A Decade of Namibian Fisheries Science
Payne, A. I. L., Pillar, S. C. and R. J. M. Crawford (Eds). *S. Afr. J. mar. Sci. 23: 337–346*
2001

DYNAMICS OF THE PELAGIC COMPONENT OF NAMIBIAN HAKE STOCKS

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A study was undertaken to investigate the spatial, diurnal and interannual dynamics of the pelagic component of Namibian hake stocks. Data were derived from trawl surveys conducted on board the R.V. *Dr Fridtjof Nansen* during the period 1991–1999. In addition to trawl surveys, acoustic methods were applied concurrently to quantify fish biomass off the bottom (above the headline). The pelagic component of hake was variable in both time and space – it was denser in the north and at depths of 200–500 m. Pelagic densities also correlated well with the density of adult fish (≥30 cm) at the bottom, but not with that of young hake (>18 and <30 cm) at the bottom. Pelagic densities were lowest at midday and highest at night, early morning and late afternoon densities being intermediate between the two. Incorporation of acoustic methods allows for at least partial account to be taken of diurnal variation in determining catchability. The fraction of the biomass off the bottom was not the same each year, thus affecting assessment and management advice for the stock, even if the survey results are treated only as relative indices of abundance. More field studies are needed to investigate the size range and species of hake active in vertical migration.

Key words: acoustic correction, bottom trawl surveys, Cape hake, vertical migration

Cape hake *Merluccius capensis* and *M. paradoxus* in southern Africa undergo vertical migration away from the seabed during the night (Payne 1989) and, to a lesser extent, also during daylight. Similar behaviour is reported from gadoids in the North Atlantic (Beamish 1966) and North Pacific (Karp and Walters 1994). Bottom trawl surveys, usually restricted to daylight, are an important and commonly used method of monitoring the status of such stocks. Variation in the fraction that migrates off the bottom by day would introduce a variable bias in the survey, so affecting the precision of biomass estimates (Godø 1994). In the Barents and Bering seas, combining or synchronizing bottom trawl surveys with acoustic surveys to cover more completely the distribution of stocks is an established procedure (Karp and Walters 1994, Jakobsen *et al.* 1997). Variation in the fraction of the Cape hake biomass caught by trawling at the bottom is also sometimes explained by variation in availability (Gordoa *et al.* 1995), most likely the result of vertical migration. A better understanding of the magnitude and dynamics of the vertical migration and distribution of the hake stocks in Namibia is, therefore, needed to improve the precision of abundance estimates from trawl surveys and hence the management of the hake stocks. Such an understanding will also enhance knowledge of the behaviour of Cape hake in general.

Hake abundance and distribution in Namibia has, since Independence in 1990, been monitored by means of bottom trawl surveys in combination with hydroacoustics, the latter used to estimate hake biomass above the headline of the trawl. A total of 17 surveys was conducted aboard the two Norwegian research vessels that carried the name *Dr Fridtjof Nansen* during the periods January 1990 to May 1993 (first vessel) and January 1994 to February 1999 (new vessel). After some pilot studies, the pelagic component of the stock, determined acoustically, was incorporated into the assessment with effect from 1991. Observations during the surveys indicate that vertical behaviour varies in both space and time, i.e. by depth and region as well as on a diurnal, seasonal and interannual basis. Since January 2000, the annual Namibian hake biomass surveys have been conducted on board commercial vessels, which do not have the necessary acoustic instrumentation to assess hake in midwater. As a result, it has become even more important to quantify the possible error introduced by excluding pelagic hake from biomass estimates.

The main objective of the current study was to analyse the abundance and dynamics of the pelagic component of the hake stock by depth and latitude, as well as by year. Seasonal variability of the pelagic component could not be analysed because the time-series lacks sufficient seasonal coverage. The study is also intended to illustrate relative diurnal trends and to show that, by incorporating acoustic estimates in assessments, vertical migration is at least partially

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Manuscript received November 2000; accepted September 2001

Table I: Timing of the hake surveys off Namibia during the years 1990–1999

Quarter	Year									
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
First	+	+		•	•		•	•	•	•
Second			•	•	•	•				
Third	+						•			
Fourth		•	•		•					

\+ Not included in the analysis

accounted for. The results from the study may, in future, contribute to estimating the proportion of the stock off the bottom where no acoustic estimate is available.

