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Diurnal variation in acoustic intensity and target strength measurements of oceanic redfish (*Sebastes mentella*) in the Irminger Sea

by

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Abstract

Since 1991, several acoustic surveys on oceanic redfish in the Irminger Sea and adjacent waters have been conducted by Icelandic scientists. During these surveys a diurnal cycle was observed in the acoustic density.

In June/July 1995, a survey was conducted in order to study the diurnal variations in the echo intensity of the oceanic redfish in the Irminger Sea. Two main areas were selected, were acoustic and biological data were collected for several days. The shape of the target strength distribution and the resulting mean scattering cross section of the oceanic redfish changed quite systematically through the day, which is believed to be due to behaviour related factors. The results verify that the diurnal variations in the echo intensity and target strength of the oceanic redfish are strongly correlated. Areal differences were observed in the degree of mixing of oceanic redfish with a scattering layer of myctophids and other organisms, which may be related to the progressively increasing hours and degree of darkness as one moves southward at these latitudes during the summer.

A dependency of target strength on depth was observed in the uppermost 200 metres.

Introduction

Since 1991, several acoustic surveys on oceanic redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters have been conducted by Icelandic scientists (Magnússon *et al.* 1992a, 1992b and 1994). In the course of these surveys it has been established that oceanic redfish is the main scatterer in the water column from 50 down to 400 m, and it is particularly common in 100-300 m depth during the feeding time period in June/July.

The conditions acoustic surveying of the oceanic redfish is in many ways ideal. The fish is rather uniformly distributed over the area, the expected variance in the measured echo intensities is relatively low and single-fish echoes are dominant, allowing more or less continuous monitoring of the target strength of the fish. A typical 20logR-echogram is shown in Fig. 1. Results on the target strength of oceanic redfish from surveys in 1991 and 1992 have been presented by Reynisson (1992). Although the conditions are in many ways favourable for acoustic surveying, some problems have been identified. One is directly related to the very scattered condition of the fish. The received echo intensity is rather weak and in order to include all echoes of interest, the setting of the integration threshold is critical (*e.g.* Aglen 1983, Kalikhman and Tesler 1983, Foote 1991). For this particular case see Magnússon *et al.* (1994) and Reynisson (1996). Another potential bias the mixing with other species. During the night a part of the scattering layer of myctophids and other organisms ascends and mixes with the redfish to such an extent that the lower depth limit of integration must be reduced, leading to an underestimation of the redfish. This and possibly behavioural related factors result often in considerably lower integration values during the night as compared to daytime values. The acoustic data from the joint Icelandic/Norwegian survey in June/July 1994 indicated a systematic diurnal variation in the acoustic abundance, most notable for the difference between day and night, but also observed through the daylight hours where little or no mixing with the myctophids occurred (Magnússon *et al.* 1994). A survey was initiated by the Marine Research Institute (MRI), Iceland, in order to study in particular the diurnal variation in the echo abundance of oceanic redfish. The preliminary analysis of the acoustic data indicated that the diurnal variations in the echo intensity and target strength of the oceanic redfish are strongly correlated (Reynisson *et al.* 1995). In this paper a more detailed analysis of the split-beam data is presented and comparison is made between the observed diurnal variation in target strength and acoustic intensity.

Material and methods

The survey was carried out on the Icelandic research vessel "Bjarni Sæmundsson" during the time period June 26 to July 11, 1995. The acoustic instruments were as follows; an EK500 split-beam echo sounder operating at 38 kHz (Bodholt *et al.* 1989) and a BI500 postprocessing system (Foote *et al.* 1991). Just prior to and after the survey the acoustic equipment was calibrated by the standard sphere method (Foote *et al.* 1987). The beam compensation of the split-beam system was checked on 3 cross sections of the beam, indicating that a bias less than 0.1 dB of the mean target strength was expected within the -6 dB limit of the two-way beam pattern. The settings of the equipment during the survey are given in Table 1.

Acoustic material for the study of the diurnal variations of oceanic redfish were collected in two main areas, positioned at about 61°07'N-36°50'W and 58°59'N-41°00'W, referred to as Area I and II respectively. The main criteria for the selection of these areas were that the acoustic abundance should be around or above the average as observed in former surveys and that the duration and degree of darkness at night should differ from one area to the other. In each area acoustic data were collected for three consecutive days and nights, on 29 June to 2 July in Area I and 3-5 July in Area II. In Area I, a selected track of 10 nm was cruised back and forth at a speed of 10 knots on the first 24 hours. For the next 48 hours trawling was undertaken in the nearest vicinity, although the cruise tracks were not as regular. In Area II, similar cruise tracks were chosen. In this case, the first 48 hours were used for acoustic data collection undisturbed by trawling. Echo integration- and split-beam data were collected from the uppermost 500 m of the water column for postprocessing. The target strength threshold used in the collection of the split-beam data was set at -60 dB.

A specially designed pelagic trawl (Gloria type-Hampiðjan, max circumference 1152 m and stretched mesh size of 32 m) with a vertical opening of about 65 m was used for biological sampling. After two hauls, the pelagic trawl winch broke down and the Gloria trawl had to be replaced by a very inefficient small pelagic trawl. Therefore, the planned standard trawling by night and day which was intended to follow up the variations in acoustic values had to be cancelled.

In the postprocessing of the acoustic back scattering volume, an integration threshold was set at -80 dB//m^2/m^3. The lower depth limit of integration was always set in such a way as to exclude the disturbing echoes from the scattering layer. A mean area back scattering coefficient (SA, m^2/nm^2) was obtained for every 1 nm sailed.

