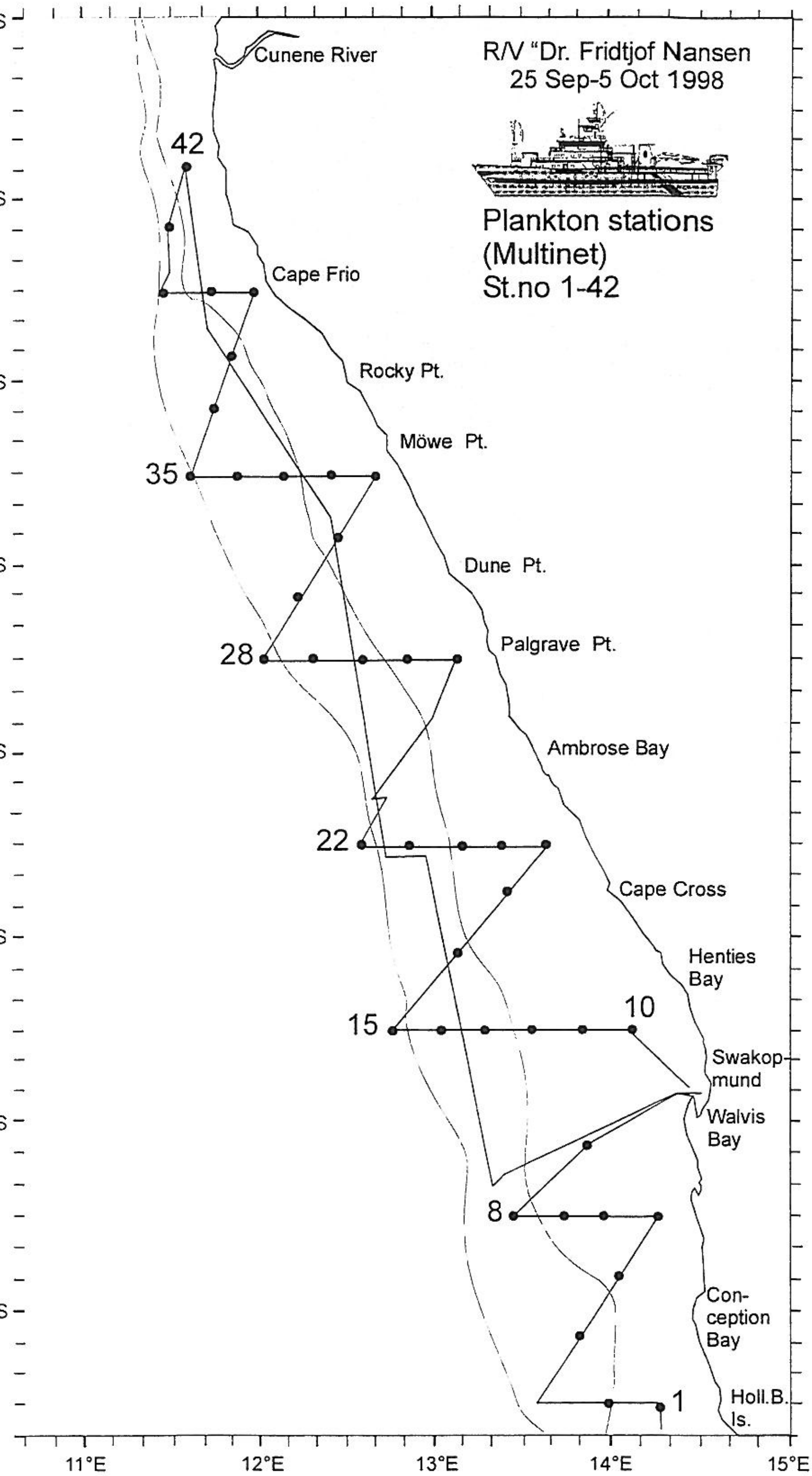


Fig. 2.3 Multinet plankton stations of
R/V "Dr. Fridtjof Nansen" 25 September - 5 October 1998

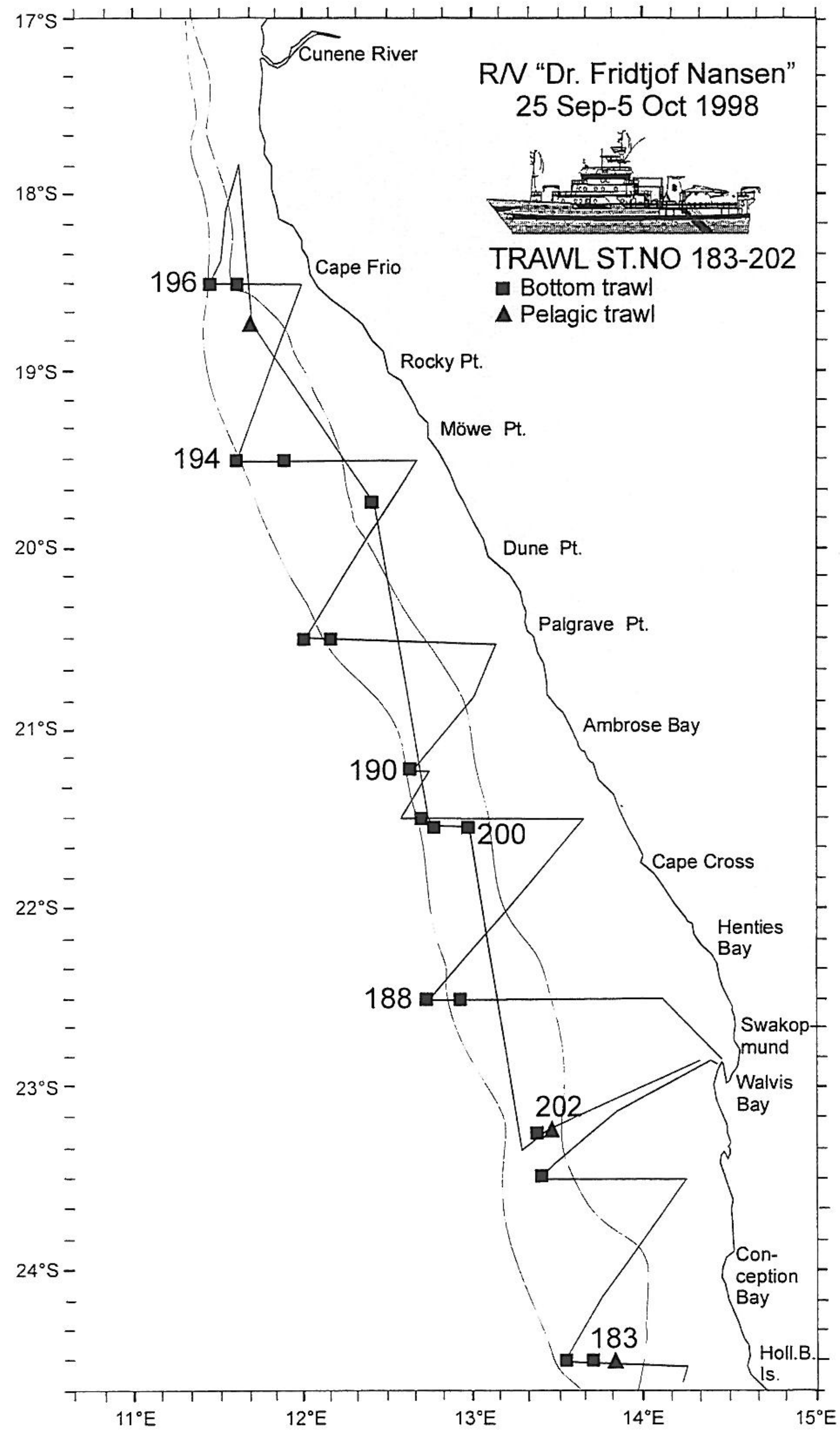


Fig. 2.4 Trawl stations of
R/V "Dr. Fridtjof Nansen" 25 September - 5 October 1998

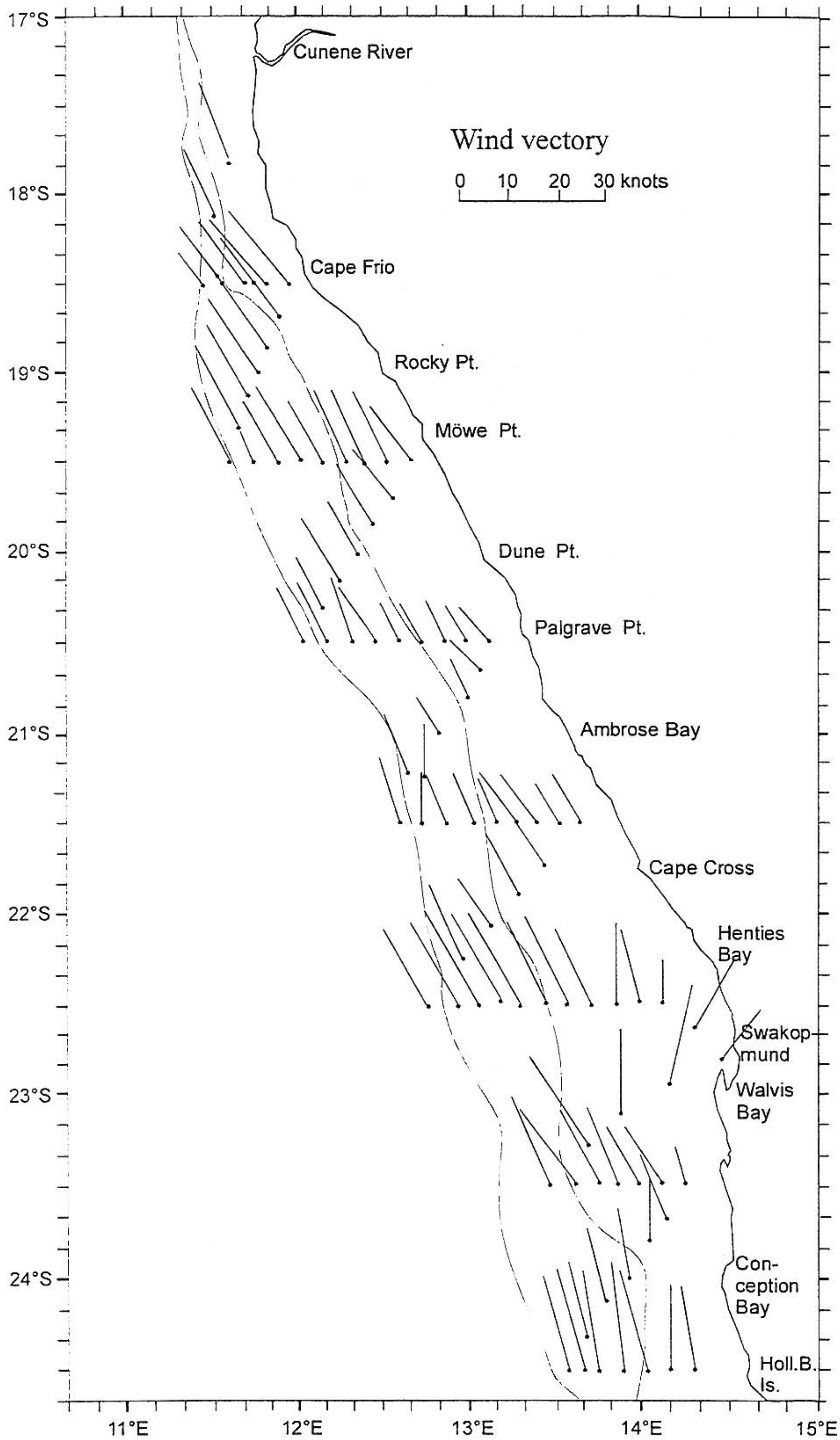


Fig. 3.1 Wind vectors in the area of investigation.

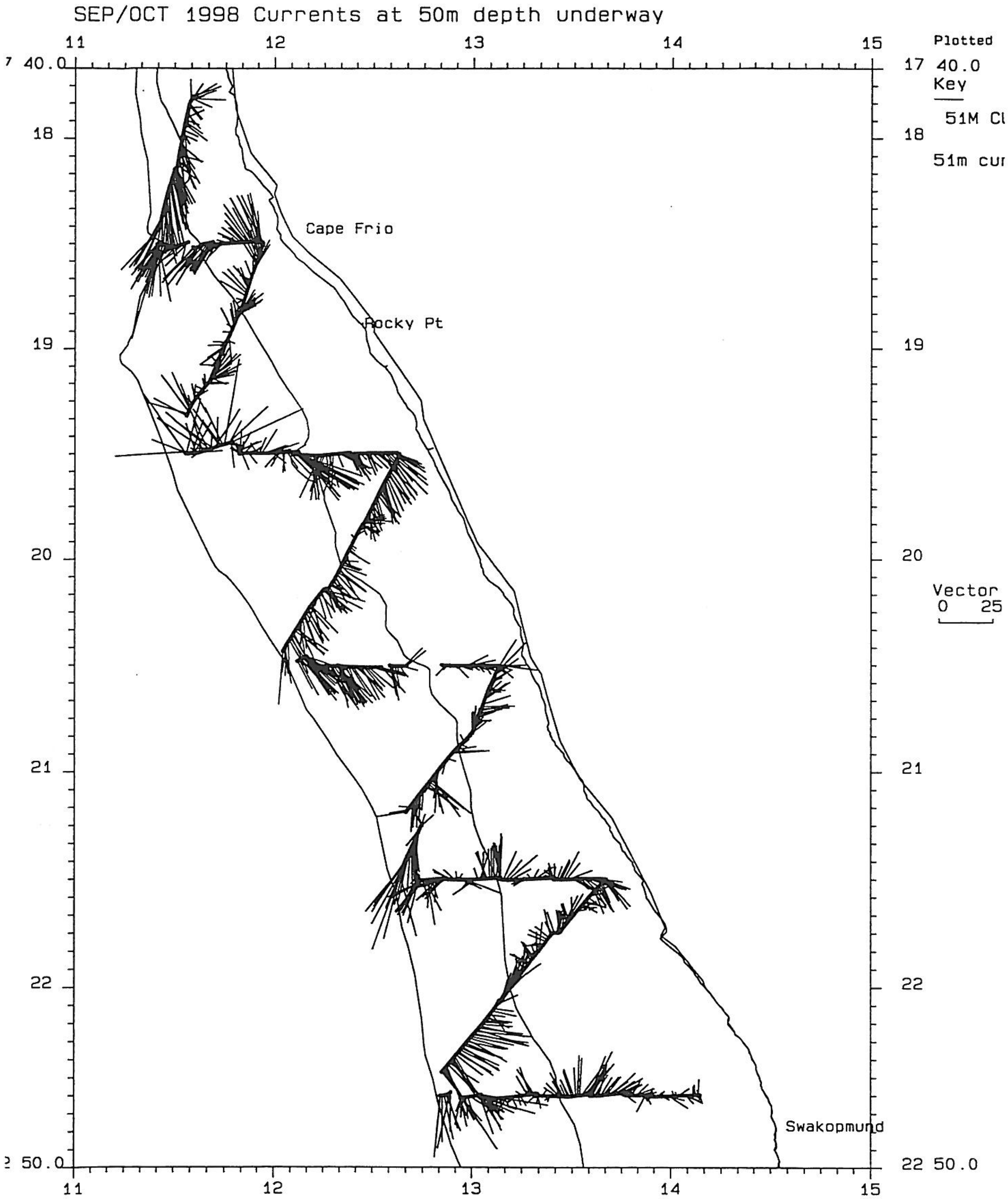


Figure 3.2 Quasi-continuous un-averaged ADCP records of the currents at 50 m depth along the ship track.

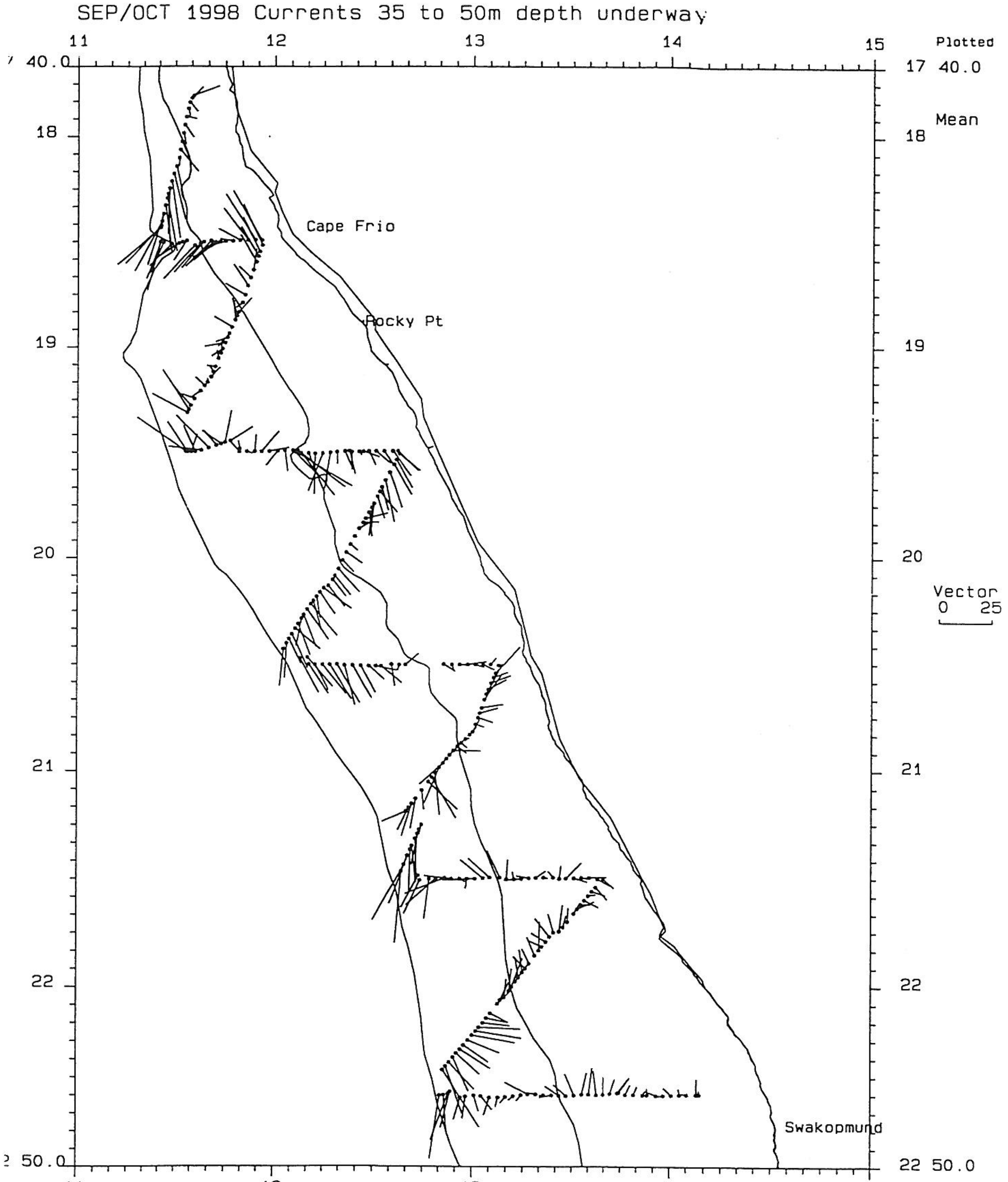


Figure 3.3 Averaged underway ADCP current vectors at 35-50 m depth.

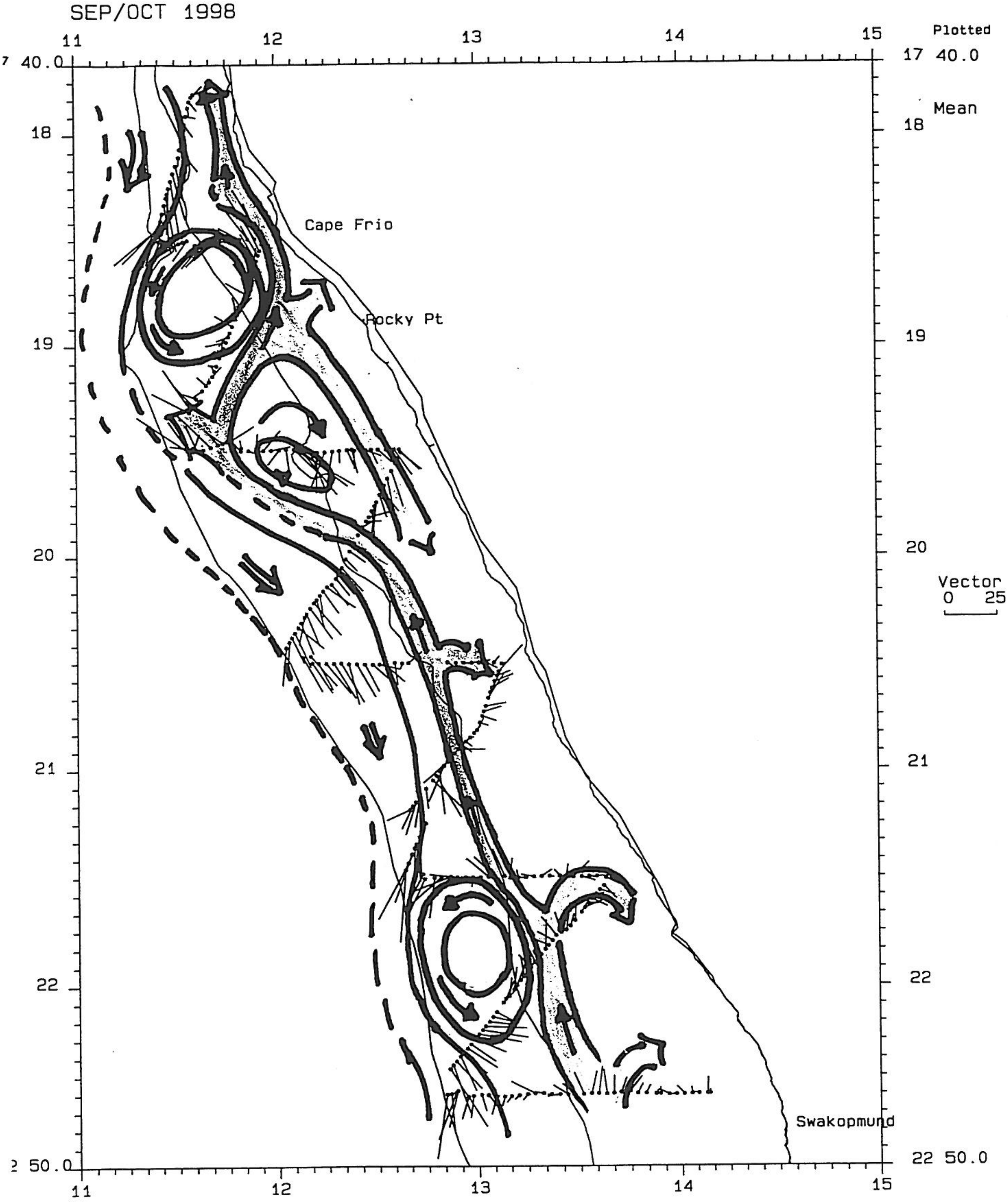


Figure 3.4 Subsurface circulation in the survey area interpreted from ADCP recordings and hydrographic data.

