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Variability in the spatial structure of three schooling pelagic species off Namibia.

By

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Abstract

Schools of horse mackerel (*Trachurus trachurus capensis*), pilchard (*Sardinops sagax*) and round herring (*Etrumeus whiteheadi*) were surveyed by conventional echo integration along systematic transects. The survey transects were steamed twice in opposite directions. The biomass of clupeoids was concentrated in a few, dense aggregations, while horse mackerel was distributed in looser concentrations over larger areas. The influence of the aggregation pattern of the different species on the precision of the acoustic estimates was analyzed with respect to spatial variability and diurnal effects. The replicability of acoustic survey estimates was considered on the basis of the two coverages of the area surveyed. The importance of survey design was emphasized when estimating the biomass of highly aggregated pelagic stocks.

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1. The first part of the report is devoted to a general survey of the situation in the country.

2. The second part of the report is devoted to a detailed analysis of the economic situation.

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6. The sixth part of the report is devoted to a detailed analysis of the international situation.

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Introduction

Four co-occurring pelagic fish species have historically supported large commercial purse seine fisheries off Namibia (Armstrong and Thomas 1989, Crawford *et al.* 1987). These include pilchard or sardine (*Sardinops sagax*), anchovy (*Engraulis capensis*), round herring (*Etrumeus whiteheadi*) and horse mackerel (*Trachurus trachurus capensis*). Major fluctuations in particularly the biomass of pilchard have recently been observed (Boyer, 1996).

Biomass estimates obtained through echo-integration form the basis for the management of these pelagic stocks. However, it is recognised that acoustic surveys are highly sensitive to changes in the aggregation patterns and acoustic detectability caused by behaviour of the fish. A large proportion of the biomass of a schooling fish population is usually contained in dense schools or aggregations and therefore the accuracy of surveys will depend greatly on encountering a sufficient number of these schools (MacLennan and MacKenzie 1988). This problem is further aggravated when the stock size is very small and the chance of detecting the few remaining schools is very low (Barange and Hampton 1997).

The aim of this paper is to examine the influence of high-density areas on the overall estimates of abundance and associated variance and to investigate structural differences between three co-occurring pelagic fish species.

Materials and Methods

Data collection

Data used for this study are acoustic records of fish density collected during April 1998 on board the *R. V. Dr. Fridtjof Nansen* using standard echo integration methodology (MacLennan and Simmonds 1992). Measurements of back-scattering strength, expressed as S_A ($m^2 \cdot nm^{-2}$) were obtained with a SIMRAD EK500 echo sounder operating at 38 kHz. Further processing of the data and apportionment of echoes to the various species was done with the SIMRAD BI500 software on a Sun workstation.

The survey grid (Figure 1) consisted of 6 transects parallel to the coast and spaced 10 nm apart. The positions of transect resulted from prior information on the distribution of pilchard obtained during a survey in March 1998. The offshore transect coincided roughly with the 200 m isobath and the expected offshore boundary of the pilchard distribution. The survey grid was repeated twice in opposite directions. The EK500 system interfaced to the Bergen Echo Integrator provided measurements of acoustic back-scattering strength, averaged over 1 nautical mile (nm) intervals. Echo partitioning between the various pelagic species was done on the basis of frequent mid-water trawl sampling. Relative density contour maps were plotted for pilchard, horse mackerel and round herring for each survey. This was done using linear kriging procedures of SURFER[®].

Data analysis

Variograms were computed to investigate the effect of aggregation pattern on variation in fish density between the three species and between surveys. This was done using the EVA software (Petitgas and Prampart 1993). In order to calculate distances between values, the latitudes and longitudes were converted to nautical miles. Isotropic (omnidirectional) experimental variograms were computed according to Matherton's (1971) variogram estimator:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i+h) - Z(x_i)]^2$$

where $Z(x_i)$ is the density for the i -th data point, and $N(h)$ is the number of pairs of points, which are a distance h apart.

To eliminate the effects of extreme values on the behavior of the variograms and investigate the nature of density effects, indicator variograms were computed. This was done by grouping the S_A values into density classes with cut-off values (z) of 1.0, 100 and 1000. Each data point was then defined as 1 if $Z(x_i) \geq z$ and 0 if $Z(x_i) < z$. Models describing the behaviour of the variograms were then computed (Cressie 1993) to compare structures between species and surveys.

To investigate diurnal effects on fish density, intervals were split into day or night categories. The division between day and night corresponded to 05:00 GMT and 17:00 GMT, based both on the time of sunrise/sunset and sun radiation values. In instances where mean hourly densities and depths were calculated, each hour lasted from half an hour before to half an hour after the specified hour. The vertical distribution of pelagic species and particularly the diel vertical migrations were investigated using the same 1 m integrated acoustic intervals. The depth of the maximum back-scattering strength for each interval was calculated as the mid-point of the 5 m vertical channel in which the echo return was the strongest.