In the analysis of the split-beam data, a tracking of individual fish was undertaken. An example of how the EK500 split-beam data may be used for target tracking has been presented by Brede *et al.* (1990). This was done in order to reduce the amount of data and more important to reduce the risk of including echoes from multiple targets in the subsequent analysis (Ehrenberg and Torkelsson, 1996). A software developed by Ona and Hansen (1991) was used for this purpose. In this particular software a target is tracked by defining a set of parameters : 1) the minimum number of single-echoes in a given track, 2) the maximum allowable depth difference between sequential echoes in a track and 3) the maximum number of missing pings in one track. These parameters were set in the following way: 1) 3 or 8 pings depending on sailing speed (10 or 3 knots), 2) 90 cm and 3) 0 ping. Echoes within a depth interval 50-300 m were included. The total number of echoes in the split-beam data obtained during the survey was of the order of 1.5 millions. The number of echoes remaining after tracking was about 150 thousand and 100 thousand in Area I and II respectively.

In order to compare the diurnal variation of the acoustic cross section of the fish (σ)* and the integrated values (SA-values), the mean of these variables was calculated for every 1 hour of the day. This was carried out separately for the two areas. In the case of the split-beam data, a lower limit on depth was set at 200 m in order to keep the possibility of double echoes at an acceptable level. The limit of the split-beam acceptance angle was set at 2.6 deg from the acoustic axis. This corresponds approximately to the -3 dB level of the two-way beam pattern. A lower limit on target strength was set at -52 dB in order to remove echoes from smaller organism.

A study of the possible depth dependence of the target strength was carried out by calculating σ within 25 m depth intervals.

Results

It was observed that during the night, the degree of mixing of the scattering layer with the oceanic redfish differed between Area I and II. In Area I the scattering layer rose no higher than to about 200 m depth. In Area II a part of the scattering layer seemed to mix thoroughly with the redfish in the whole water column.

The shape of the TS-distribution of the oceanic redfish changed quite systematically through the day. At mid-day the distribution was clearly unimodal but became progressively more bimodal as night-time approached. As an example the TS-distribution obtained during every 3 hours interval in Area I is shown in Fig. 2.

The mean values of Sa and σ within each 1 hour intervals of the day and other relevant information are given in Table 2. The average σ within a whole day (00-24 GMT) and during daytime (06-22 GMT), obtained from the hourly mean of σ, results in a target strength of -40.0

* The target strength (TS) is defined as $TS=10\log(\sigma/4\pi)$, where σ is the acoustic cross section of the target (Urick, 1983).

dB and -39.7 dB respectively. The diurnal variations in SA and σ are shown in Fig. 3 and Fig. 4. The correlation between SA and σ is quite high. Least-mean-squares linear regression of these variables results in a correlation coefficient $r=0.94$

A clear indication of the depth dependence of the target strength was observed in the uppermost 200 metres. The mean acoustic cross section and standard error calculated within every 25 m depth interval from 100-300 m is given in Table 3. Only data obtained during daylight hours (06-22 GMT) are included. Fig. 5 shows how σ from the two areas is related to depth.

In table 4., an overview on length and weight of the oceanic redfish is given. Assigning equal weight to Area I and II, the mean length is 36.9 cm and the mean weigth is 640 g.

Discussion

As shown in Fig. 2, the shape of the TS-distribution of the redfish changed progressively through the day. The most likely explanation for this observation is that the behavioural pattern of the redfish is changing. No visible up- or downwards migration of the redfish could be observed from the echograms. This does not exclude that the fish may be altering its tilt angle progressively through the day, either because of the changing light or because of the search for food. The latter may be connected to the diurnal up-down migration of the smaller organism. It is known that the tilt angle distribution of fish can greatly affect the target strength distribution observed (Nakken and Olsen, 1977). At a frequency of 38 kHz, commercial fish are highly directive scatterers of sound, and for a wide tilt angle distribution a bimodal distribution of target strength is quite likely. The extra peak at around -56 dB observed during the night is believed to be due to smaller organism, *e.g.* myctophids. This part of the TS-distribution was more or less removed by the tracking process, most probably because of the requirement of at least three echoes at the same depth in sequential transmissions (pings). Otherwise the resulting target strength distributions, obtained before and after tracking, were quite similar. A further reduction of accepted echoes, by restricting the position angles within individual tracks, was not undertaken. It was noted that in general the tracks were moving across the beam as expected, but due to the inevitable rolling and heaving of the ship and the time lag between pings, these did show a certain degree of randomness.

The diurnal variations in SA and σ are strongly correlated. However, at certain times of the day, the variation in SA is not fully accounted for by the variation in σ, especially during night time, *i.e.* from around 10-11 at night until about 5-6 (GMT) in the morning. The most likely explanation is the ascent of the scattering layer during the night, which influenced the setting of the lower depth limit of integration. This is especially evident in Area II. In Area I, the mixing with the scattering layer was not as pronounced. At that latitude the scattering layer rose no higher than to 200 m depth. This difference in behaviour is most likely explained by the progressively increasing hours and degree of darkness as one moves southward at these latitudes during the summer. Possible changes in species composition of the scattering layer may also account for this difference.

In the uppermost 100-200 m the target strength decreases with depth. Below 250 m, a sudden increase is noted (Fig. 5). At depths below 275 m, the measured target strength increased even further (not shown in Fig. 5). By letting the acceptance angle range from 1.1-4.4 degrees, equivalent to -0.5 to -9 dB of the two-way beam pattern, a change in σ was observed (Fig. 6). Below the 2.6 deg limit used in the calculations presented, σ was fairly stable. Above the 3.5 deg limit, σ increased with depth below 175 m, indicating an increase in accepted multiple echoes.

Soule *et al.* (1996) have shown that the split-beam system is likely to accept multiple echoes if the number of fish in a single pulse volume approach or exceed one. A further check on the quality of the split-beam data was carried out by estimating the number of fish within a single pulse volume. Using the highest observed SA-values (values in Fig. 1 are typical) within each 50 m depth interval over 1 nm sailed, a target strength of -40 dB and a detection angle of 10 deg, the number of fish within a single pulse volume was estimated. At 200-250 m depth this number was less than 0.1 and even lower above 200 m. Assuming a random distribution of the fish, this implies less than 10 % probability for multiple targets. Below 250 m this number did increase slightly, up to 0.15 fish maximum, but the increase in the acoustic cross section was much more severe (Table 3). This could indicate small-scale local patchiness of the fish and/or that noise is affecting the results at this depth.

