ENVIRONMENTAL INFLUENCES ON THE DAYTIME VERTICAL DISTRIBUTION OF CAPE HAKES AND IMPLICATIONS FOR DEMERSAL TRAWL ESTIMATES OF HAKE ABUNDANCE OFF THE WEST COAST OF SOUTH AFRICA

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RALTON MAREE

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To my father, Arnie, whom I miss dearly

CONTENTS

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ABSTRACT

The demersal fishery off the west coast of South Africa experiences decreased catches per unit effort of hake, *Merluccius capensis* and *M*. *paradoxus*, following the onset of strong south easterly winds. Research has demonstrated that, during daylight hours, Cape hakes migrate vertically in the water column in response to strong south easterly winds, decreasing their availability to the bottom trawl. Hydroacoustic, trawl and environmental data were collected off the West Coast during both calm and wind-swept periods in an attempt to understand the forces that initiate this behaviour, its spatial variability and the implications for demersal trawl estimates of abundance. Near-bottom currents appear to be the primary factor influencing the vertical distribution of the demersal fish community, of which hake constitutes a large proportion, during daylight hours. Correlation between wind and near-bottom currents suggest that the poleward component of the currents increase in velocity within eight hours following the onset of south easterly winds. The fish avoid boundary layers where currents change direction and speed dramatically, and seem to concentrate in waters with relatively stable current regimes. This result questions the assumption of CPUE-based assessment models that hake availability to the bottom trawl is constant or varies randomly. The incorporation of acoustic assessment techniques to demersal surveys has potential, but may be most valuable by supplementing swept-area estimates of abundance, since the sampling efficiency of these methods varies within the water column. The incorporation of wind indices and gear performance data to Cape hake assessment models have been identified as useful considerations for the future.

CHAPTER 1

INTRODUCTION

The Cape hakes, *Merluccius capensis* and *M. paradoxus* constitute the basis of the South African demersal fishery, dominating demersal catches by some 70% (Payne and Punt 1995). The hake fishery is the

largest and most important fishery off the coast of South Africa, sustaining total allowable catches of approximately 152 000 tons annually between 1996 and 1998, contributing an approximate landed value of R3.3 million annually (Anon 1998). Both hake species occupy a distribution range with a northern limit off northern Namibia, which extends south along the South African west and south coasts until the abundance of both species decreases east of 25° E (Payne 1995). As the name implies, shallow water hake, *M. capensis* occur from shallow, inshore regions to a maximum depth of approximately 400 m, whereas deep water hake, *M. paradoxus* are seldom found shallower than 150 m but occur to depths of 900 m (Botha 1985, Payne and Punt 1995). Smaller fish generally occur in shallower waters in both species, with adult fish inhabiting deeper offshore regions. Off the west coast of South Africa, *M. paradoxus* is the major contributor to demersal landings whereas *M. capensis* is predominant in catches along the south coast (Payne and Punt 1995). These statistics are primarily due to hake-targeted effort within these two regions, where commercial fleets operate at greater depths along the West Coast due to the relatively narrow continental shelf where depth increases rapidly with distance offshore. Here the shelf is narrow and the continental slope less steep than off the South Coast, where hake effort is directed across the relatively shallow, wider continental shelf.

Due to well-defined diurnal vertical migrations, both commercial operators and research vessels target Cape hakes during daylight hours, when individuals are associated closely with the seabed and availability to the bottom trawl is greater than during hours of darkness. As is the case with many demersal fish species (Beamish 1966, Sandeman 1969, Atkinson 1989, Michalsen *et al*. 1996), hake undertake extensive vertical migrations during the evening hours, which commence at dusk and terminate at sunrise when individuals return from a pelagic to the demersal environment (Inada 1981, Gordoa *et al*. 1995, Payne and Punt 1995, Pitcher and Alheit 1995, Pillar and Barange 1997). Vertical migrations after sunset are commonly linked to feeding behaviour, when hake prey on pelagic fish, and return to the seabed when satiated (Bowman and Bowman 1980, Livingstone 1983, Prenski 1986, Gordoa and Macpherson 1991, Pillar and Barange 1993, Pitcher and Alheit 1995). These migrations may however not occur solely as a feeding behaviour, as Payne *et al.* (1987), Roel and Macpherson (1988), and Pillar and Barange (1995) showed that hake do not necessarily feed daily, albeit that they perform daily vertical migrations. Pillar and Barange (1997) suggest that vertical migrations occurring as a mechanism of predator avoidance may also be unlikely, since hake migrations occur at the level of the individual and not the population. Whatever the reason for these diurnal migrations, they are recurring and well-defined, reducing hake availability to the bottom-trawl to levels that do not warrant commercial hake-targeted effort during the hours of darkness.

Similarly, demersal biomass assessment surveys conducted by Marine and Coastal Management (MCM) off the South African coast restrict trawling operations to daylight hours. During demersal surveys, it is intended that trawling operations be commenced half an hour after sunrise, and terminated half an hour prior to sunset (R. Tilney, MCM, pers. comm.), in order to eliminate potential bias due to the decreased availability of Cape hakes to the bottom trawl. It is crucial that no trawling occurs during dusk and dawn, as assessments derived from research survey data are based on the central assumption that hake availability to the demersal trawl is constant between trawls and between surveys. If trawling does occur during these periods, when diurnal migratory patterns decrease the availability of Cape hakes to the trawl, this assumption is violated. For this reason, demersal trawls are standardised, being restricted to daylight hours during demersal assessment surveys off the west coast of South Africa.

Should the availability of Cape hakes to the bottom trawl be variable during daylight hours as it is during the evening hours, bias may be introduced to catch per unit effort (CPUE) based demersal stock assessments. The vertical distribution dynamics of Cape hakes during daylight hours is extremely important in this regard, as assessment assumptions are similarly violated if a large proportion of the demersal fish stock decrease their availability to the bottom trawl during the day. The demersal fishery off the west coast of South Africa has provided evidence that this may indeed be the case. Commercial operators experience decreased daytime CPUE of Cape hakes following the onset of south easterly (SE) winds. This phenomenon is commonly reported by the industry, who experience catch rates similar to those during the hours of darkness, forcing vessels to steam many miles in search of fishing grounds yielding greater catches (B. Rose, Irvin & Johnson Pty. (Ltd), pers. comm.). Skippers often use wind direction, water colour and temperature to predict poor or large hake catches (A. Thomas, Irvin & Johnson Pty. (Ltd)), pers. comm.).

If the vertical spatial dynamics of Cape hakes are indeed influenced by environmental factors such as wind stress, the implications of these to stock assessment procedures need to be considered. Because past and present South African Cape hake assessment models are based on CPUE data which may be either fisheries dependant or independent (Glazer 1998), environmental factors that have an impact on CPUE may introduce a source of bias to CPUE used as an indicator of trends of abundance. Central to assessment models based on catch rate data is the assumption that CPUE is proportional to abundance (in the case of fisheries dependant data), or that CPUE is proportional to density (which is then multiplied by the stratum area to provide an index of abundance) in the case of research surveys (Glazer 1998, Godø *et al*. 1999). This assumption requires a linear relation between catch rates and abundance levels, implying that fish availability to the bottom trawl is constant. Should evidence indicate that the vertical distribution (and therefore the availability to the bottom trawl) of Cape hakes is highly variable during daylight hours, and that errors in catchability over time may not be entirely random, this central assumption is violated. Similarly, because the density of Cape hakes above the trawl headrope is assumed to be random during research surveys over space and time (R. Leslie, MCM, pers. comm), evidence that indicates a relation between Cape hake vertical spatial distributions and particular environmental parameters may violate this assumption.

The above scenario initiated a research project to investigate the influence of the environment on the temporal and spatial dynamics of hake vertical distributions off the South African west coast during the day and the subsequent implications for management of the hake resource in this region. During 1998 and 1999, research surveys were conducted aboard the *F.R.S. Algoa, F.R.S Africana* and *R.V. Dr. Fridjof Nansen*, to collect environmental and fish density data in an attempt to understand the spatial and temporal variability of Cape hake daytime vertical migrations in response to variable environmental parameters. For the first time during demersal surveys aboard South African research vessels, hydroacoustic data were collected on a regular basis to investigate and quantify the movement of vertical fish densities within the water column, and the implication that these migrations may have for demersal trawl abundance estimates.

A Cape hake vertical distribution survey was conducted aboard the *F.R.S. Algoa* during February 1998 to test the hypothesis that Cape hake daytime vertical distributions are influenced by the onset of SE winds. During this survey, a suite of environmental data were collected and compared to synoptic fish density data to gain a better understanding of the forces that influence Cape hake daytime vertical distribution in space and time.

During January 1999, hydroacoustic, demersal gear performance and catch data were collected to investigate the influence that vertical spatial dynamics during the day have on Cape hake estimates of abundance. In an attempt to reduce bias incorporated into assessment models (via the sole use of CPUE data) when daytime Cape hake vertical distributions are variable, the potential application of acoustic and gear performance data to demersal research surveys was investigated. Data were also collected aboard a survey on the *R.V. Dr. F. Nansen* during June 1998 to supplement data collected aboard the other two vessels.

The primary objectives of this study may be isolated as follows:

To investigate the spatial and temporal dynamics associated with Cape hake daytime vertical distributions and how these distributions may be influenced by ambient environmental conditions.

To determine how the daytime vertical distribution of Cape hakes influences bottom trawl estimates of abundance.

To investigate the potential application of hydroacoustic techniques to demersal assessment surveys.

CHAPTER 2

ENVIRONMENTAL INFLUENCES ON THE DAYTIME VERTICAL DISTRIBUTION OF CAPE HAKES OFF THE WEST COAST OF SOUTH AFRICA

2.1. INTRODUCTION

It is widely documented that the physical environment has great influence on the distribution and biology of commercially exploited fish species. The interpretation of behavioural responses to the environment constitutes a potentially powerful tool to determine dominant factors that control variability in fish populations (Crawford *et al.* 1990). Large scale oceanic variability has been shown to influence the distribution and abundance of both pelagic (Crawford *et al.* 1990, Roy *et al.* 1992, Laevastu 1993, Korrûbel *et al.* 1998) and demersal (Crawford *et al.* 1990, Nilssen *et al.* 1993, Laevastu 1993, Mackas *et al.* 1997) fish resources.

Surface wind has an important influence on barotropic processes over the continental shelf and may play a vital role in ocean variability with space and time (Shannon *et al.* 1990). Although wind-induced changes in the ocean may affect fish, few studies have related wind to fish behaviour or fish catch rates (Laevastu 1993, Le Clus *et al*. 1998). At Lowestoft, Harden Jones and Scholes (1980) and Scholes (1982) found that catch rates of plaice were significantly reduced during prevailing northerly winds, albeit cod did not seem to show the same response. In the Benguela system, catch rate fluctuations of Agulhas sole, *Austroglossus pectoralis* are associated with deviations in the wind field, when high and low catches are associated with north-westerly and south-easterly winds respectively (Le Clus *et al.* 1998). Saithe have been reported to disperse from fishing grounds in the Lofoten area following the onset of northerly winds (Mohr 1964) and demersal stock migrations in the Barents Sea have been reported to be influenced by the wind (Laevastu 1993). Ehrich and Stransky (1999) also reported that strong winds may influence the structure of trawl sampled fish assemblages, finding that demersal fish catch rates in the German Bight only increased significantly approximately two days following gale force winds.

Despite the above, the influence of wind on catch rates is likely to be circumstantial rather than causative. Although fisheries off the west coast of southern Africa are affected by wind-induced fluctuations in the environment, the connection between wind and fish catches is indirect (Andrews 1974). Le Clus *et al.* (1998) conclude that it is unknown whether *A. pectoralis* catches and wind exhibit a causal relationship while Harden Jones and Scholes (1980) attribute poor plaice catches to wave-induced oscillations and subsequent high turbidity near the bottom as opposed to wind *per se*. Similarly, in the Benguela upwelling region, hake vertical migrations following the onset of south easterly winds may respond to environmental variability which is initiated by these winds. In other regions, as off the west coast of Canada (Mackas *et al.* 1997) and the Barents Sea (Michalsen *et al*. 1996, Aglen *et al*. 1999), Pacific hake, *M. productus,* and cod, *Gadus morhua* respectively have been shown to be influenced by the intensity and direction of current flows.

The Cape hakes have strong depth-related distribution patterns. *M. paradoxus* occur in abundance predominantly in deep water, associating their distribution with cold, highly oxygenated water. *M. capensis* inhabit shallow inshore waters, and are subject to greater variations in environmental conditions than deep water hake, particularly temperature and oxygen. Although each Cape hake species occupies a spatial niche, large ontogenetic variation exists within the spatial distribution of each species. In both species, small fish generally occur in shallower water than larger fish (Botha 1985, Payne and Punt 1995), thereby increasing the environmental variation to which each species may be subject. These variations complicate studies regarding the environmental influence on two species that are managed and exploited as one combined stock (Glazer 1998).

A variety of environmental parameters have been shown to influence either the distribution or abundance of hakes. Payne (1995) suggests that temperature changes associated with depth may play an important role in the spatial abundance trends observed for the two species of Cape hake. In the northern Benguela, Macpherson *et al.* (1991) postulated that hake concentrate closer to the seabed during warm SST conditions as indicated by a strong relationship between SST and *M. capensis* catch rates. During the warm Benguela Niño years of 1983 and 1984 however, hake catchability was observed to decrease relative to the cooler years before (Crawford *et al.* 1990).

Fish may migrate in response to low oxygen levels, as total energy demands are increased in order to maintain a steady oxygen supply to the tissues (Kramer 1987). Although field studies have demonstrated positive correlations between oxygen concentrations and vertical fish distribution, they are often circumstantial, as evidence of distribution responses to oxygen may be influenced by alternate factors that are correlated with low oxygen levels in natural systems (Kramer 1987). The tolerance of Cape hakes to low oxygen concentrations has been shown to vary both between species and ontogenetically within the same species (Roel and Bailey 1987). While adults are absent, juvenile *M. capensis* are abundant in oxygen-deficient waters, suggesting not only that juveniles possess physiological means of tolerating oxygen deficiency but perhaps also the development of a survival strategy to avoid predation by adult fish.

Although they are few, studies concerning the influence of the physical environment on Cape hake distribution and abundance, are generally restricted to data derived from CTD casts. As a result, temperature, salinity and oxygen have received most consideration when relating hake distribution and biomass to environmental parameters (Bailey 1986, Bailey and Giddey 1986, Roel and Bailey 1987, Macpherson *et al.* 1991). This study attempts to incorporate a suite of environmental parameters that have traditionally not been considered when investigating biological responses to environmental changes in the Benguela system off the coast of South Africa. In addition to the customary investigation of temperature, salinity and oxygen influences, ambient densities of seawater, turbidity levels and wind and current magnitudes and direction are investigated and related to biological gradients.

This study also attempts to incorporate the use of hydroacoustic data, which have been utilised scantly in demersal studies locally (e.g. Huse *et al*. 1998). By sampling the entire water column, acoustic biological densities are available in the 'trawl blind' zone and provide a useful indication of both vertical migration patterns and biological responses to the environment, specifically during windy and non-windy periods. The method allows for comparison between biological and environmental gradients with depth throughout the water column, supplementing traditional CPUE data that have been used solely for similar studies during the past.

The majority of studies regarding environmental influences upon Cape hakes are discussed on a macroscale both spatially and temporally i.e. spatial scales of hundreds of kilometres using pooled annual data sets. In addition, this study concentrates on changes within spatial and temporal mesoscales i.e. within kilometres and hours. The intention of this study is to improve the understanding of environmental influences on Cape hake daytime vertical distribution within the same temporal scale that environmental forces change their behaviour, such as changes in wind field and velocity.

2.2. METHODS

Three vessels collected spatial and temporal information used in the analysis during 1998 and 1999. During February 1998, hydroacoustic, trawl and environmental data were collected during a demersal cruise aboard *F.R.S. Algoa* between the 200 and 500 meter isobaths west of the Cape Peninsula (Fig. 2.1a). The cruise was designed specifically to investigate hake vertical distribution patterns during the day in response to changes in environmental parameters, and particularly wind patterns. Three experiments were conducted during the cruise. During the first, data were collected along a cruise grid to investigate both horizontal and vertical spatial variability across the continental shelf between the 200 and 500 m isobaths. Transects perpendicular to the coast enabled sampling on either side of a well-defined oceanic front. The second experiment, a 24 hour sampling period, was conducted at a fixed locality where environmental and biological data were collected at regular intervals. This experiment aimed to minimise spatial variability in the data and to investigate synoptic changes in biological and environmental gradients during a period of intense SE winds. Finally, data were collected along an onshore-offshore transect to ascertain whether demersal fish migrations responded to the environmental changes observed, and occurred across the width of the continental shelf or merely the shelf break region. Hydroacoustic data was collected continuously throughout the cruise, while midwater trawls were deployed to identify the composition of acoustic midwater backscattering layers at regular intervals.

During June 1998, hydroacoustic, trawl and environmental data obtained aboard the *R.V*. *Dr. Fridjof Nansen* were collected off the coast of Namibia, south of Walvis Bay (Fig. 2.1b). Synoptic demersal trawls and CTD casts were deployed at a fixed locality during daylight hours over a period of approximately 6 days. These data were collected at a fixed locality to minimise spatial variability in the data, and to supplement the environmental and CPUE data set collected aboard the *F.R.S. Algoa* and *F.R.S. Africana*.

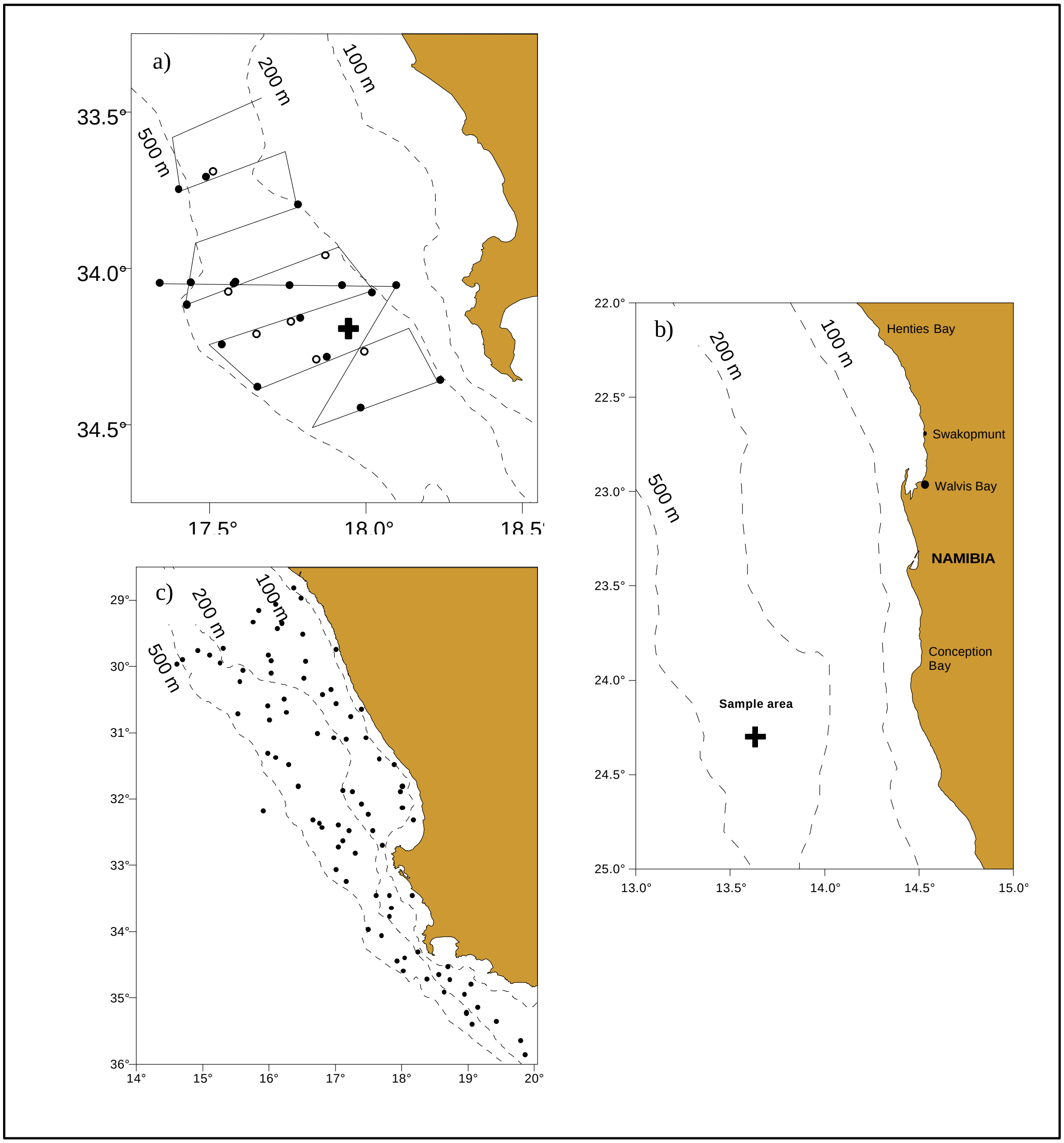

Fig. 2.1. Spatial and temporal sampling was conducted west of the Cape Peninsula aboard *F.R.S. Algoa* (a), off the Namibian coast aboard *Dr. Fridjof Nansen* (b) and during the annual demersal biomass assessment survey aboard *F.R.S. Africana* off the west coast of South Africa (c). During the *F.R.S Algoa* cruise (a), data were collected along a sampling grid, during a 24 hour station (depicted by the cross) and along an offshore transect. Open and closed dots denote trawl and CTD stations respectively. Dots in figure (c) refer to trawl and CTD stations.

Routine biological and environmental data collected during the annual MCM West Coast demersal biomass assessment survey aboard the *F.R.S. Africana* during January 1999 contributed to the analysis. Samples within the survey area were collected between the coast and a depth of 500 meters, from the western Agulhas Bank in the south to the Orange River mouth in the north (Fig. 2.1c). Synoptic environmental, hydroacoustic and CPUE data were collected during each trawling operation to investigate the relationship between environmental variables, acoustic densities and demersal catch rates, supplementing the data sets collected aboard the *F.R.S. Algoa* and *R.V. Dr. F. Nansen*.

2.2.1. Biological data

2.2.1.1. Trawl data

Bottom trawl operations were conducted using a standard German 180-foot bottom trawl fitted with a pilchard netting cod-end liner aboard the *F.R.S Algoa* and *F.R.S. Africana*, and a Gisund Super two-panel bottom trawl aboard the *R.V. Dr. F. Nansen*. Trawling was restricted to daylight hours on the latter surveys while trawls were deployed during both daylight and evening hours aboard the *F.R.S. Algoa*.

Midwater trawls were conducted with an Engels 308 net fitted with an anchovy cod-end liner on the *F.R.S. Algoa* during both daylight and evening hours.

2.2.1.2. Hydroacoustic data

During all cruises, continuous hydroacoustic records were logged at frequencies of 38 kHz and 120 kHz using a hull mounted, sphere-calibrated SIMRAD EK 500 scientific echo-sounder system (sounder settings used are indicated in Appendix A). Backscattering echoes with a spatial resolution of approximately 5 m horizontally (at a vessel speed of approximately 10 knots) and 0.5 - 1.4 m vertically were collected using Sonardata Echolog software (on the *F.R.S. Algoa* and *Africana*) and the Bergen Echo Integrator (BEI 500) system on the *R.V. Dr. Fridjof Nansen*. To compare hydroacoustic with hydrological data, acoustic echoes were integrated over relevant horizontal and vertical bins using Sonardata Echoview software.

Densities were computed from the backscattering area per unit of sea surface, expressed as Sa:

$$Sa = r\ ´\ s$$

where: r = fish density

s = backscattering cross-section

2.2.2. Environmental data

2.2.2.1. Data collection aboard research vessels.

Sea surface temperature (SST) data were derived from hull mounted temperature sensors aboard the *F.R.S. Algoa* and *Africana*, and logged on the vessel's Data Distribution System (DDS). Vertical temperature and salinity profiles throughout the entire depth of the water column were obtained at all CTD stations, before or after each trawl on the *F.R.S. Africana* and *R.V. Dr. F. Nansen* surveys, and at regular intervals on the F.R.S. Algoa survey. A General Oceanics Co, Inc. Mark IIIC/WOCE CTD profiler was deployed from the *F.R.S Algoa* and *F.R.S. Africana* and a Seabird 911 probe from the *R.V. Dr. Fridjof Nansen*.

The density of seawater, expressed in parts per thousand (‰), was computed using CTD data (Gill 1982) from all CTD casts.

Oxygen concentrations from selected samples were measured by applying the standard Winkler titration method (Strickland and Parsons 1972).

Turbidity values were obtained at all CTD stations by means of a Sea Tech 25cm path-length transmissometer deployed with the CTD. The transmissometer is designed to provide accurate *in situ* measurements of beam transmission and the concentration of suspended matter in relatively turbid waters. Turbidity is expressed in millivolts (mV), where transmittance may be computed as a percentage of the maximum transmittance. 100 % transmittance equals approximately 84 mV (Roberts *et al*. in prep.), calculated by calibrating the transmissometer in distilled water. O% transmittance (i.e. maximum turbidity) translates to approximately 4 mV, calibrated by blanking the transmissometer beam source to simulate maximum turbidity.

Aboard the *F.R.S. Algoa* and *Africana*, wind velocity and direction data were collected and logged onto the DDS. These data were investigated to relate periods of south easterly winds to the vertical distribution patterns of Cape hakes.

Current data were measured during February 1998 aboard the *F.R.S. Algoa* by means of an RDI 150 kHz hull-mounted Acoustic Doppler Current Profiler (ADCP). The ADCP operates by transmitting four acoustic beams into the water column and computes the current direction and velocity by resolving the Doppler shift of these beam reflections from different depth layers to a depth of 250 m (Boyd *et al*. 1992, Ona 1994). Current recordings while the vessel was steaming at speeds higher than 6 knots, when the vessel made significant course changes or during trawling operations were omitted from the analysis, as were readings within 15% of the total depth from the ocean bottom. Recorded ensembles were individually assessed and only those that were recorded at slow steaming speeds and at CTD stations were averaged. Ensembles displaying large error components were omitted from the averaging procedure. Suitable ensembles were averaged according to bottom and navigation tracking procedures.

2.2.2.2. Retrospective wind and current data

A synoptic wind and current data series were collected off the west coast of South Africa at Cape Columbine. The wind and current data include 82 days of hourly records during the summer months of December to February 1982. The current data series was collected by means of a moored current meter at a depth of 230 m positioned on the continental shelf off Cape Columbine (32°43.85 S, 17°36.23 E). The current meter was moored 25 m off the ocean bottom and therefore these current data represent near-bottom ocean currents.

The Cape Columbine current and wind time series data were subjected to spectral analyses in order to identify and characterise cyclical patterns. The analysis is concerned with cyclical patterns within the data, and operates by breaking complex time series into their sinusoidal Fourier components. For this purpose, the data are converted into the frequency domain where cyclical components are separated at different frequencies. The analysis then seeks for correspondence between the peaks of the separated wind and current Fourier components within the frequency domain. Cycle frequencies identified by significant peaks in the spectral curves were converted to time units as follows:

$$hours = \frac{1}{frequency}$$

The phase relationship between the two series was investigated, in order to determine the lag period between corresponding peaks. By identifying the amplitude in radians and period of the peak, the lag period was calculated (Chatfield 1989):

$$Lag = \frac{Radians \cdot Period}{2p}$$

2.2.3. Spatial analysis

Spatial displays and contour maps from biological and environmental data were generated on the basis of kriging principles, using the geostatistical software package SURFER® for Windows (Golden Software Inc.). Kriging has extensively been used to present fisheries and acoustic data (Barange and Hampton 1997, Maravelias and Haralabous 1995, Maravelias *et al*. 1996). The method uses weighted average interpolation algorithms to produce a regularly spaced array of values from irregularly spaced data. The weighting technique is based on the modelled statistical variance between paired samples plotted as a function of the distance between the samples (MacLennan and Simmonds 1995).

