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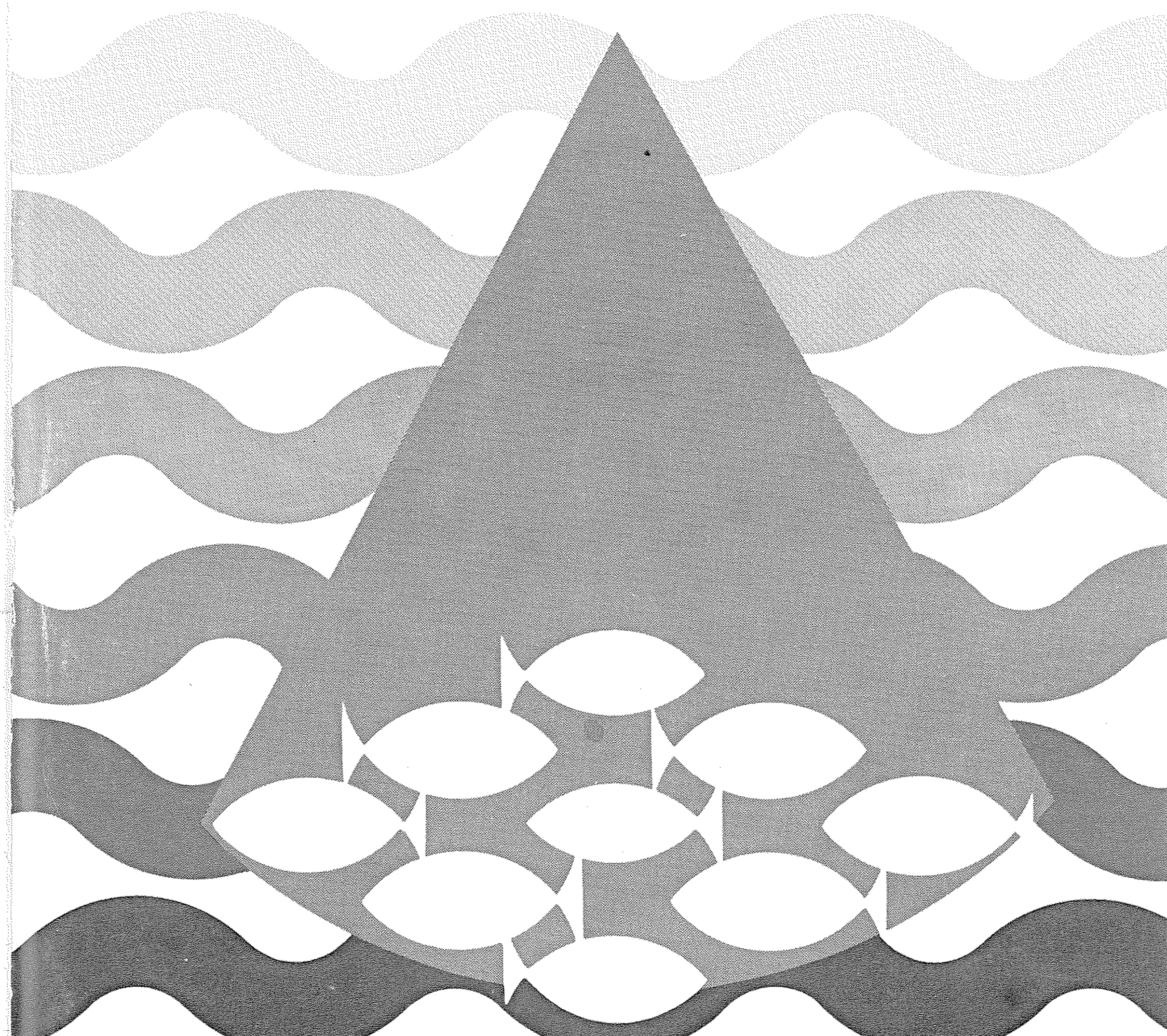

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ABUNDANCE AND PRODUCTION OF LANTERNFISH (MYCTOPHIDAE) IN THE WESTERN AND NORTHERN ARABIAN SEA

By

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ABSTRACT

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The mesopelagic fauna of the western and northern Arabian Sea between Mogadisco and the Indo-Pakistanean border was studied on cruises with R.V. "Dr. Fridtjof Nansen" during 1975—1976.

A deep scattering layer was observed over the whole area at depths between 250 and 350 m. In the northwestern part of the area, and sometimes in the Gulf of Aden, an additional layer was found between about 100 and 200 m.

Benthosema pterotum and *B. fibulatum* were the most abundant species in the area, but *Diaphus* spp. were also numerous. The *Benthosema* species seemed to have a life cycle of one year or less.

The biomass was estimated by using a 38 kHz echosounder and the electronic integration technique. The area was covered five times, and the estimated abundance of mesopelagic fish was about 100 million tonnes (range 60—150 million tonnes). Estimates from the spring were higher than those from summer and autumn.

When using a 1360 mesh pelagic trawl, catch rates as high as 20 tonnes/hour of trawling were reached.

INTRODUCTION

Studies on the fish fauna of the Arabian Sea, carried out from R.V. "Dr. Fridtjof Nansen" during the years 1975–1976, showed that the mesopelagic fish were far more abundant than any of the other fish groups (ANON. 1977a). Examinations of eggs and larvae from the area (AHLSTROM 1968, NELLEN 1973, FURSA 1973, ALI KHAN 1976) give the same indication. The studies of eggs and larvae and the adult fish showed that the myctophids are the dominant group of mesopelagic fish.

Taxonomy and distribution of myctophids from the Arabian Sea have been studied by NAFPAKTITIS and NAFPAKTITIS (1969), by KOTTHAUS (1972) and NAFPAKTITIS (1978), but their life history, ecology and abundance are largely unknown. There are, however, several studies of the ecology of the mesopelagic fauna in the eastern Indian Ocean and the western Pacific (e.g. LEGAND and RIVATON 1967, 1969, LEGAND *et al.* 1972) and in the more southerly parts of the western Indian Ocean (BRADBURY *et al.* 1971, MAKSHTAS and RYABTSEV 1973). In these waters some acoustical work has also been carried out, but no abundance estimates have been made (e.g. HALL 1971, 1973).

A general description of the hydrography of the Arabian Sea has been given by WYRTKI (1973). WOOSTER *et al.* (1967) pointed out that there is an "extremely high rate of primary productivity and zooplankton in the Arabian Sea, especially along the western side". They also stated that the primary productivity is "as large as or larger than that encountered in such upwelling areas as the eastern boundary currents along the coast of Peru, or off West Africa". A review of studies of primary production and an analysis of the transfer between primary and secondary production was published by CUSHING (1973).

The present study is based on the cruises with R.V. "Dr. Fridtjof Nansen", covering the area between Mogadisco in Somalia and the India-Pakistan border twice in 1975 and three times during 1976. It aims to give an indication of the abundance of mesopelagic fish and their production in the western and northern parts of the Arabian Sea. The behaviour of this fauna and various aspects of the ecology of the more important species are also discussed.

MATERIALS AND METHODS

The area of the Arabian Sea between Mogadisco and the India-Pakistan border (Fig. 1) was covered as follows:

Cruises 1, 2	14 January – 3 July		1975
Cruise 3	17 August	– 22 November	1975
Cruise 4	9 January	– 31 March	1976
Cruise 5	9 April	– 23 June	1976
Cruise 6	22 August	– 23 November	1976

Maps showing survey grids and other details are given in the cruise reports (ANON. 1975, 1976a, b, c, 1977b).

The acoustic equipment consisted of three scientific sounders (120, 50 and 38 kHz). Two electronic echo integrators with two channels each were coupled to the 38 kHz echo sounder. The 38 kHz sounder was operated at a basis range of 0 – 250 m with an extra paper recorder covering the depth 250 – 500 m. The effect of the transducer was 10 kW, the pulse length 0.6 ms and he band width 1 kHz. The angular

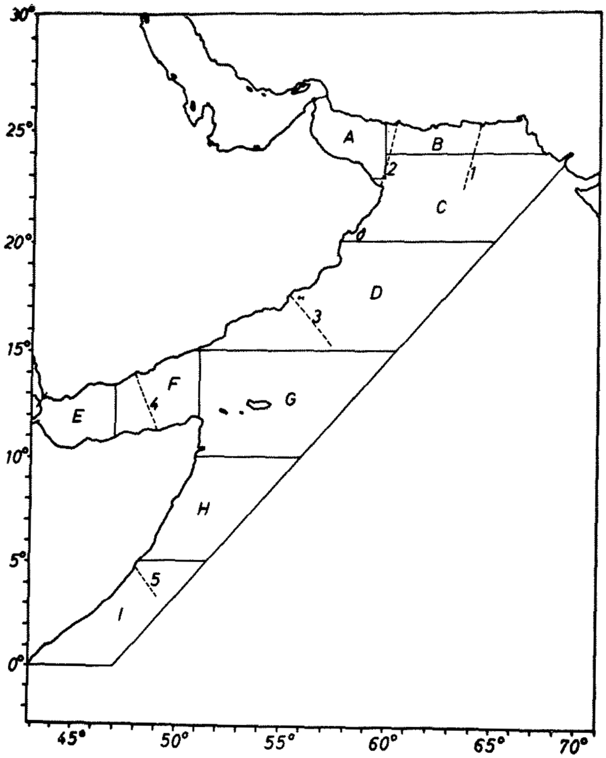


Fig. 1. The investigated area. A—I The sub-areas and 1—5 the sections referred to in the text.

aperture between 3 dB points was 7.5° and the source level 130.2 dB/1 μBar ref. 1 m. The TVG (time varied gain) was 20 lg R +2 αR where R is the distance between the transducer and the target, and α is the attenuation coefficient. On cruises 1 and 2 the source level was 132.0 dB/1 μBar ref. 1 m. The integrator readings were therefore divided by 1.5 to make them comparable with those of the other cruises.

The echo integrators (NAKKEN and VESTNES 1970, FORBES and NAKKEN 1972) integrated the echo intensities in four depth slices between 8 and 450 m.

The fundamental background for the integration method is: When a time varied gain compensating for one way geometrical spreading and two ways absorption of the sound is applied, and the voltage of each echo is squared before integration, the output M of the echo integrator is linearly related to the number of fish per unit area in the integrated depth columns (see FORBES and NAKKEN 1972).

The number of fish per unit area P_A can be written $P_A = CM + d$ where C expresses the number of fish per unit area which contributes one unit to the integrated echo intensity, and d is the lowest density which can be recorded (MIDTTUN and NAKKEN 1977). M is measured in millimeters deflection per nautical mile (n. mile) and averaged over five n. miles. The density coefficient C depends on fish species and size and on the characteristics of the sounder and integrator system used:

$$C = C_i \cdot C_s \cdot l^{-b} \qquad (1)$$

where C_i is an instrumentation constant, l is fish length and C_s and b are constants for a given species (NAKKEN 1975). Usually b is close to 2 (NAKKEN and OLSEN 1977).

In order to arrive at a density coefficient C in terms of weight per unit area, one has to multiply equation (1) with the average weight $\overline{W}$ of the fish

$$C_W = C \cdot \overline{W} = (C_1 \cdot l^{-2}) \cdot (C_2 \cdot l^3) \qquad (2)$$

where C_1 refers to a particular integration system applied on a particular species of fish, and C_2 is the condition factor in the length weight equation. The weight of fish per unit area C_W, which contributes one unit of the integrated echo intensity, is then:

$$C_W = C \cdot l \qquad (3)$$

The numerical value of C_W applied to the R.V. "Dr. Fridtjof Nansen" data was 10.5 tonnes/mm/n. mile × square n. mile. This figure was established for a mixture of fish species with an average length of about 17 cm (ANON. 1977a). The density coefficients used in the present study were calculated from equation (3) using:

$$C_W = 10.5 \cdot \frac{l}{17} \qquad (4)$$

where l is the mean length (cm) of the observed mesopelagic fish. Hence, the estimates of abundance arrived at for mesopelagic fish are based on the assumption that the scattering properties of these fish at 38 kHz are similar to those of other pelagic fish.

Continuous watch was kept on the acoustic instruments, and fishing was carried out whenever the echo sounder recordings changed their characteristics. Every day the acoustic data were scrutinized and compared with data from fishing stations. Integrator contributions from false bottom, wakes etc. were deleted, and the remaining integrator readings were grouped in four categories: small pelagic fish, mesopelagic fish, demersal fish and plankton and 0-group fish.

In addition to identification of the sound scatterers, fishing was also carried out in order to obtain samples for biological studies. The most commonly used gear was a 1360 mesh pelagic trawl with 1 cm inner net in the cod end. Occasionally a 1600 mesh pelagic trawl or a bottom trawl was used. Details about the gears are given by ANON. (1975). A krill trawl designed by Institute of Fisheries Technology Research (BELTESTAD and BRUNVOLL 1975) was also used at some stations. During all fishing operations with the pelagic trawls the net sonde was used to monitor the position of the trawl relative to the fish.

On all cruises the myctophids were sorted out, and the volume was measured or estimated. On cruises 1, 3, 5 and 6 random samples were preserved in formaline and brought back to the laboratory for examination. On cruise 4 identification and biological studies were carried out on board immediately after capture, and additional samples were preserved and brought to the laboratory.

Standard length was measured to the nearest millimeter of all the fish studied. To make the measurements from cruise 4 comparable with those made on preserved material, the equation,

$$l_{preserved} = 0.981\, l_{fresh} - 0.55$$

established for *Benthosema glaciale*, was used (GJØSÆTER 1973).

Sex, maturity stage and stomach contents were also studied in some samples. Otoliths were taken from a few fish to count primary growth rings. These otoliths were dehydrated in alcohol and cleared with creosote. Larger otoliths were ground down to give a thin section before counting of the rings.

RESULTS

DISTRIBUTION OF SPECIES

The species identified during all cruises, except the *Diaphus* species, are listed in Table 1. The table does not give a complete picture of the species taken as only the most numerous were worked up in some of the samples. Most of the material was worked up before the publication of the revision of Indian Ocean *Diaphus* prepared by NAFPAKTITIS (1978). Some identifications have, however, been carried out based on reference specimens kindly identified by Dr. Nafpaktitis and on descriptions based on specimens from other areas (Table 2). As expected from the distribution of the sampling, the neritic and surface migrating species were dominant. Most of the species are well known from the area, but many of the records from the Gulf of Aden are new, as this area has been little studied previously.

Area A. Gulf of Oman (Fig. 1)

Benthosema pterotum was the only myctophid species caught in the area. Larval studies (NELLEN 1973) gave the same result.