MATERIAL AND METHODS

The study uses point sample data collected by standard trawl and rigging used by the R.V. *Dr Fridtjof Nansen* between November 1991 and February 1999. Sætersdal *et al*. (1999) give a full description of survey design and the methods used during the surveys. The surveys followed a systematic transect design, with stations semi-randomly allocated along transects. A typical haul had a duration of 30 minutes and covered about 0.015 square nautical miles. The pelagic component of the stock was assessed using a Simrad EK500 scientific echo-sounder. From 1994, a Bergen echo-integrator (BEI) post-processing system, which allows for better discrimination of acoustic targets, was also used. The timing of all surveys from 1990 to 1999 is shown in Table I, including two surveys in 1990 and one in 1991 that are not included in the current analysis because the acoustic part of those surveys was still under development. From 1996, the period January–February was established as the standard period for hake surveys in Namibia in an attempt to synchronize them with surveys of Cape hake off the west coast of neighbouring South Africa. The aim was to facilitate a more complete picture of the status of hake stocks in the region; South Africa by then already had a time-series of annual hake surveys dating back to 1983 (Payne *et al*. 1985).

The data from the surveys were quality-controlled and stored in the Nansis database. Catch records of *M. capensis* and *M. paradoxus* were converted to densities expressed in tons per square nautical mile by means of the Nansis software (Strømme 1992) and then retrieved from the database. These values were linked to information pertaining to the station, namely survey number, sample quality, depth, position and time of day. Only daylight stations were used in the analysis, except where the purpose was to examine diurnal variation. Daylight was defined as 06:00–18:00 UTC (Universal Time Co-ordinated) at the start of each trawl. Trawls outside this period were classified as night or twilight trawls. Namibian standard time was UTC+2 h until January 1995 and UTC+1 h thereafter. Juvenile hake (≤18 cm) were not included in the analysis, because their ecology is different from that of adult fish. Such juveniles generally form vertically migrating pelagic schools in shallow water. Chłapowski and Krzeptowski (1980) and Macpherson *et al*. (1982) found pelagic schools of juvenile *M. capensis* off central Namibia, mainly inshore in areas not sampled during the hake surveys (Sætersdal *et al*. 1999).

Densities of pelagic hake linked to a point sample of bottom fish are expressed in the database through an acoustic correction factor (*ACF*), c_a, defined as the factor to be applied to bottom density estimates in order to obtain estimates of total fish density at each trawl station:

$$c_a = 1 + \frac{d_p}{d_d} \quad , \qquad (1)$$

where d_p is the pelagic density estimate obtained from acoustic methods and d_d is the demersal density estimate obtained from the swept-area method. The pelagic component was thus obtained from

$$d_p = (c_a - 1)d_d \quad . \qquad (2)$$

A weighted mean *ACF* was obtained by survey and species from

$$\bar{c}_a = \frac{\sum_{i=1}^{n} c_a d_d}{\sum_{i=1}^{n} d_d} \quad . \qquad (3)$$

It indicates the magnitude by which the swept-area estimate should be raised to obtain a total estimate