2.3. RESULTS

2.3.1. Relationship between wind patterns and vertical distribution of a deep scattering layer

Prior to the hake vertical distribution cruise west of the Cape Peninsula, between 6-17 February 1998 (Fig. 2.2), upwelling events induced by strong SE winds generated a well-defined oceanic front, being portrayed by a large change in SST across the continental shelf. Cold, upwelled waters dominated the inshore region, extending offshore and southwards during that period. At the start of the cruise, the oceanic front had weakened slightly, but remained well-defined. Wind vectors during the cruise period (which were filtered to remove the effect of land-sea breezes) illustrate that north westerly winds dominated the initial stages of the cruise, but were soon replaced by south easterly winds, which prevailed and strengthened throughout the remainder of the cruise (Fig. 2.3).

Figure 2.4 illustrates typical acoustic echograms (a) prior to and (b) during periods of SE winds along the survey grid conducted aboard *F.R.S. Algoa* (Fig. 2.1a). Prior to the onset of SE winds a deep scattering layer is concentrated closely to the seabed. Following the onset of SE winds however, the deep scattering layer displays a vertical migration response by migrating to a depth of approximately 60 m above the seabed, resulting in a decreased availability to demersal trawl gear and a subsequent decrease in CPUE.

Mean acoustic densities derived from the integration of backscattering energy over sampling distances of half nautical miles revealed a significant ($P<0.01$) difference between acoustic densities prior to and after the onset of SE winds (Fig. 2.5). Within a zone of 5 m above the seabed, densities before the onset of SE winds were significantly higher than after ($P<0.01$), indicating that fish availability to demersal trawl gear, which operates to a maximum of 5 m above the seabed, is reduced during strong SE wind periods. The phenomenon is confirmed by a significant difference between the acoustic densities before and after the onset of SE winds within a zone of 50 - 60 m above the bottom

(P<0.01). Prior to SE winds, low acoustic densities in midwater are reflected by high fish concentrations near the seabed, but as SE winds commence, a dramatic density increase in the midwater is associated with a decrease in the near-bottom zone, indicating a rapid vertical migration of the deep scattering layer. The migration is similarly reflected in the CPUE, with total demersal and *M. paradoxus* catches decreasing by approximately 3 and 4 times respectively from pre-wind catches (Fig. 2.6 and Table 2.1). Similarly, near-bottom acoustic densities decreased by approximately 7 times following the onset of SE winds.

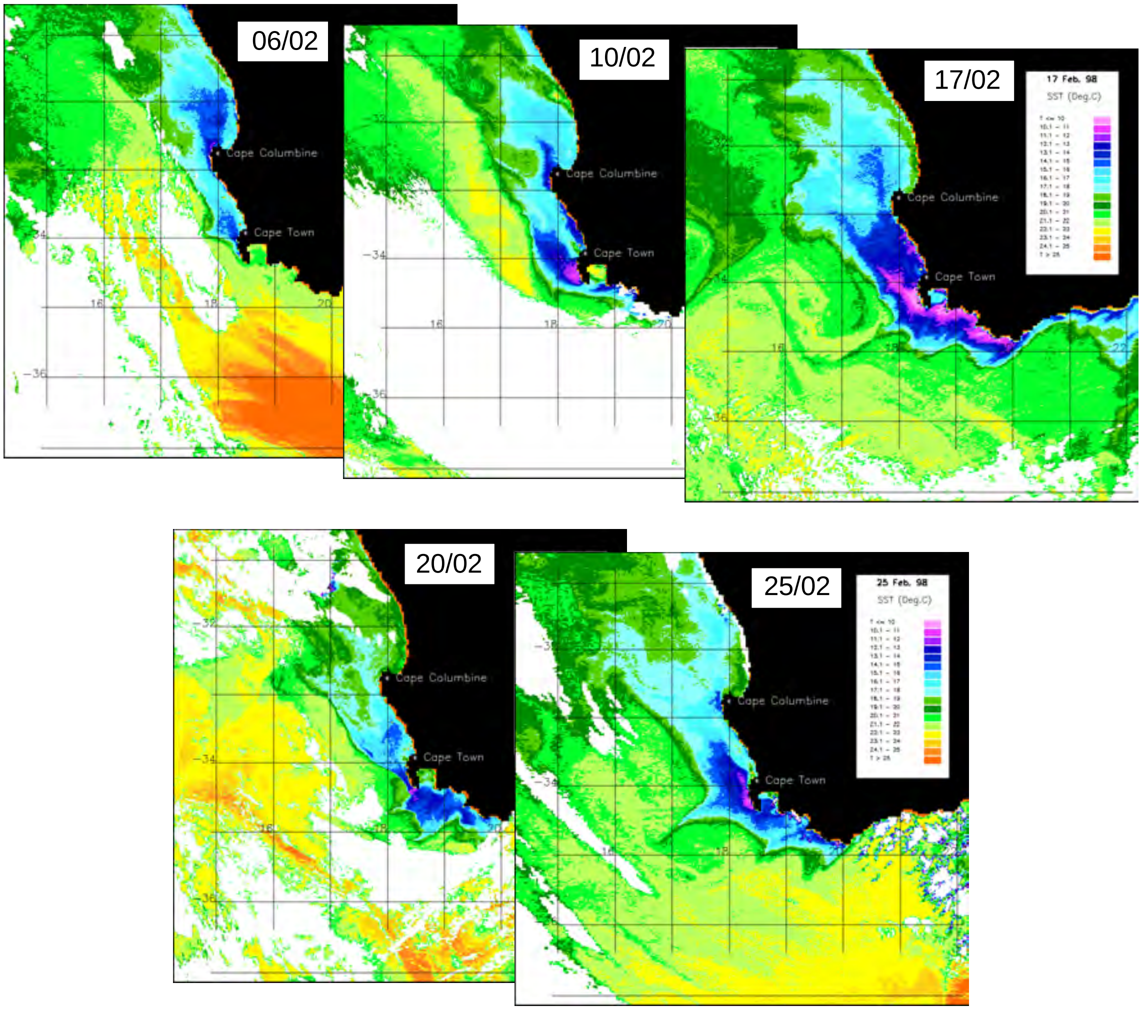

Fig. 2.2. NOAA satellite images representing SST over a 20 day period during February 1998. Conditions during the hake vertical distribution survey (20-26 February) are depicted in the two lower images.

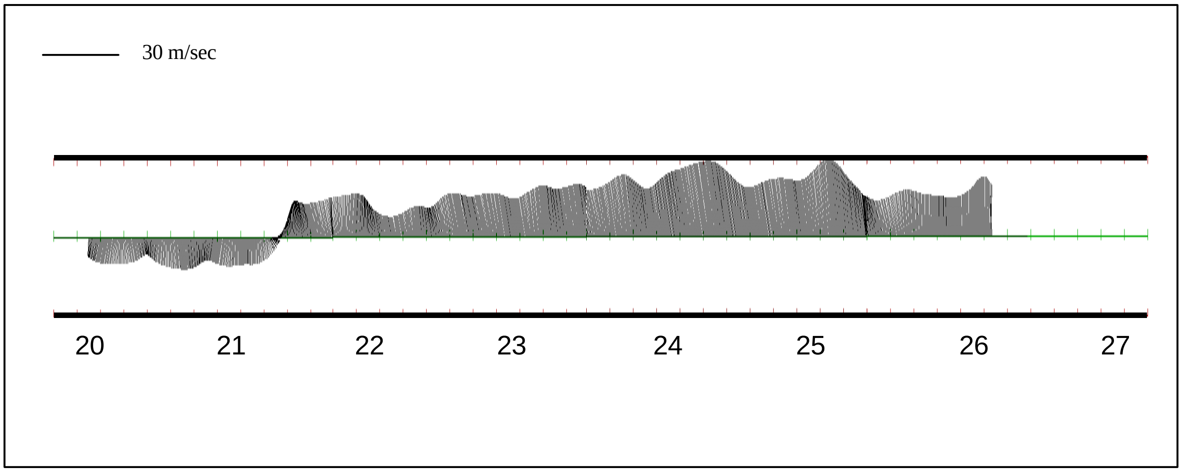

Fig. 2.3. Filtered wind stick-vector diagram depicting wind conditions collected aboard the *F.R.S. Algoa* during the hake vertical distribution cruise from 20-26 February 1998

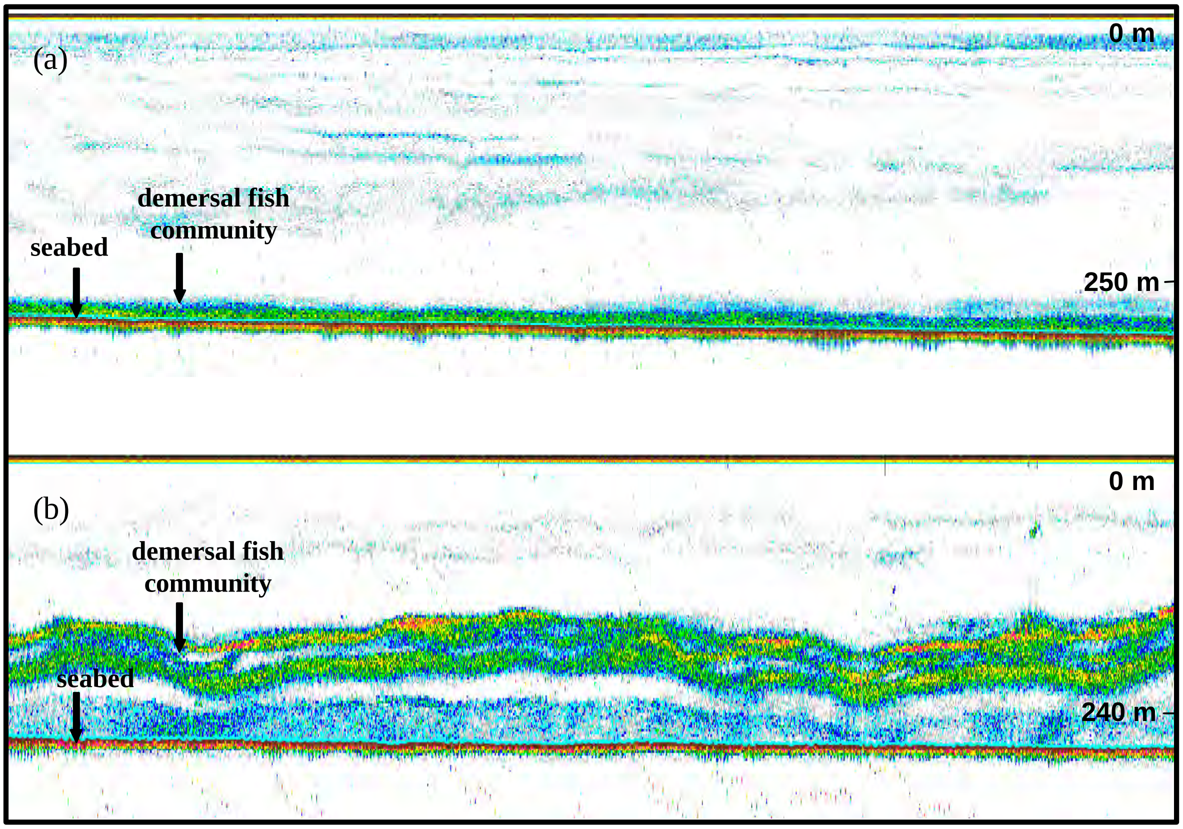

Fig. 2.4. Typical daytime hydroacoustic echograms during (a) the absence and (b) the presence of strong south easterly winds. Data presented in the figures were collected along the sampling grid at nearby positions of 34° 03.25 S; 17° 35.05 E at 09h30 (a), and 34° 02.41 S; 17° 35.24 E at 11h00 (b) on the 21 February 1998.

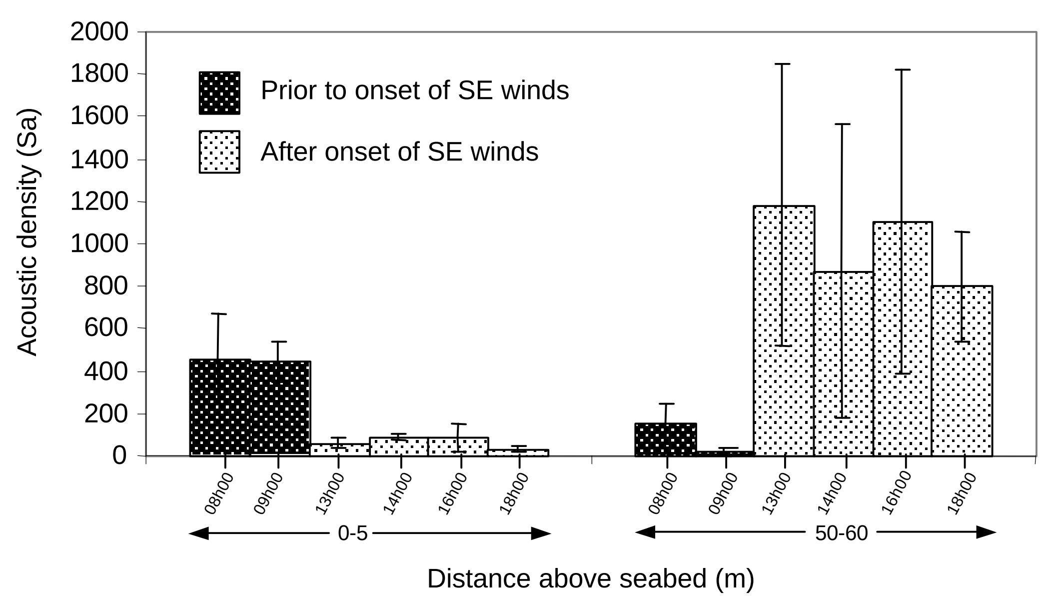

Fig.2.5. Acoustic densities within two layers, 0-5 and 50-60 m above the seabed at various stations along the sampling grid conducted aboard *F.R.S. Algoa* during February 1998. The vertical bars indicate the standard deviation of the mean.

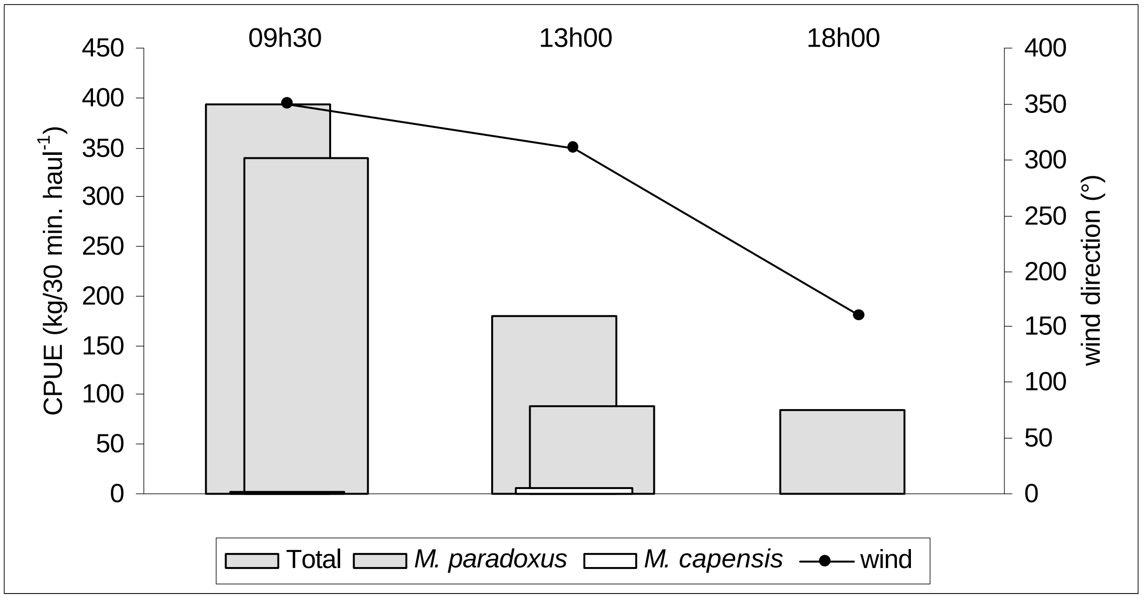

Fig. 2.6. Total demersal and Cape hake CPUE prior to, and following the onset of SE winds at trawl stations along the sampling grid aboard F.R.S. Algoa during February 1998.

Table 2.1. Catch and acoustic density ratios between samples collected prior to and after SE winds, and those collected at a fixed location during day and night aboard *F.R.S. Algoa* during February 1998.

SAMPLING AREA	CATCH RATIO			ACOUSTIC DENSITY RATIO
	Total	*M. capensis*	*M. paradoxus*	Sa
Grid survey Before/after wind	2.94	-	3.85	6.95
24 hour station Day/night	1.15	1.23	1.08	-

2.3.2. Relationship between fish distribution and ambient environmental parameters

Before establishing the mechanism whereby wind transmits its influence through to Cape hake vertical dynamics, it needs to be determined whether a particular oceanographic variable appears to be influencing hake vertical distribution directly. SST during the survey period in February 1998 are depicted in Figure 2.7. As the increasing SE wind induced upwelling events, upwelled cold water was prevalent inshore with a displacement of warm water offshore, separated by a well-defined oceanic front. SST plotted along an onshore-offshore transect indicated that a rapid change in temperature occurred between 15 and 21 °C, with the position of the front being indicated suitably by the 18 °C isotherm (Fig. 2.8). This corresponds to Macpherson *et al*. (1991) who similarly define the oceanic front by the presence of the 18 °C isotherm.

Spatial variability of acoustic backscattering energy throughout the cruise grid area showed a strong biological association with the position of the oceanic front in the upper layers of the water column (Fig. 2.9). Acoustic densities were greatest on the inshore, cold side of the front, and a strong onshore-offshore density gradient corresponded to the onshore-offshore variability in SST. In the near-bottom region however, acoustic densities showed that the strong biological gradient was not as prevalent.

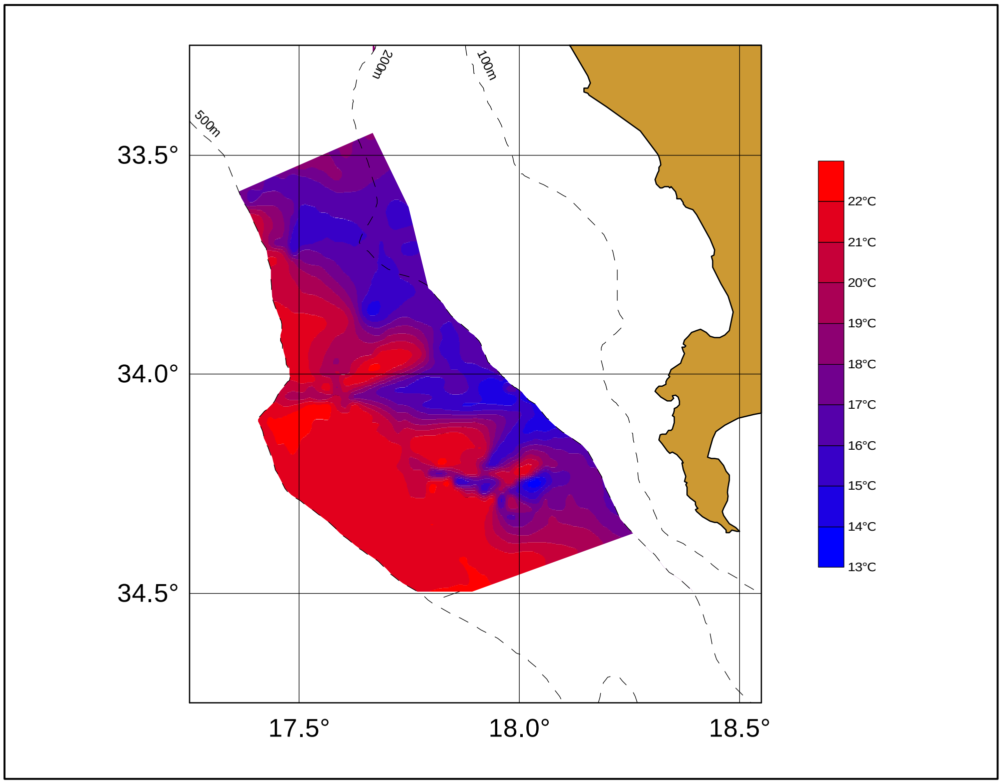

Fig. 2.7. SST contour plot derived from data collected along the sampling grid aboard *F.R.S. Algoa* during February 1998. A well-defined oceanic front is located approximately midway between the 200 and 500 m isobaths.

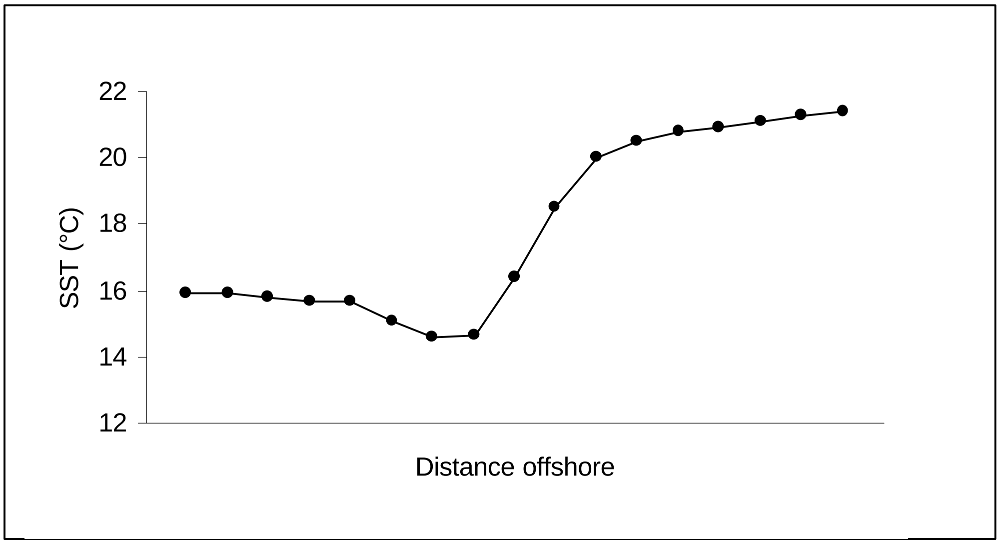

Fig. 2.8. SST plotted along an onshore-offshore leg of the survey grid (Fig. 2.1a), depicting the position of the oceanic front. The inshore region is characterised by low SST with a displacement of warmer water further offshore.

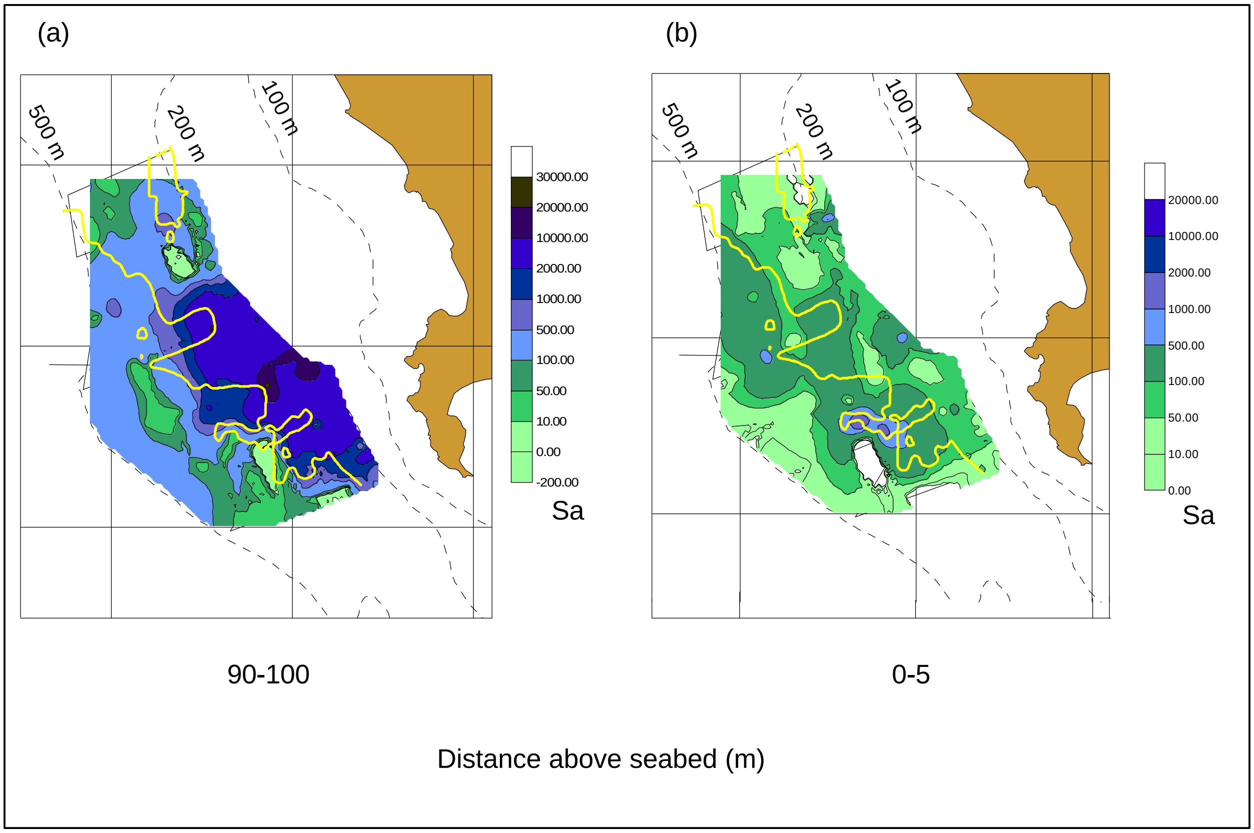

Fig 2.9. Acoustic backscattering densities at a depth of (a) 90-100 m above the seabed and (b) 0-5 m above the seabed. The position of the oceanic front (18 °C isotherm) is indicated by the yellow line.

Temperatures sampled at CTD stations along the sampling grid revealed significant variations between mean surface (i.e. first 5 m of the water column) ($P<0.05$) and mean bottom (i.e. last 5 m of the water column) ($P<0.05$) temperatures at twelve CTD stations (Fig 2.10). Major variations in SST occurred across the position of the oceanic front. Although bottom temperatures varied significantly along the grid, an association with bottom temperature variation and depth seemed apparent. This trend is confirmed by a significant ($P<0.01$) strong, negative relationship between bottom temperatures and depth (Fig. 2.11a). Greater depths are associated with warm SST, with SST below 15°C being restricted to depths shallower than 250 m (Fig. 2.11b).