Results

The distribution of pilchard, horse mackerel and round herring as measured during both surveys is presented in Figure 2. Some differences in the distribution and relative density of pilchard and round herring were noted between the 1st and 2nd surveys. The distribution of pilchard during both surveys was very patchy. Dense areas of both pilchard and round herring recorded during the first survey were not observed during the second survey. Horse mackerel were found over the entire survey area and the distributions for both surveys were very similar. The mean density of pilchard and round herring recorded during the second survey decreased by 77 and 90 % respectively (Table I). Horse mackerel densities were, however, very similar during both coverages of the

area. It is very clear from both the distributions and the CV's of the densities that a few large values contributed greatly to the mean and the variance of pilchard and round herring.

The shape of cumulative density distributions for the three species (Figure 3) supports this interpretation. In the case of horse mackerel the curve rises smoothly with smaller values contributing just as much to the mean as larger values. Both the pilchard and round herring distributions are extremely positively skewed. For pilchard, the highest value recorded adds approximately 45 % to the total biomass. As the shape of the distributions also reflects the dispersion characteristics of the populations assessed, inferences can be made about the different shoaling patterns of the three species. The horse mackerel curve is very smooth and more convex than the other two curves indicating a greater amount of dispersion compared to pilchard and round herring. Both pilchard and round herring are clupeoids forming dense shoal aggregations and this is evident from the shape of their density curves. Most of the biomass is located in a few dense concentrations covering very small areas. This highlights the need to sample these dense areas in a statistically defensible manner.

Isotropic variograms computed from the S_A values detected little or no structure in the distributions of all species during both surveys (Figure 4). All variograms were highly erratic with no linear increase in variance with distance. As all distributions were positively skewed, the influence of high values dominated the behavior of the variograms and no inferences of the underlying structure could be made. It must be noted that the isotropic variograms are dominated by the along-shore effects, given the different sampling effort in both directions. Anisotropic variograms were also computed, but due to the small number of pairs of points in the cross shelf direction, the results were not considered representative of the underlying structures.

To investigate the effects of density on the variograms, indicator variograms were also computed as previously described. Table II indicates the proportion of values falling into each category as well as their contribution to the overall mean and variance. It is clear

that a very small proportion of S_A values fall into the highest cut-off category ($z \geq 1000$) but that they constitute most of the mean and the variance. This is particularly prominent for pilchard and round herring where less than 10 % of the values contribute to more than 95 % of the variance and more than 70 % of the mean and is accentuated by the small integration unit used (1 n.mile). The largest difference, however, is seen in the $z \geq 100$ class, where although the proportion of values is high for horse mackerel, they add very little to the variance.

Indicator variograms (Figure 5) confirmed the influence of the high values on the behavior of variograms computed from the raw data. They indicated relatively large structures (> 15 nm) for all three species at the lowest cut-off level ($z \geq 1$) during the first survey. With higher cut-off levels, the variograms of both pilchard and round herring showed no spatial structure. This clearly indicates that high-density patches are smaller than the integration unit (1 nm) and/or that they occur randomly throughout the study area. Structure was, however, still present at the highest cut-off level for horse mackerel. This pattern was similar during the second survey with the autocorrelation range gradually decreasing for horse mackerel at greater cut-off levels (Table III), as expected by theory (Petitgas 1993). Little structure could, however, be inferred from the variograms of pilchard and round herring even at the lowest cut-off level during the second survey, suggesting a breakdown of the aggregation structures between both surveys.

Vertical migrations and diurnal variation in density may influence the patterns of spatial structure. If part of the population is not acoustically accessible during certain times of the day, then the variograms will not be reflecting the structure of the entire population. For this reason, vertical migration patterns during the surveys were investigated. The mean depth at which all three species were recorded for each survey is shown in Figure 6. Large scale vertical migration of horse mackerel was noted with the mean depth at night being between 20 and 30 meters from the surface, whilst during the day mean depths ranged between 30m and over 80 m. No clear signs of vertical migration were evident from the depth distributions of pilchard and round herring. Both species seemed to

maintain a depth of between 10 and 20 m throughout the day and night. No fish recordings above 10 m were made, indicating that the entire population was within survey limits.

Furthermore, mean density estimates indicated that the highest estimates of density were made during the day (Figure 7) when fish are most likely to be deeper in the water column. Horse mackerel mean densities were much higher during the day than at night, possibly also indicating more aggregation of fish during the day compared to the night. Pilchard density peaked at around sunrise whilst round herring density peaked at around sunset. Throughout the rest of the period densities were very low. These results will, however, be influenced by the large amount of zero values recorded for pilchard and round herring, making it difficult to draw any main conclusions about diurnal variation in the density of these two species. Alternatively, density variations may be an artifact caused by differential TS for both day and night targets, as has been observed in other species (Huse *et al.*, 1998)

From the above it is possible that diurnal density effects may have influenced the structural analysis of the horse mackerel population as day and night densities were very different. Pilchard and round herring variograms would, however, not have been effected at the same scale because except for one peak in the density of each, densities remained similar during the day and night.