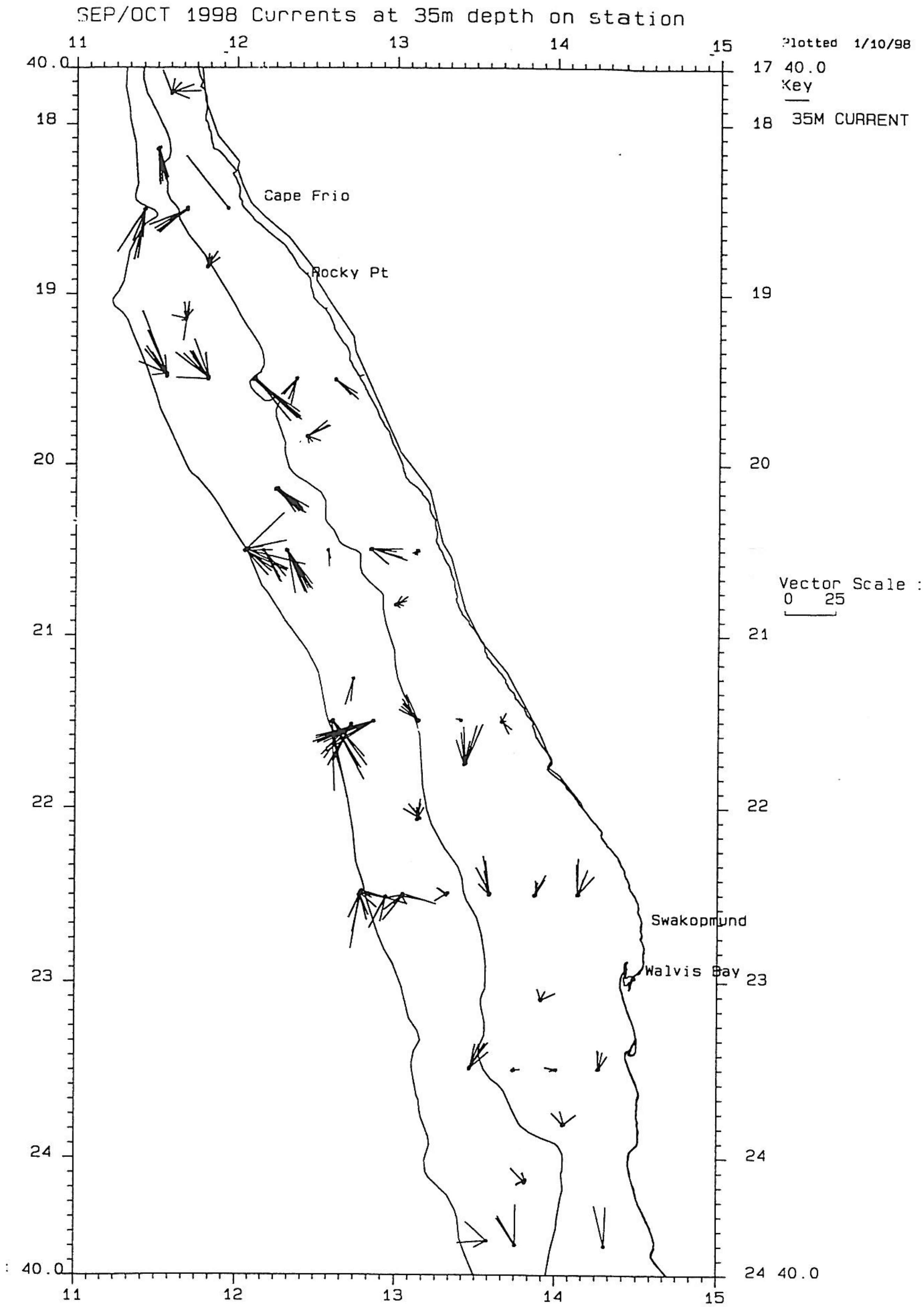


Figure 3.5a Five-minutes averaged ADCP current vectors for 35 m depth at the CTD stations.

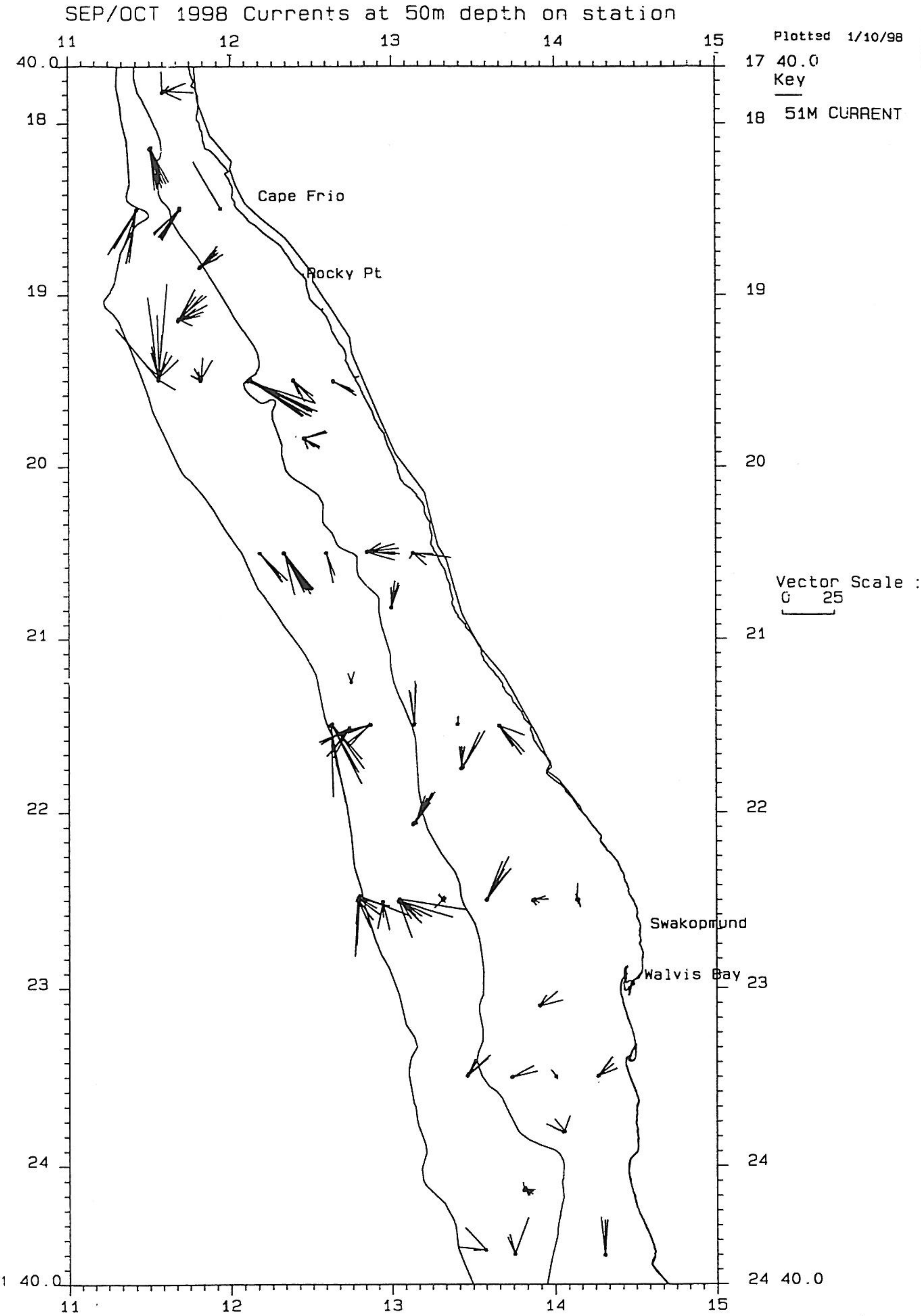


Figure 3.5b Five-minutes averaged ADCP current vectors for 50 m depth at the CTD stations.

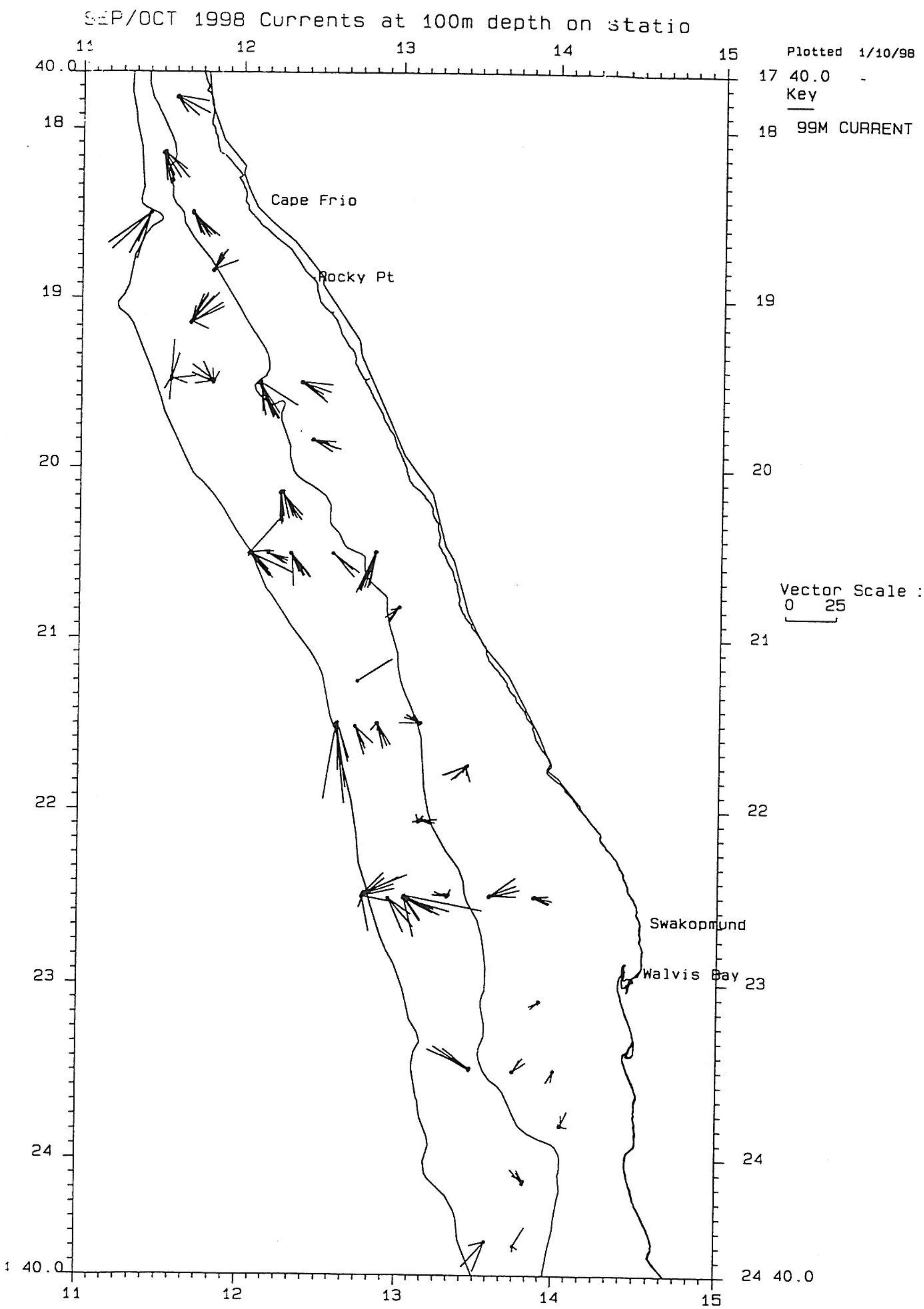


Figure 3.5c Five-minutes averaged ADCP current vectors for 100 m depth at the CTD stations.

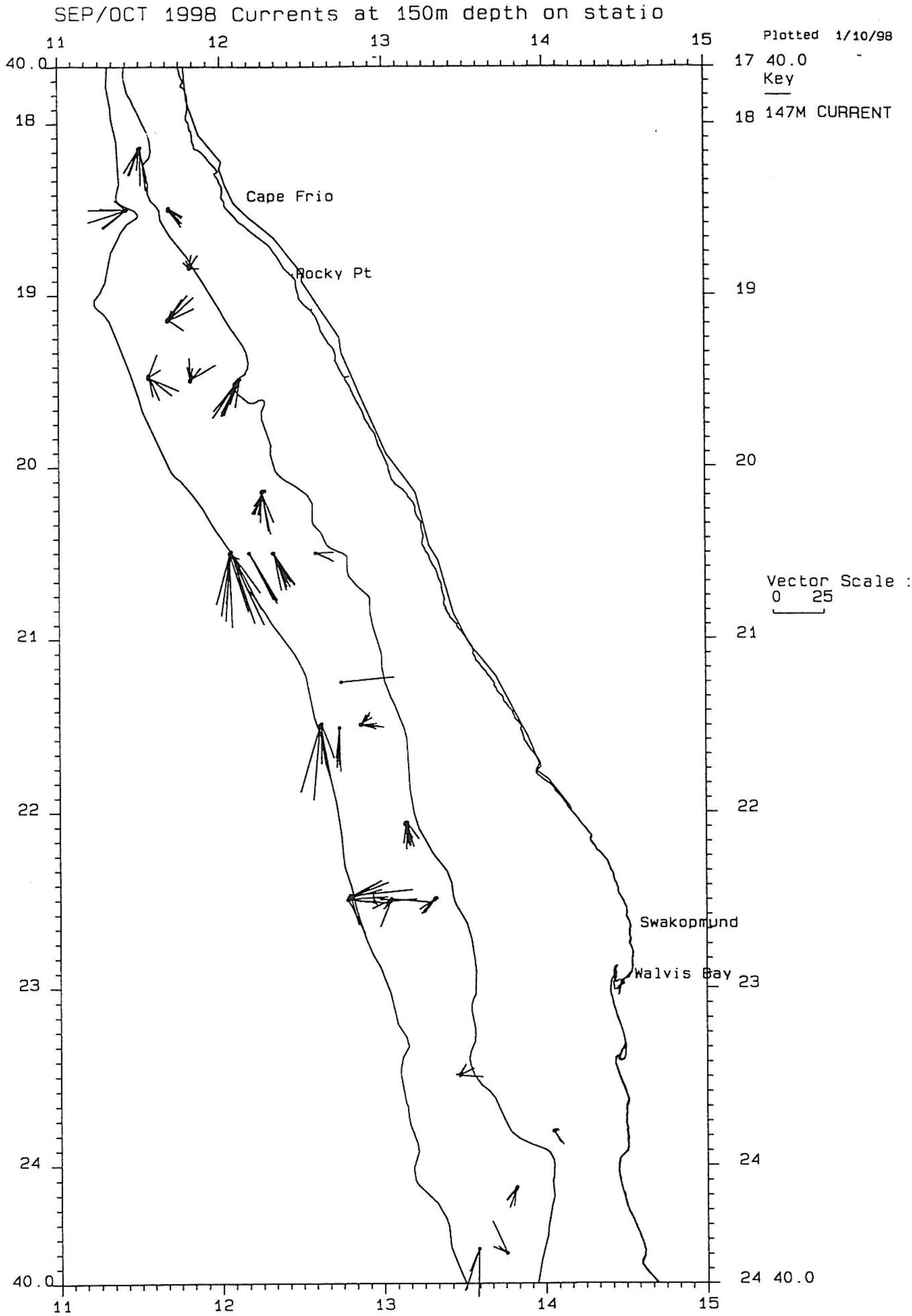


Figure 3.5d Five-minutes averaged ADCP current vectors for 150 m depth at the CTD stations.

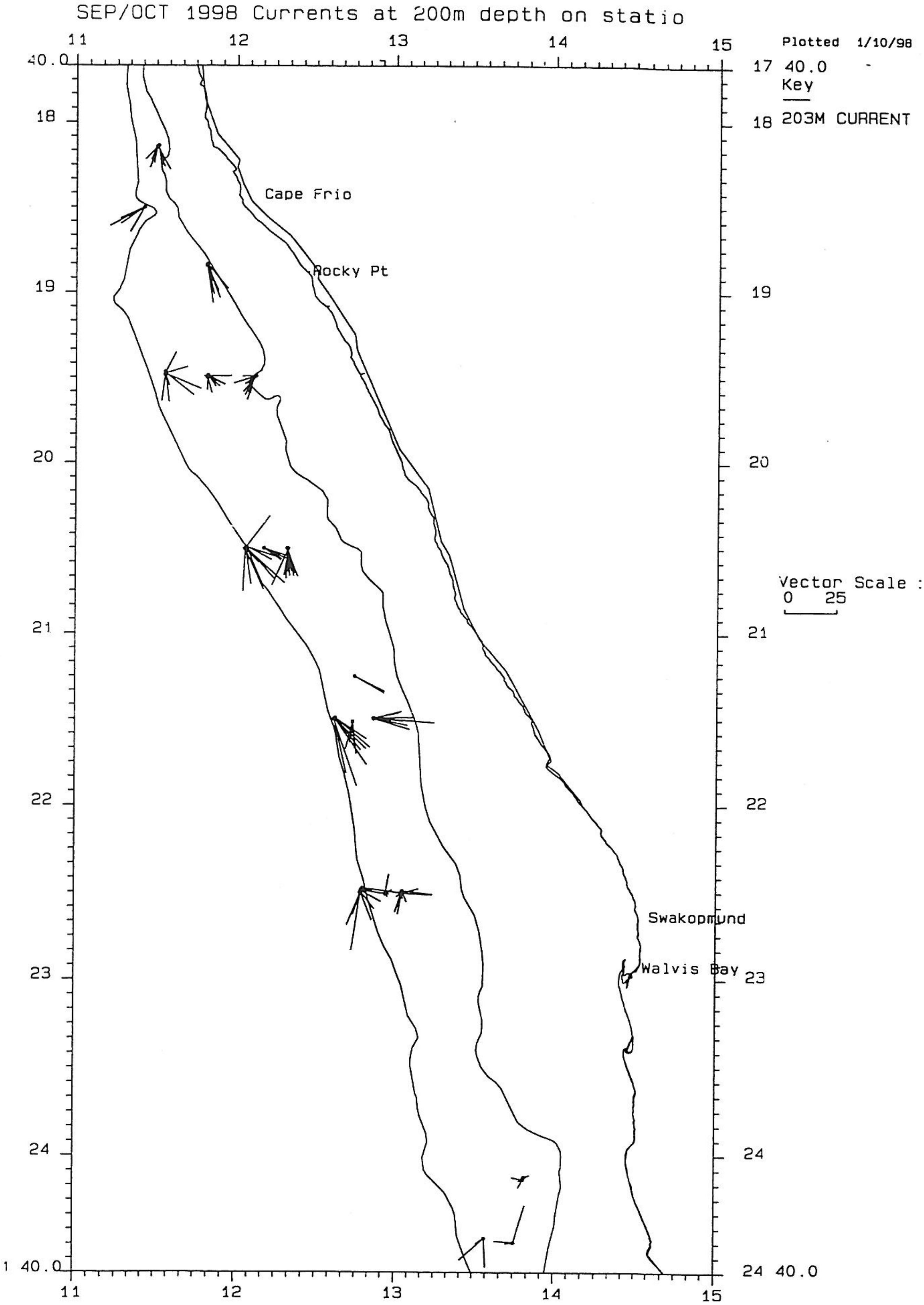


Figure 3.5e Five-minutes averaged ADCP current vectors for 200 m depth at the CTD stations.

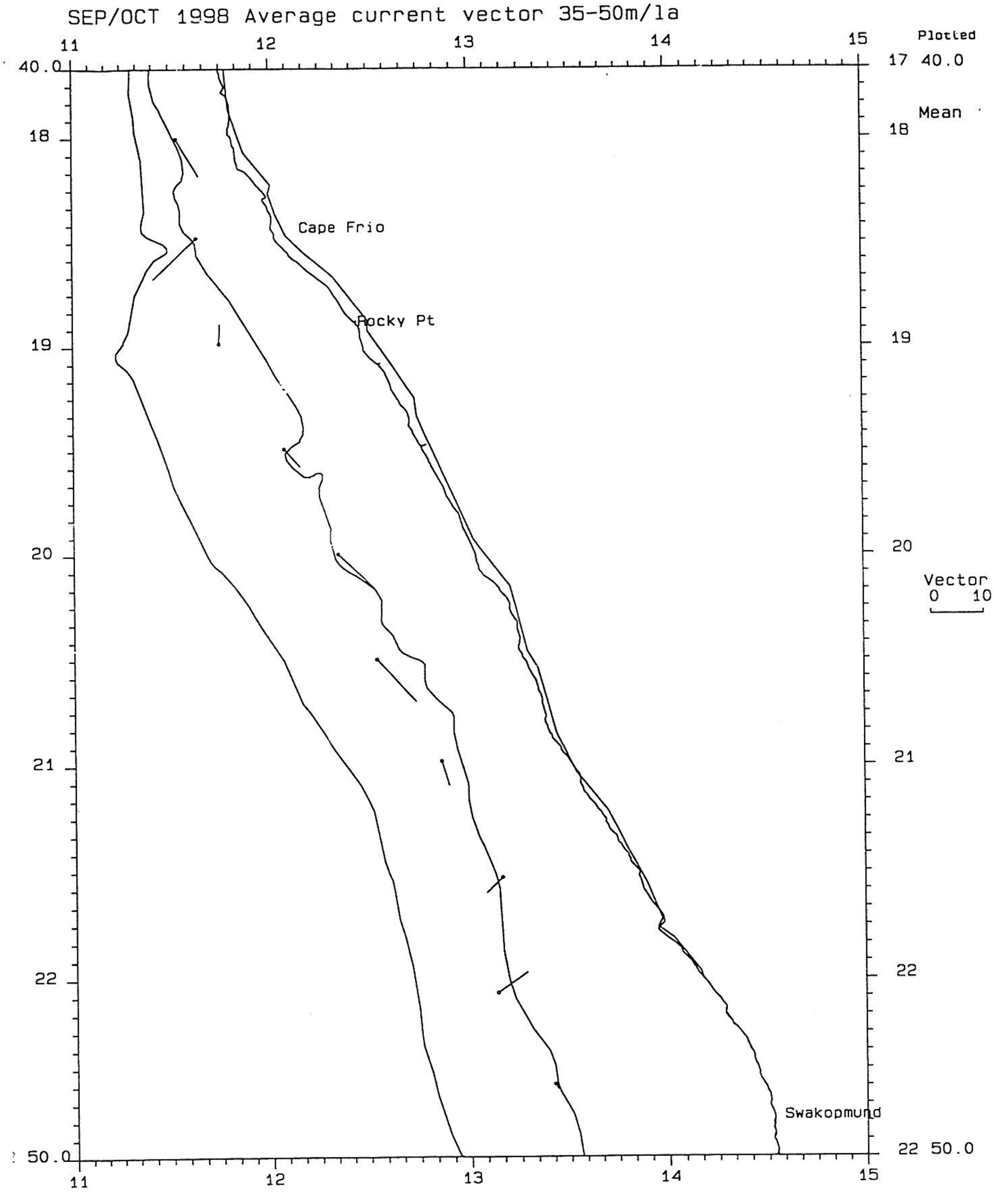


Figure 3.6 Mean ADCP current vector averaged over every half degrees of latitude, 35-50 m depth.

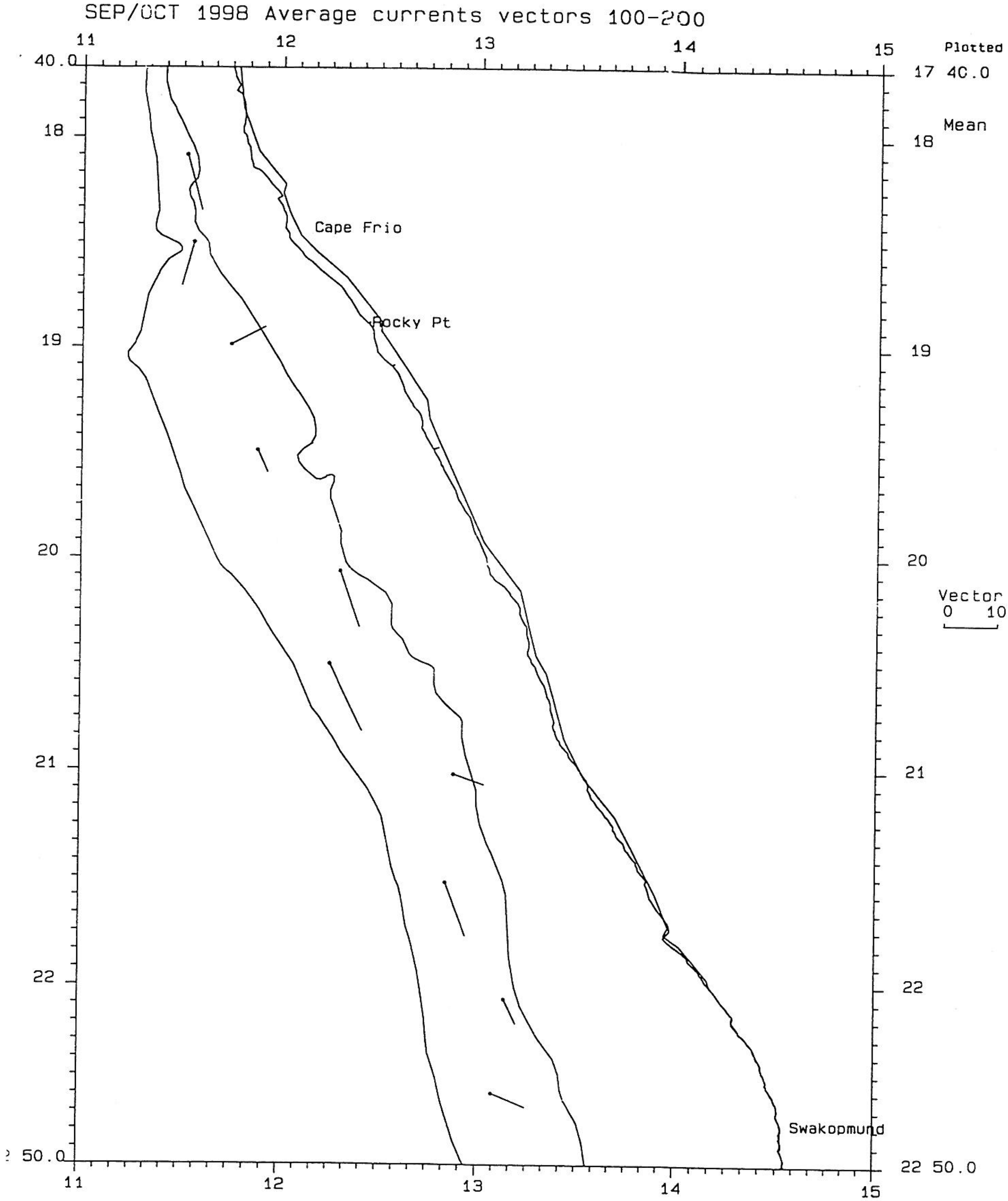


Figure 3.7 Mean ADCP current vector averaged over every half degrees of latitude, 100-200 m depth.