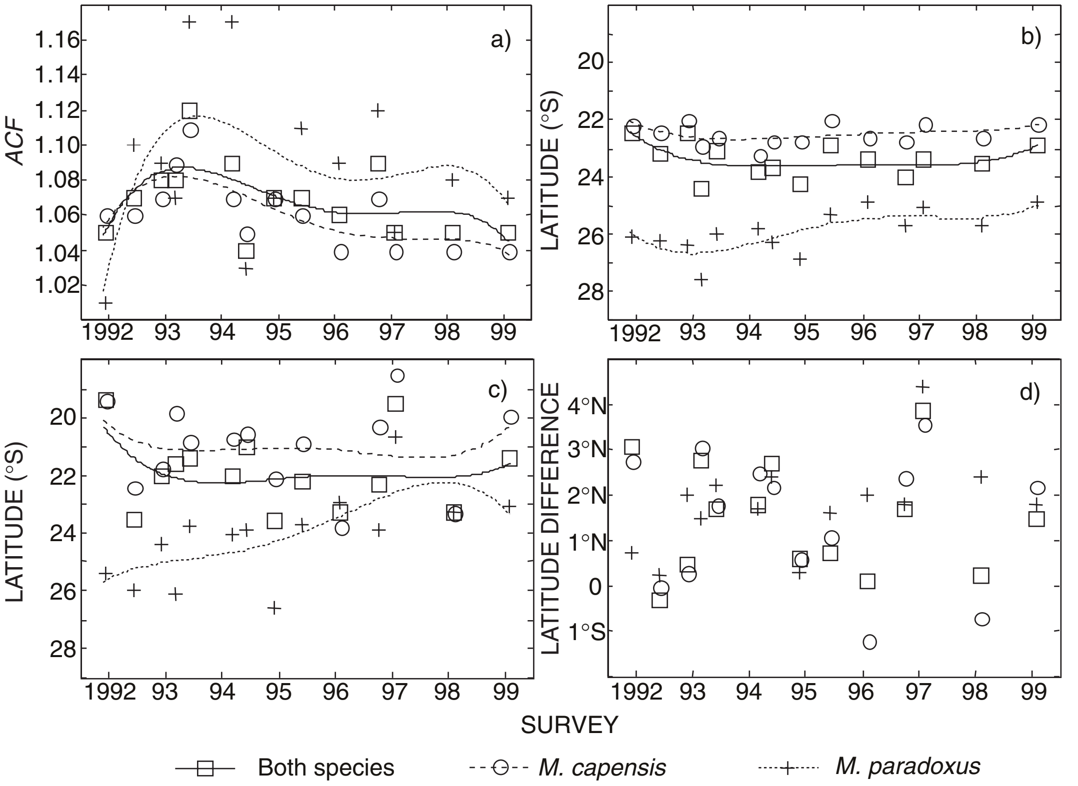

Fig.1: Survey time-series of (a) weighted mean acoustic correction factor *ACF*, (b) weighted mean latitude of demersal densities from trawl catches, (c) weighted mean latitude of pelagic densities associated with bottom trawl stations, (d) difference between weighted mean latitude of pelagic and demersal densities. Polynomial trend lines are shown

that includes fish above the headline of the trawl. An *ACF* of 1.05, for example, means that the demersal biomass index has been raised by 5%.

The weighted mean latitude, used to indicate latitudinal changes in fish distribution between surveys, was calculated as

$$L\bar{a}t = \frac{\sum_{i=1}^{n} Lat_i d_i}{\sum_{i=1}^{n} d_i} \quad , \qquad (4)$$

where Lat_i is the latitude at station *i*, in decimals, and d_i is the pelagic or demersal density at station *i*. The difference in latitude between pelagic and demersal gravity points was obtained by subtracting the demersal gravity points from the pelagic ones.

The mean *ACF*, used to indicate latitudinal and depth differences, was calculated by survey:

$$\bar{c}_{a,j} = \frac{\sum_{i=1}^{n} c_{a,j}}{n_j} \quad , \qquad (5)$$

where *n* is the number of stations at that depth or in that latitudinal stratum *j*. Mean pelagic and demersal densities were also calculated by substituting *ACF* with density in Equation 5, to investigate the spatial distribution of Cape hake.

Similar calculations to those of Equation 4 were also used to express the weighted mean depths of different size-classes of Cape hake, substituting latitude with bottom depth. For the size-dependent analysis, the two hake species were pooled and the catch rates split into young (>18 and <30 cm) and adult (≥30 cm) fish, using length frequency distributions. This analysis was done to establish whether vertical migration is related to fish size.

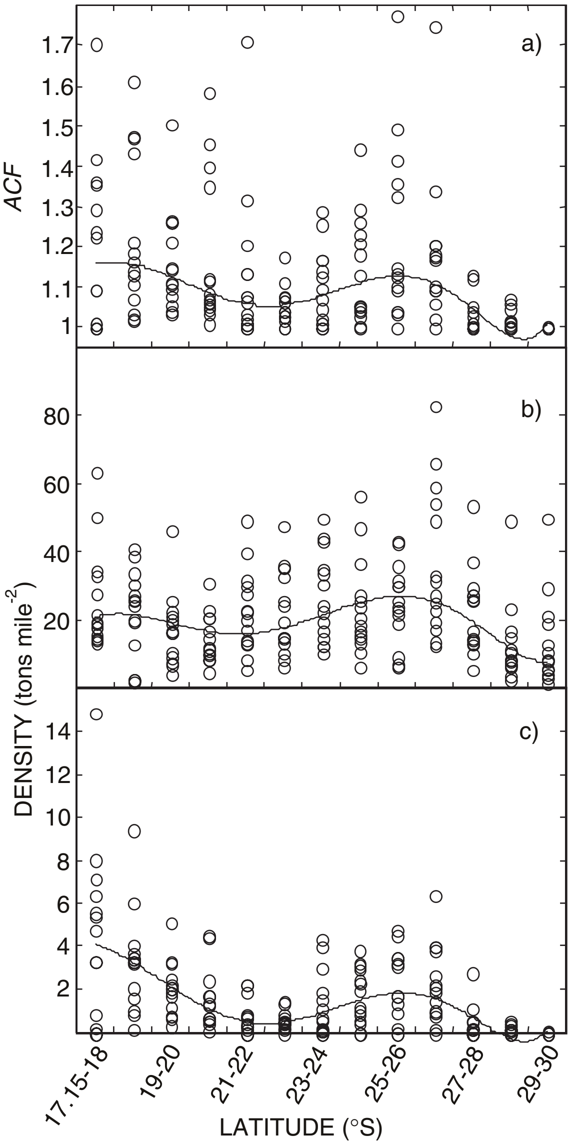

Fig. 2: Distribution by latitude of survey means of (a) acoustic correction factor *ACF*, (b) demersal hake densities from trawl catches, (c) pelagic hake densities from acoustic registrations associated with bottom trawl stations. Polynomial trend lines are shown

