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ESTIMATES OF THE ABUNDANCE OF MESOPELAGIC FISH OFF SOUTHERN NORWAY AND WEST OF THE BRITISH ISLES 1971-1976

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ABSTRACT

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Mesopelagic fish were studied using 38 and 50 kHz echo sounders and electronic integrators on cruises covering the Norwegian Deep, Skagerrak, the slope north of the North Sea and west of the British Isles during 1971-1976. Samples of the fish were taken using commercial pelagic trawls.

In Norwegian waters *Maurolicus muelleri* was the dominant species and the estimated stock size in the area covered ranged between 20 000 and 1 600 000 tonnes. No seasonal variation in abundance could be traced.

West of the British Isles *Notoscopelus kroeyeri* seemed most important, followed by *M. muelleri*. Estimated stock size ranged between about 0.3 to 13 million tonnes.

All the stock size estimates are tentative, as the density coefficient used to convert echo abundance to fish biomass is not known for the species involved, and a coefficient worked out for another fish species had therefore to be used.

INTRODUCTION

During cruises with the research vessels of the Institute of Marine Research, Bergen, covering the Norwegian Deep, Skagerrak, the slope north of the North Sea and waters west of the British Isles, acoustical recordings of mesopelagic fish were often obtained (e.g. Hamre og Nakken 1970, 1971, Olsen 1972). During daytime these recordings were usually found at depths between 150 and 300 m, while during nighttime they came up to the surface layers.

No attempts have been made to assess the abundance of the fish causing these recordings, although it has been pointed out that they must represent a large biomass (Blindheim et al. 1971). They probably play an important part in the pelagic eco-system in the area and studies in other parts of the world have shown that mesopelagic fish may be a large potential resource for future fisheries (Gjøsæter and Kawaguchi 1980, Gulland 1983). Probably they can be caught in the North Sea-area too with suited gears (see Olsen 1972).

The present paper presents acoustical data on mesopelagic fish from cruises in Norwegian waters and west of the British Isles, and on the basis of these it is attempted to derive tentative estimates of the abundance of mesopelagic fish in these areas.

MATERIALS AND METHODS

The material used in this study was collected during cruises with R/V "G.O. Sars" and R/V "Johan Hjort" of the Institute of Marine Research, Bergen. A list of the cruises is given in Table 1, which also gives references to maps showing survey grids and other details.

A 38 kHz echo sounder and three electronic echo integators were used onboard R/V "G.O. Sars". The effect of the transducer was 10 kW, the pulse length 0.6 msec and the band width 1 kHz. The beam width was 5° x 5.5° between the 3 dB points. The time varied gain, TVG, was $20 \lg R + 2\alpha R$, where R is the distance between the transducer and the target and α is the attenuation coefficient.

On R/V "Johan Hjort" a 50 kHz echo sounder and one analogous integrator were used. The transducer effect was 1 kW and pulse length, band width and TVG were similar to that of the equip-

Table 1

List of cruises where echo abundance of mesopelagic fish was measured

Year	Month	Ship	References
West of the British Isles.			
1972	February-March	G.O. Sars	Jakupsstovu og Midttun 1972
1973	March-April	G.O. Sars	Jakupsstovu, Olsen og Midttun 1973
1974	March	G.O. Sars	Buzeta and Nakken 1975
1975	May	G.O. Sars	Jakupsstovu og Midttun 1977
1976	March-April	G.O. Sars	Jakupsstovu og Midttun 1977
Norwegian Deep and north-east of Faroe Islands.			
1971	October	G.O. Sars	Jakupsstovu 1974
1972	June-July	G.O. Sars	Iversen et al. 1974
1972	September-October	G.O. Sars	Jakupsstovu 1974
1973	May	Johan Hjort	Jakupsstovu 1974
1973	October	G.O. Sars	Jakupsstovu 1974
1974	November-December	G.O. Sars	Kismul 1975
1975	April-May	G.O. Sars	Kismul 1976
1975	May-June	Johan Hjort	Kismul 1976
1976	May-June	Johan Hjort	Kismul 1977
1976	November-December	G.O. Sars	Kismul 1977

ment on "G.O. Sars".

On both vessels 120 kHz echo sounders were continuously run.

The output (M) of the echo integrator is lenearly related to the number of fish per unit area (P_a) in the integrated depth columns (Forbes and Nakken 1972). This relationship can be written:

$$P_a = CM + d \qquad (1)$$

where C is number of fish per unit area needed to contribute one unit to the integrated echo intensity, and d is the lowest density which can be recorded (Midttun and Nakken 1977). The density coefficient C depends on fish species and size and on the characteristics of the echo sounder/integrator system used:

$$C = C_i \; C_s \; \ell^{-b} \qquad (2)$$

Here C_i is an instrumentation constant, ℓ is fish length and C_s and b are constants for a given species. When ℓ is small compared to wave length the difference between species is small (Nakken and Olsen 1977).