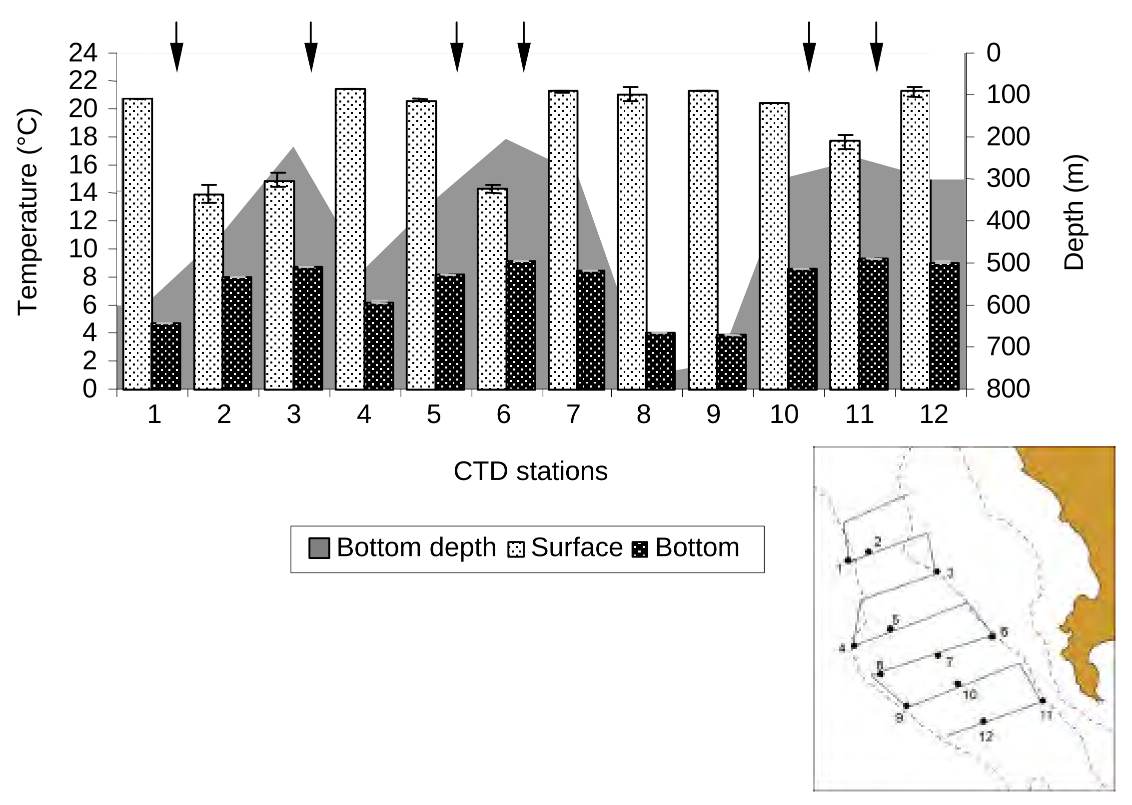

Fig. 2.10. Bottom and SST variability along the survey grid at CTD stations depicted in the inset. The grey background depicts the bottom depth at each CTD station. The arrows denote the position of the oceanic front. Error bars indicate the standard deviation of the mean.

Acoustic echograms recorded during the 24 hour cycle clearly show a strong diurnal vertical migration pattern by the backscattering layer (Figs. 2.12-2.14). The ecological significance of the diurnal migration pattern during this period occurs during daylight hours, when the deep backscattering layer did not migrate to the seabed, remaining at a depth of approximately 60 m above the bottom. This behavioural response is reflected in demersal trawl CPUE over the 24 hour period (Fig. 2.15). Not only were daytime catches of hakes low relative to total catches, they were not significantly different to catches at night for *M. capensis* (P>0.05) or *M. paradoxus* (P>0.05) (Table 2.1). Vertical environmental profiles illustrated no association between the vertical position of the backscattering layer and vertical changes in temperature (Fig. 2.12a), salinity (Fig. 2.12b), density (Fig 2.13a) or turbidity (Fig. 2.13b).

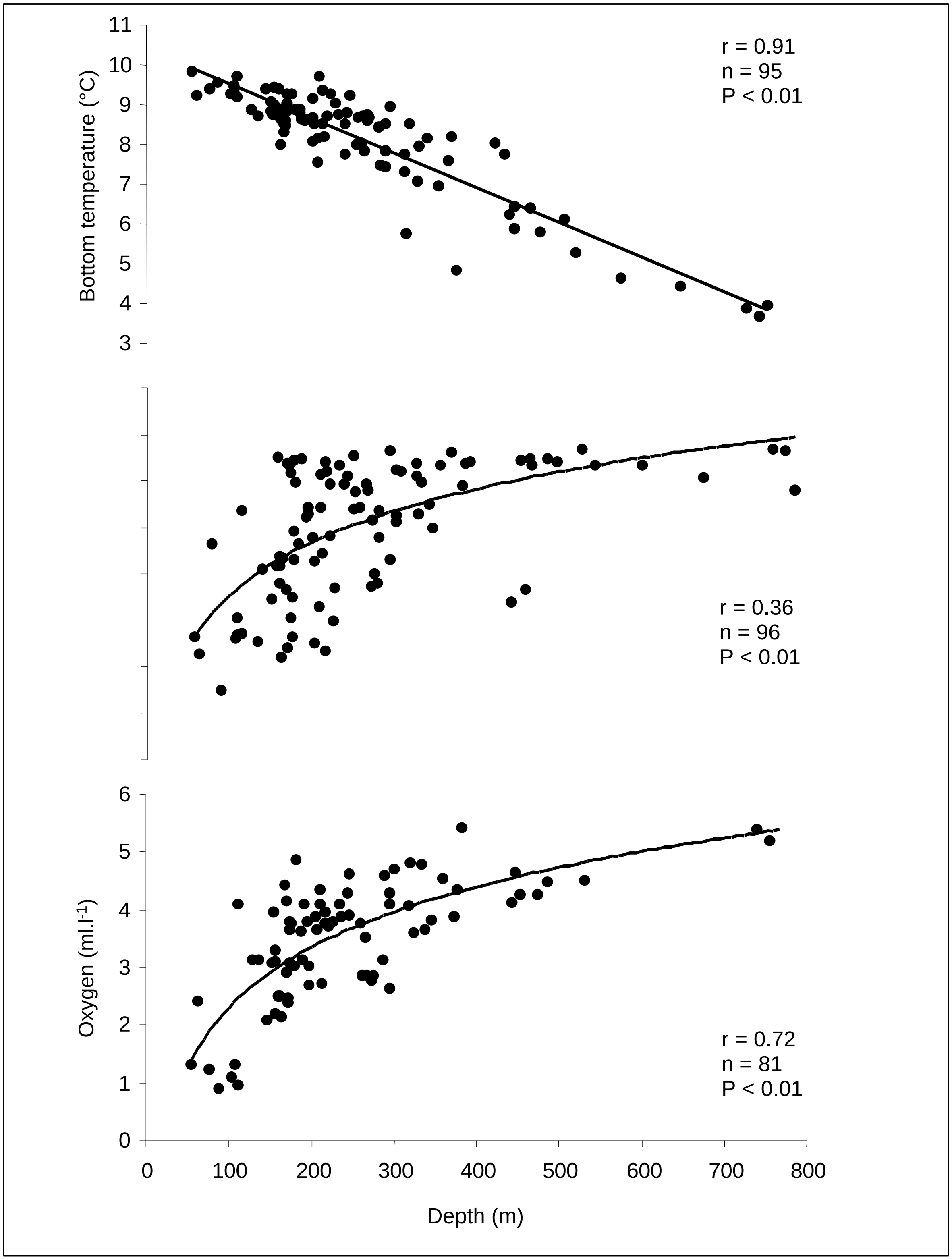

Fig. 2.11. Relationship between (a) bottom temperature, (b) surface temperature and (c) bottom oxygen concentrations with depth during *F.R.S Algoa* and *Africana* surveys off the west coast of South Africa

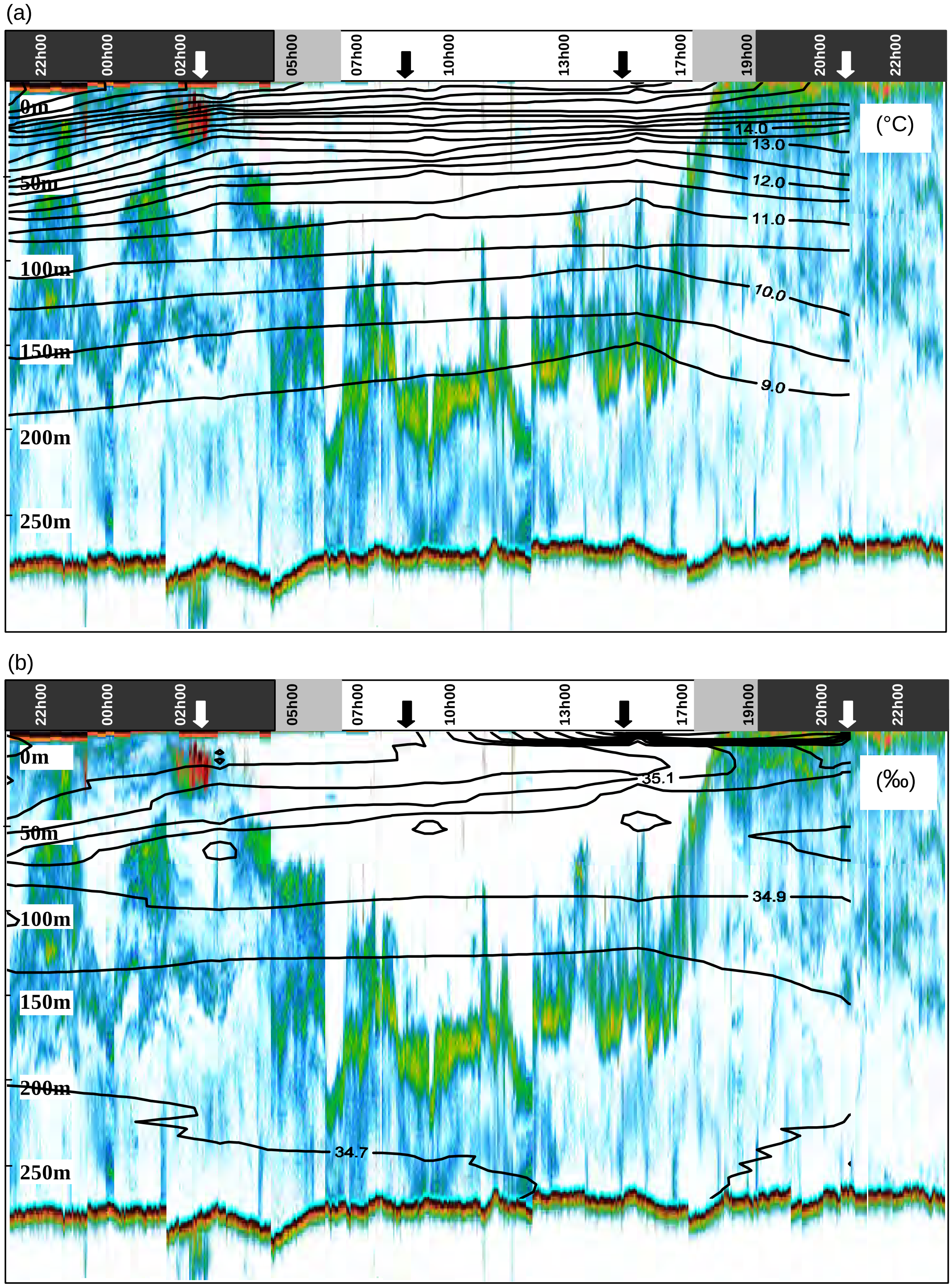

Fig. 2.12. Vertical spatial variability of acoustic backscattering energy during a 24 hour period at a fixed station and its spatial relation to vertical temperature (a) in °C and salinity (b) in ‰ profiles. The arrows indicate CTD sample times.

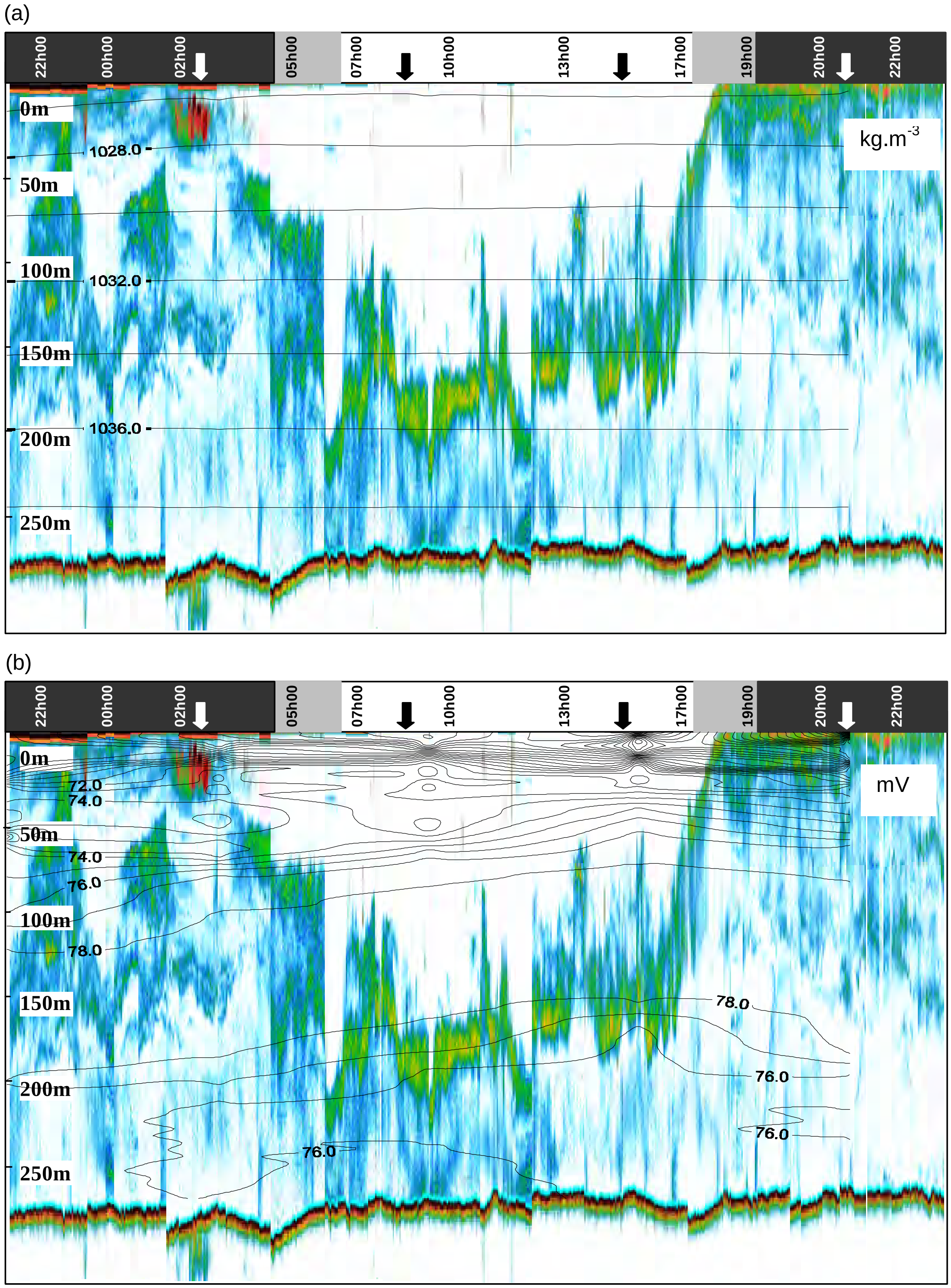

Fig. 2.13. Vertical spatial variability of acoustic backscattering energy during a 24 hour period at a fixed station and its spatial relation to vertical density (a) in kg.m^{-3} and turbidity (b) in mV profiles. The arrows indicate CTD sample times.

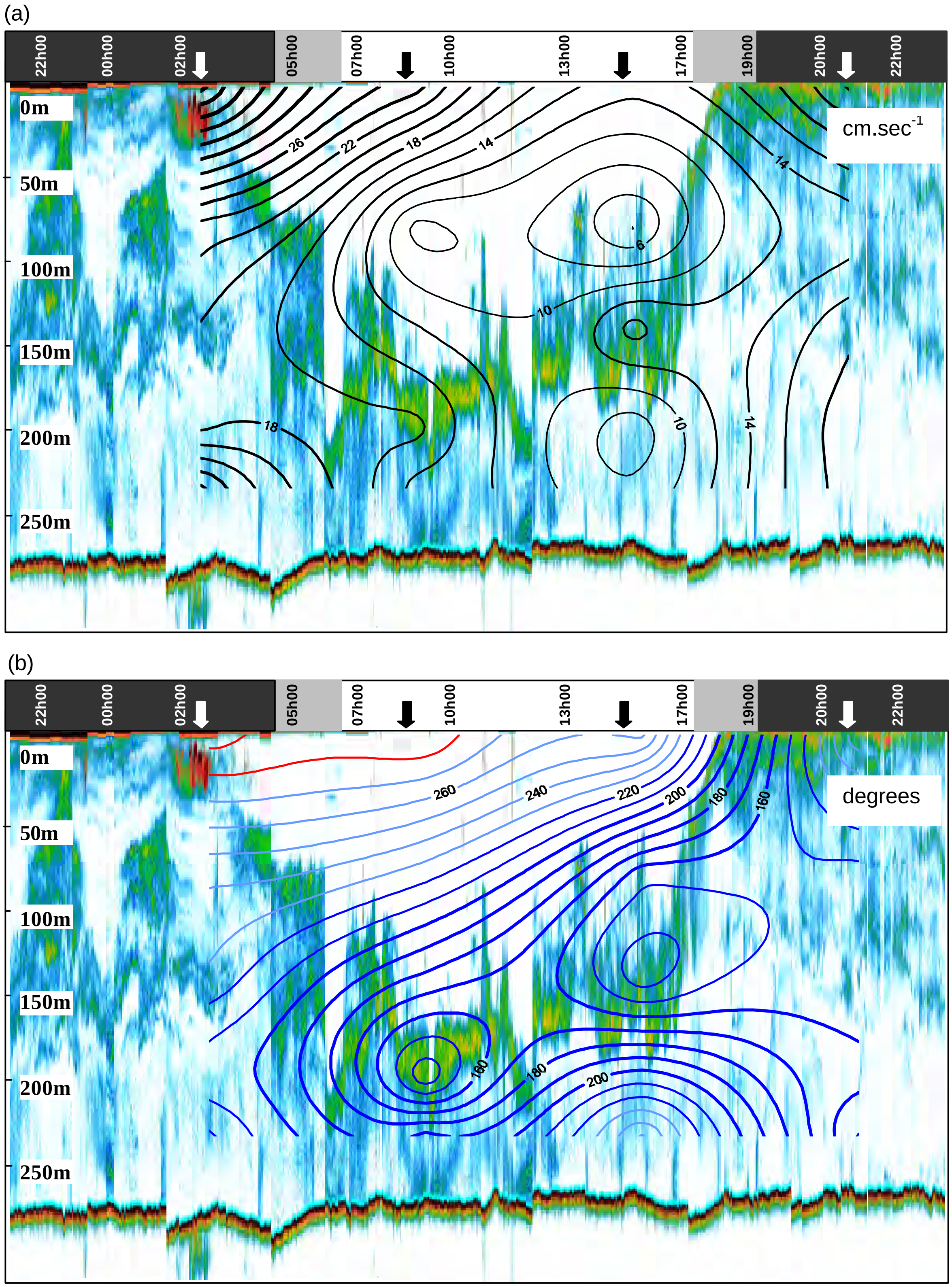

Fig. 2.14. Vertical spatial variability of acoustic backscattering energy during a 24 hour period at a fixed station and its spatial relation to vertical current velocity (a) in cm.sec^{-1} and direction (b) in degrees profiles. The arrows indicate CTD sample times. Dark blue and light blue lines in Figure (b) represent currents with strong and weak southerly components respectively. Red lines represent currents with a northerly component.

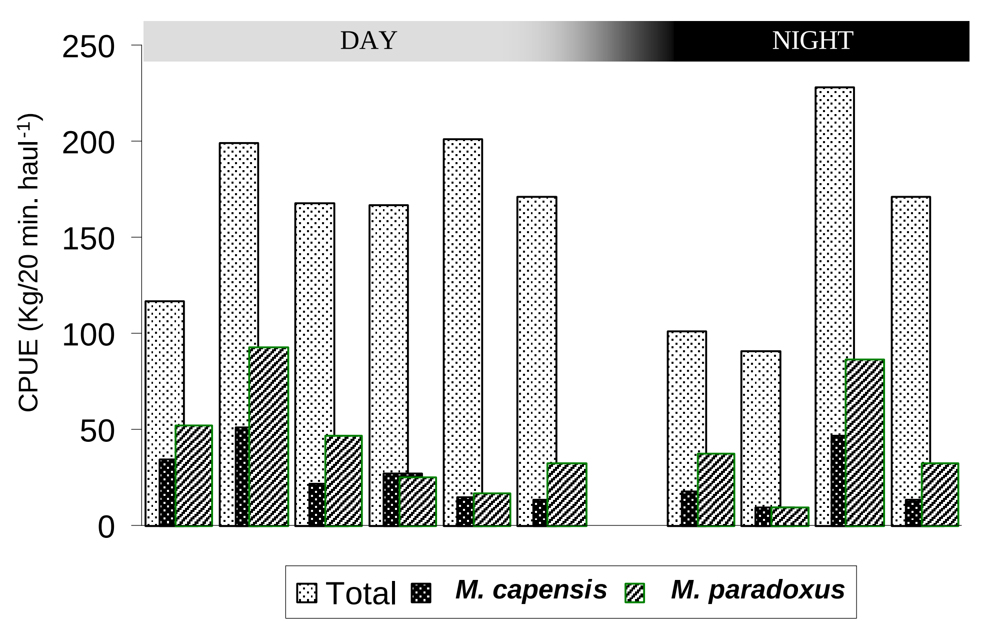

Fig. 2.15. Demersal trawl CPUE during the 24 hour period at a fixed station off the west coast of South Africa.

ADCP derived vertical current profiles displayed an interesting association with the vertical position of the deep scattering layer (Fig. 2.14). Although current velocities (Fig. 2.14a) did not show a large vertical change between the deep scattering layer and the seabed, the fish positioned themselves in the midwater where currents velocities were relatively slow, between 8 and 12 cm.sec^{-1}. The current direction, illustrated in Figure 2.14b suggests the presence of an environmental boundary between the scattering layer and the seabed depicted by a dramatic change in the direction of near bottom currents in a short vertical distance. The fish are distributed in water with a stable current direction flowing in a southerly direction.

Bottom oxygen concentrations plotted against CPUE (Fig. 2.16) show a weak relationship with both the total catch and the total hake catch. The parallel regression slopes suggest that hake and the rest of the demersal community exhibit a similar response to ambient oxygen concentrations. When the hake species are investigated separately, Figure 2.17 shows greater catches of *M. paradoxus* associated with high oxygen concentrations. This association may however be circumstantial, as *M. paradoxus* biomass tends to increase with depth as does bottom oxygen concentrations (Fig. 2.11c).

Historical oxygen records, over a period of ten years, extracted from the MCM oceanographic database show an increase in mean oxygen concentrations with depth across the entire shelf off the West Coast, and oxygen concentrations below 2 $ml.l^{-1}$ are restricted to localised inshore regions (Fig. 2.18a). Critically low oxygen concentrations are therefore not common during summer across the majority of the continental shelf, as minimum oxygen concentrations are restricted to regions shallower than approximately 200 m (Fig. 2.18b).

In this study, CPUE obtained at fixed localities off the South African west coast and the Namibian coast aboard the *F.R.S. Algoa* and R.V. *Dr. Fridjof Nansen* respectively, show that large catches of *M. capensis* occurred in water with relatively low oxygen concentrations off Namibia, while off the west coast of South Africa, relatively smaller catches were associated with high oxygen concentrations (Fig. 2.19).

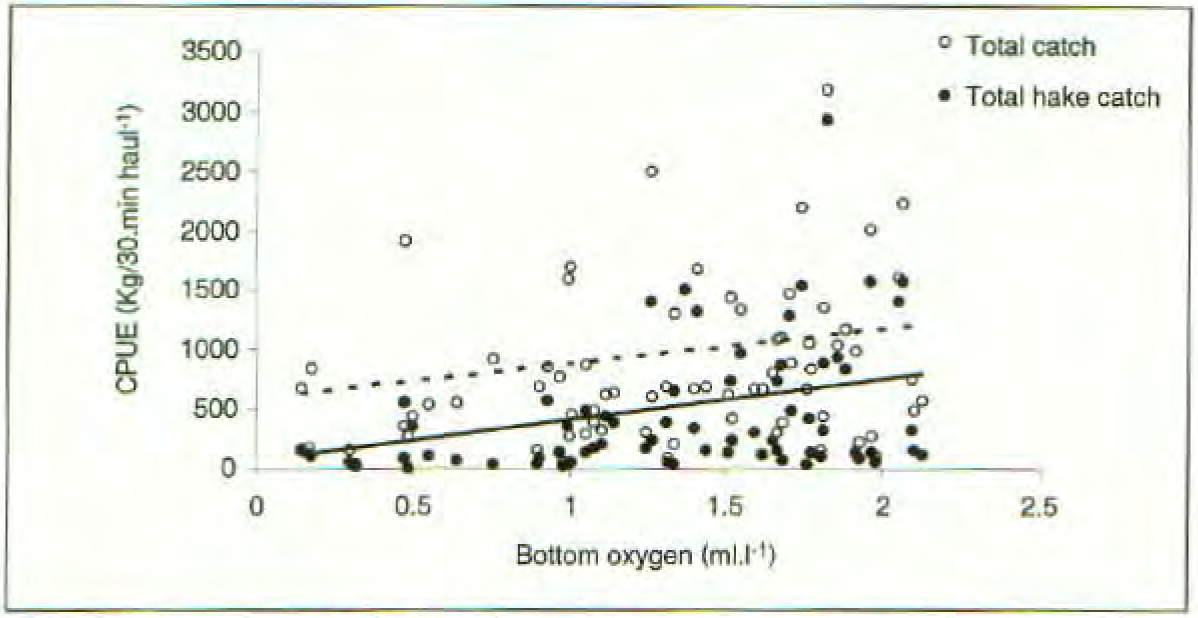

Fig. 2.16. Demersal trawl CPUE plotted against bottom oxygen concentrations collected off the west coast of South Africa.

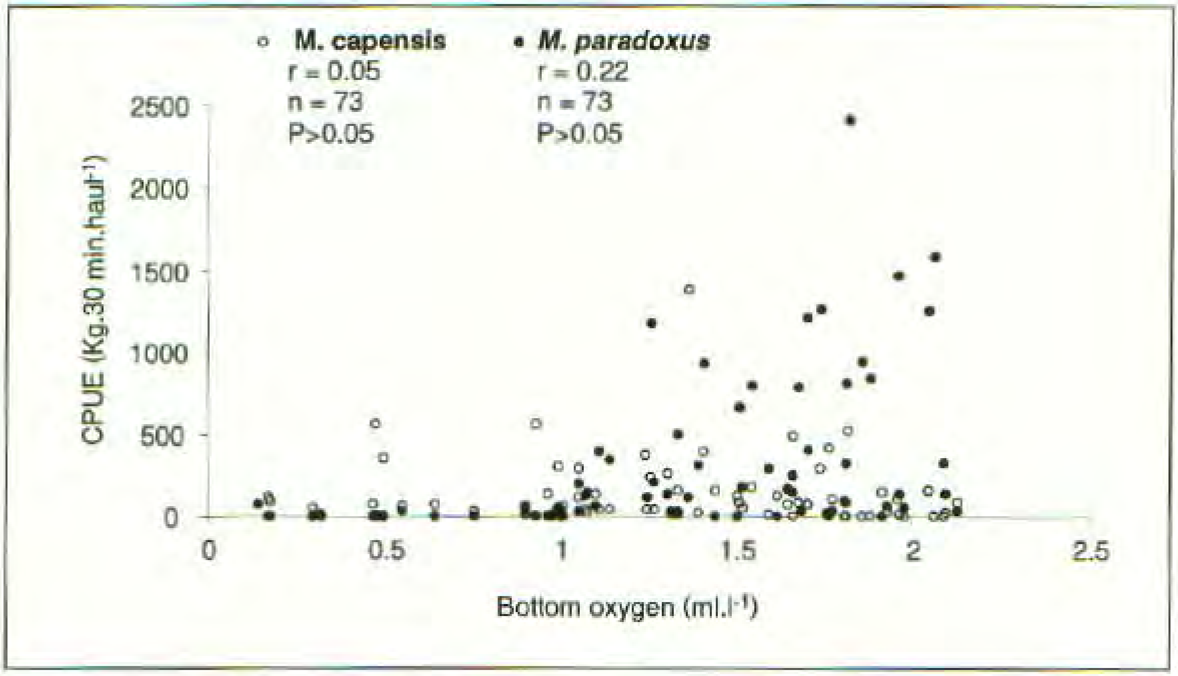

Fig. 2.17. Bottom oxygen concentration relationship with *M.capensis* (○) and *M. paradoxus* (●) CPUE. Data were collected during the annual West Coast demersal biomass assessment survey aboard *F.R.S. Africana*.