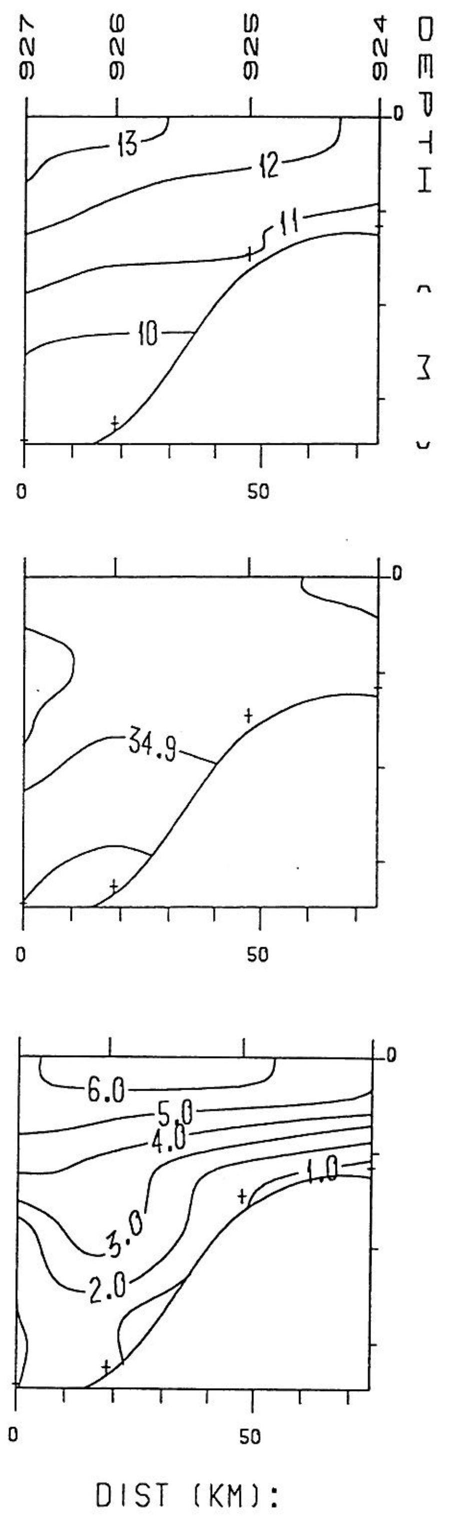


Figure 3.8 Temperature (° C), salinity and oxygen concentration (ml/l) at section Hollams Bird Island - west (24° 30' S) (stations 924 -927)

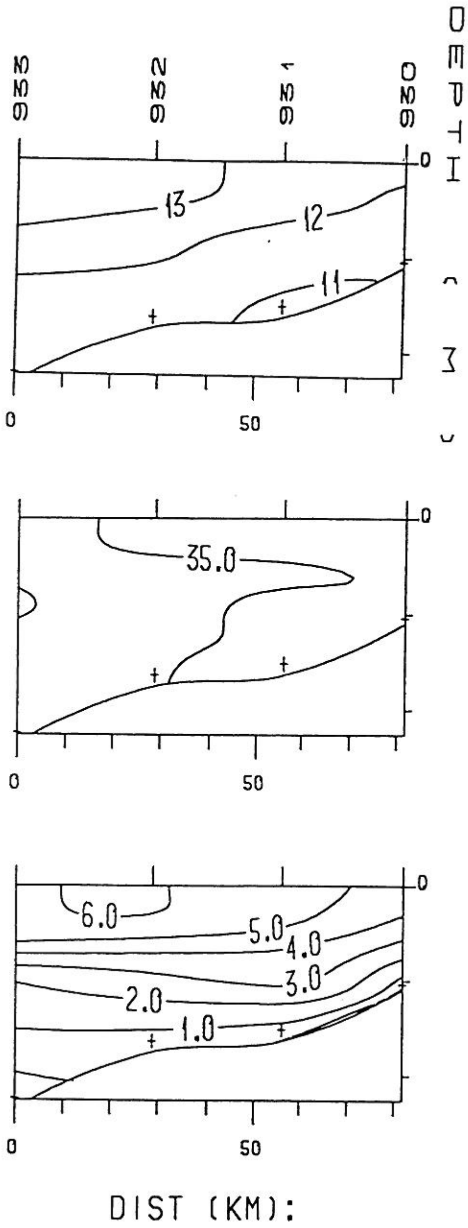


Figure 3.9 Temperature (° C), salinity and oxygen concentration (ml/l) at section Sandwich Harbour - west (23° 30' S) (stations 930 -933)

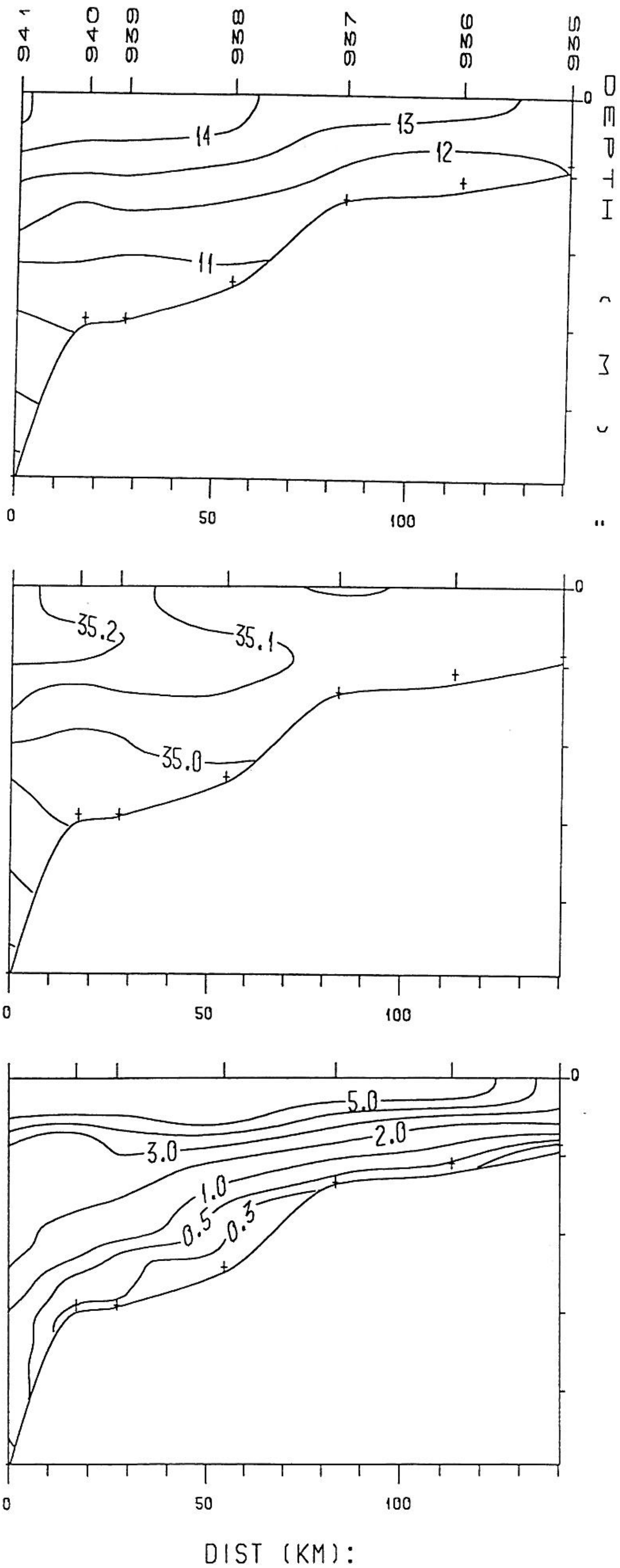


Figure 3.10 Temperature (° C), salinity and oxygen concentration (ml/l) at section to the north of Swakopmund - west (22° 30' S) (stations 935 -941)

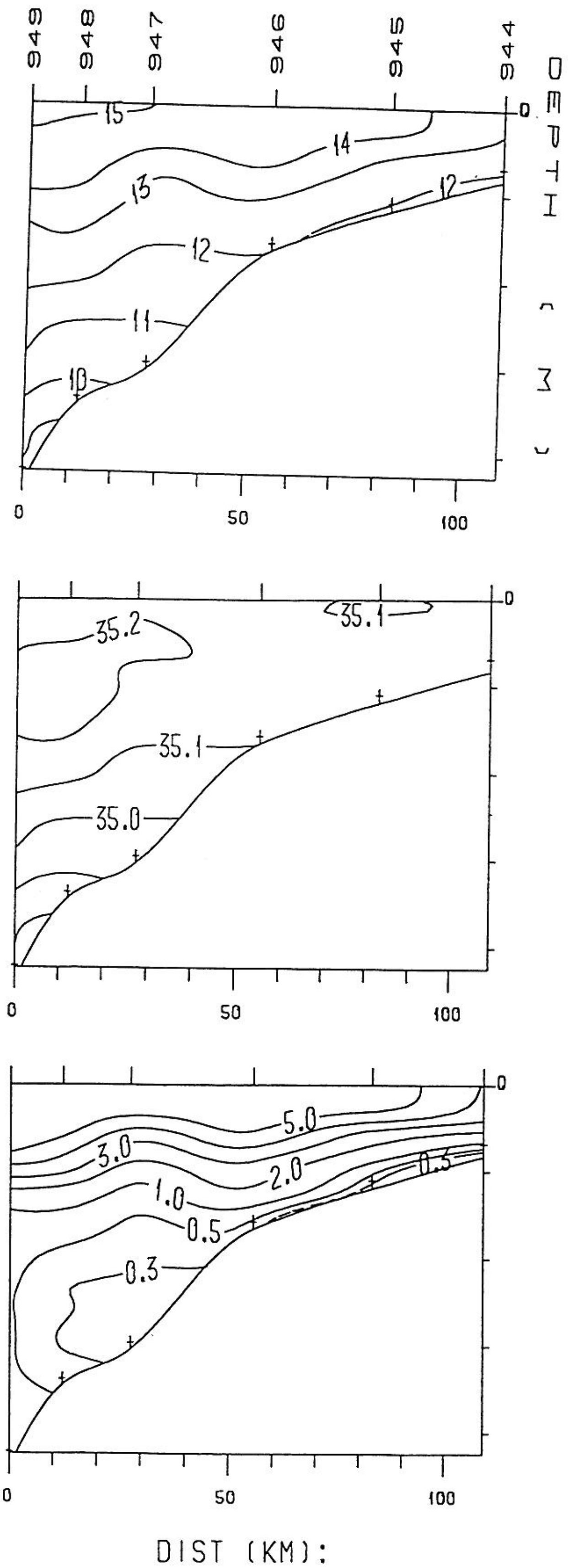


Figure 3.11 Temperature (° C), salinity and oxygen concentration (ml/l) at section to the north of Cape Cross - west (21° 30' S) (stations 944 -949)

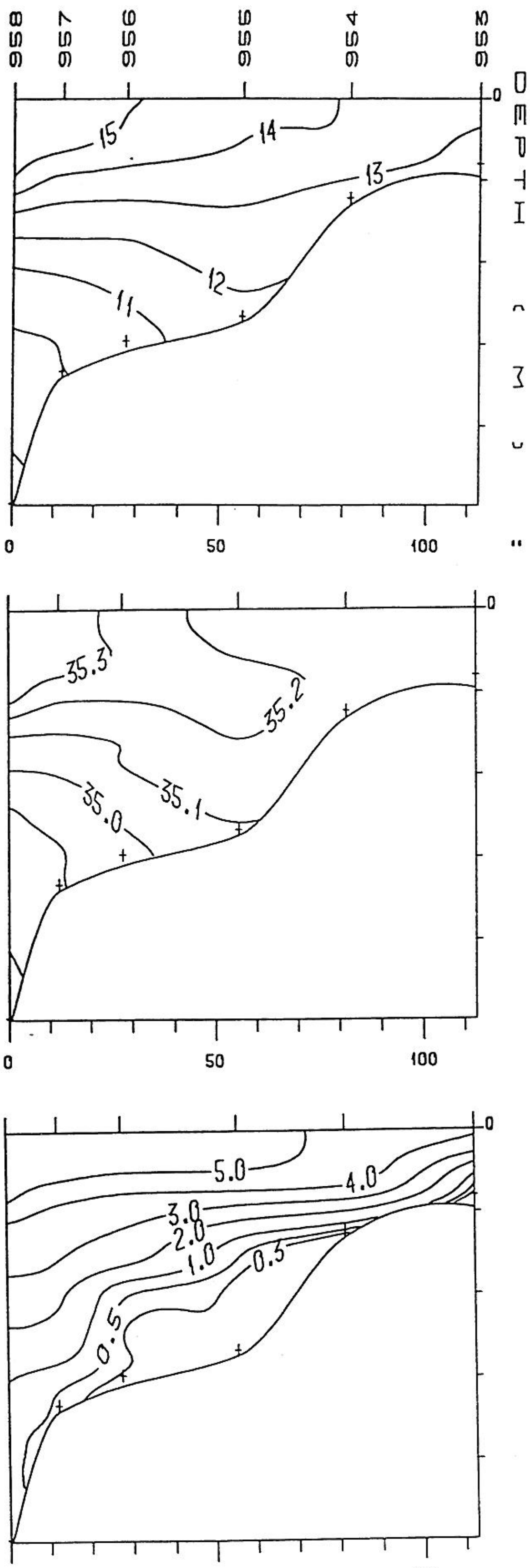


Figure 3.12 Temperature (° C), salinity and oxygen concentration (ml/l) at Palgrave Point - west (20° 30' S) (stations 953 -958)

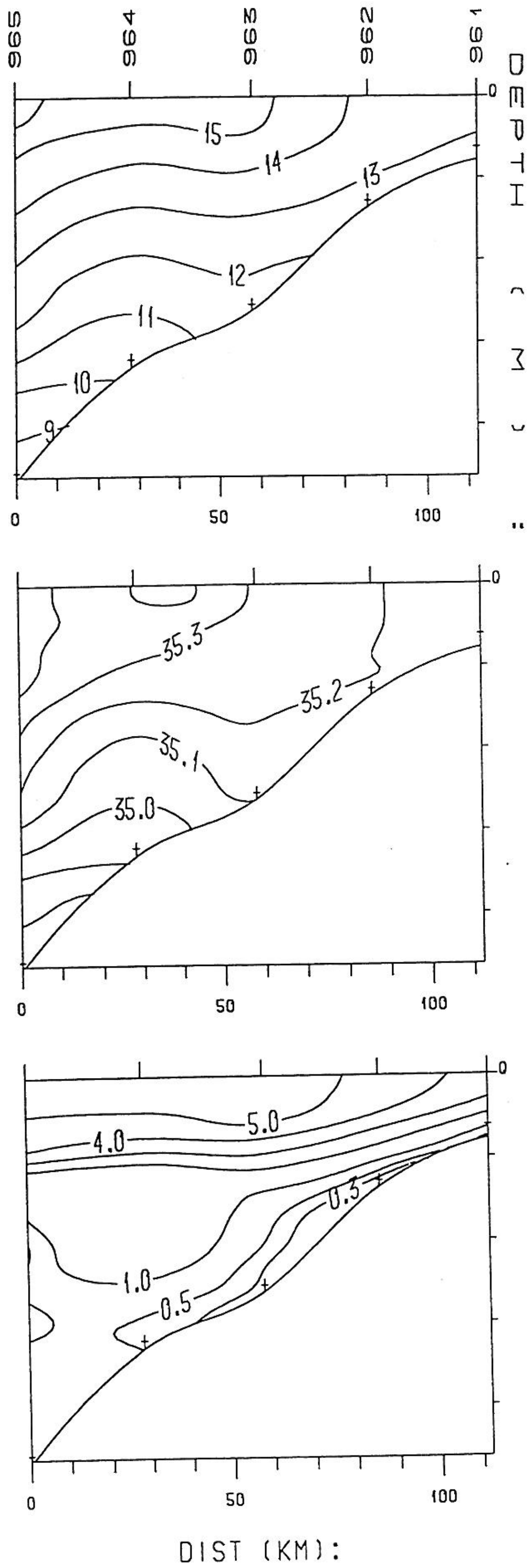


Figure 3.13 Temperature (° C) , salinity and oxygen concentration (ml/l) at section Möwe Point - west (19° 30' S) (stations 961 -965)