The density coefficient for myctophids is not known. It has therefore been necessary to use the coefficient for some other small pelagic fish, and the values worked out for capelin on R/V "G.O. Sars" have been applied (Table 2).

Table 2

Density coefficient $C_i\ C_s$ and the exponent b from the equation $C = C_i\ C_s\ \ell^{-b}$ for capelin

Year	$C_i\ C_s$ number/mm x n.mile^2	b	Authors
1971	9.4×10^6	1.72	Nakken and Dommasnes 1975
1972	9.4×10^6	1.72	Nakken and Dommasnes 1975
1973	3.0×10^6	1.72	Nakken and Dommasnes 1975
1974	1.8×10^6	1.72	Nakken and Dommasnes 1975
1975	5.0×10^6	1.72	Hamre and Røttingen 1977
1976	8.1×10^6	1.91	Dommasnes and Røttingen 1977

The relationship between integrated echo intensities obtained by R/V "G.O. Sars" and R/V "Johan Hjort" varied during the period of investigation (Table 3).

Table 3

Relationship between integrator values from R/V "G.O. Sars" and R/V "Johan Hjort". Parameters from the equation $M_{GOS} = aM_{JH} + b$.

Year	a	b	Authors
1973	2.00	13.6	Nakken and Dommasnes 1975
1975	0.54	18.0	Dommasnes, Nakken and Røttingen 1976
1976	0.45	14.0	Dommasnes and Røttingen 1977

Continuous watch was kept on the acoustic instruments, and every day the acoustic data were scrutinized to group the recordings and corresponding integrator readings into categories of scatterers. These categories were recognised by their appearance and behaviour, and trawling, using a 1600 mesh or a 1360 mesh pelagic trawl, was frequently carried out to verify the identifications.

RESULTS

West of the British Isles

West of the British Isles, cruises were conducted annually during spring from 1972 to 1976. During 1975 only the area north of 58° was covered.

The distribution of integrated echo abundance is shown in Fig. 1-5. The highest values were generally obtained around the Porcupine bank, although there were usually no recordings above the most shallow part of the bank. Another area with high values was sometimes found around Rockall.

Generally, the mesopelagic fish layer could be identified by its appearance and its vertical migration and therefore little trawling was carried out for identification purposes. The few trawl catches available showed that among the mesopelagif fish *Notoscopelus kroeyeri* was generally dominant, with *Maurolicus muelleri* and *Benthosema glaciale* ranging next. Due to the selectivity of the gears used it is almost impossible to assess the relative importance of these species.

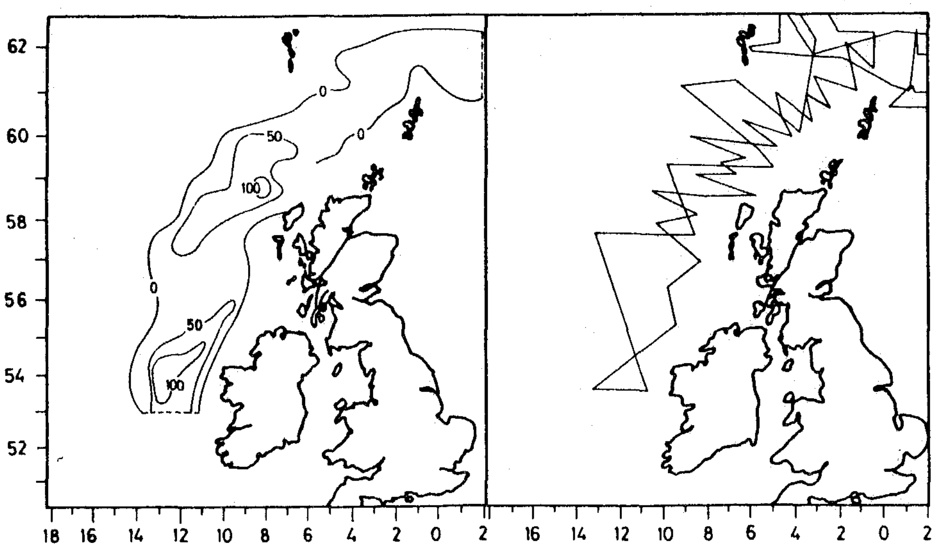

Fig. 1. Integrated echo intensities (mm deflection) of meso-pelagit fish in February-March 1972. The survey routes are indicated.