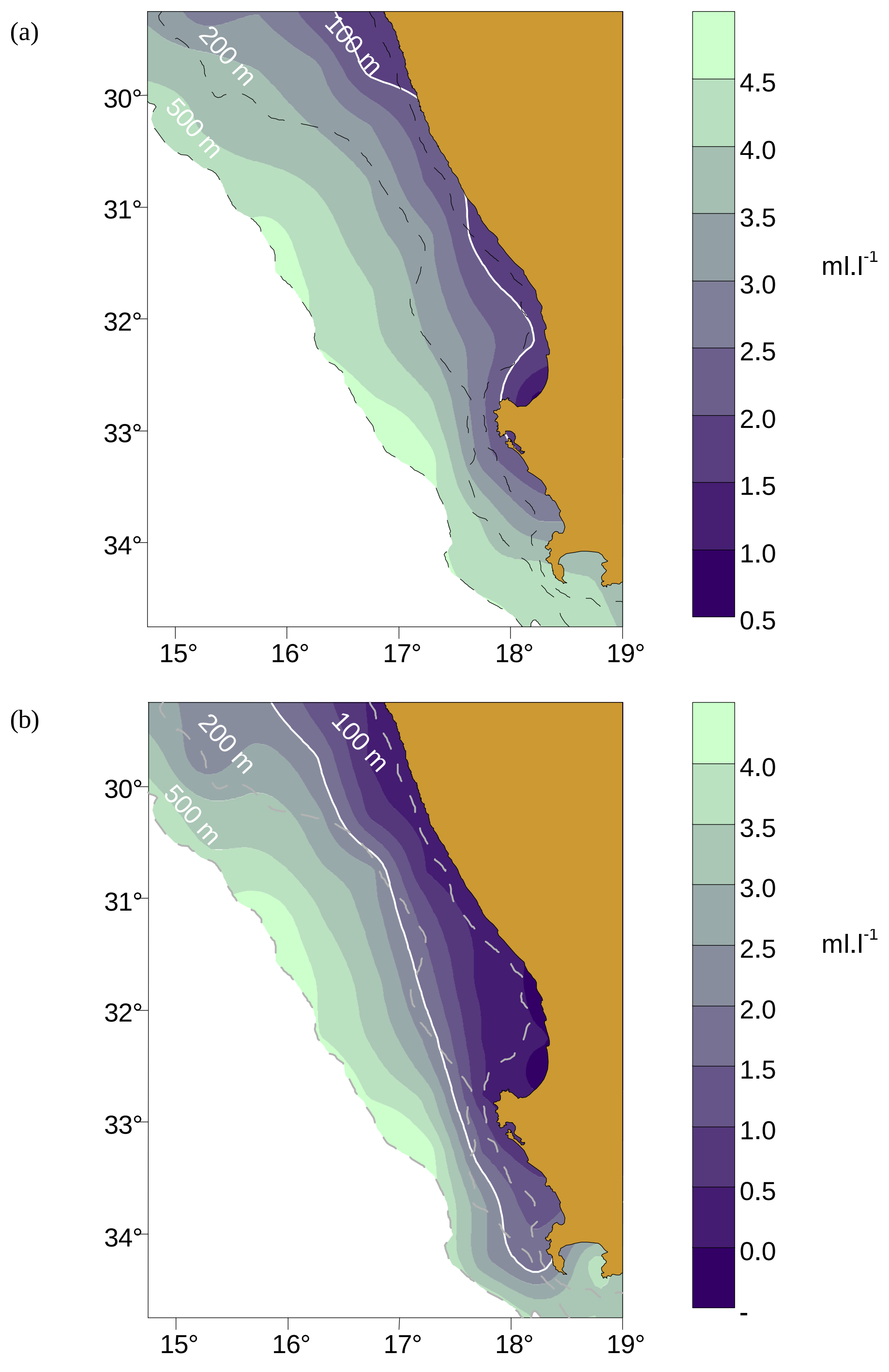

Fig. 2.18. Historical mean (a) and minimum (b) bottom oxygen concentrations over a period of 10 years during summer months over the continental shelf off the west coast of South Africa. The white line represents the 2 ml.l^{-1} contour.

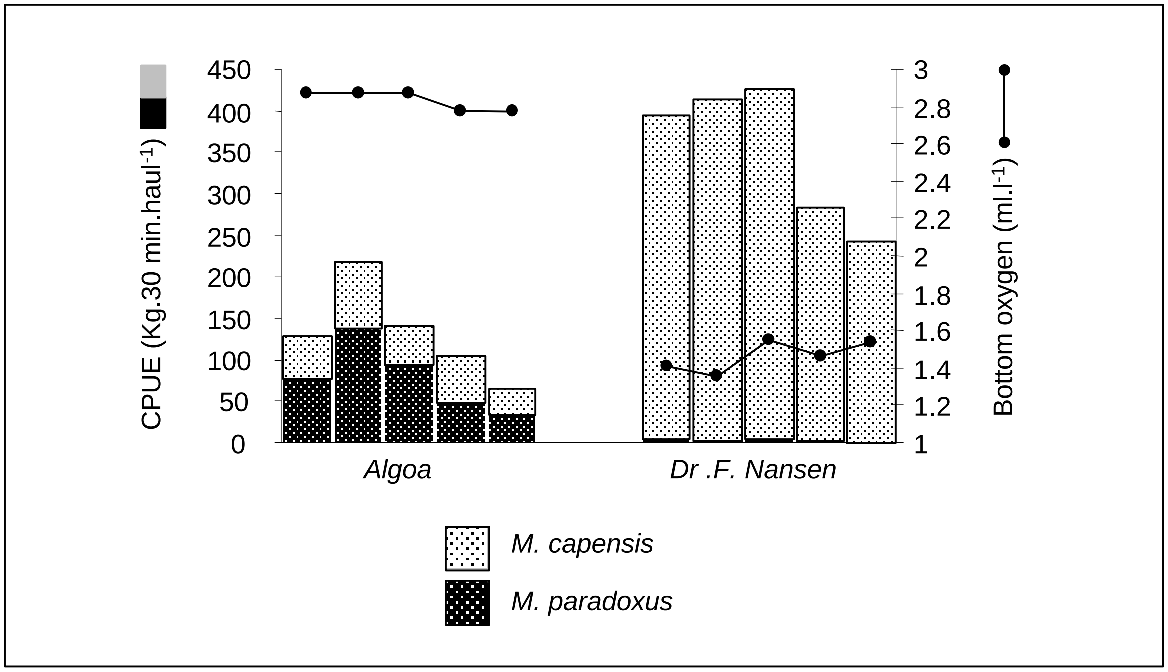

Fig. 2.19. Demersal trawl CPUE and bottom oxygen concentration at two fixed localities off the west coast of South Africa (*F.R.S. Algoa*) and Namibia (*R.V. Dr. F. Nansen*).

Figure 2.20 illustrates acoustic backscattering energy integrated along the offshore transect illustrated in Figure 1a. Vertical spatial variability seems to be persistent across the entire shelf. A well-defined environmental boundary seems to be present at the shelf edge, being depicted by a sharp decrease in backscattering energy in an offshore direction at the shelf edge. Backscattering energy did not seem to be associated with vertical temperature (Fig. 2.20a), salinity (Fig. 2.20b) or density (Fig. 2.21a) profiles. Turbidity contours along the offshore transect sloped steeply within the vicinity of the shelf edge indicating the presence of a horizontal turbidity gradient in this region (Fig. 2.21b). The dramatic change in acoustic backscattering energy showed a spatial association with the 77 mV contour. Currents depicted in Figure 2.22 were contoured to a maximum depth of 250 m, the maximum depth at which the ADCP aboard *F.R.S. Algoa* can collect accurate data. ADCP data collected along the offshore transect revealed the presence of a strong southerly current at the surface above the shelf edge. Inshore, currents were relatively slower, with a prominent mass of southward flowing water approximately 5 nm offshore. At a depth of approximately 240 m off the shelf edge, ADCP data indicates the presence of a boundary zone, where water movement changes form a southerly to northerly direction with depth.

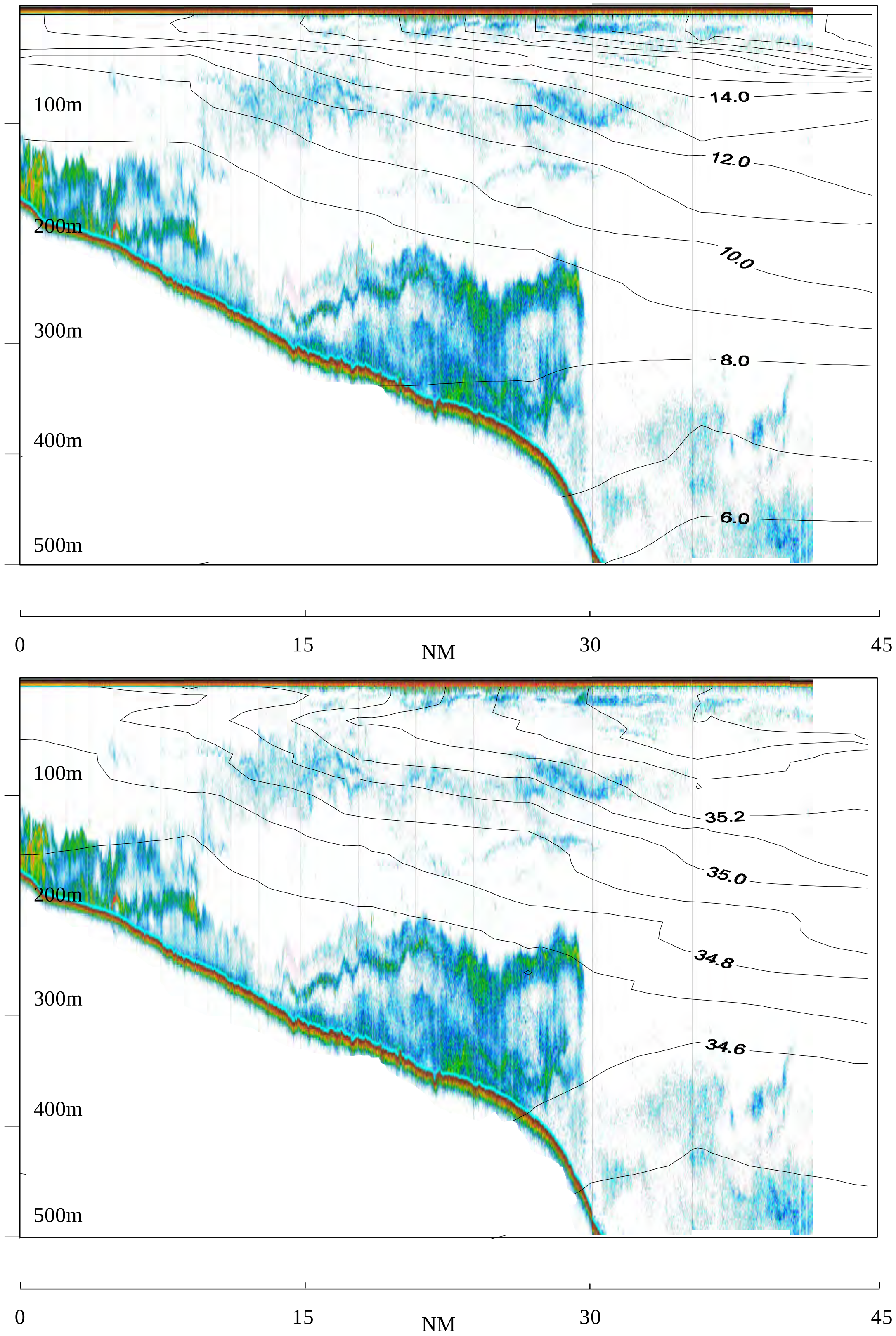

Fig. 2.20. Spatial variability in acoustic backscattering energy and temperature (a) in °C and salinity (b) in ‰ along the offshore transect off the west coast of South Africa.

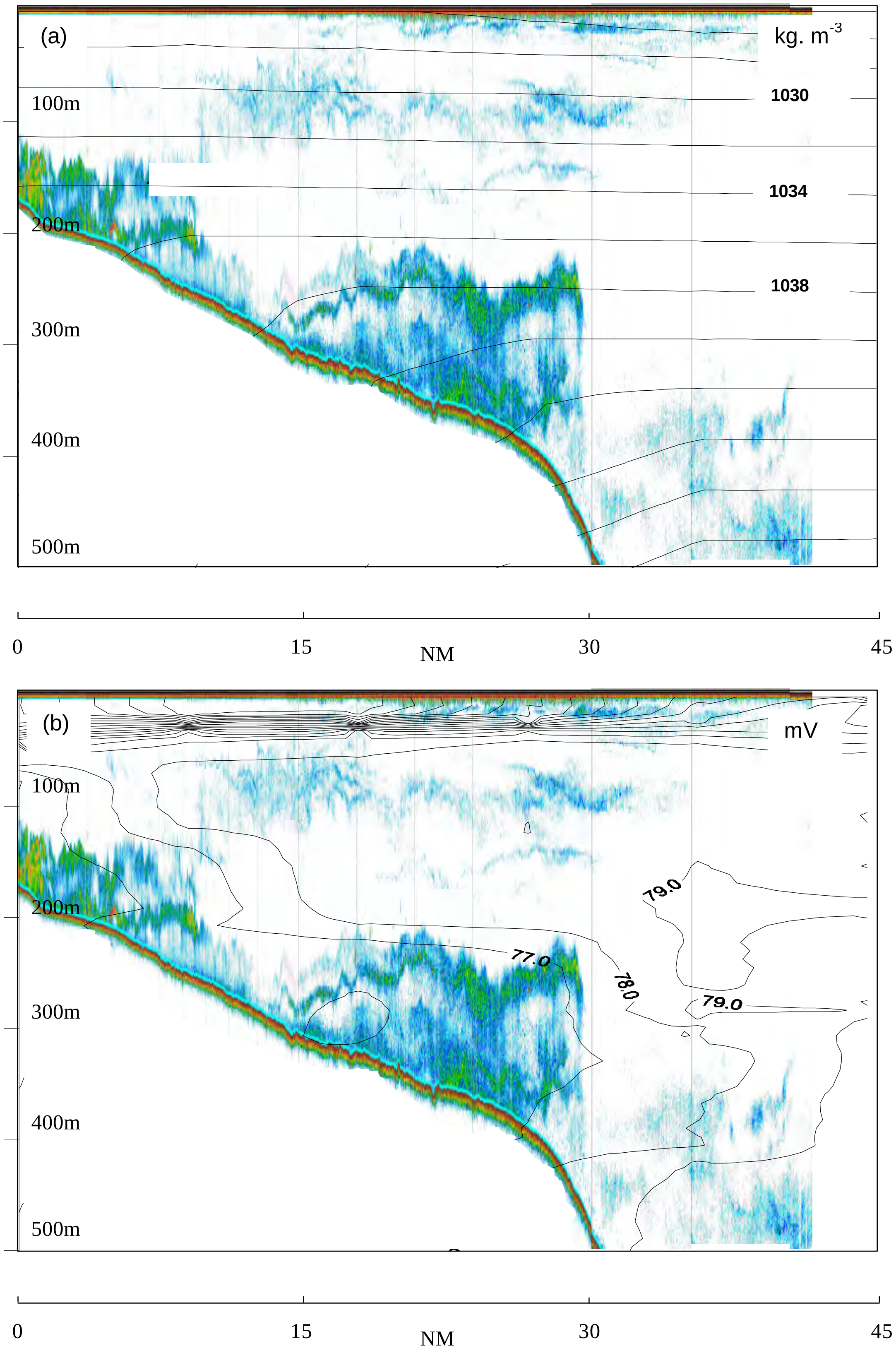

Fig. 2.21. Spatial variability in acoustic backscattering energy and density (a) in kg.m^{-3} and turbidity (b) in mV along the offshore transect off the west coast of South Africa.

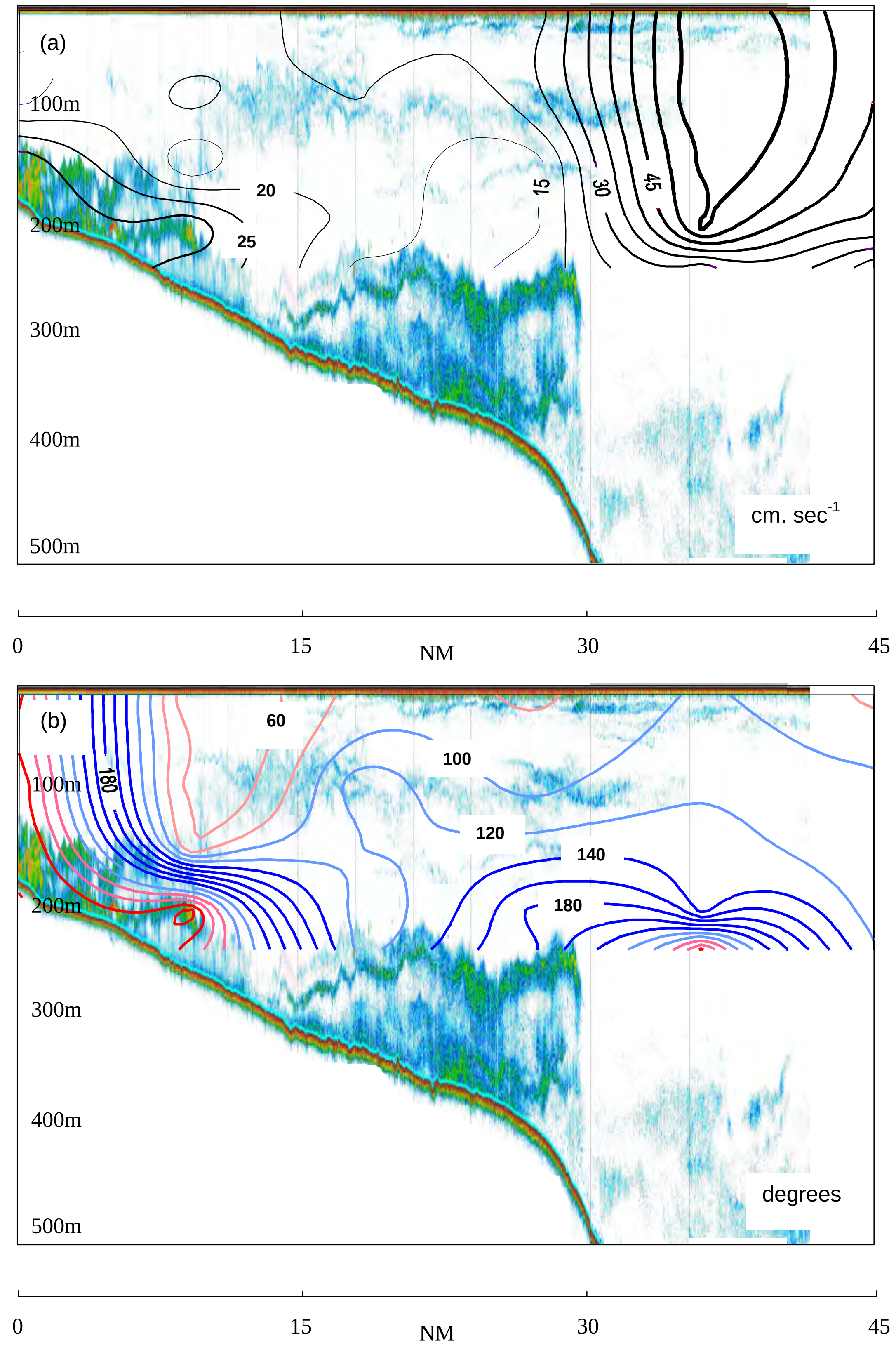

Fig. 2.22. Spatial variability in acoustic backscattering energy, current velocity (a) in cm.sec^{-1} and direction (b) in degrees along the offshore transect off the west coast of South Africa. Dark lines in Figure (b) represent currents with a strong southerly (blue) and northerly (red) component, and light lines a weak southerly (blue) and northerly (red) component.

2.3.3. Spectral analyses of wind and current patterns

Autospectra derived from spectral analyses are represented in Figure 2.23. In both current (Fig. 2.23a) and wind (Fig. 2.23b) data series, two significant peaks were resolved. Significant current peaks occurred at frequencies of 0.0046 and 0.0075 cycles per hour, which translate to 9.05 and 5.5 days respectively, while significant wind peaks occurred at frequencies of 0.0055 and 0.0078 per hour, translating to 7.57 and 5.34 days respectively (Table 2.2). Therefore, in both the wind and current data series, cycles in the wind and current fields occur at similar frequencies, indicating a strong relation between demersal current and wind fields in this region.

In order to compute the lag period between the wind and data series, the phase spectrum of the autocorellation analysis was generated (Fig.2. 23c). The amplitude (in radians) derived from the phase spectrum (at the frequency being investigated) is used to calculate the lag period between the wind and current data series. The lag period between wind and current frequencies of approximately 0.0076 cycles.hour^{-1} (bold values in Table 2.2) was investigated as this frequency represents the 5-6 day wind reversals that are responsible for the fluctuation between northerly and southerly winds (G. Nelson, MCM, pers. comm.). This frequency corresponds to an amplitude of 0.42 radians, translating to a lag period of 8.7 hours (Table 2.2).

Table 2.2. Translation of cycle frequencies derived by spectral analyses to the time domain. Bold values refer to the 5-6 day wind reversals.

	AUTOCORRELATION		PHASE			
	Significant peak frequency	Days	Significant peak frequency	Days	Amplitude	Lag (hours)
WIND	0.0055 **0.0078**	7.57 **5.34**	0.0076	5.48	0.42	**8.7**
CURRENT	0.0046 **0.0075**	9.05 **5.5**				

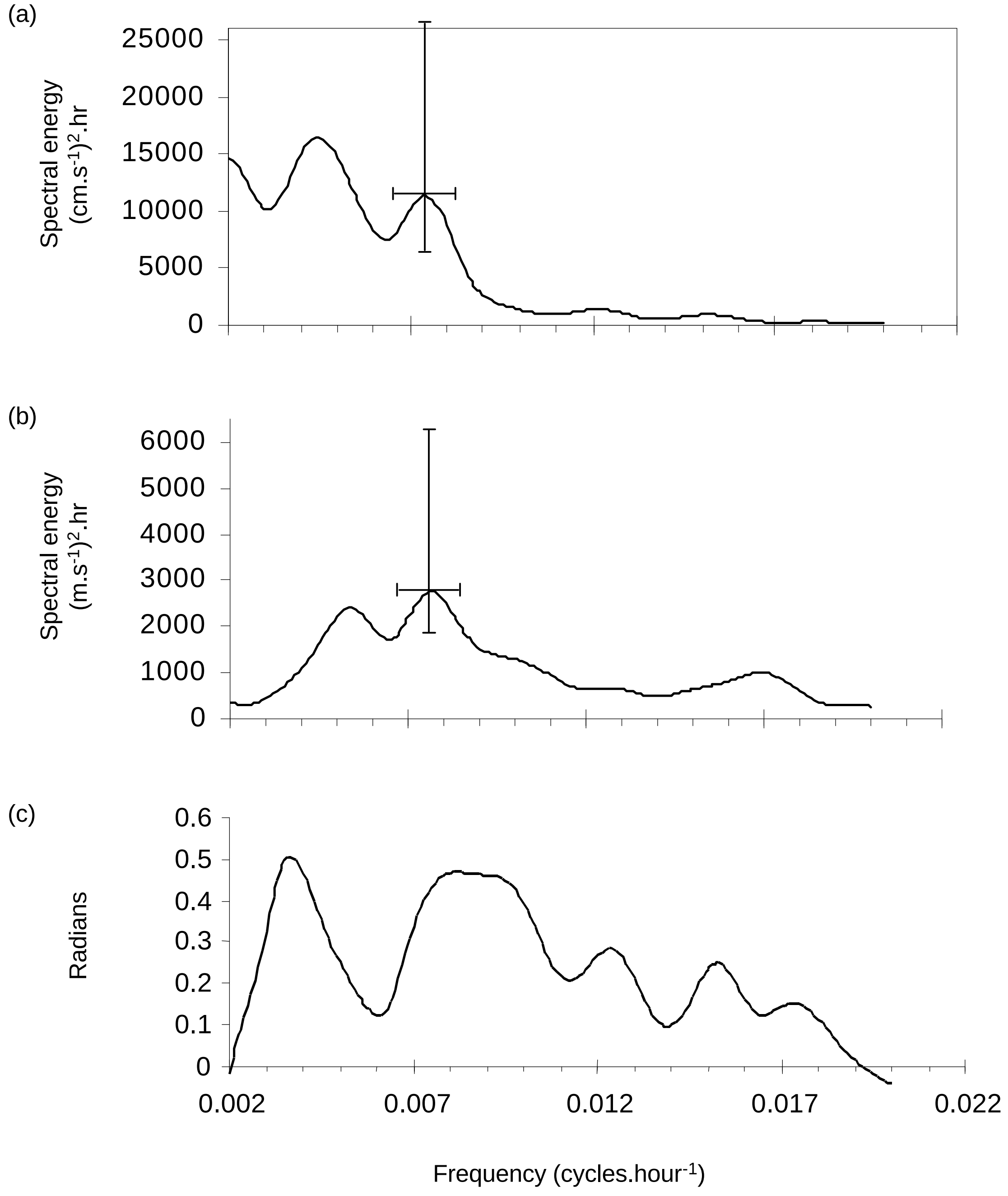

Fig. 2.23. Current (a) and wind (b) autospectra and phase spectrum (c) for time series data collected at Cape Columbine. The vertical and horizontal bars in the autospectra depict standard deviations and frequency bandwidth of the 5-6 day wind frequencies respectively.

2.4. DISCUSSION

A comparison of acoustic densities and CPUE between samples collected prior to and after the onset of SE winds confirmed that deep scattering layers (which are assumed to include Cape hakes) may migrate vertically from the seabed during strong SE winds. While the observations are a 'snapshot', they confirm observations of decreased CPUE values during bouts of SE wind by commercial operators. Catches prior to the SE wind were on average 2.94 and 3.85 times greater than those following the onset of the wind for the total demersal catch and *M. paradoxus* catch respectively. On average, the 'pre-south easterly' wind acoustic densities in the region 0-5 m above the bottom were almost 7 times those of post-wind samples. Acoustic echograms integrated during the 24 hour station and the offshore transect, which were both sampled during strong bouts of SE winds, confirm the vertical spatial variability of fish distributions that are reflected in CPUE data. The ecological significance of the response to these winds can be seen during daylight hours at the 24 hour station, when the deep backscattering layer does not return to the seabed after sunrise. The difference between day and night demersal catches is small, with catch ratios between day and night being close to 1 for both hake species, confirming the absence of hake near the seabed during the day.