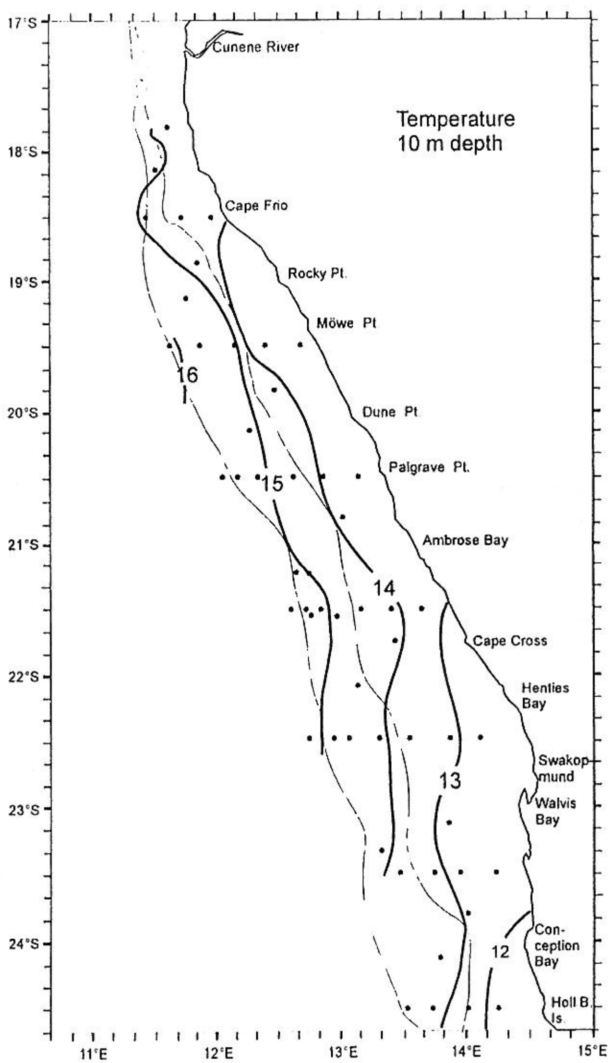


Fig. 3.14 Temperature at 10 m depth

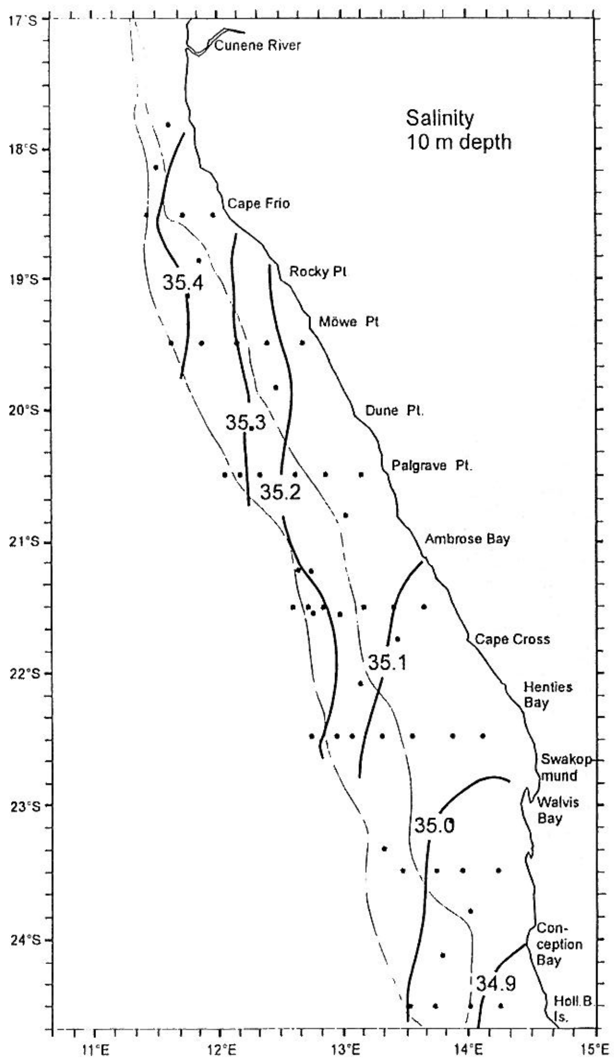


Fig. 3.15 Salinity at 10 m depth

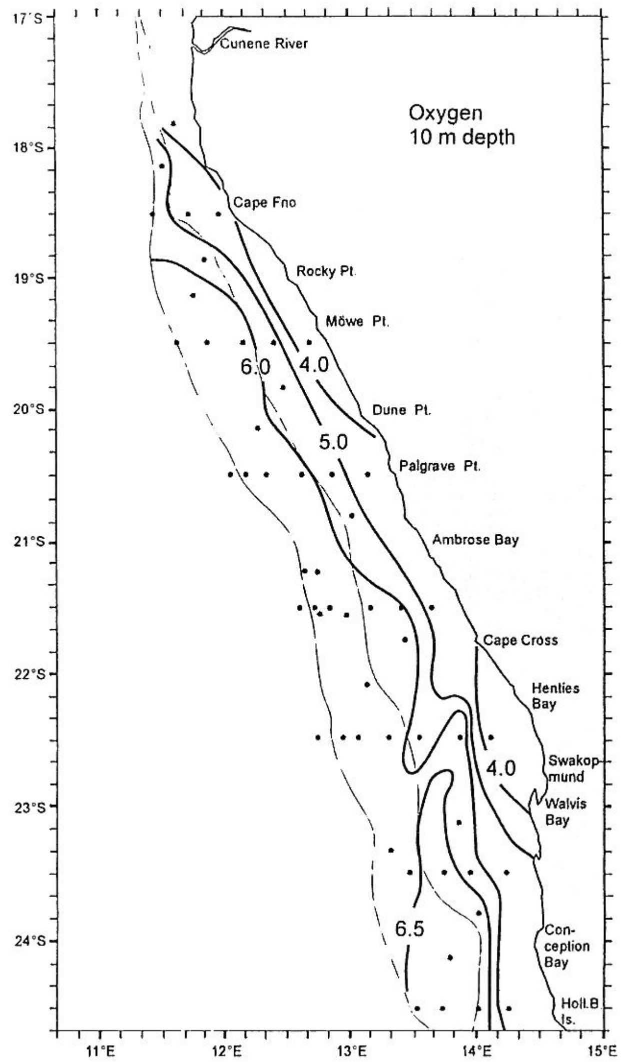


Fig. 3.16 Oxygen at 10 m depth

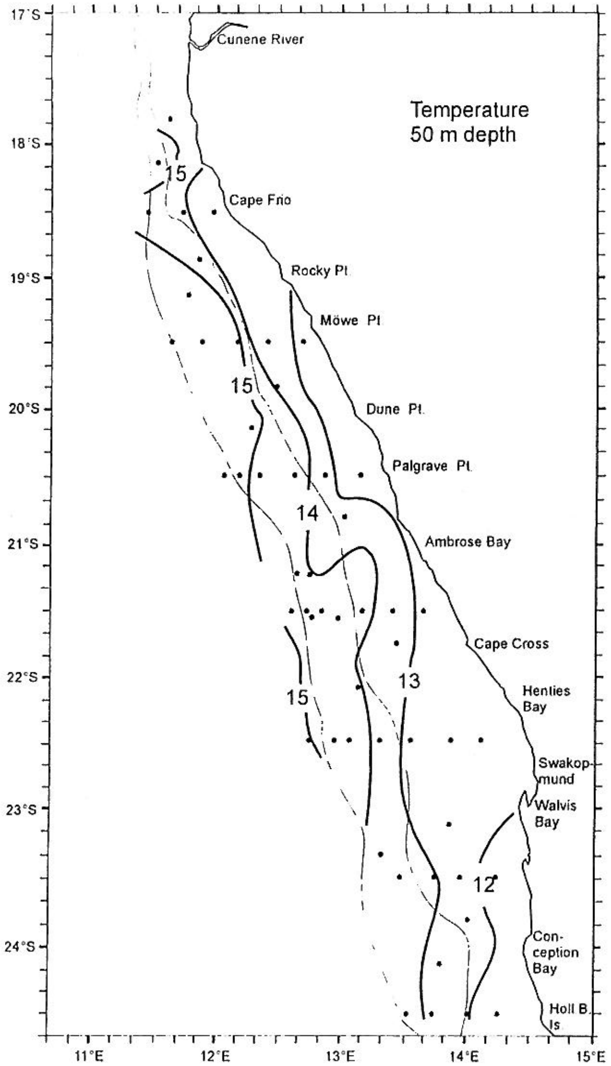


Fig. 3.17 Temperature at 50 m depth

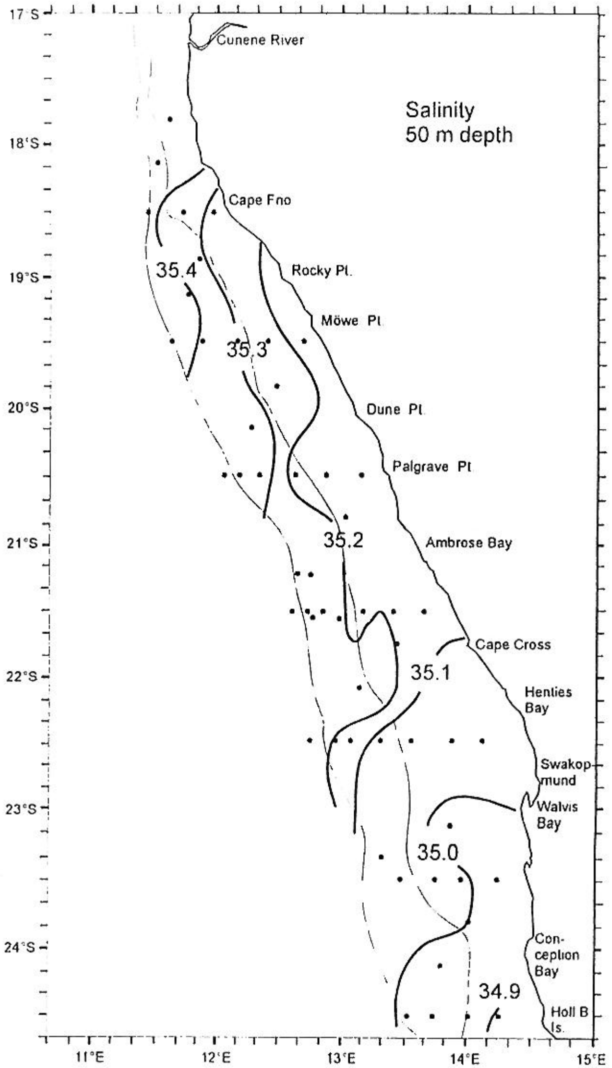


Fig. 3.18 Salinity at 50 m depth

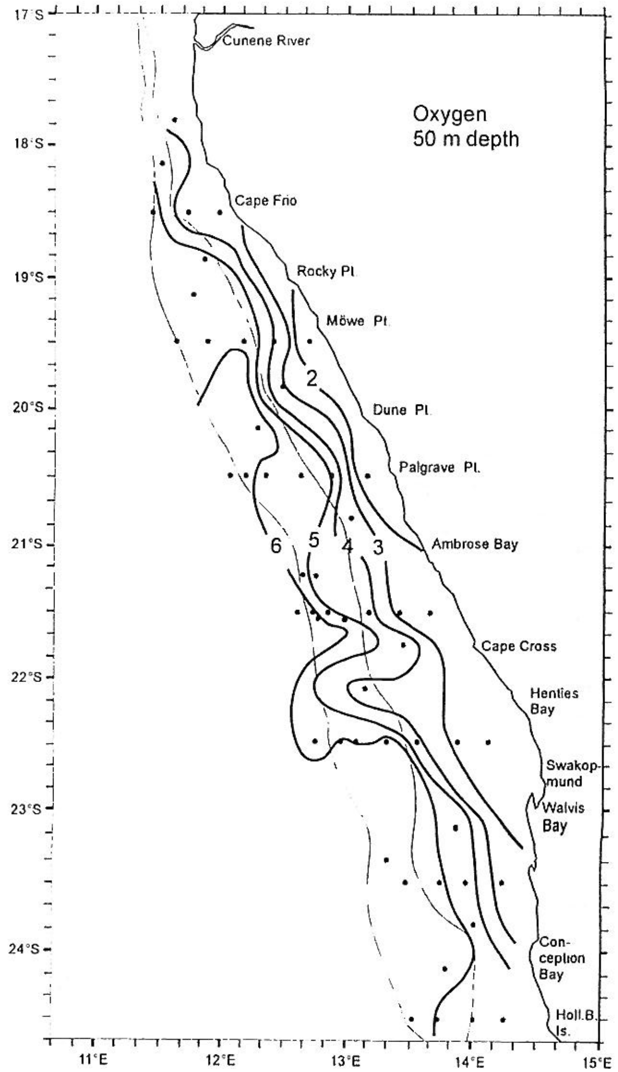


Fig. 3.19 Oxygen at 50 m depth

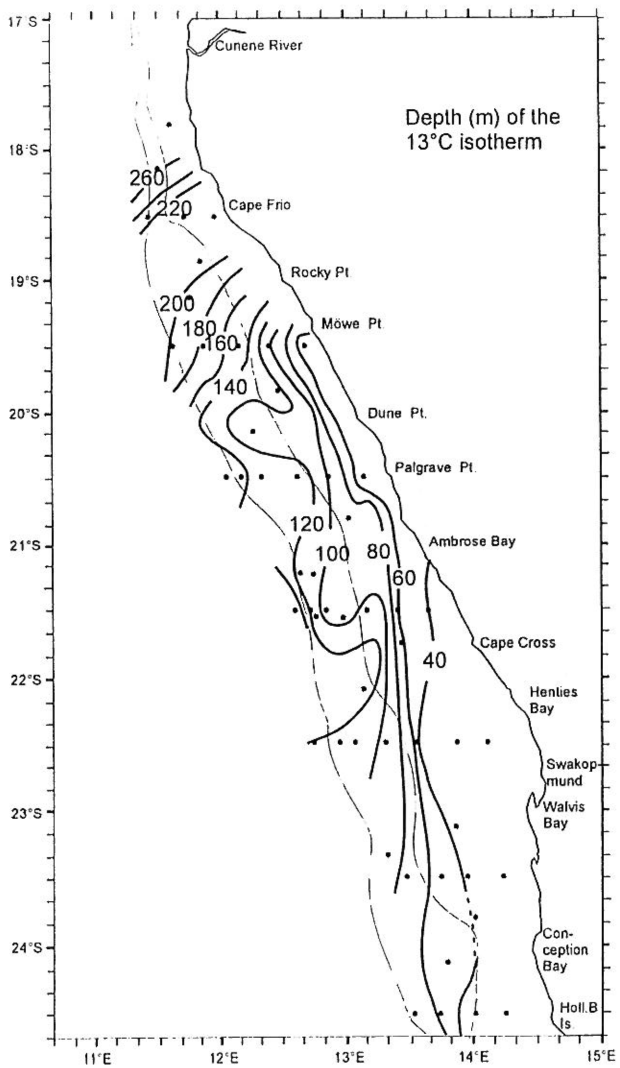


Fig.3.20 Depth (m) of the 13°C isotherm

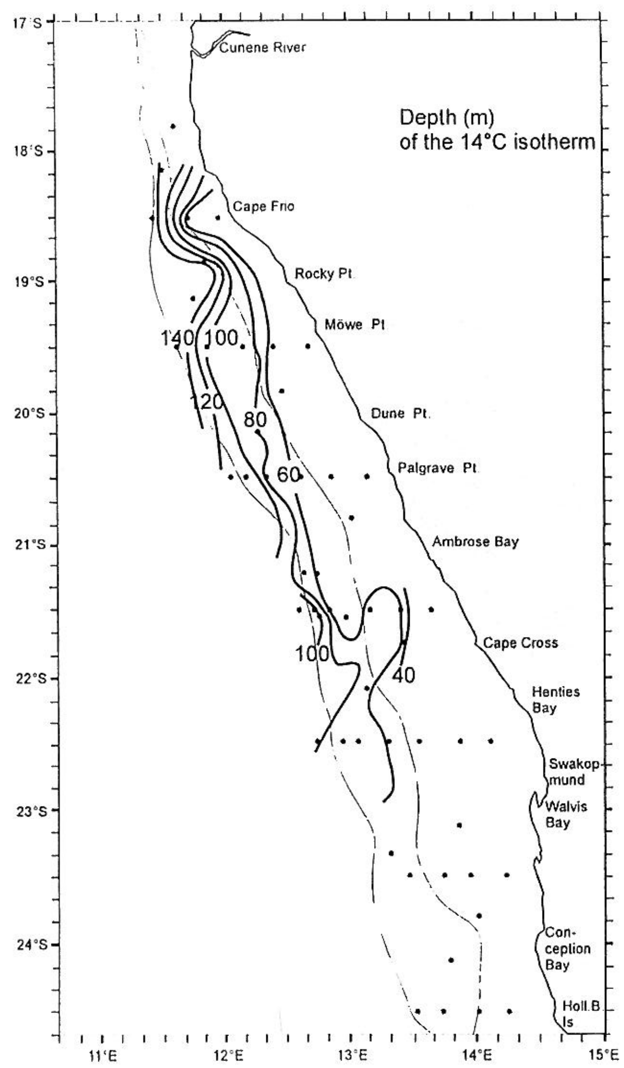


Fig.3.21 Depth (m) of the 14°C isotherm

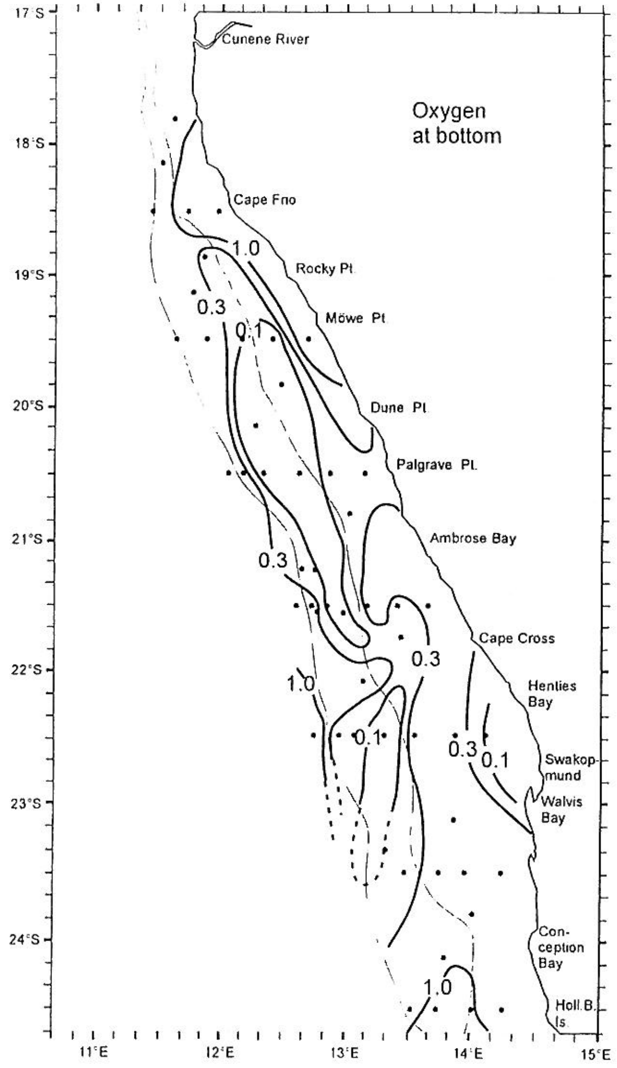


Fig.3.22 Oxygen concentration at the bottom

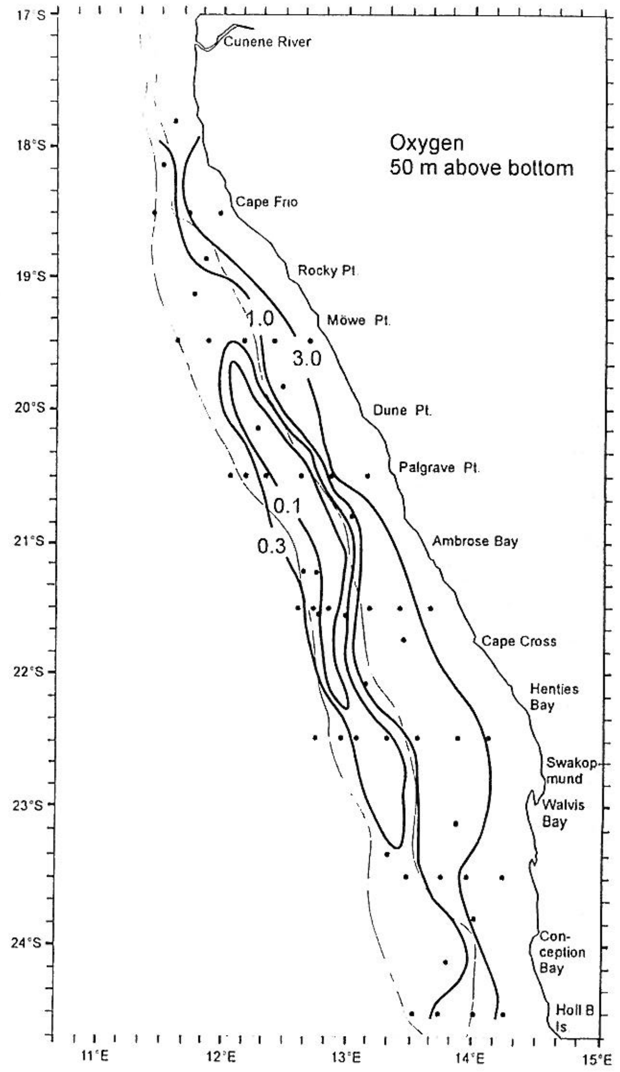


Fig.3.23 Oxygen concentration 50 m above the bottom

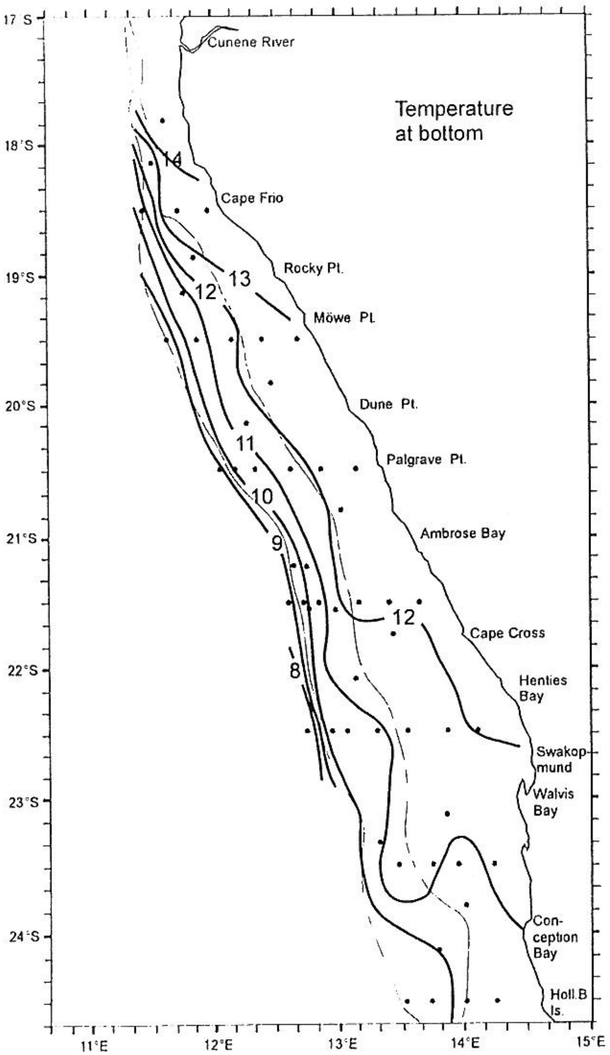


Fig. 3.24 Temperature at the bottom

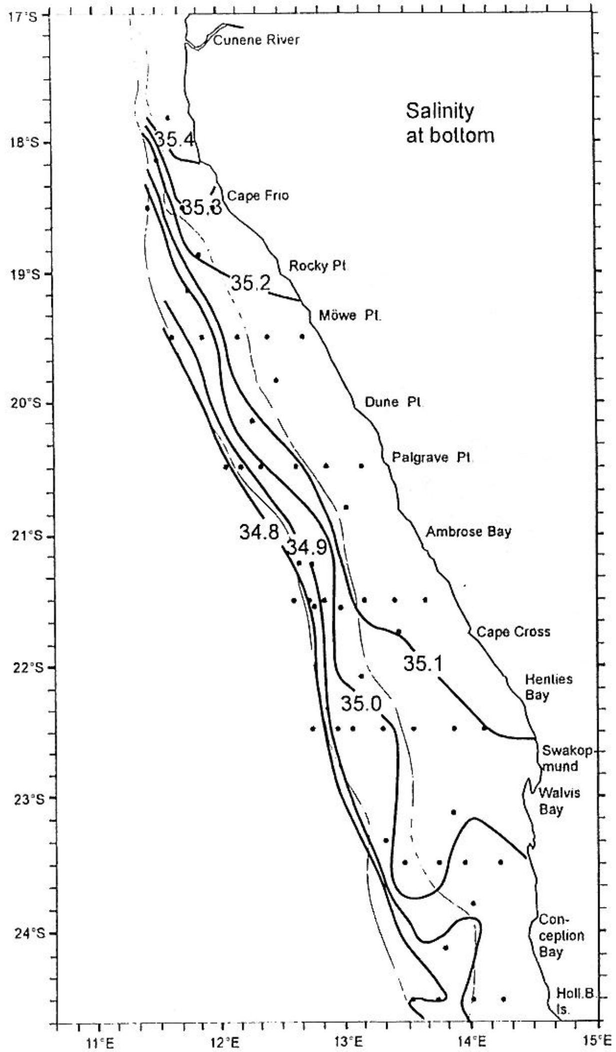


Fig. 3.25 Salinity at the bottom

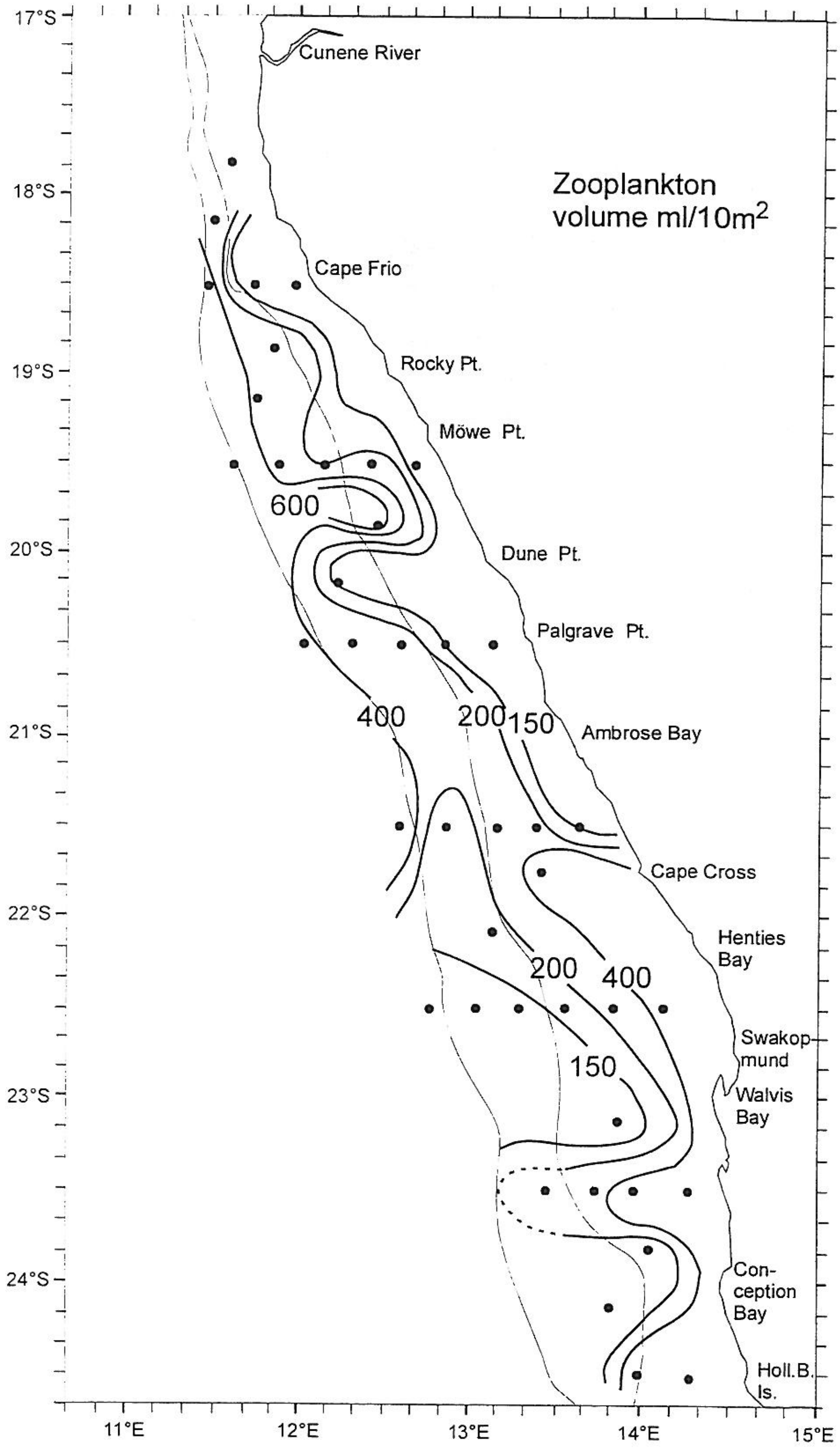


Fig. 2.26 Distribution of zooplankton volume (ml/10m2)

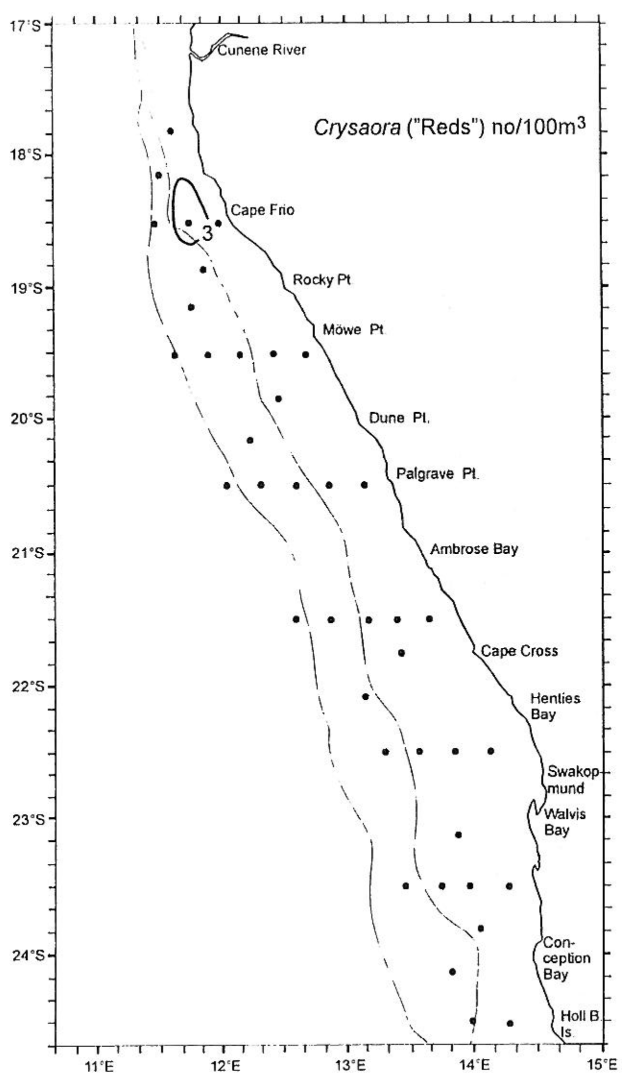


Fig. 3.27 Distribution of "Reds" *Crysaora* (#/100m^3)

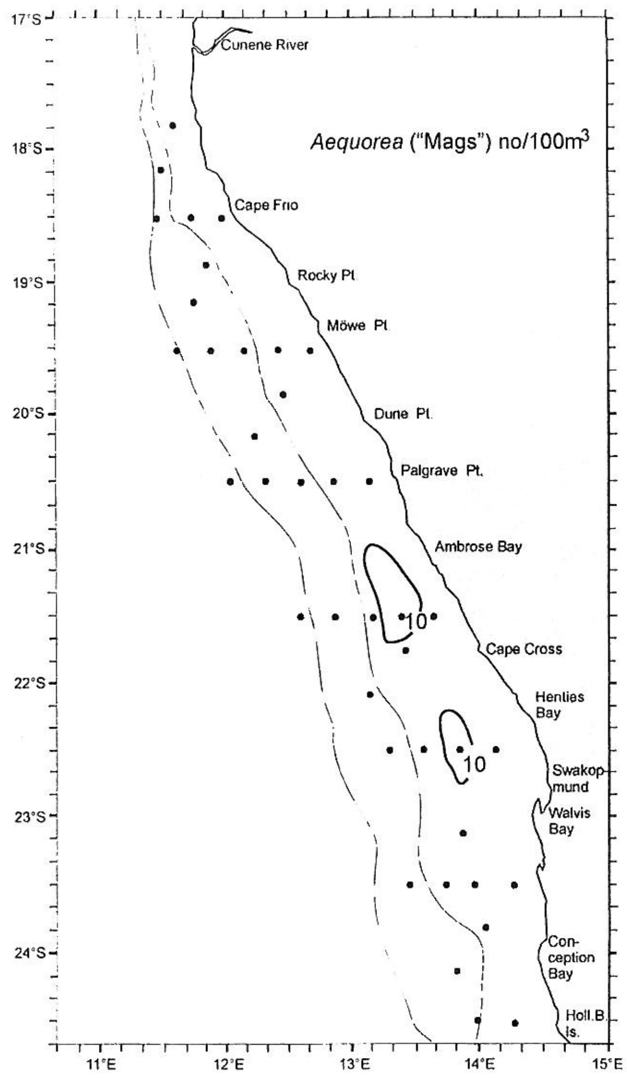


Fig. 3.28 Distribution of "Mags" *Aequorea* (#/100m^3)