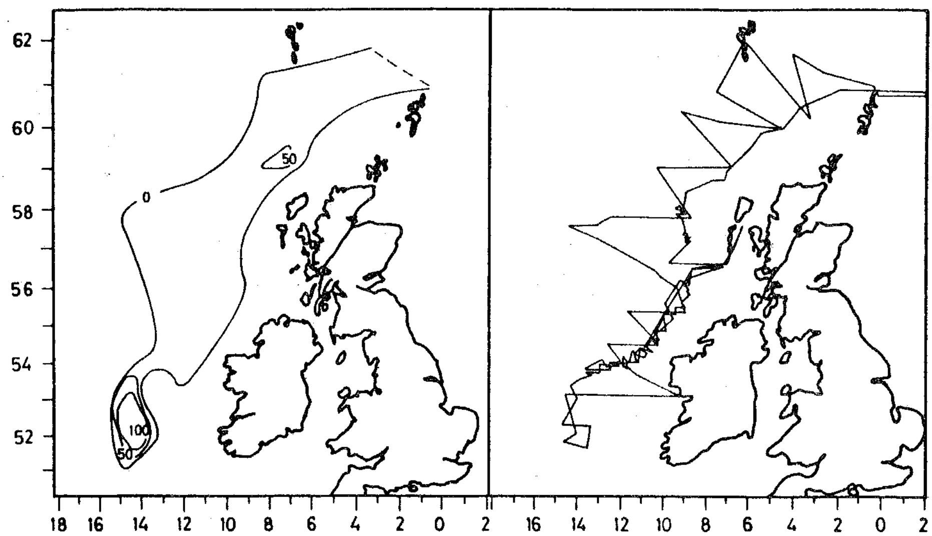

Fig. 2. Integrated echo intensities (mm deflection) of meso-pelagic fish in March-April 1973. The survey routes are indicated.

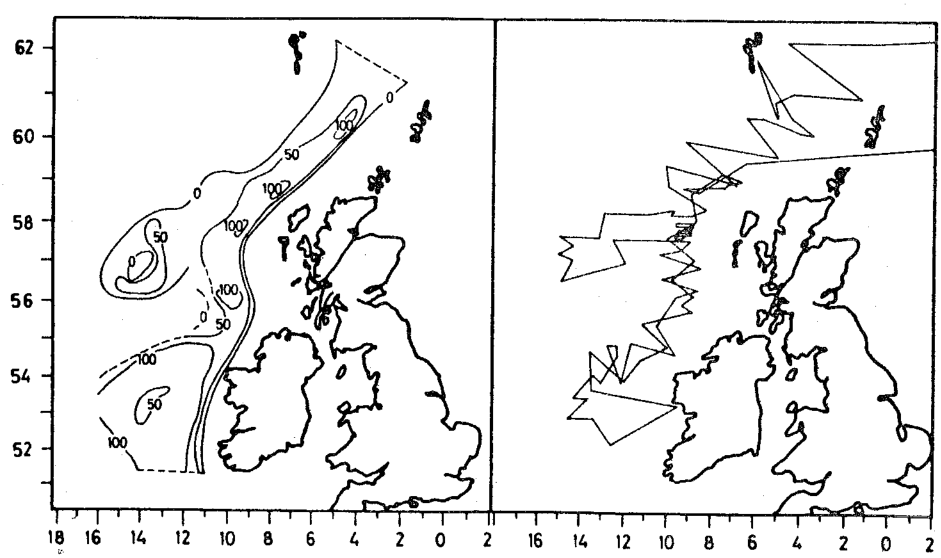

Fig. 3. Integrated ehco intensities (mm deflection) of meso-pelagic fish in March 1974. The survey routes are indicated.

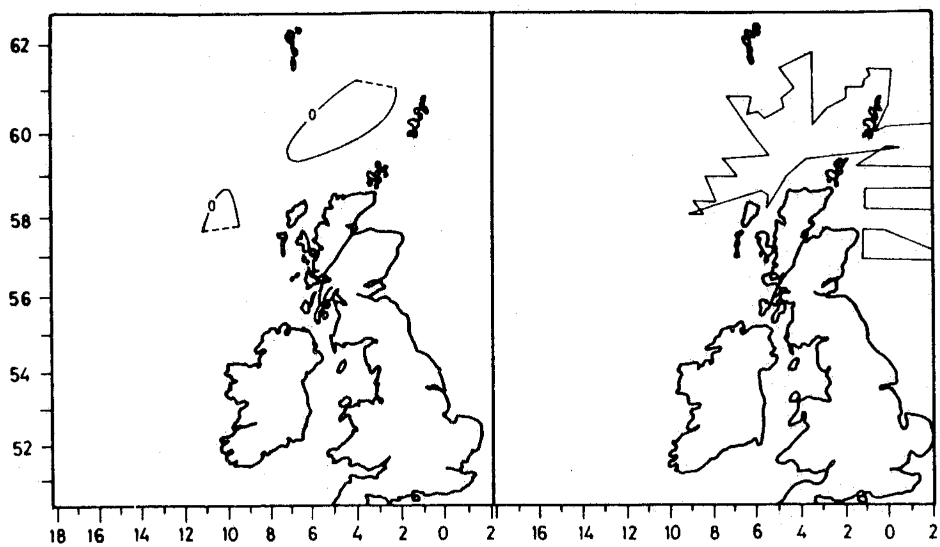

Fig. 4. Integrated echo intensities (mm deflection) of meso-pelagic fish in May 1975. The survey routes are indicated.