These results are, however, largely based on acoustic records of backscattering energy of scattering layers, with no direct evidence to ascertain whether midwater scattering layers included Cape hake. Unfortunately, midwater trawls could not be deployed during the day, when it was assumed that hake were distributed in midwater. Consequently, these results are discussed with the assumption that the midwater scattering layers examined included hake, because demersal trawl catches of hake were lower than expected during the day, and did not differ significantly to those at night. However, hake would not necessarily need to be within the scattering layer (50-60 m above the seabed) to avoid capture by the trawl. It is therefore recommended that future sampling strategies to study daytime midwater occurrence of hake should include midwater trawls in order to directly assess the composition of pelagic scattering layers.

A well-defined diurnal pattern is however apparent, depicting the daily vertical migrations that hakes perform (Botha 1985, Payne and Punt 1995, Pitcher and Alheit 1995). This vertical spatial variability seems to be persistent throughout the continental shelf during these windy periods. The offshore transect echogram illustrates the presence of an ecologically significant phenomenon at the vicinity of the shelf edge where acoustic backscattering depicts an abrupt boundary in fish distribution.

While there was a spatial correspondence between acoustic density gradients in the upper layers of the water column and the position of the oceanic front, the influence of the oceanic front does not seem to extend deep into the water column. Bottom temperatures, which change linearly with depth irrespective of surface wind or temperature conditions, confirm that temperature variability near the seabed is far less pronounced than in the surface layers. Roel and Bailey (1987) and Bailey and Giddey (1986) recorded similar results amidst large variations in SST and report the presence of a stable demersal temperature regime within the study area.

Warm SST at greater depths occurs due to the persistence of oceanic fronts, which are maintained by SE wind-induced upwelling events during summer (Shannon 1995). These events result in an offshore displacement of warm surface water throughout most of the season, which is associated with greater depths and therefore related to lower bottom temperatures. Low SST are restricted to the inshore region and therefore not associated with extremely low bottom temperatures.

Magnuson *et al*. (1981) found that demersal fish off the coast of Oregon responded to the presence of an oceanic front by an increase in the number of species and individuals. Although the front is reported to extend from the surface to the demersal environment, it is located in relatively shallow waters of approximately 30 m and therefore differs to open-ocean fronts. In the Benguela system, thermal fronts of this nature do not occur (Roel and

Bailey 1987). Macpherson *et al*. (1991), after obtaining a good relationship between hake biomass and SST in southern Namibia, propose that surface conditions may be a good indication of near-bottom conditions and therefore may exist as a potential tool to predict hake catches. Similarly, Roel and Bailey (1987) suggest that the distribution of *M. paradoxus* is influenced by thermal gradients at the sea surface. Although the underlying cause of the relationship remains speculative, results from the current analysis suggest that increased hake catches would not be associated with bottom temperatures. According to Crawford *et al*. (1990), research surveys indicate that year classes of hake spawned during warm SST years were much poorer than those spawned during cool SST years. Nevertheless, although Cape hakes may show an association with either bottom or SST over hundreds of kilometres or over annual time scales, daily temperature variations do not seem to dramatically influence the distribution of Cape hakes.

The daytime vertical distribution of the demersal scattering layer during a fixed 24 hour period did not seem to be influenced by vertical changes in temperature, which remained stable within the near-bottom region. Mackas *et al*. (1997) presents similar results where the vertical distribution of *M. productus* off Vancouver Island does not show a strong relationship with changes in temperature or salinity. Along the onshore-offshore transect, vertical changes in temperature did not seem to influence the vertical position of the scattering layer either. Due to similar temperature regimes across the shelf, at and beyond the shelf edge, it seems unlikely that temperature variability is responsible for the observed ecological boundary at the shelf break.

A strong association between the vertical spatial dynamics of Cape hakes and variability in oxygen concentrations within the study area does not seem apparent either. Although large catches of *M. paradoxus* are associated with higher oxygen concentrations, the trend may strongly be influenced by depth. Within deep water where *M. paradoxus* are abundant, oxygen concentrations are higher than in shallow inshore waters. *M. capensis* show no association with oxygen concentrations being as abundant in high or low oxygen concentrations. The shallow inshore region over the continental shelf, where *M. capensis* are predominant is subject to great variations in the environment, which suggests that *M. capensis* may have adopted effective survival strategies such as tolerating oxygen deficiencies (Roel and Bailey 1987).

It is generally accepted that water containing oxygen concentrations of less than 2 $ml.l^{-1}$ is considered to be oxygen-deficient (De Decker 1970, Bailey *et al.* 1985, Chapman and Shannon 1985), in which biological communities can generally not be sustained. Although water containing oxygen concentrations between 2 and 5 $ml.l^{-1}$ is referred to as 'oxygen-depleted', the concentrations are generally sufficient to support biological communities. Therefore, 2 $ml.l^{-1}$ provides a convenient value that distinguishes between 'normal' and 'critically low' oxygen concentrations in this discussion.

Temporal and spatial variation of dissolved oxygen concentrations within the Benguela upwelling system have been well documented, highlighting oxygen-deficient water as a common feature off the Namibian coastline (Bailey *et al.* 1985, Chapman and Shannon 1985, Bailey 1986, Bailey and Giddey 1986, Crawford *et al.* 1990, Mas-Riera *et al.* 1990, Shannon 1995, Hamukuaya *et al.* 1998). Off the coast of South Africa, poorly oxygenated water is not as predominant, although localised, inshore oxygen-poor regions do occur. Chapman and Shannon (1985) attribute oxygen-deficient water in the Benguela system to two major sources. The first source originates from the tropical south east Atlantic off the coast of Angola which is often carried south by a poleward undercurrent west of the shelf break at a depth of approximately 300 m. This water however seldom extends further south than 25° S and therefore does not influence the continental shelf off the coast of South Africa. The second source of oxygen-deficient water originates through biochemical activity, where oxygen is depleted locally and may be advected over the shelf. Although local oxygen-depletion is most pronounced in the northern Benguela (Chapman and Shannon 1985), two main centres of oxygen-depleted water occur off the South African coast. The northern centre occurs in the Orange bight, stretching along the inshore waters south of

Luderitz to north of Hondeklip Bay, and the southern centre occurs in St. Helena Bay, near the Columbine upwelling centre (Visser 1969, Shannon 1995). Despite the presence of these centres, oxygen-deficient water throughout the continental shelf region off South Africa is not as prominent as off Namibia, where dissolved oxygen is an important factor influencing the faunal diversity of demersal fish communities. Oxygen concentrations below 1 $ml.l^{-1}$ are common predominantly throughout the inshore region of the Namibian shelf during summer and winter and are associated with poor faunal diversity (Mas-Riera *et al.* 1990), poor abundance (Bailey *et al.* 1985) and a displacement of hake from their typical habitat, resulting in high mortalities to predation (Hamukuaya *et al.* 1998). Roel and Bailey (1987) show that adult hake exhibit a significantly weak positive correlation with a rate of oxygen change, and although they suggest that these hake congregate in offshore, more highly oxygenated environments, the relationship may be circumstantial rather than causal.

Considering this evidence, it seems plausible that oxygen concentrations influence the spatial distribution of Cape hakes only at critically low levels (below 1.5 - 2 $ml.l^{-1}$). Leming and Stuntz (1984) describe a similar situation, where demersal finfish catch rates at bottom oxygen concentrations below approximately 2.5 $ml.l^{-1}$ are virtually zero, but vary without any apparent dependence on oxygen concentrations above this level. It therefore seems that oxygen will play a more important role in the distribution of Cape hakes off the coast of Namibia and shallow, inshore waters off the west coast of South Africa than over the deeper regions of the South African continental shelf.

Although, during this analysis, a marked difference in the vertical spatial distribution of both hake species occurred before and after south-easterly winds, critically low oxygen levels were not prevalent during the same periods. Historical oxygen records extracted from the MCM Oceanographic Database show that during summer months, when SE winds predominate, mean bottom oxygen values lower than 2 $ml.l^{-1}$ are not common beyond the 100 m isobath. Although the minimum oxygen concentrations obtained from sample replicates indicate that concentrations of 2 $ml.l^{-1}$ may be present further offshore, the low oxygen conditions do not extend beyond the 200 m isobath. These data conform to the major oxygen-deficient centres identified by Visser (1969). During summer, the data suggests that critically low levels of oxygen are not common over the majority of the continental shelf and therefore should not have adverse mesoscale effects upon Cape hake distributions. Low levels of bottom oxygen do not seem to be induced by strong south easterly winds and hence do not seem to provide a causative explanation to strongly associated wind-vertical migration patterns that Cape hakes exhibit.

Sea water density throughout the water column, which is dependent upon temperature, salinity and depth, demonstrated a linear relationship with depth during the study period. Vertical migration patterns of the demersal scattering layer were not strongly related to either salinity or density values which were stable at any given depth. Vertically, salinity and density patterns exhibited no dramatic boundary zones where rapid value changes occur and these conditions remain stable irrespective of prevailing, or altering wind conditions. Roel and Bailey (1987) report similar conditions and dismiss salinity as an important factor influencing hake abundance, primarily due to the narrow salinity ranges that occur in shelf waters of the Benguela system. Numerous studies in the Benguela system confirm that salinity values over the shelf vary in a narrow range (Visser 1969, Bailey and Giddey 1986, Nelson *et al.* 1998). These studies do not document the change of salinity in response to wind shifts, but show that salinity values are altered by upwelling phenomena, thereby being indirectly influenced by the wind. The influence that these relatively small changes in salinity have on the spatial distribution of Cape hakes (or the change in salinity magnitude that is required to influence hake distribution) remains uncertain, but indications are that larger changes in magnitude will need to occur. The extensive diurnal vertical migrations that hake undergo in small temporal scales suggest that both salinity and density do not play an important role in controlling their distribution, as migrating hake are exposed to changing ambient salinity and density environments that are strongly correlated to depth. Physiological adaptations to the swim bladder and blood system enable these extensive migrations (Pitcher and Alheit 1995), suggesting that density gradients be easily coped with.

Although turbidity values along the offshore transect showed variability with depth, suggesting the presence of an environmental boundary that may influence demersal fish distributions, the percentage transmittance is very small between the turbidity values. Since the maximum transmittance equals approximately 84 mV (Roberts *et al*. in prep.), the horizontal difference between 77 mV and 79 mV at the shelf break along the offshore transect is negligibly small, translating to a transmittance of 92 and 94 % respectively. In terms of the transmittance therefore, it cannot be concluded that the dramatic change in acoustic backscattering energy at the shelf edge is due to a horizontal turbidity change. Similarly, turbidity values with depth recorded during the 24 hour station, although showing a change from 78 to 76 mV from 50 m above the seabed to the bottom, do not represent a vertical environmental ‘barrier’. As is the case along the offshore transect, the water is very clear, changing from a transmittance of 93 to 90 % respectively.

Although the vertical migration of Cape hakes responds strongly to increasing south easterly winds, no plausible evidence exists to suggest a cause-effect relationship. It is therefore essential to investigate the influence that wind may have on ambient environmental parameters within the water column where hakes are distributed. As opposed to bottom temperature, salinity density and turbidity, currents seem to be strongly coupled to wind patterns, responding to changes in wind speed and direction (Halpern 1974, Laevastu 1993). Philander and Yoon (1982), Clarke (1989), Smith (1989), and Nelson (1989) provide evidence that prevailing wind stress may influence demersal currents, while currents throughout the water column have been documented to influence both vertical and horizontal positioning of fish (Laevastu 1993, Michalsen *et al*. 1996, Mackas *et al*. 1997, Aglen *et al*. 1999).

Over a period of 24 hours at the fixed station off the South African west coast, the deep scattering layer revealed a spatial association with demersal current regimes during daylight hours, by migrating vertically to a depth where current regimes were stable, both in terms of magnitude and direction. Hakes constitute a large proportion of this scattering layer, indicated by poor demersal trawl CPUE beneath this deep scattering layer. A narrowing of the isolines beneath the scattering layer indicates the presence of a current boundary where currents change direction within a short distance, creating an environmental boundary that demersal fish may avoid. The spatial distribution of hake and other demersal targets relative to ambient currents concur with those of Mackas *et al.* (1997), investigating the distribution of *M. productus* off Vancouver Island. In both studies, pelagic hake were distributed within relatively stable current layers, with velocities of 5-10 cm.s^{-1} off Vancouver Island and 8-14 cm.s^{-1} off the South African west coast. As off Vancouver Island, a variable undercurrent persisted with strong cross-isobath components in places, although the prevailing flow occurred alongshore. Løkkeborg (1994) confirmed that North Sea cod and haddock respond differently to baited longlining hooks when different currents prevail, suggesting that these species probably avoid strong currents as a strategy of energy optimisation, being active during periods of moderate or low current velocity and seeking shelter when currents are strong. The response of both species to hooks decreases as the current velocity increases, with two to three times the number of fish being present during current regimes below 18 cm.s^{-1}. Similarly, Michalsen *et al*. (1996) investigated the influence of near bottom currents on cod and haddock vertical distributions and found that fish descend to the bottom during periods of decreasing or low current speeds, while leaving the bottom when current speeds were high or increasing. Aglen *et al*. (1999) found similar results, showing that the highest acoustic densities of demersal fish in the Barents Sea coincided with either falls in current velocity or the minimum daytime current velocities.

It seems possible that currents may also play an important role in the horizontal distribution of fish along the offshore transect to the west of the Cape Peninsula. Currents in the upper 250 m of the water column suggest that both the magnitude and direction create a horizontal environmental barrier with depth at the shelf edge. At a depth of approximately 250 m off the shelf edge, currents change from a southerly to a northerly direction rapidly with depth, and also tend to have greater velocities in this region. If these current regimes are indeed maintained below 250 m within this region, this may present a cause-effect relationship between the observed horizontal fish distribution at the shelf edge and current regimes with depth.

Spectral analyses applied to a synoptic wind and demersal current data series off Cape Columbine revealed that demersal currents may indeed be influenced strongly by surface winds. Two repeating, corresponding cycles, the first translating to a period of approximately 8 days and the second approximately 5.5 days occurred between wind and current patterns. The persistence of a 7-9 day cycle during summer can be explained by the lifespan of cyclones that pass from west to east across the south of the continent (Nelson and Hutchings 1983). Cyclonogenesis occurs to the south west of the continent, where cyclonic systems start as frontal waves, develop into mature systems and decay into occluded systems towards the end of the cycle period (Laevastu 1993). The second significant cycle, translating to 5.3 and 5.5 days for wind and current data respectively, may be attributed to the persistence of frontal systems derived from cyclonic activity (G. Nelson, pers. comm.). Clockwise cyclonic circulation generates numerous spiral fronts along its path during its lifespan, each of which may persist for periods of up to 11 days. The temporal scale of the lag period between the cycles is important to determine whether the causal relationship is relevant to hake vertical migration, as it was observed during the sampling cruises that hake migration in response to increasing south easterly winds were initiated within a few hours. The phase spectrum, which represents the amplitude of the cyclical phase difference between both data series revealed a lag period of 8-9 hours between the initiation of wind activity and a current response. The lag period of this wind-current response is significant, as it occurs within the temporal scale of biological responses. A lag period in excess of several hours would suggest that demersal current shifts occur after hake vertical migrations commence and therefore not promote a cause-effect hypothesis.

The short lag period between wind initiation and current response at 230 m is explained by pressure field adjustments rather than by vertical mixing processes from the sea surface. Although inertial oscillations observed in the surface mixed layer of the ocean are generated by local winds (Halpern 1974), the wind-driven mixed layer is confined to the upper ocean, extending to a depth of 25-30 m during periods of high wind stress (Halpern 1974, Ridderinkhof 1992, D'Asaro and Dairiki 1997). It is clear that wind-driven mixing is not relevant when considering current responses at great depths, whereas pressure changes provide a plausible interpretation. As south easterly wind stress increases, a response in the current is caused by the propagation of a pressure effect through the water column, brought about by a wind-forced change in the level of the ocean (Nelson 1989). The resultant cross-shelf elevation of the ocean surface generates a barotropic poleward flow across the continental shelf (Nelson 1989). Philander and Yoon (1982) describe the propagation of eastern boundary poleward undercurrents by the onset of alongshore wind stress. An accelerating surface jet is driven by the wind introducing an undercurrent in the opposite direction. Along the west coast of South Africa, current response to wind accord to Philander and Yoon (1982), and Nelson (1989), with a predominant poleward near-bottom current component during south easterly winds.

In conclusion, the results from this study suggest that the spatial and temporal mesoscale vertical distribution of Cape hakes is not influenced to any great extent by 'CTD' derived environmental parameters, but that near-bottom current regimes seem to play a more important role in influencing these vertical migrations. Spectral analyses indicate a strong relationship between wind and current fields, with surface winds initiating a barotropic influence upon near-bottom currents within a period of approximately eight hours, thereby explaining the apparent association between prevailing winds and Cape hake vertical distributions. It seems that hakes migrate vertically to avoid depths with unstable current regimes, decreasing their availability to the bottom trawl. The relatively small changes in vertical turbidity levels suggest that these are not as important in influencing hake vertical distributions and that currents seem to be the primary factor in this regard.

CHAPTER 3

THE INFLUENCE OF FISH DAYTIME VERTICAL DISTRIBUTION ON SWEPT - AREA ESTIMATES OF CAPE HAKES AND THE APPLICATION OF ACOUSTIC TECHNIQUES TO ESTIMATE DEMERSAL FISH ABUNDANCE

3.1. INTRODUCTION

The potential application of acoustic assessment techniques to demersal abundance surveys is primarily based on the ability to sample abundance within the ‘trawl blind’ zone, defined as the region of the water column above the headrope that is not sampled by the demersal trawl gear. This may be extremely useful, as a better understanding of biological distributions and abundance within the ‘trawl blind’ and trawl zones presents the potential to not only apply supplementary acoustic data to swept-area CPUE data, but also to investigate the variance of abundance within trawl samples. Despite the potential however, both physical and biological limitations have hindered the application of acoustic techniques to demersal assessment surveys.

As opposed to the use of acoustic techniques in the pelagic environment, the proximity of fish aggregations to the seabed introduces complications when collecting and analysing acoustic data. The most notable problem in this regard is that of the acoustic dead zone, defined as the distance equivalent to half a pulse length above the seabed (Ona and Mitson 1996, Aglen 1994). Within half a pulse length from the seabed, fish and bottom echoes overlap, with the implication that fish targets close to the seabed cannot be separated from bottom echoes and therefore remain undetected. Detectability errors associated with this depth anomaly increase with depth, and it is clear that this limitation greatly influences the reliability of acoustic estimates of demersal fish abundance, particularly when the greater proportion of the population are associated closely with the seabed.

Despite the inherent problems associated with acoustic processing near the seabed, the technique has made a substantial contribution to many demersal assessment procedures in the Northern Hemisphere since the early 1970’s. In all these scenarios, acoustic techniques are utilised in conjunction with demersal trawl estimates of abundance, being used mainly to generate relative indices of abundance (Thorne 1977, Engås and Godø 1986, Godø and Wespestad 1993, Michalsen *et al*. 1996, Aglen *et al*. 1999, Korsbrekke and Nakken 1999). While using acoustic data to resolve targets above the acoustic dead zone (and the trawl headrope), these studies minimise bias due to detectability limitations and utilise acoustics to sample within the 'trawl blind' zone. In fact, combined abundance indices derived from trawl and acoustic density data collected in unison has been considered a more accurate estimation of the true fish stock than either method on its own (Godø and Wespestad 1993). This is primarily due to different sampling fractions associated with the techniques, where demersal trawls are more suited to collect abundance data within the acoustic dead zone, and acoustic abundance data collection is valuable within the 'trawl blind' zone, where acoustic detectability is increased (Godø and Wespestad 1993, Michalsen *et al*. 1996, Aglen *et al*. 1999, Lawson and Rose 1999).

The successful combination of trawl and acoustic estimates of abundance requires the collection of suitable gear performance data in order to define the extent of the trawl swept volume or the extent of the vertical mouth opening, by tracking the height of the headrope above the seabed. In most of the studies mentioned above, gear performance data were routinely collected to quantify the swept area or volume. Besides being vital for successful definition of sampled volumes, gear performance data provides the opportunity to investigate the '*in situ*' fishing efficiency of the demersal trawl.

Despite many important demersal fisheries being monitored through combined acoustic and bottom trawl surveys, current South African demersal biomass assessments are based solely on catch data derived from swept-area surveys, with no hydroacoustic contribution. Because MCM research vessels are equipped with state-of-the-art acoustic echosounders, the potential exists to implement routine acoustic collection procedures to supplement CPUE data. Demersal acoustic data collection will be particularly relevant when environmental factors influence the vertical distribution of target species, such as in the southern Benguela upwelling system, when SE winds influence Cape hake vertical distributions (Chapter 2). During these conditions, bias introduced to CPUE data may potentially be reduced via the incorporation of acoustic fish density data.

The aim of this study is to quantify trawl gear performance aboard *F.R.S. Africana* using the SCANMAR net sonar system and compare *in situ* trawl gear dimensions with assumed dimensions that are included into assessment models. Secondly, this study aims to establish the usefulness of acoustic techniques to estimate fish biomass within the near bottom layers of the water column and therefore its potential contribution to demersal stock assessments in the South African context.

3.2. METHODS

Hydroacoustic, CPUE and trawl gear performance data were collected during the annual MCM West Coast demersal biomass assessment survey aboard the *F.R.S. Africana* during January 1999. Spatial variability of the sample stations is presented in Figure 2.1(c).

3.2.1. Data collection

3.2.1.1. Hydroacoustic data

During the entire survey, acoustic data were recorded during trawling operations at a frequency of 38 kHz using a hull-mounted, sphere-calibrated (calibrated prior to the survey) SIMRAD EK 500 scientific echo-sounder system (sounder settings used are indicated in Appendix A). Acoustic backscattering energy was integrated using Sonardata Echoview integrating software and acoustic densities were expressed as backscattering area per unit sea surface (Sa).

3.2.1.2. Trawl data

CPUE data were collected according to a swept area random stratified survey by deploying a German 180-foot bottom trawl with a pilchard netting cod end liner during daylight hours. A detailed description of the sampling strategy is outlined by Badenhorst and Smale (1991).

3.2.1.3. Gear performance data

Trawl gear performance data were derived by means of a SCANMAR net sonar system. By means of four net-mounted sensors, the SCANMAR system has the capability to record the depth of the trawl headrope, the distance between the fishing line and the seabed (footrope clearance), the vertical distance between the headrope and the fishing line (net mouth opening) and the horizontal distance between the wings on either side of the mouth (wingspread). These data are actively transmitted to a passive hull-mounted receiver and visually displayed as illustrated in Figure 3.1. Gear performance data were recorded at two minute intervals during the entire length of each bottom trawl operation. Unfortunately, the trawl gear along with the SCANMAR system was lost at sea a few days into the survey. Attempts to recover the gear proved unsuccessful and therefore the collection of gear performance data was prematurely ended. As a result, a data set of only 27 trawls contributed to this analysis.

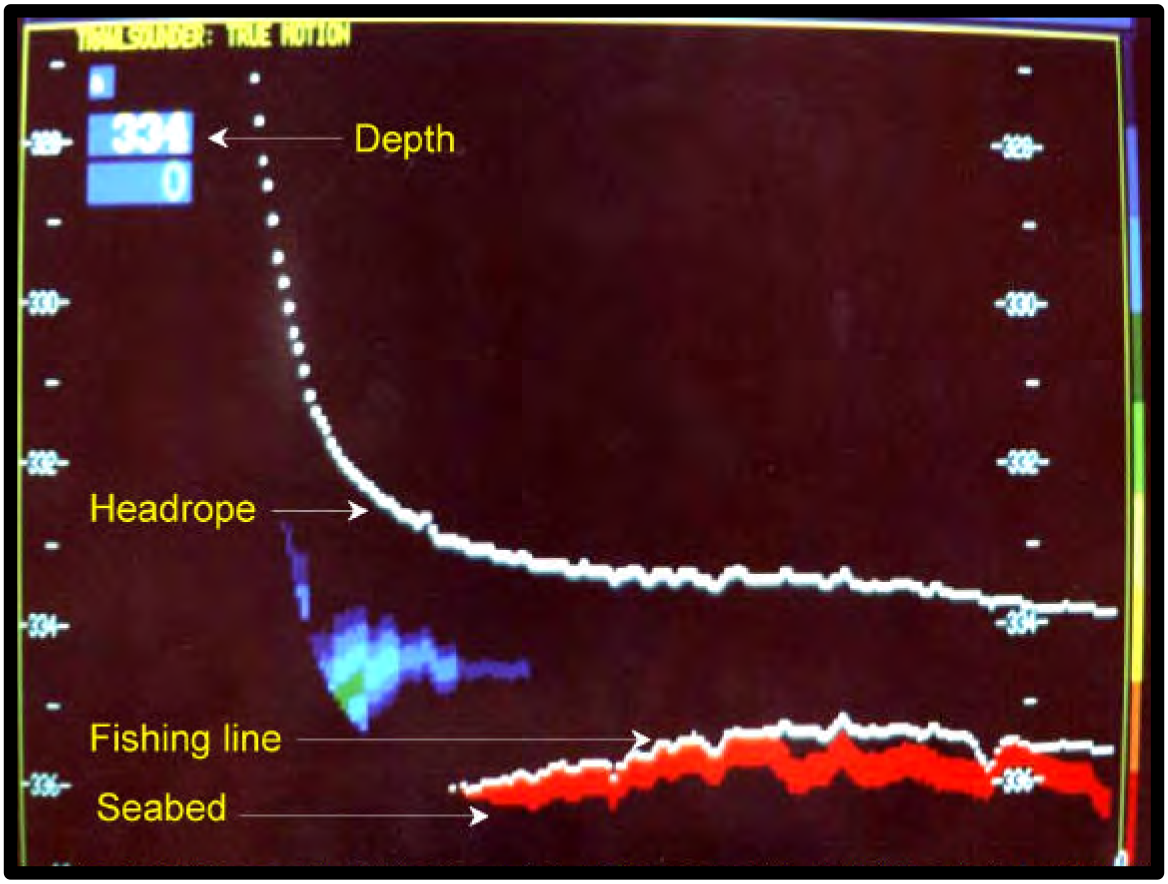

Fig. 3.1. Visual SCANMAR net sonar system display of *in situ* bottom trawl gear performance.

3.2.2. Data analysis

3.2.2.1. Acoustic echo-integration

Acoustic traces collected at a frequency of 38 kHz were recorded during all bottom trawling operations for which SCANMAR data were available and integrated using Sonardata Echoview acoustic processing software. To obtain spatial correspondence between acoustic and trawled swept areas, the towing gap (Fig. 3.2) between acoustic and trawl samples was applied to integrated acoustic traces, being calculated for each trawl operation as follows:

$$(wl)^2 = (d)^2 + (tg)^2$$

where: wl = warp length (m)
d = depth (m)
tg = towing gap (m)

Once the towing gap was calculated, acoustic records during the deployment of the net were extracted on the basis of GPS and vessel towing speed information.