The average σ obtained during hours 00-24 and 06-22 GMT, results in a target strength of -40.0 and -39.7 dB respectively. This is comparable to the results presented by Reynisson (1992), where a target strength of -40.0 dB was obtained for oceanic redfish with mean lenght of 36.9 cm. The depth dependency of the target strength presented is also quite comparable to the results obtained in the depth interval 100-200 m in 1991-1992.

Comparing Area I and II, the target strength is on the average 0.5 dB higher in Area I. The observed difference in mean fish length (≈1 %) hardly accounts for this. A more likely explanation is the natural variability in target strength due to *e.g.* behaviour, stomach fullness and other biological factors.

It is important to quantify how the diurnal variations may affect the acoustic estimates of the biomass of oceanic redfish and how a survey may be planned in order to minimize the effect of these variations. Using data from the last main column in Table 2 (Mean of Area I & II), the hourly mean of the observed fish density (ρ=SA/σ) was estimated, using a time variable σ as opposed to σ averaged over 00-24 and 06-22 hours GMT (Fig. 7). Looking separately at the results from the two time intervals, the average densities differ by less than 1 %, while the variance decreases by about 60 % when using time dependent σ instead of a constant one. Even greater change in variance is observed when comparing average values from the whole day as opposed to values obtained during daylight hours. Using a σ averaged over 24 hours of the day is more or less what has effectively been done in the acoustic surveys on oceanic redfish conducted by Iceland in 1991-1994. This does not take into account the varying degree of mixing and the resulting loss of redfish echoes in the processing of the acoustic data. Another possibility would be to use a higher integration threshold, thus often excluding the weaker echoes from myctophids and other small organisms. This could lead to an underestimation, progressively increasing with depth, unless measures were taken to correct the integrated values (Reynisson, 1996). A more attractive strategy might be to plan the survey in a manner that minimizes the area covered during night-time. The time lost could to a certain degree be used for obtaining biological samples, thus increasing the coverage during day-time. In the planning of the joint Icelandic/German/Russian survey on oceanic redfish conducted in June/July 1996 (Magnússon *et al.* 1996) this was taken into consideration. This may not affect the estimated number of fish significantly (about 10 %), but can certainly decrease the variance.

References

Aglen, A. 1983. Echo integrator threshold and fish density distribution. FAO Fisheries Report No. 300, pp 35-44.

Bodholt, H., Nes, H. and Solli, H. 1989. A new echo sounder system. Proceedings of IOA 11(3), pp 123-130.

Brede, R., Kristensen, H., Solli, H. and Ona, E. 1990. Traget tracking with a split-beam echo sounder. Rapp.P.-v. Réun. Cons. int. Explor. Mer. 189: 254-263. 1990

Ehrenberg, J. E. and Torkelson, T. C. 1990. Application of dual-beam and split-beam target tracking in fisheries acoustics. ICES J. Mar. Sci., 53: 329-334. 1996

Foote, K. G., H. P. Knudsen, G. Vestnes, D. N. MacLennan and E. J. Simmonds 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. Cooperative Research Report, Conseil International pour l'Exploration de la Mer. 144.

Foote, K. G., Knudsen, H. P., Korneliussen, R. J., Nordbö, P. E. and Röang, K. 1991. Postprocessing system for echo sounder data. The Journal of the Acoustical Society of America, Vol. 90, pp 37-47.

Foote, K. G. 1991. Acoustic sampling volume. The Journal of the Acoustical Society of America, Vol. 90, pp 959-964.

Kalikhman, I. L. and Tesler W. D. 1983. The effective parameters of the real acoustic beam. FAO Fisheries Report No. 300, pp 9-17.

Magnússon, J., Magnússon, J. V. and Reynisson, P. 1992a. Report on the Icelandic survey on oceanic redfish in the Irminger Sea, in June 1991. ICES C. M. 1992/G:64

Magnússon, J., Magnússon, J. V., Reynisson, P., Hallgrímsson, I., Dorchenkov, A., Pedchenko, A. and Bakay, Y. 1992b. Report on the Icelandic and Russian acoustic surveys on oceanic redfish in the Irminger Sea and adjacent waters, in May/July 1992. ICES C. M. 1992/G:51

Magnússon, J., Nedreaas; K. H., Magnússon, J. V., Reynisson, P. and Sigurðsson, Þ. 1994. Report on the joint Icelandic/Norwegian survey on oceanic redfish in the Irminger Sea and adjacent waters, in June/July 1994. ICES C. M. 1994/G:44

Magnússon, J., Magnússon, J. V., Sigurðsson, Þ., Reynisson, P., Hammer, C., Bethke, E., Pedchenko, A., Gavrilov, E., Melnikov, S., Antsilerov, M. and Kiseleva, V. 1996. Report on the joint Icelandic/German/Russian survey on oceanic redfish in the Irminger Sea and adjacent waters in June/July 1996. ICES C. M. 1996/G:8

Nakken, O. and Olsen, K. 1977. Target strength measurements of fish. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 170: 52-69.

Ona, E. and Hansen, D. 1991. Software for target tracking with split-beam echo sounders. USER MANUAL. Institute of Marine Research, Bergen, Norway, Oct. 1991.

Reynisson, P. 1992. Target strength measurements of oceanic redfish in the Irminger Sea. ICES C. M. 1992/B:8

Reynisson, P. 1996. Evaluation of threshold-induced bias in the integration of single-fish echoes. ICES J. Mar. Sci., 53: 354-350. 1996

Soule, M. A., Barange, M., and Hampton, I. 1995. Evidence of bias in estimates of target strength obtained with a split-beam echo sounder. ICES J. Mar. Sci., 52: 139-144.

Urick, R. J. 1983. Principles of Underwater Sound for Engineers. 3rd edn. McGraw-Hill, New York, 384 pp.

Table 1.
Settings of acoustic instruments on r/v Bjarni Sæmundsson.