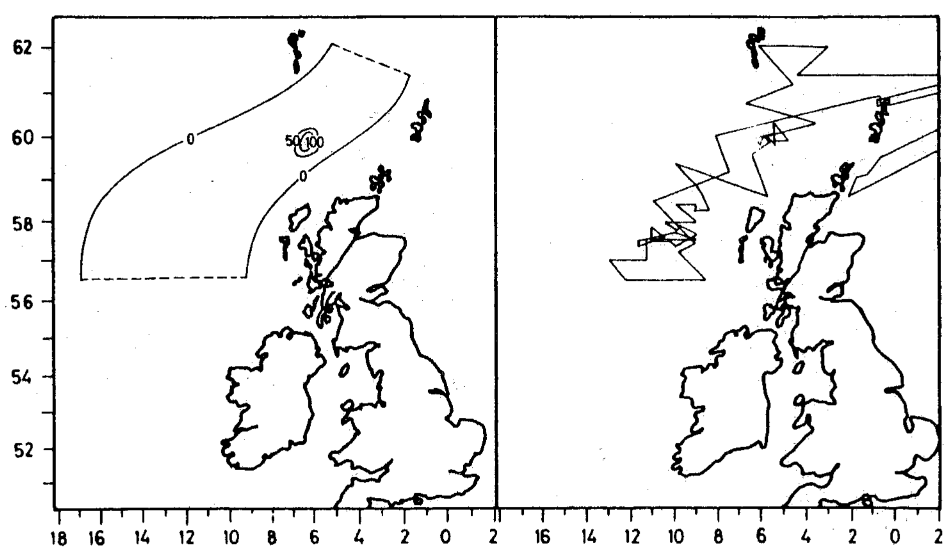

Fig. 5. Integrated echo intensities (mm deflection) of meso-pelagic fish in March-April 1976. The survey routes are indicated.

Table 4 shows fish abundance based on the supposition that *N. kroeyeri* was the only scatterer and that it has the same sound reflecting properties as capelin. The mean lengths and corresponding weights are computed from Gjøsæter (1981a). If *M. muelleri* is supposed to be the only scatterer, the total abundance will be about one third as high (Table 4).

Table 4

Integrated echo intensities and estimates of abundance of mesopelagic fish in the areas shown in Fig. 1-5.

		Abundance estimates					
		I *N. kroeyeri* only			II *M. muelleri* only		
Year	Integrated echo intensities mm/n.mile x n.mile^2	ℓ(cm)	W(g)	tonnes x 10^6	ℓ(cm)	W(g)	tonnes x 10^6
1972	4.7×10^6	9.6	14.6	13.00	5.2	1.9	5.00
1973	1.9×10^6	11.2	23.0	2.10	5.2	1.9	0.64
1974	1.0×10^7	9.7	15.1	5.40	5.2	1.9	2.00
1975	1.8×10^5	11.5	24.9	0.33	5.2	1.9	0.10
1976	3.1×10^5	11.3	23.6	0.93	5.2	1.9	0.33

As the data on size distribution of *M. muelleri* are more sparse, one mean length and weight is used for all the years (Gjøsæter 1981b). The last estimate is obviously too low as there are several other larger scatterers than *M. muelleri* present. On the other hand, *N. kroeyeri* has a partly or completely fat-filled swimbladder (Bone 1973) which makes it a much poorer sound reflector than capelin, and this will tend to make the first estimate much too low. However, on the whole, it seems that the first estimate may be closer to the truth than the last one.

B. glaciale also has a fat-filled swimbladder, at least when adult (Zahuranec and Puch 1971), and it therefore probably contributed little to the scattering layers observed.

During the cruises in 1972, 1973 and 1974 integrated echo intensities above 100 mm/n.mile were observed over large areas (Fig. 1-5). Using the same conversion factors as in row I of

Table 4, this corresponds to 81, 32 and 16 g/m² surface area respectively for the three years.

Norwegian Deep and adjacent areas

In the Norwegian Deep and north of the North Sea plateau *M. muelleri* was the dominant species of the mesopelagic fish, although *B. glaciale* and *N. kroeyeri* were also caught. These were found in a scattering layer typically lying between 100 and 250 m during day and near the surface during night (Fig. 6).

