

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

By

JAKOB GJØSÆTER

Department of Fisheries Biology, University of Bergen, Norway

## ABSTRACT

GJØSÆTER, J. 1981. Abundance and production of lanternfish (Myctophidae) in the western and northern Arabian Sea. *FiskDir. Skr. Ser. HavUnders.*, 17: 215—251.

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.

*Benthoema pterotum* and *B. fibulatum* were the most abundant species in the area, but *Diaphus* spp. were also numerous. The *Benthoema* 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 NAFFAKTITIS and NAFFAKTITIS (1969), by KOTTHAUS (1972) and NAFFAKTITIS (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, MAKSHITAS 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 the band width 1 kHz. The angular

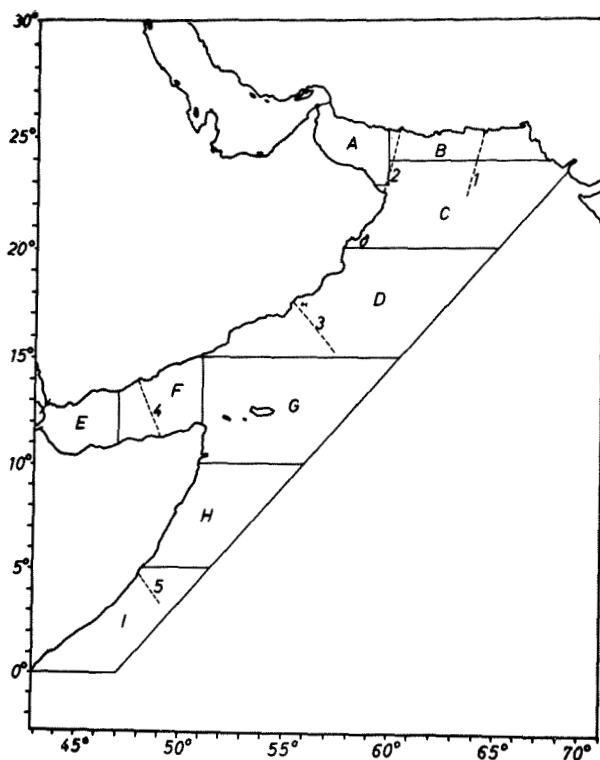


Fig. 1. The investigated area. A—I The sub-areas and 1—5 the sections referred to in the text.

aperture between 3 dB points was  $7.5^\circ$  and the source level  $130.2 \text{ dB}/1 \mu\text{Bar}$  ref. 1 m. The TVG (time varied gain) was  $20 \lg R + 2 aR$  where  $R$  is the distance between the transducer and the target, and  $a$  is the attenuation coefficient. On cruises 1 and 2 the source level was  $132.0 \text{ dB}/1 \mu\text{Bar}$  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:

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

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  $\bar{W}$  of the fish

$$C_w = C \cdot \bar{W} = (C_1 \cdot l^{-2}) \cdot (C_2 \cdot l^3) \quad (2)$$

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:

$$C_w = C \cdot l \quad (3)$$

The numerical value of  $C_w$  applied to the R.V. "Dr. Fridtjof Nansen" data was 10.5 tonnes/mm/n. mile  $\times$  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:

$$C_w = 10.5 \cdot \frac{1}{17} \quad (4)$$

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,

$$l_{\text{preserved}} = 0.98l_{\text{fresh}} - 0.55$$

established for *Benthoosema 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 NAFFAKTITIS (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)

*Benthoosema 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
<i>Electrona rissoi</i> (Cocco)									x
<i>Hygophum proximum</i> Becker		x			x	x	x	x	x
<i>Benthoosema fibulatum</i> (Gilbert & Cramer)		x	xx	xx		xx	x	x	xx
<i>B. pterotum</i> (Alcock)	xx	xx	xx	xx	xx	xx	xx		x
<i>Myctophum nitidulum</i> Garman						x	x		
<i>M. spinosum</i> (Steindachner)				x	xx	x	x		
<i>M. aurolaternatum</i> Garman						x			
<i>M. obtusirostrum</i> Tåning						x			
<i>M. brachygnathum</i> (Bleeker)								x	xx
<i>Symbolophorus evermanni</i> (Gilbert)		x		x	xx	x	xx		x
<i>Lampadena luminosa</i> (Garman)						x			
<i>Lampanyctus tenuiformes</i> Brauer						x	x		x
<i>L. macropterus</i> Brauer				x					
<i>L. nobilis</i> Tåning									x
<i>Bolinichthys longipes</i> (Brauer)		x	x	x		x			x
<i>Ceratoscopelus warmingi</i> (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
<i>D. coeruleus</i> Klunzinger	+	+
<i>D. diademophilus</i> Nafpaktitis		+
<i>D. garmani</i> Gilbert	+	+
<i>D. lobatus</i> Nafpaktitis		+
<i>D. luetkeni</i> Brauer		+
<i>D. parri</i> Tåning		+
<i>D. regani</i> Tåning		+
<i>D. thiollierei</i> Fowler	+	+

#### Area B. Coast of Pakistan

*Benthoosema 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. *Benthoosema 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 1976) 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, *Benthoosema 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 *Benthoosema 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 *Lamppanyctus macropterus* were also caught.

The near-shore mesopelagic fauna of this area has not been studied previously. A comparison with the data of NAFFAKTITIS and NAFFAKTITIS (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, *Benthoosema 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 proximum* 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 *Benthoosema 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*, *Lamppanyctus 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 *Benthoosema 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*

*Benthoosema 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. *Benthoosema pterotum* was the only myctophid fish found in the area, and during daytime this species was distributed in two layers. The upper one (layer

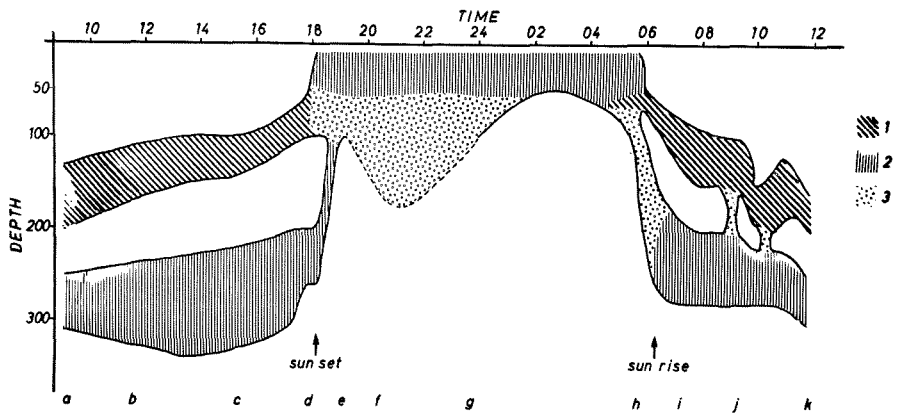


Fig. 2. The vertical migration observed during the diurnal stations in the Gulf of Oman, March 1976. 1) Schools and very dense aggregations, 2) dense recordings, 3) scattered recordings. a—k refer to the echograms in Fig. 3.





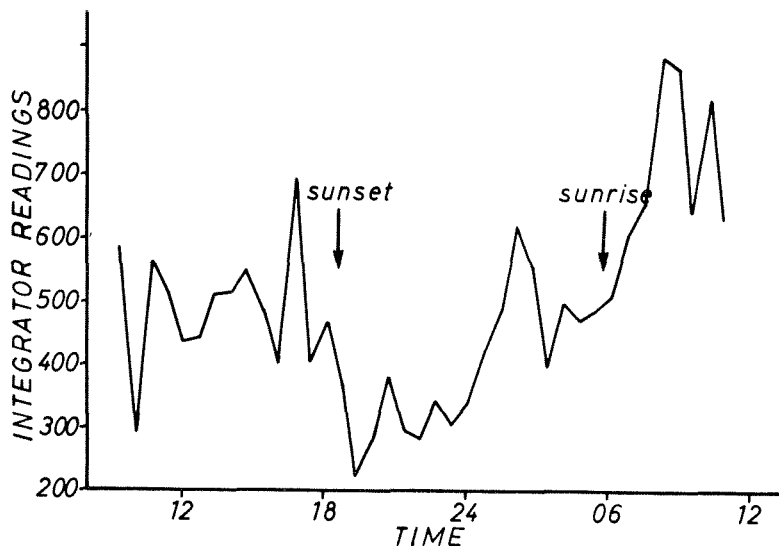


Fig. 4. Five mile averages of integrator deflection in mm/nautical mile from the diurnal station in the Gulf of Oman (see Fig. 2.).