Echo sounder/integrator	Simrad EK500 (rev. 3.01)/BI500
Frequency	38 kHz
Transmitter power	2000 W
Absorbtion coefficient	10 dB/km
Pulselength	1.0 ms
Bandwidth	3.8 kHz
Transmission rate	0.7 pings/s
Transducer type	ES38-B, hull-mounted
2-way beam angle	-20.6 dB
Integration threshold in BI500	-80 dB
TS-threshold in split-beam operation	-60 dB
Pulselenght criteria in split-beam operation	0.7 and 1.4 of nom. pulselenght
Maximum gain compensation	-6.0 dB (one-way beam pattern)
Maximum Phase deviation	2.0 deg

Table 3.
Observations of mean scattering cross section of oceanic redfish by areas and depth during daylight hours (06-22 GMT). Standard error (s.e.) of σ is given. The mean values in the two last columns are obtained by giving the measurement in Area I and II equal weight. Note that σ±s.e. should be divided by 1000 to get the correct value.

	Area I				Area II				Mean of Area I & II	
Depth range	No.	σ	s.e.	TS	No.	σ	s.e.	TS	σ	TS
100-125	873.	1.55	.04	-39.1	213.	1.57	.08	-39.0	1.56	-39.1
125-150	4224.	1.47	.02	-39.3	1514.	1.38	.03	-39.6	1.43	-39.5
150-175	7193.	1.37	.01	-39.6	3937.	1.34	.02	-39.7	1.35	-39.7
175-200	9373.	1.36	.01	-39.7	5718.	1.29	.01	-39.9	1.32	-39.8
200-225	9669.	1.33	.01	-39.8	7813.	1.30	.01	-39.9	1.31	-39.8
225-250	7881.	1.32	.01	-39.8	8019.	1.27	.01	-39.9	1.30	-39.9
250-275	4260.	1.38	.02	-39.6	4190.	1.40	.02	-39.5	1.39	-39.6
275-300	764.	1.84	.05	-38.3	577.	2.79	.06	-36.5	2.32	-37.3

Table 4.
Observations on lenght (cm) and weight (g) of oceanic redfish by areas and sex.

	Males		Females		Total			
	No	Mean length	No.	Mean length	No	Length range	Mean lenght	Mean weight
Area I	117	36.4	95	37.8	212	26-43	37.1	652
Area II	42	36.6	14	37.3	56	30-45	36.7	629

Table 2.
Observations of mean area back scattering coefficient (SA) and acoustic cross section (σ) of oceanic redfish by areas and time of day in the depth interval 100-200 m. The standard error (s.e.) of Sa and σ is given. Note that σ±s.e. should be divided by 1000 to get the correct value. The mean values in the three last columns and in the two last rows are obtained by giving separate measurement equal weight.

	Area I						Area II						Mean of Area I & II		
GMT	No.	SA	s.e.	No.	σ	s.e.	No	SA	s.e.	No.	σ	s.e.	SA	σ	TS
00-01	15	48.4	2.2	335	1.31	.03	20	28.2	1.9	948	.98	.02	38.3	1.14	-40.4
01-02	17	35.9	1.3	1254	1.07	.02	20	15.7	1.4	362	.88	.04	25.8	.97	-41.1
02-03	19	37.5	2.1	1630	1.13	.02	20	18.4	1.2	186	.71	.03	28.0	.92	-41.3
03-04	19	40.5	1.8	1614	1.18	.02	20	19.3	1.3	210	.59	.02	29.9	.89	-41.5
04-05	19	39.5	2.0	1453	1.09	.02	19	15.7	1.1	372	1.11	.04	27.6	1.10	-40.6
05-06	21	43.9	2.0	1351	1.12	.02	20	32.5	2.0	937	1.02	.02	38.2	1.07	-40.7
06-07	22	53.7	2.2	1537	1.16	.02	20	43.8	1.6	838	1.03	.02	48.8	1.10	-40.6
07-08	21	51.9	2.2	1793	1.25	.02	20	41.8	1.7	701	1.18	.03	46.9	1.21	-40.1
08-09	19	63.5	2.6	1114	1.35	.02	20	49.7	1.5	425	1.23	.03	56.6	1.29	-39.9
09-10	16	61.3	3.2	1315	1.31	.02	20	49.7	2.8	628	1.31	.03	55.5	1.31	-39.8
10-11	16	62.8	3.6	1447	1.40	.02	20	57.1	2.4	1059	1.25	.02	60.0	1.33	-39.8
11-12	15	54.8	2.2	994	1.33	.02	20	48.6	3.0	841	1.34	.02	51.7	1.33	-39.7
12-13	20	64.2	2.8	1359	1.42	.02	22	57.9	2.7	838	1.29	.02	61.1	1.35	-39.7
13-14	17	61.6	2.1	1010	1.36	.02	32	52.2	2.3	404	1.39	.03	56.9	1.37	-39.6
14-15	16	68.4	3.2	904	1.54	.02	21	59.3	3.3	474	1.31	.03	63.8	1.42	-39.5
15-16	13	69.8	2.0	815	1.43	.03	20	62.2	2.8	582	1.28	.02	66.0	1.36	-39.7
16-17	17	67.1	2.1	811	1.52	.02	20	61.4	3.3	637	1.39	.03	64.3	1.46	-39.4
17-18	17	63.2	2.3	1083	1.36	.02	20	67.8	3.5	760	1.50	.02	65.5	1.43	-39.4
18-19	16	60.6	2.9	2031	1.39	.02	20	61.3	2.0	618	1.34	.02	61.0	1.36	-39.6
19-20	19	62.2	2.2	2482	1.37	.02	20	61.9	3.0	925	1.34	.02	62.1	1.36	-39.7
20-21	15	65.8	4.2	2272	1.40	.02	20	59.4	2.6	660	1.31	.02	62.7	1.35	-39.7
21-22	27	54.7	1.8	648	1.35	.03	20	53.9	2.4	963	1.31	.02	54.3	1.33	-39.7
22-23	18	50.0	1.8	1393	1.24	.02	20	44.1	2.1	711	1.15	.02	47.1	1.19	-40.2
23-24	17	44.9	1.5	829	1.30	.03	20	39.20	2.4	729	1.06	.02	42.0	1.18	-40.3
00-24	24	55.3	2.1	24	1.31	.03	24	45.9	3.3	24	1.18	.04	50.6	1.24	-40.0
06-22	16	61.6	1.3	16	1.37	.02	16	55.5	1.8	16	1.23	.02	58.6	1.34	-39.7