Discussion

The analysis of spatial structure, using geostatistical techniques has elucidated to variability in the spatial structures of the three co-occurring species and is relevant for the planning of future biomass surveys in the region.

Although mean densities and variances have been compared between surveys, it is important to remember that the data is highly autocorrelated, and given the systematic survey design, the averages cannot be compared statistically using classic sampling theory as the variances are biased. Another vital consideration in terms of the design of

this study, is the direction of the transects. As fish aggregation patterns are often related to both bathymetric and hydrographic features, it is assumed that the maximum density gradient would normally be found in the cross-shelf direction. Sampling in the along-shore direction, is therefore not ideal as the transects are more likely either to over sample or under sample the high-density areas.

The similar structures observed for horse mackerel during both surveys indicates homogeneity in the distributions and a certain degree of stationarity. This enables similar estimates of biomass to be obtained during successive coverages of the same area. The lack of structure during the second survey for pilchard and round herring for even the lowest cut-off level is probably a consequence of the patchiness of these clupeoid distributions at a range smaller than the ranges studied. Similar structural analysis performed by Barange and Hampton (1997) and Coetzee (1997) on South African pilchard and Porteiro *et al* (1995) for Atlantic sardine indicated very small autocorrelation distances of less than 10 nm. These findings indicate that a transect spacing of less than 10 nm is required to adequately sample pilchard distributions. Furthermore, there were also indications of vessel avoidance particularly by pilchard during the second survey. This was confirmed by catches made by fisherman in the survey area at the time. As part of the population was not recorded, it is therefore possible that the underlying structure of the population would not have been accurately reflected.

The lack of structure in the clupeoid variograms suggests that when a school is encountered, it is not possible to predict where the next one may be found (Petitgas, 1993). The horse mackerel variograms, however, indicate an increase in variance with an increase in distance between points. They also show a gradual decrease in autocorrelation range with increase in cut-off densities, which reflects a gradual transition between low and high values.

Furthermore, it may be assumed from the density distribution curves that because horse mackerel were more dispersed than the clupeoids, the probability of encountering horse mackerel would be greater. This is also evidenced from the similar estimates of biomass of horse mackerel obtained from the two surveys. It may therefore be possible to obtain more

accurate estimates of horse mackerel with less sampling effort and simpler survey design than that which is necessary for an accurate pilchard or round herring estimate. This has also been observed in the southern Benguela, where pilchard surveys tend to have higher variances than anchovy estimates (Hampton 1992, Barange and Hampton 1997).

Because of the skewness of the clupeoid density distributions, it is obvious that these survey estimates of density and variance rely greatly on the 'hit or miss' of a few extremely high values. In the case of this survey, removal of only one pilchard value reduces the biomass estimate by approximately 45 % and the variance by 90 %. It is therefore clear that an adequate sampling effort and a carefully designed survey are essential to ensure that these scarce but high density schools are sampled in an unbiased and efficient manner. However, it must be remembered that the data analysed is highly correlated, and therefore that survey means cannot be tested for statistical significance. The results obtained in this paper would most likely result in higher CV's than surveys designed according to random sampling theory (Jolly and Hampton 1991) where densities are averaged along the transects surveyed.

The short autocorrelation ranges of the pilchard and round herring variograms at even the lowest densities indicate that, should a stratified random sampling be used in future surveys, a small average inter-transect distance be obtained (Barange and Hampton 1997). However, because this is not always possible due to time and financial constraints, some form of adaptive sampling strategies should be implemented whereby inter-transect spacing is reduced substantially as soon as high-density areas are encountered (Barange and Hampton 1997). This would ensure improved sampling of the high densities areas and a more accurate estimate of the survey mean. Importantly though, care must be taken to ensure an unbiased estimate of both the mean and the variance.

The results obtained clearly indicate that pelagic surveys in the region should be designed according to the specific structural patterns of the target species, while a single design may not be the most efficient for all pelagic species.

Acknowledgements

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Table I. Comparative density estimates for both surveys.

Species	Survey 1				Survey 2			
	Mean	CV	n	n > 0	Mean	CV	n	n > 0
Pilchard	10.59	0.58	764	121	2.53	0.35	781	56
Round herring	6.59	0.39	764	163	0.52	0.20	781	65
Horse mackerel	30.46	0.11	764	482	33.63	0.11	781	522

Table II. Contribution to overall mean density and variance of each of the cut-off indicator variables. Also shown are the proportion of values which fall into each class and the probabilities $P(Z(x))$ of values exceeding the cut-off levels (z).