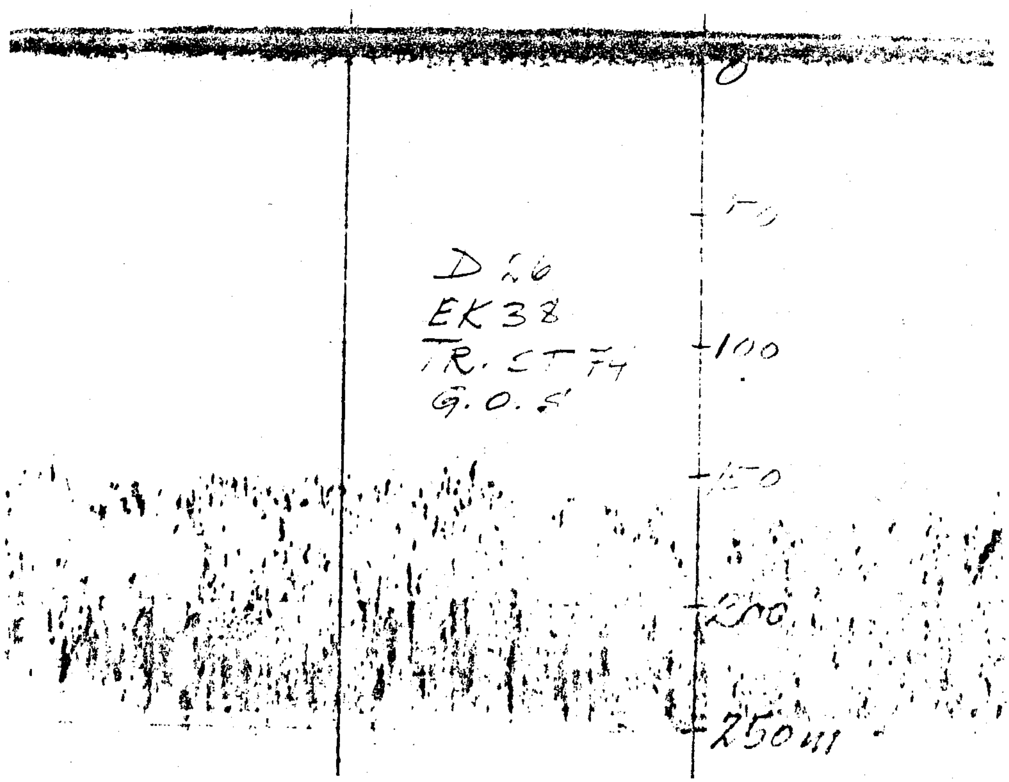

Fig. 6. Echo recording of mesopelagic fish, mainly *Maurolicus muelleri*, March 1973.

1971. A survey was conducted during October, covering the area from Skagerrak to about 62°N. Mesopelagic fish were found in the northern part of the area (Fig. 7), but the density was generally low and the highest average density recorded over more than five miles was about 25 g/m². The estimated abundance in the area studied was about 156 000 tonnes (Table 5).

1972. The area from Skagerrak to about 61°N was covered by a survey conducted during June-July and by another covering the same area during Septembe-October. On the first cruise (Fig. 8) mesopelagic fish were recorded over a wide area, and fairly high concentrations, more than 30 g/m², were found along the western and southern slopes of the Norwegian Deep. The total abundance was about 380 000 tonnes. During the second cruise the distribution area was much smaller (Fig. 9), the densities lower and the estimated abundance only 200 000 tonnes.

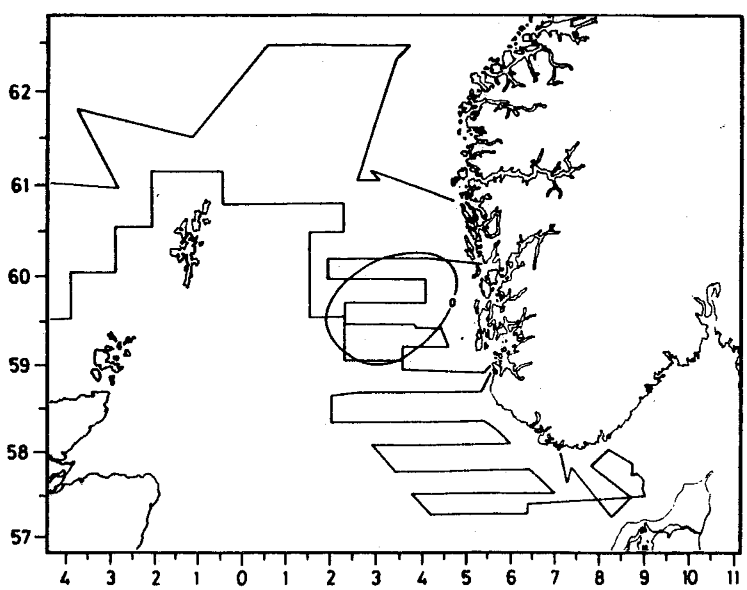

Fig. 7. Integrated echo intensities (mm deflection) of mesopelagic fish in October 1971. The survey routes are inticated.

Table 5

Integrated echo intensidies and corresponding estimated abundance of *M. muelleri* in the areas shown in Fig. 7-16. Brackets indicate that the value is estimated using the data given in Table 3.