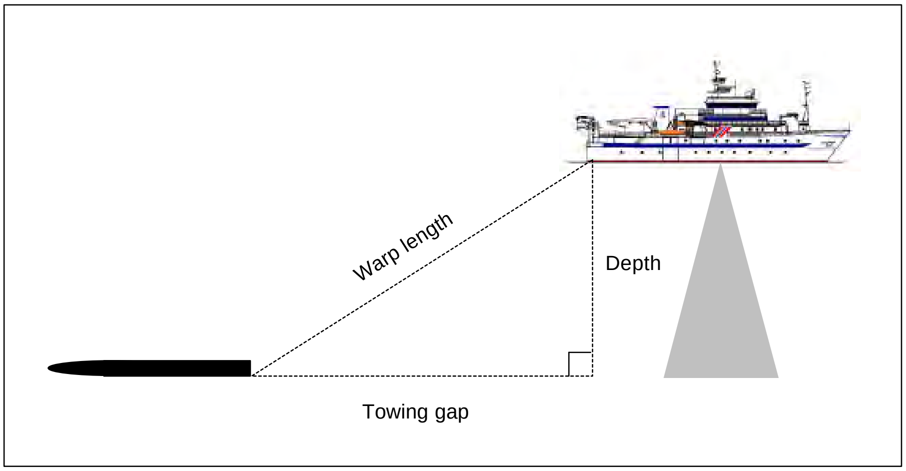

Fig. 3.2. The relationship between warp length and depth to calculate the towing gap between the vessel and the trawl mouth.

Catch data were normalised by standardising acoustic and trawl sampling areas and volumes (Fig. 3.3). Sample areas and volumes were calculated as follows (all units in meters):

$$\textit{Acoustic swept area} = \pi r^2 + [(2r)(td)]$$

$$\textit{Trawl swept area} = (mw)(td)$$

$$\textit{Acoustic swept volume} = \pi r^2 h + [(2r)(td)(h)]$$

$$\textit{Trawl swept volume} = (mw)(td)(h)$$

where: r = radius of acoustic beam on the seabed (see Fig. 3.3)
td = towing distance
mw = mouth width of the demersal trawl (fixed for all trawls)
h = mean height of the trawl headrope above the seabed (derived from the SCANMAR net sonar system).

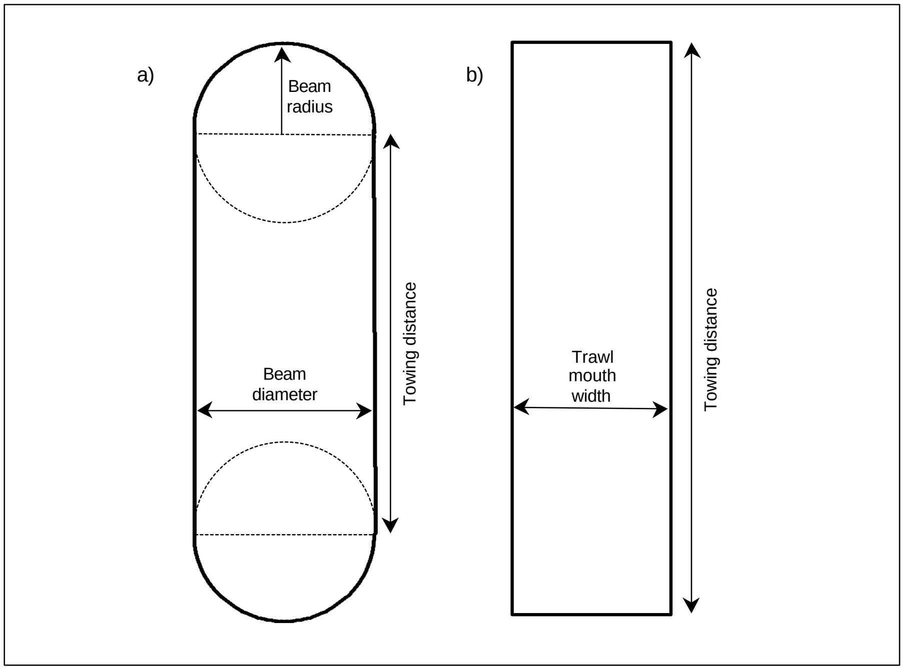

Fig. 3.3. Acoustic (a) and trawl (b) swept areas during a bottom trawl operation. Trawl and acoustic volumes are calculated using the same parameters, including the SCANMAR derived mean vertical mouth opening.

The radius of the acoustic beam on the seabed (Fig. 3.4) was calculated as follows:

$$\tan(0.5y) = \frac{radius}{depth}$$

where: $y =$ ES38B transducer equivalent beam angle

For all calculations, the mouth width of the *F.R.S. Africana* trawl gear was assumed to be 26 m as is currently incorporated in South African hake stock assessments (R. Leslie, MCM, pers. comm.).

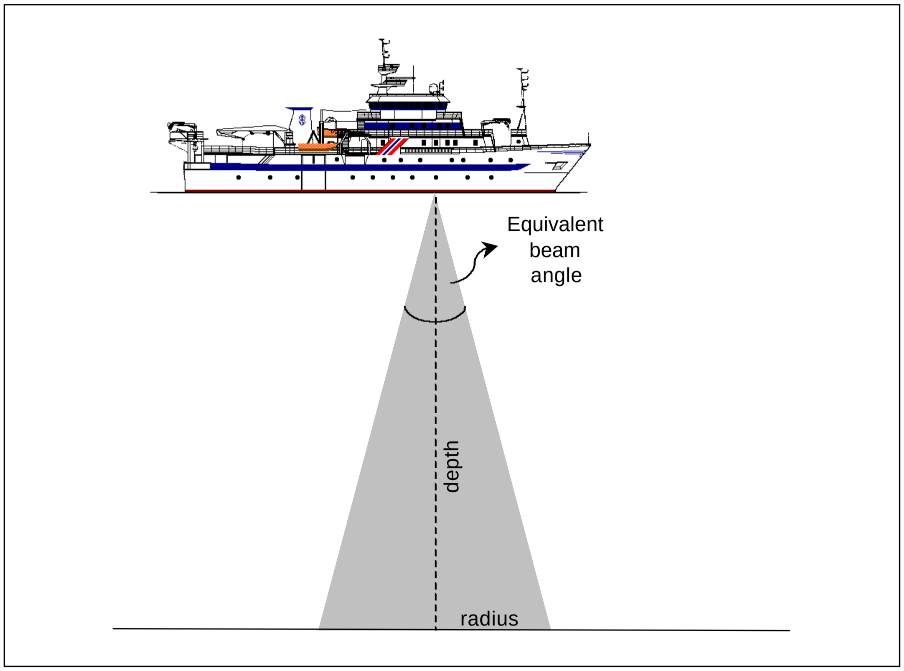

Fig. 3.4. The relationship between the depth and equivalent beam angle to calculate the radius of the acoustic beam.

Acoustic densities for each trawl sample were obtained by integrating the SCANMAR derived distance of the vertical net opening above the seabed during the true trawl duration. To ensure that no bottom echoes were integrated, an integration backstep margin of 0.5 m was applied to all acoustic traces, except one trace where a backstep margin of 0.7 m was applied due to a rocky substrate. The extent of the acoustic dead zone was determined according to Ona and Mitson (1996) for each trawl sample, where the integration dead zone is equal to the sum of the acoustic dead zone, the backstep zone and the partial integration zone:

$$IDZ = ADZ + BSZ + PIZ$$

where: IDZ = Integration dead zone
ADZ = Acoustic dead zone
BSZ = Backstep margin zone
PIZ = Partial integration zone

The acoustic dead zone, backstep margin zone and partial integration zones were computed as follows (Ona and Mitson 1996):

$ADZ = 2.83 \times 10^{-3} \times (depth)$
$BSZ = 0.5\ m\ (0.7\ m \text{ for one acoustic trace})$
$PIZ = c \times g / 4$

where: c = speed of sound = $1500\ m.sec^{-1}$
g = pulse duration = 1 ms

Based on the central assumption that the vertical density of fish is equal throughout the trawl zone, the total trawl acoustic density was computed by adding the detected acoustic density within the trawl zone to the dead zone-corrected acoustic density. The dead zone-corrected density was calculated by expressing the acoustically detected density as a proportion of the total vertical trawl zone height (in meters), and then multiplying the vertical extent of the acoustic deadzone (in meters) by this proportion, as follows:

$$Sa_{(dead\ zone\ corrected)} = \frac{Sa_{(detected)}) \times \mathrm{IDZ}}{h}$$

where: *Sa* = acoustic density
IDZ = Integration dead zone
h = SCANMAR derived height of vertical trawl opening

3.2.2.2. Acoustic estimation of fish density

Corrected acoustic densities for each trawl were correlated to corresponding normalised trawl catch data to determine whether acoustics methods are useful to estimate the biomass of fish within the trawl zone of the water column. Because each fish species has a particular reflectivity function based on its morphological characteristics, such as the presence and shape of the swimbladder, relationships between catch and acoustic densities were computed using several combinations of the species caught by the trawls. Other decision criteria included natural vertical fish distributions and vertical fish behaviour in response to trawl gear.

Fish layers recorded above the trawl headrope prior to the passing of the trawl mouth were integrated and related to trawl catches to investigate possible diving responses of demersal fish to approaching trawl gear in the Benguela system.

3.3. RESULTS

By monitoring the fishing line clearance from the seabed derived from SCANMAR data, it is possible to record the precise moment after deployment at which the trawl gear establishes contact with the seabed, as well as the moment after hauling at which the fishing line is no longer in contact with the bottom. Figure 3.5 illustrates the true trawl duration compared to the trawl duration estimated by the trawl masters. Apart from two trawl samples, the true effort is greater than the estimated effort, resulting in higher CPUE and therefore an overestimation of hake abundance (Fig. 3.6). The difference in CPUE between the true and estimated effort ranges from 0 to 21 % between trawls (Fig. 3.6).

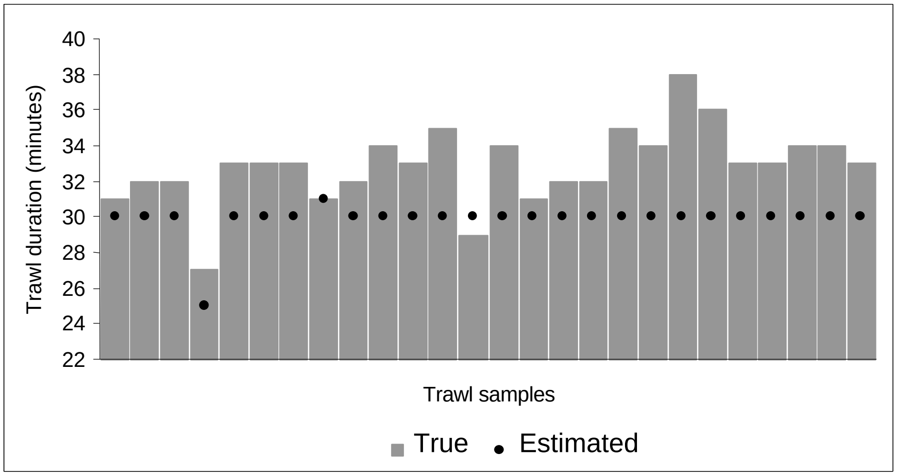

Fig. 3.5. The true trawl duration (as calculated from SCANMAR data) compared to the estimated trawl duration. In 93 % of the trawls, effort was underestimated.

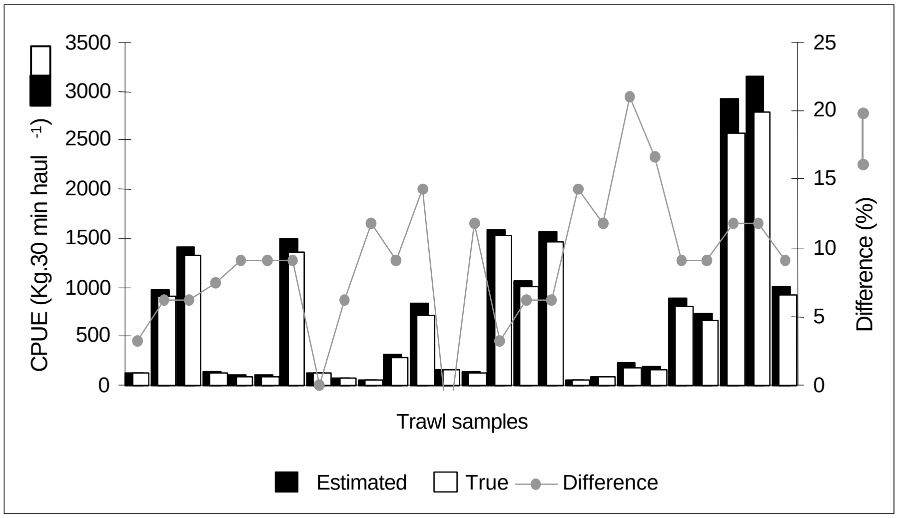

Fig. 3.6. CPUE calculated from true and estimated effort derived from SCANMAR data. The difference between the two may vary by up to 21 %.

The variability of the vertical mouth opening (distance between the fishing line and the headrope) is illustrated in Figure 3.7. Throughout the trawl sample data set, vertical mouth openings ranged from 1 to 4.1 m, with a mean between the trawl samples of 1.93 m. In addition to increased effort, vertical trawl opening variability contributes to greater variability between trawl swept volumes.

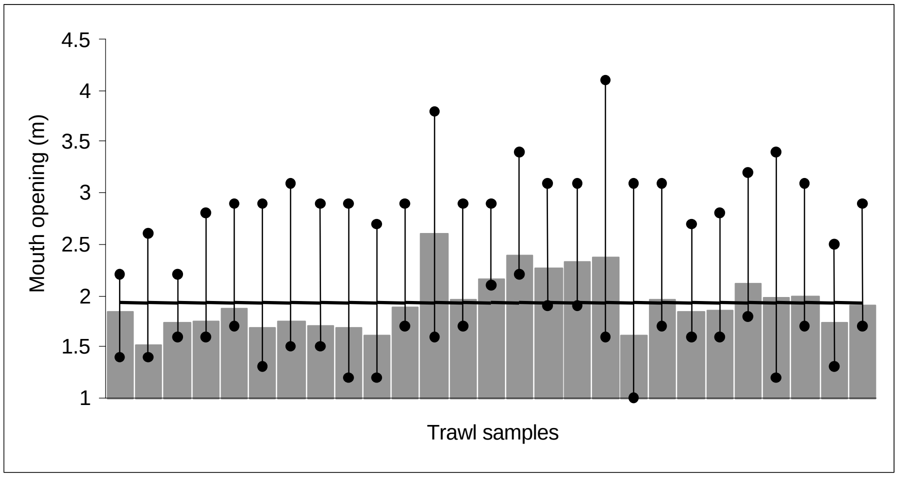

Fig. 3.7. Mean trawl vertical mouth opening of all trawls for which SCANMAR data were available. The vertical bars indicate the range of the mouth opening at each trawl sample. The horizontal solid line indicates the mean between all trawl samples.

The clearance between the fishing line and the seabed ranges from 0 to 1.4 m with a mean of 0.21 m between all trawl samples (Fig. 3.8). Variable clearance between the fishing line and the seabed may influence the efficiency of the bottom trawl and have important consequences for effort calculations.

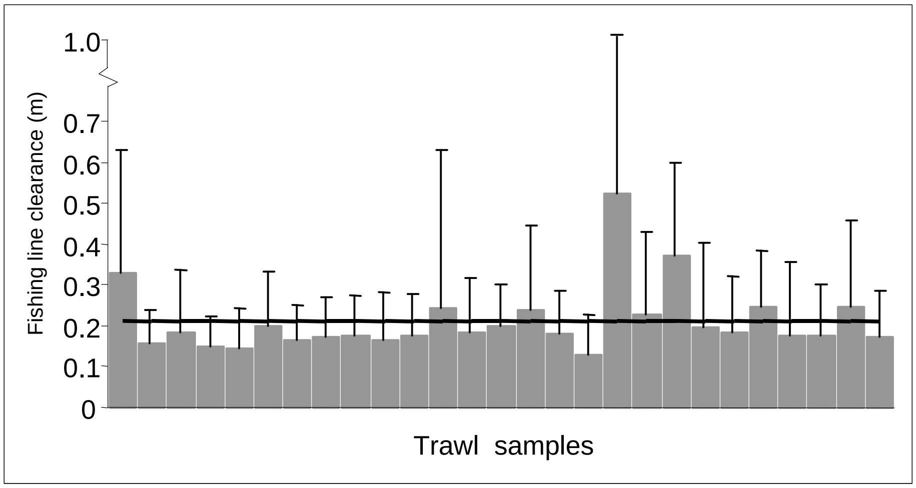

Fig. 3.8. Mean fishing line clearance from the seabed during the true trawl duration of all trawls for which SCANMAR data were available. The vertical bars indicate the standard deviation of the mean. The solid horizontal line indicates the mean between all trawl samples.

The towing gap between the vessel and the trawl gear was calculated for each trawl using the warp length and the depth. A strong relationship (r^2 = 0.98) enables a rapid calculation of the towing gap for any given depth (Fig. 3.9) by applying the linear regression where towing gap = 2.5173 (depth) + 43.75.

Acoustic swept area and volume increases with depth due to the conical shape of the acoustic beam. Trawl swept area and volume are constant irrespective of depth (Fig. 3.10). Variance of both trawl and acoustic swept volume at the same depth occurs due to effort (towing duration) and vertical mouth opening variance. Acoustic and trawl swept area variance occurs due to effort (towing duration) variance.

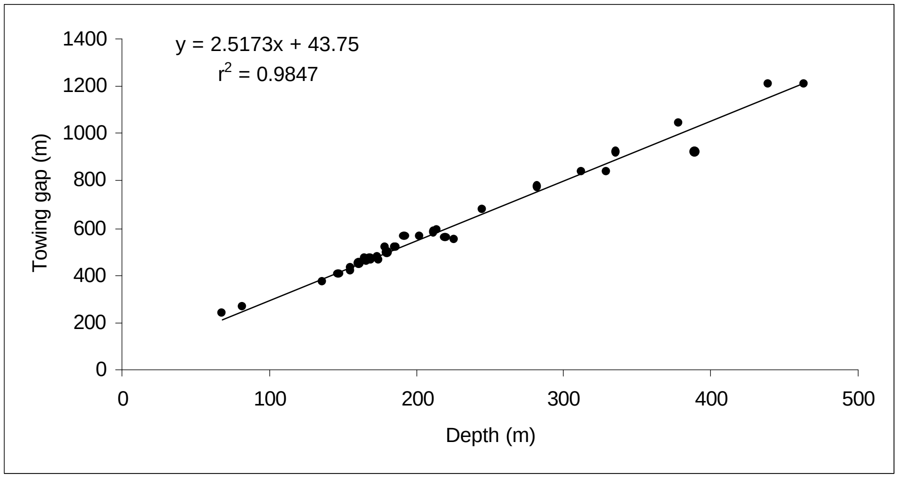

Fig. 3.9. The relationship between towing gap (calculated using warp length and depth) and depth

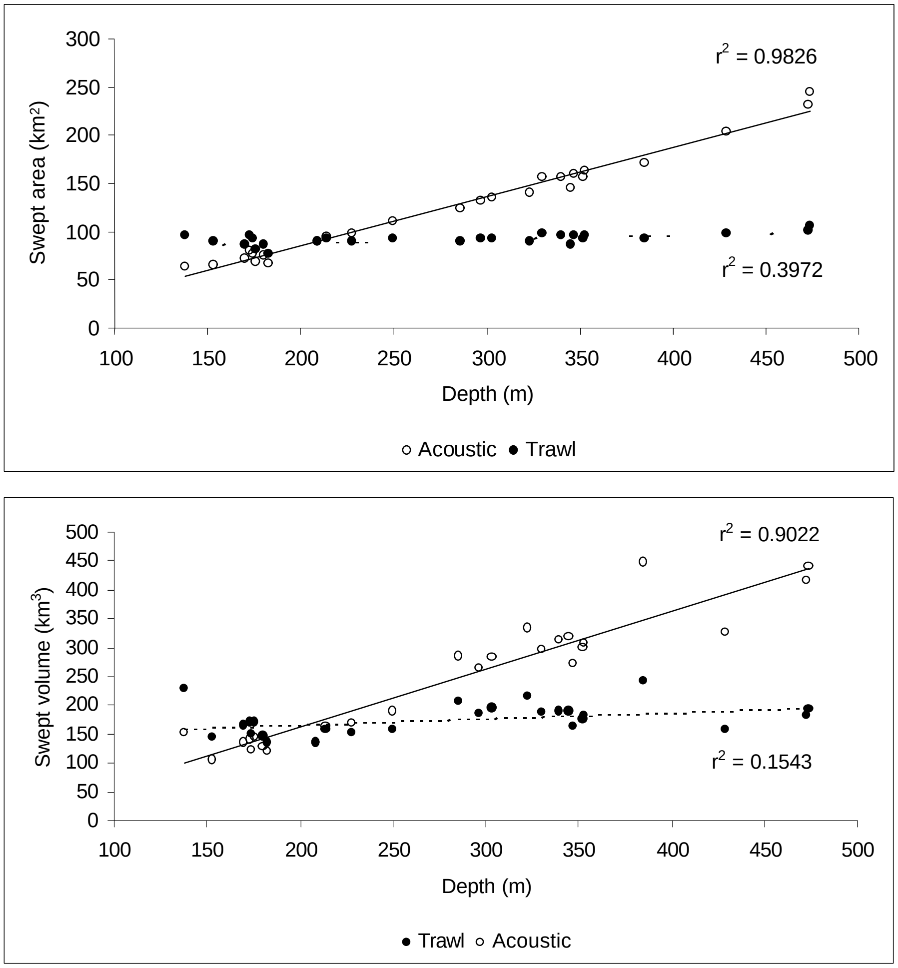

Fig. 3.10. The relationship between trawl and acoustic swept area and volume with depth.

The ratio between the computed integration dead zone (*IDZ*) and the SCANMAR derived height of the trawl mouth opening (*h*) shows that the *IDZ* is approximately equal to *h* for many trawls and may even exceed *h* for some trawls (Fig. 3.11). A mean ratio of 0.87 occurred between the *IDZ* and *h* of all trawl samples.

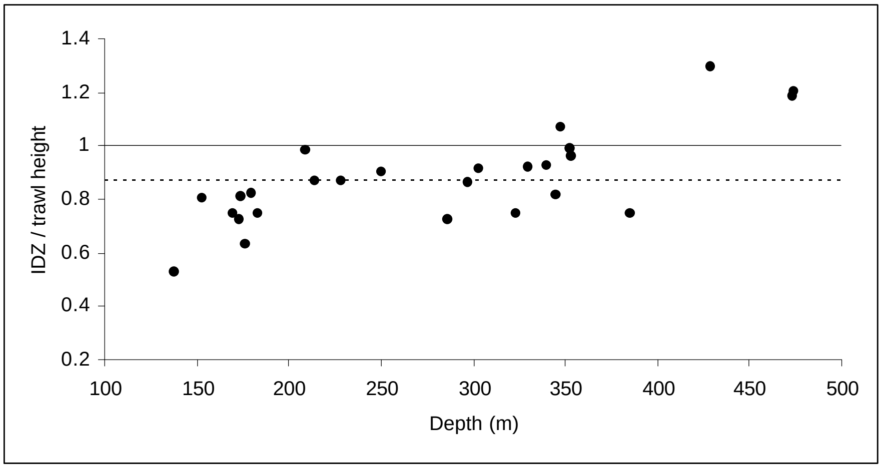

Fig. 3.11. Ratio between the integration dead zone (*IDZ*) and the SCANMAR derived demersal trawl mouth height at various trawl depths. The broken horizontal line depicts the mean ratio between all trawl samples.

Correlations between the normalised catches and dead zone-corrected trawl acoustic densities are all poor, irrespective of species omissions (Fig 3.12). Diving behaviour of species may contribute to these poor correlations as illustrated in Figure 3.13, where the acoustic echogram corresponding to a trawl when 2161 kg of horse mackerel was caught suggests that these fish may have been distributed in the pelagic environment before the trawl approached. In this particular trawl, horse mackerel constituted 57 % of the total catch, with hake comprising 39% and a few other species 4 %. However, no direct evidence exists to ascertain whether pelagic schools included horse mackerel, and it is therefore assumed that this may be case.

Correlating normalised trawl catches and cumulative acoustic densities in three zones above the headrope to account for diving behaviour did not improve the relationship between catch and acoustic density (Table 3.1). Correlations remained poor irrespective of species ommisions within all three zones.

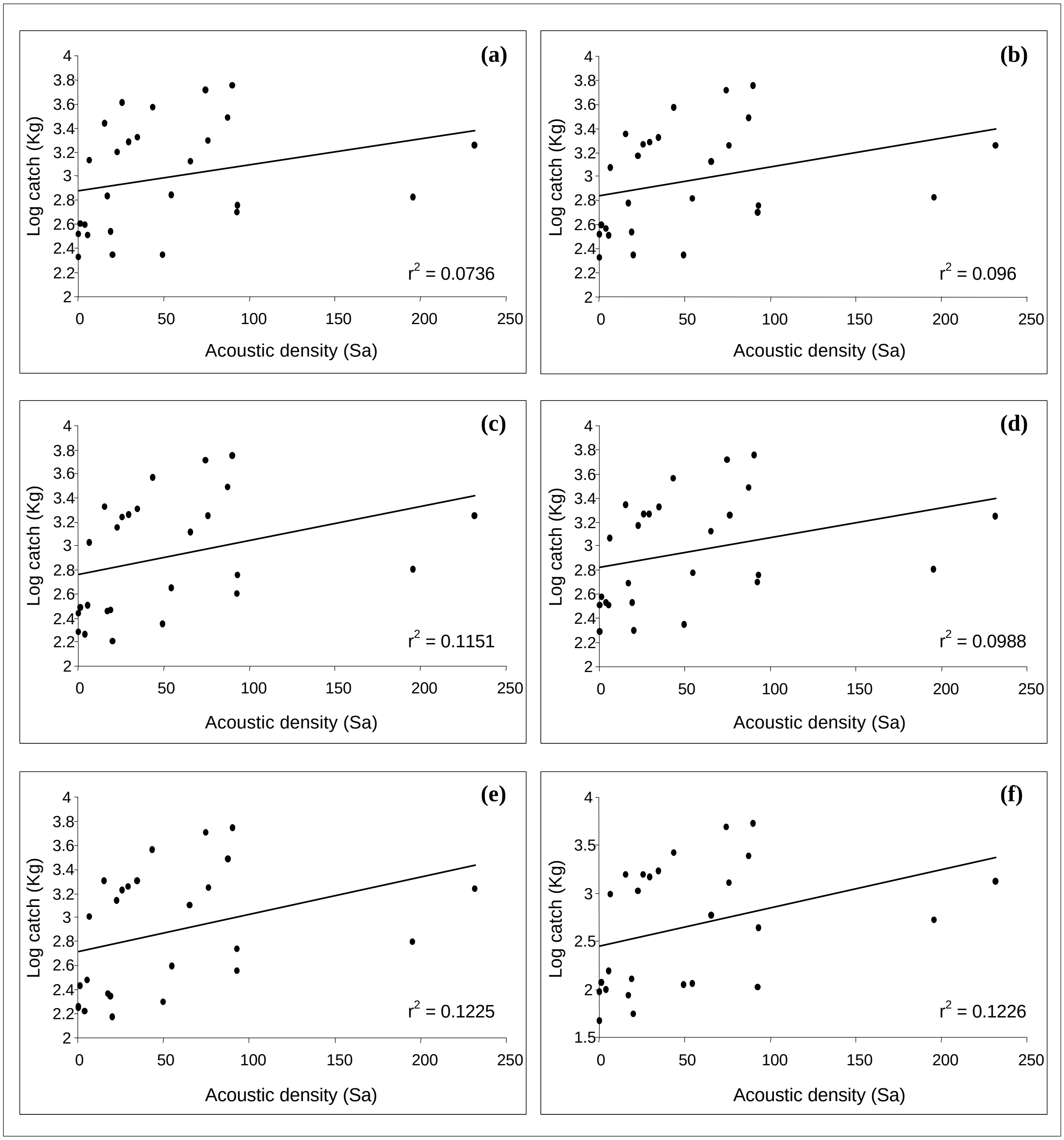

Fig. 3.12. Correlations between normalised trawl catches and acoustic densities within the trawl zone.
(a) includes all free swimming species caught in the trawl.
(b) includes all free swimming species caught excluding horse mackerel.
(c) includes all free swimming species caught excluding horse mackerel and all elasmobranchs.
(d) includes all free swimming species caught excluding horse mackerel and skates only.
(e) includes all free swimming species caught excluding horse mackerel, all elasmobranchs and monkfish.
(f) includes only Cape hake caught in the trawl.