Survey 1				
Species	Cut-off (z)	$P(Z(x)) \geq (z)$	% Mean	% Variance
Pilchard S_A	1	0.156	100	99.6
	100	0.049	98.3	99.6
	1000	0.013	91.3	99.5
Round herring S_A	1	0.213	100	99.3
	100	0.043	95.7	99.2
	1000	0.013	88.4	99.1
Horse mackerel S_A	1	0.630	100	95.9
	100	0.380	98.2	93.6
	1000	0.115	71.4	92.6
Survey 2				
Pilchard S_A	1	0.072	100	99.0
	100	0.034	96.5	99.0
	1000	0.064	69.5	95.9
Round herring S_A	1	0.083	100	97.1
	100	0.023	74.4	92.6
	1000	-	-	-
Horse mackerel S_A	1	0.668	100	96.7
	100	0.389	97.4	94.5
	1000	0.119	75.5	93.6

Table III. Model parameters fitted to indicator variograms.

PILCHARD						
Indicator	Survey 1			Survey 2		
	Range	Sill	Nugget	Range	Sill	Nugget
$S_A > 1$	16	0.105	0.036	-	-	-
$S_A > 100$	-	-	-	-	-	-
$S_A > 1000$	-	-	-	-	-	-
ROUND HERRING						
$S_A > 1$	25	0.175	0.0051	-	-	-
$S_A > 100$	-	-	-	-	-	-
$S_A > 1000$	-	-	-	-	-	-
HORSE MACKEREL						
$S_A > 1$	35	0.23	0.04	39	0.19	0.06
$S_A > 100$	16	0.165	0.09	25	0.125	0.12
$S_A > 1000$	9	0.055	0.055	20	0.102	0.021
<p>Exponential models best fitted all variograms and are described as follows: (Cressie, 1991):</p> <p>$\gamma(h;\theta) = 0$ or C_0 when $h = 0$,</p> <p>$\gamma(h;\theta) = C_0 + C_e \{1 - 10^{(-h/\alpha_e)}\}$ when $h \neq 0$</p> <p>where C_e is the sill due to the exponential structure and α_e is the range parameter of the exponential structure.</p>						