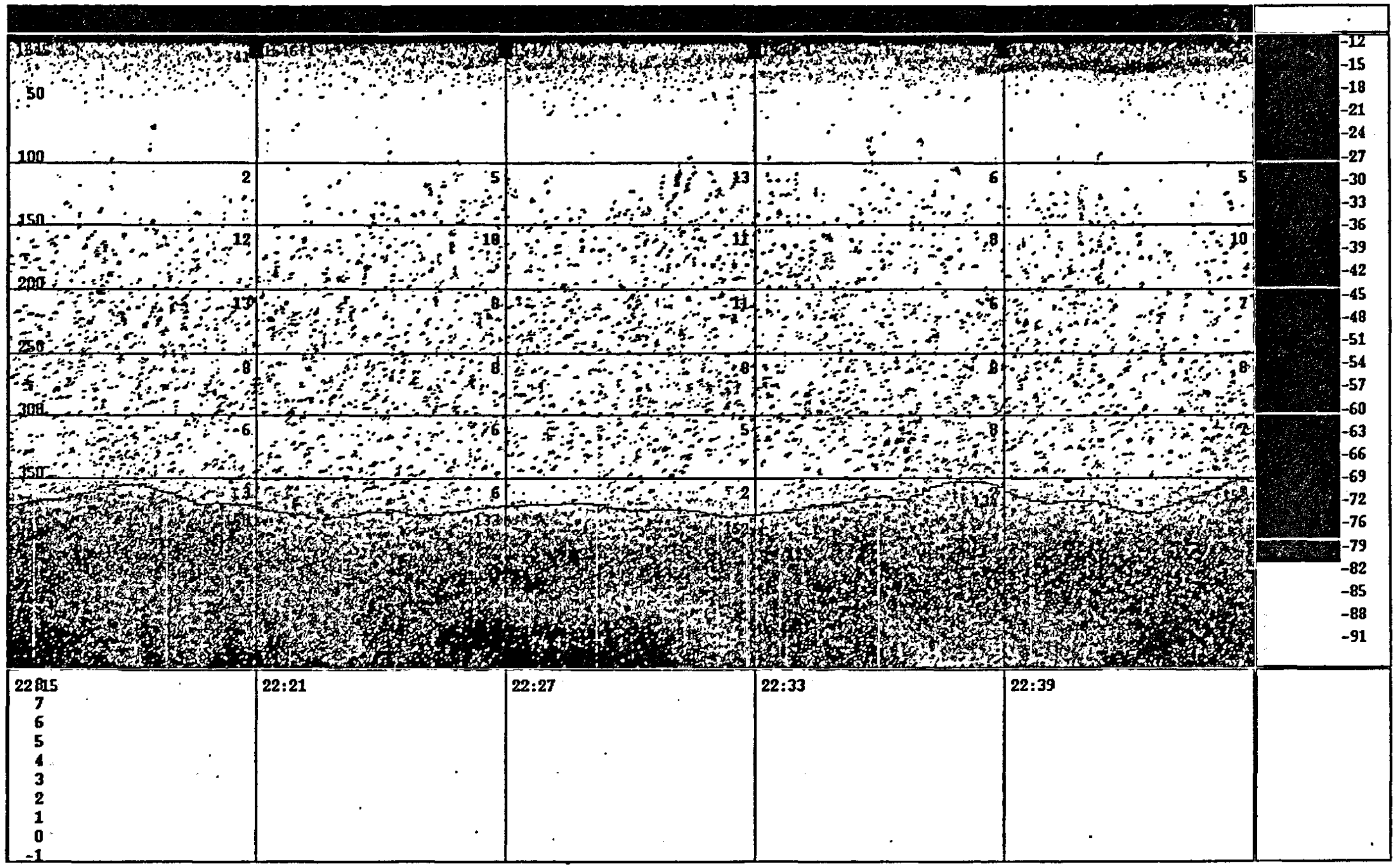

Fig. 1. Typical 20logR-echogram of oceanic redfish during daylight hours. Pure redfish registrations are observed from 100 m down to about 350 m. Below 350-400 m, a rather dense scattering layer of smaller organism is observed. Integrator values in 50 m depth intervals from 100-350 m are shown for each 1 nm sailed.