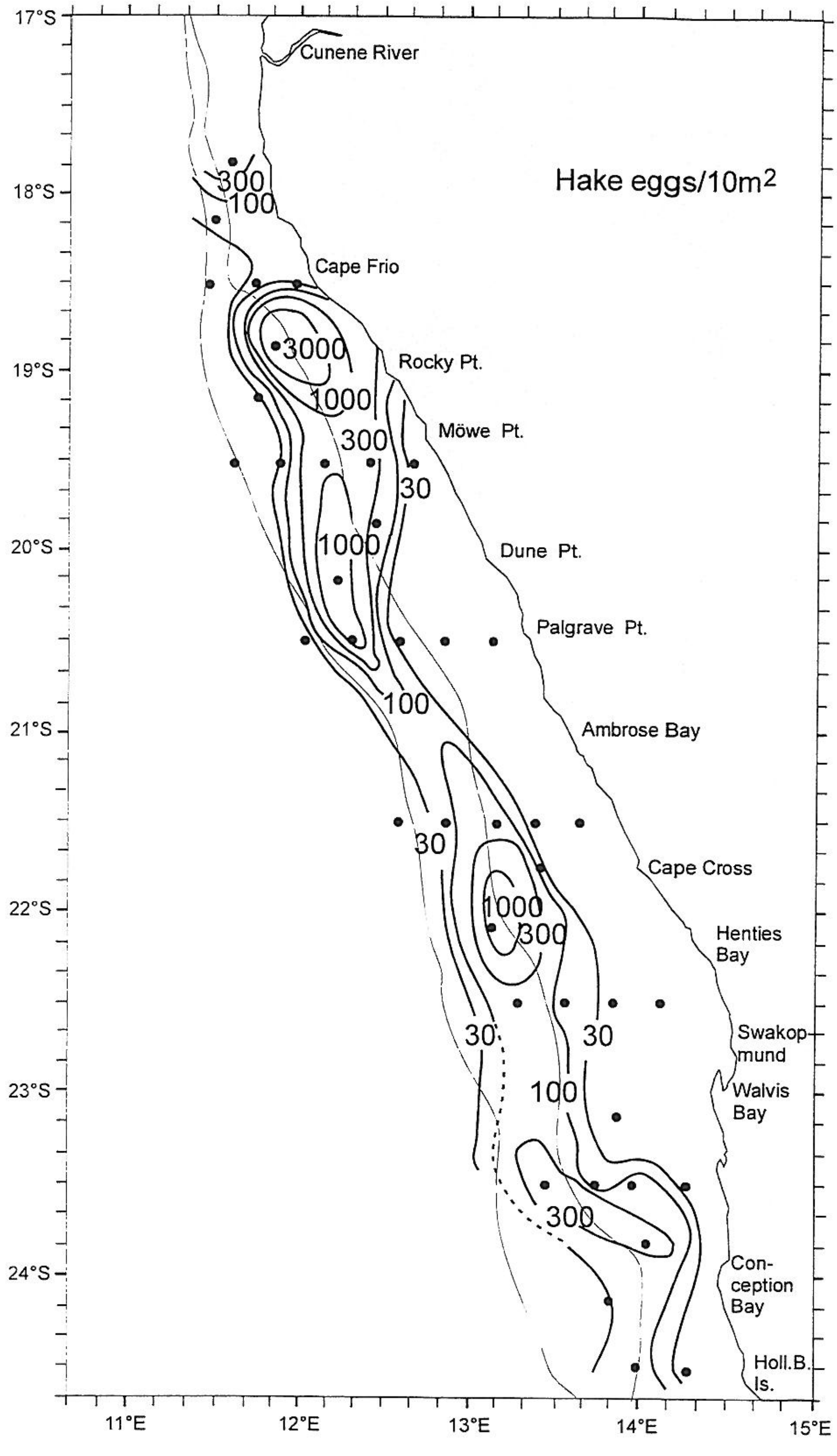


Fig. 3.29 Distribution of hake eggs (#/10m^2), all stages.

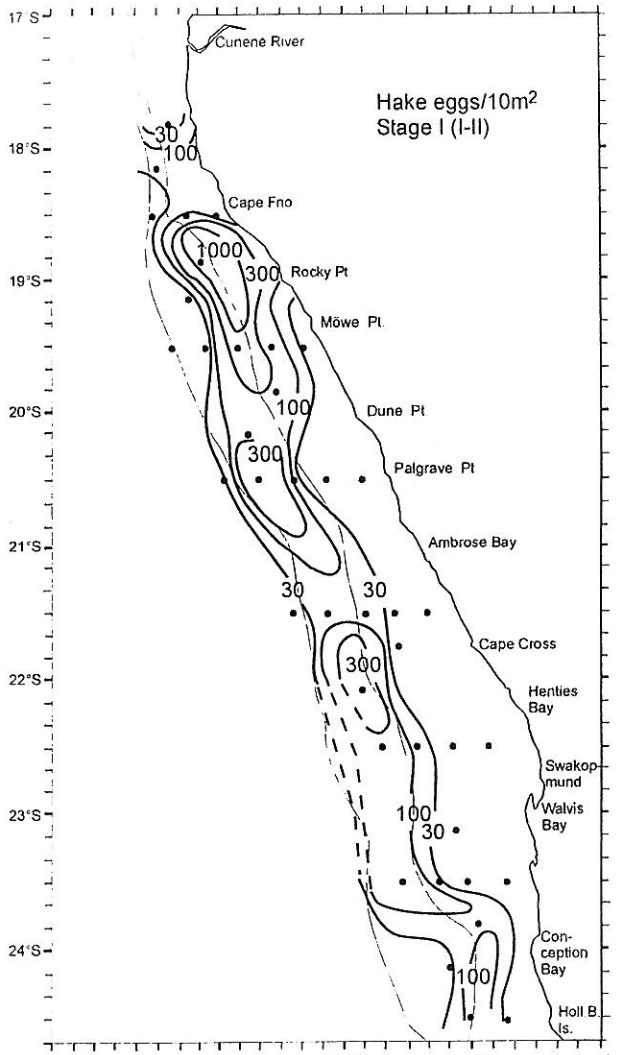


Fig. 3.30 Hake eggs/10m²
Stage I (I-II)

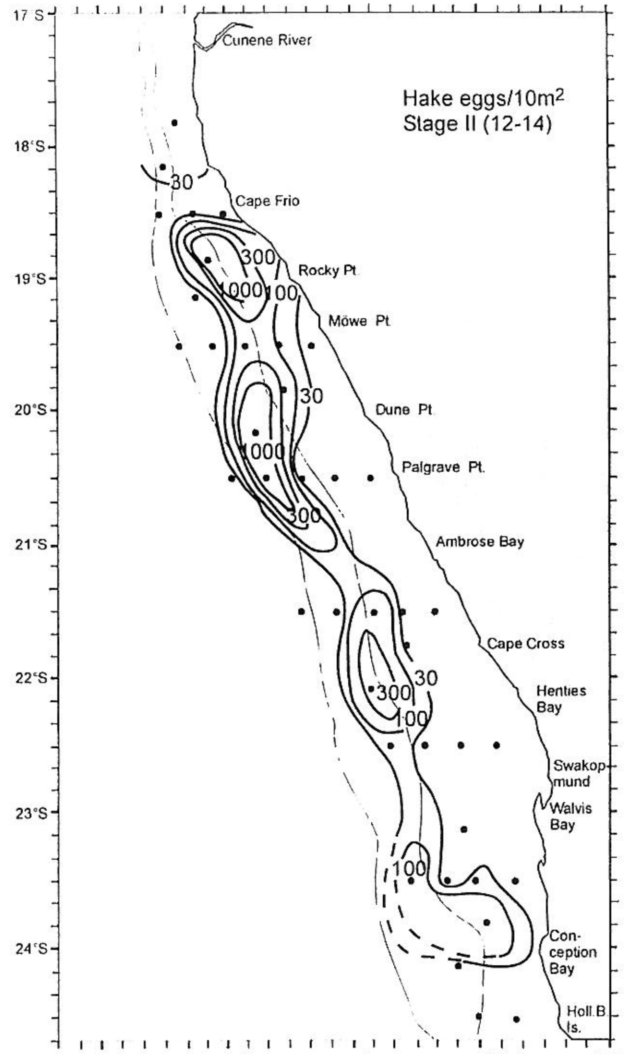


Fig. 3.31 Hake eggs/10m²
Stage II (I2-14)

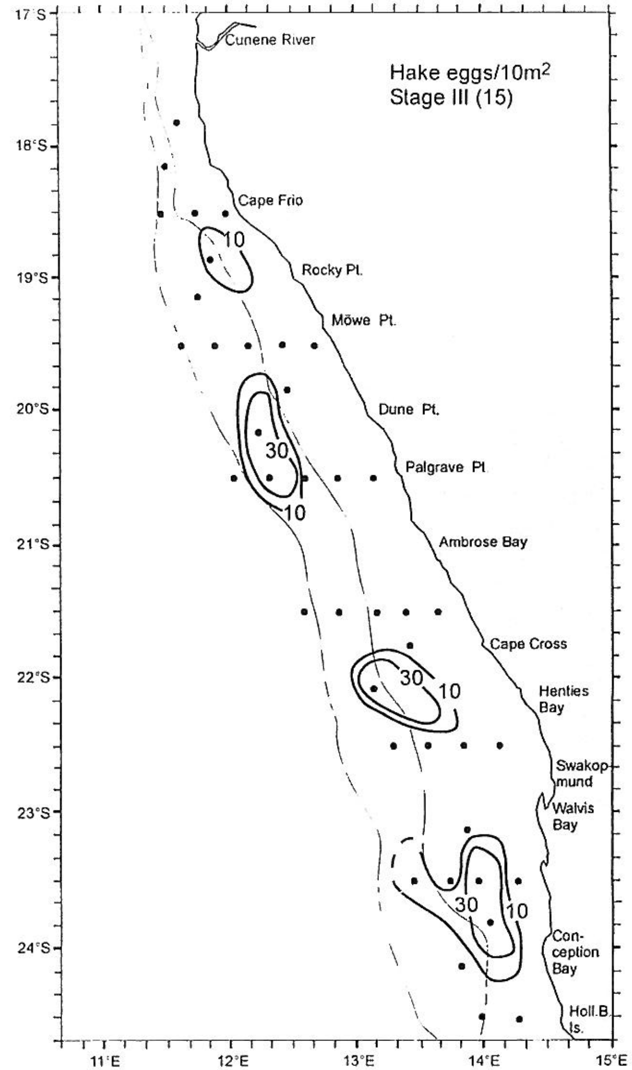


Fig. 3.32 Hake eggs/10m²
Stage III (I5)

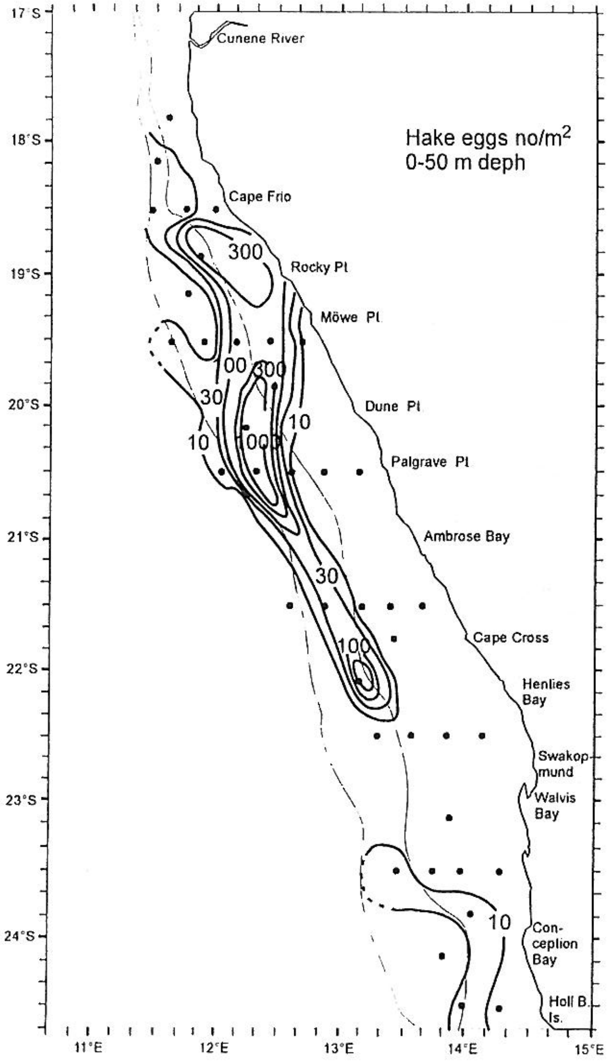


Fig. 3.33 Distribution of hake egg, all stages, 0-50 m depth (#/10m^2)

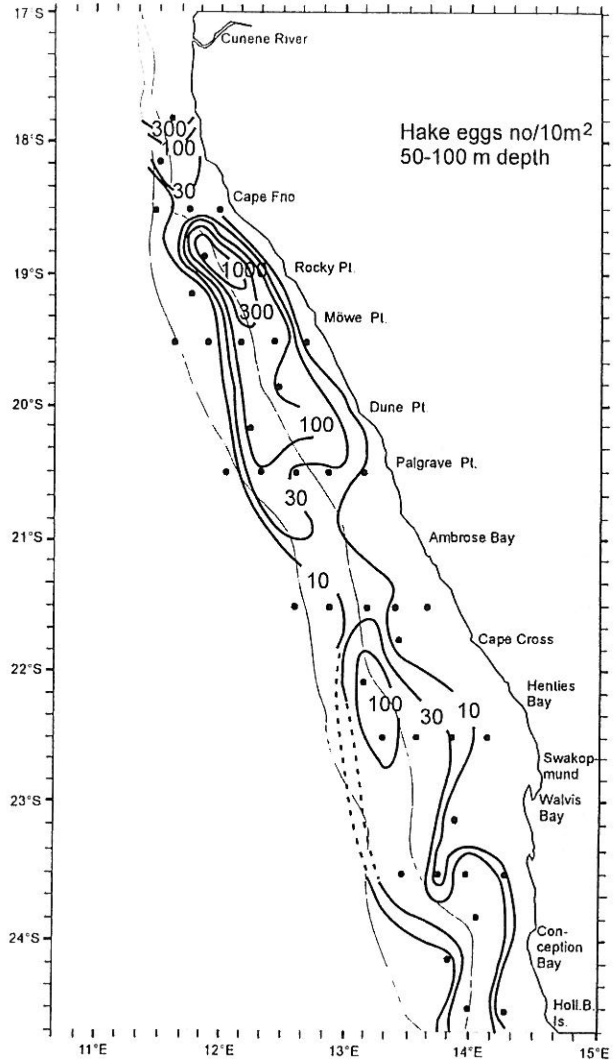


Fig. 3.34 Distribution of hake egg, all stages, 50-100 m depth (#/10m^2)

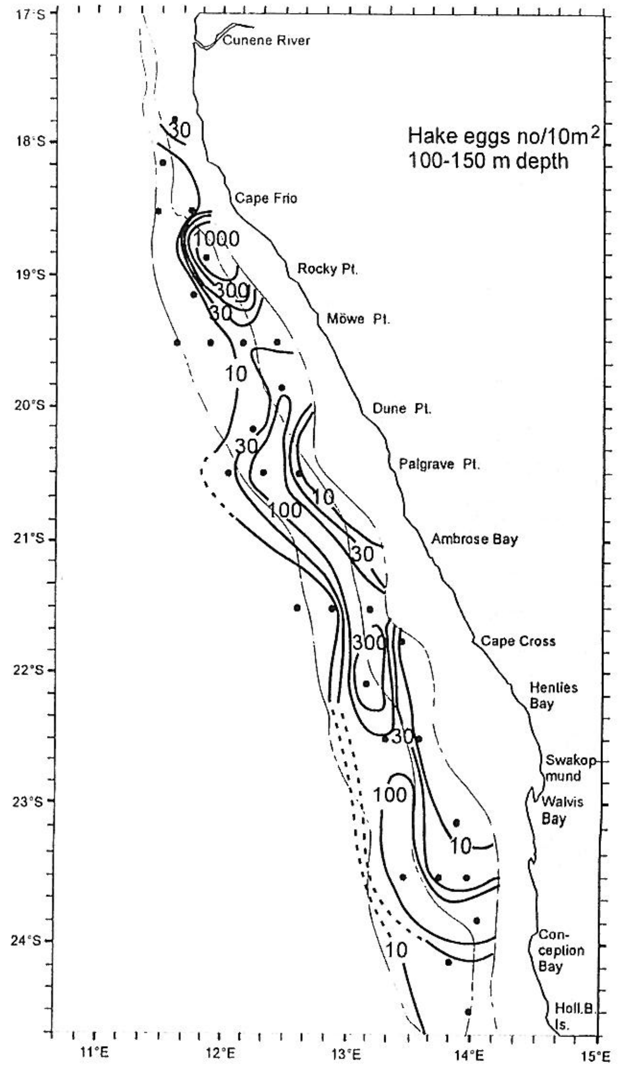


Fig. 3.35 Distribution of hake egg, all stages, 100-150 m depth (#/10m^2)

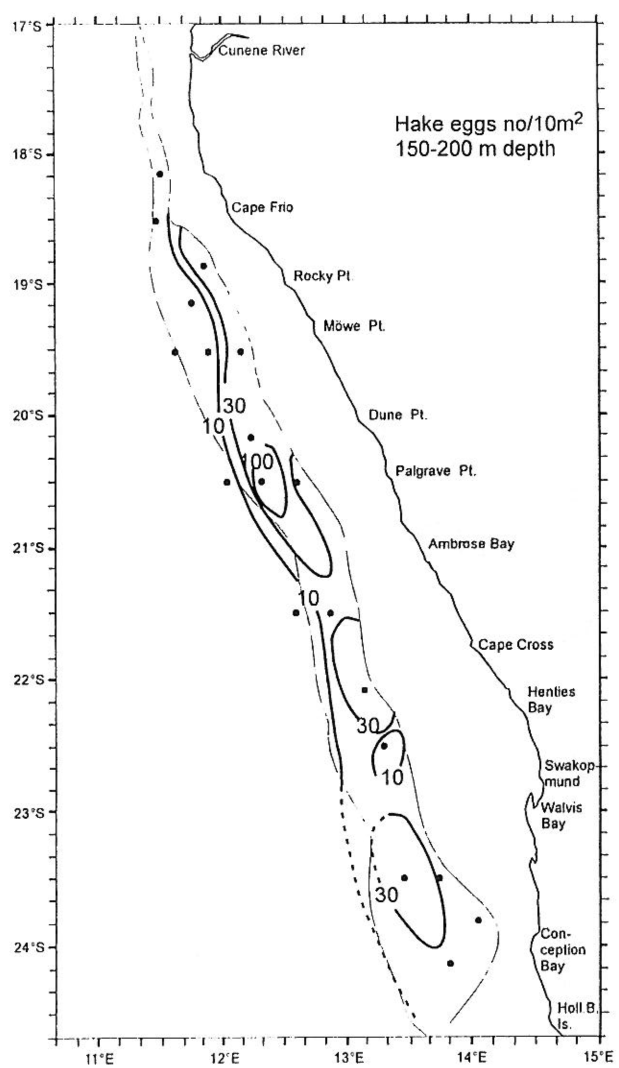


Fig. 3.36 Distribution of hake eggs, all stages, 150-200 m depth (#/10m^2)

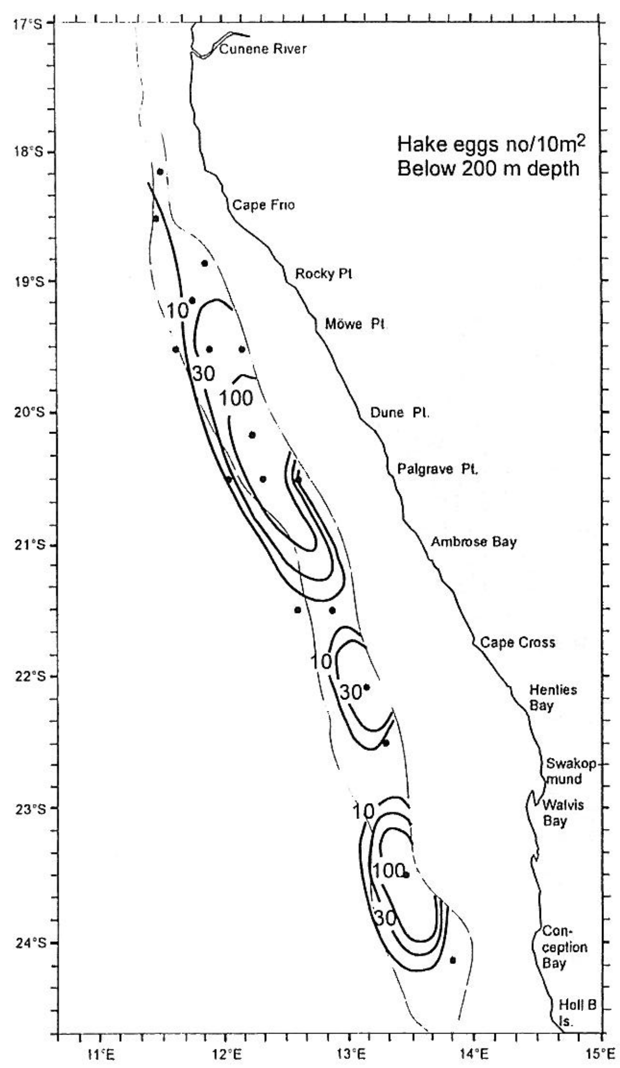


Fig. 3.37 Distribution of hake eggs, all stages, below 200 m depth (#/10m^2)

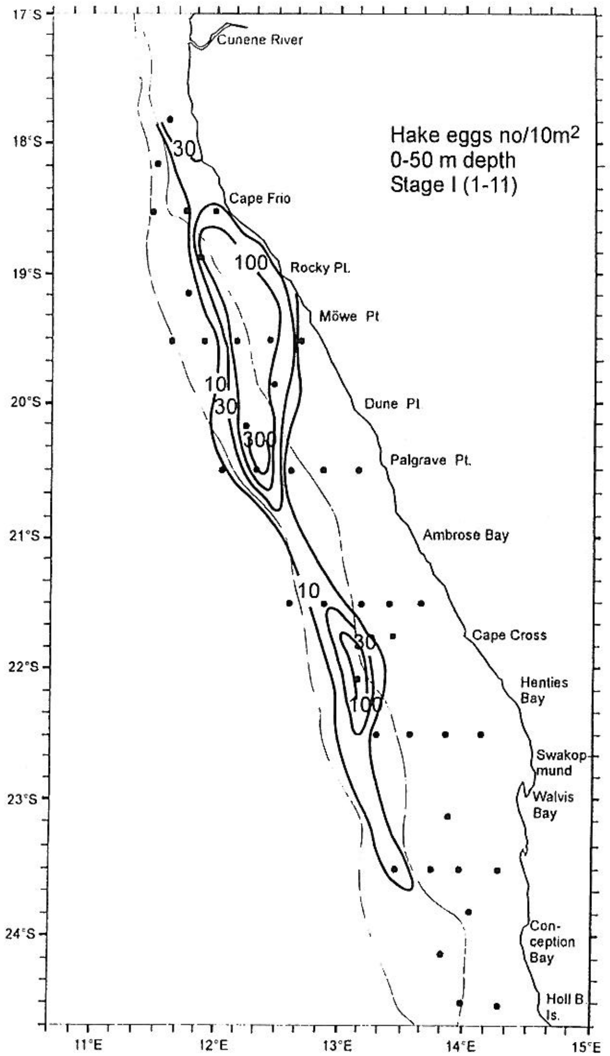


Fig. 3.38 Distribution of hake eggs, stage I, 0-50 m depth (#/10m^2)