Table 1. Myctophid species identified from cruise 1 to 6 of R. V. "Dr. Fridtjof Nansen". xx dominant on one or more cruises, x present.

Species	Area A	B	C	D	E	F	G	H	I
Electrona rissoi (Cocco)									x
Hygophum proximum Becker		x			x	x	x	x	x
Benthosema fibulatum (Gilbert & Cramer)		x	xx	xx		xx	x	x	xx
B. pterotum (Alcock)	xx	xx	xx	xx	xx	xx	xx		x
Myctophum nitidulum Garman						x	x		
M. spinosum (Steindachner)				x	xx	x	x		
M. aurolaternatum Garman						x			
M. obtusirostrum Tåning						x			
M. brachygnathum (Bleeker)								x	xx
Symbolophorus evermanni (Gilbert)		x		x	xx	x	xx		x
Lampadena luminosa (Garman)						x			
Lampanyctus tenuiformes Brauer						x	x		x
L. macropterus Brauer				x					
L. nobilis Tåning									x
Bolinichthys longipes (Brauer)		x	x	x		x			x
Ceratoscopelus warmingi (Lütken)						x			

Table 2. *Diaphus* species identified from cruises 1—6 of R.V. "Dr. Fridtjof Nansen".

Species	South of 10°N	North of 10°S
D. coeruleus Klunzinger	+	+
D. diademophilus Nafpaktitis		+
D. garmani Gilbert	+	+
D. lobatus Nafpaktitis		+
D. luetkeni Brauer		+
D. parri Tåning		+
D. regani Tåning		+
D. thiollierei Fowler	+	+

Area B. Coast of Pakistan

Benthosema pterotum was dominant in this area on all the cruises. Ranging next in abundance were various *Diaphus* of which *D. thiollierei* and *D. garmani* have been identified. *Benthosema fibulatum*, *Hygophum proximum*, *Symbolophorus evermanni* and *Bolinichthys longipes* were occasionally caught.

As in area A, little sampling of mesopelagic fish has been carried out previously, but larval samples (Nellen 1973, Ali Khan 197)6 support the impression of a low species diversity.

Area C. The Arabian coast and the oceanic area between 20° N and 24° N

On cruises 3 and 6, both during the autumn, *Benthosema pterotum* was dominant. During cruise 4, in the early spring, *B. pterotum* and *B. fibulatum* were about equally abundant. Various *Diaphus* species and *Bolinichthys longipes* were also present. These results differ little from those obtained by KOTTHAUS (1972) from the same area.

Area D. Arabian Coast between 15° N and 20° N

On cruise 3 *Benthosema fibulatum* was the dominant species, while *B. pterotum* and *B. fibulatum* were about equally abundant on cruise 4. On cruises 5 and 6 various *Diaphus* species dominated of which *D. regani*, *D. thiollierei* and *D. garmani* were the most abundant species. *D. luetkeni* was also identified. *Myctophum spinosum*, *Symbolophorus evermanni*, *Bolinichthys longipes* and *Lampanyctus macropterus* were also caught.

The near-shore mesopelagic fauna of this area has not been studied previously. A comparison with the data of NAFPAKTITIS and NAFPAKTITIS (1969) shows that the fauna of the offshore region is much more diverse than in the nearshore zone.

Area E. Gulf of Aden, west of 47° E

In the inner part of the Gulf of Aden, *Benthosema pterotum* was the dominant species except on cruises 3 and 6, both carried out during autumn. During cruise 3 *Symbolophorus evermanni* dominated, and during cruise 6 *S. evermanni* and *B. pterotum* were equally abundant. Next in rank were *Diaphus spp.* and *Myctophum spinosum. M. nitidulum, M. aurolaternatum* and *Hygophum priximum* were also observed. Neither of the *Symbolophorus*, *Myctophum* nor *Hygophum* species seem to have been reported from the Gulf of Aden previously. For *M. nitidulum* the records from the Gulf of Aden are the northernmost known from the Indian Ocean.

Area F. Gulf of Aden between 47° E and 51° E

The myctophid fauna of the outer part of the Gulf of Aden was the most diverse observed during the cruises. Dominating species were *Benthosema fibulatum*, *B. pterotum* and *Diaphus spp.* Of the species identified from this area (see Table 1) *Hygophum proximum*, the *Myctophum* species, *Symbolophorus evermanni*, *Lampadena luminosa*, *Bolinichthys longipes*, *Lampanyctus tenuiformes* and *Ceratoscopelus warmingi* are not previously reported from the Gulf of Aden. For *L. luminosa* this record seems to be a northward extension of its known range in the Indian Ocean.

Area G. Somali Coast between 10° N and 15° N

On cruises 3, 4 and 6 *Benthosema fibulatum* was the dominant species in this area while *Symbolophorus evermanni* was most abundant during cruise 1. *B. pterotum*, *Hygophum proximum*, *Myctophum nitidulum*, *M. spinosum*, and *Lampanyctus tenuiformes* were also caught. Several *Diaphus* species were abundant but only *D. regani* and *D. thiollierei* have been identified. The records are within the known geographical range of these species.

Areas H and I. Coast of Africa between 0° N and 10° N

Benthosema fibulatum, *Myctophum brachygnathum* and *Diaphus spp.* dominated the catches. Of other species *Electrona rissoi*, *Hygophum proximum*, *B. pterotum*, *Symbolophorus evermanni*, *Bolinichthys longipes*, *Lampanyctus tenuiformes*, *L. nobilis*, *Diaphus garmani* and *D. thiollierei* were also caught. The catch of *B. pterotum* at 3°17'N is a southward extension of the known range of this species in the Arabian Sea. Later this species has also been caught off Mozambique (GJØSÆTER and BECK 1981).

BEHAVIOUR

To study the diurnal variation in the behaviour of the fish and its influence on the echo recordings, a diurnal station was conducted in the Gulf of Oman (24°35'N 57°11'E) from 5th to 6th March 1976. *Benthosema pterotum* was the only myctophid fish found in the area, and during daytime this species was distributed in two layers. The upper one (layer

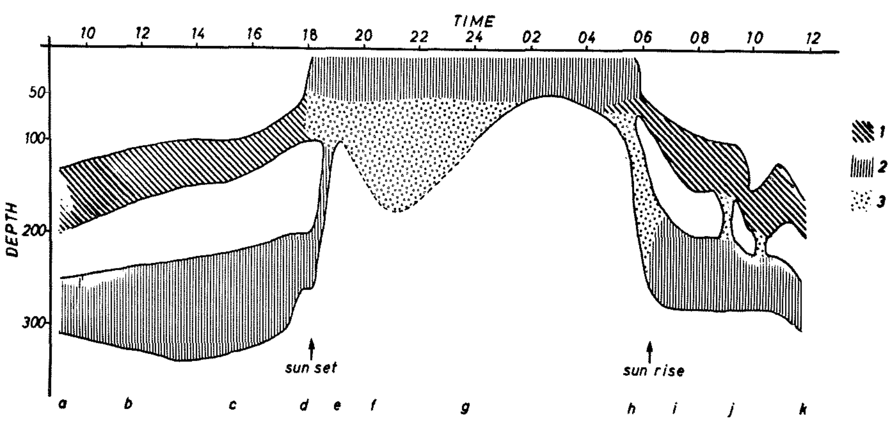


Fig. 2. The vertical migration observed during the diurnal stations in the Gulf of Oman, March 1976. 1) Schools and very dense aggregations, 2) dense recordings, 3) scattered recordings. a—k refer to the echograms in Fig. 3.

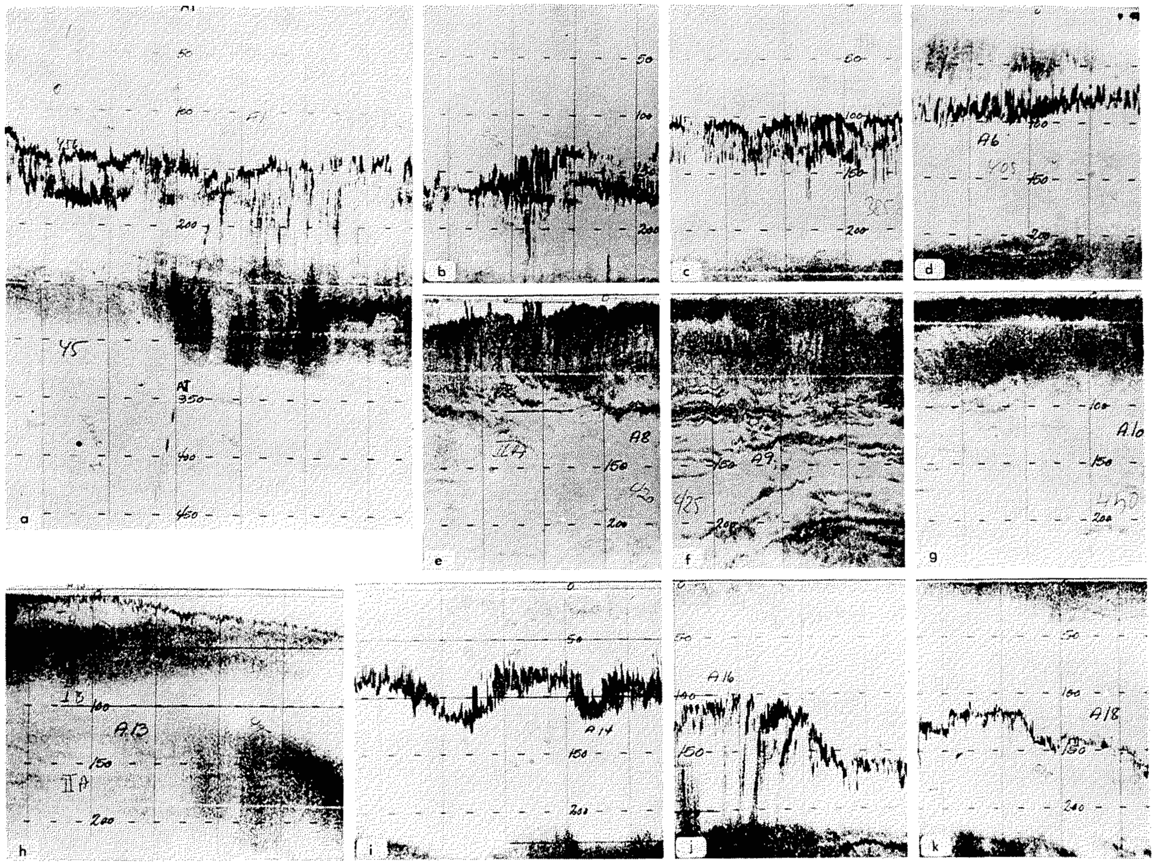


Fig. 3. Echo recordings obtained during the diurnal station in the Gulf of Oman. a—k refer to Fig. 2.

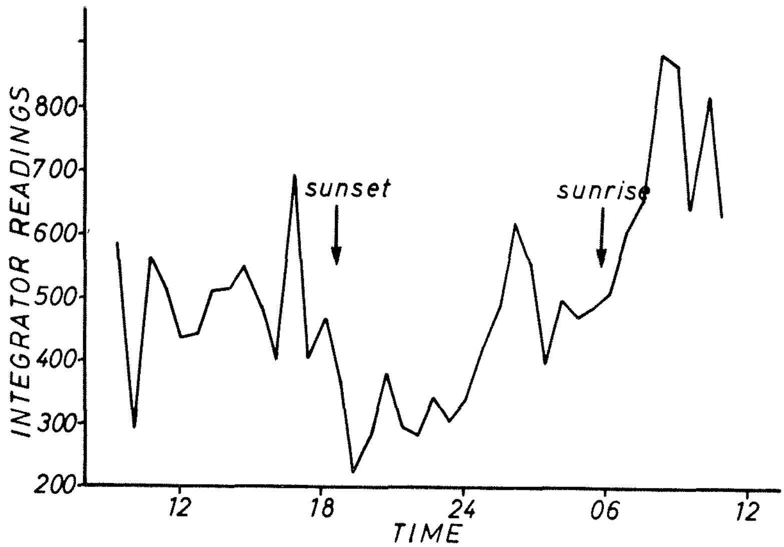


Fig. 4. Five mile averages of integrator deflection in mm/nautical mile from the diurnal station in the Gulf of Oman (see Fig. 2.).

A) generally lays between 130 and 200 m depth (Fig. 2 and 3). During the first day, its mean contribution to the integrated echo intensity was 292 mm/n.mile (Fig. 4). This layer consisted of very dense aggregations and often discrete schools. The lower layer (B), which was more diffuse, generally laid between 220 and 300 m, sometimes extending down to about 350 m. Its contribution to the integrated echo intensity was 200 and 348 mm/n.mile during the first and the second days respectively. Both layers were sampled, but no difference in length, maturity of gonads, fullness of stomachs or of digestion of the stomach contents could be observed between fish from the two layers. The migration towards the surface started about 33 minutes before sunset, and the two layers joined at depths between 10 and 100 m within half an hour after sunset. During night the most dense concentrations were observed between 10 and 50 m depths, but more diffuse recordings were obtained down to about 200 m. About 30 minutes before sunrise the layers separated and migrated down to their daytime depths. The integrated echo intensity rose from about 300 mm/n.mile to 500 mm/n.mile during the night, probably due to fish drifting or swimming into the area.

During daytime the depth of layer A corresponded approximately to the O_2 minimum where less than 1.5 ml/l of O_2 was present (Fig. 5). The salinity and temperature also had minima at this depth. Comparison of hydrographical data and fish distribution from other areas showed that the myctophids were often found in water with less than 0.5 ml O_2/liter

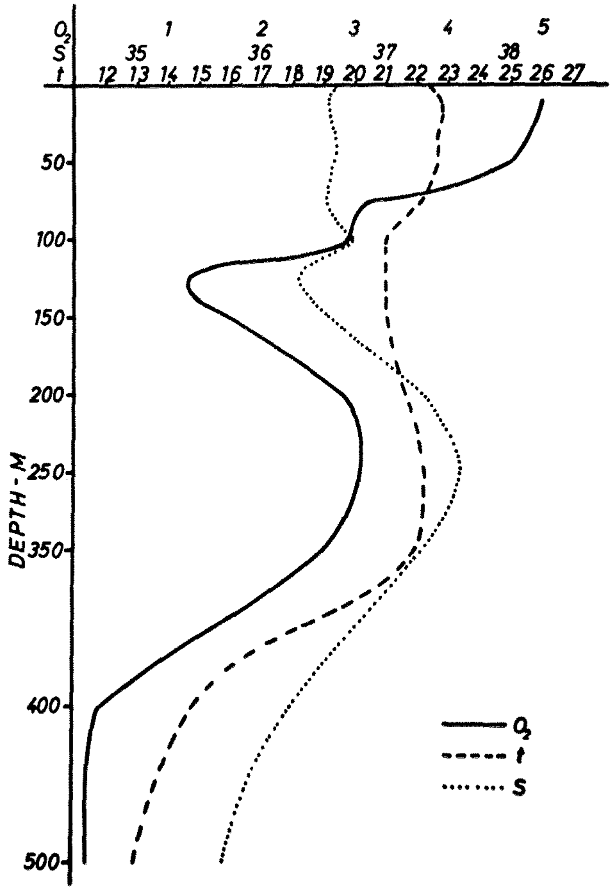


Fig. 5. Vertical distribution of temperature, salinity and oxygen at the diurnal station in the Gulf of Oman, March 1976. O_2 in g/l, S ‰, t C°.