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

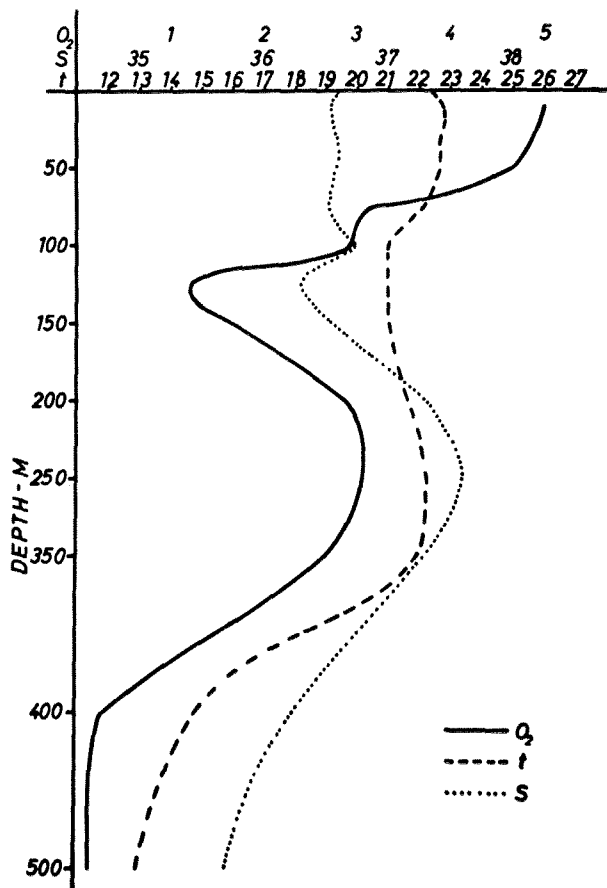


Fig. 5. Vertical distribution of temperature, salinity and oxygen at the diurnal station in the Gulf of Oman, March 1976.  $O_2$  in g/l,  $S$  ‰,  $t$   $^{\circ}C$ .

(Fig. 6). The migration pattern observed during the diurnal station was rather typical of the neritic areas where *Benthoosema perotum* 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.

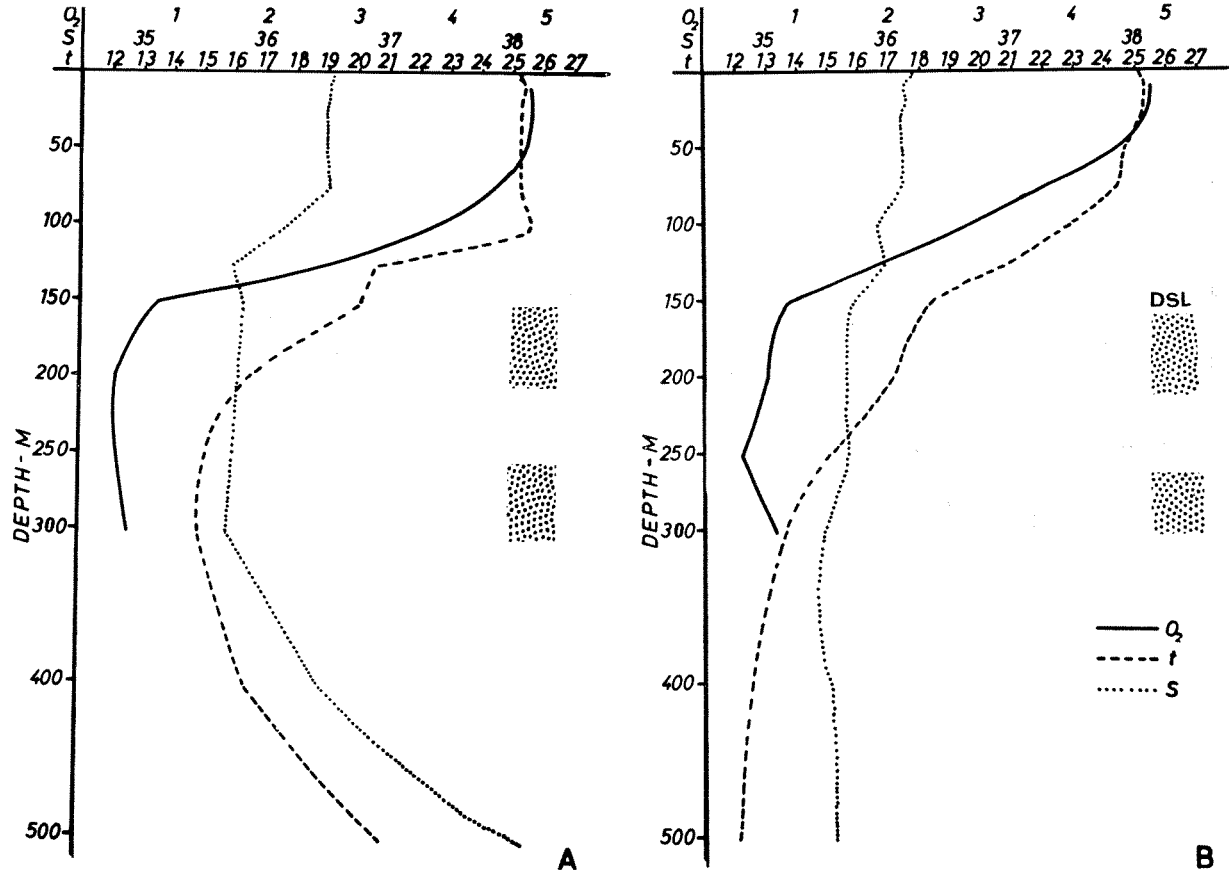


Fig. 6. Depth of DSL and vertical distribution of temperature, salinity and oxygen from two stations off Pakistan.  $O_2$  in g/l,  $S$  ‰, and  $t$  C°.

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 <sup>ns</sup>	0.56 <sup>ns</sup>	3.03 <sup>xx</sup>	−0.94 <sup>ns</sup>	−1.41 <sup>ns</sup>
2		−2.69 <sup>xx</sup>	1.44 <sup>ns</sup>	−0.59 <sup>ns</sup>	2.14 <sup>x</sup>	2.02 <sup>x</sup>
3	2.06 <sup>x</sup>	0.50 <sup>ns</sup>	0.55 <sup>ns</sup>	2.94 <sup>xx</sup>	−2.98 <sup>xx</sup>	4.46 <sup>xxx</sup>
4	−1.51 <sup>ns</sup>		−1.84 <sup>ns</sup>	−2.23 <sup>x</sup>	2.81 <sup>xx</sup>	−2.63 <sup>xx</sup>
5	1.04 <sup>ns</sup>		−0.96 <sup>ns</sup>	−2.62 <sup>xx</sup>	−0.85 <sup>ns</sup>	0.50 <sup>ns</sup>

<sup>ns</sup> not significant

<sup>x</sup>  $p < 0.05$

<sup>xx</sup>  $p < 0.01$

<sup>xxx</sup>  $p < 0.001$

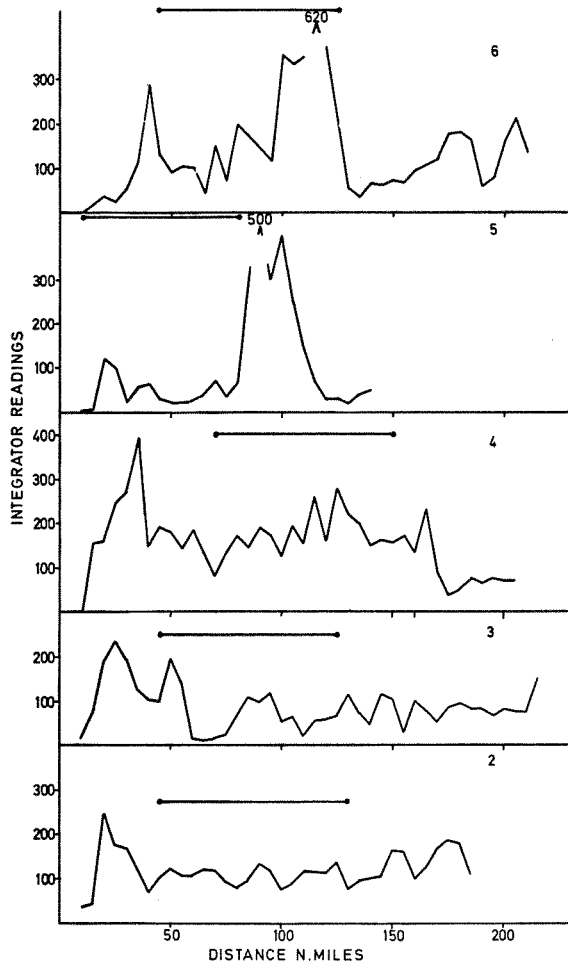


Fig. 7. Five mile averages of integrator deflection in mm/n.mile along the five sections shown in Fig. 1. — day recordings. 1—6) Cruise numbers.