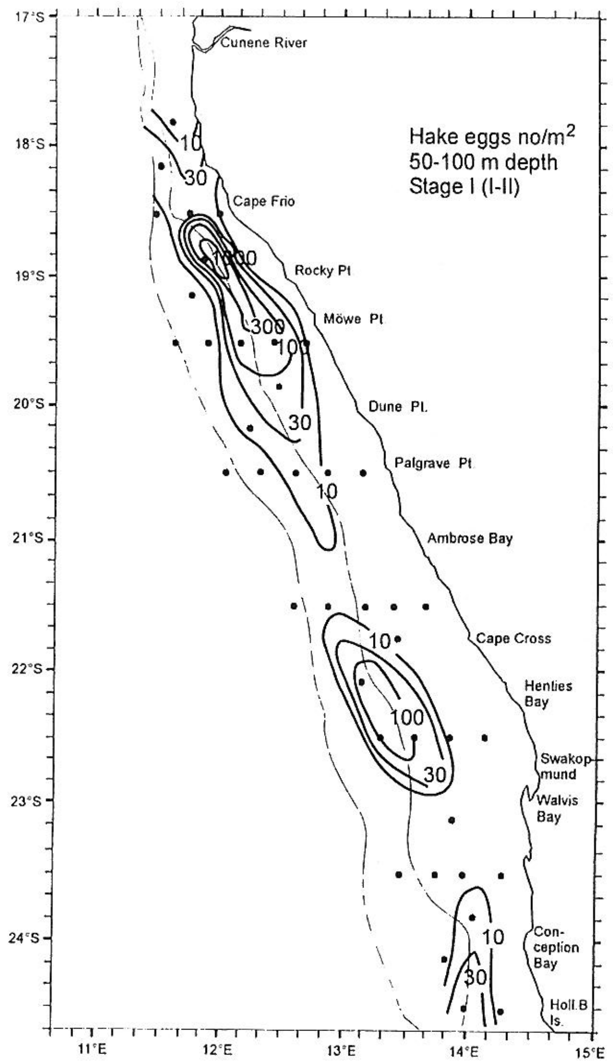


Fig. 3.39 Distribution of hake eggs, stage I, 50-100 m depth (#/10m^2)

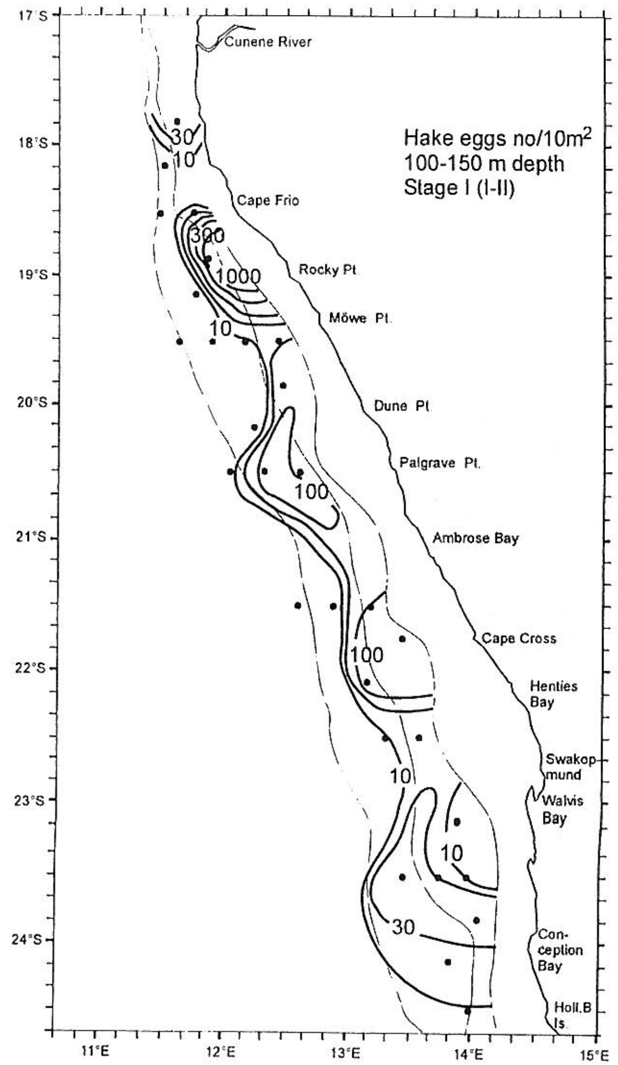


Fig. 3.40 Distribution of hake eggs, stage I, 100-150 m depth (#/10m^2)

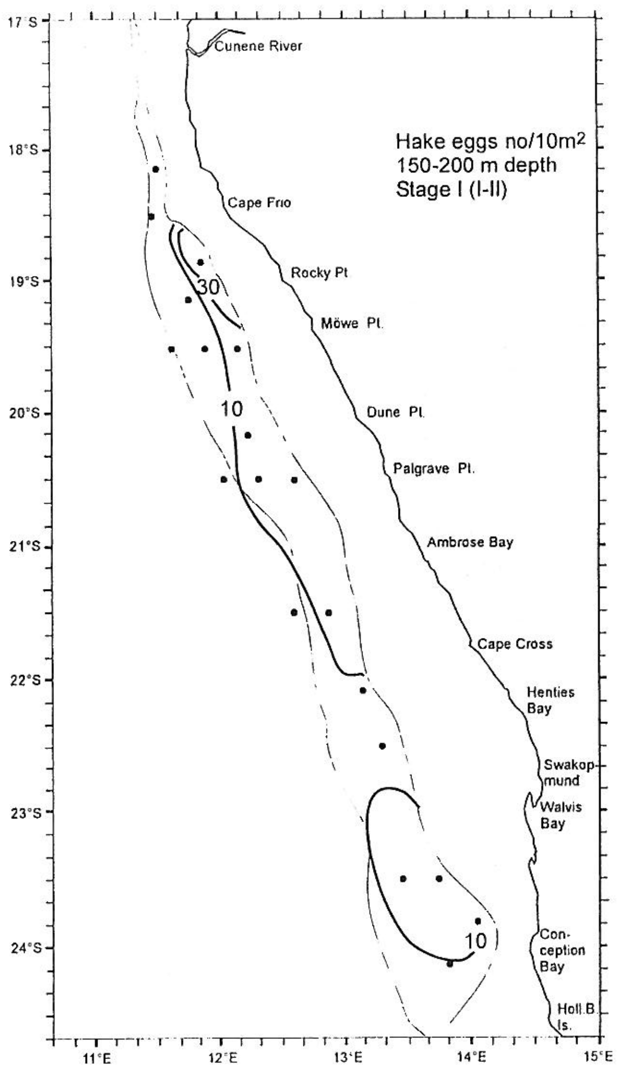


Fig. 3.41 Distribution of hake eggs, stage I, 150-200 m depth (#/10m^2)

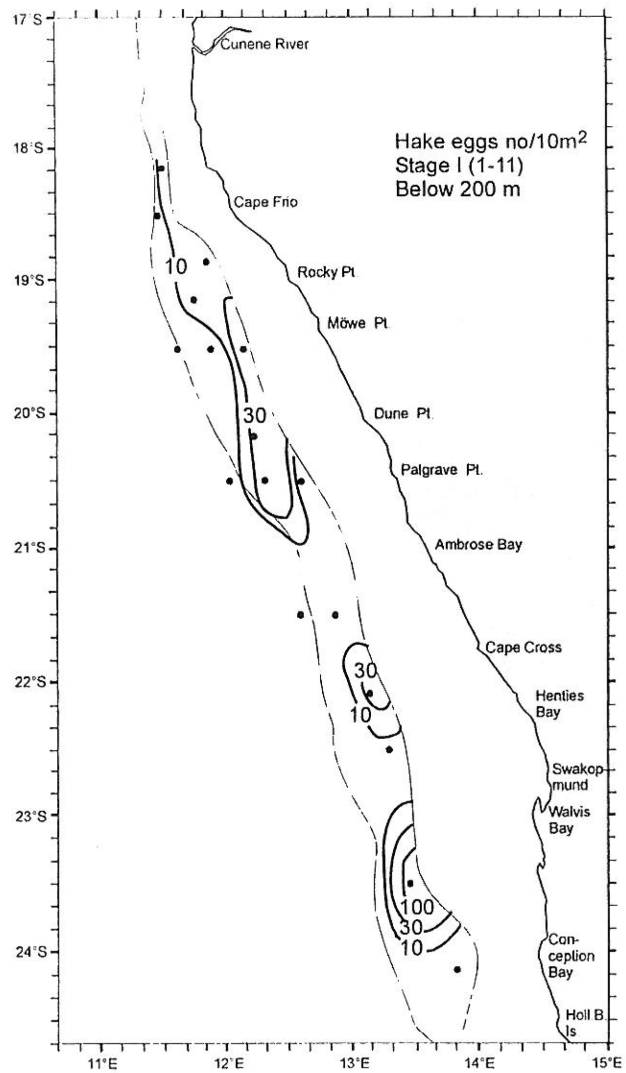


Fig. 3.42 Distribution of hake eggs, stage I, below 200 m depth (#/10m^2)

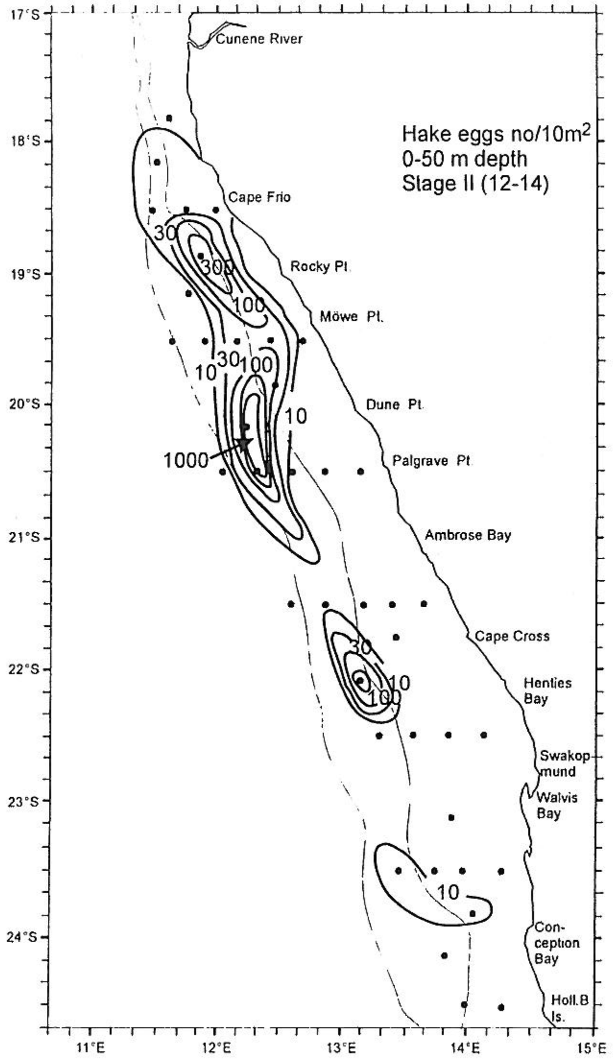


Fig. 3.43 Distribution of hake eggs, stage II, 0-50 m depth (#/10m^2)

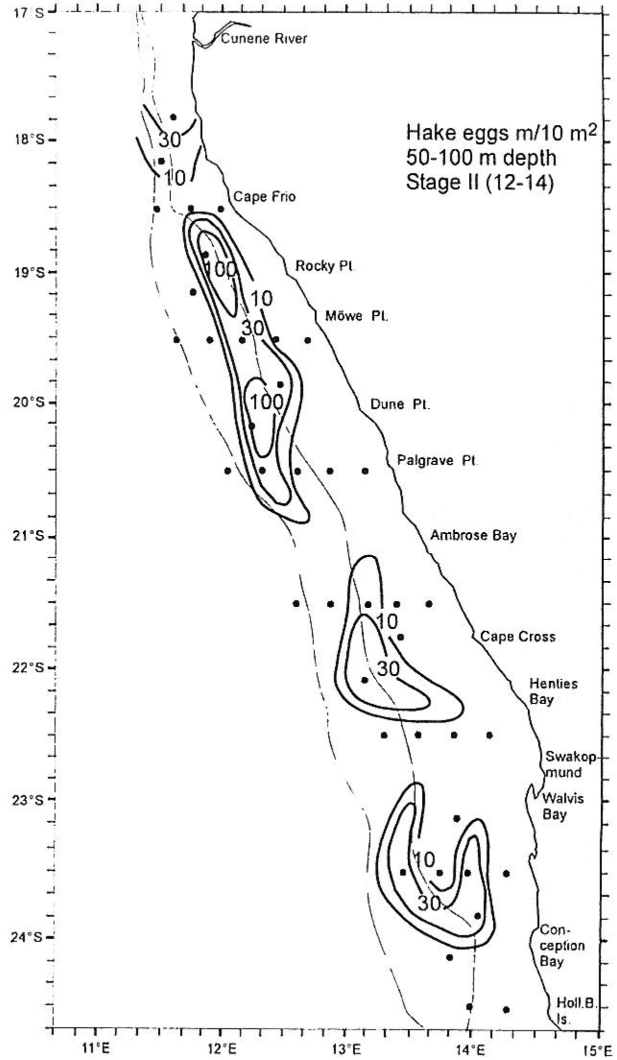


Fig. 3.44 Distribution of hake eggs, stage II, 50-100 m depth (#/10m^2)

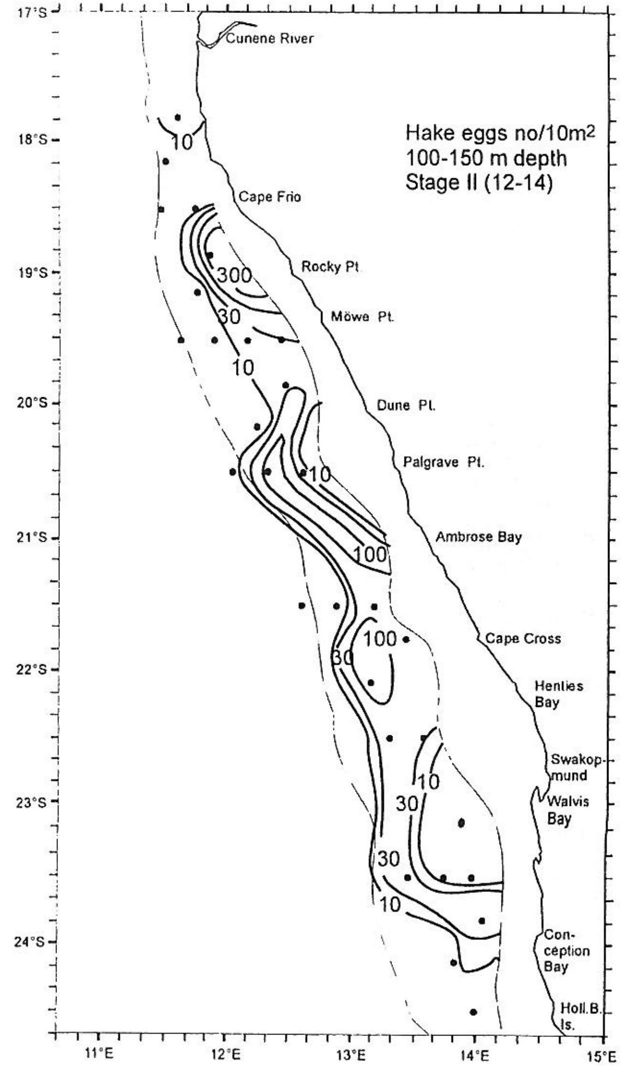


Fig. 3.45 Distribution of hake eggs, stage II, 100-150 m depth (#/10m^2)

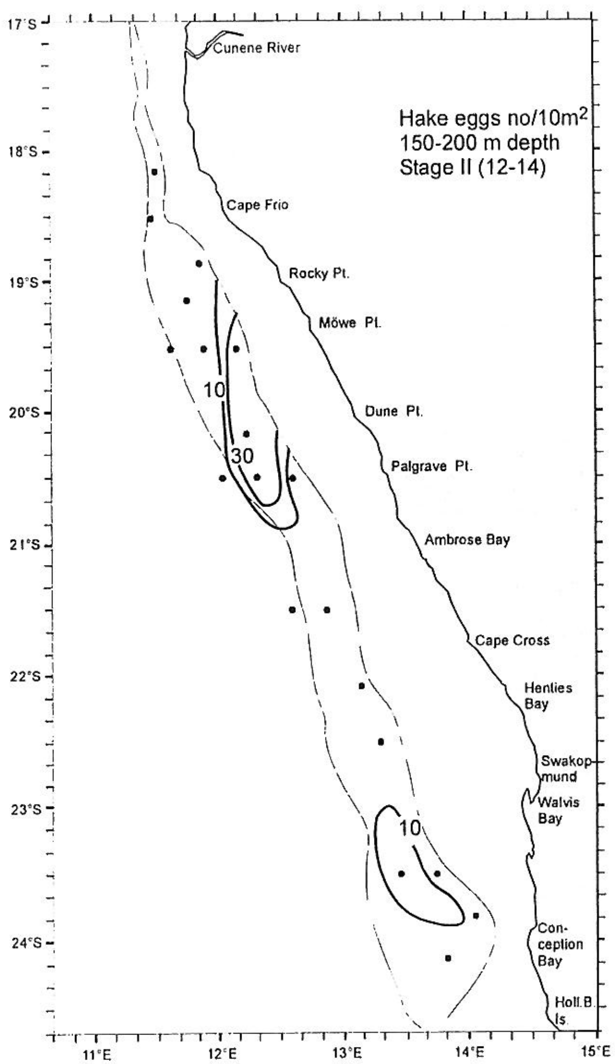


Fig. 3.46 Distribution of hake eggs, stage II, 150-200 m depth (#10m^2)

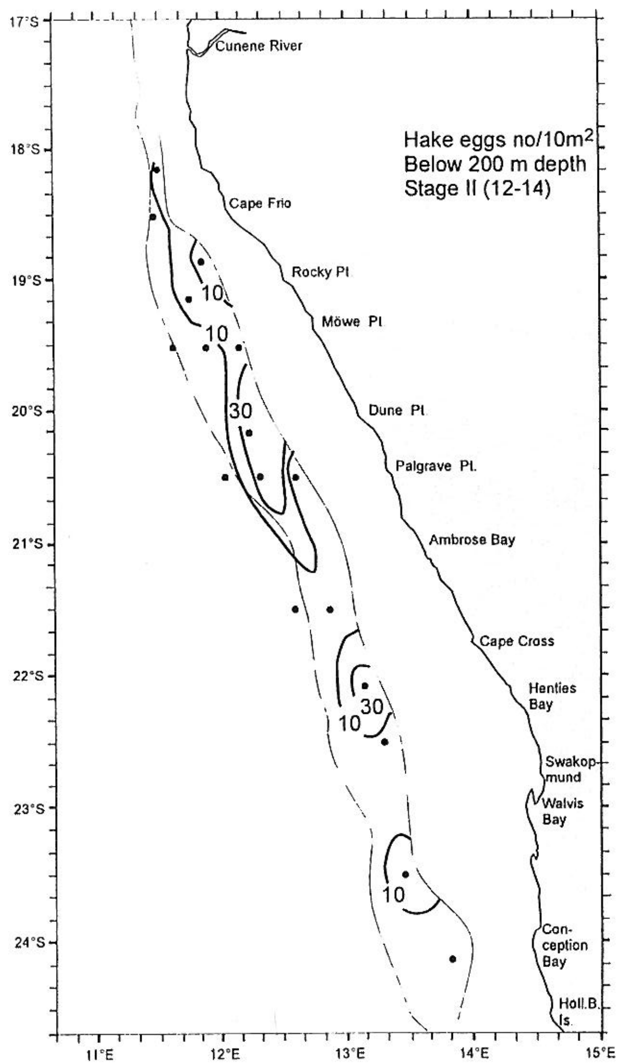


Fig. 3.47 Distribution of hake eggs, stage II, below 200 m depth (#10m^2)

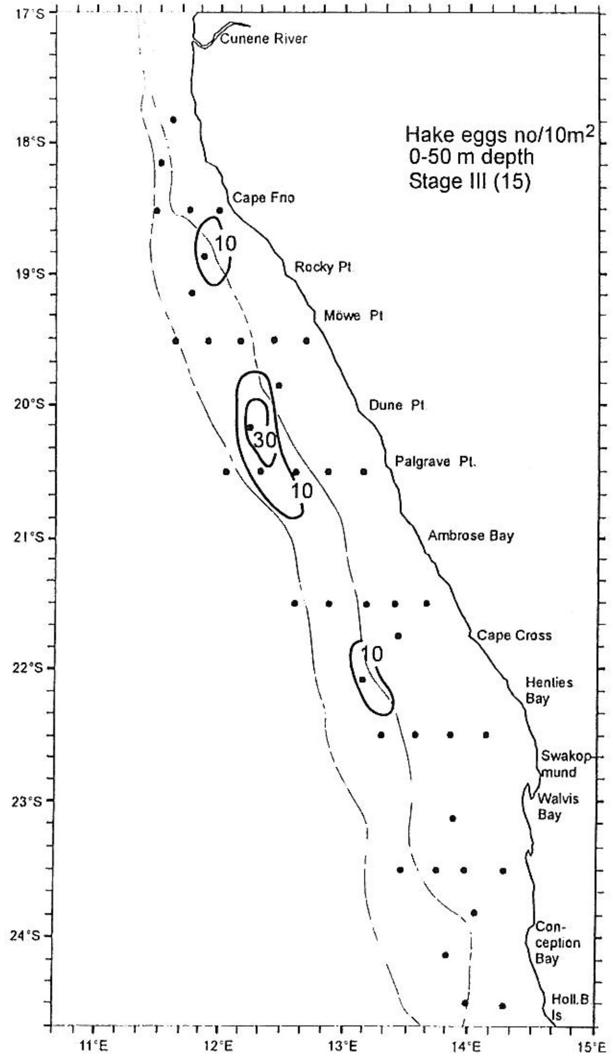


Fig 3.48 Distribution of hake eggs, stage III, 0-50 m depth (#/10m²)

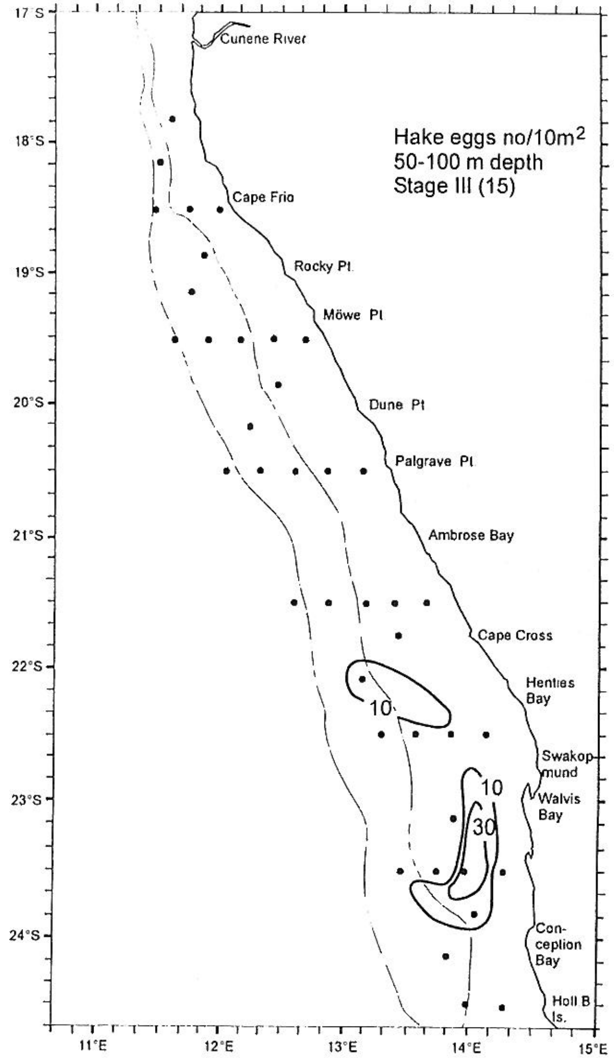


Fig 3.49 Distribution of hake eggs, stage III, 50-100 m depth (#/10m²)

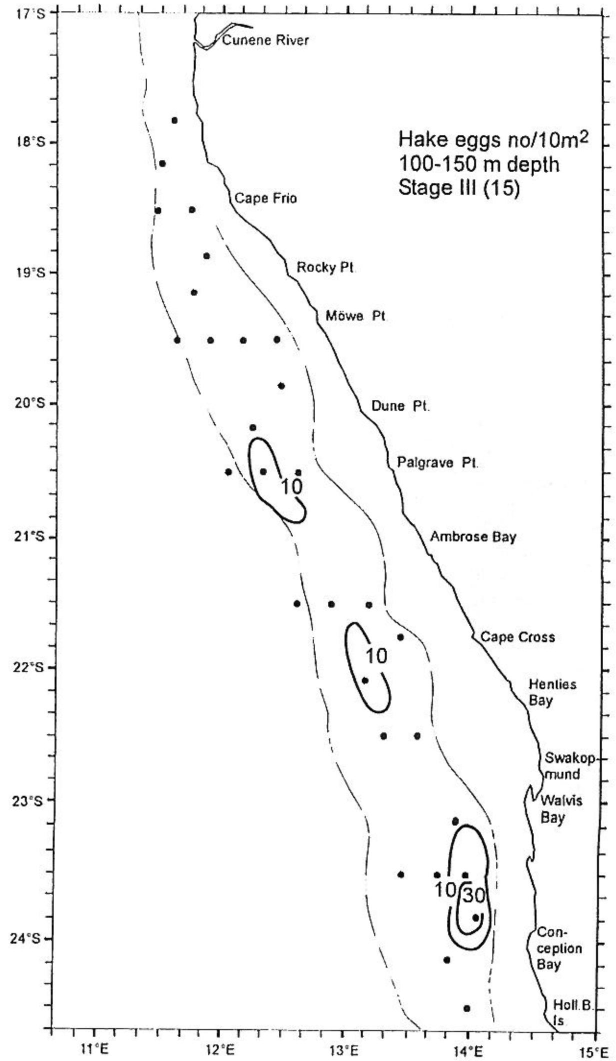


Fig 3.50 Disrtibution of hake eggs, stage III, 100-150 m depth (#/10m²)