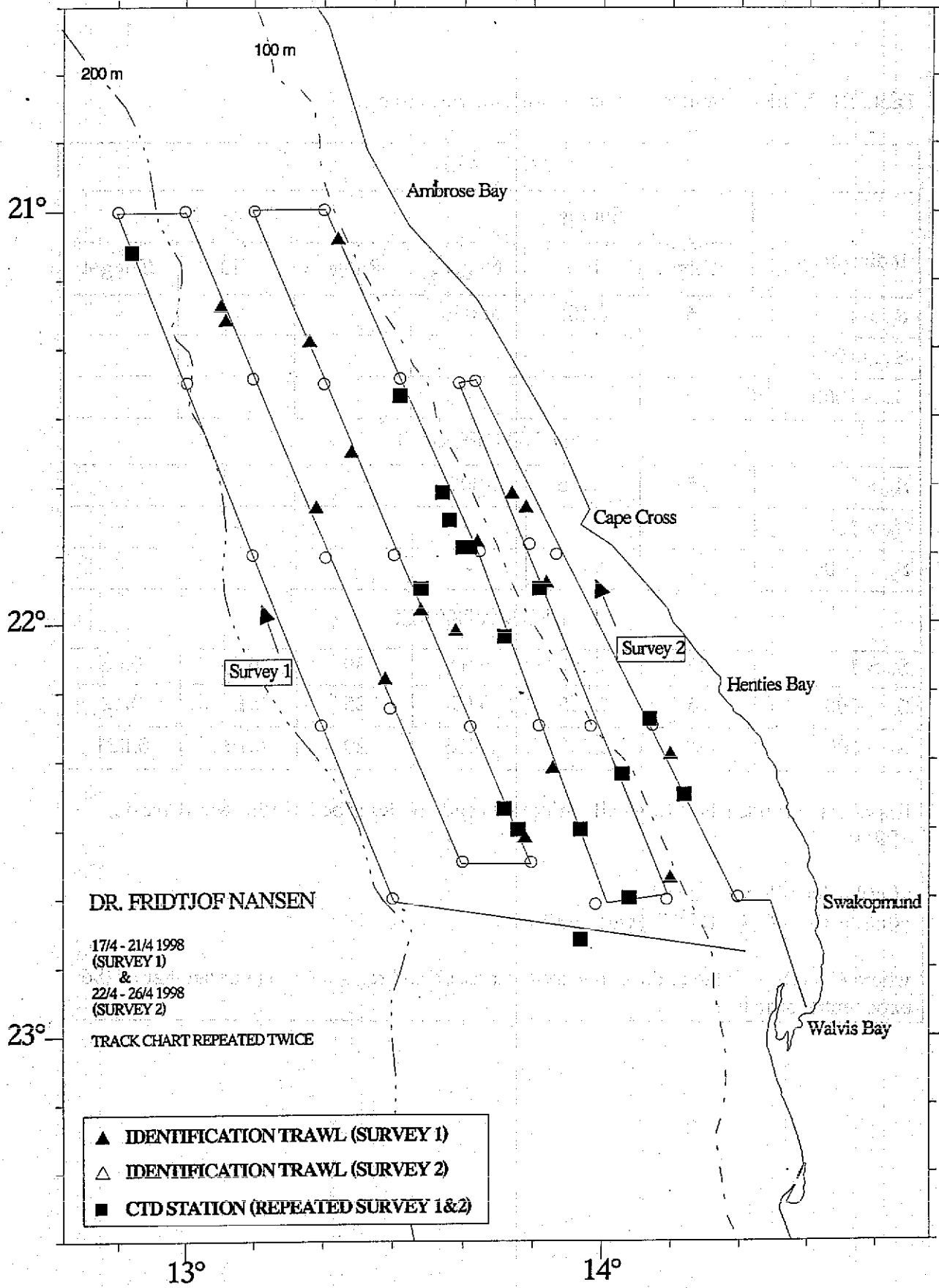


Figure 1. Course track showing trawling and hydrographic stations between Walvis Bay and Ambrose Bay.

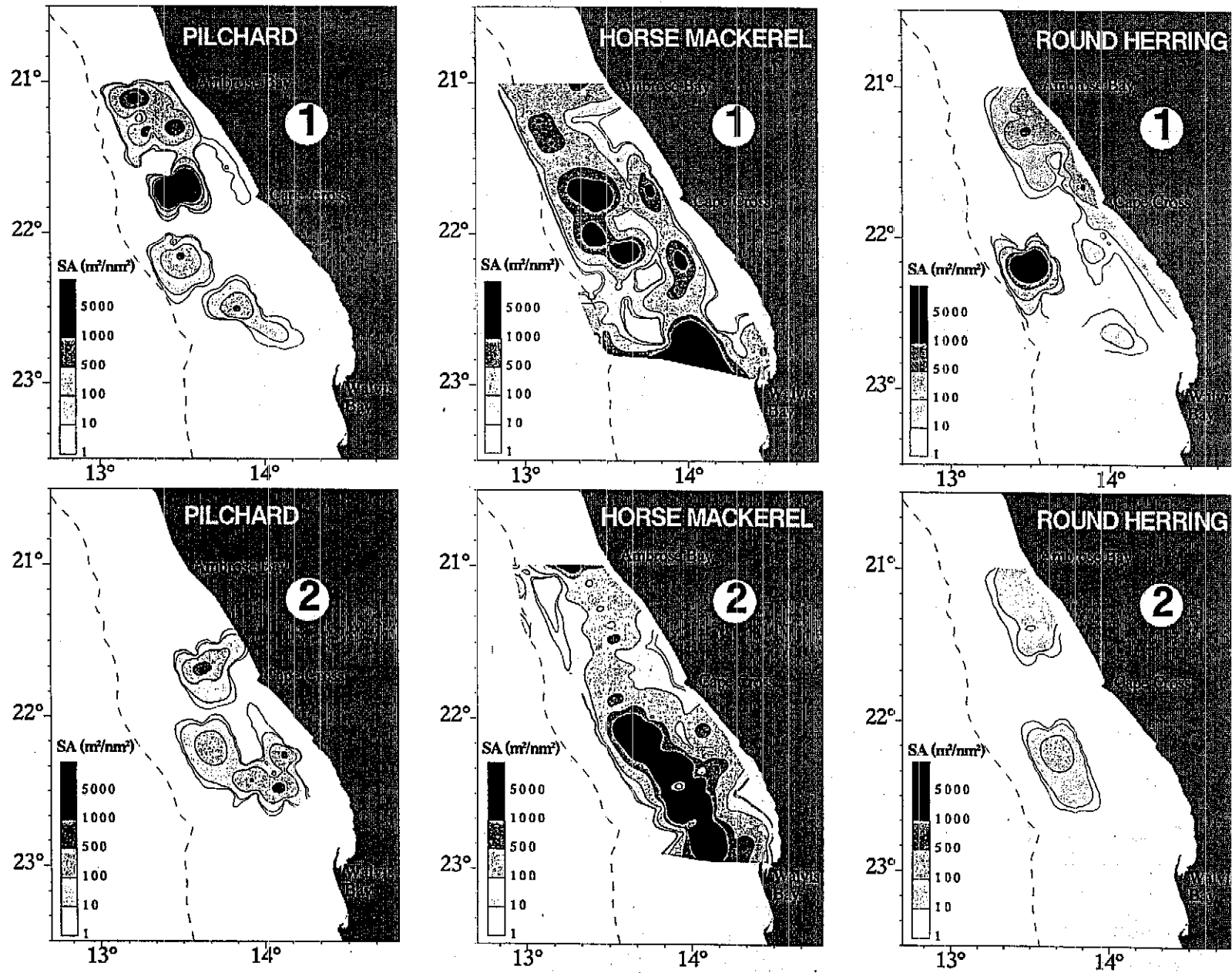


Figure 2. Distribution and relative abundance of pilchard, horse mackerel and round herring recorded during survey 1 and 2.