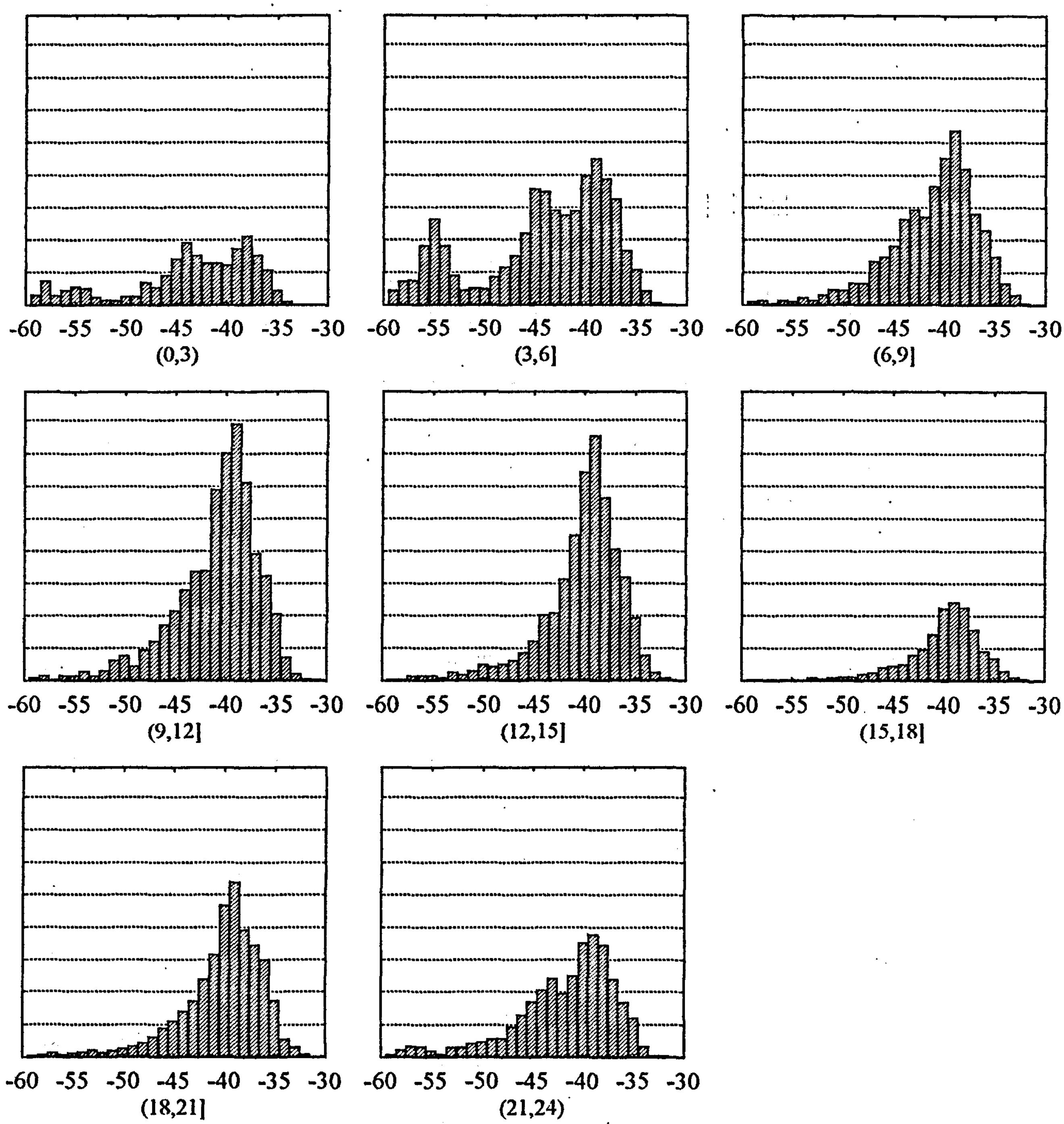

Fig. 2. TS-distributions of oceanic redfish obtained during every three hours interval in Area I. The scale showing the number of observations is identical in all cases.

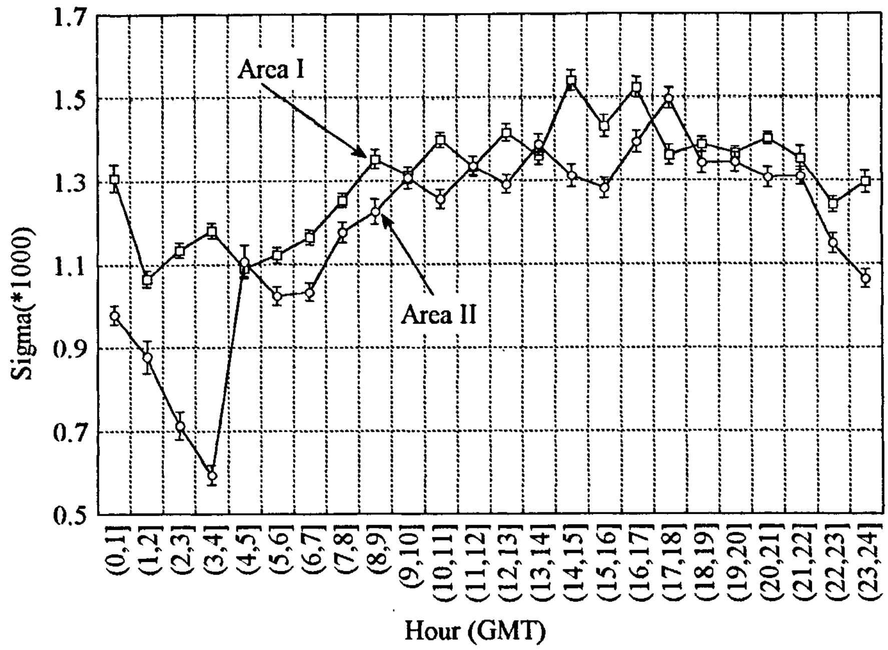

Fig. 3. Diurnal variations of the mean acoustic cross section (σ) of oceanic redfish averaged over 1 hour time intervals in Area I and II. Standard error is indicated.

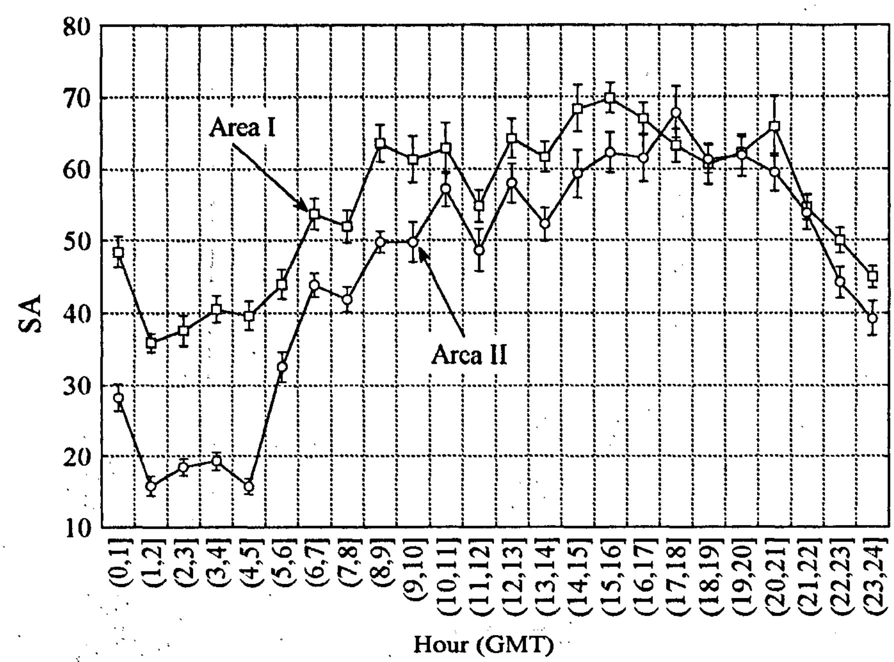

Fig. 4. Diurnal variations of the mean area back scattering coefficient (*SA*) of oceanic redfish averaged over 1 hour time intervals in Area I and II. Standard error is indicated.