Year	Month	Fig.	Integrated echo intensities mm/n.mile x n.mile^2 G.O. Sars, Johan Hjort	Abundance estimates tonnes x 10^3
1971	10	7	1.6×10^5	156
1972	6-7	8	3.9×10^5	380
	9-10	9	2.0×10^4	20
1973	5	10	(3.4×10^5) 1.3×10^5	110
	10	11	2.5×10^5	78
1974	11-12	12	1.0×10^6	187
1975	4-5	13	9.0×10^4	47
	5-6	14	(2.2×10^5) 6.0×10^4	114
1976	5-6	15	(2.4×10^5) 3.0×10^5	240
	11-12	16	1.6×10^6	1600

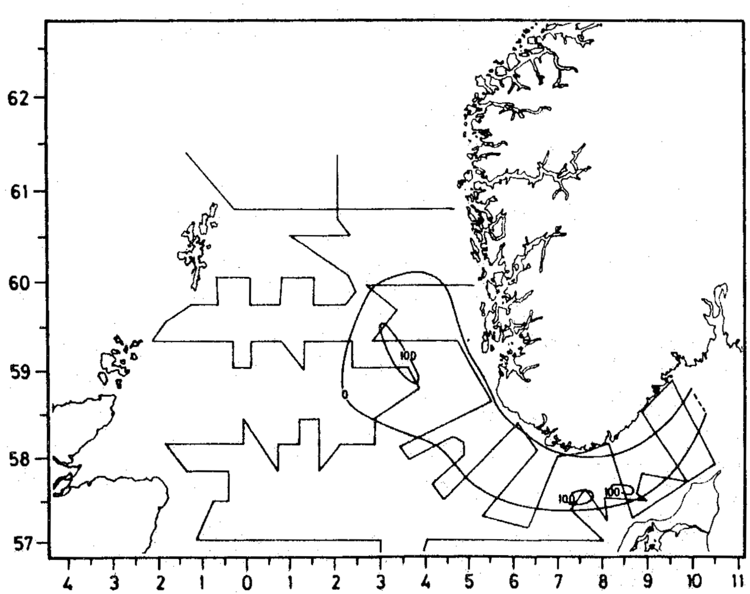

Fig. 8. Integrated echo intensities (mm deflection) of meso-pelagic fish in June-July 1972. The survey routes are indicated

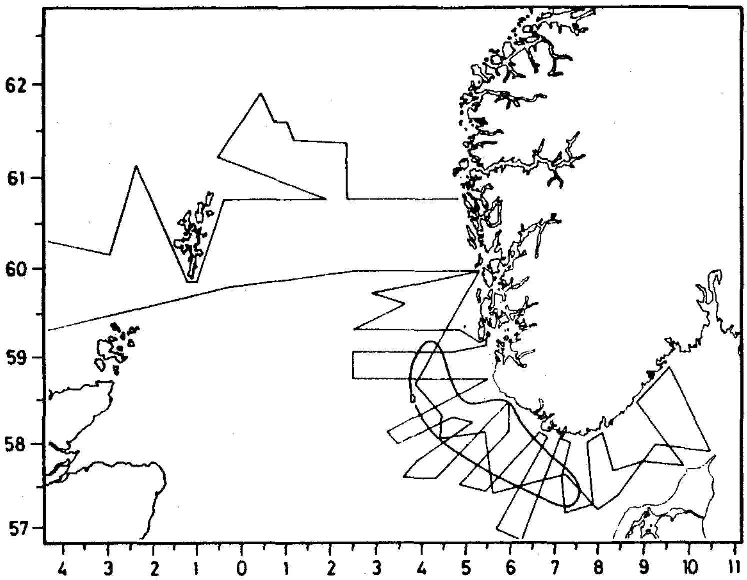

Fig. 9. Integrated echo intensities (mm deflectin) of meso-pelagic fish in September-October 1972. The survey routes are indicated.

1973. A cruise covering the area from the western part of Skagerrak to about 62°N was conducted during May, and another coverage of the same area took place during October, but only to about 60°N.

During the first of these cruises (Fig. 10) the mesopelagic fish had a restricted distribution area along the western slope of the Norwegian Deep, from about 59°N and northwards.

During the second cruise the distribution was more souterly (Fig. 11). During both cruises the density was low, and total abundance was estimated to be 110 000 and 78 000 tonnes respectively.

1974. A cruise covering the area from Skagerrak to about

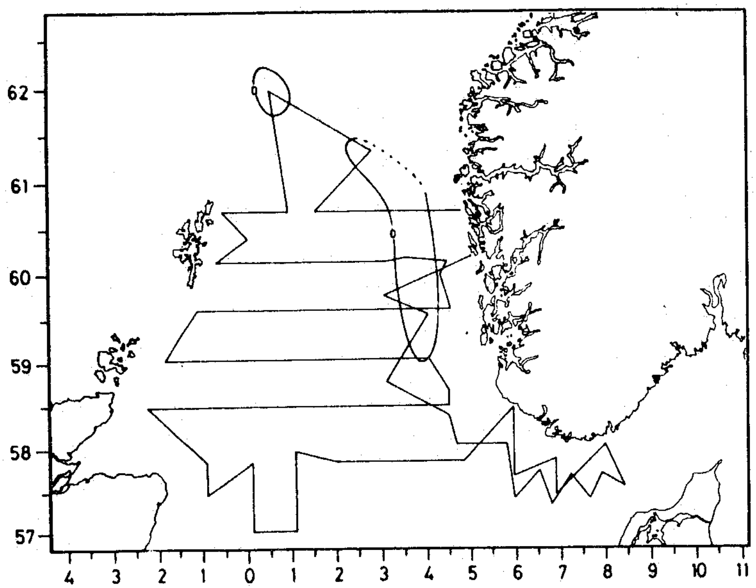

Fig. 10. Integrated echo intensities (mm deflection) of mesopelagic fish in May 1973. The survey routes are indicated.