- 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.

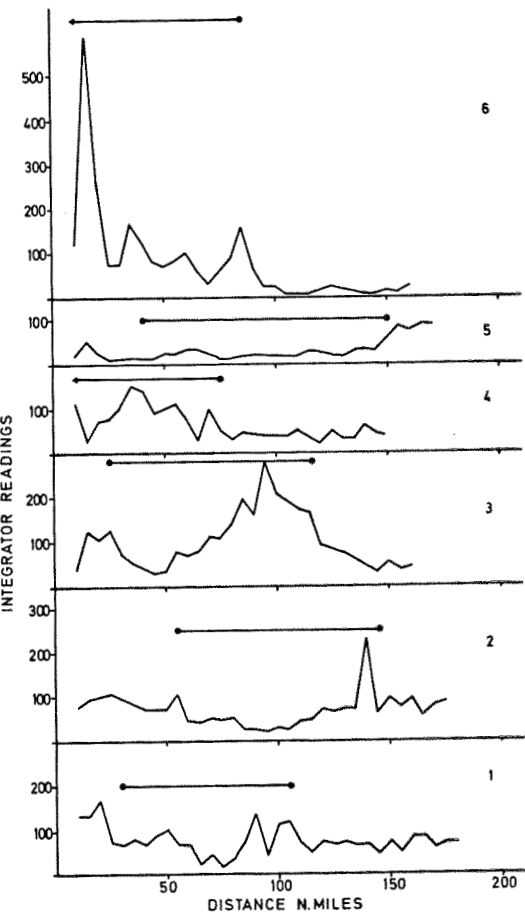
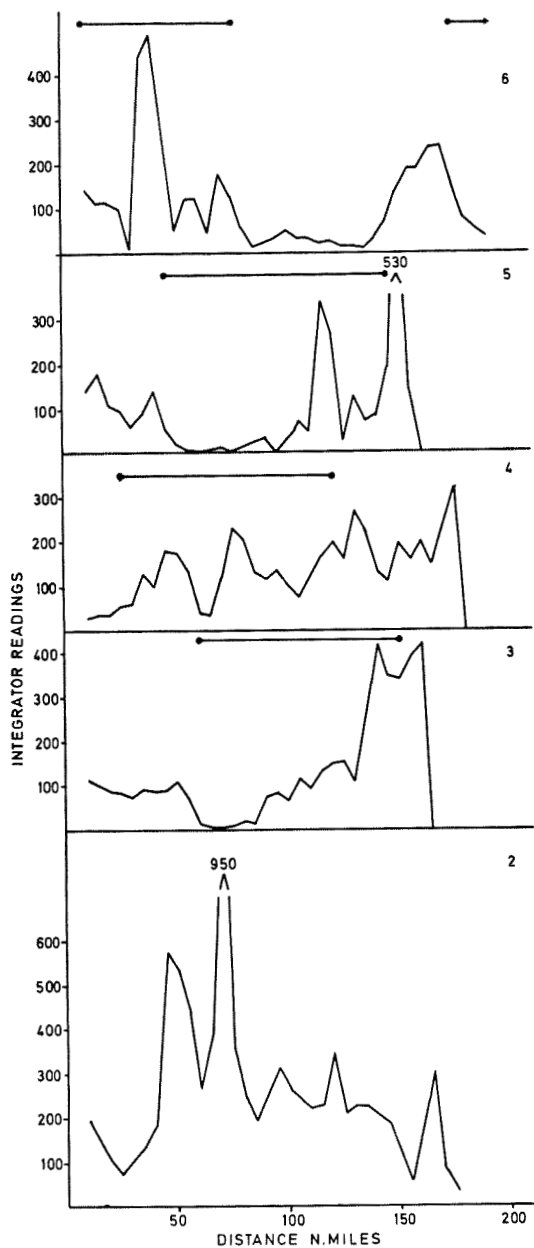


Fig. 7 C.

Fig. 7 B.

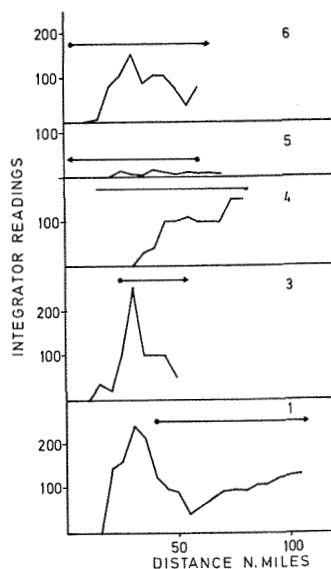
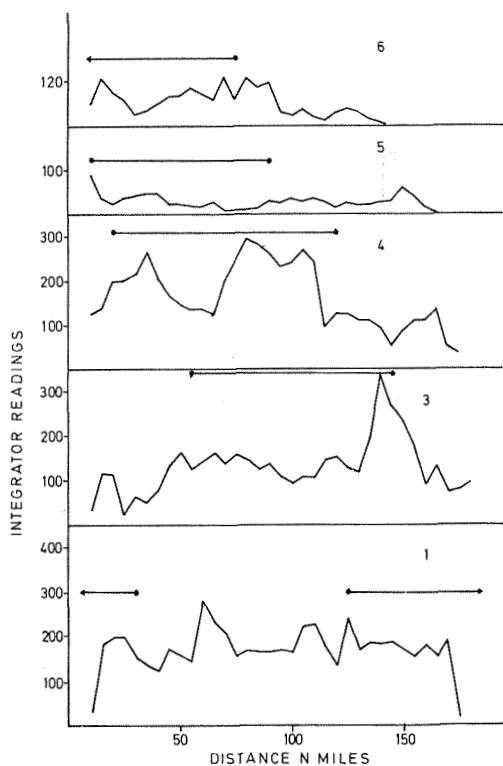


Fig. 7 E.

Fig. 7 D.

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  $114.5 \pm 48.9$  and  $106.8 \pm 53.2$  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

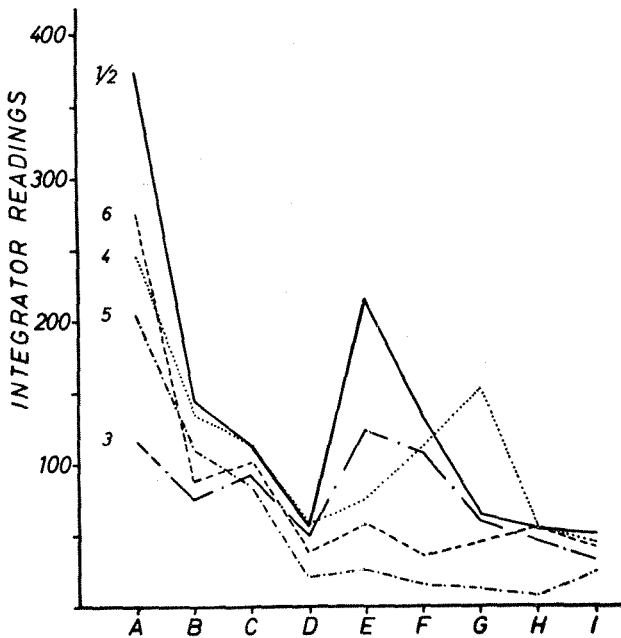


Fig. 8. Mean integrator deflection in mm/n.mile in 9 subareas (A–I) shown in Fig. 1. 1–6) Cruise number.