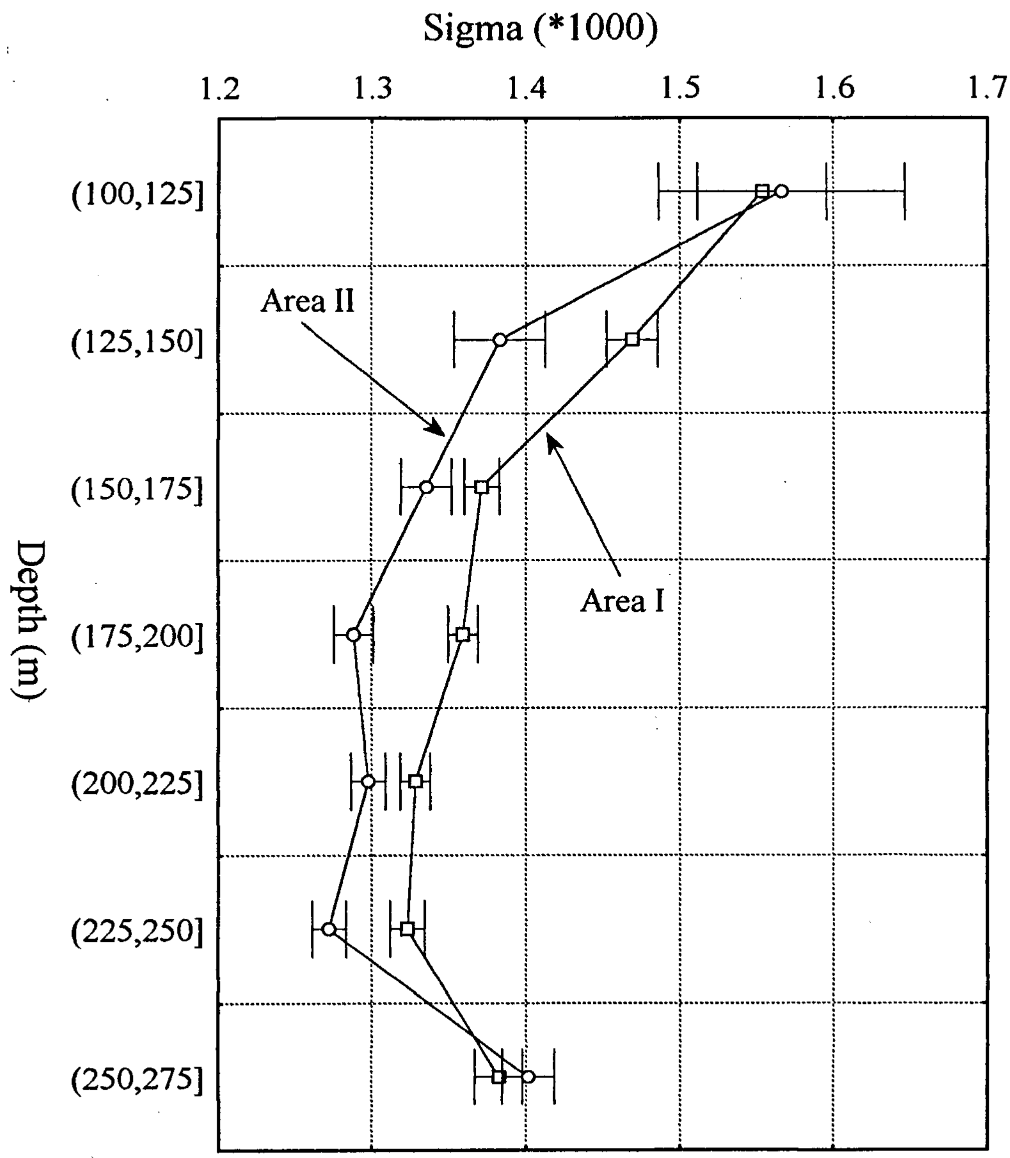

Fig.5. The mean acoustic scattering cross section of oceanic redfish in 25 m depth intervals from Area I and II.

