Aspects of the distribution and ecology of the Myctophidae from the Western and Northern Arabian Sea

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

A DSL laying in depths between about 250 and 350 m was found in the whole area. In the north-western 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 seem to have a life cycle of one year or less.

The biomass was estimated using a 38 kHz echo sounder and electronic integration technique. The area was covered five times and the estimated abundance of mesopelagic fish was 102 million tons (range 56-148 million tons). Estimates from the spring were higher than those from summer and autumn.

With 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 fishes were far more abundant than any of the other fish groups (ANON. 1977a). Examination of eggs and larvae from the area (AHLSTROM 1968, NELLEN 1973, FURSA 1973, ALI KHAN 1973) give the same indication. The studies of eggs and larvae and of the adult fish indicate that the myctophids is the dominant group of mesopelagic fish.

Taxonomy and distribution of myctophids from the Arabian Sea have been studied by NAFFAKTITIS & NAFFAKTITIS (1969) and by KOTTHAUS (1962). 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 (e.g. LEGAND & RIVATON 1967, 1969, LEGAND et al. 1972) and in the more southerly parts of the western Indian Ocean (BRADBURY et al. 1970, MAKHSTAS & RYBATSEV 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 e.g. WYRTKI (1973). WOOSTER et al. (1967) pointed out that there is "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 Indo-Pakistani 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 some of the more important species are also treated.

The cruises of R/V "Dr. Fridtjof Nansen" mainly covered the near-shore areas. Only the upper 450 meter layer was sampled with the echo integrator system and most trawling was also carried out in this layer. The deeper living mesopelagic and bathypelagic fishes are therefore not covered representatively and the neretic and surface migrating myctophids are dominating in the material.

**MATERIAL AND METHODS**

The material used in this study was collected during the cruises of R/V "Dr. Fridtjof Nansen" in the Arabian Sea between Mogadisco and the Indo-Pakistanean border. The area (Fig. 1) was covered five times:

- **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 basic 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 msec and the bandwidth 1 kHz. The angular aperture between 3 dB points was 7.5° and the source level 130.2 dB/1μ 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 dB/1μ 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 & VESTNES 1970, FORBES & NAKKEN 1972) were integrating the echo intensities in four depth slices between 8 and 450 meters.

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 & 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 (THORNE & WOODEY 1970, MIDTTUN & NAKKEN 1977). $M$ is measured in millimeter deflection per nautical mile and averaged over five miles. The density coefficient $C$ depends on fish species and size and on the characteristics of the sounder and integrator system used:

$$C = C_i \cdot C_s \cdot l^{-b}$$  \hspace{1cm} (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 two (NAKKEN & OLSEN 1977).

In order to arrive at a density coefficient $C$ in terms of weight per unit area, we have to multiply equation 1 with the average weight $\bar{W}$ of the fish

$$C_W = C \cdot \bar{W} = (C_1 \cdot l^{-2}) \cdot (C_2 \cdot l^3)$$  \hspace{1cm} (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:

$$C_W = C \cdot \bar{W}$$  \hspace{1cm} (3)
The numerical value of $C_W$ applied to the "Dr. Fridtjof Nansen" data was 10.5 tonnes/mm per nautical mile. square nautical 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 are calculated from equation 3 using

$$ C_W = 10.5 \cdot \frac{\lambda}{17} $$

where $\lambda$ is the mean length (in cm) of the observed mesopelagic fishes. Hence, the estimates of abundance arrived at for mesopelagic fish are based on the assumption that the scattering properties of these fishes at 38 kHz are similar to those of 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 to 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 O-group fish.

In addition to identification of the sound scatterers, fishing was also carried out in order to get 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 & BRUNVOLL 1975) was also used at some stations.

During all fishing operations with the pelagic trawls the netsonde 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
to the laboratory for examination. On cruise 4 identification and biological studies were carried out on board immediately after the 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

\[ \ell_{\text{preserved}} = 0.98 \ell_{\text{fresh}} - 0.55 \]

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

In some samples the sex, maturity stage and the content of food in the stomachs were also studied. Otoliths were taken from a few fishes to count primary growth layers. The otoliths were studied by microscope with 150-300 x magnification.