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	—	—	—	—	<i>B. pterotum</i>	<i>B. fibulatum</i>	<i>S. evermanni</i>	<i>B. fibulatum</i>	<i>M. brachygnatum</i>
	[32]	[31]	[35]	[37]	30	80	75	80	<i>B. fibulatum</i> 60
3	<i>B. pterotum</i>	<i>B. pterotum</i>	<i>B. pterotum</i>	<i>B. fibulatum</i>	<i>S. evermanni</i>	—	<i>B. fibulatum</i>	—	<i>B. fibulatum</i>
	40	35	35	50	50	[55]	60	[55]	47
4	<i>B. pterotum</i>	<i>B. pterotum</i>	<i>B. pterotum</i>	<i>B. fibulatum</i>	<i>B. pterotum</i>	<i>B. fibulatum</i>	<i>B. fibulatum</i>	—	<i>Diaphus</i> spp.
	32	31	<i>B. fibulatum</i> 35	<i>B. pterotum</i> 37	38	<i>B. pterotum</i> 35	37	[38]	<i>B. fibulatum</i> 38
5	<i>B. pterotum</i>	<i>B. pterotum</i>	—	<i>Diaphus</i> spp.	<i>B. pterotum</i>	—	—	<i>Diaphus</i> spp.	<i>Diaphus</i> spp.
	33	35	[35]	42	33	[80]	[75]	62	45
6	<i>B. pterotum</i>	<i>B. pterotum</i>	<i>B. pterotum</i>	<i>Diaphus</i> spp.	<i>M. spinosum</i>	<i>Diaphus</i> spp.	<i>B. fibulatum</i>	—	<i>M. brachygnatum</i>
	32	34	34	40	<i>B. pterotum</i> 31	40	80	[80]	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<sup>2</sup> × 10<sup>3</sup>.

Cruise no.	Period	Area									Total (488.1)
		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)	
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<sup>2</sup> 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<sup>2</sup> 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 &gt; 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, mycto- phids kg	Myctophids kg/hour	Dominant species
	<i>1975</i>								
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	<i>B. pterotum</i>
239	7.11	B	P	250	day	610	600	1200	<i>B. pterotum</i>
	<i>1976</i>								
281	31.1	E	P	85	night	410	405	810	<i>B. pterotum</i>
310	22.2	D	P	280	day	2000	2000	6000	<i>B. fibulatum</i>
314	26.2	D	P	270	day	250	230	460	<i>B. pterotum</i>
319	28.2	A	P	20	night	900	800	1600	<i>B. pterotum</i>
320	29.2	A	P	20	night	1500	1500	3000	<i>B. pterotum</i>
325	5.3	A	P	140	day	800	780	1560	<i>B. pterotum</i>
326	5.3	A	P	20	night	450	440	880	<i>B. pterotum</i>
327	5.3	A	P	100	day	450	430	860	<i>B. pterotum</i>
329	6.3	A	P	20	night	5000	5000	10000	<i>B. pterotum</i>
330	6.3	A	P	130	day	650	650	1300	<i>B. pterotum</i>
352	26.3	C	P	90	day	300	200	400	<i>B. pterotum</i>
419	25.5	D	KT	200	day	1500	1500	3000	<i>Diaphus</i> spp.
427	3.6	C	P	130	day	10000	10000	20000	<i>B. pterotum</i>
433	10.6	B	P	100	dawn	1000	1000	2000	<i>B. pterotum</i>
434	10.6	B	P	175	day	600	500	1000	<i>B. pterotum</i>
436	13.6	C	P	20	night	300	300	600	<i>B. pterotum</i>
448	20.6	A	P	15	night	1500	1300	2600	<i>B. pterotum</i>
449	20.6	A	KT	20	night	800	700	1400	<i>B. pterotum</i>
450	20.6	A	KT	30	night	1500	1300	2600	<i>B. pterotum</i>
451	20.6	A	P	30	night	500	400	800	<i>B. pterotum</i>
469	29.8	B	P	300	day	1000	1000	1000	<i>B. pterotum</i>
543	26.10	G	BT	120	night	10000	9600	19000	<i>B. fibulatum</i>

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.

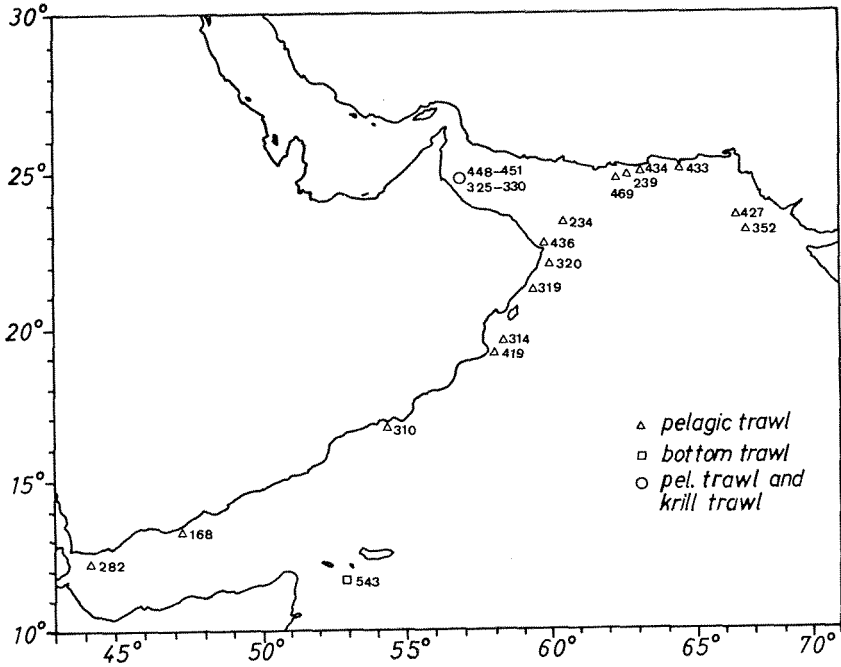


Fig. 9. Map showing trawl stations giving more than 400 kg meso-pelagic fish/hr. trawling.

#### BIOLOGY OF THE IMPORTANT SPECIES

##### *Benthoosema 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.

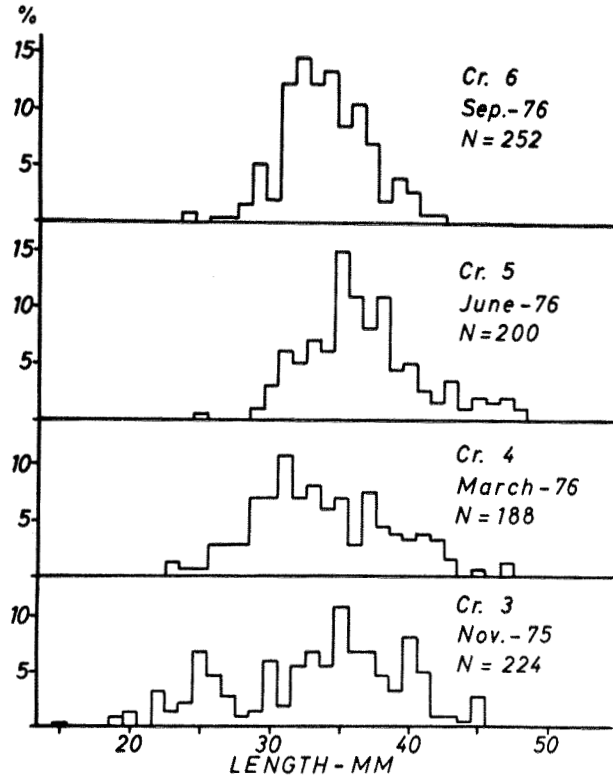


Fig. 10. Length distribution of *Benthosema pterotum* caught off Pakistan.

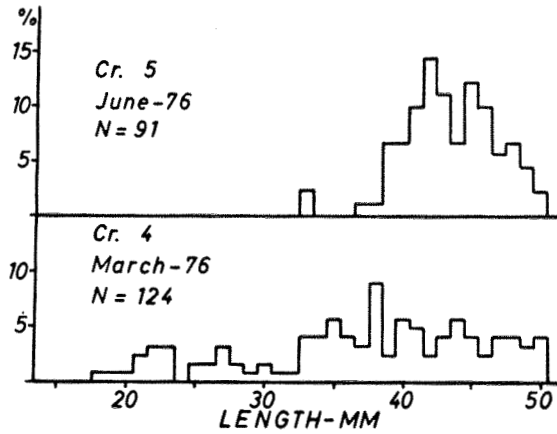


Fig. 11. Length distribution of the light coloured *Benthosema pterotum* caught in the Swatch off Pakistan.