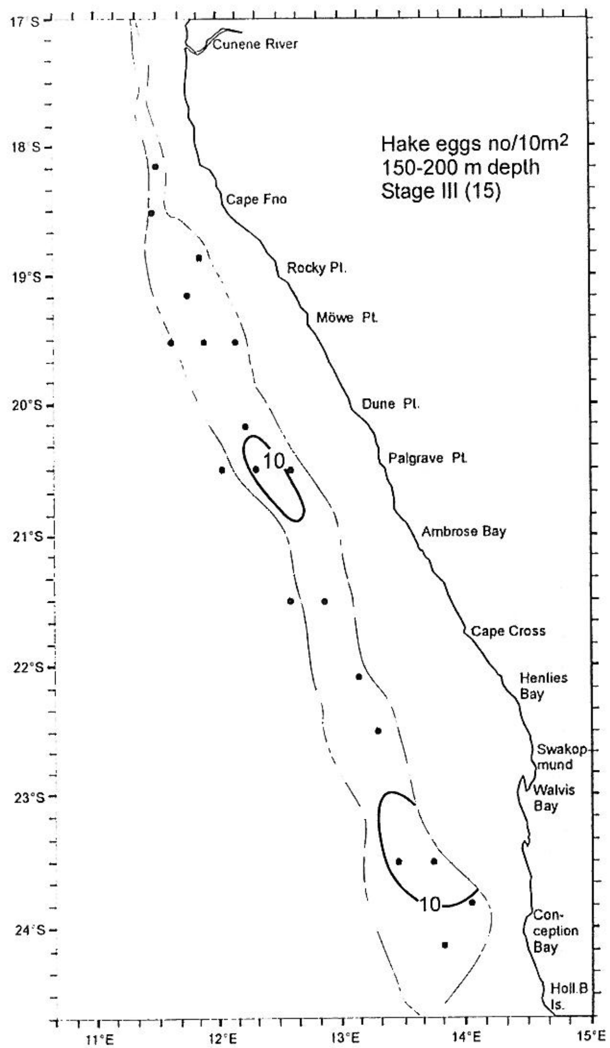


Fig 3.51 Distribution of hake eggs, stage III, 150-200 m depth (#/10m²)

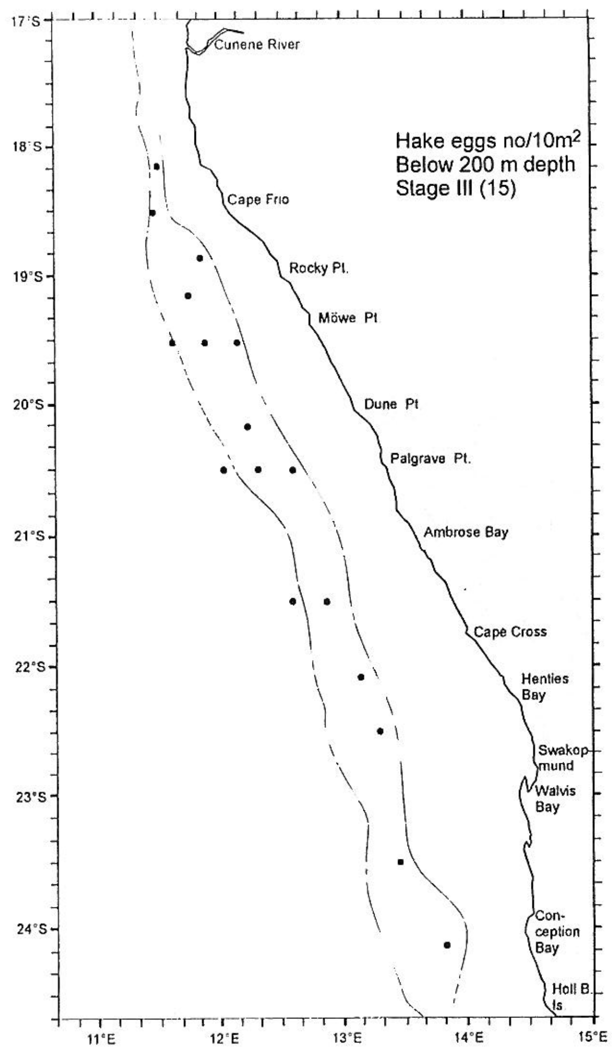


Fig 3.52 Distribution of hake eggs, stage III, below 200 m depth (#/10m²)

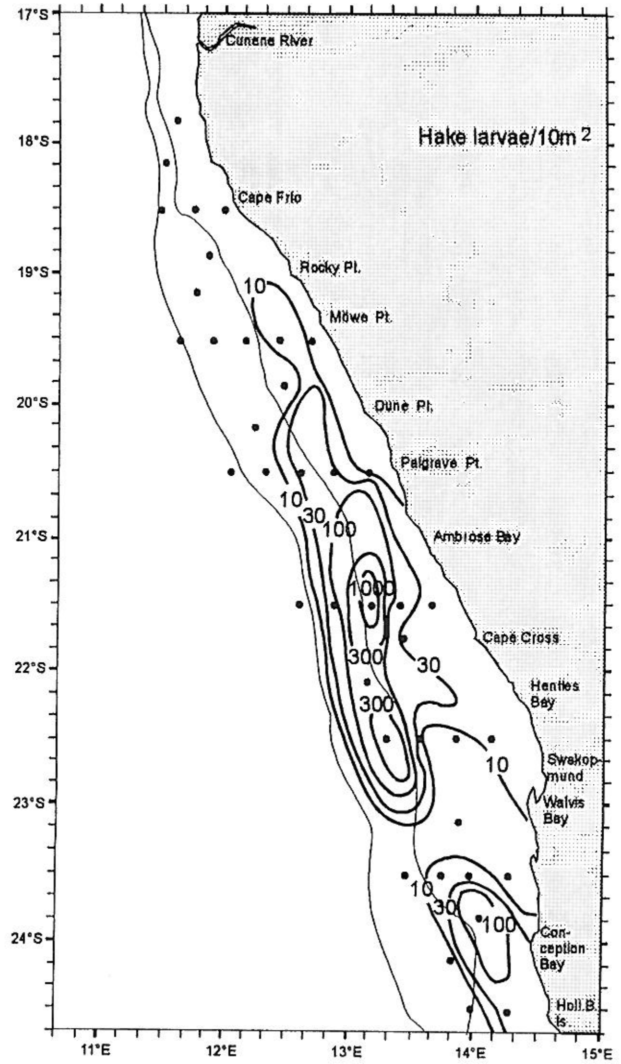


Fig. 3.53 Distribution of hake larvae (#/10m^2)

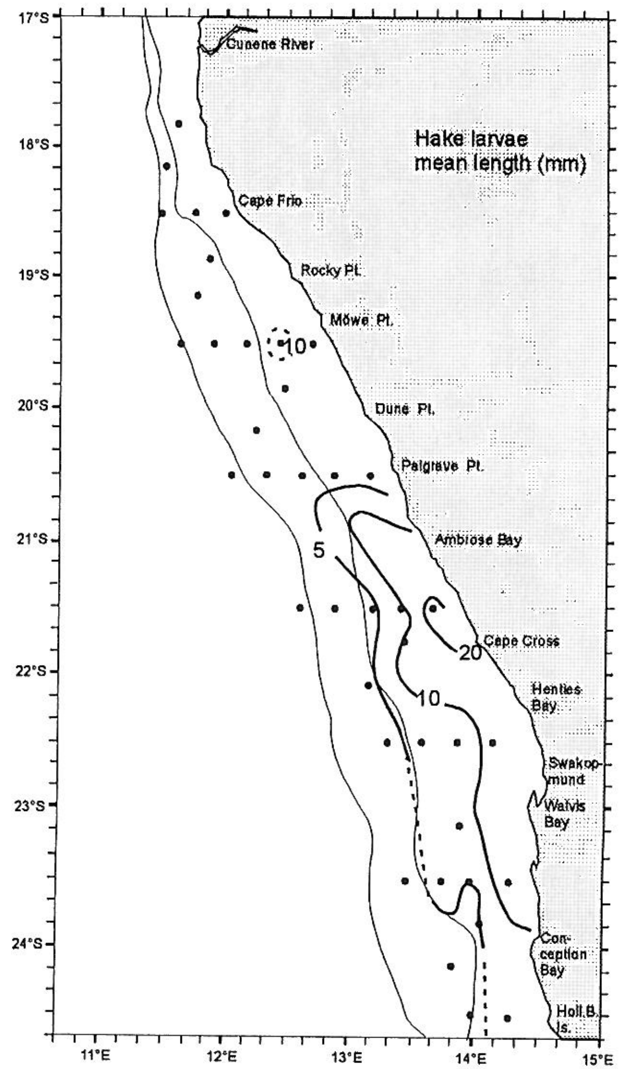


Fig. 3.54 Average length (mm) of hake larvae in the area of investigation

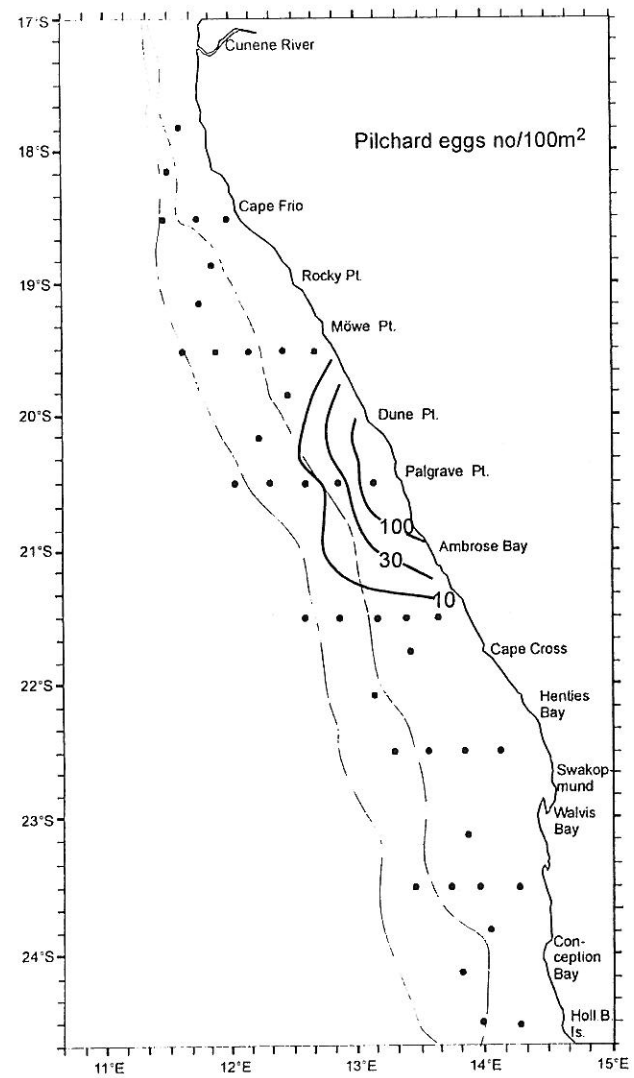


Fig. 3.55 Distribution of pilchard eggs (#/100m^2)

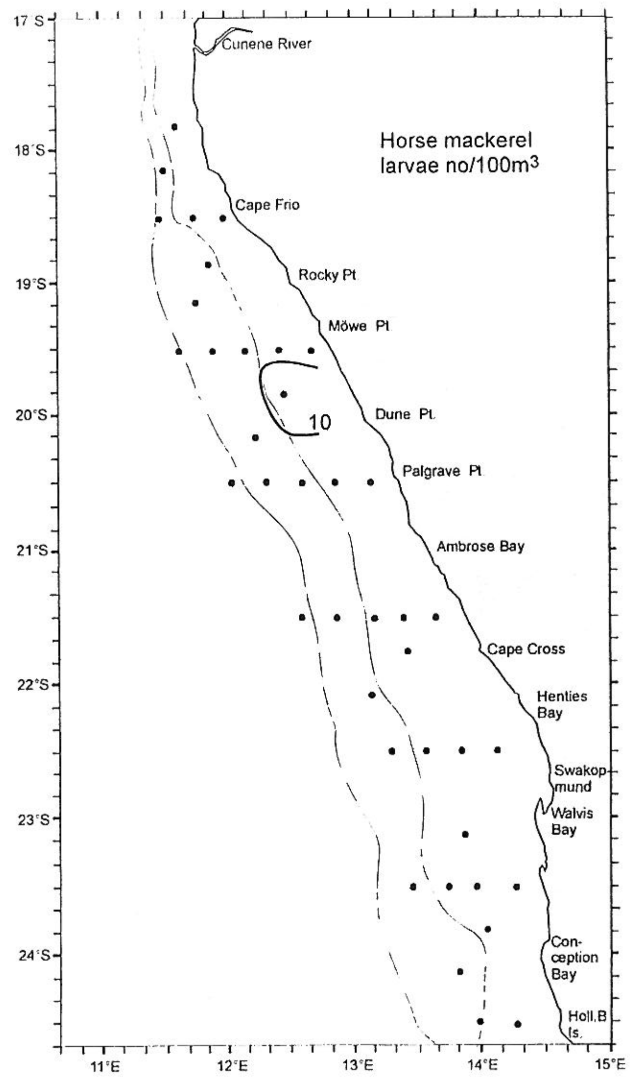


Fig. 3.56 Distribution of horse mackerel larvae (#/100m^3)

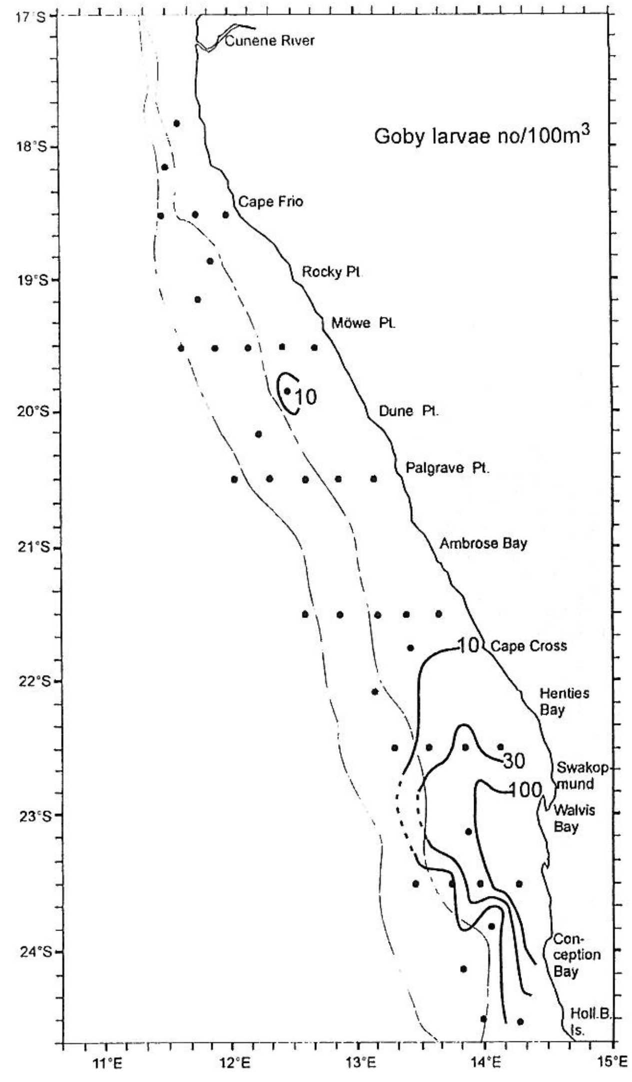


Fig. 3.57 Distribution of goby larvae (#/100m^3)

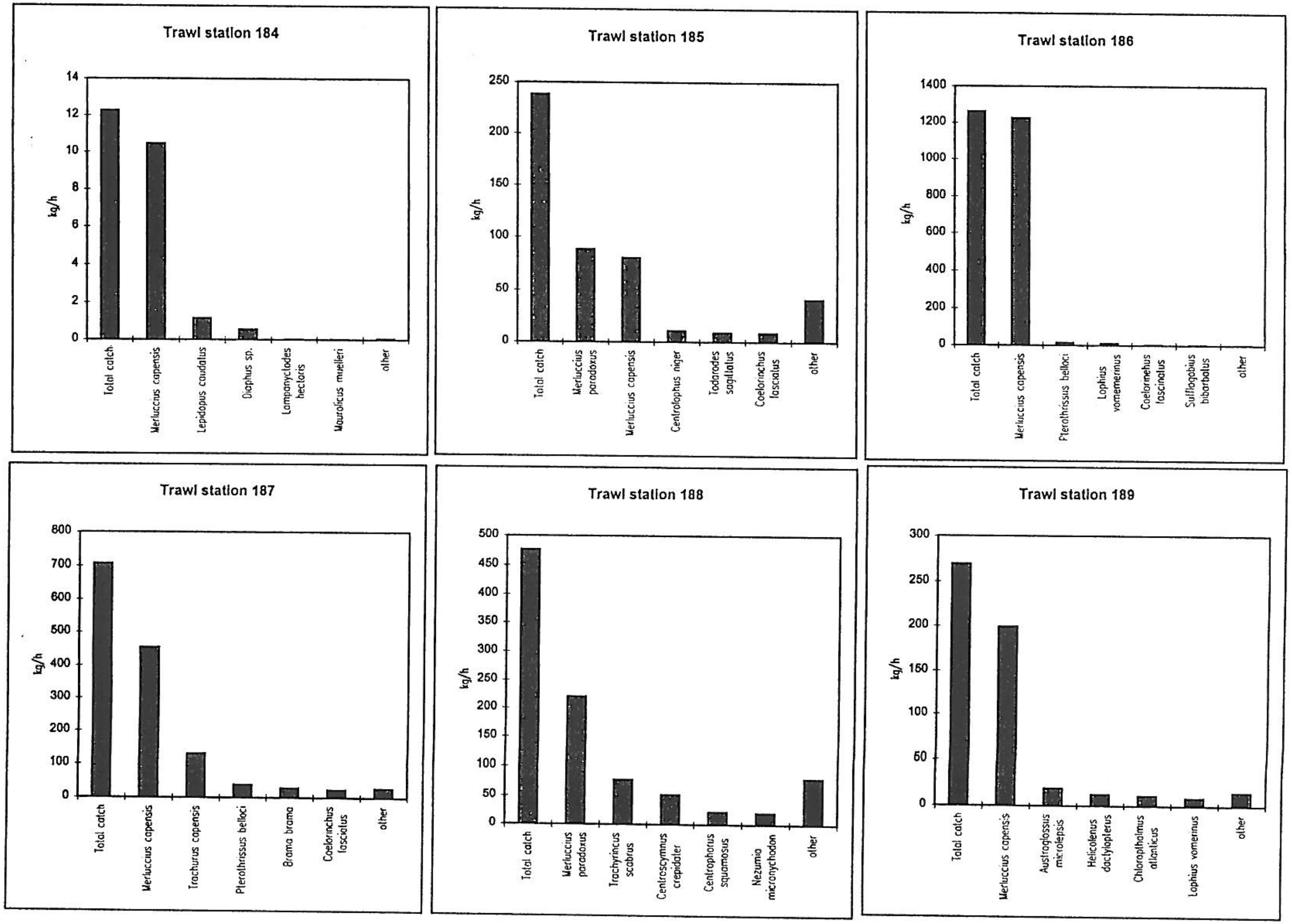


Figure 3.58a Total trawl catch in kg/trawl hour and species composition of the five most abundant fish species together with the sum of the remaining species, Trawl stations 184-189.

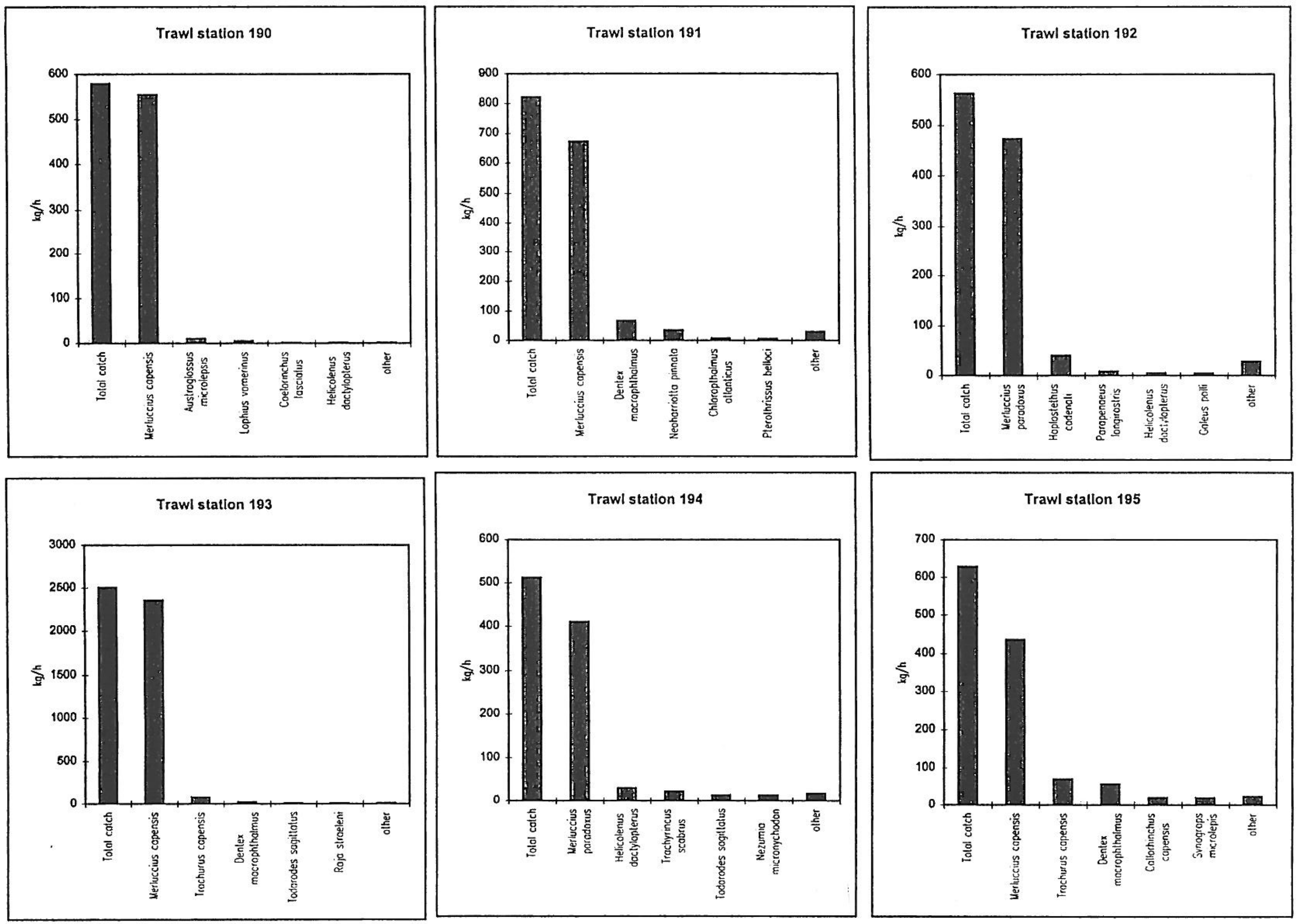


Figure 3.58b Total trawl catch in kg/trawl hour and species composition of the five most abundant fish species together with the sum of the remaining species, Trawl stations 190-195.