**RESULTS**

**DISTRIBUTION OF SPECIES**

The species identified, except the *Diaphus* species, from the cruises are listed in Table 1. This table does not give a complete picture of the species taken as only the most numerous species are worked up in some of the samples. The genus *Diaphus* are only partly worked up and a more complete treatment of this genus must await the revision of Indian Ocean *Diaphus* being prepared by NAPPAKTITIS (pers. comm.). Some identifications have, however, been carried out based on reference specimens kindly identified by Dr. Nafpaktitis (Table 2).

As expected from the distribution of the sampling, the neretic and surface migrating species are dominating. 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.

Area B. Coast of Pakistan

Benthosema pterotum was dominating in this area too on all the cruises. Ranging next in abundance were various Diaphus species of which D. thiollierei and D. ashmeadi(?) have been identified. Benthosema fibulatum, Hygophum proximum, Symbolophorus evermanni and Bolinichthys longipes were occasionally caught.

As in area B no sampling of mesopelagic fish has been carried out previously but larval samples (NELLEN 1973, ALI KHAN 1976) supports the impression of a low diversity.

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

On cruises 3 and 6, both from autumn, Benthosema pterotum was dominating. During cruise 4 from 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° and 20°N.

On cruise 3, Benthosema fibulatum was the dominating 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. ashmeadi(?) were the most abundant species. D. lütkeni was also identified. Myctophum spinosum, Symbolophorus evermanni, Bolinichthys longipes and Lampanyctus macropterus were also caught.

The nearshore mesopelagic fauna of this area has not been studied previously. A comparison with NAPPAKTITIS & NAPPAKTITIS (1969) data from the offshore regions between the same latitudes suggests that the fauna there is much more
diverse than the nearshore fauna.

Area E. Gulf of Aden, West of 47°E.

In the inner part of the Gulf of Aden, Benthosema pterotum was the dominating 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. Ranging next 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 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 C. Somali Coast between 10° and 15°N.

On cruises 3, 4 and 6 Benthosema fibulatum was the dominating species in this area, while Sympolophorus 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 are identified. The records are within the known geographical range of these species.
Areas H and I. Coast of Africa between 0 and 10°N.

_Benthosema fibulatum, Myctophum brachygnathum_ and _Diaphus_ spp. dominated the catches. Of other species _Electrona rissoi, Hygophum proximum, B. pterotum, Symbo-
lophorus evermanni, Bolinichthys longipes, Lampanyctus tenuiformes, L. nobilis, Diaphus garmani_ and _D. thoillierei_ were caught. The catch of _B. pterotum_ at 3°17'N is a southward extension of the known range of this species in African waters.

**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 5 to 6 March 1976. _Benthosema pterotum_ was the only myctophid fish found in the area and during daytime this was distributed in two layers. The upper one (layer A) generally lay between 130 and 200 m depth (Figs. 2, 3). During the first day, its mean contribution to the integrated echo intensity was 292 mm per nautical mile. This layer consisted of very dense aggregations and often discrete schools. The lower layer (B), which was more diffuse, generally lay between 220 and 300 m, sometimes extending down to about 350 m. Its contribution to the integrated echo intensity was 200 and 348 mm per n.mile during the first and the second day 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 fishes from the two layers. The migration towards the surface started about 30 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 depth 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 was raising from about 300 mm per n.mile to
500 mm per n.mile during the night, probably due to fish drifting or swimming into the area.

During daytime the depth of the A layer approximately corresponded to the $O_2$-minimum where less than 1.5 ml/l of $O_2$ were 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 $O_2$ per liter (Fig. 6). The migration pattern observed during the diurnal station is rather typical of the neretic areas where *Benthosema pterotum* and *B. fibulatum* dominated.

In offshore areas a DSL in depth varying 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 night. In some areas an additional layer was observed between about 350 and 500 m depth. 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.

The echo recordings obtained at the diurnal station (Fig. 4) 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 meters, 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 five miles 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 day were similar to those 345 made during 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 the summer 1977 by MYRSETH (in prep.). The data from section 1 from the Pakistani area were therefore analysed separately. The result \( t = 0.74 \) \( p < 0.05 \) was consistent with that based on the whole material.

The integrated echo intensities along six sections (see Fig. 1) extending between 40 and 200 miles offshore were recorded (Fig. 7). To test whether there was a consistent relation between integrated intensities and distance from the shore, a regression of the transformed integrator outputs \( \ln(M+1) \) on the distance from the shore was carried out. The significance of the regression coefficients was tested using analysis of variance tests (e.g. ZAR 1974). Of the 26 tests carried out, 16 were significantly different from zero (Table 3). Of these, 12 were positive, i.e. the echo intensities increased with distance from shore, and four were negative.