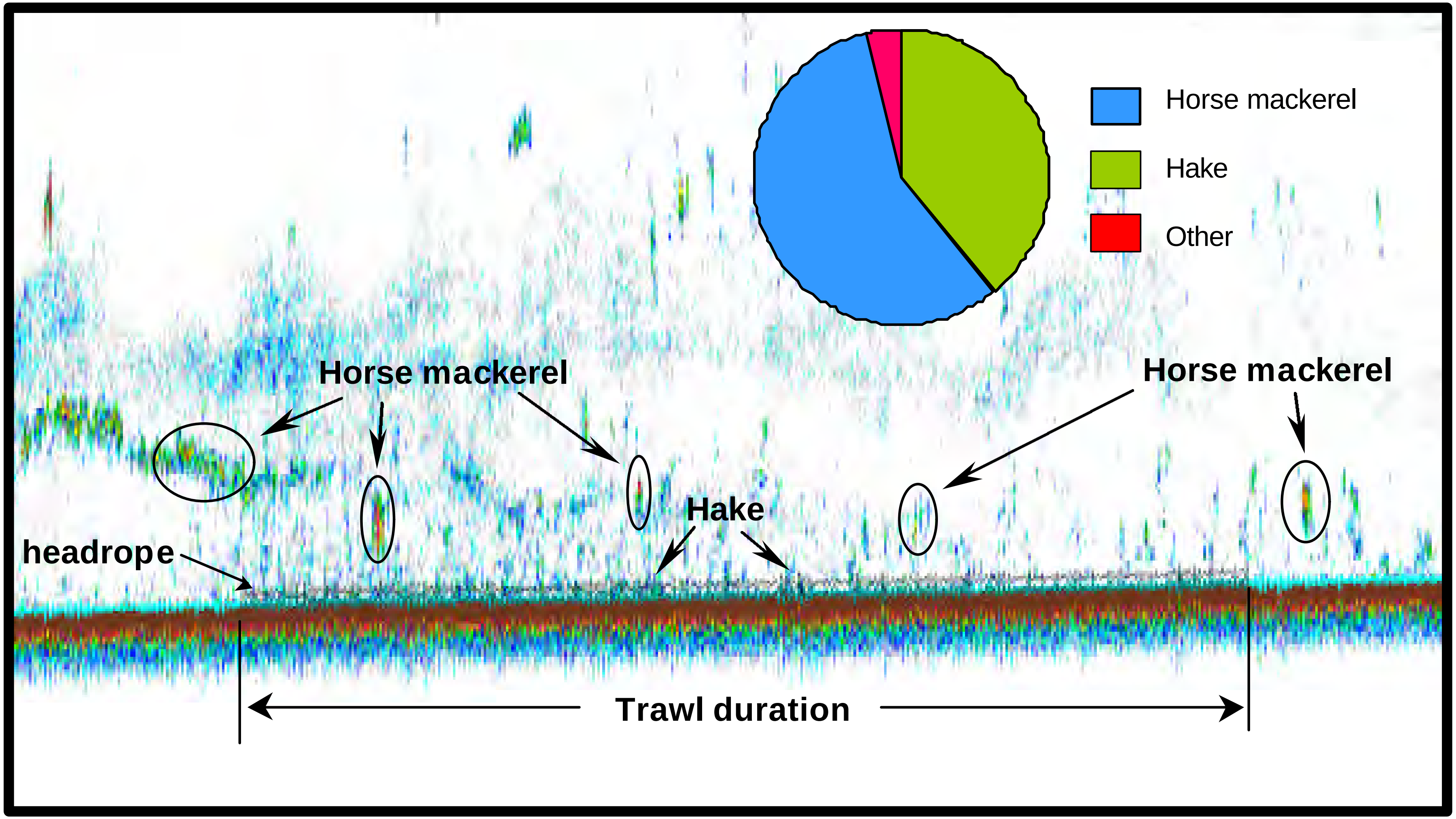

Fig. 3.13. Acoustic echogram and total catch composition (pie diagram) of a trawl in which over 2 tons of horse mackerel were caught. The absence of horse mackerel schools within the trawl zone suggests that pelagic horse mackerel initiate a strong diving response to approaching trawl gear.

Table 3.1. Correlations between normalised trawl catches and acoustic densities within three zones (0-5, 0-10 and 0-20 m) above the seabed. Species categories (a-f) are identical to those presented in Figure 3.12.

SPECIES	CORRELATION COEFFICIENT (r^2)		
	Bottom - 5 m	Bottom – 10 m	Bottom – 20 m
(a)	0.048	0.031	0.023
(b)	0.067	0.045	0.034
(c)	0.076	0.053	0.048
(d)	0.068	0.046	0.035
(e)	0.082	0.058	0.053
(f)	0.07	0.051	0.062

The species complexity of demersal trawls included in this analysis is illustrated in Figure 3.14. The number of species caught ranges from 17 to 34 species between all trawl stations.

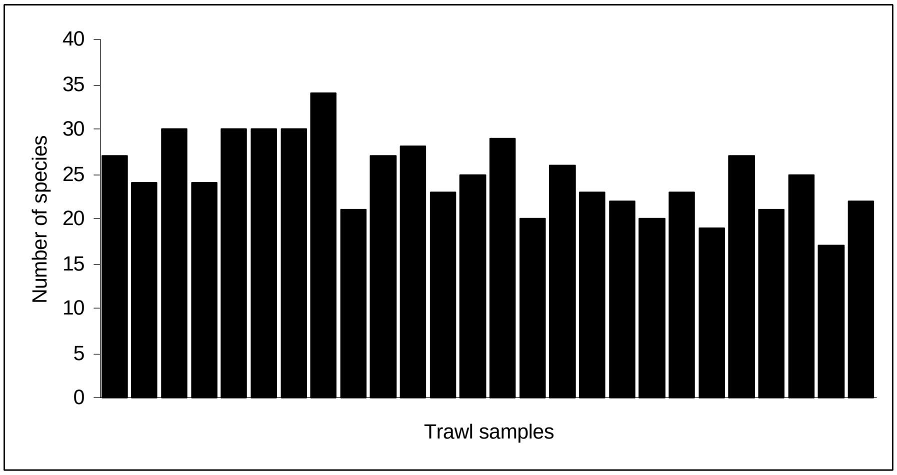

Fig. 3.14. Variation in the total number of species caught by demersal trawls during this analysis.

3.4. DISCUSSION

Due to the loss of the SCANMAR net sonar system, it is important to note that the available gear performance data are limited. The findings in this analysis however emphasise the need to obtain and utilise additional gear performance data, as gear performance has important consequences for survey results. For the purpose of this thesis, the current results are considered to be a good indication of gear performance trends during demersal surveys in the southern Benguela and are discussed accordingly.

Gear performance data are particularly useful to assessment surveys that incorporate CPUE data collected by a swept-area method survey design. Since effort and swept area calculations are based on fundamental assumptions that all trawls constantly fish effectively and within a constant area (Engås 1994), gear performance data provides the opportunity to test these assumptions and to normalise effort (and therefore catch) data should these assumptions be violated. As reviewed by Engås (1994), evidence in this analysis indicates that effective gear performance may be highly variable and the precision of subsequent CPUE determinations may therefore be compromised. Bottom trawl surveys are based on the assumption that catch is related to the invariable catchability coefficient (q) of the sampling gear, which is comprised of two components; fish availability (q_a) to the gear and the fishing efficiency (q_e) of the gear (Godø 1994). Variable gear performance has a large influence on q_e and therefore on CPUE. The opportunity to investigate trawl gear performance is particularly relevant to demersal biomass assessment cruises off the South African coast, where to date no gear performance data are considered during CPUE determination (R. Leslie, MCM, pers.comm.). In 93 % of the trawls investigated during this analysis, SCANMAR data indicated that effort was being consistently underestimated. This translates to an overestimation of demersal fish (and particularly hake) abundance for each trawl. Albeit that the difference between estimated and true CPUE may be as great as 21 % for some trawl samples, it may be argued that this difference is negligibly small for many other trawls. The cumulative effect of a consistent overestimation in all trawls however may result in a marked overestimate of a stock or fish in a region when CPUE from all trawls during an assessment survey are included.

Vertical trawl mouth opening and fishing line clearance from the seabed also indicate that effort, which is assumed to be constant throughout any tow, may be highly variable. Although in a South African context the headrope height from the seabed is not incorporated into demersal biomass assessments (Payne *et al*. 1984), variability in vertical mouth opening may be reflected in the catches. In South African demersal biomass assessments, escapement of fish over the headrope is assumed to be random, in which case the random variance of the mouth opening will introduce merely a source of imprecision but not bias. This assumption may however be severely violated should vertical biological densities not be homogenous, thereby introducing bias between either individual trawls or surveys. Changes in demersal fish vertical distribution patterns induced by environmental parameters (Chapter 2) or age-based vertical distribution variation within and between species (Engås and Godø 1989, Godø and Wespestad 1993) for example, may contribute to vertical densities that are not homogenous.

All correlations in this analysis between trawl acoustic densities and catches are poor, irrespective of species omissions. Previous studies that compare acoustic and bottom trawl fish densities have reported similar findings (Godø and Wespestad 1993), where cod and haddock survey acoustic density estimates within the trawl volume are consistently lower than the densities suggested by the catch data (Jin 1990, Aglen 1996). Consistently lower acoustic densities may stem from variations in acoustic detectability due to the inability of echosounders to detect all fish and species that are present (Lawson and Rose 1999) and the possible increase of fish density close to the seabed. Due to dead zone problems that reduce the effective acoustic swept volume and the limited vertical sampling range of demersal trawl gear, the two sampling methods measure a different proportion of the stock and therefore have different sampling efficiencies (Godø and Wespestad 1993, Michalsen *et al*. 1996). While catch compositions and length distributions are restricted to the vertical opening of the net where dead zone problems inhibit acoustic sampling, pelagic fish occur in the trawl blind zone but are available to be sampled acoustically. A major consequence of these differing sampling efficiencies would be that a high availability of fish to the bottom trawl is associated with a low acoustic detectability and *vice versa*.

Combinations of species omissions were based on their potential contribution to the trawl acoustic density due to either anatomical or behavioural differences. Horse mackerel, *Trachurus trachurus capensis* for example, have been reported to initiate a strong diving response to approaching trawl gear (Barange and Hampton 1994). The acoustic echogram recorded during a trawl in which 2.1 tons of *T. trachurus* was caught suggests that no dense schools of this species occurred within the trawl zone. It is therefore probable that dense horse mackerel schools above the trawl headrope initiated a diving response to the trawl gear, thereby increasing their availability to the trawl. Because the dense pelagic schools were not sampled to determine their composition, it is assumed that these schools included dense aggregations of horse mackerel. Despite the possibility that the large aggregation of horse mackerel reflected in the catch may have been within the acoustic dead zone prior to the tow, the strong diving behaviour of this species in response to approaching trawl gear (Barange and Hampton 1994) provides a plausible explanation to support the diving hypothesis. As a result, horse mackerel was omitted from catch records in an attempt to improve the correlation between acoustic and catch densities. Despite varying amounts of horse mackerel being caught throughout the analysis, their omission did not improve correlations.

Considering that the swimbladder is responsible for 90-95 % of the total reflected acoustic backscattering energy from fish (Foote 1980, Ona 1990), the omission of elasmobranchs from catch data samples was justified due to the lack of a swimbladder in these species (Smith and Heemstra 1995). Although a large number of elasmobranchs were caught throughout this analysis, their omission did not improve correlations between catches and acoustic densities.

Poor correlation between acoustic and trawled fish densities may stem from the assumption that fish density is constant from the trawl headrope to the seabed. Many variables influence both natural fish behaviour and fish behaviour in response to trawl gear. If the vertical density of fish within the trawl zone is variable, this assumption, which is central to acoustic density calculations, may be violated and therefore a highly probable source of error. Vertical fish densities may differ either due to responses of some species to approaching trawl gear or to variations in the natural behaviour of species. The response of species to approaching trawl gear has been well documented (Ona 1988, Ona and Godø 1990, Aglen 1994, Barange and Hampton 1994, Godø 1994, Aglen *et al*. 1999) and has been shown to have important consequences for both the acoustic detectability and the trawl availability of various fish species. In the South African context, fish response to trawl gear is particularly well illustrated by horse mackerel, *T. trachurus capensis* behaviour in the near demersal environment. As discussed above, diving behaviour of this species may introduce error by increasing their availability to the trawl but not their acoustic detectability. Detectability may in fact decrease, as the target strength of horse mackerel has been shown to decrease by as much as 12 dB during trawling operations (Barange and Hampton 1994). The diving response by many species in response to approaching trawl gear is in fact considered by many authors to be so perpetual, that cumulative acoustic densities, derived from the trawl zone and pelagic layers above the headrope, are correlated to catch data (Aglen 1996, Michalsen *et al*. 1996, Korsbrekke and Nakken 1999). As reviewed by Godø (1994), demersal fish tend to swim towards the seabed in response to vessel or trawl gear noise. In the Barents Sea, cod have been reported to dive 50-100 m between the vessel and the mouth of the trawl gear (Ona and Godø 1990). Despite diving hypotheses, the relation between trawl catches and the acoustic densities above the headrope prior to the arrival of the trawl mouth remained poor. This may largely be influenced by the fishing efficiency (q_e) of the trawl gear, where poor fishing line performance for example may aid the escapement of diving species, or by fish availability to the trawl gear (q_a), where fast swimming or diving species may escape from the trawl mouth. For most of the trawls during this study, however, the height of the acoustic dead zone is approximately equal to that of the vertical trawl mouth, decreasing the likelihood that acoustic and trawl densities will be strongly related. This poor correlation may be the case even if fish do not react to the trawl gear or even if gear performance were not compromised.

The poor correlations between catches and acoustic densities within the trawl zone may be also be an artefact of complex demersal trawl catches. During the *F.R.S. Africana* survey, a minimum number of 17 species were caught, ranging to a maximum of 34 species. Complications are introduced due to the differing acoustic reflectivity of all species, having an effect on the total backscattering energy which is then related to the catch. If catch compositions remained fairly consistent, it could be argued that the error too is constant, but this is hardly the case with catch compositions changing in both the number per species and the number of species caught over space and time. Similarly, herding effects by the trawl gear may be species or area dependant, which will influence the catches but not necessarily the acoustic densities if species prone to herding are encountered. By the same token, the avoidance of fish due to the approaching vessel or trawl gear may influence acoustic but not necessarily trawl estimates of abundance.

Variations in the natural vertical density of fish may be an important factor contributing to the poor correlations between acoustic and catch densities. These variations may be species-dependant, age-dependent within the same species (Engås and Godø 1989, Godø and Wespestad 1993) or influenced by the environment (see Chapter 2, Michalsen *et al*. 1996, Aglen *et al*. 1999). The length-frequency or age-class of individual trawls may introduce evidence that fish density is not homogenous throughout the trawl zone, thereby violating this central assumption on which trawl zone acoustic densities are dependant. Small fish have been reported to concentrate close to the seabed (Engås and Godø 1989, Godø and Wespestad 1993) and therefore increase their availability to the bottom trawl. A close association with the seabed reduces acoustic detectability, but detectability is increased as the fish age by a weaker association with the seabed (Godø and Wespestad 1993). According to Korsbrekke and Nakken (1999), the winter vertical distribution of cod and haddock in the Barents Sea occurs between the seabed and 100 m above the seabed, decreasing in density with distance from the seabed. This may suggest that vertical fish densities within the trawl zone are not constant as assumed, but that a logarithmic density distribution with distance from the seabed may be more accurate.

In addition to the potential diving behaviour of various fish species in response to approaching trawl gear, large variability in the fishing line clearance from the seabed may contribute significantly to the poor relation observed between acoustic and catch densities. According to Engås and Godø (1989), demersal trawl and acoustic surveys severely underestimate younger cod age groups due to escapement under the fishing line. This underestimation may be species-dependant, as some species tend to dive more readily than others and is largely influenced by the performance of the fishing line during trawling operations (Engås and Godø 1989). Evidence indicates that during this analysis, fishing line clearance from the seabed was indeed highly variable, introducing the potential for diving species to escape under the trawl gear. If substantial escapement does occur, acoustically detected fish may not be represented in the catch, thereby introducing an element of imprecision when attempting to correlate acoustic and trawl densities. Information regarding the efficiency of the fishing line during trawling operations may arguably be the most valuable gear performance contribution to South African demersal biomass assessments. Because SCANMAR data are displayed in ‘real-time’, an important advantage is the capability to monitor the *in situ* clearance between the fishing line and the seabed and therefore to adjust the warp length or towing speed to ensure effective fishing line operation. Alternatively, should ‘real-time’ display of gear performance data not be available due to technical reasons, the capability to store data enables the performance of the fishing line to be investigated and related to catch data queries or effort calculations. Routine collection of SCANMAR gear performance data during demersal biomass assessment cruises is therefore extremely valuable, providing a useful tool to identify and potentially rectify bias incorporated into swept-area estimates of abundance.

Considering that fish distributed close to the seabed favour bottom trawl surveys, while limiting the efficiency of acoustic sampling and the opposite situation when fish are pelagically distributed, it is perhaps not surprising that acoustic and trawl estimates of abundance show a very weak relationship. Godø and Wespestad (1993) suggest that a strong relation should in fact be highly unlikely, since a high detectabiliy for acoustic sampling will correspond to a low availability for demersal trawls and *vice versa*. As a result, independent measurements of relative abundance using the two methods may at times be negatively related, depending upon a pelagic or near-bottom fish distribution, thereby producing indices that do not reflect similar levels of abundance (Godø 1994). This is however relevant to situations such as those in the southern Benguela system, when Cape hake vertical distributions are influenced by environmental parameters. In fact, these circumstances emphasise the potential importance of acoustic techniques to demersal surveys, as no other method is available to sample hake that have migrated from the seabed. Godø and Wespestad (1993) agree, recognising that vertical changes in the density of the demersal fish population will affect fish availability to the two survey techniques differently. The findings presented in Chapter 2 of this thesis therefore suggest that acoustic assessment techniques may prove invaluable for future demersal assessment applications.

CHAPTER 4

DISCUSSION
AND
FUTURE CONSIDERATIONS

Evidence presented in this thesis indicates that the influence of environmental variables (current regimes in particular) may be highly relevant to the spatial and temporal variability of Cape hake vertical distributions during the day. Although the relevant literature reports strong associations between Cape hakes and various environmental parameters at the macro spatial and temporal scales, near-bottom currents appear to be more important than 'CTD' derived environmental parameters in influencing hake vertical distributions at meso- and micro scales. It has been demonstrated that the influence of ambient current regimes on biological processes may potentially influence swept-area estimates of abundance in the southern Benguela upwelling system, since daytime hake vertical migrations in response to unstable near-bottom current regimes decrease the availability of hakes to the demersal trawl. Because data presented in this study suggest that the availability of demersal fish (and particularly Cape hakes) may not be entirely random over space and time as CPUE based assessment models assume, it is extremely important to recognise the factors that influence this availability and the implications for biomass assessments. This analysis has confirmed that hake vertical distributions during the day seem to be associated with SE wind conditions, with the influence of the wind being mediated to the demersal environment through near-bottom currents. Because Cape hakes assume a pelagic distribution following the onset of SE winds, hydroacoustic techniques provide a suitable method of quantifying fish densities within the 'trawl blind' zone, thereby potentially reducing bias between swept-area trawl or survey abundance estimates.

Although this study suggests a relationship between Cape hake daytime vertical dynamics and vertical changes in current regimes, the results differ from most relevant literature in that current direction seems to be more important than current velocity (e.g. Løkkeborg 1994, Michalsen *et al*. 1996, Mackas *et al*. 1997, Aglen *et al*. 1999). As fish migrations are generally perceived to be influenced primarily by current velocities which fish tend to avoid, the results presented in this study are interesting in the sense that fish aggregations seem to avoid zones where currents change in direction. It is however possible that hakes may experience discomfort in unstable current regimes where currents change direction within short distances, having to expend energy to maintain their position in a turbulent environment, much the same as in high current velocity conditions. Løkkeborg (1994) suggested that energy optimisation is the most important reason for fish migrations in currents of high velocity, moving to areas where energy expenditure could be minimised. If this is the case, the issue is raised as to why hakes would expend energy to migrate to depths of 60 m above the seabed to avoid unstable currents when moving closer to the seabed would be a seemingly more energy-efficient option. It is highly likely that, because hakes have physiological adaptations to the swimbladder and blood system (Pitcher and Alheit 1995) vertical migrations are not energetically expensive at all. This is supported by the fact that hakes perform extensive vertical migrations on a daily basis, covering a range of depths from as deep as 600 m to the surface in relatively short periods. This suggests that hakes may be adequately adapted to perform extensive vertical migrations with relative ease.

It needs to be emphasised that, despite the relationship between wind (and therefore currents) and the vertical distribution dynamics of Cape hakes in the meso- time and space scales, the results presented in this analysis are derived from a single survey which represents approximately two weeks during the summer. It is therefore imperative that this work be considered as 'pioneering' research that needs to be validated by future sampling and hypothesis testing. The most notable requirement for such an analysis would be the collection of additional data during periods of little or no SE winds to supplement the few data that were available for this study. In this regard, it is advised that CPUE, acoustic and environmental (particularly current) data be collected during 24 hour stations in the absence of prevailing SE winds. To validate the hypothesis that Cape hake vertical migrations during the day are initiated by changing demersal current regimes (which in turn are influenced by the onset of SE winds), stable demersal currents and high hake densities close to the seabed during periods of little or no SE wind would be required. It should also be aimed in future studies to improve the identification of sound scattering layers and other acoustic targets at depths of interest.

Not only is the temporal validation during different environmental conditions important, but also the validation of spatial Cape hake vertical distribution dynamics. Despite demersal currents having been shown to have a strong relationship with wind patterns during this study, these results are based on time series data at one location (viz. Cape Columbine) only. This limited spatial sample highlights the question as to whether similar wind-current relationships will be applicable elsewhere along the continental shelf, particularly at different depths. To answer this question, supplementary current, wind and catch data at various locations across the continental shelf need to be considered.

Despite the relationship between Cape hake vertical distributions and near-bottom current regimes, the influence of light on vertical migrations cannot be ignored. In the South African context, the lack of suitable light data in this study precludes any conclusions as to the role that ambient light levels play in the daytime vertical positioning of Cape hakes. To understand the influence that light levels have on hake vertical distribution, it is necessary first to consider the role that light plays in the strong diurnal patterns that hake exhibit. Whether diurnal vertical migrations take place by hake positioning themselves vertically in the water column according to ambient light levels, or whether these migrations are endogenous rhythms that are triggered by changes in light intensity will give important clues as to the importance of light in vertical migration patterns. During daylight hours, demersal light intensity may vary according to transparency throughout the water column (Neilson and Perry 1990), which is influenced by spatial and temporal variations in phytoplankton densities (Armstrong *et al.* 1987, Brown and Hutchings 1987, Brown 1992, Mitchell-Innes and Pitcher 1992, Pitcher *et al.* 1992) or turbidity of the water (Levy 1990). It has also been hypothesised that the orientation of sea swells (and the ‘white water’ from their breaking crests) created by SE winds, combined with the angle of solar radiation during the months when SE winds are prevalent, may result in a decreased penetration of sunlight with depth (L. Hutchings, MCM, pers. comm.).

The uncertainty regarding the role that light may play in Cape hake vertical distributions highlights the need to address this question and more importantly, to implement means of collecting suitable light data, albeit on an experimental basis. It is suggested that when they arise, opportunities for the collection of these data be taken without hesitation. A point in case is the potential for the collection of light data with depth aboard the *R.V. Dr. Fridjof Nansen*, during her term in the south eastern Atlantic Ocean. Equipped with a suitable light sensor, the potential exists for this vessel to collect these data when operating during demersal assessment surveys off the west coast of South Africa.

The results presented in this study have highlighted the need to broaden the collection of environmental parameters during demersal assessment surveys on a routine basis. Traditionally in the Benguela upwelling system, the suite of environmental parameters that have been investigated when studying Cape hake distributions have been restricted to temperature, salinity and oxygen (Bailey 1986, Bailey and Giddey 1986, Roel and Bailey 1987, Macpherson *et al.* 1991). This study implies that these 'traditionally sampled' parameters may be less important in influencing the spatial dynamics of demersal fish than other 'less sampled' variables. For example, as presented by Mackas *et al*. 1997, Michalsen *et al*. 1996 and Aglen *et al*. 1999, this study indicates that currents (of which no data are currently collected during South African demersal biomass assessment surveys) may greatly influence demersal fish vertical distributions, having implications for demersal trawl estimates of abundance.

In the South African context, the application of hydroacoustic techniques to demersal biomass assessment surveys, albeit at its infancy, has potential. The first application to which acoustic techniques may prove invaluable is in, as in this thesis, studies on behavioural biology and the implications of these for survey-based abundance estimates. These studies may include natural variations in fish behaviour or behavioural changes in response to approaching vessels or fishing gear. The potential value of acoustic techniques for stock assessment purposes may prove to be more difficult, but potentially useful if utilised in the correct manner. In this regard, the acoustic sampling fraction within the water column needs to be recognised, and used to supplement CPUE data that are collected where the acoustic dead zone limits the effective collection of acoustic data. Conversely, acoustic sampling within the ‘trawl blind’ region (i.e. the water column above the fishing gear headrope) has the potential to be extremely useful, providing an indication of the fish densities that are not sampled by the demersal trawl.

The potential that acoustic assessment techniques have for demersal survey applications is boosted by the fact that research surveys provide a relative index of abundance as opposed to absolute biomass estimates. The use of acoustic techniques for absolute estimates of demersal fish abundance would be highly difficult, primarily due to the difficulty in allocating proportions of backscattering energy to extremely complex catches. Difficulties associated with the identification of demersal acoustic targets are probably the largest stumbling block for the development of demersal acoustic assessment techniques. Furthermore, absolute estimates of abundance require accurate target strengths of individual species present in the community. Given the difficulty involved in target strength estimation (MacLennan and Simmonds 1995, Soule *et al*. 1996), the use of relative rather than absolute estimates of abundance may be more advisable. However, despite the potential of acoustic techniques and their application to demersal survey scenarios, some ground needs to be covered before acoustic techniques can make a meaningful contribution. The identification of targets is the primary problem, as target strengths of various demersal species need to be investigated.