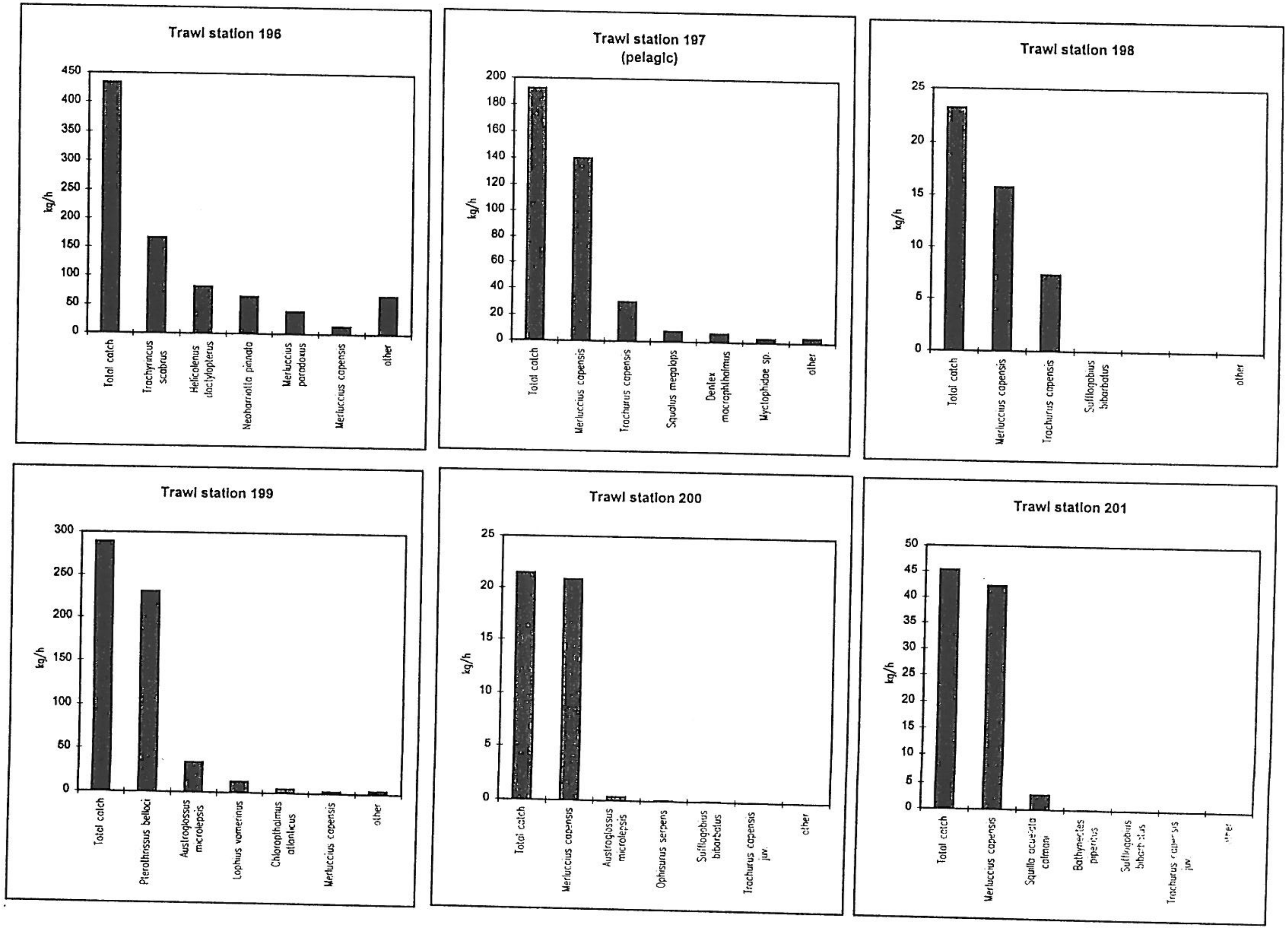


Figure 3.58c Total trawl catch in kg/trawl hour and species composition of the five most abundant fish species together with the sum of the remaining species, Trawl stations 196-201.

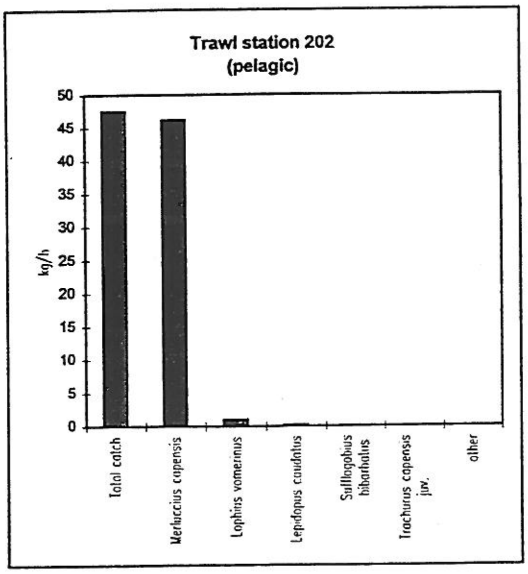


Figure 3.58d Total trawl catch in kg/trawl hour and species composition of the five most abundant fish species together with the sum of the remaining species, Trawl station 202.

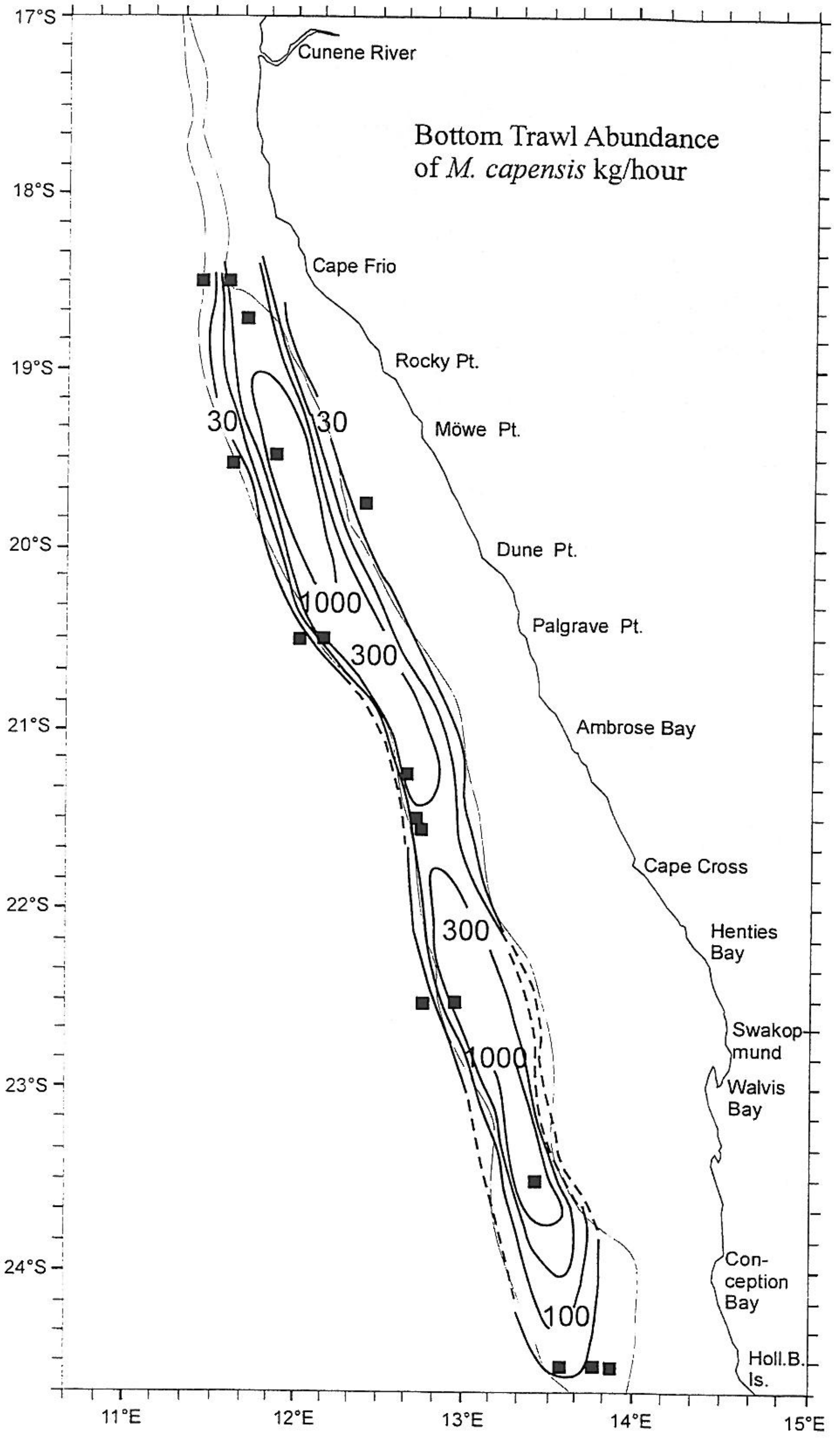


Fig. 3.59 Distribution of *M. capensis* in kg/trawl hour.

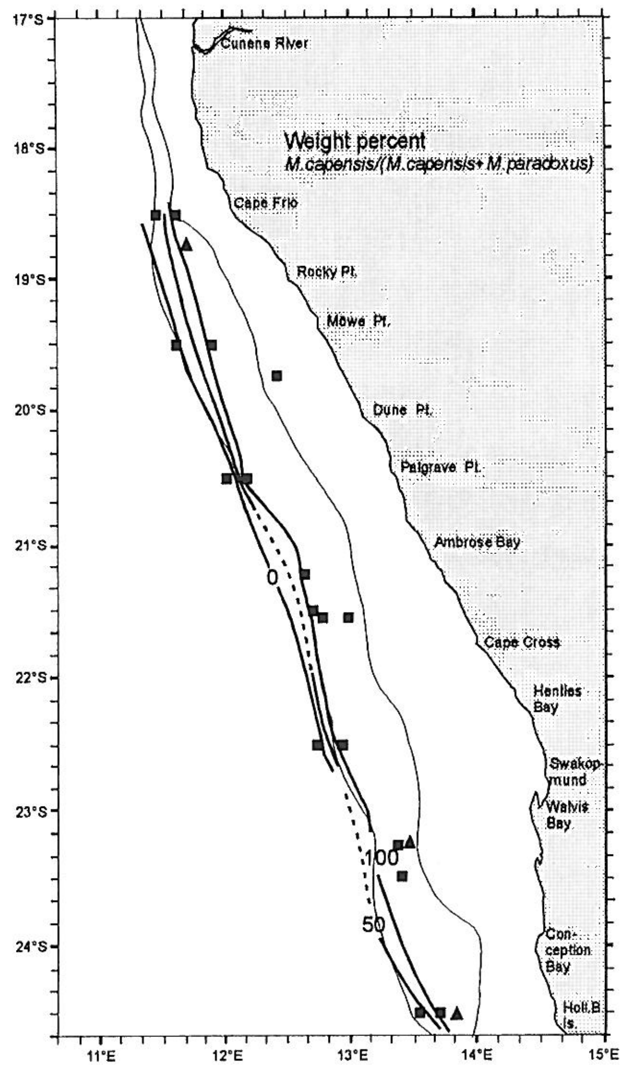


Fig. 3.60 Ratio (in percent) of the weight of *M. capensis* compared to the weight of all hakes at trawl stations

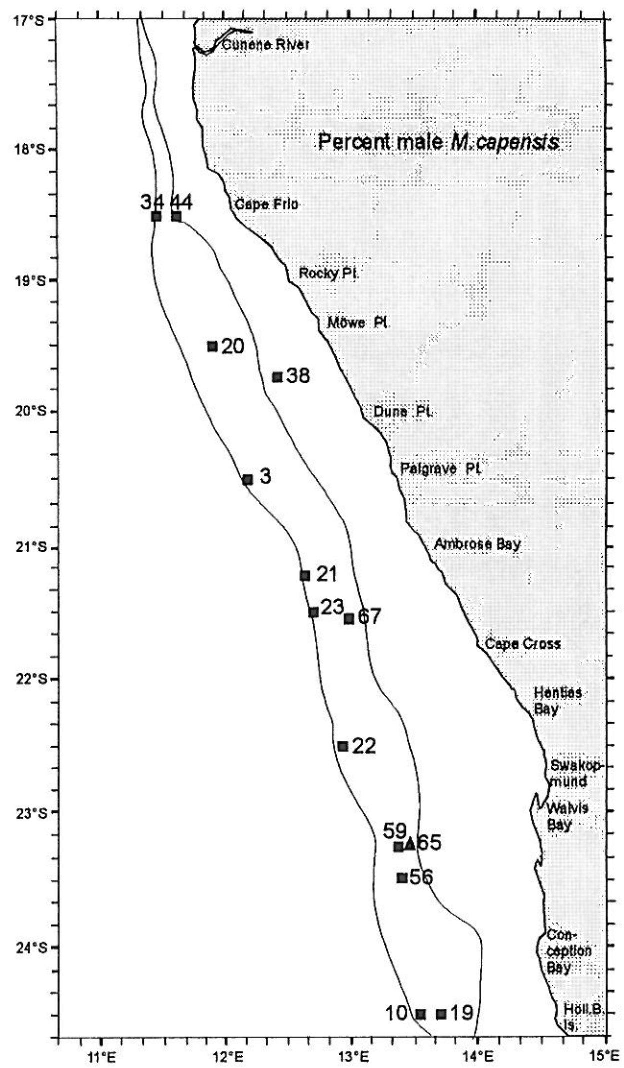


Fig. 3.61 Number in percent of male *M. capensis* compared to the total number *M. capensis.*

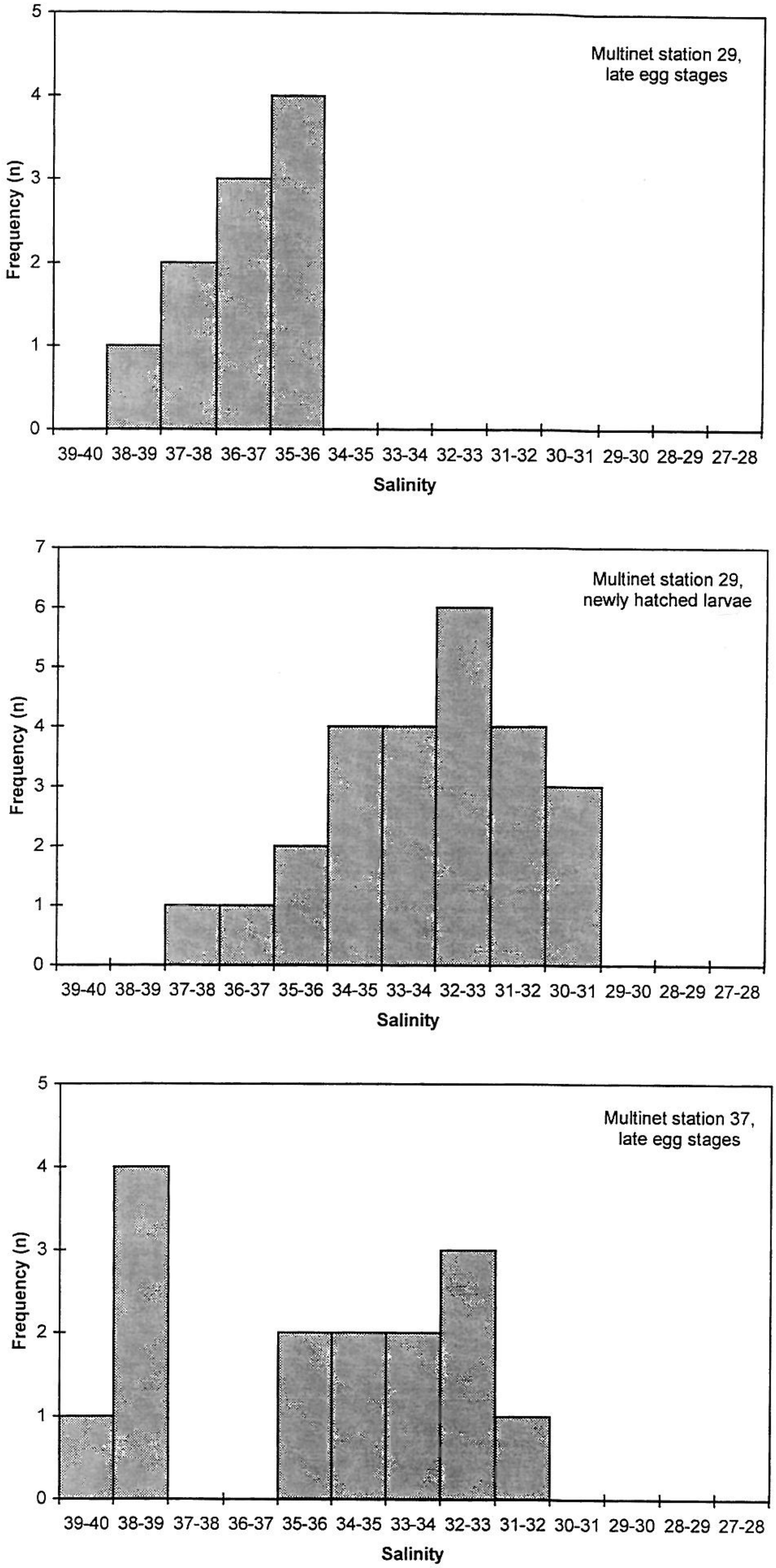
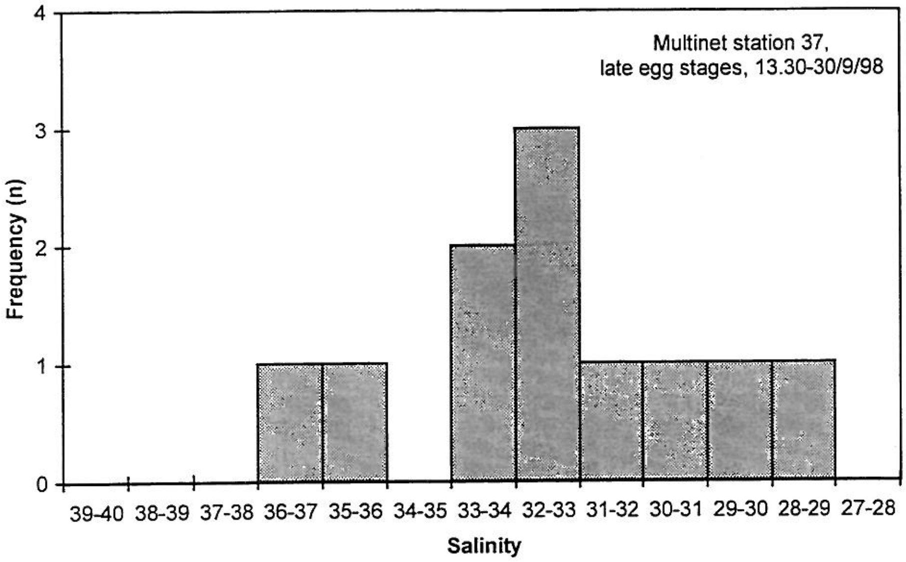


Figure 3.62. Neutral buoyancy of hake eggs and larvae collected in the Multinett. Larvae were hatched in the buoyancy column.



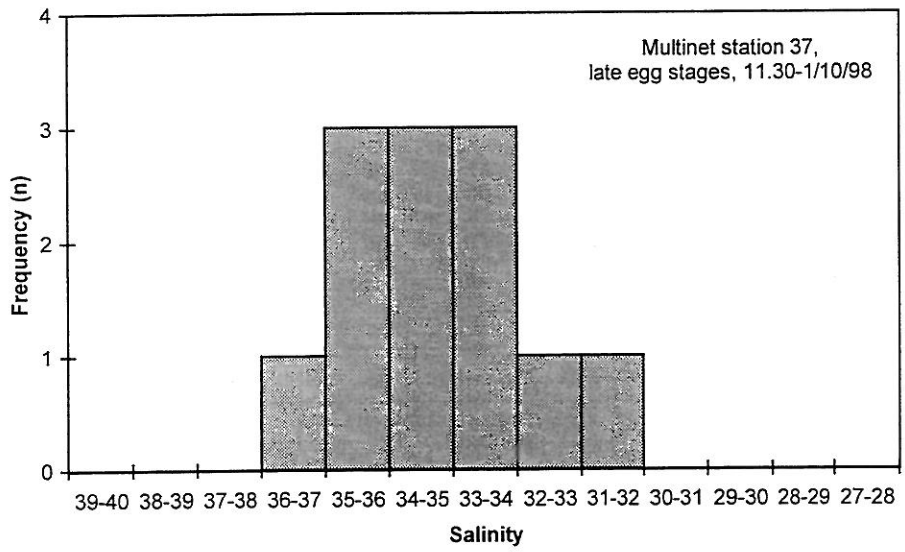


Figure 3.63. Buoyancy of pilchard eggs collected in the multinet. The measurements were done the first and second day after introduction to the column.

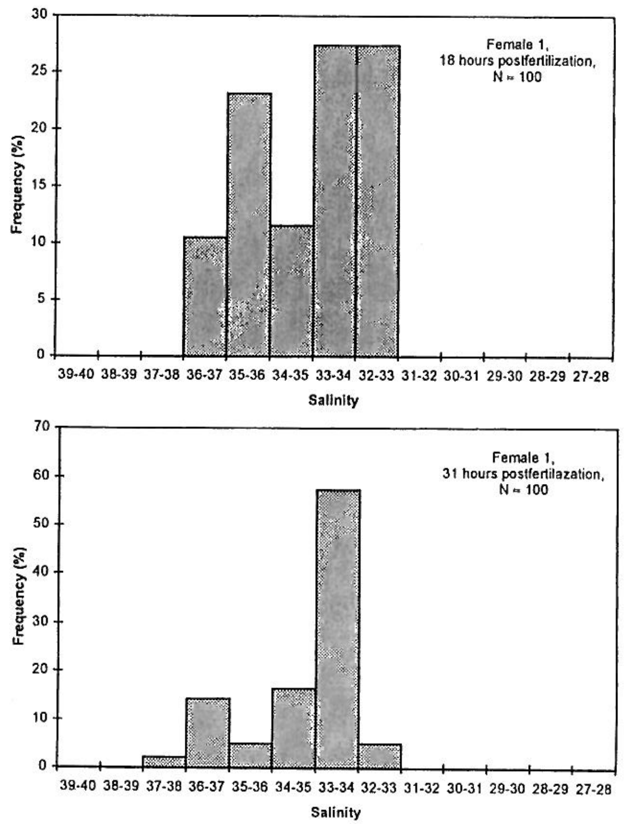


Figure 3.64. Neutral buoyancy of artificially fertilized hake eggs taken from female no 1 caught at trawl station 201.

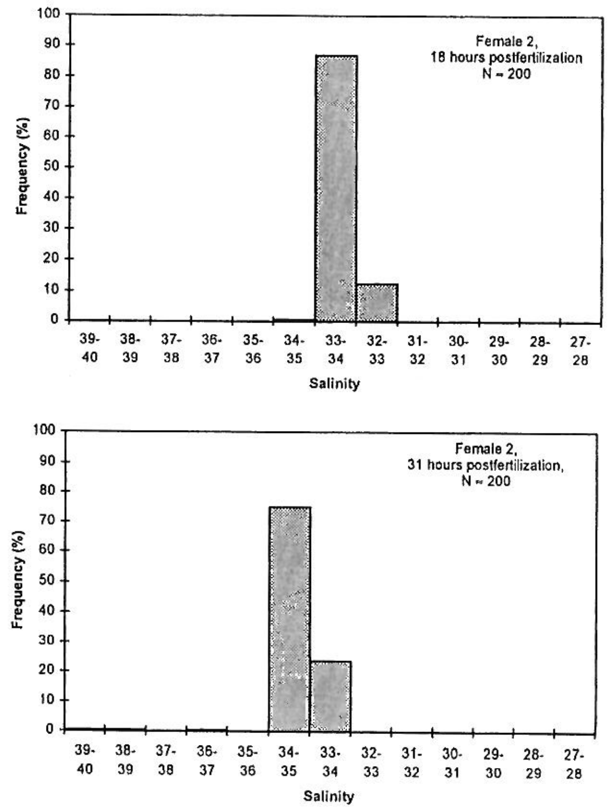


Figure 3.65. Neutral buoyancy of artificially fertilized hake eggs taken from female no 2 caught at trawl station 201.

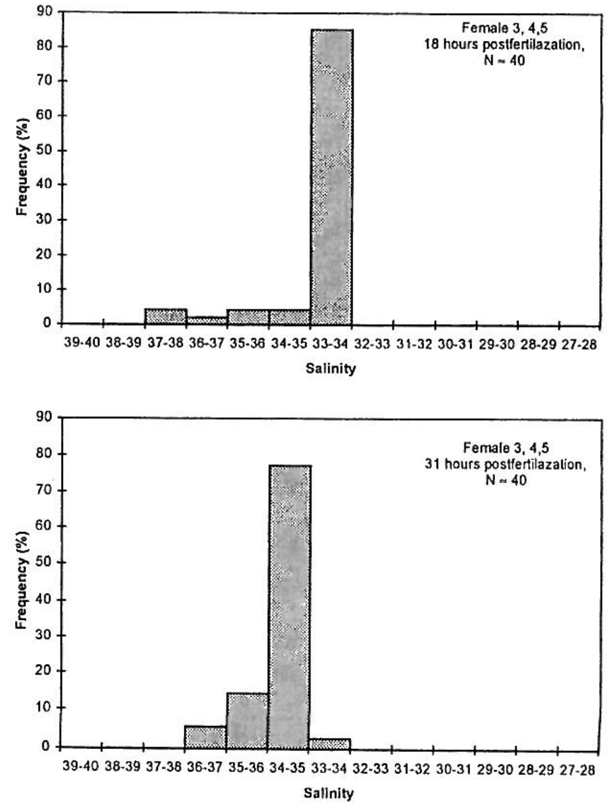


Figure 3.66. Neutral buoyancy of artificially fertilized hake eggs taken from females no 3, 4, 5 caught at trawl station 202.