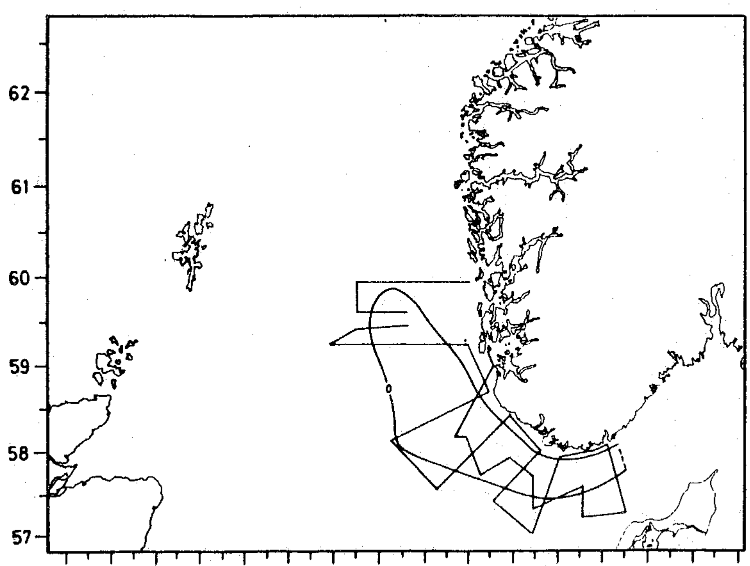

Fig. 11. Integrated echo intensities (mm deflection) of mesopelagic fish in October 1973. The survey routes are indicated.

61°N along the Norwegian Deep and the area north of the Faroe Islands was conducted during November-December. Mesopelagic fish were observed in three areas (Fig. 12). In the area off south-west Norway the density was low, while denser concentrations (15-25 g/m²) were observed in the two northern areas.

The northern distribution areas stretched beyond the area covered by the cruises. Within the area covered, the abundance of mesopelagic fish was about 187 000 tonnes.

1975. The Norwegian Deep from about 6°E to 63°N was covered during a cruise conducted during April-May, as was the area extending from 7°E to about 62°N during May-June.

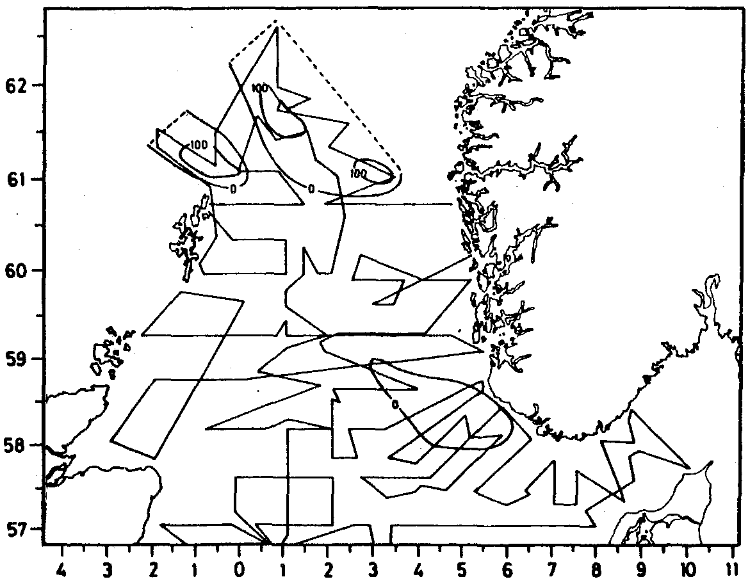

Fig. 12. Integrated echo intensities (mm deflection) of mesopelagic fish in Novembe-Decembe 1974. The survey routes are indicated.

During the first cruise (Fig. 13) dense concentrations were observed from about 61°N and northwards. The highest average concentrations observed over five miles were 160 g/m² . The estimated abundance in the area covered was 114 000 tonnes, but

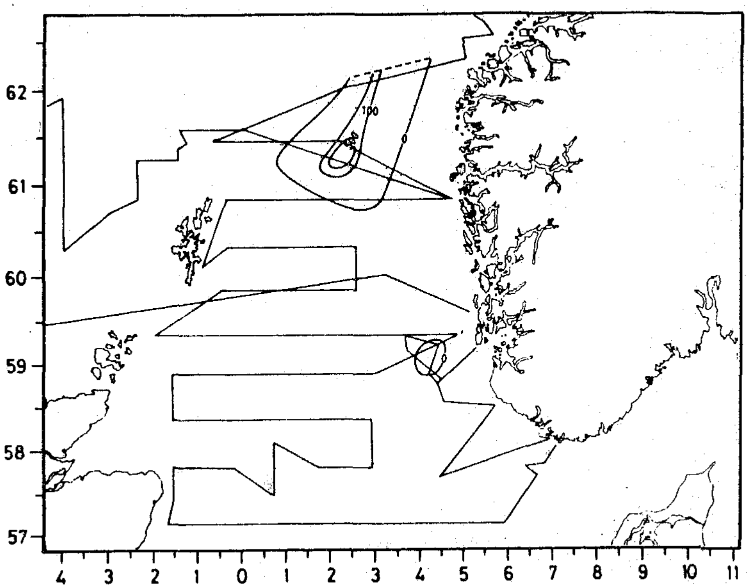

Fig. 13. Integrated echo intensities (mm deflection) of meso-pelagic fish in April-May 1975. The survey routes are indicated