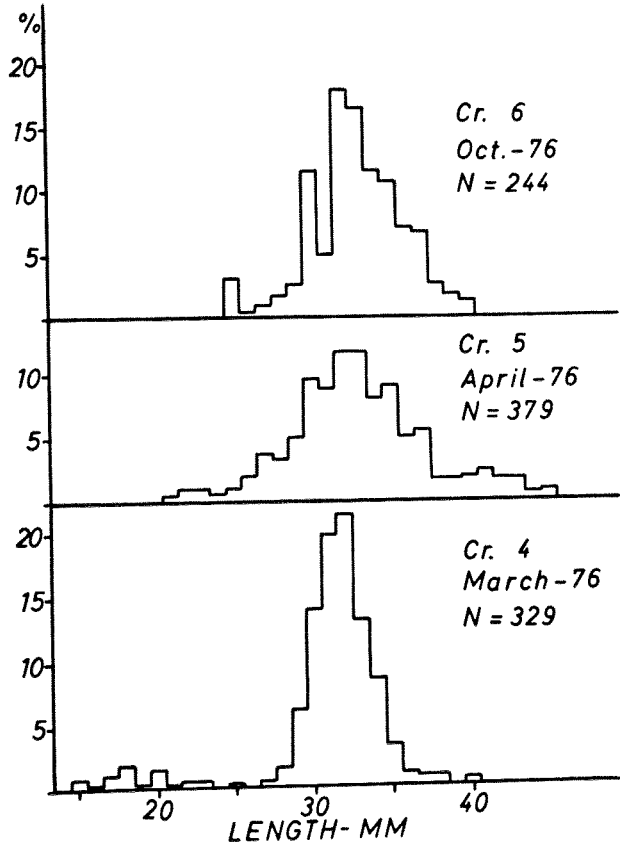


Fig. 12. Length distribution of *Benthosema pterotum* caught in the Gulf of Oman.

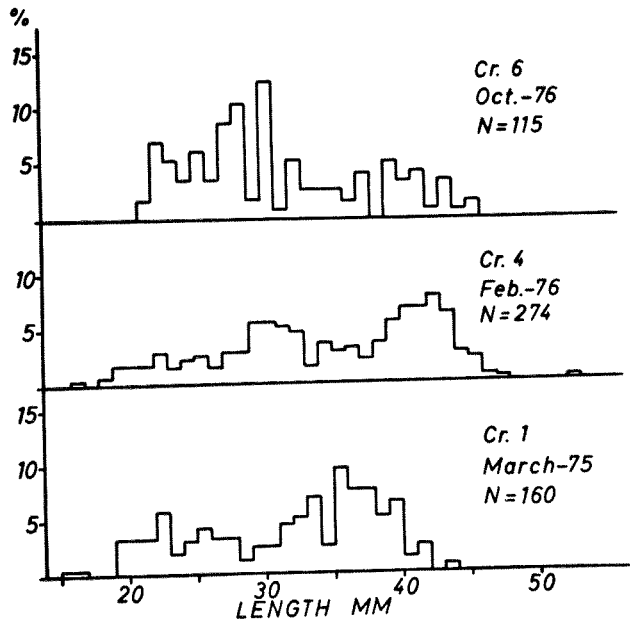


Fig. 13. Length distribution of *Benthosema pterotum* caught in the Gulf of Aden.

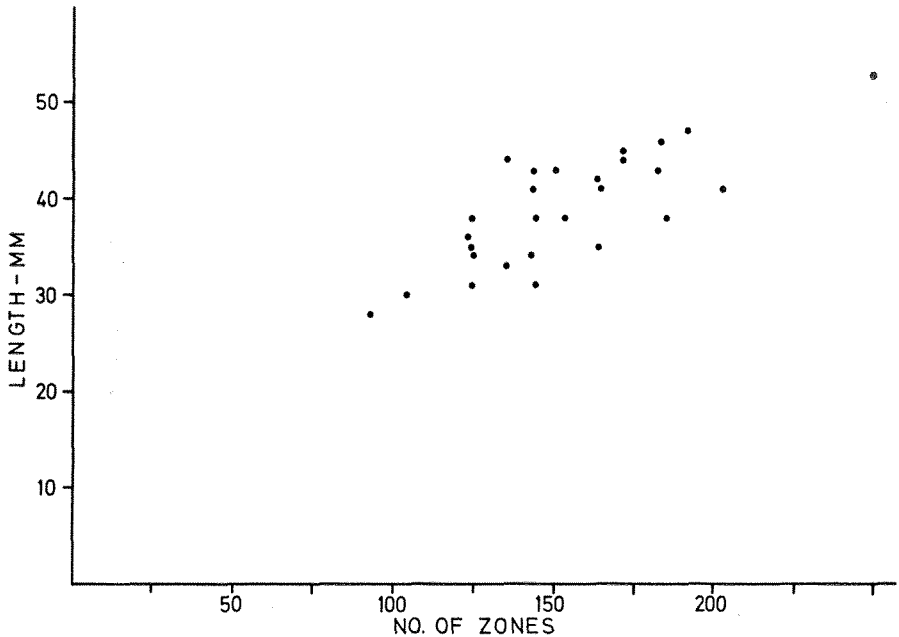


Fig. 14. Relation between length and number of primary rings in the otoliths of *Benthosema pterotum*.

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 September–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.

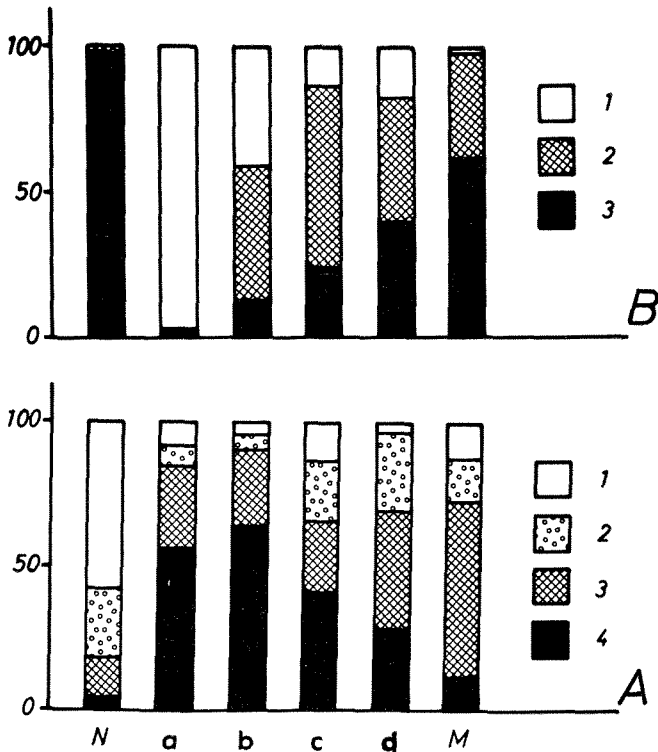


Fig. 15. Diurnal variation in degree of filling (A) and stage of digestion (B) of stomach contents of *Benthoosema pterotum* caught at the diurnal station in the Gulf of Oman March 1976. N) Noon; a, b, c, d) night stations, M) morning. 1—4 degree of filling (A) and stage of digestion (B) (see text).

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 *Benthoosema 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).

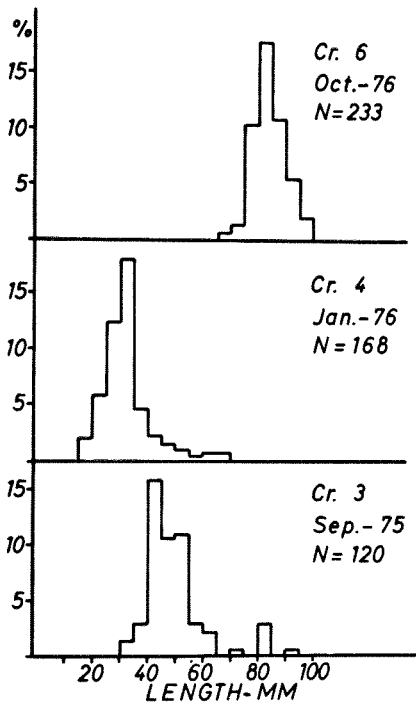


Fig. 16. Length distribution of *Benthoosema fibulatum* caught off Somalia.