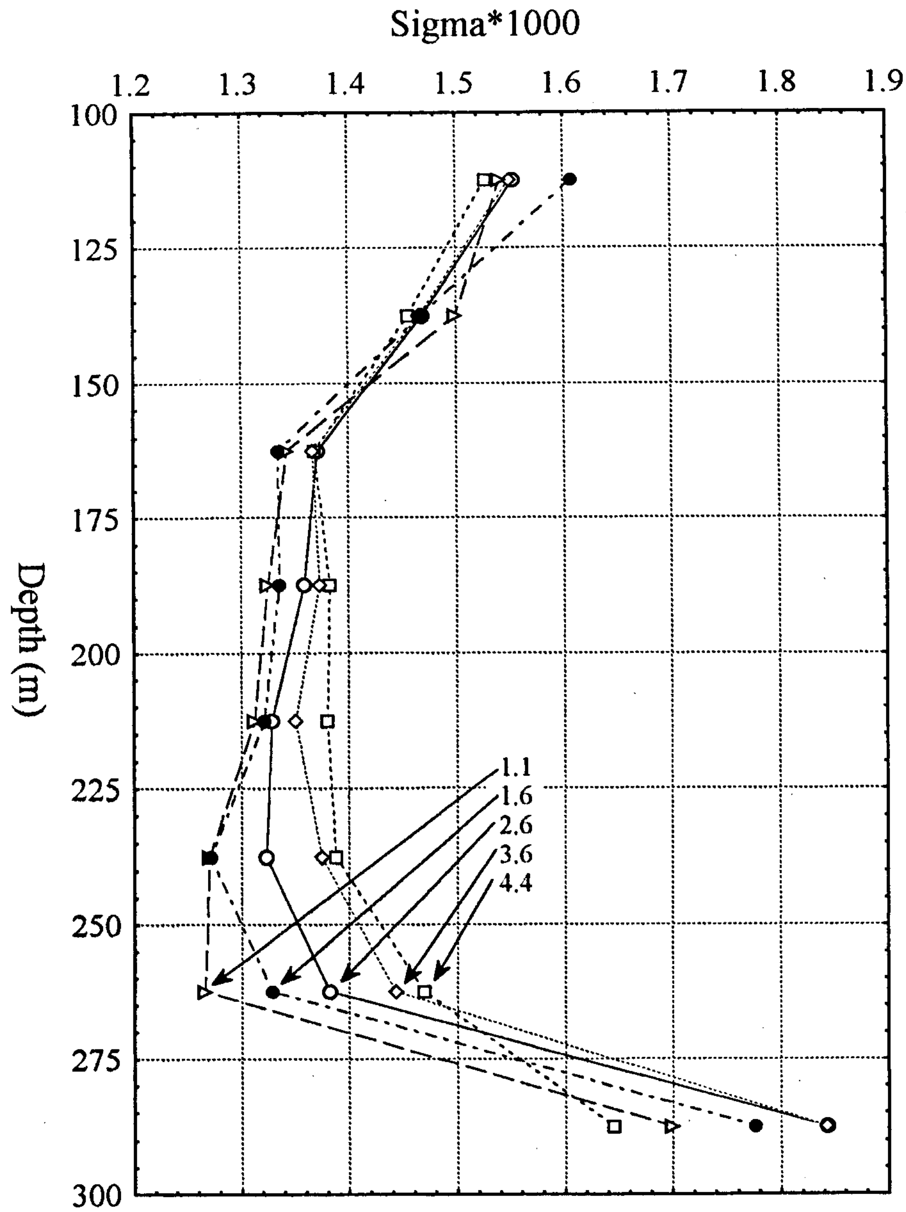

Fig. 6. The mean acoustic cross section (σ) obtained in Area I within 25 m depth intervals, for different limits on the beam acceptance angle (1.1, 1.6, 2.6, 3.6 and 4.4 deg).

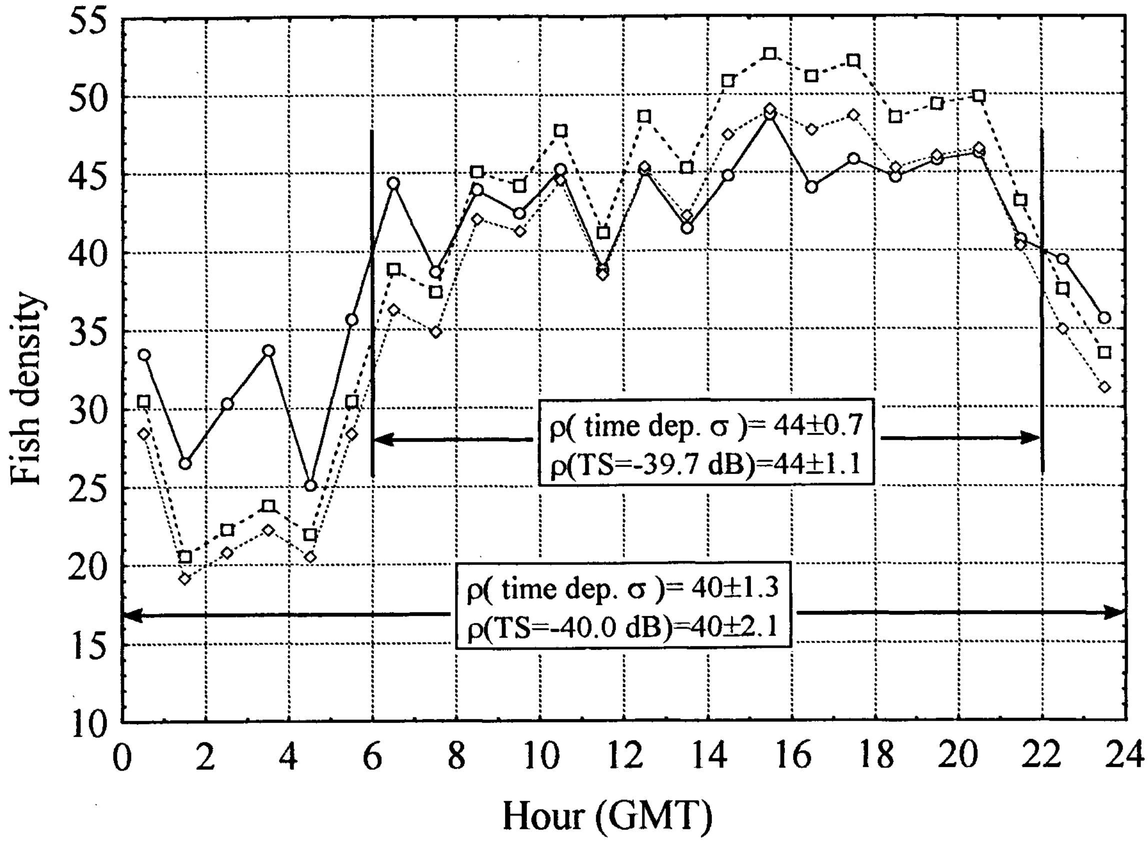

Fig. 7. Fish density (ρ) (mean of Area I and II) averaged over 1 hour time intervals of the day using a) —O— time dependent σ, b) ---□--- time average of σ over 00-24 GMT and c) ....◊... time average of σ over 06-22 GMT. The overall mean density within the hours 06-22 and 00-24 GMT is given in the figure as well as the standard error in each case.