(Fig. 6). The migration pattern observed during the diurnal station was rather typical of the neritic areas where *Benthosema pterotum* and *B. fibulatum* dominated.

In areas far from the shore and off the eastern coast of Somalia a DSL varying in depths between about 250 – 350 m was the most general feature. This layer was similar to layer B at the diurnal station, and it migrated towards the surface during the night. In some areas an additional layer was observed between about 350 and 500 m depths. This layer gave much more diffuse recordings on the 38 kHz echo sounder, and it contributed little to the integrated echo intensities as compared to the other layers. This layer, or parts of it, was sometimes found at the same depth also during night time.

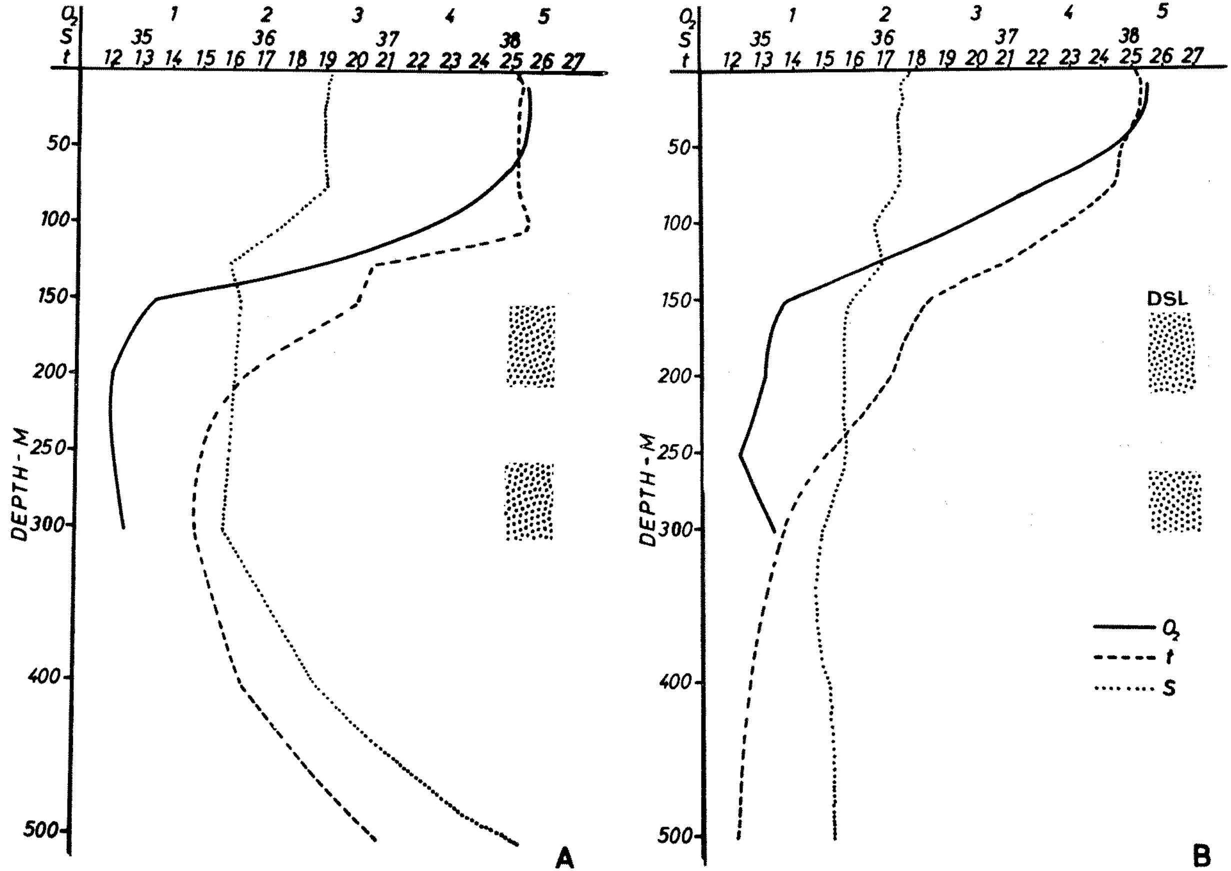


Fig. 6. Depth of DSL and vertical distribution of temperature, salinity and oxygen from two stations off Pakistan. O_2 in g/l, S ‰, and t C°.

The echo recordings obtained at the diurnal station may suggest a decrease in echo abundance during sunrise and an increase during sunset. The variation due to other sources makes it, however, impossible to draw any conclusions. To further study whether there is a diurnal variation in the echo recordings from mesopelagic fish in the upper 450 m, data from some sections (Nos. 1 – 6 on Fig. 1) were analysed (Fig. 7). To test whether there was a difference in mean abundance during day and night, the recordings were transformed using $\ln(M+1)$ where M is the five mile average of integrator deflection per n.mile. The values obtained during sunrise or sunset were not included in the analysis. The hypotheses that the mean of the 400 recordings of M made during the day were similar to those 345 made during the night, could not be rejected ($t = 1.19$, $p > 0.05$). It is therefore concluded that although part of the fish stock may occasionally stay above the upper limit of integration (8 m) during the night or below the lowest limit (450 m) during the day, this does not give a serious difference between day and night recordings. These results contrast, however, with those obtained off Pakistan during summer 1977 by MYRSETH (in prep.). The data from section 1 from Pakistanean area were therefore analysed separately. The result ($t = 0.74$, $p > 0.05$) was consistent with that based on the whole material.

To find whether there was a consistent trend in the relationship between echo abundance and distance from the shore along the section shown in Fig. 1, a hypothesis of randomness was tested against a trend. A non-parametric method described by LEHMANN (1975, p. 290 – 297) was used. In 12 of the 26 tests carried out, the hypothesis that the echo abundance was randomly distributed was rejected. In 7 cases a positive trend, i.e. increasing abundance towards the shore, was indicated, and in 5 cases a negative one (Table 3).

Table 3. Values of z and corresponding significance from a trend analysis (see text). Positive values indicate positive and negative values indicate negative trend in echo abundance towards the shore.

Section	Cruise					
	1	2	3	4	5	6
1		1.03^{ns}	0.56^{ns}	3.03^{xx}	-0.94^{ns}	-1.41^{ns}
2		-2.69^{xx}	1.44^{ns}	-0.59^{ns}	2.14^{x}	2.02^{x}
3	2.06^{x}	0.50^{ns}	0.55^{ns}	2.94^{xx}	-2.98^{xx}	4.46^{xxx}
4	-1.51^{ns}		-1.84^{ns}	-2.23^{x}	2.81^{xx}	-2.63^{xx}
5	1.04^{ns}		-0.96^{ns}	-2.62^{xx}	-0.85^{ns}	0.50^{ns}

^{ns} not significant ^{x} $p<0.05$ ^{xx} $p<0.01$ ^{xxx} $p<0.001$

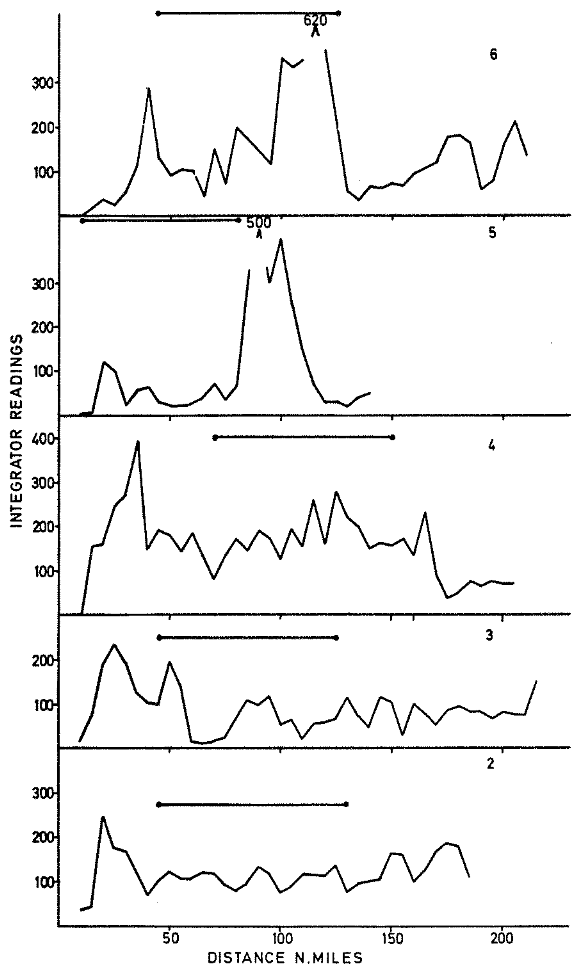


Fig. 7. Five mile averages of integrator deflection in mm/n.mile along the five sections shown in Fig. 1. ———— day recordings. 1—6) Cruise numbers.

A. Section 1, off the coast of Pakistan.
B. Section 2. Gulf of Oman.
C. Section 3. Off the Kuria Muria Islands.
D. Section 4. Gulf of Aden.
E. Section 5. Off eastern Somalia.

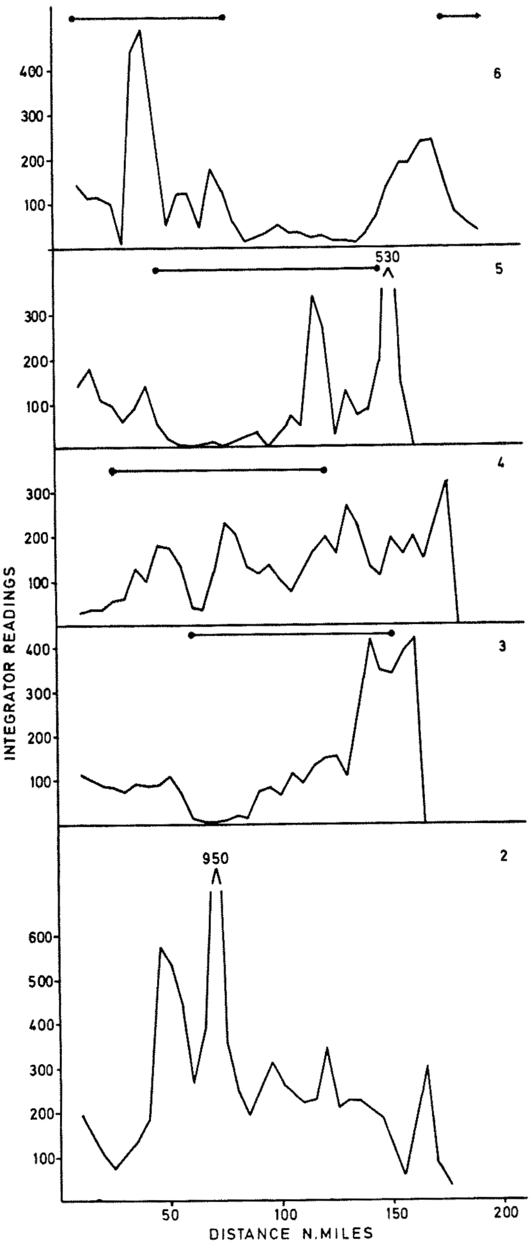
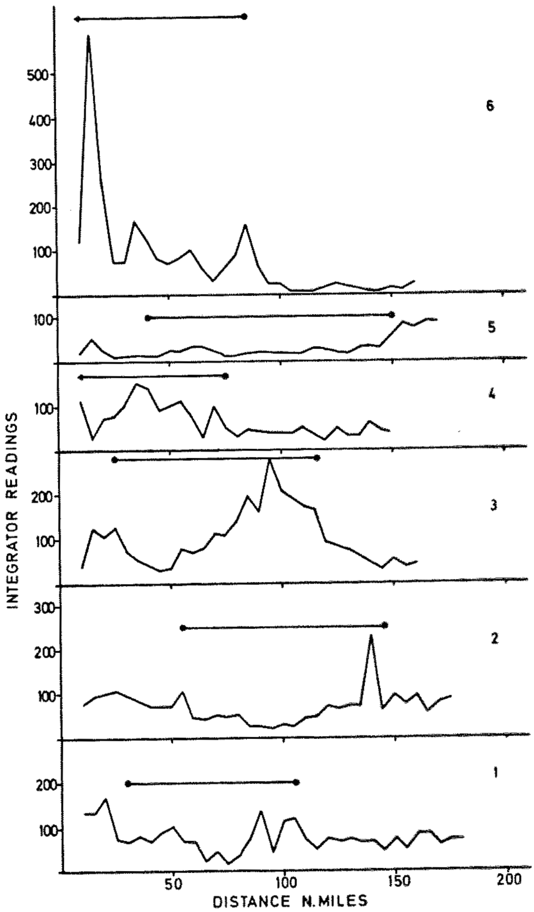

6
5
530
4
3
2
950
INTEGRATOR READINGS
DISTANCE N.MILES

Fig. 7 B.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INTEGRATOR READINGS
DISTANCE N.MILES

Fig. 7 C.

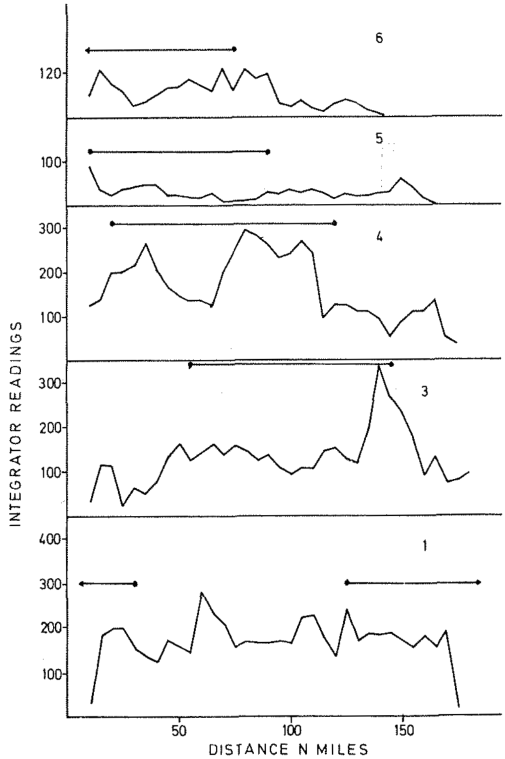

Fig. 7 D.