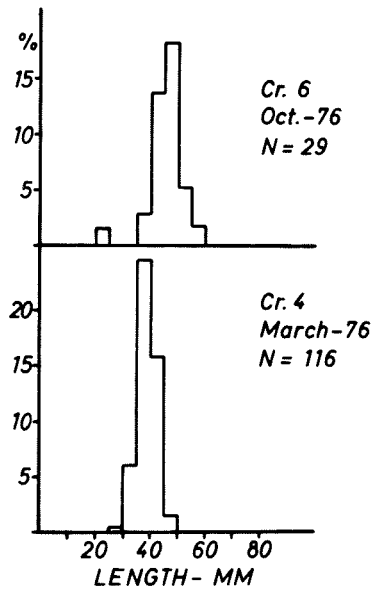


Fig. 17. Length distribution of *Benthoosema fibulatum* caught in the northern Arabian Sea.

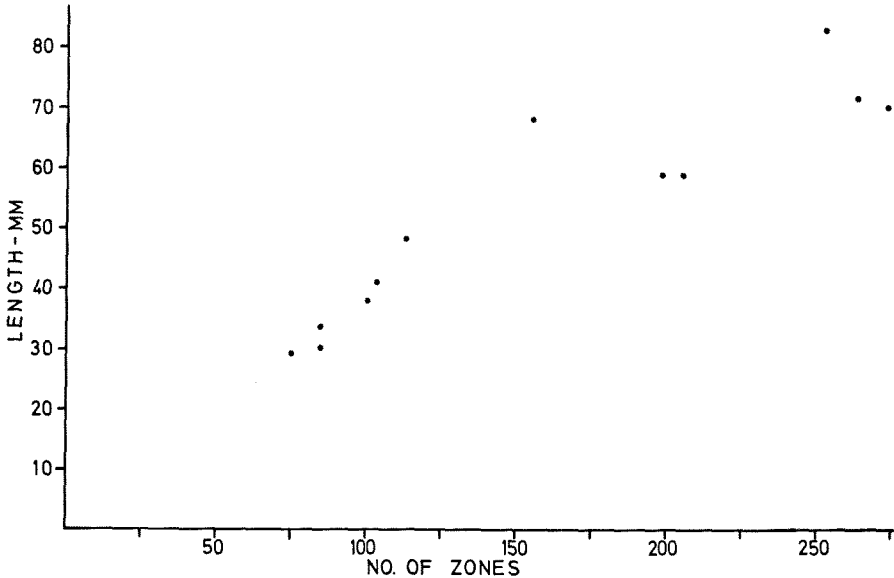


Fig. 18. Relation between length and number of primary rings in the otoliths of *Benthosema fibulatum*.

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).

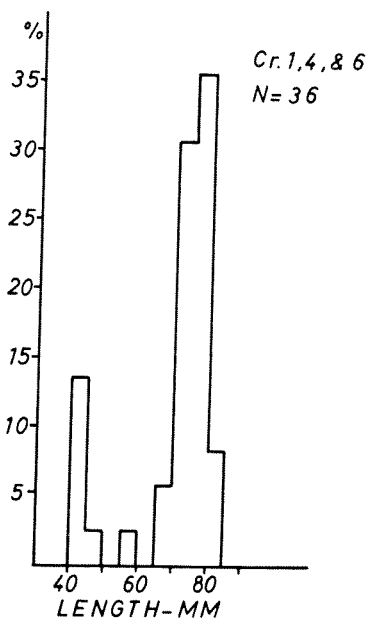


Fig. 19. Length distribution of *Symbolophorus evermanni* caught in area G.

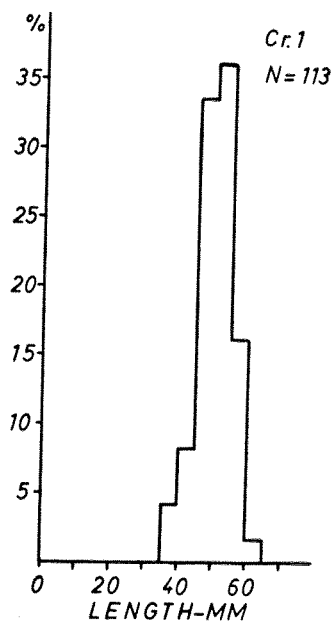


Fig. 20. Length distribution of *Myctophum brachygnatum* caught in area I.

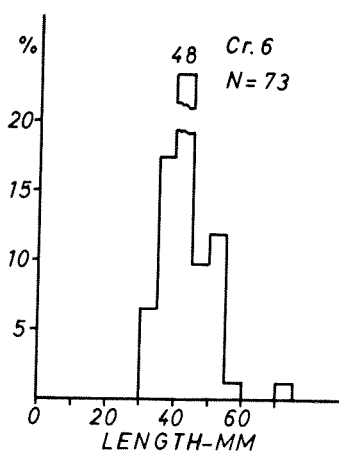


Fig. 21. Length distribution of *Myctophum spinosum* caught in area E.

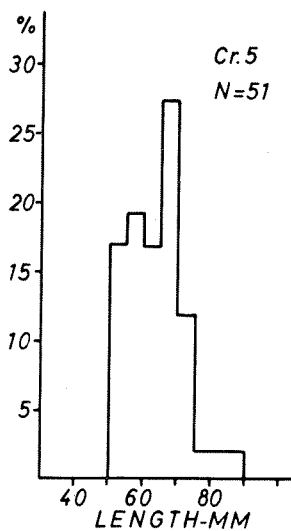


Fig. 22. Length distribution of *Diaphus thiollierei* caught in area D.

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.

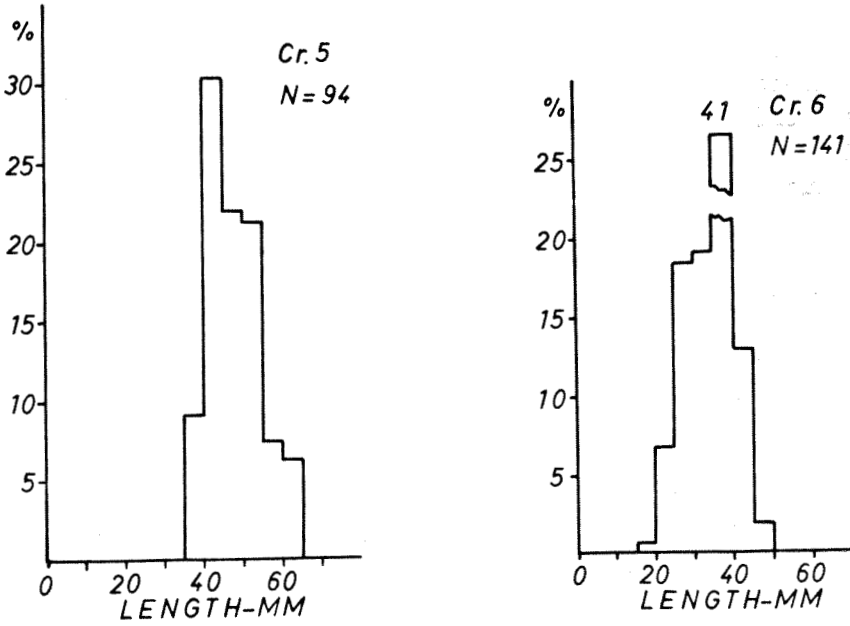


Fig. 23. Length distribution of *Diaphus regani* caught in areas B and D.

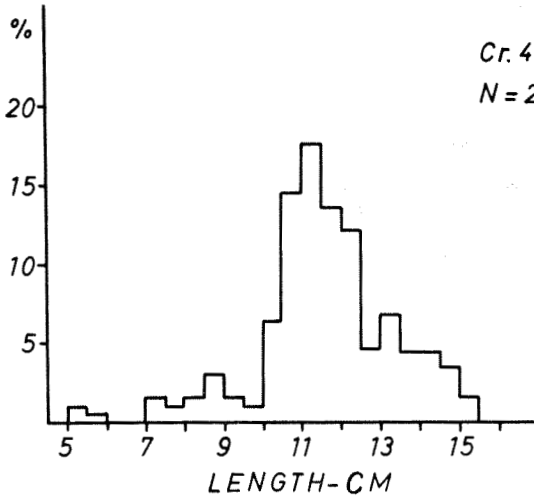


Fig. 24. Length distribution of *Diaphus coeruleus*.