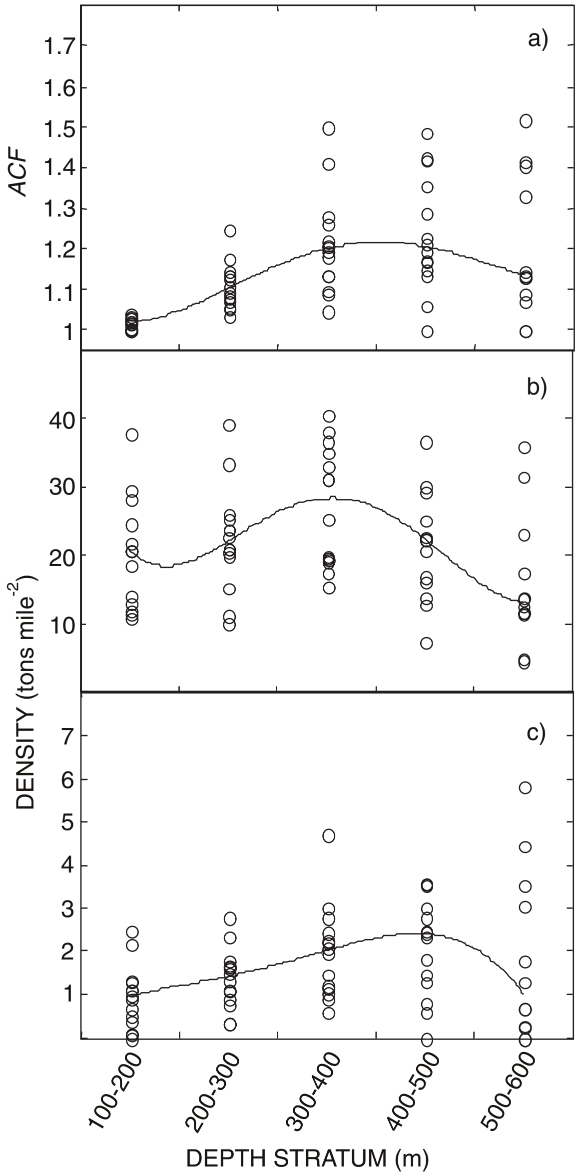

Fig. 3: Distribution by depth strata of survey means of (a) acoustic correction factor *ACF*, (b) demersal densities of hake from trawl catches, (c) pelagic hake densities from acoustic registrations associated with bottom trawl stations. Polynomial trend lines are shown

RESULTS

The distribution by survey of the weighted mean *ACF* for the two Cape hake species separately and combined is given in Figure 1a. The means, in terms of both species combined, fell within the range 1.04–1.12. Analysing the two species separately, the trend in *ACF* was similar: a high *ACF* for *M. capensis* mirrored a high *ACF* for *M. paradoxus*. However, the

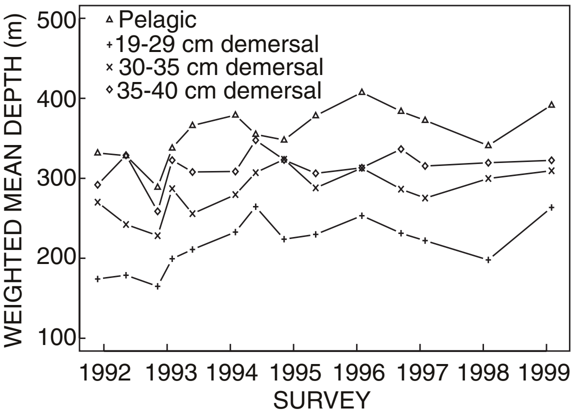

Fig. 4: Survey time-series of weighted mean depth of the pelagic component and three size-classes of Cape hake (both species combined)

ACF for *M. paradoxus* tended to be higher than that of *M. capensis*.