Three useful future considerations that stem from this study regarding demersal biomass assessments off the west coast of South Africa may be isolated. The first deals with the influence of SE winds on demersal (and particularly Cape hake) CPUE and the potential application of a wind index to assessment models. The incorporation of wind into stock assessment models will differ depending upon its contribution to research or commercial fisheries CPUE data. Currently, Cape hake biomass assessments off the west coast of

South Africa are based on commercial CPUE data which are standardised by applying General Linear Modelling (GLM) techniques to account for variance between the data. The standardisation procedure is applied to remove the effect of factors that may bias CPUE over time, as commercial data are not collected on the basis of a balanced design (Glazer 1998). The factors that may potentially have an impact on CPUE, and are therefore incorporated into the standardisation procedure, include factors such as depth, vessel power and latitude, but include no environmental parameters *per se*. The nearest environmental factor incorporated into the GLM is that of season, as it can be argued that environmental factors such as wind have a strong seasonal component. The seasonal factor incorporated is however determined according to calendar months, suggesting that these categories may not be a suitable surrogate for seasonal wind patterns. Based on the results of this study, the incorporation of a wind factor into the standardisation procedure therefore has merit, and may improve the West Coast CPUE regression slope statistics presented by Glazer (1998). This is despite the finding of this study that hake vertical distributions are associated with current regimes as opposed to wind patterns *per se*, because the strong relationship between wind and currents justifies using accessible wind data as a surrogate for less accessible current data. Although it can be argued that commercial operators do not remain in areas where catches are poor, thereby minimising the effect that wind will have on the CPUE regression statistic, the CPUE series is extremely large (spanning over many years), and should therefore provide sufficient data during windy periods to justify such an analysis.

Because the West Coast demersal biomass assessment surveys conducted by MCM are always performed during the summer months (January-February) when SE winds predominate, the influence of wind on vertical hake distributions may introduce a greater source of bias. The influence of wind should be recognised during these surveys, as wind patterns may vary significantly not only on a daily, but also on a seasonal scale between surveys. Under these circumstances, it would be appropriate to incorporate a correction factor to research CPUE data collected during prevailing SE conditions, when hake abundance may be severely underestimated. This improves the opportunity for hydroacoustic techniques to contribute to demersal surveys, as hake behavioural changes can be monitored and quantified in the pelagic environment.

The second useful application that is highlighted by this study is the need for the routine collection of gear performance data during South African demersal biomass assessment surveys. As discussed in Chapter 3, gear performance systems enable effort to be quantified, which can be corrected *'in situ'* during trawling operations or used to explain retrospective variance in the catch data, thereby reducing bias incorporated into swept-area indices of abundance. The routine collection of gear performance data may arguably be the most valuable contribution to South African swept-area biomass assessment surveys in the short term, since the implementation of a gear performance data collection system and subsequent data collection may occur relatively rapidly. Although the incorporation of gear performance data into assessment models may require data collection from several surveys before a meaningful contribution can be made, the immediate benefits include the capability to monitor the variance between gear performance parameters from individual trawls. Most importantly, the routine collection of gear performance data will provide the opportunity to investigate these performance parameters in the short term, which may be compared to assumed performance values that are currently incorporated into West Coast demersal biomass assessment models.

Finally, albeit at an early stage, this study highlights the potential for acoustic techniques to contribute to demersal surveys. The incorporation of an acoustic relative index of abundance may be highly relevant as a contribution to the assessment of a resource that shows a large degree of vertical spatial variability. This study therefore agrees with the proposal of Godø and Wespestad (1993), where the use of two sampling techniques which sample different fractions of the water column can be combined to reduce the bias involved with the use of one survey method alone.

APPENDIX A

SIMRAD EK 500 Scientific echo-sounder transceiver menu settings

../TRANSCEIVER MENU

	38 kHz	120 kHz
Mode	Active	Active
Transducer Type	ES38B	ES120-7
Transd. Sequence	Off	Off
Transducer Depth	0.00m	0.00m
Absorption Coef.	10 dB/km	38 dB/km
Pulse Length	Medium	Long
Bandwidth	Wide	Wide
Max. Power	2000 W	1000 W
2-Way Beam Angle	-20.6 dB	-20.5 dB
Sv Transd.Gain	27.14 dB	24.52 dB
TS Transd. Gain	27.14 dB	24.52 dB
Angle Sens. Along	21.9	21.5
Angle Sens. Athw.	21.9	21.5
3 dB Beamw. Along	7.1 dg	7.0 dg
3 dB Beamw. Athw.	7.1 dg	7.3 dg
Alongship Offset	0.0 dg	0.0 dg
Athw.ship Offset	0.0 dg	0.0 dg

REFERENCES

AGLEN, A. (1994) Sources of error in acoustic estimation of fish abundance. In: *Marine Fish Behaviour in capture and abundance estimation*, Fernö, A. & Olsen, S. (eds.) Fishing News Books, pp. 107-133

AGLEN, A. (1996) Impact of fish distribution and species composition on the relationship between acoustic and swept-area estimates of fish density. *ICES J. mar. Sci*. **53**: 501-505

AGLEN, A., ENGÅS, A., HUSE, I., MICHALSEN, K. & STENSHOLT, B.K. (1999) How vertical fish distribution may affect survey results. *ICES J. mar. Sci*. **56**: 345-360

ANDREWS, W.R.H. (1974) The relevance of upwelling research to fisheries management off the west coast of Southern Africa. *South African Shipping News and Fishing Industry Review*. **29**(5): 60-61

ANON. (1998). *Fishery Industry Handbook, South Africa, Namibia and Mocambique*. 26th edition

ARMSTRONG, D.A., MITCHELL-INNES, B.A., VERHEYE-DUA, F., WALDRON, H. & HUTCHINGS, L. (1987) Physical and biological features across an upwelling front in the southern Benguela. In: *The Benguela and Comparable Ecosystems*. Payne, A.I.L., Gulland, J.A. & Brink, K.H. (eds). *S. Afr. J. mar. Sci*. **5**: 171-190

ATKINSON, D.B. (1989) Diel Movements of Beaked Redfish and the Implications of These for Stratified Random Bottom Trawl Estimates of Biomass and Abundance. *N. Am. J. Fish. Mgmt* **9**: 163-170

BADENHORST, A. & SMALE, M.J. (1991) The distribution and abundance of seven commercial trawlfish from the Cape south coast of South Africa 1986-1990. *S. Afr. J. mar. Sci*. **11**: 377-393

BAILEY, G.W. (1986) Hake recruitment cruise, January - February 1986. *Environmental data report. Internal report* No. 95, Sea Fisheries Research Institute, Cape Town.

BAILEY, G.W. & GIDDEY, M. (1986) Hake recruitment cruise, January 1986. *Environmental data report. Internal report* No. 96, Sea Fisheries Research Institute, Cape Town.

BAILEY, G.W., BEYERS, C.J.de B. & LIPSCHITZ, S.R. (1985) Seasonal variation of oxygen deficiency in waters off southern South West Africa in 1975 and 1976 and its relation to the catchability and distribution of the Cape rock lobster *Jasus lalandii*. *S. Afr. J. mar. Sci*. **3**: 197-214

BARANGE, M. & HAMPTON, I. (1994) Influence of trawling on *in situ* estimates of Cape horse mackerel (*Trachurus trachurus capensis*) target strength. *ICES J. mar. Sci*. **51**: 121-126

BARANGE, M. & HAMPTON, I. (1997) Spatial structure of co-occurring anchovy and sardine populations from acoustic data: implications for survey design. *Fish. Oceanogr*. **6**(2): 94-108

BEAMISH, F.W.H. (1966) Vertical Migration by Demersal Fish in the Northwest Atlantic. *J. Fish. Res. Bd. Canada* **23**(1): 109-139

BOTHA, L. (1985) Occurrence and distribution of Cape hakes *Merluccius capensis* Cast. and *M. paradoxus* Franca in the Cape of Good Hope area. *S. Afr. J. mar. Sci*. **3**: 179-190

BOWMAN, R.E. & BOWMAN, E.W. (1980) Diurnal variation in the Feeding Intensity and Catchability of Silver Hake (*Merluccius bilinearis). Can. J. Fish. Aquat. Sci*. **37**: 1565-1572

BOYD, A.J., TAUNTON-CLARK, J. & OBERHOLSTER, G.P.J. (1992) Spatial features of the near-surface and midwater circulation patterns off western and southern South Africa and their role in the life histories of various commercially fished species. In: *Benguela Trophic Functioning*. Payne, A.I.L., Brink, K.H., Mann, K.H. & Hilborn, R. (eds). *S. Afr. J. mar. Sci*. **12**: 189-206

BROWN, P.C. (1992) Spatial and seasonal variation in chlorophyll distribution in the upper 30 m of the photic zone in the southern Benguela/Agulhas ecosystem. In: *Benguela Trophic Functioning*. Payne, A.I.L., Brink, K.H., Mann, K.H. & Hilborn, R. (eds). *S. Afr. J. mar. Sci*. **12**: 515-525

BROWN, P.C. & HUTCHINGS, L. (1987) The development and decline of phytoplankton blooms in the southern Benguela upwelling system. 1. Drogue movements, hydrography and bloom development. In: *The Benguela and Comparable Ecosystems*. Payne, A.I.L., Gulland, J.A. & Brink, K.H. (eds). *S. Afr. J. mar. Sci*. **5**: 357-391

CHAPMAN, P. & SHANNON, L.V. (1985) The Benguela ecosystem Part II. Chemistry and related processes. *Oceanogr. Mar. Biol. Ann. Rev*. **23**: 183-251

CHATFIELD, C. (1989) The Analysis of Time Series: An Introduction. Chapman & Hall, pp. 241

CLARKE, A.J. (1989) Theoretical Understanding of Eastern Ocean Boundary Poleward Undercurrents. In: *Poleward Flows along Eastern Ocean Boundaries*. Neshyba, S.J., Mooers, C.N.K., Smith, R.L. & Barber, R.T. (eds.). New York, Springer. (Coast. Estuar. Stud. 34).

CRAWFORD, R.J.M., SIEGFRIED, W.R., SHANNON, L.V., VILLACASTIN-HERRERO, C.A. & UNDERHILL, L.G. (1990) Environmental influences on marine biota off Southern Africa. *S. Afr. J. Sci*. **86**: 330-339

D'ASARO, E.A. & DAIRIKI, G.T. (1997) Turbulence Intensity Measurements in a Wind-Driven Mixed Layer. *J. phys. Oceanogr*. **27**: 2009-2022

DE DECKER, A.H.B. (1970) An oxygen-depleted subsurface current off the West Coast of South Africa. *Investl. Rep. Div. Sea Fish. S. Afr*. **84**: 1-24

EHRICH, S. & STRANSKY, C. (1999) Fishing effects in northeast Atlantic shelf seas: patterns in fishing effort, diversity and community structure. VI. Gale effects on vertical distribution and structure of a fish assemblage in the North Sea. *Fish. Res*. **40**: 185-193

ENGÅS, A. (1994) The Effects of Trawl Performance and Fish Behaviour on the Catching Efficiency of Demersal Sampling Trawls. In: *Marine Fish Behaviour in capture and abundance estimation*, Fernö, A. & Olsen, S. (eds.) Fishing News Books, pp. 45-68

ENGÅS, A. & GODØ, O.R. (1986) Influence of Trawl Geometry and Vertical Distribution of Fish on Sampling with Bottom Trawl. *J. Northw. Atl. Fish. Sci*. **7**:35-42

ENGÅS, A. & GODØ, O.R. (1989) Escape of fish under the fishing line of a Norwegian sampling trawl and its influence on survey results. *J. Northw.Atl. Fish. Sci*. **7**: 35-42

FOOTE, K.G. (1980) Importance of the swimbladder in acoustic scattering by fish: a comparison of gadoid and mackerel target strength. *J. acoust. Soc. Am.* **67**: 2084-2089

GILL, A.E. (1982) Atmosphere-Ocean Dynamics. Academic Press, Inc., London, pp. 662

GLAZER, J.P. (1998) The applications of general linear modelling methods to estimate trends in abundance of the hake and rock lobster stocks off South Africa. *Unpublished M.Sc. thesis*, University of Cape Town, South Africa. pp. 239

GODØ, O.R. (1994) Factors affecting the reliability of groundfish abundance estimates from bottom trawl surveys. In: *Marine Fish Behaviour in capture and abundance estimation*, Fernö, A. & Olsen, S. (eds.) Fishing News Books, pp. 166-199

GODØ, O.R. & WESPESTAD, V.G. (1993) Monitoring changes in abundance of gadoids with varying availability to trawl and acoustic surveys. *ICES J. mar. Sci*. **50**: 39-51

GODØ, O.R., WALSH, S.J. & ENGÅS, A. (1999) Investigating density-dependant catchability in bottom-trawl surveys. *ICES J. mar. Sci*. **56**: 292-298

GORDOA, A. & MACPHERSON, E. (1991) Diurnal variation in the feeding activity and catch rate of Cape hake (*Merluccius capensis* and *M. paradoxus*) off Namibia. *Fish. Res*. **12**: 299-305

GORDOA, A., MACPHERSON, E. & OLIVAR, M.P. (1995) Biology and fisheries of Namibian hakes (*M. paradoxus* and *M. capensis*). In: *Hake: Fisheries, ecology and markets*, Alheit, J. & Pitcher, T.J (eds.) Chapman & Hall, pp. 49-88

HALPERN, D. (1974) Observations of the Deepening of the Wind-Mixed Layer in the Northeast Pacific Ocean. *J. Phys. Oceanogr*. **4**: 434-466

HAMUKUAYA, H., O’TOOLE, M.J. & WOODHEAD, P.M.J. (1998) Observations of severe hypoxia and offshore displacement of Cape hake over the Namibian shelf in 1994. In: *Benguela Dynamics*. Pillar, S.C., Moloney, C.L., Payne, A.I.L. & Shillington, F.A. (eds). *S. Afr. J. mar. Sci*. **19**: 57-59

HARDEN JONES, F.R. & SCHOLES, P. (1980) Wind and the catch of a Lowestoft trawler. *J. Cons. int. Explor. Mer*, **39**(1): 53-69

HUSE, I., HAMUKUAYA, H., BOYER, D.C., MALAN, P.E. & STRØMME, T. (1998) The diurnal vertical dynamics of Cape hake and their potential prey. In: *Benguela Dynamics*. Pillar, S.C., Moloney, C.L., Payne, A.I.L. & Shillington, F.A. (eds). *S. Afr. J. mar. Sci*. **19**: 365-376

INADA, T. (1981) Studies on the Merlucciid Fishes. *Bull. Far Seas Fish. Res. Lab*. **18**: 114-120

JIN, X. (1990) Acoustic estimation of near seabed fish abundance. *Unpublished M. phil. thesis*, University of Bergen, Norway, pp. 81

KORRÛBEL, J.L., BLOOMER, S.F., COCHRANE, K.L., HUTCHINGS, L. & FIELD, J.G. (1998) Forecasting in South African pelagic fisheries management: the use of expert and decision support systems. In: *Benguela Dynamics*. Pillar, S.C., Moloney, C.L., Payne, A.I.L. & Shillington, F.A. (eds). *S. Afr. J. mar. Sci*. **19**: 415-423

KORSBREKKE, K. & NAKKEN, O. (1999) Length and species-dependent diurnal variation of catch rates in the Norwegian Barents Sea bottom-trawl surveys. *ICES J. mar. Sci*. **56**: 284-291

KRAMER, D.L. (1987) Dissolved oxygen and fish behaviour. *Env. Biol. Fish*. **18**(2): 81-92

LAEVASTU, T. (1993) Marine climate, weather and fisheries. Fishing News Books, pp. 204

LAWSON, G.L. & ROSE, G.A. (1999) The importance of detectability to acoustic surveys of semi-demersal fish. *ICES J. mar. Sci*. **56**: 370-380

LE CLUS, F., AGENBAG, J.J., HENNIG, H.F-K.O., ROBERTS, M.J., GRÜNDLINGH, M.L., SIMS, P.F. & STRUTHERS, M.J. (1998) Seasonal and Interannual variability in wind field and commercial catch rates of *Austroglossus pectoralis* (Soleidae). In: *Benguela Dynamics*. Pillar, S.C., Moloney, C.L., Payne, A.I.L. & Shillington, F.A. (eds). *S. Afr. J. mar. Sci*. **19**: 377-390

LEMING, T.D. & STUNTZ, W.E. (1984) Zones of coastal hypoxia revealed by satellite scanning have implications for strategic fishing. *Nature*, **310**: 136-138

LEVY, D.A. (1990) Sensory Mechanism and Selective Advantage for Diel Vertical Migration in Juvenile Sockeye Salmon, *Oncorhynchus nerka*. *Can. J. Fish. Aquat. Sci*. **47**: 1796-1802

LIVINGSTONE, P.A. (1983) Food habits of Pacific whiting, *Merluccius productus*, off the west coast of North America, 1967 and 1980. *Fish. Bull*. **81**(3): 629-636

LØKKEBORG, S. (1994) Fish Behaviour and Longlining. In: *Marine Fish Behaviour in capture and abundance estimation*, Fernö, A. & Olsen, S. (eds.) Fishing News Books, pp. 9-27

MACKAS, D.L., KIESER, R., SAUNDERS, M., YELLAND, D.R., BROWN, R.M. & MOORE, D.F. (1997) Aggregation of euphausiids and Pacific hake (*Merluccius productus*) along the outer continental shelf off Vancouver Island. *Can. J. Fish. Aquat. Sci*. **54**: 2080-2096

MACLENNAN, D.N. & SIMMONDS, E.J. (1995) Fisheries Acoustics. Chapman & Hall. pp. 325

MACPHERSON, E., MASÓ, M., BARANGE, M. & GORDOA, A. (1991) Relationship between measurements of hake biomass and sea surface temperature off southern Namibia. *S. Afr. J. mar. Sci*. **10**: 213-217

MAGNUSON, J.J., HARRINGTON, C.L., STEWART, D.J. & HERBST, G.N. (1981) Responses of macrofauna to short-term dynamics of a Gulf Stream front on the Continental Shelf. In: *Coastal and Estuarine Sciences 1. Coastal upwelling*. Richards, F.A. (ed). Washington, D.C. American Geophysical Union. pp. 441-448

MARAVELIAS, C.D. & HARALABOUS, J. (1995) Spatial distribution of herring in the Orkney/Shetland area (northern North Sea): A geostatistical analysis. *Neth. J. Sea Res*. **34**(4): 319-329

MARAVELIAS, C.D., REID, D.G., SIMMONDS, E.J. & HARALABOUS, J. (1996) Spatial analysis and mapping of acoustic survey data in the presence of high local variability: geostatistical application to North Sea herring (*Clupea harengus*). *Can. J. Fish. Aquat. Sci*. **53**: 1497-1505

MAS-RIERA, J., LOMBARTE, A., GORDOA, A. & MACPHERSON, E. (1990) Influence of Benguela upwelling on the structure of demersal fish populations off Namibia. *Mar. Biol.* **104**: 175-182

MICHALSEN, K., GODØ, O.R. & FERNÖ, A. (1996) Diel variation in the catchability of gadoids and its influence on the reliability of abundance indices. *ICES J. mar. Sci.* **53**: 389-395

MITCHELL-INNES, B.A. & PITCHER, G.C. (1992) Hydrographic parameters as indicators of the suitability of phytoplankton populations as food for herbivorous copepods. In: *Benguela Trophic Functioning*. Payne, A.I.L., Brink, K.H., Mann, K.H. & Hilborn, R. (eds). *S. Afr. J. mar. Sci*. **12**: 355-365

MOHR, H. (1964) Changes in the behaviour of fish due to environment and motivation and their influence on fishing. *ICNAF Environmental Symposium, Rome*, Contrib. G-3

NEILSON, J.D. & PERRY, R.I. (1990) Diel Vertical Migrations of Marine Fishes: an Obligate or Facultative Process? *Adv. mar. Biol*. **26**:115-168

NELSON, G. (1989) Poleward motion in the Benguela area. In: *Poleward Flows along Eastern Ocean Boundaries*. Neshyba, S.J., Mooers, C.N.K., Smith, R.L. & Barber, R.T. (eds.). New York, Springer. (Coast. Estuar. Stud. 34).

NELSON, G. & HUTCHINGS, L. (1983) The Benguela Upwelling Area. *Prog. Oceanog*. **12**: 333-356

NELSON, G., BOYD, A.J., AGENBAG, J.J. & DUNCOMBE RAE, C.M. (1998) An upwelling filament north-west of Cape Town, South Africa. In: *Benguela Dynamics*. Pillar, S.C., Moloney, C.L., Payne, A.I.L. & Shillington, F.A. (eds). *S. Afr. J. mar. Sci*. **19**: 75-88

NILSSEN, E.M., PEDERSEN, T., HOPKINS, C.C.E., THYHOLDT, K. & POPE, J.G. (1993) Recruitment variability and growth of northeast Arctic cod: influence of physical environment, demography, and predator-prey energetics. *ICES CCC Symposium* No. 30

ONA, E. (1988) Observations of cod reaction to trawling noise. *ICES Fisheries Acoustic Science and Technology WG*, 20-22 April 1988, Ostend, Belgium.

ONA, E. (1990) Physiological factors causing natural variations in acoustic target strength of fish. *J. mar. biol. Ass. U.K*. **70**: 107-127

ONA, E. (1994) Recent Developments of Acoustic Instrumentation in Connection with Fish Capture and Abundance Estimation. In: *Marine Fish Behaviour in capture and abundance estimation*, Fernö, A. & Olsen, S. (eds.) Fishing News Books, pp. 200-213

ONA, E. & GODØ, O.R. (1990) Fish reaction to trawling noise: the significance for trawl sampling. *Rapp. P.-v. Réun. Const. int. Explor. Mer*, **189**: 159-166

ONA, E & MITSON, R.B. (1996) Acoustic sampling and signal processing near the seabed: the deadzone revisited. *ICES J. mar. Sci.* **53**: 677-690

PAYNE, A.I.L. (1995) Cape hakes. In: *Oceans of Life off southern Africa*, Payne, A.I.L. & Crawford, R.J.M. (eds.) Vlaeberg publishers, pp. 136-147

PAYNE, A.I.L. & PUNT, A.E. (1995) Biology and fisheries of South African Cape hakes (*M.capensis* and *M. paradoxus*). In: *Hake: Fisheries, ecology and markets*, Alheit, J. & Pitcher, T.J (eds.) Chapman & Hall, pp. 15-47

PAYNE, A.I.L., LESLIE, R.W. & AUGUSTYN, C.J. (1984) Hake stock assessments in ICSEAF Divisions 1.6 and 2.1/2.2. *Colln. scient. Pap. int. Commn SE. Atl. Fish.* **11**(2): 23-33

PAYNE, A.I.L., ROSE, B. & LESLIE, R.W. (1987) Feeding of hake and a first attempt at determining their trophic role in the South African west coast marine environment. In: *The Benguela and Comparable Ecosystems*. Payne, A.I.L., Gulland, J.A. & Brink, K.H. (eds). *S. Afr. J. mar. Sci*. **5**: 471-501

PHILANDER, S.G.H. & YOON, J.-H. (1982) Eastern Boundary Currents and Coastal Upwelling. *J. phys. Oceanogr*. **12**: 862-879

PILLAR, S.C. & BARANGE, M. (1993) Feeding selectivity of juvenile Cape hake *Merluccius capensis* in the southern Benguela. *S. Afr. J. mar. Sci*. **13**: 255-268

PILLAR, S.C. & BARANGE, M. (1995) Diel feeding periodicity, daily ration and vertical migration of juvenile Cape hake off the West Coast of South Africa. *J. Fish. Biol*. **47**: 753-768

PILLAR, S.C. & BARANGE, M. (1997) Diel variability in bottom trawl catches and feeding activity of the Cape hakes off the west coast of South Africa. *ICES J. mar. Sci.* **54**: 485-499

PITCHER, G.C., BROWN, P.C. & MITCHELL-INNES, B.A. (1992) Spatio-temporal variability of phytoplankton in the southern Benguela upwelling system. In: *Benguela Trophic Functioning*. Payne, A.I.L., Brink, K.H., Mann, K.H. & Hilborn, R. (eds). *S. Afr. J. mar. Sci*. **12**: 439-456

PITCHER, T.J. & ALHEIT, J. (1995) What makes a hake? A review of the critical biological features that sustain global hake fisheries. In: *Hake: Fisheries, ecology and markets*, Alheit, J. & Pitcher, T.J (eds.) Chapman & Hall, pp. 1-14

PRENSKI, L.B. (1986) Studies on hake, *Merluccius capensis* Castelnau, 1861, from off Namibia. II. Studies on food and feeding. *Acta ichthyol. pisca*. **16**: 3-19

RIDDERINKHOF, H. (1992) On the effects of variability in meteorological forcing on the vertical structure of a stratified watercolumn. *Continent. Shelf Res.* **12**(1):25-36

ROBERTS, M.J., van den BERG, M. & NEEDHAM, N. (in prep.) Benthic turbidity events may force chokka squid to spawn in deeper water.

ROEL, B.A. & BAILEY, G.W. (1987) Preliminary investigation of the relationship between hake abundance and hydrological parameters in the Benguela system. *Colln scient. Pap. int. Commn SE. Atl. Fish*. **14**(2): 193-201

ROEL, B.A. & MACPHERSON, E. (1988) Feeding of *Merluccius capensis* and *M. paradoxus* off Namibia. *S. Afr. J. mar. Sci*. **6**: 227-243

ROY, C., CURY, P. & KIFANI, S. (1992) Pelagic fish recruitment success and reproductive strategy in upwelling areas: environmental compromises. In: *Benguela Trophic Functioning*. Payne, A.I.L., Brink, K.H., Mann, K.H. & Hilborn, R. (eds). *S. Afr. J. mar. Sci*. **12**: 135-146

SANDEMAN, E.J. (1969) Diurnal Variation in Availability of Different Sizes of Redfish, Sebastes mentella. *ICNAF Research Bulletin* **6**: 35-46

SCHOLES, P. (1982) The effect of wind direction on trawl catches; an analysis of haul-by-haul data. *J. Cons. int. Explor. Mer*, **40**(1): 81-93

SHANNON, L.V. (1995) The physical environment. In: *Oceans of Life off southern Africa*, Payne, A.I.L. & Crawford, R.J.M. (eds.) Vlaeberg publishers, pp. 12-27

SHANNON, L.V., AGENBAG, J.J., WALKER, N.D. & LUTJEHARMS, J.R.E. (1990) A major perturbation in the Agulhas retroflection area in 1986. *Deep-Sea Res*. **37**(3): 493-512

SMITH, R.L. (1989) Poleward Flows along Eastern Ocean Boundaries: An Introduction and Historical Review. In: *Poleward Flows along Eastern Ocean Boundaries*. Neshyba, S.J., Mooers, C.N.K., Smith, R.L. & Barber, R.T. (eds.). New York, Springer. (Coast. Estuar. Stud. 34).

SMITH, M.M. & HEEMSTRA, P.C. (eds.) (1995) Smith's Sea Fishes. Macmillan, Johannesburg. pp. 1047.

SOULE, M., HAMPTON, I. & BARANGE, M. (1996) Potential improvements to current methods of recognizing single targets with a split-beam echo-sounder. *ICES J. mar. Sci.* **53**: 237-243

STRICKLAND, J.D.H. & PARSONS, T.R. (1972) Determination of Dissolved Oxygen. In: *A practical handbook of Seawater Analysis*. Fish. Res. Board. Canada Bull. **167**: 21-26

THORNE, R.E. (1977) Acoustic assessment of Pacific hake and herring stocks in Puget Sound, Washington and southeastern Alaska. *Rapp. P.-v. Réun. Const. int. Explor. Mer*, **170**: 265-278

VISSER, G.A. (1969) Analysis of Atlantic waters off the West Coast of southern Africa. *Investl. Rep. Div. Sea Fish. S. Afr*. **75**: 1-26