Off the Pakistani coast (section 1) four of the five tests were nonsignificant. In the Gulf of Oman (section 2) intensity increased offshore on cruises 2 and 4, but decreased on cruise 6. For the other cruises the tests were nonsignificant. Off the Kuria Muria Islands (section 3) echo intensities decreased offshore on cruises 4 and 6 and increased on cruise 5. In the Gulf of Aden (section 4) and off Al Arar (section 5) most cruises showed a significant increase in echo intensity with increasing distance from the shore.

Although not obvious from the sections, an increased echo intensity was often observed from the 200 m depth contour and about 1-2 miles offshore or less. It seems, however, safe to conclude that generally the survey design in relation to the shore is of minor importance compared to other sources of variance.
The sections off 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 fishes 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 these 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. Fishes that were only caught in bottom trawl, e.g. Diaphus coerules, are not included in the mean. Table 4 also shows the species mainly contributing to the recordings. When no samples were available for an area, the lengths at stations close to the border of the area or the length in the same area at another cruise conducted at the same time of the year was used.

Based on these mean lengths an integration constant $CW$ was calculated for each area and each survey. The more accurate method recommended by FORBES & 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 referred to mesopelagic fish in each area and for each cruise are shown in Fig. 9 and the corresponding abundance estimates in Table 5.

The total abundance recorded during one survey varied between 56 million tons (summer 1977) and 148 million tons (spring 1976) with a mean of 102 million tons. Both the spring surveys (cruises 1, 2 and 4) gave higher abundances than the summer (cruise 5) and the autumn cruises (cruises 3 and 6).
As indicated by the sections (Fig. 7), the differences in abundance between the cruises were the same both near shore and offshore. 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 is supposed to rise above 450 m during nighttime.

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 88 and 35 fish or 63 g and 25 g per m² surface area. The lowest density, 9 mm deflection, was recorded off north-western Somalia during summer and corresponds to about 2 fish or 5 g per m² surface area.

CATCH RATES

Trawling was carried out to identify sound scatterers and to get biological samples and in a few cases to compare a krill trawl and a pelagic fish trawl. Although it was no specific goal to get large catches, high catch rates were obtained at some stations. 26 stations gave catch rates higher than 400 kg per hour of trawling (Table 6). Of these, 18 stations gave catch rates of 1000 kg/hour or more and six of 5000 kg/hour or more. The highest catch rate recorded was 20,000 kg/hour (st. 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 south-west of Socotra. One of the stations was taken with bottom trawl and the others with pelagic trawl. Thirteen of the stations were taken during daytime, twelve during nighttime and one at dawn.

The species composition was studied in 24 of the catches. Benthosema pterotum was the only one or the dominating species at 21 of these stations and B. fibulatum at two of them. At one station Diaphus spp. were most abundant.
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 opening of the other one, the two gears 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 part of the fish.

BIOLOGY OF IMPORTANT SPECIES

*Benthosema pterotum*

*B. pterotum* seems to grow to a maximum size of about 50 mm, but 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 not included in Figure 10. Between March 1976 and June 1976 there is an indication of growth, but fish taken in September the same year are smaller again.

Fig. 11 shows that a population of *B. pterotum* with much lighter colour than those commonly observed (GJØSÆTER in prep.) 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.

The rings in the otoliths commonly regarded as daily growth zones (PANELLA 1974, BROTHERS, MATHEWS & LASKER 1976) were counted in sixteen otoliths from *B. pterotum* caught during cruise 4. The zones were often indistinct and difficult to count. Fig. 14 shows that there was no increase in number of zones with length of fish, but unfortunately only otoliths from adult fish were available for counting. If the zones are laid down daily, they show that the fish may reach its maximum size in less than half a year, and they
may have two generations a year.

The reproduction of this species is studied by MAKHDOOM (in prep.) who has shown that breeding takes place all the year but with maxima in March - June and September - November. These two reproduction periods may explain the bimodality in some of the length distributions. It is therefore suggested that the fish lives more than half a year and the small size of it makes it unreasonable that it should live for more than one year.

The type 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 had eaten amphipods.