Figure 1b shows how the centre of distribution for the demersal component of the hake stock varies by survey. The weighted mean latitude of the point samples expresses this centre of distribution (gravity point). The gravity point for *M. capensis* seemed to stabilize at around 22°S, although the distribution shifted slightly south of that during 1993 and 1994. The trend in gravity point for *M. paradoxus* was generally northwards from 1991 to 1995, but with fallbacks in February 1993 and November 1994. From 1996 to 1999, when annual surveys were fixed at the beginning of the year, the centre varied little (25–26°S). Nevertheless, by combining the data for the two species, the trend line generally followed that of *M. capensis*, which is not surprising given that *M. capensis* is the dominant species off Namibia (Payne 1989, Gordoa *et al.* 1995, Sætersdal *et al.* 1999). Variation in the gravity point for the pelagic component of the stocks is shown in Figure 1c. There was no clear interannual trend in the gravity point distribution of *M. capensis*, except perhaps a greater variability after 1995. For *M. paradoxus* the trend was similar to that of the demersal component of the stock, namely a gradual northward shift in the gravity point distribution, though with a higher variability than the demersal component after 1995.

The difference in latitude between the pelagic and demersal gravity points for each species and both species combined is shown in Figure 1d. During most surveys, the difference was positive, i.e. the pelagic gravity point was north of the demersal one. This suggests that pelagic behaviour of Cape hake was more pronounced in the northern part of the survey area. The survey mean *ACF* sorted by latitude and expressed by scatter plot is shown in Figure 2a. Mean *ACF* was generally higher in the north than in the south, as was inter-survey variability. South of 27°S, mean *ACF* was generally low and did not exceed 1.13. Mean densities of the demersal component, both species combined (Fig. 2b), were generally higher in the north and between 24 and 27°S. Lowest densities were in the south and perhaps also between 20 and 23°S. Mean densities of the pelagic component (Fig. 2c) followed the same latitudinal pattern as that of the demersal component, suggesting possible density-dependence of the two components. The latitudes with high means were associated with high variability.

The spread of the survey mean *ACF*, sorted by depth, is shown in Figure 3a. Mean *ACF* was generally low in shelf waters (100–200 m), but it increased over the slope towards the 500 m isobath. Survey mean *ACF*s exceeding 1.3 were restricted to bottom depths of 300–500 m. Demersal densities (Fig. 3b) were highest between 300 and 400 m deep. Pelagic densities (Fig. 3c) were low on the shelf but increased over the slope towards the 400 m isobath. Higher densities of the demersal component over the shelf (100–200 m) were not associated with higher densities of the pelagic component, as reflected by the lower mean *ACF* at such depths (Fig. 3a). This could indicate that young hake, in contrast to juveniles (which form pelagic schools), are not as active in vertical migration and stay at the bottom in midshelf waters. The high inter-survey variability of demersal densities on the shelf (100–200 m) probably reflects the stochastic and seasonal character of the recruitment process, because juvenile hake normally enter the demersal zone at about 18 cm long, during the period October–December each year (Strømme *et al.* 1999).

Figure 4 shows the survey distribution of the weighted mean depth for four categories: pelagic and three size-classes of demersal hake. The mean depth of pelagic hake was consistently deeper than that of the three demersal size categories, indicating that daylight vertical migration is mainly associated with fish over the slope, the habitat dominated by bigger fish.

Sample data were also split into young and adult fish, using catch rates and associated length frequency samples. Figure 5a shows the density estimates of adult fish plotted against pelagic densities. The trend was approximately linear when a logarithmic scale was used. Figure 5b is a similar plot for young fish against pelagic densities. For that plot the relationship appears to be more stochastic, and little correlation can be seen between the two variables. Figure 5c is a box plot of the depth distribution of point samples grouped by three types of catches:

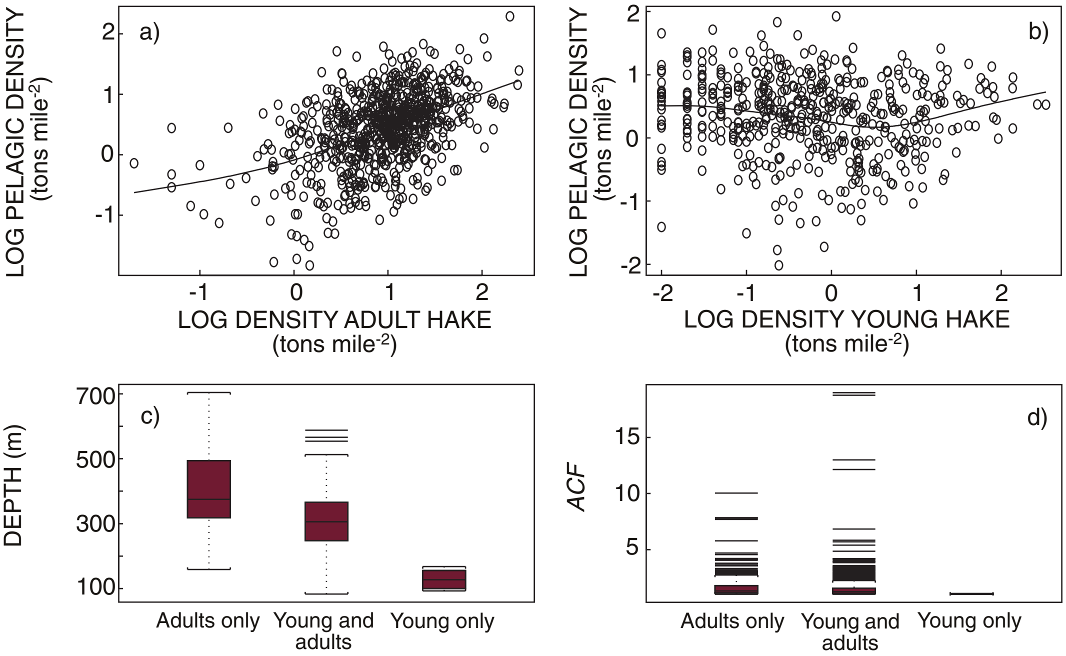

Fig. 5: Pelagic densities at trawl stations plotted against (a) adult hake at the bottom and (b) young hake at the bottom, both with Loess-type trend lines shown; (c) box plot expressing the depth range of three categories of size combinations at trawl stations, adults with no young hake, adults and young hake mixed, and young hakes with no adults, (d) acoustic correction factor sorted by the same categories as in (c)

(i) those with adult hake only,
(ii) those with adult and young hake present,
(iii) those with young hake only.

Samples of young hake only were found in shallower water, whereas most of the samples of adult hake only were found in deep water, mixed samples occurring between the two.

A box plot of the distribution of *ACF*, using the same categories as above, is shown in Figure 5d. The *ACF* was very low where catches of young fish only were observed. Table II shows some basic statistics for the three categories. The mean correction factors for catches of young fish only, young and adult fish mixed and adult fish only were 1.003, 1.17 and 1.35 respectively. Restricting this analysis just to stations where pelagic hake were observed acoustically, the respective means for the three groups above became 1.03, 1.59 and 1.74.

The results shown in Figure 4 suggest that the pelagic component is mainly associated with the presence of adult fish at the bottom. If the *ACF* for the category mixed adults and young were to be adjusted and applied only to the adult component of the catch, mean *ACF* would increase from 1.17 to 1.26 for all stations and from 1.59 to 1.80 for stations with pelagic records (*ACF* >1.0; Table II, last row).

Figure 6a shows the average *ACF* from stations where hake was present, sorted in one-hour bins (UTC). Around midday (10:00–13:00 UTC) the average *ACF* was 1.10, inferring a 10% increase of the demersal estimate. At daybreak, around 05:00 UTC in January/February, the average correction was some 30%, but it reduced to about 20% two hours later. From 15:00 UTC, the correction factor started to increase from its low midday level and exceeded 20% around 18:00. It must be stressed here that *ACF* values late at night and in the early morning (20:00–23:00 and 00:00–04:00 UTC) are drawn from very few samples that perhaps are not fully representative. These ACF values were also from a few catches made in very deep water, where hake density is generally low and diurnal vertical migration triggered by light is unlikely because light does not penetrate to such depths. In Figure 6b the same data are sorted in 3-hour bins. This procedure smooths the data in Figure 6a and shows the cyclic pattern from dawn to dusk more clearly.