## 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, Astrostethidae 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 north-eastern 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  $\text{m}^2$  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  $\text{m}^3$  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  $320 \text{ m}^2$ . 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  $1.3 \text{ g/m}^3$  or 0.6 and  $1.6 \text{ fish/m}^3$  respectively. Station No. 419 taken during daytime in the upper DSL gave  $6.3 \text{ g/m}^3$ , corresponding to about 8  $\text{fish/m}^3$  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<sup>3</sup> 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<sup>3</sup>. Based on acoustic measurements they obtained estimates varying from 13 to 130 fish per 1000 m<sup>3</sup>. CLARKE (1973), studying myctophids in the Hawaiian area, arrived at about 0.55 fish/m<sup>2</sup> 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, *Benthoosema 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 *Benthoosema 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 *Benthoosema* 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<sup>-1</sup> 180 day<sup>-1</sup> during the SW monsoon and 50 gCm<sup>-1</sup> 180 day<sup>-1</sup> in the NE monsoon. These values can be converted to gram wet weight using the factor 0.065 (see CUSHING 1971). A primary production about 4.2 kgm<sup>-2</sup> year<sup>-1</sup> is then found. The area studied was about 1.7 × 10<sup>12</sup> m<sup>2</sup>, and the primary production was therefore 7.1 × 10<sup>9</sup> tonnes year<sup>-1</sup>. An assumed mean production of mesopelagic fish of about 1 × 10<sup>8</sup> ton year<sup>-1</sup> 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<sup>9</sup> tonnes year<sup>-1</sup> or 0.6 kgm<sup>-2</sup> year<sup>-1</sup>. 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.

#### ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to O. Nakken, leader of the "Pelagic Fish Assessment Survey North Arabian Sea", for making this study possible, for many useful discussions and for valuable comments on the manuscript.

I also wish to thank the captain, the crew and the scientific staff participating on R.V. "Dr. Fridtjof Nansen" for collecting samples of the mesopelagic fauna.

I am also much indebted to Dr. B.G. Nafpaktitis for identifying some of the *Diaphus* species collected, and to Dr. O. Dragesund, Dr. J. Gray and Dr. S. Vader for helpful comments on the manuscript.

My thanks are also due to I.M. Beck for able assistance through all phases of this study, to H. Ullebust for drawing the figures, to C. Hamilton for English proof reading and J. Silchenstedt for typing the manuscript.

## REFERENCES

- AHLSTROM, E.H. 1968. Appraisal of the IIOE larval fish collection at IOBC, Cochin, India. *UNESCO Inf. Pap.*, 137: 1—10.
- ALI KHAN, J. 1976. Distribution and abundance of fish larvae off the coast of West Pakistan. *Marine Biology*, 37: 305—324.
- ANON. 1975. Report on cruise Nos 1 and 2 of R.V. "Dr. Fridtjof Nansen". *Indian Ocean Fishery and Development Programme. Pelagic Fish Assessment Survey North Arabian Sea, FAO*: 1—15. 6 tab., 38 fig.
- ANON. 1976a. Report on cruise No 3 of R.V. "Dr. Fridtjof Nansen". *Indian Ocean Fishery and Development Programme. Pelagic Fish Assessment Survey North Arabian Sea, FAO*: 1—9. 1 tab., 40 fig.
- ANON. 1976b. Report on cruise No 4 of R.V. "Dr. Fridtjof Nansen". *Indian Ocean Fishery and Development Programme. Pelagic Fish Assessment Survey North Arabian Sea, FAO*: 1—8. 1 tab., 30 fig.
- ANON. 1976c. Report on cruise No 5 of R.V. "Dr. Fridtjof Nansen". *Indian Ocean Fishery and Development Programme. Pelagic Fish Assessment Survey North Arabian Sea, FAO*: 1—10. 1 tab., 27 fig.
- ANON. 1977a. Final report. Survey results of R.V. "Dr. Fridtjof Nansen". *Indian Ocean Fishery and Development Programme. Pelagic Fish Assessment Survey North Arabian Sea, FAO*: 1—26. 9 tab., 5 fig.
- ANON. 1977b. Report on cruise No 6 of R.V. "Dr. Fridtjof Nansen". *Indian Ocean Fishery and Development Programme. Pelagic Fish Assessment Survey North Arabian Sea, FAO*: 1—9. 1 tab., 45 fig.
- BAIRD, R.C., WILSON, D.F., BECKETT, R.H. and HOPKINS, T.L. 1974. *Diaphus taaningi* Norman, the principal component of a sound scattering layer in the Cariaco Trench, Venezuela. *J.Mar. Res.*, 32: 301—312.
- BAIRD, R.C., HOPKINS, T.L. and WILSON, D.F. 1975. Diet and Feeding chronology of *Diaphus taaningi* (Myctophidae) in the Cariaco Trench. *Copeia*, 1975: 356—365.
- BELTESTAD, A.K. and BRUNVOLL, L. 1975. Fangst og deteksjon av krill. Tokt med "G.O. Sars" 1.april til 15.mai 1975. FTFI Notat: 1—11 [In Norwegian, Mimeo.]
- BRADBURY, M.G., ABBOTT, D.P., BOVBERG, R.V., MARISCAL, R.N., FIELDING, W.C., BARBER, R.T., PEARSE, V.B., PROCTOR, S.J., OGDEN, J.C., WOURMS, J.P., TAYLOR, L.R., CRISTOFFERSON, J.G., CRISTOFFERSON, J.P., MCPHEARSON, R.M., WYNNE, M.J. and STROMBORG, P.M. JR. 1971. Studies on the fauna associated with the deep scattering layers in the equatorial Indian Ocean, conducted on R.V. "Te Vega" during October and November 1964. P. 409—452 in FARQUHAR, G.B. ed. *Proceedings of an international symposium on biological sound scattering in the ocean. Rep No 005*. Maury Center for Oceanic Science, Washington.
- BROTHERS, E.B., MATHEWS, C.P. and LASKER, R. 1976. Daily growth increments in otoliths from larval and adult fishes. *Fishery Bull. Fish Wildl. Serv. U.S.*, 74: 1—8.
- CLARKE, T.A. 1973. Some aspects of the ecology of lantern-fishes (Myctophidae) in the Pacific Ocean near Hawaii. *Fishery Bull. Fish Wildl. Serv. U.S.*, 71: 401—434.
- CUSHING, D.H. 1971. Upwelling and fish production. *Adv. Mar. Biol.*, 9: 255—334.
- CUSHING, D.H. 1973. Production in the Indian Ocean and the transfer from the primary to the secondary level. P. 475—486 in ZEITZCHEL, B. ed. *The Biology of the Indian Ocean*. Springer Verlag, Berlin.
- DALEN, J., RAKNES, A. and RØTTINGEN, J. 1976. Target strength measurements and acoustic biomass estimation of capelin and 0-group fish. *Coun. Meet. Int. Coun. Explor. Sea*, 1976 (B:37): 1—13. 8 figs. [Mimeo.]