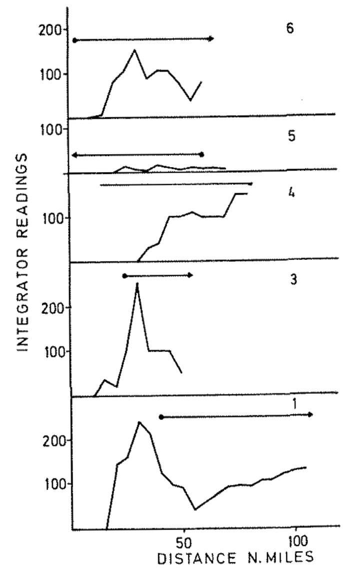

Fig. 7 E.

For the section off the Pakistan coast (section 1) one of five was significant. In the Gulf of Oman (section 2) echo abundance increased with distance from the shore on cruise 2 and decreased on cruises 5 and 6. Off the Kuria Muria Islands (section 3) echo abundance increased offshore on cruise 5 and decreased on cruises 1, 4 and 6. In the Gulf of Aden cruises 4 and 6 showed increasing trend offshore and cruise 5 an increase towards the shore. Off Al Arar (section 5) there was an increase offshore on cruise 4.

Although not obvious from the sections, an increased echo intensity was often observed from the 200 m depth contour and about 1 – 2 n.miles offshore or less. It seems, however, safe to conclude that the survey design, in relation to the shore, is generally of minor importance compared to other sources of variance.

The sections off the Kuria Muria Islands were run twice in April 1975. The mean and standard deviations of the integrated intensities were 114.5 ± 48.9 and 106.8 ± 53.2 respectively. A test carried out on the transformed data $[\ln(M+1)]$ showed that the two means were not significantly different ($t = 0.8$, $p > 0.05$).

ABUNDANCE ESTIMATES

To estimate the abundance of mesopelagic fish, the mean integrator reading for each of the areas A – I (Fig. 1) was multiplied by the size of the area outside the 200 m depth contour. For each of the areas an average fish length was calculated (Table 4), so that the lengths were approximately weighted by the numerical abundance in the layers where they were caught. Fish that were caught only with a bottom trawl, e.g. *Diaphus coeruleus*, are not included in the mean.

Table 4 also shows the species mainly contributing to the recordings. In some cases no samples were available from a given area. Then, lengths from adjacent stations or lengths from the same area during another cruise conducted at the same time of the year were used.

Based on these mean lengths, an integration constant C_W was calculated for each area and each survey. The more accurate method recommended by FORBES and NAKKEN (1972), when several species or length groups contribute to the recordings, was not used as the extra accuracy is probably not justified by the data. The mean integrator readings referring to mesopelagic fish in each area and for each cruise are shown in Fig. 8 and the corresponding abundance estimates in Table 5.

The total abundance, recorded during one survey, varied between 56 million tonnes (summer 1977) and 148 million tonnes (spring 1976), with a mean of 102 million tonnes. All the spring surveys (cruises 1, 2

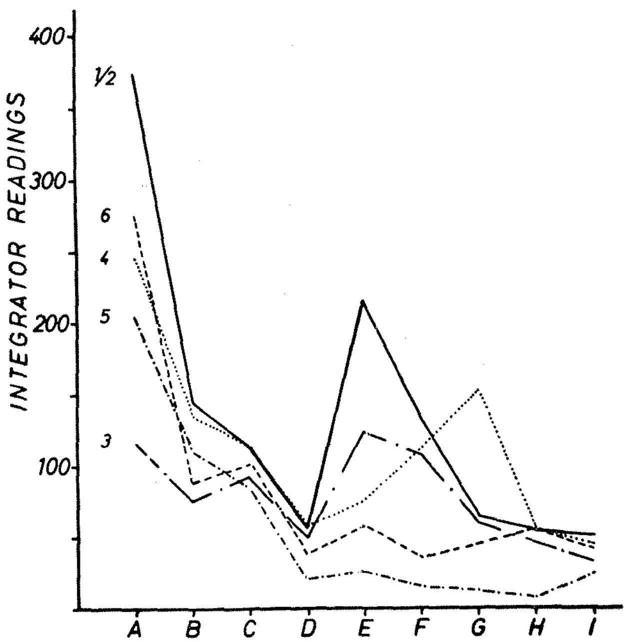

Fig. 8. Mean integrator deflection in mm/n.mile in 9 subareas (A—I) shown in Fig. 1. 1—6) Cruise number.

Table 4. Species giving the main contribution to the echo abundance, and mean length (in mm.) of the contributing fish. Numbers in brackets are estimates.

Cruise No	Area								
	A	B	C	D	E	F	G	H	I
1,2	— [32]	— [31]	— [35]	— [37]	*B. pterotum* 30	*B. fibulatum* 80	*S. evermanni* 75	*B. fibulatum* 80	*M. brachygnatum* *B. fibulatum* 60
3	*B. pterotum* 40	*B. pterotum* 35	*B. pterotum* 35	*B. fibulatum* 50	*S. evermanni* 50	— [55]	*B. fibulatum* 60	— [55]	*B. fibulatum* 47
4	*B. pterotum* 32	*B. pterotum* 31	*B. pterotum* *B. fibulatum* 35	*B. fibulatum* *B. pterotum* 37	*B. pterotum* 38	*B. fibulatum* *B. pterotum* 35	*B. fibulatum* 37	— [38]	*Diaphus* spp. *B. fibulatum* 38
5	*B. pterotum* 33	*B. pterotum* 35	— [35]	*Diaphus* spp. 42	*B. pterotum* 33	— [80]	— [75]	*Diaphus* spp. 62	*Diaphus* spp. 45
6	*B. pterotum* 32	*B. pterotum* 34	*B. pterotum* 34	*Diaphus* spp. 40	*M. spinosum* *B. pterotum* 31	*Diaphus* spp. 40	*B. fibulatum* 80	— [80]	*M. brachygnatum* 50

Table 5. Estimated abundance of mesopelagic fish in the areas investigated (in million tonnes). Numbers in brackets are size of the areas in n.miles$^2 \times 10^3$.

Cruise no.	Period	Area									Total
		A (26.6)	B (27.7)	C (95.0)	D (109.1)	E (30.2)	F (43.6)	G (89.3)	H (37.1)	I (29.5)	(488.1)
1.2	Spring 75	20	8	23	15	12	28	26	10	6	148
3	Autumn 75	8	6	19	17	12	16	20	6	3	107
4	Spring 76	13	7	23	15	5	11	31	5	3	113
5	Summer 76	11	7	17	6	2	4	6	1	2	56
6	Autumn 76	15	5	20	11	3	4	20	3	3	84
Mean		13	7	20	13	7	13	21	5	3	102

and 4) gave higher abundances than the summer (cruise 5) and the autumn cruises (3 and 6).

As indicated by the sections (Fig. 7), the differences in abundance between the cruises were the same both near the shore and far off the shore. A difference in vertical distribution between seasons may give a difference as observed, if a larger part of the fish is found below 450 m during summer and autumn than during spring. This should, however, lead to a diurnal variation in abundance as most of the myctophids are supposed to rise above 450 m during night time.

The highest densities were usually recorded in the Gulf of Oman where the mean recordings varied between 374 and 118 mm deflection, corresponding to approximately 300 and 110 fish or 215 and 80 g/m^2 surface area. The lowest mean density, 9 mm deflection, was recorded off northwestern Somalia during summer and corresponds to about 3 fish or 7 g/m^2 surface area.

CATCH RATES

Trawling was carried out to identify sound scatterers and to obtain biological samples, and also in a few cases to compare a krill trawl with a pelagic fish trawl. Although there was no specific goal to get large catches, high catch rates were obtained at some stations. Twenty-six stations gave catch rates higher than 400 kg/h. The highest catch rate recorded was 20 000 kg/h (station 427).

Eleven of the stations listed in Table 6 were from the Gulf of Oman (Fig. 9), six from Pakistanean waters, six from the coast of Arabia, two from the Gulf of Aden and one from southwest of Socotra. One of the stations was worked with a bottom trawl and the others with a pelagic trawl. Thirteen of the stations were taken during day time, twelve during night time and one at dawn.

Table 6. Trawl stations with catch rates of myctophids > 400 kg/hour. P = pelagic trawl (1360 meshes), KT = krill trawl, BT = bottom trawl.

St. nr.	Date	Area	Trawl	Trawl-depth m	Time	Total catch kg	Catch, myctophids kg	Myctophids kg/hour	Dominant species
	1975								
168	19.9	F	P	180	day	5210	5000	9400	
219	17.10	C	P	180	day	1500	1500	3000	
234	3.11	C	P	40	night	300	230	400	*B. pterotum*
239	7.11	B	P	250	day	610	600	1200	*B. pterotum*
	1976								
281	31.1	E	P	85	night	410	405	810	*B. pterotum*
310	22.2	D	P	280	day	2000	2000	6000	*B. fibulatum*
314	26.2	D	P	270	day	250	230	460	*B. pterotum*
319	28.2	A	P	20	night	900	800	1600	*B. pterotum*
320	29.2	A	P	20	night	1500	1500	3000	*B. pterotum*
325	5.3	A	P	140	day	800	780	1560	*B. pterotum*
326	5.3	A	P	20	night	450	440	880	*B. pterotum*
327	5.3	A	P	100	day	450	430	860	*B. pterotum*
329	6.3	A	P	20	night	5000	5000	10000	*B. pterotum*
330	6.3	A	P	130	day	650	650	1300	*B. pterotum*
352	26.3	C	P	90	day	300	200	400	*B. pterotum*
419	25.5	D	KT	200	day	1500	1500	3000	*Diaphus* spp.
427	3.6	C	P	130	day	10000	10000	20000	*B. pterotum*
433	10.6	B	P	100	dawn	1000	1000	2000	*B. pterotum*
434	10.6	B	P	175	day	600	500	1000	*B. pterotum*
436	13.6	C	P	20	night	300	300	600	*B. pterotum*
448	20.6	A	P	15	night	1500	1300	2600	*B. pterotum*
449	20.6	A	KT	20	night	800	700	1400	*B. pterotum*
450	20.6	A	KT	30	night	1500	1300	2600	*B. pterotum*
451	20.6	A	P	30	night	500	400	800	*B. pterotum*
469	29.8	B	P	300	day	1000	1000	1000	*B. pterotum*
543	26.10	G	BT	120	night	10000	9600	19000	*B. fibulatum*

The species composition was studied in 24 of the catches. *Benthosema pterotum* was the only species or the dominant one at 21 of these stations, and *B. fibulatum* was dominant at two of them. *Diaphus* spp. were most abundant at one station.

A comparison between the 1360 mesh pelagic trawl and the krill trawl showed that, although the opening of the krill trawl was only a quarter of the other one, the two types of gear caught equal quantities of fish (Anon. 1976c). This indicates that a large part of the fish entering the pelagic trawl is filtered off through the meshes while the much smaller meshes of the krill trawl retain a larger percentage of the fish.

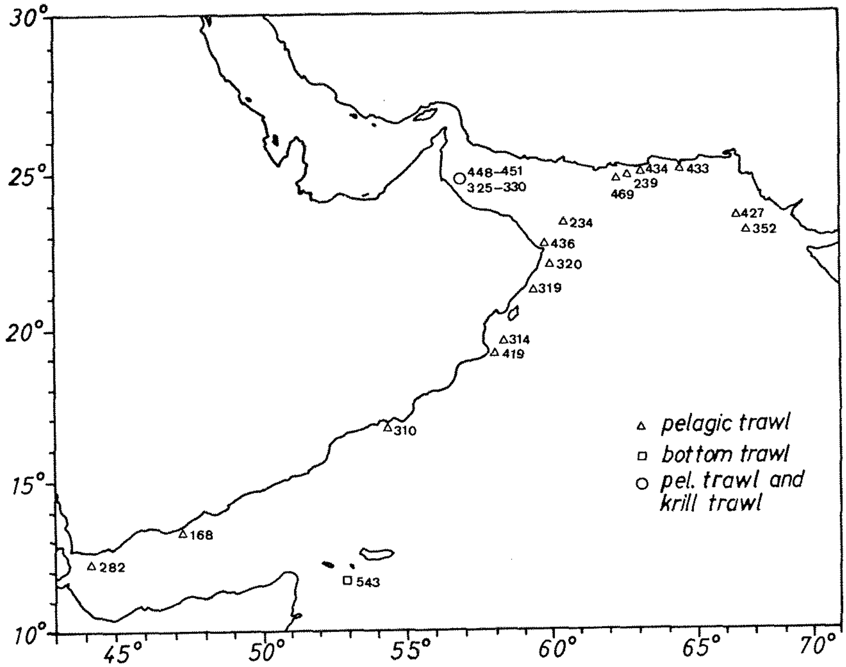

Fig. 9. Map showing trawl stations giving more than 400 kg meso-pelagic fish/hr. trawling.

BIOLOGY OF THE IMPORTANT SPECIES

Benthosema pterotum

B. pterotum seems to grow to a maximum size of about 50 mm though specimens larger than 45 mm are rare. Fig. 10 shows the length distribution of *B. pterotum* caught off Pakistan. The distribution from cruise 3 is bimodal. On cruise 4 juveniles between 5 and 10 mm were caught, but have not been included in Fig. 10 as they were too small to be caught at the same rate as the larger fish. Between March 1976 and June 1976 there was an indication of growth, but fish taken in September the same year were smaller again.

Fig. 11 shows that a population of *B. pterotum*, which had much lighter pigmentation than that commonly observed (GJØSÆTER unpubl.) caught in the Swatch had a larger mean size than the dark coloured fish.

Fish caught in the Gulf of Oman were smaller than those taken off Pakistan (Fig. 12) while those taken in the Gulf of Aden were generally larger (Fig. 13). They also had a bimodal distribution.