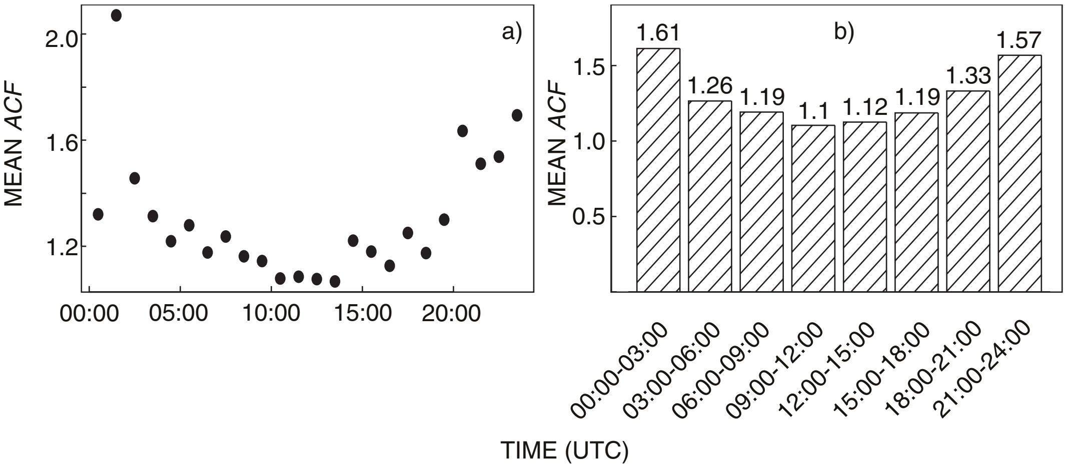

Fig. 6: Mean acoustic correction factor from all hauls in all surveys 1992–1999 sorted by (a) one-hour bins and (b) three-hour bins

DISCUSSION

Several types of errors can be introduced when combining estimates from acoustic and trawl surveys. The main problems are the lack of well-tested intercalibration factors to combine estimates of the two methods into a single index of abundance (Godø 1994) and difficulties in discriminating hake when, at times, dense scattering layers from other organisms are present in the pelagic zone. Despite these limitations, inclusion of a pelagic density index in the total density estimate for a species such as hake is a definite improvement (Sætersdal *et al*. 1999). Experience indicates that the fraction of the stock off the bottom varies greatly both in space and time. Therefore, the methods currently being used have tried to make the best use of the techniques and data available, on the understanding that further improvements can be expected following further experimentation, in addition to the development of better acoustic equipment, able to discriminate more accurately between targets.

In the present analysis it has been assumed that hake are not subject to size-selective catchability. Unpublished data (I. Huse and J. W. Waldemarsen, Institute of Marine Research, Bergen) seem to indicate that hake off Namibia, and *M. capensis* in particular, exhibit little or no herding. Their behaviour in response to a trawl also seems to be rather less active than that of other gadoids (see review by Godø 1994). This could be due to the low oxygen levels usually encountered at the bottom over the Namibian shelf (Hart and Currie 1960), perhaps inhibiting the ability of hake to swim actively in bursts. The high turbidity in Namibian waters could also be influential, light levels 400 m deep as low as some 10^{-6} lux having been recorded even during sunny days (Huse *et al.* 1998). Improvements in understanding the effects of

Table II: Statistics of Namibian hake samples sorted by category

Category	All daylight stations				All daylight stations with a pelagic correction			
	n	Mean bottom density	Mean *ACF*	Mean depth	*n*	Mean bottom density	Mean *ACF*	Mean depth
Adults only	486	15.4	1.35	386	229	17.8	1.74	405
Adults and young	1 686	14.6+8.0	1.17	265	486	15.5+5.6	1.59	307
Young only	60	90.8	1.003	129	5	16.5	1.03	161
Adults corrected where adults and young were caught	1 686	14.6	1.26	265	186	15.5	1.80	307

environmental conditions on the behaviour of hake in the Benguela ecosystem is the focus of a number of ongoing local, regional and international research projects (Hampton *et al.* 1999).

M. capensis migrate off the bottom into midwater, a behaviour mainly associated with spawning (Botha 1973, 1986, Olivar *et al.* 1988). In addition, vertical migration at night, probably in search of food, is common and well documented (Payne *et al.* 1987, Payne and Punt 1995). Pelagic behaviour during daylight is not well documented, but seasonal changes in catch rates are sometimes ascribed to changes in availability to the fisheries as a result of pelagic behaviour (Gordoa *et al.* 1995). The current study has shown that pelagic behaviour of Cape hake is highly variable in both space and time. It can be geographically restricted and its extent varies between years, but the results of the current study show that it may well be related to the presence of adult hake at the bottom. There was a positive relationship between the abundance of adult hake at the bottom and hake in the pelagic zone, but no relationship between young hake (>18 and <30 cm) at the bottom and pelagic behaviour. The same was observed for cod in the Svalbard area (Godø and Wespestad 1993). When that population consists of young cod, the distribution is closer to the bottom, but when abundant year-classes attain an age of 2–3+ years, the distribution extends more into the pelagic zone. However, a lack of pelagic test hauls in the current hake data may cast some doubt on such an observation.

The pelagic density of *M. paradoxus* seems to be higher than that of *M. capensis* (Fig. 1a). However, this finding has to be interpreted carefully in view of the fact that *M. paradoxus* inhabit deeper water than *M. capensis*. Several authors (Engås and Godø 1986, Godø 1994) have attributed the regularity of vertical migration to a depth factor. In addition, the *M. paradoxus* stock consists mainly of adults migrating in from the south along the slope, giving a narrower size range to the species' distribution. That could well be the main reason for the apparent greater pelagic density of *M. paradoxus*, rather than a species-dependent behavioural difference between the two species of Cape hake.