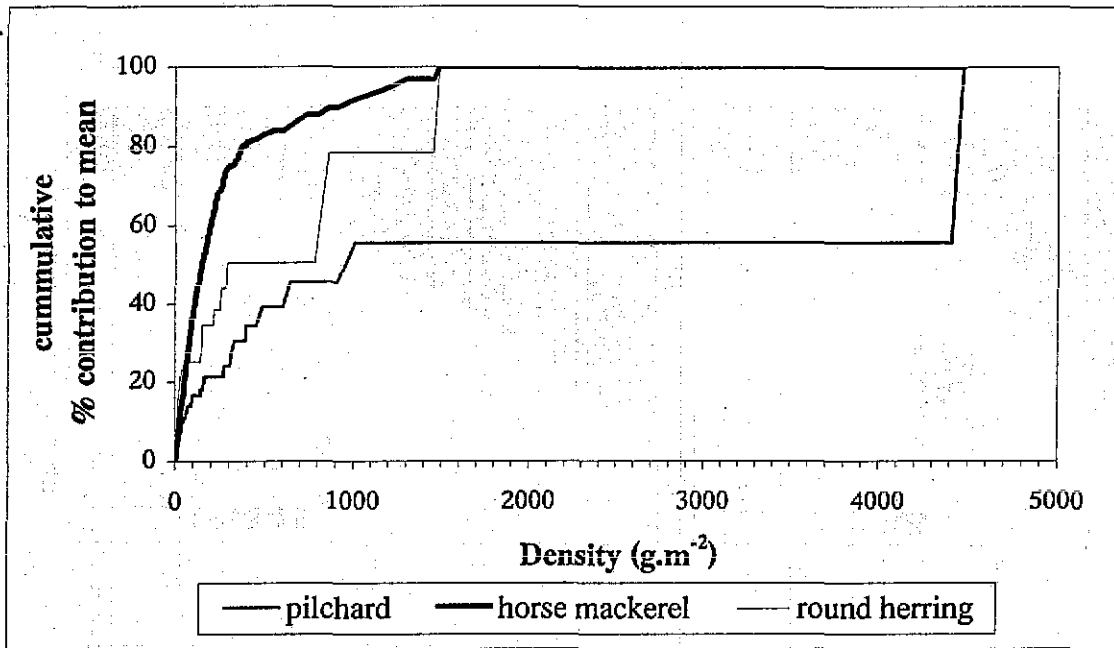


Figure 3. Cumulative density distributions of both surveys combined for all three species.