The sizes of 117 food items from 14 fishes were measured. The mean size was 1.16 mm (sp = 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: some contents, 3: half filled, and 4: full or extended. The digestion was classified as 1: newly ingested, 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.

At the first night station taken two hours after the sunset, 96% of the fish had newly ingested food items and about 55% of the fish had full or extended stomachs. Only 8% were empty.

The stage of digestion increased during the night, and 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% at the second night station (about 4 hours after sunset) and then decreased steadily. Number 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 daytime.

**B. fibulatum**

Length distribution of *B. fibulatum* from the Somalia 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).

Otolith rings were counted in twelve specimens all caught during cruise 4 (Fig. 18) and showed a rather close relationship to length. The rings were also clearer and more distinct than in *B. pterotum*. If the zones are laid down daily they suggest a life cycle of one year, although the fish probably may start to breed when half a year old.

The smallest mature fish found during cruise 4 measured 40 mm. Most of the fish caught on cruise 6 were ripe, spawning or had recently spawned. MAKHDOOM (in prep.) found that *B. pterotum* mainly spawn during April - June and during September - November.

**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 got estimates of density of fish in reasonable agreement with estimates based on catch rates. McCARTNEY (1976) working off Western Africa concluded, however, 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 was 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 were few other organisms as euphausiids, sergestid prawns or siphonophores in the DSLs. Thirdly, all the fish species contributing significantly to the biomass had gas-filled swim bladders, making them good acoustic targets.

The shallow position of the DSLs probably is related to the high production and therefore low transparency of the water (DICKSON 1972). Farther south, where the production is lower, the DSLs also have a deeper position (BRADBURY et al. 1970).

Although the trawls had no closing device, the acoustic netzonde 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 south-east of the Kuria Muria Island yielded mostly Champsodon sp. But the occurrence of large quantities of these fishes seemed to be restricted both in time and in room. 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 north-eastern Arabian Sea.

During nighttime 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 relation between the recordings on the 38 kHz and the 120 kHz echo sounder were also taken into consideration. The similarity in the echo abundance of mesopelagic fish obtained during daytime and during nighttime 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 & STUBBS 1970, SHEARER 1970, DALEN, RAKNES & RØTTINGEN 1976, McCARTNEY 1976, NAKKEN & 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 swim bladders gives resonance at frequencies lying between approximately

\[
\frac{2 \sqrt{D + 10}}{\lambda} \quad \text{and} \quad \frac{3 \sqrt{D + 70}}{\lambda} \ \text{kHz}
\]

where \( \lambda \) is fish length in centimeters and \( D \) is depth in meters. When a 38 kHz sounder is applied and the depth is less than about 400 m, a fish must therefore be smaller than about 1.5 cm to give resonance. But there is doubt about what will happen when fish length approaches wavelength. For 38 kHz wavelength is about 4 cm, and most of the fish considered in the present study is therefore in the critical zone. All calculations are, however, based on the assumption that the relation \( C = \text{constant} \lambda^b \) (see page 3) is applicable to all the length groups considered.

In the Gulf of Oman the acoustic measurements indicated a density of 25-63 \textit{Benthalosema 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 0.3 to 0.6 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 has an opening of about 320 m². If the whole opening is catching myctophids with 100 per cent efficiency, st. Nos. 449 and 450 both taken during night (Table 5) would indicate a density of 0.5 and 1.3 g m⁻³ or 0.6 and 1.6 fish per m³ respectively. A station (No.419) taken during daytime in the upper DSL gave 6.3 g m⁻³ corresponding to about 8 fish per m³ filtered water. These figures are underestimates, as the efficiency of the gear is obviously less than 100 per cent. These stations were, however, taken in areas where the density was higher than the mean one 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. (1954) found about one fish per 1000 m³ of 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 m³. Based on acoustic measurements they got estimates varying from 13 to 130 fish per 1000 m³. CLARKE (1973) studying myctophids in the Hawaiian area got about 0.55 fish/m² based on catch rates.