The current study shows that, in general, the pelagic hake biomass is higher off northern than off southern Namibia and, independently, higher in the 300–500 m depth zone. This does not necessarily point to any causal relationship between vertical migration and special properties in these habitats. The spatial relationship could well be indirect, because Namibia's northern latitudes and the 300–500 m depth zone are generally dominated by adult fish, the presence of which seems to relate more strongly to pelagic behaviour, as shown in this study. Cape hake tend to have a size-specific depth distribution, whereby mean length increases with depth (Payne 1989, Sætersdal *et al.* 1999, Burmeister 2000).

Figure 6b suggests a diurnal cycle in the vertical migration of hake. Soon after daybreak, hake migrate towards the bottom, a process completed at about 09:00 UTC. Then, from about 15:00 UTC, they seem to start migrating up the water column. Despite this seemingly robust conclusion, the absolute figures of the acoustic correction should be treated with caution, because the trawl and acoustic systems are not yet fully intercalibrated. The purpose, in the context of this study, was more to illustrate relative diurnal trends and to show that, by incorporating acoustic estimates in the assessment, vertical migration could, at least partially, be accounted for.

Diurnal variation in the catch rate of gadoids in the North Atlantic is well known (Engås and Soldal 1992, Michalsen *et al.* 1996, Casey and Myers 1998, Aglen *et al.* 1999, Korsbrekke and Nakken 1999). The effects of such diurnal variation on abundance estimation have been discussed by Engås and Soldal (1992) and Aglen *et al.* (1999). A diurnal study on Namibian Cape hake conducted on the basis of 12 trawls at a fixed location, six by day and six by night, has indicated that *M. capensis* has a more dynamic pelagic behaviour than *M. paradoxus* (Huse *et al.* 1998). Those findings are not confirmed by the results of this study (Fig. 1a), the *ACF* of *M. paradoxus* being generally higher than that of *M. capensis*. On the other hand, acoustic pilot studies on pelagic hake off the coast of South Africa in February 2000 and 2001, carried out during regular trawl surveys, show low abundance, or even general absence, of hake in/from the pelagic zone during daylight (TS, unpublished data). Most of the hake encountered during that study were *M. paradoxus*, suggesting that that species does not migrate vertically as actively as *M. capensis*, lending weight to the conclusion of Huse *et al.* (1998). However, the lack of pelagic trawls during normal trawl surveys makes it difficult to ascertain whether or not it is one species or a specific size range of both species that is more active in vertical migration.

CONCLUSIONS

This paper brings into renewed focus a long-standing problem in surveying Cape hake by bottom trawl, i.e. the changes in availability attributable to vertical migration. The results have shown that changes in availability could, at least partially, be accounted for by incorporating acoustic estimates of the pelagic component of the stock in an assessment of stock status. Diurnal variation in availability is also partly accounted for. Taking cognizance of such a correction may well allow extended sampling, i.e. more working hours per day, and therefore more trawls per day, because the surveying (and trawling) times would be able to approach more closely the hours of migration of Cape hake close to daybreak and nightfall without introducing serious bias into the results.

At present, bottom trawl surveys to monitor Namibian hake stocks are conducted by commercial trawlers, which do not have specialized acoustic instrumentation to quantify the pelagic biomass. The results of this study indicate that the component of Cape hake biomass off Namibia could be a significant 5–15% of the demersal biomass, a range of 9.5% ([1.15–1.05]/1.05×100%). Therefore, even if trawl survey estimates are only used as relative indices of abundance, there may be an error as large as 10% of the total biomass estimate. This is due to unaccounted changes in availability if the two survey indices, from swept-area and acoustics, are assumed to be well intercalibrated. If pelagic hake were mainly adults, as this study indicates, the error would be bigger, perhaps twice as large. In the 17 surveys carried out in the period 1990–1999, fish >35 cm long constituted on average 52% of the total biomass, but with a range of 30–64% (Strømme *et al.* 1999). More systematic and experimental sampling (both at the bottom and in the pelagic zone) throughout 24-h cycles, at locations with more pronounced variations in fish density, are needed. This would assist in obtaining better intercalibration and facilitate drawing conclusions on the species and size ranges most active in vertical migration. In turn, this information could be used to model the pelagic biomass more precisely on the basis of the composition in trawl catches only, so improving the precision of swept-area trawl survey estimates where direct observations on the pelagic component are not available.

ACKNOWLEDGEMENTS

We thank Dr A. I. L. Payne (CEFAS, U.K.) and an anonymous reviewer for the valuable suggestions that allowed us to focus and improve the manuscript.

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