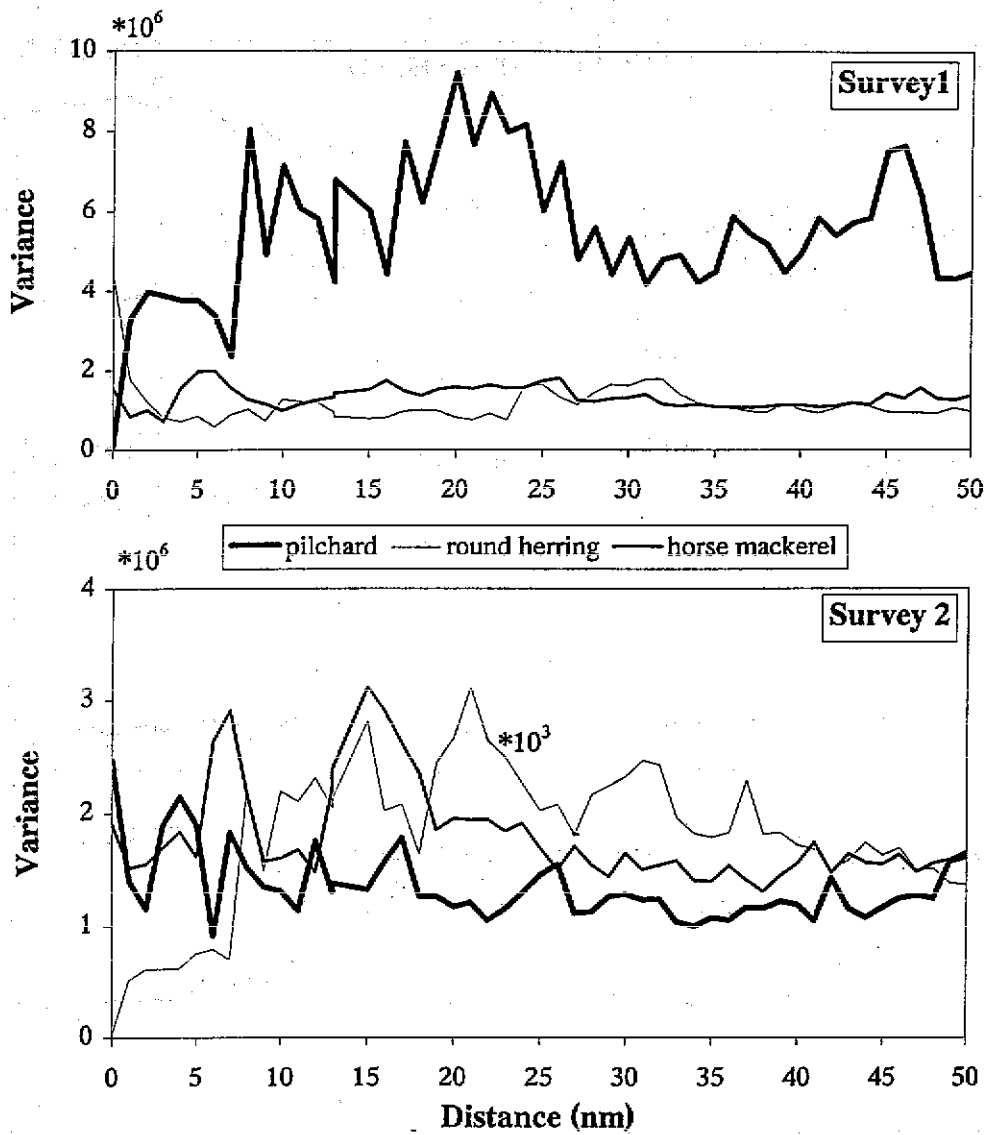


Figure 4. Isotropic variograms for each species from data collected during both surveys.

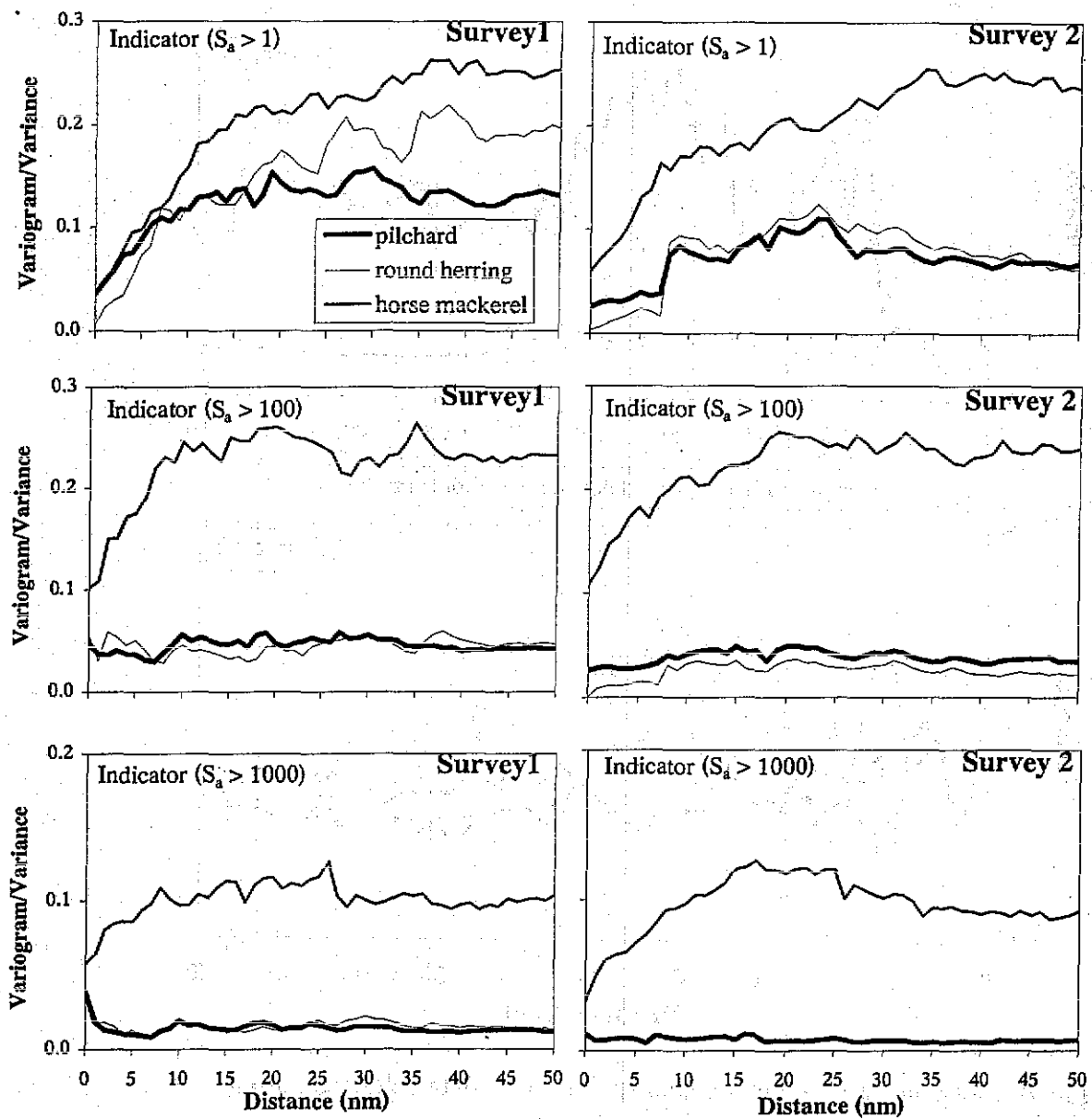


Figure 5. Comparison of isotropic indicator variograms for cut-off (Z) > 1, 100 and 1000 for each species and both surveys.