From the size data and the counting of otolith zones it is tentatively concluded that the two most important species, Benthosema pterotum and B. fibulatum have a life cycle of one year or shorter. 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 had a one year life cycle. LEGANG (1967) drew the same conclusion for Notolychnus valdiviae reaching about 30 mm. Boreal species as Stenobrachius leucopsaurus (SMOKER & 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 about 80-90 mm during its first year of life (GJØSÆTER in prep.). The growth rates assumed for the Benthosema species therefore do not seem unreasonable. 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 "Dr. Fridtjof Nansen" is about 220 gCm\(^{-1}\) 180 day\(^{-1}\) in the SW monsoon and 50 gCm\(^{-1}\) 180 day\(^{-1}\) in the NE monsoon. These values can be converted to gram wetweight using the factor 0.065 (see CUSHING 1971), and a primary production about 4.2 kgm\(^{-2}\) year\(^{-1}\) is found. The area studied is about 1.7 \times 10^{12} m\(^2\) and the primary production is therefore 7.1 \times 10^{9} ton year\(^{-1}\). An assumed mean production of mesopelagic fish about 1 \times 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 is about 1 \times 10^{9} ton 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 trophical level is assumed, the mesopelagic fish is utilizing the entire secondary production.

It has been shown in other areas too that the production of mesopelagic fish is higher than should be expected from the primary production figures (CLARKE 1973). This may partly be explained by higher efficiency than 10% in oceanic waters (e.g. GRAZE 1970) or by production by bacterioplankton (VINOGRA DOV 1973).

In the northern part of the Arabian Sea myctophids were often observed at very low oxygen concentrations. The same was observed by KINZER (1969). From studies in Californian waters DUNLAP (1970) concluded that there was no general relationship between oxyclines and DSL. BAIRD et al. (1974) found Diaphus taanin gi in water with oxygen concentrations 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 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) con-
cluded that *D. taanigi* from the Cariaco Trench feed little, if at all, during daytime. 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 they feed during day in the oxygen minimum zone.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to Mr. 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.

Thank is also due to Miss I.M. Beck for able assistance through all phases of this study, to Mr. H. Ullebust for drawing the figures and to Miss. J. Silchenstedt for typing most of the manuscript.

I am much indebted to Dr. B.G. Nafpaktitis for identifying part of the *Diaphus* species collected.
REFERENCES


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.

<table>
<thead>
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<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>Hygophum proximum Becker</td>
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<td>x</td>
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<td>x</td>
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<td>x</td>
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<tr>
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<td>xx</td>
<td>xx</td>
<td>xx</td>
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<td>xx</td>
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<tr>
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<td>xx</td>
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<td>xx</td>
<td>xx</td>
<td>xx</td>
<td>xx</td>
<td>xx</td>
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<td>x</td>
<td>x</td>
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Table 2. **Diaphus** species identified from cruise 1 to 6 of R/V "Dr. Fridtjof Nansen".

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<th>North of $10^\circ$ S</th>
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</tr>
<tr>
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</tr>
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<td>D. luetkeni Brauer</td>
<td></td>
<td>+</td>
</tr>
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<td>D. parri Tåning</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>D. regani Tåning</td>
<td></td>
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</tr>
<tr>
<td>D. thiollierei Fowler</td>
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Table 3. Values of F and corresponding significance of analysis of variance tests of the regression of echo abundance on the distance from the shore.

+ indicate increase and - decrease in echo abundance with increasing distance.

<table>
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<th>Section</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>1</td>
<td>+3.11ns</td>
<td>+0.02ns</td>
<td>-0.19ns</td>
<td>+4.36ns</td>
<td>+5.67*</td>
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<tr>
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<td>+15.06**</td>
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<td>+8.50*</td>
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ns not significant
* p < 0.05
** p < 0.01
*** p < 0.001
Table 4. Species giving the main contribution to the echo abundance and mean length for the contributing fish. Numbers in brackets are estimated.

<table>
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<th>D</th>
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<td>75</td>
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<td>60</td>
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<td>B. pterotum</td>
<td>B. pterotum</td>
<td>B. fibulatum</td>
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<td>35</td>
<td>35</td>
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<td>50</td>
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<td>B. pterotum</td>
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<td>B. pterotum</td>
<td>B. pterotum</td>
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Table 5. Estimated abundance of mesopelagic fish in the areas investigated (in million tons).

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<th>Area A</th>
<th>Area B</th>
<th>Area C</th>
<th>Area D</th>
<th>Area E</th>
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<td>17</td>
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Table 6. Trawl stations with catch rates of myctophids > 400 kg/hour. P = pelagic trawl (1360 meshes), KT= krill trawl, BT= bottom trawl.