- DICKSON, R.R. 1972. On the relationship between ocean transparency and the depth of sonic scattering layers in the North Atlantic. *J. Cons. perm. int. Explor. Mer*, 34: 416—422.
- DUNLAP, C.R. 1971. A reconnaissance of the deep scattering layers in the eastern tropical Pacific and the Gulf of California. P. 395—408 in FARQUHAR, G.B. ed. *Proceedings of an international symposium on biological sound scattering in the ocean. Rep. No 005*. Maury Center for Ocean Science, Washington.
- FORBES, S.T. and NAKKEN, O. eds. 1972. Manual of methods for fisheries resources survey and appraisal, part 2. The use of acoustic instruments for fish detecting and abundance estimation. *FAO. Man. Fish. Sci.*, (5): 1—138.
- FURSA, T.I. 1973. The distribution of fish plankton in the North-eastern part of the Arabian Sea. *J. Ichthyol.*, 13: 536—542.
- GJØSÆTER, J. 1973. Age, growth and mortality of the myctophid fish, *Bentosema glaciale* (Reinhardt), from western Norway. *Sarsia*, 52: 1—14.
- GJØSÆTER, J. 1981. Life history and ecology of the myctophid fish *Notoscopelus elongatus kroeyeri* from the north-east Atlantic. *FiskDir. Skr. Ser. HavUnders.*, 17: 133—152.
- GJØSÆTER, J. and BECK, I.M. 1981. Mesopelagic fish off Mozambique. *FiskDir. Skr. Ser. HavUnders.*, 17: 253—265.
- GRAZE, N.V. 1970. The biomass and production of different trophic levels in the pelagic communities of south seas. P. 458—468 in STEELE, J.H. ed. *Marine food chains*. Univ. of Calif. Press., Berkeley.
- HALL, M. 1971. Volume backscattering in the South China Sea and the Indian Ocean. *J. Acoust. Soc. Amer.*, 50: 940—945.
- HALL, M. 1973. Volume backscattering in the Tasmanian Sea, The Coral Sea and the Indian Ocean. *J. Acoust. Soc. Amer.*, 54: 473—477.
- HALLIDAY, R.G. 1970. Growth and vertical distribution of the glacier lanternfish, *Bentosema glaciale*, in the North-western Atlantic. *J. Fish. Res. Bd Can.*, 27: 105—116.
- HASSAN, S.M. Reproduction of *Bentosema pterotum* and *B. fibulatum* from the Arabian Sea (in prep.).
- HOLTON, A.A. 1969. Feeding behaviour of a vertically migrating lanternfish. *Pacific Sci.*, 23: 325—331.
- JOHNSON, H.R., BACKUS, R.H., HERSEY, J.B. and OWEN, D.M. 1956. Suspended echosounder and camera studies of midwater sound scatters. *Deep-Sea Res.*, 3: 266—272.
- KAMPA, E.M. 1971. Photoenvironment and sonic scattering. P. 51—58 in FARQUHAR, G.B. ed. *Proceedings of an international symposium on biological sound scattering in the sea. Rep. No. 005*. Maury Center for Ocean Science, Washington.
- KINZER, J. 1969. On the quantitative distribution of zooplankton in deep scattering layers. *Deep-Sea Res.*, 16: 117—125.
- KOTTHAUS, A. 1972. Fische des Indischen Ozeans. Ergebnisse der ichthyologischen Untersuchungen während der Expedition des Forschungsschiffes "Meteor" in den Indischen Ozean, Oktober 1964 bis Mai 1965. A. Systematischer Teil, 4. Iniomi (Nachtrag: Fam. Myctophidae). "Meteor" *Forsch.-Ergebnisse Reihe D.*, 12: 12—35.
- LEGAND, M. 1967. Cycles biologiques des poissons mesopelagiques dans l'est de l'Océan Indien. Première note. *Scopelopsis multipunctatus* Brauer, *Gonostoma* sp., *Notolychnus valdiviae* Brauer. *Cah. O.R.S.T.O.M. sér. Océanogr.*, 5: 47—71.

- LEGAND, M. ET RIVATON, J. 1967. Cycles biologiques des poissons mésopélagiques dans l'est de l'océan Indien. Deuxième note. Distribution moyenne des principales espèces de l'ichtyofaune. *Cah. O.R.S.T.O.M. sér. Océanogr.*, 5: 73—98.
- LEGAND, M. ET RIVATON, J. 1969. Cycles biologiques des poissons mésopélagiques de l'est de l'océan Indien. Troisième note: Action prédatrice des poissons micro-nectoniques. *Cah. O.R.S.T.O.M., sér. Océanogr.*, 7: 29—45.
- LEGAND, M., BOURRET, P., FOURMANOIR, P., GRANDPERRIN, R., GUEREDRAT, J.A., MICHEL, A., RANGUREL, P., REPELIN, R. ET ROGER, C. 1972. Relations trophiques et distributions verticales en milieu pélagiques dans l'océan Pacifique Inter-tropical. *Cah. O.R.S.T.O.M. sér. Océanogr.* 10: 303—393.
- LEHMANN, E.L., 1975. *Nonparametrics: Statistical methods based on ranks*. Mc.Graw-Hill, Book Company, New York, 457 p.
- MAKSHITAS, YA.P. and RYABTSEV, YU. YA. 1973. Results of observations of sound-scattering layers in the Atlantic and Indian Oceans during the expedition of the R.V. "Sergey Vivilov". *Oceanology*, 13: 418—423.
- MCCARTNEY, B.S. 1976. Comparison of the acoustic and biological sampling of the sonic scattering layers: R.R.S. "Discovery" SOND Cruise. *J. Mar. Biol. Ass. U.K.*, 56: 161—178.
- MCCARTNEY, B.S. and STUBBS, A.R. 1971. Measurements of the target strength of fish in dorsal aspect, including swimbladder resonance. P. 180—210 in FARQUHAR, G.B. ed. *Proceedings of an international symposium on biological sound scattering in the ocean. Rep. No. 005*. Maury Center for Ocean Science, Washington.
- MIDTUN, L. and NAKKEN, O. 1977. Some results of abundance estimation studies with echo integrators. *Rapp. P.-v. Réun. Cons. int. Explor. Mer*, 170: 253—258.
- MYRSETH, B. Abundance, biology and chemical composition of mesopelagic fish off the coast of Pakistan. (in prep).
- NAKKEN, O. 1975. On the problem of determining the relationship between integrated echo intensity and fish density. *Coun. Meet. int. Coun. Explor. Sea, 1975*: (B:26): 1—8. [Mimeo.]
- NAKKEN, O. and OLSEN, K. 1977. Target strength measurements of fish. *Rapp. P.-v. Réun. Cons. int. Explor. Mer*, 170: 52—69.
- NAKKEN, O. OG VESTNES, G. 1970. Ekkointegratoren. Et apparat for å måle fisketetthet. *Fiskets Gang*, 56: 932—936. [In Norwegian.]
- NAFFAKTITIS, B.G. and NAFFAKTITIS, M. 1969. Lanternfishes (Family Myctophidae) collected during cruises 3 and 6 of the R.V. "Anton Bruun" in the Indian Ocean. *Bull. Los Angeles County Mus. Nat. Hist. Science*, 5: 1—79.
- NAFFAKTITIS, B.G. 1978. Systematics and distribution of lanternfishes of the genera *Lobianchia* and *Diaphus* (Myctophidae) in the Indian Ocean. *Bull. Los Angeles County Mus. Nat. Hist. Science*, 5: 1—79.
- NELLEN, W. 1973. Kinds and abundance of fish larvae in the Arabian Sea and the Persian Gulf. P. 413—430 in ZEITZCHEL, B. ed. *The Biology of the Indian Ocean*. Springer-Verlag, Berlin.
- ODATE, S. 1966. Studies on the fishes of the family Myctophidae in the Northeastern Sea of Japan. III. The determination of the age and growth of Susuki-Kadaka, *Myctophum affine* (Lütken). *Bull. Tohoku reg. Fish. Res. Lab.*, 26: 35—43. [In Jap.]
- PANNELLA, G. 1974. Otolith growth patterns: an aid in age determination in temperate and tropical fishes. P. 28—39 in BAGENAL, T.B. ed. *The ageing of Fish*. Unwin Brothers Ltd., Old Woking, Surrey.

- SHEARER, L.W. 1971. Comparisons between surface-measured swimbladder volumes, depth of resonance, and the 12 kHz echograms at the time of capture of sound scattering fishes. P. 453—471 in FARQUHAR, G.B. ed. *Proceedings of an international symposium on biological sound scattering in the ocean. Rep. No 005*. Maury Center for Ocean Science, Washington.
- SMOKER, W. and PEARCY, W.G. 1970. Growth and reproduction of lanternfish *Stenobrachius leucopsarus*. *J. Fish. Res. Bd Can.*, 27: 1265—1275.
- VINOGRADOV, M.E. 1971. Studies of the life activity of oceanic biological systems. P. 1—9 in VINOGRADOV, M.E. ed. *Life activity of pelagic communities in the ocean tropics*. Transl. 1973. Israel Progr. Scient. Transl. Jerusalem.
- WOOSTER, W.S., SCHAEFER, M.K. and ROBINSON, M.K. 1967. Atlas of the Arabian Sea for fishery oceanography. *Univ. Calif. IMR Ref.*, 67—12: 1—35. 140 plates.
- WYRTKI, K. 1973. Physical oceanography of the Indian Ocean. P. 18—36 in ZETZCHEL, B. ed. *The Biology of the Indian Ocean*. Springer-Verlag, Berlin.
- ZAR, J.H. 1974. *Biostatistical analysis*. Prentice-Hall Inc., Englewood Cliffs, N.J., 620 p.

Received 30 January 1981

Printed 6 October 1981