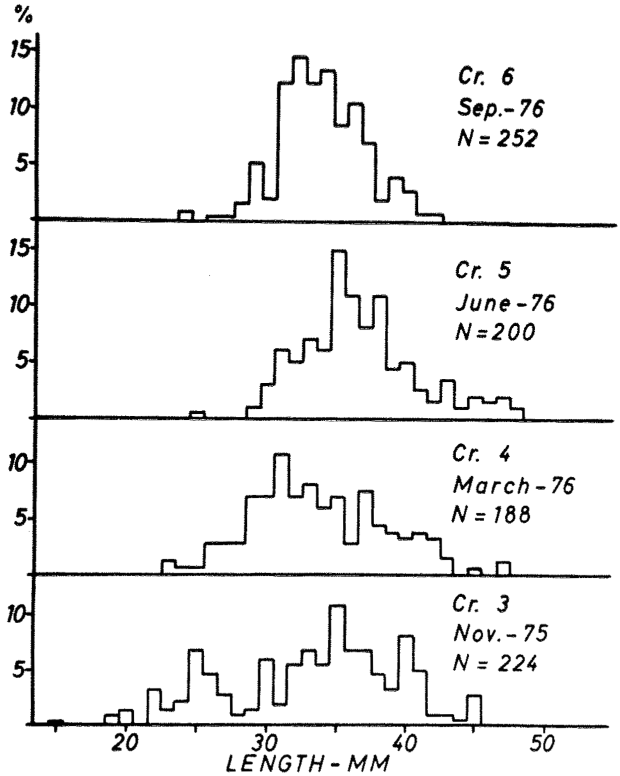

Fig. 10. Length distribution of *Benthosema pterotum* caught off Pakistan.

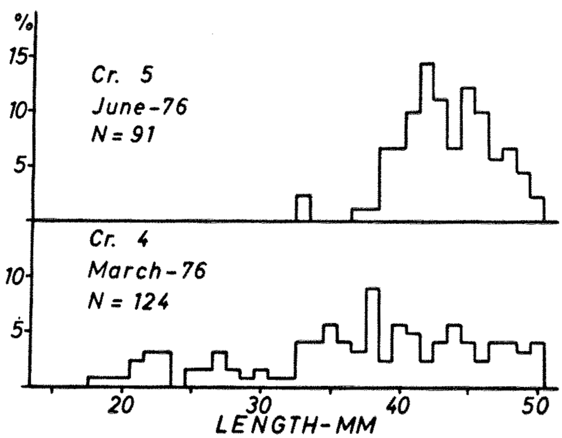

Fig. 11. Length distribution of the light coloured *Benthosema pterotum* caught in the Swatch off Pakistan.

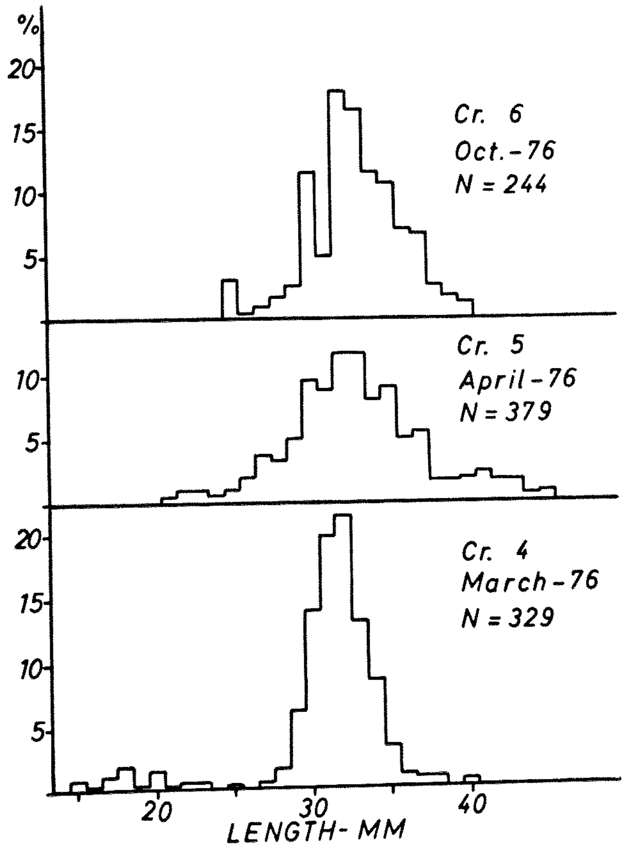

Fig. 12. Length distribution of *Benthosema pterotum* caught in the Gulf of Oman.

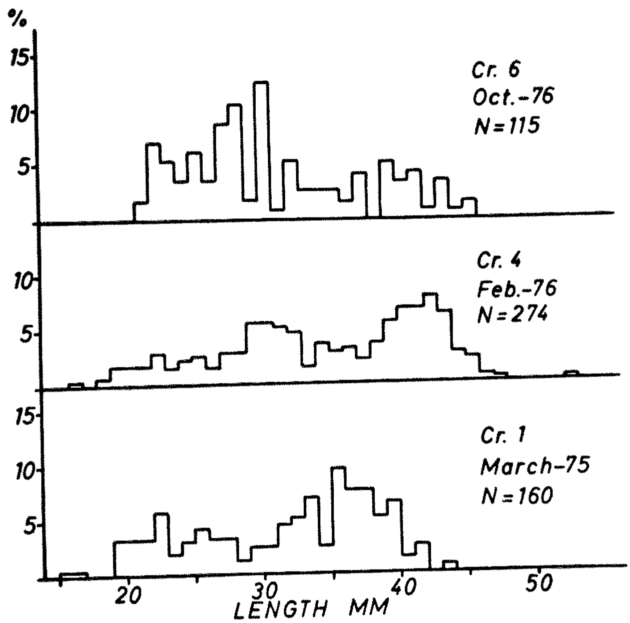

Fig. 13. Length distribution of *Benthosema pterotum* caught in the Gulf of Aden.

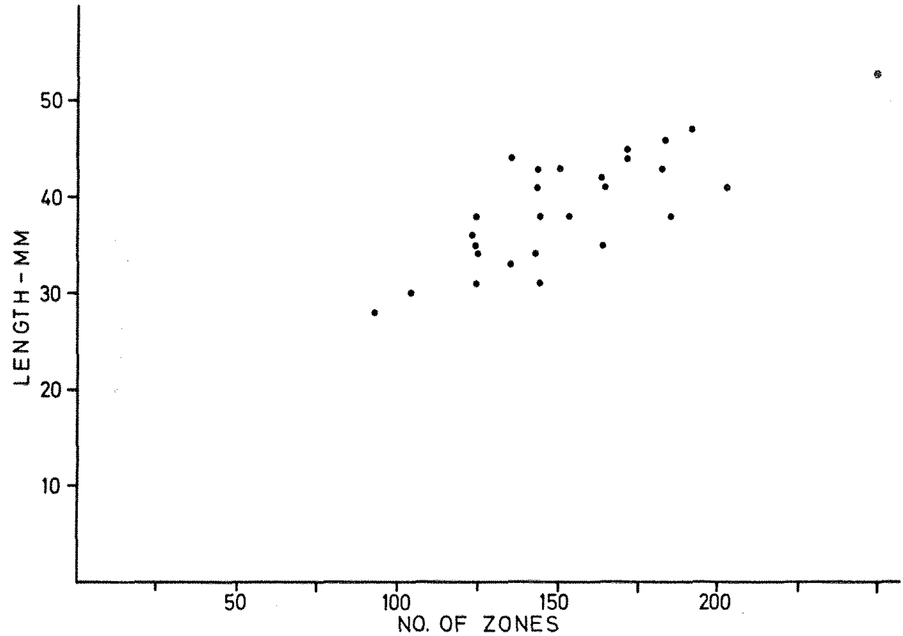

Fig. 14. Relation between length and number of primary rings in the otoliths of *Benthosema pterotum*.

The rings in the otoliths, commonly regarded as daily growth marks (PANNELLA 1974, BROTHERS, MATHEWS and LASKER 1976), were counted in 27 otoliths from *B. pterotum* caught during cruise 4 (from the Gulf of Aden and the coast of north-western Arabia).

Fig. 14 shows that there was an increase in number of rings with length of fish, but, unfortunately, only otoliths from adult fish were available for counting. If the rings are laid down daily, they show that the fish may reach its maximum size in about six months, and they may have two generations a year.

Fig. 14 suggests fast growth during the first three or four months of life and slow growth later. Generally, the rings counted in the otoliths, were broad near the center and very narrow near the edge. This also supports a growth pattern with fast growth in the first months and a slower growth thereafter. The data cannot give any clues to seasonal variation in growth rate. Neither does it show whether there is a correlation between gonad maturation and growth. The length distributions (Fig. 10 – 13) show some variation between months, but it seems difficult to deduce any growth pattern from these differences.

The reproduction of these species has been studied by HASSAN (in prep.) who has shown that breeding takes place all the year, but with maxima in March – June and Setpember – November.

The types of stomach contents were studied on cruise 4. Of 120 stomachs with identifiable contents, 85 contained copepods, 28 various crustacea larvae, 10 euphausiids, 7 gastropods, 7 ostracods and 2 contained amphipods. The sizes of 117 food items from 14 fish were measured. The mean size was 1.16 mm (SD = 0.52) and the range 0.50 – 2.83 mm.

Records of degree of filling and state of digestion of the stomach contents from fish taken at the diurnal station in the Gulf of Oman are shown in Fig. 15. Stomachs were classified as, 1: empty, 2: partly digested, and 3: much digested. At noon, more than 50% of the fish had empty stomachs and only 4% had full stomachs. The digestion was well advanced (3) in more than 90% of the fish.

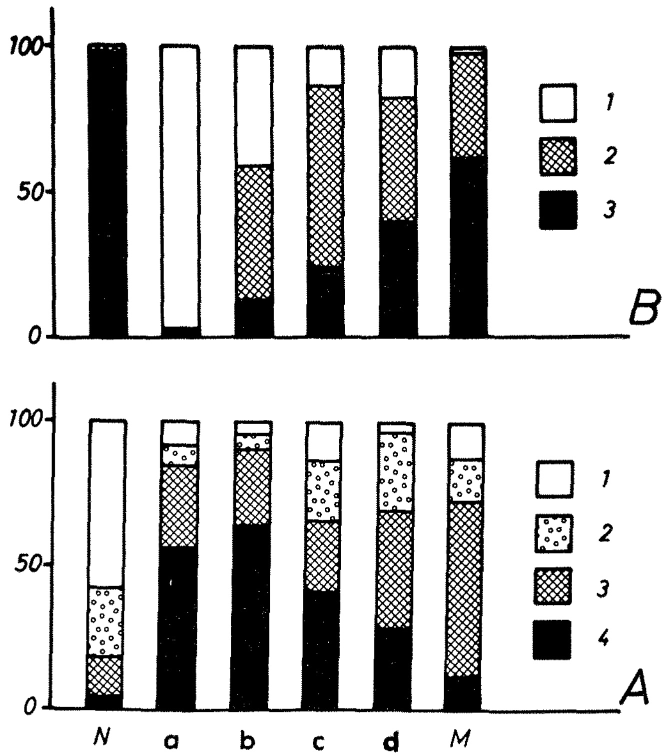

Fig. 15. Diurnal variation in degree of filling (A) and stage of digestion (B) of stomach contents of *Benthosema pterotum* caught at the diurnal station in the Gulf of Oman March 1976. N) Noon; a, b, c, d) night stations, M) morning. 1—4 degree of filling (A) and stage of digestion (B) (see text).

At the first night station taken two hours after sunset, 96% of the fish had newly ingested food items, and about 55% had full or extended stomachs. Only 8% were empty. The stage of digestion increased during the night. In the morning 62% of the fish contained much digested food and 35% partly digested food. The percentage of fish having full or extended stomachs reached a maximum of about 64% during the second night station (about 4 hours after sunset) and then decreased steadily. Numbers of half-filled stomachs increased during the latter part of the night and reached a maximum in the morning. These data suggest that *Benthosema pterotum* feed most intensively during the first part of the night, and little feeding seems to take place during day time.

B. fibulatum

Length distribution of *B. fibulatum* from the Somali coast (Fig. 16) shows a growth in mean length between January 1975 and October 1975. Fish taken in the northern Arabian Sea were much smaller on both cruises, but they also showed growth between the cruises (Fig. 17).

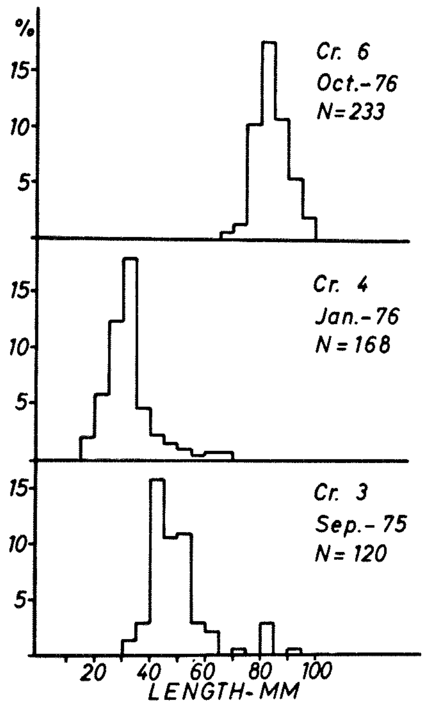

Fig. 16. Length distribution of *Benthosema fibulatum* caught off Somalia.

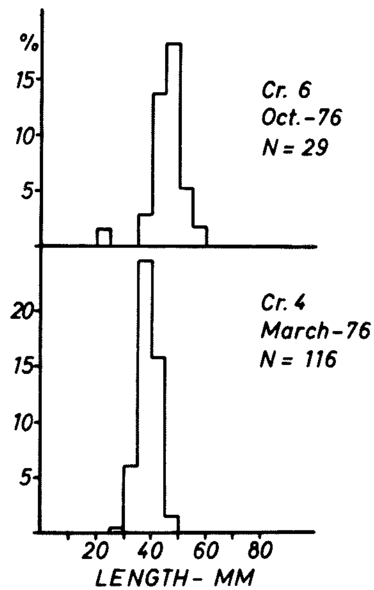

Fig. 17. Length distribution of *Benthosema fibulatum* caught in the northern Arabian Sea.