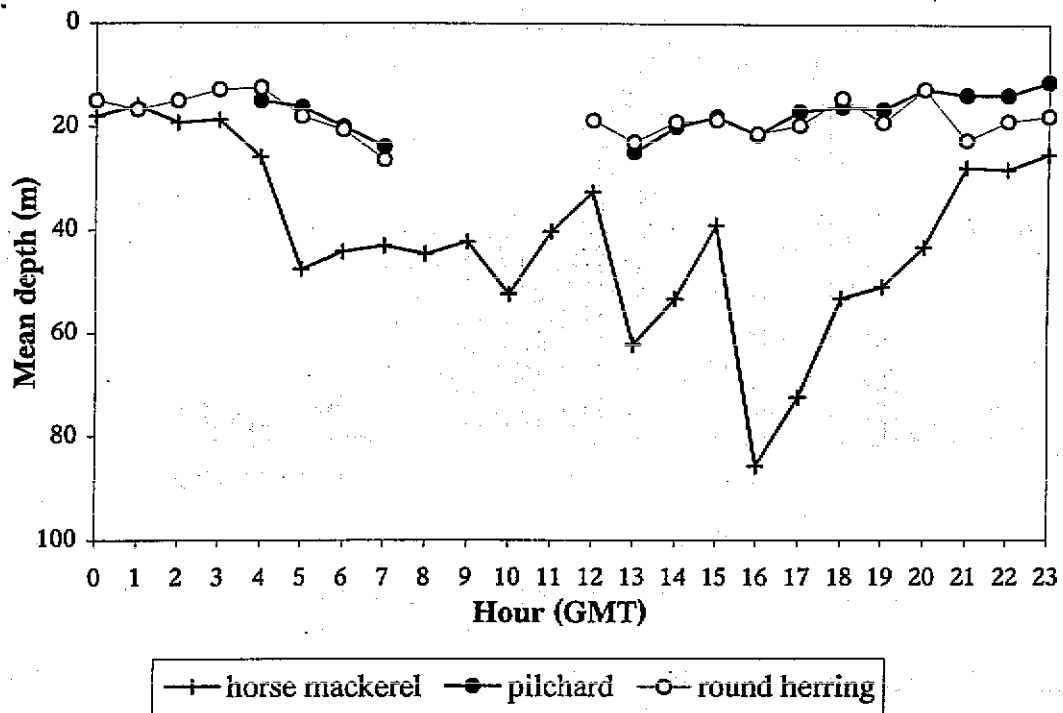


Figure 6. Mean depth at which each species was recorded throughout the surveys at each hour.

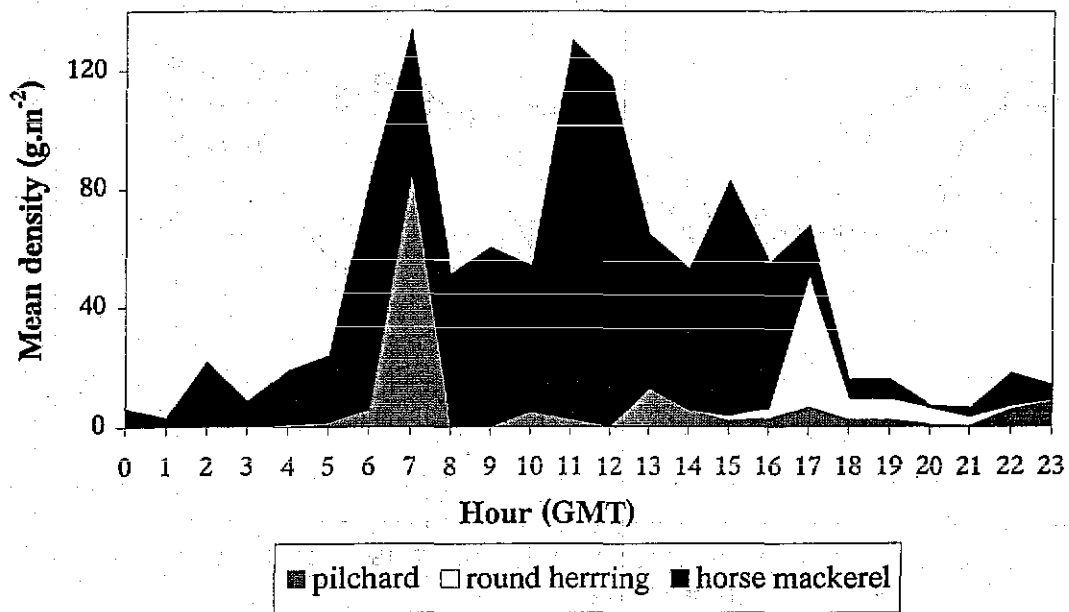


Figure 7. Mean density estimates for each hour class.