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<th>St.nr.</th>
<th>date</th>
<th>area</th>
<th>trawl</th>
<th>depth m</th>
<th>time</th>
<th>total catch</th>
<th>myctophids kg</th>
<th>dominating species</th>
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<td>19.9</td>
<td>F</td>
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<td>night</td>
<td>300</td>
<td>230</td>
<td>400</td>
</tr>
<tr>
<td>239</td>
<td>7.11</td>
<td>B</td>
<td>P</td>
<td>250</td>
<td>day</td>
<td>610</td>
<td>600</td>
<td>1200</td>
</tr>
</tbody>
</table>

1975:

| 281    | 31.1 | E    | P     | 85      | night| 410         | 405             | 810               |
| 310    | 22.2 | D    | P     | 280     | day  | 2000        | 2000            | 6000              |
| 314    | 26.2 | D    | P     | 270     | day  | 250         | 230             | 460               |
| 319    | 28.2 | A    | P     | 20      | night| 900         | 800             | 1600              |
| 320    | 29.2 | A    | P     | 20      | night| 1500        | 1500            | 3000              |
| 325    | 5.3  | A    | P     | 140     | day  | 800         | 780             | 1560              |
| 326    | 5.3  | A    | P     | 20      | night| 450         | 440             | 880               |
| 327    | 5.3  | A    | P     | 100     | day  | 450         | 430             | 860               |
| 329    | 6.3  | A    | P     | 20      | night| 5000        | 5000            | 10000             |
| 330    | 6.3  | A    | P     | 130     | day  | 650         | 650             | 1300              |
| 352    | 26.3 | C    | P     | 90      | day  | 300         | 200             | 1300              |
| 419    | 25.5 | D    | KT    | 200     | day  | 1500        | 1500            | 3000              |
| 427    | 3.6  | C    | P     | 130     | day  | 10000       | 10000           | 20000             |
| 433    | 10.6 | B    | P     | 100     | dawn | 1000        | 1000            | 2000              |
| 434    | 10.6 | B    | P     | 175     | day  | 600         | 500             | 1000              |
| 436    | 13.6 | C    | P     | 20      | night| 300         | 300             | 600               |
| 448    | 20.6 | A    | P     | 15      | night| 1500        | 1300            | 2600              |
| 449    | 20.6 | A    | KT    | 20      | night| 800         | 700             | 1400              |
| 450    | 20.6 | A    | KT    | 30      | night| 1500        | 1300            | 2600              |
| 451    | 20.6 | A    | P     | 30      | night| 500         | 400             | 800               |
| 469    | 29.8 | B    | P     | 300     | day  | 1000        | 1000            | 1000              |
| 743    | 26.10| G    | BT    | 120     | night| 10000      | 9600            | 19000             |
Fig. 1. The investigated area. A - I: the subareas and 1 - 5: the sections referred to in the text.

Fig. 2. The vertical migration observed during the diurnal station 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 miles averages of integrator deflection in mm per nautical mile from the diurnal station in the Gulf of Oman.

Fig. 5. Vertical distribution of temperature, salinity and oxygen at the diurnal station in the Gulf of Oman.
Fig. 6. Depth of DSL and vertical distribution of temperature, salinity and oxygen from two stations off Pakistan.

Fig. 7

Five miles averages of integrator deflection in mm per nautical mile along five sections.
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 and E. section 5, off eastern Somalia.

2 - 6: cruise number.
Fig. 7 B.

Fig. 7 C.
Fig. 7 D.

Fig. 7 E

Fig. 8. Mean integrator deflection per nautical mile in mm in the 9 subareas (A - I). 1 - 6: cruise number.
Fig. 9. Map showing trawl stations giving more than 400 kg per hour trawling of mesopelagic fish.

Fig. 10. Length distribution of *Benthosema pterotum* caught off Pakistan.
Fig. 11. Length distribution of the light coloured *Benthosema pterotum* caught in the Swatch.

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 zones in the otoliths of *Benthosema pterotum*.

Fig. 15. Diurnal variation in degree of filling (A) and stage of digestion (B) of stomach contents of *Benthosema pterotum* caught at the diurnal in the Gulf of Oman.

N: noon; 1,2,3,4: night stations; M: morning.
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 zones in the otoliths of *Benthosema fibulatum*. 