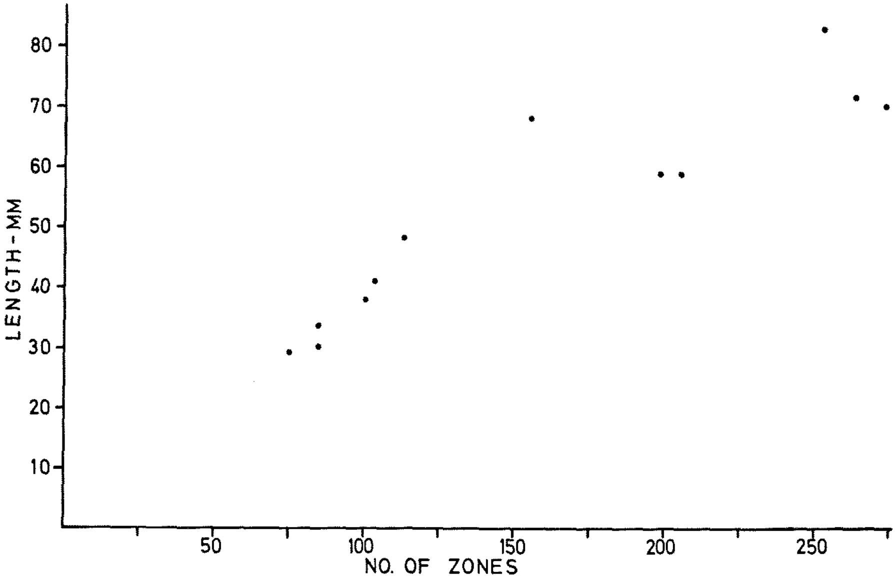

Fig. 18. Relation between length and number of primary rings in the otoliths of *Benthosema fibulatum.*

Growth rings were counted in the otoliths from twelve specimens, all caught during cruise 4 (Fig. 18). The number of rings showed a rather close relationship to length. The rings were also clearer and more distinct than in *B. pterotum.* If the rings are laid down daily, they suggest a life cycle of one year. As in *B. pterotum*, growth seems to be fast during the first months of life and slow later.

On cruise 4 the fish less than about 40 mm long were immature while most of the larger fish were maturing or ripe. Most of the fish caught on cruise 6 were ripe, spawning or had recently spawned. Fish from the northern part of the Arabian Sea were generally immature.

Other species

Symbolophorus evermanni, which dominated in area G on cruise 1, had a bimodal size distribution (Fig. 19), but the samples were too small to draw conclusions about growth.

Myctophum brachygnatum, dominating in area I on cruises 1 and 6, and *M. spinosum* dominant in area E on cruise 6, had both a single mode (Fig. 20, 21).

The *Diaphus* species, which dominated in some areas, also had one mode (Fig. 22, 23). *D. regani*, which were important in area D, were significantly larger on cruise 5 (spring 1976) than on cruise 6 (autumn 1976).

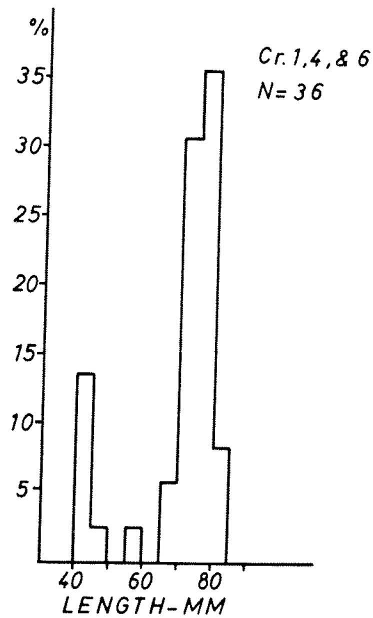

Fig. 19. Length distribution of *Symbolophorus evermanni* caught in area G.

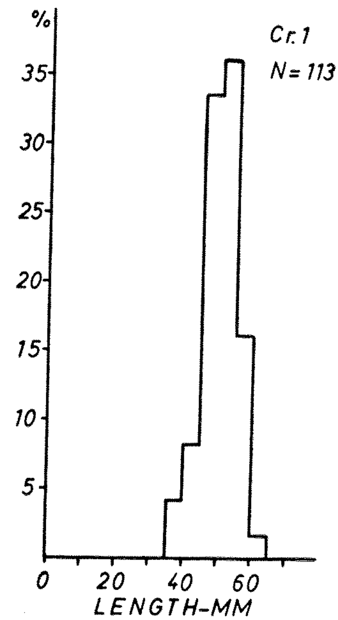

Fig. 20. Length distribution of *Myctophum brachygnatum* caught in area I.

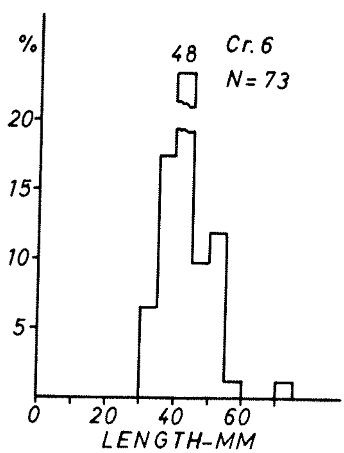

Fig. 21. Length distribution of *Myctophum spinosum* caught in area E.

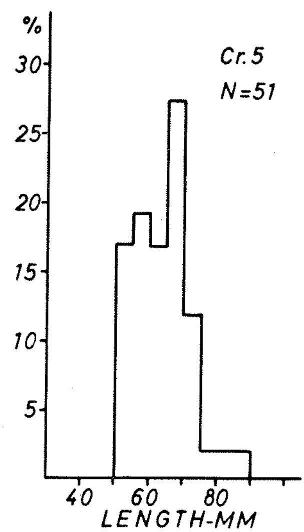

Fig. 22. Length distribution of *Diaphus thiollierei* caught in area D.

The largest species caught was *Diaphus coeruleus*, taken by bottom trawl along the continental slope both day and night (Fig. 24). The material available is not suited for further analysis of the biology of this species.

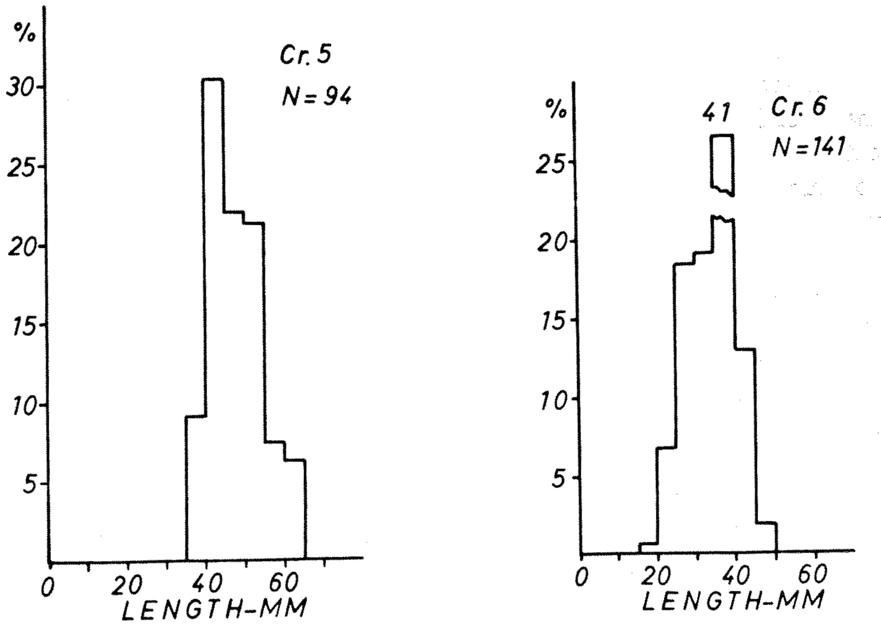

Fig. 23. Length distribution of *Diaphus regani* caught in areas B and D.

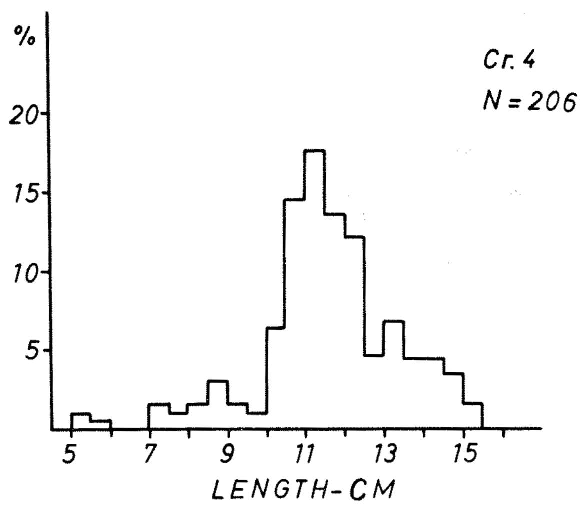

Fig. 24. Length distribution of *Diaphus coeruleus*.

DISCUSSION

Although the acoustic properties of the DSL have frequently been studied and "scattering strength of water column" has been measured (e.g. HALL 1971, 1973), few attempts have been made to use these data for estimating biomass of mesopelagic fish. BAIRD *et al.* (1974) measured volume-reverberation of a DSL in the Cariaco Trench and obtained estimates of fish densities in reasonable agreement with estimates based on catch rates. However, McCARTNEY (1976), working off Western Africa, concluded that a calibrated sounder in the range 10 – 30 kHz could be a useful tool, but "the records can be little more than a guide to net sampling programmes".

Several factors make the Arabian Sea better suited for abundance estimation of mesopelagic fish with acoustic methods than most other areas. Firstly, most of the biomass ascribed to mesopelagic fish is distributed in layers above 400 meters which makes the signal/noise level favourable, and which is within the TVG range of the equipment used. Secondly, there are few other organisms such as euphausiids, sergestid prawns or siphonophores in the DSLs. Thirdly, all the fish species contributing significantly to the biomass have gas-filled swim-bladders, making them good acoustic targets.

The shallow position of the DSLs is probably related to the high production, and therefore low transparency of the water (KAMPA 1971, DICKSON 1972). Further south, where the production is lower, the DSLs also have a deeper position (BRADBURY *et al.* 1971).

Although the trawls had no closing device, the acoustic net sonde made it possible to see whether the trawl caught the organisms in the DSL, and whether the catches from deep layers were contaminated from more shallow ones. The identification of the DSL organisms seems therefore reliable. During daytime the catches from the DSLs usually contained myctophids with only small contributions from other groups. On cruise 1, however, some large catches of *Synagrops* sp. showed that this fish contributed significantly to the DSL in the Gulf of Aden, and on cruise 4 a station southeast of Kuria Muria Island yielded mostly *Champsodon* sp. However, the occurrence of large quantities of these fish seemed to be restricted both in time and in area. Sometimes the catches from the deepest DSL gave various Gonostomatidae, Sternoptychidae, Astronesthidae and other deep-sea families, but generally they were of minor importance. Invertebrates, which are sometimes supposed to make up an important part of the DSLs, were seldom caught in large quantities. The same conclusion was drawn by KINZER (1969), working in the northeastern Arabian Sea.

During night time it was more difficult to distinguish the mesopelagic fish from plankton organisms. To solve the problem, the surface plankton was supposed to give constant echo both day and night. Therefore, when other factors were similar, the integrated echo intensity from plankton during the day was subtracted from the night recordings. Composition of the trawl catches and the relationship between the recordings on the 38 kHz and the 120 kHz echosounders were also taken into consideration. The similarity in the echo abundance of mesopelagic fish obtained during day time and during night time, seems to indicate that the method used did not introduce serious bias.

The transformation of integrated echo intensities to fish biomass is a difficult point. There are many studies of acoustic properties of myctophids and other small fish (e.g. McCartney and Stubbs 1971, Shearer 1971, Dalen, Raknes and Røttingen 1976, McCartney 1976, Nakken and Olsen 1977). These studies have shown that the density coefficient C becomes less dependent on the species and on the tilt angle as the fish length decreases towards the wavelength. It is also known that fish with swimbladders give resonance at frequencies lying between approximately

$$\frac{2\sqrt{D+10}}{l} \text{ and } \frac{3\sqrt{D+70}}{l} \text{ kHz}$$

where l is fish length in centimeters and D is depth in meters. Therefore, when a 38 kHz sounder is applied and the depth is less than about 400 m, a fish must be smaller than about 1.5 cm to give resonance. There is, however, doubt about what happens when fish length approaches wavelength. For 38 kHz, wavelength is about 4 cm, and most of the fish considered in the present study, were therefore in the critical zone. All calculations are, however, based on the assumption that the relationship $C = \text{constant } l^{-b}$ (see page 218) is applicable to all the length groups considered.

In the Gulf of Oman the acoustic measurements indicated a density of about 100 – 300 *Benthosema pterotum* per m^2 surface area. Supposing that they are distributed in two DSLs with a total depth range of 100 m, this corresponds to about 1 to 3 fish per m^3 in these layers. The density in the upper layer during night may be of the same order of magnitude.

The krill trawl used, had an opening of about 320 m^2. If the trawl caught myctophids with 100% efficiency, station Nos 449 and 450, both taken during night (Table 5), would indicate densities of 0.5 and 1.3 g/m^3 or 0.6 and 1.6 $fish/m^3$ respectively. Station No. 419 taken during daytime in the upper DSL gave 6.3 g/m^3, corresponding to about 8 $fish/m^3$ filtered water. These figures are underestimates as the efficiency of the gear was obviously less than 100%. These stations were, however, taken in areas where the density was higher than the average for the whole Gulf.

Various estimates of population densities in DSLs have been published, all giving much lower values than those obtained in the present study. JOHNSON *et al.* (1956) found about one fish per 1000 m^3 water. Based on catch rates, BAIRD *et al.* (1974) estimated the density of *Diaphus taaningi* in the Cariaco Trench to about 2 fish per 1000 m^3. Based on acoustic measurements they obtained estimates varying from 13 to 130 fish per 1000 m^3. CLARKE (1973), studying myctophids in the Hawaiian area, arrived at about 0.55 fish/m^2 based on catch rates.

From the size data and the counting of growth rings in the otoliths, it can be tentatively concluded that the two most important species, *Benthosema pterotum* and *B. fibulatum*, have a life cycle of one year or less. Few studies of tropical myctophids have been carried out, but BAIRD *et al.* (1974) concluded that *Diaphus taaningi*, reaching a size of about 40 mm, probably have a one-year life cycle. LEGAND (1967) drew the same conclusion for *Notolychnus valdiviae* reaching about 30 mm. Boreal species as *Stenobrachius leucopsaurus* (SMOKER and PEARCY 1970) and *Benthosema glaciale* (HALLIDAY 1970, GJØSÆTER 1973) reach about 32 mm after one year, *Myctophum affine* reach about 36 mm (ODATE 1966) while *Notoscopelus kroeyeri* seem to grow to about 80 – 90 mm during their first year of life (GJØSÆTER 1981). The growth rates assumed for the *Benthosema* species therefore seem reasonable. Consequently, the yearly production of these species is as high as, or higher than, their standing stock.

From the figures given by CUSHING (1973) the mean primary production in the area covered by R.V. "Dr. Fridtjof Nansen" is about 220 gCm^{-1} 180 day^{-1} during the SW monsoon and 50 gCm^{-1} 180 day^{-1} inthe NE monsoon. These values can be converted to gram wet weight suing the factor 0.065 (see CUSHING 1971). A primary production about 4.2 kgm^{-2} $year^{-1}$ is then found. The area studied was about 1.7×10^{12} m^2, and the primary production was therefore 7.1×10^9 tonnes $year^{-1}$. An assumed mean production of mesopelagic fish of about 1×10^8 ton $year^{-1}$ represents therefore between 1 and 2% of the primary production.

CUSHING (1973) also presented estimates of secondary production and using his figures, the secondary production in the area studied seems to be about 1×10^9 tonnes $year^{-1}$ or 0.6 kgm^{-2} $year^{-1}$. Thus, the production of mesopelagic fish is about 10% of the secondary production. It seems, therefore, that if an ecological efficiency of 10% at each trophic level is assumed, the mesopelagic fish utilize the entire secondary production.

It has been shown in other areas also that the production of mesopelagic fish is higher than might be expected from the primary production figures (CLARKE 1973). This may be partly explained by efficiency higher than 10% in oceanic waters (e.g. GRAZE 1970) or by bacterio-plankton production (VINOGRADOV 1973).

In the northern part of the Arabian Sea myctophids were often observed in waters with very low oxygen concentrations. The same was noted by KINZER (1969). From studies in Californian waters, DUNLAP (1971) concluded that there was no general relationship between oxyclines and DSL. BAIRD *et al.* (1974) found *Diaphus taaningi* in water with oxygen concentrations of about 0.35 ml/l in the Cariaco Trench.

KINZER (1969) observed full stomachs with contents showing only slight traces of digestion in *Benthosema pterotum* found in the oxygen minimum in the Arabian Sea, and concluded that they feed on copepods in this layer. He also found a few *Diaphus* spp. which were all empty. BAIRD *et al.* (1975) concluded that *D. taaningi* from the Cariaco Trench feed little, if at all, during day time. HOLTON (1969), who studied feeding of *Triphoturus mexicanus*, found mainly empty stomachs during the day and he wrote that "it is possible that this fish does not continue digestion of the food it has consumed in the surface waters, but regurgitates the undigested portion while descending in order to reduce metabolic oxygen needs while residing in oxygen minimum waters". The present data show that the *Benthosema* species do not regurgitate their food when descending. It is not clear, however, whether the presence of little digested food sometimes found in their stomachs indicates that they stop digestion to save oxygen or that they feed during day in the oxygen minimum zone.

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MESOPELAGIC FISH OFF MOZAMBIQUE

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ABSTRACT

GJØSÆTER, J. and BECK, I.M. 1981. Mesopelagic fish off Mozambique. *FiskDir. Skr. Ser. HavUnders.*, *17:* 253—265.

The mesopelagic fauna off Mozambique was studied on five cruises of R.V. "Dr. Fridtjof Nansen" during 1977 and 1978. It primarily consisted of Myctophids. At most stations, *Benthosema fibulatum* or *Diaphus* spp. were dominant.

The abundance was estimated using a 38 kHz echo sounder and electronic integrators. In a zone from the shore to about 200 nautical miles (n. miles) about 5 to 9 million tonnes of mesopelagic fish were estimated to be present. No seasonal variation in abundance was observed. Catch rates were generally low.

INTRODUCTION

The mesopelagic fish seem to be an important potential resource for future fisheries. Large stocks of myctophids have been observed in the Arabian Sea and off southwest Africa. Species distributions have been studied off south Africa (GRINDLEY and PENRITH 1965, HULLEY 1972, a and b) and off Kenya and Somalia (KOTTHAUS 1972, GJØSÆTER 1981). Collections from oceanic waters from about 20°N to 45°S were studied by NAFPAKTITIS and NAFPAKTITIS (1969) and NAFPAKTITIS (1978). There seems to be little information on mesopelagic fish from Mozambique and adjacent waters although some collections of *Diaphus* from this area were treated by NAFPAKTITIS (1978).

From August 1977 to June 1978 the Norwegian research vessel "Dr. Fridtjof Nansen" surveyed fisheries resources off Mozambique (SÆTRE and SILVA 1979). During these surveys, data on mesopelagic fish were collected.

The purpose of the present paper is to describe the distribution of collected species and to give a preliminary estimate of abundance based on acoustical methods. Some aspects of the biology of the species involved are also discussed.

MATERIALS AND METHODS

R.V. "Dr. Fridtjof Nansen" worked off Mozambique from August 1977 to June 1978. The whole coast was covered four times. Details on cruise tracks and the work carried out are described in the cruise reports (ANON. 1977, 1978 a, b and c).

R.V. "Dr. Fridtjof Nansen" is a 150-foot combined stern trawler and purse seiner. The main engine of 1500 Hp gives a maximum speed of 13 knots. The boat carries two pelagic trawls and one bottom trawl. A satellite navigator allows a very precise determination of position.

ACOUSTICS

The acoustic equipment consists of three scientific sounders (120, 50 and 38 kHz), two echo integrators, each of two channels, one sonar (18 kHz) and one net-sonde (50 kHz). The two echo integrators were coupled to the 38 kHz sounder.

Echo integrator values were read at each n.mile and averaged over five n.miles. Continuous watch was kept on the acoustical instruments, and fishing was conducted whenever the echo recordings changed characteristics. The acoustical data were scrutinized once a day. Integrator contributions due to false bottoms, wakes etc. were deleted, and the readings were split into four categories: small pelagic fish, demersal fish, plankton and fish larvae and mesopelagic fish.

Following FORBES and NAKKEN (1972) the output of an echo integrator is proportional to the fish density:

$$P_A = C_W \cdot M \qquad (1)$$

where P_A is the fish density expressed in weight per unit area, M is the integrator reading and C_W a conversion coefficient depending on the fish species and size, as well as on the characteristics of the sounder and integrator used. It can be shown that C_W is proportional to the length of the fish (NAKKEN 1975, NAKKEN and OLSEN 1977).

A value of C_W of 10.5 tonnes/mm and n.mile^2 was established for a mixture of mainly pelagic species with an average length of about 17 cm on a previous cruise of R.V. "Dr. Fridtjof Nansen". The density coefficients, C_W, used in the present study will then be:

$$C_W = 10.5 \; \frac{l}{17} \qquad (2)$$

where l is the mean length in cm of the observed species. More details on the acoustical methods applied, and a discussion of the reliability of acoustic estimates of biomass of mesopelagic fish are given by GJØSÆTER (1981).

FISHING GEAR

The pelagic trawl had an opening of 16×16 fathoms, usually corresponding to a height of 17 m when fishing. It was operated with superkrubs doors and 120 m bridles and always used together with a net sonde.

The bottom trawl covered a track of about 60 m between the doors when fishing with 40 m bridles. The footrope was equipped with 0.5 m bobbins, and the effective vertical opening of the net was 6.5 – 7.0 m.

A cover net with small meshes was used on both trawls.

BIOLOGICAL SAMPLES

From all catches mesopelagic fish were sorted out and the volume measured or estimated. From some catches, samples were also preserved for species identification and for biological studies. The stations where such samples were collected, are shown in Fig. 1.

RESULTS AND DISCUSSION

SPECIES COMPOSITION AND DISTRIBUTION

The composition of the species in all catches was studied during a cruise in April – June 1978, and in some during January – March 1978. A list of species caught on these cruises is given in Table 1. Preliminary identification carried out at sea during the other cruises suggests that the dominant species were the same.

Benthosema fibulatum was caught both in bottom and pelagic trawl in the whole area, and was dominant at most stations south of 20°S. The species is very abundant in the northwestern Indian Ocean (GJØSÆTER 1981), and KOTTHAUS (1972) caught specimens as far south as about 5°S in the Indian Ocean. GRINDLEY and PENRITH (1965) reported the occurrence of *B. fibulatum* off the Natal coast, but further examination has shown that the specimen reported is *B. suborbitale* (HULLEY pers.com.) However, another specimen from their material (42°11'S, 19°26'E) showed in fact to be *B. fibulatum* (HULLEY pers.com.). Based on these records and the present observations, *B. fibulatum* seems to be present in coastal waters along the whole east Africa.

At the station (25°14'S, 34°33.5'E) *B. pterotum* was the only species caught. The catch was about 7 kg. Previously, *B. pterotum* was known in the Arabian Sea south to about 3°N off east Africa (GJØSÆTER 1981). The present record seems to be the first from the southern Indian Ocean.

These specimens could not be distinguished from *B. pterotum* from the northern Arabian Sea in their distribution of photophores, but they had

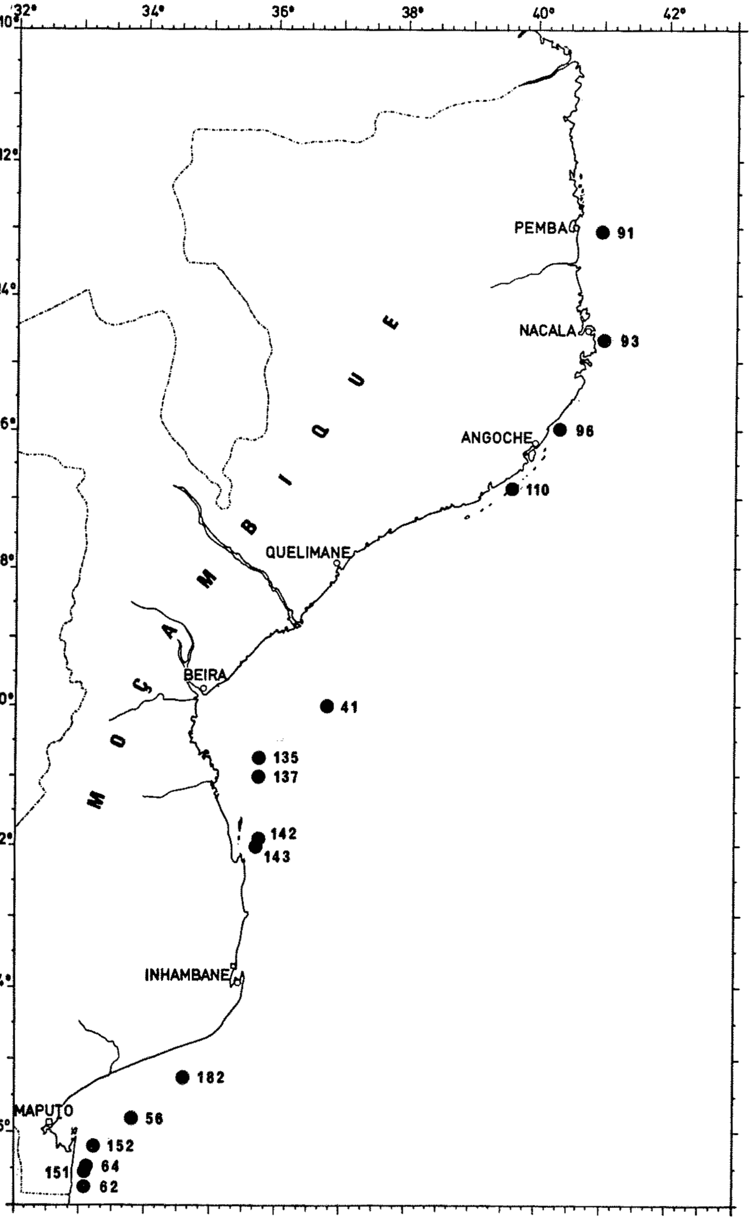

Fig. 1. Fishing stations where mesopelagic fish were caught off Mozambique.

Table 1. Species identified during cruises 3 and 4 of R.V. "Dr. Fridtjof Nansen". 1 and 2 indicate first and second species in abundance, + indicates presence in sample.

AREA	NORTHERN AREA			SOFALA BANK				BAZARUTO		DELAGOA		INHACA			
St. no.	91	93	96	41	100	135	137	142	143	56	182	64	62	152	151
Bentosema fibulatum		+	+			1	2	1		2			1	1	+
B. pterotum											1				
Hygophum hygomi				+											
Myctophum spinosum	+														
M. obtusirostrum			+												
M. asperum				+											
M. aurolaternatum				+											
Symbolophorus evermanni	1		+												
Diaphus garmani			1			2	+	+		+					
D. nielseni		1	+		2		+								
D. watasei				1					2	1		1		2	1
D. suborbitale			+												
D. thiollierei		+			+					+					
D. perspicillatus		2	2	2	1	+	+								
Lampanyctus sp.	2		+												
Maurolicus muelleri							1	+	1						2
Polymetme corythaeola														+	

Table 2. Number of gill rakers on the first gill arch of *Benthosema pterotum* from the Indian Ocean.

Number of gill rakers	Frequency of occurrence		
	Position		
	21°37′N 59°37′E	24°37′N 57°11′E	25°14′S 34°33,5′E
6+1+14			1
15			1
7+1+13			1
14			5
15			12
16			7
17			1
8+1+16	2		2
17	6	7	
18	1	9	
19		1	
9+1+15	1		
16			
17	2		
18		2	
19		1	
Mean nr.	26.00	26.90	23.10

a lower number of gill rakers on the first gill arch (Table 2). Although the difference in this single character does not justify description of a new species, it warrants further studies on the taxonomy of *B. pterotum* stocks along the east coast of Africa.

Hygophum hygomi was caught at only one station, at about 20°S latitude. This species apparently has a bisubtropical distribution (BEKKER 1965). NAFPAKTITIS and NAFPAKTITIS (1969) caught this species between about 20°S and 35°S in the Indian Ocean.

Myctophum spinosum and *M. aurolaternatum* were caught at one station each, between 13° and 15°S. NAFPAKTITIS and NAFPAKTITIS (1969) caught both species southwards to 10°S in the Indian Ocean.

M. asperum and *M. aurolaternatum* were caught at one station at about 20°S latitude. NAFPAKTITIS and NAFPAKTITIS (1969) caught *M. asperum* between 10°N and 10°S and *M. aurolaternatum* between 5°N and 10°N in the Indian Ocean.

Symbolophorus evermanni was the dominant species at one station at about 13°S and was present at one station near 16°S. Previously NAFPAKTITIS and NAFPAKTITIS (1969) recorded this species south to about 15°S in offshore waters.

Diaphus garmani was caught between 16°S and 26°S. It was the most abundant species in a night haul with pelagic trawl at 50 m depth at 16°S. It ranked second in a bottom trawl haul at 50 m depth at about 21°S. The records fall within the known range for this species as described by NAFPAKTITIS (1978).

D. nielseni was caught from 15°S to 21°S. At 15°S it was the dominant species. This species was only caught with the pelagic trawl. *D. nielseni* is previously known from this area (NAFPAKTITIS 1978).

D. watasei was caught between 22°S and 27°S where it ranked first or second in three bottom trawl hauls at depths between 265 and 460 m. It was never caught with the pelagic trawl. NAFPAKTITIS (1978) recorded this species between 5°S and 28°S.

D. perspicillatus was caught at five stations between 14°S and 21°S. At one station (14°S) it was the dominant species, and at two station the second dominant. It was caught with both thep elagic trawl and the bottom trawl. NAFPAKTITIS (1978) recorded *D. perspicillatus* from the same area.

D. suborbitale was caught at one and *D. thiollierei* at two stations between 14°S and 17°S. Neither of them were abundant. *D. suborbitale* has previously only been recorded between 7°N and 8°S in the Indian Ocean (NAFPAKTITIS 1978, GJØSÆTER 1981), and therefore the present catch localities (17°S) probably are a southern extension of the distribution of this species. *D. thiollierei* has previously been recorded from this area.

Maurolicus muelleri was caught at four stations between 21°S and 27°S. At two of these stations it was the dominant species and at one it ranked second. It was caught both with pelagic and bottom trawls. *M. muelleri* has a world-wide distribution. It has been captured off south Africa (GREY 1964), but apparently not off Mozambique.

Polymetme corythaeola was caught in a bottom trawl at one station (26°S). This species is previously known from the Indian Ocean off Natal (about 29°S–30°S) and in the northern Indian Ocean south to about 5°S off Zanzibar. The present record suggests that it may be distributed continuously along the east African coast.

BEHAVIOUR

Mesopelagic fish were observed in most of the area studied. In offshore waters a deep-scattering layer (DSL) was usually observed. Sometimes this layer was found below 500 m which was the lower limit for the echo integration carried out to estimate fish abundance. At sunset the DSL, or part of it, migrated towards the surface and during night it was situated in the upper 100 m (Fig. 2). Usually the DSL consisted of dispersed fish, and schools were seldom observed. Generally, the fish density was highest close to the continental slope.

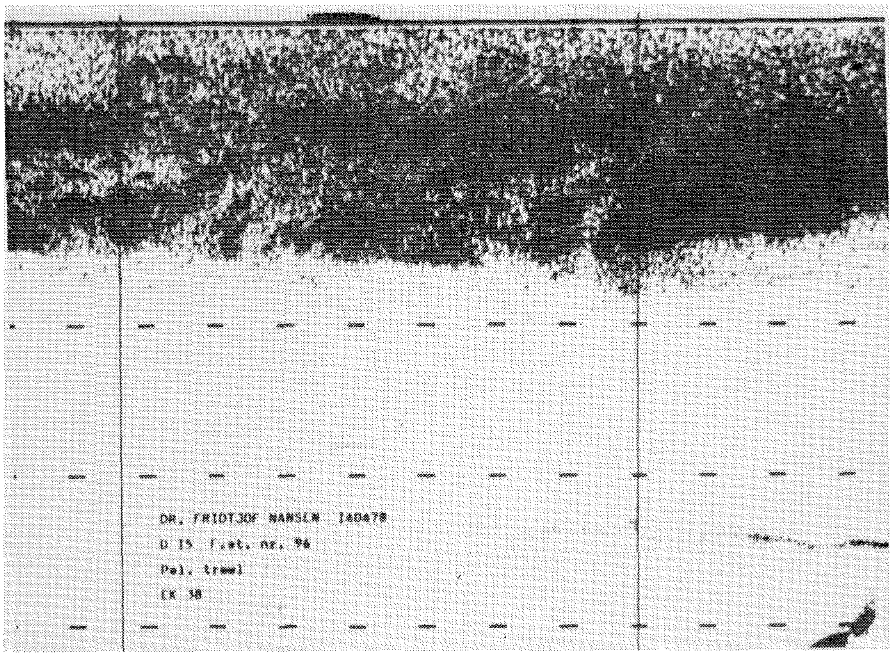

Fig. 2. Mixture of plankton and mesopelagic fish during night time. Distance between horizontal lines 50 m.

Along most of the coast, a scattering layer was found above the bottom at depths between 300 and 350 m. Mesopelagic species were also observed close to the bottom in more shallow waters (Fig. 3). *Diaphus watasei* was found in this bottom layer both day and night. During daytime *Benthosema fibulatum* and *Maurolicus muelleri* were also caught in this layer.

BIOLOGICAL OBSERVATIONS

Observations on the biology of mesopelagic fish species were made on the January-March 1978 and April-June 1978 cruises. Fig. 4 gives the length distributions of the sampled species.

Benthosema fibulatum, which was the most abundant species, ranged in length between about 30 and 90 mm. There was no difference in size distribution between samples from March and from May 1978.

Primary growth rings in the otoliths, which are supposed to be formed daily (PANNELLA 1974), were studied in a few fish, and the results seem to confirm the conclusion that *B. fibulatum* reaches its maximum size in about one year (GJØSÆTER 1981).

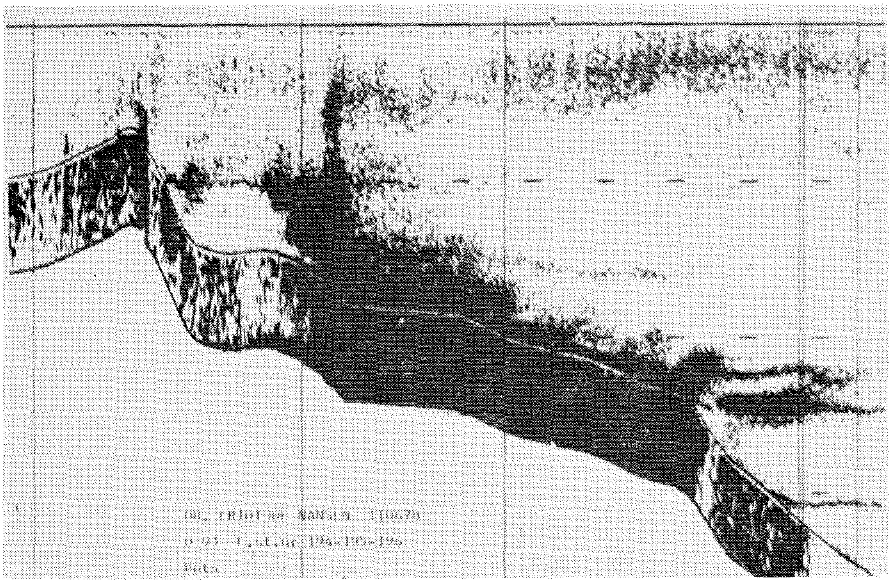

Fig. 3. Recordings of mesopelagic fish along the continental slope. Distance between horizontal lines 50 m.

Gonads and stomach contents were studied in a sample from March 1978. Most of the gonads were mature or ripening. Copepods and euphausids were the most important food items.

The catch of *B. pterotum* consisted of adult fish only. A few gonads were studied, and they were all maturing or ripe. Therefore, there seems to be little doubt that the species spawn in this area. The biology of these two species is further discussed by GJØSÆTER (1981).

Ranking after *Benthosema fibulatum*, *Diaphus perspicillatus* was the most abundant species in the area. The length of this species ranged between about 20 and 60 mm. NAFPAKTITIS (1978) found mature eggs in females ranging between 48 and 54 mm in the Indian Ocean. For Hawaiian waters, CLARK (1973) suggests that the species reaches maturity after one year (note: *D. elucens* is a synonym).

D. nielseni was also fairly common in the catches. This species ranged in length between 30 and 50 mm with a mode between 35 and 40 mm. NAFPAKTITIS (1978) found three females, measuring 32–36 mm, which had ripe gonads.

Diaphus watasei was often abundant in bottom trawl catches. This large species ranged in length between 80 and 170 mm. Fish caught during March 1978 had a slightly lower modal length than those caught during May 1978. The gonads were studied in one sample from March 1978. Only females were caught and they were, with few exceptions, ripe. The

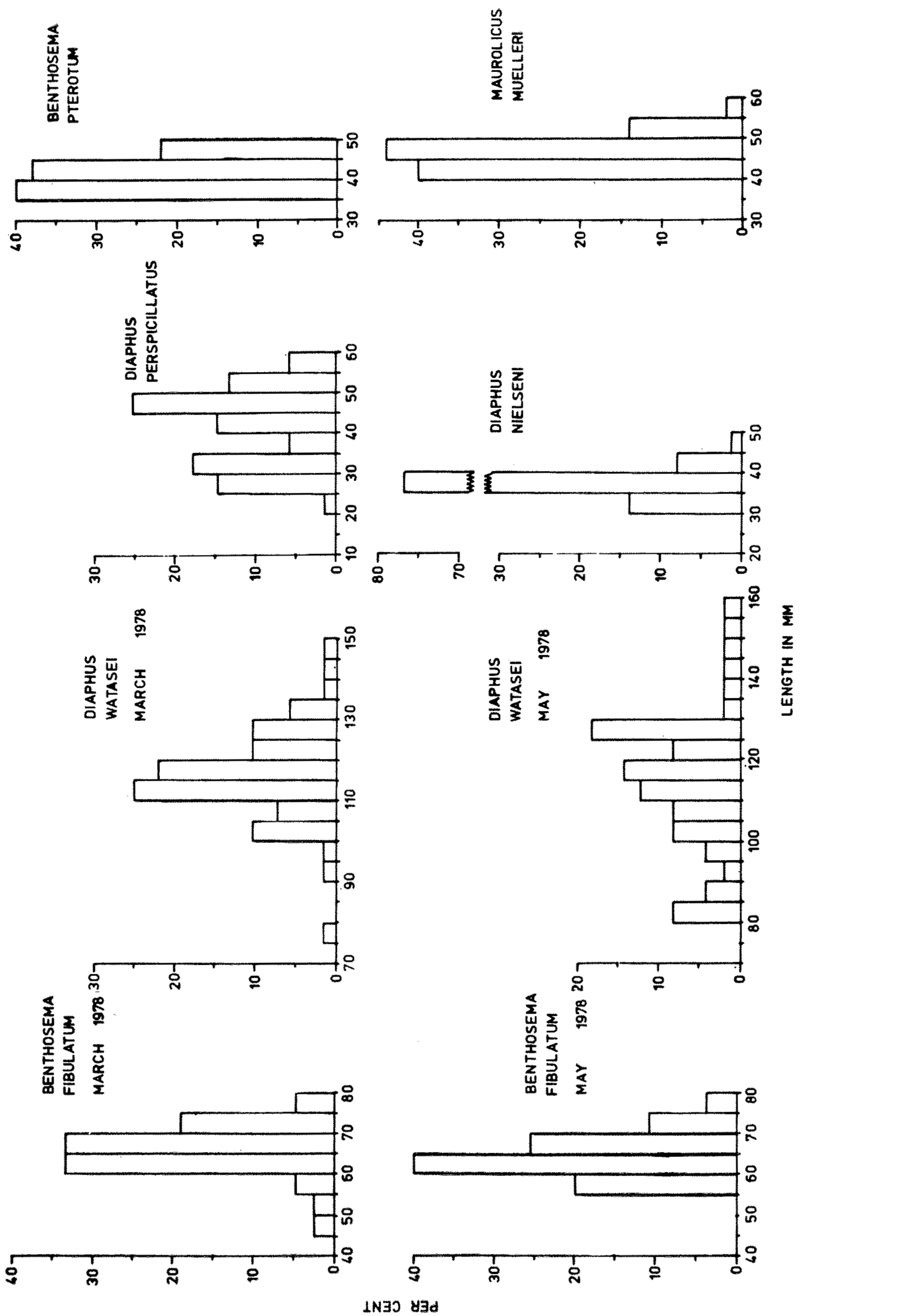

Fig. 4. Length distribution of some mesopelagic fishes caught off Mozambique.

smallest ripe female observed, was 110 mm. NAFPAKTITIS (1978) found ripe females measuring between 124 and 157 mm in the same area. Stomachs contained euphausids, prawns, small squids and copepods. Myctophids were also observed in one stomach, but the species could not be identified due to advanced digestion. *D. watasei* is usually caught close to the bottom. Juveniles are, however, supposed to live pelagically.

Maurolicus muelleri was fairly common in parts of the area studied. Only adult specimens, ranging in size between 40 and 60 mm, were caught.

ABUNDANCE

The abundance of mesopelagic fish has been calculated from acoustical data and the length composition of the catches (Table 3). As length data are only available from two cruises, and no significant difference could be observed between those data, the same lengths, 40 mm for the area north of 18°S and 50 mm for the area south of 18°S, were used for all surveys.

The estimate obtained from the first cruise is probably an underestimate as the source level of the acoustic equipment at that time was lower than on the later cruises. Although this is partly compensated for in the calculations, the detection threshold was different in such a way that small concentrations of weak targets, such as mesopelagic fish, were not included in the integrated echo abundance.

The other estimates, 5.5–8.5 million tonnes for the whole area, are fairly uniform.

Based on the material available, it is not possible to demonstrate any consistant differences in abundance between seasons or between areas. In general, however, it seems that the area from the 200 m depth contour

Table 3. Abundance estimates (in million tonnes) of mesopelagic fish in zones of 0—30 n.miles and 30—200 n.miles off the 200 m depth contour off Mozambique.

Cruise no.	South of 18°S		North of 18°S		Total
	0—30 n.miles	30—200 n.miles	0—30 n.miles	30—200 n.miles	
1	1.2	1.0	0.02	0.3	2.5
2	0.4	2.9	0.8	1.7	5.8
3	0.9	5.9	0.2	1.5	8.5
4	1.1	1.2	0.5	2.7	5.5
Mean	0.9	4.5	0.4	1.6	5.6

to 30 n.miles seaward of this line has a higher density of mesopelagic fish than the more offshore areas.

Averaging over the three last cruises, which are supposed to give the most reliable estimates, the following densities were observed:

	0–30 n.miles	30–200 n.miles
N of 18°S	9.1 g/m^2	6.4 g/m^2
S of 18°S	11.0 g/m^2	4.5 g/m^2

These mean densities are much lower than those generally observed in the northern Arabian Sea (GJØSÆTER 1981), but they are still high enough to be of commercial interest. An approximate estimate of maximum potential yield of an unexploited stock can be derived from the equation:

$$Y\ max = 0.5\ MB_O$$

where M is the instantaneous mortality rate and B_O the size of the virgin stock (GULLAND 1970). The mortality of the mesopelagic fish in the area is not known, but the mean instantaneous mortality rate for the most important species is probably at least 2. Therefore, according to the equation above, the maximum potential yield may be similar to the stock size. This is, however, a first approximation only, and any fishery must be closely followed to discover signs of recruitment failure or other adverse effects on the stock at an early stage.

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