the northern extension of the distribution area is not known.

During the last cruise, conducted only about a month after the first one, mesopelagic fish were observed south of about 61°N (Fig. 14), but the concentrations were still very low and the abundance was about 47 000 tonnes. The northern area, where the best recordings were made during the first cruise, was not covered.

1976. A cruise covering the Norwegian Deep from about 7°E and northwards and the area north of the North Sea plateau was conducted during May-June, and one covering Skagerrak, the Norwegian Deep and the area north of the North Sea plateau up to about 63°N was carried out during November-December.

During the first cruise (Fig. 15) mesopelagic fish were

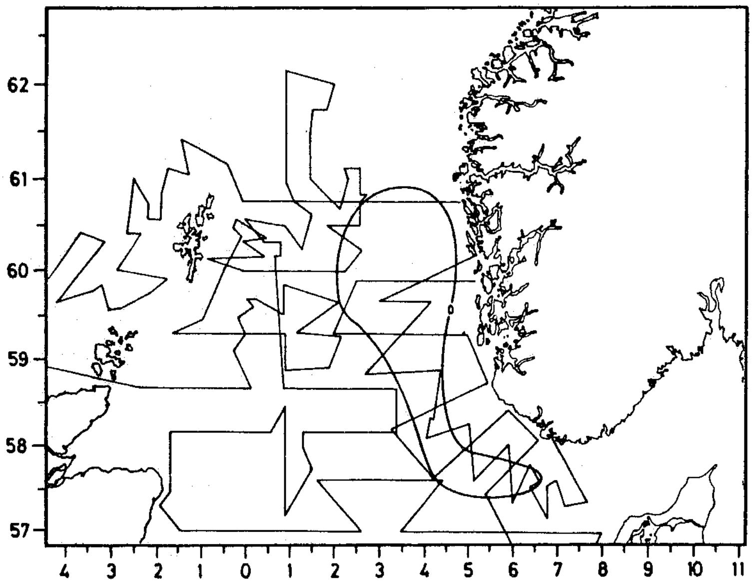

Fig. 14. Integrated echo intensities (mm deflection) of meso-pelagic fish in May-June 1975. The survey routes are indicated.

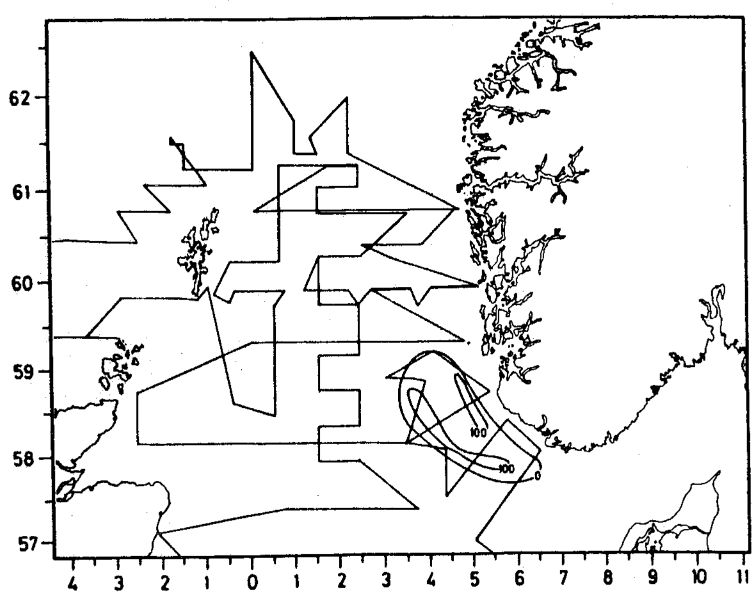

Fig. 15. Integrated echo intensities (mm deflection) of meso-pelagic fish in May-June 1976. The survey routes ar indicated.

recorded off south-western Norway with densities of about 30 g/m² in a narrow band along both sides of the Norwegian Deep. The total abundance was about 240 000 tonnes.

During the last cruise, mesopelagic fish were found in one area south of Norway (Fig. 16) and in one area from about 60°N and northwards. The extentions of this area are not known. In the northern part of the area there were densities above 35 g/m² over several hundred square nautical miles and the highest five mile average was about 300 g/m². The total abundance within the area studies was 1600 000 tonnes.

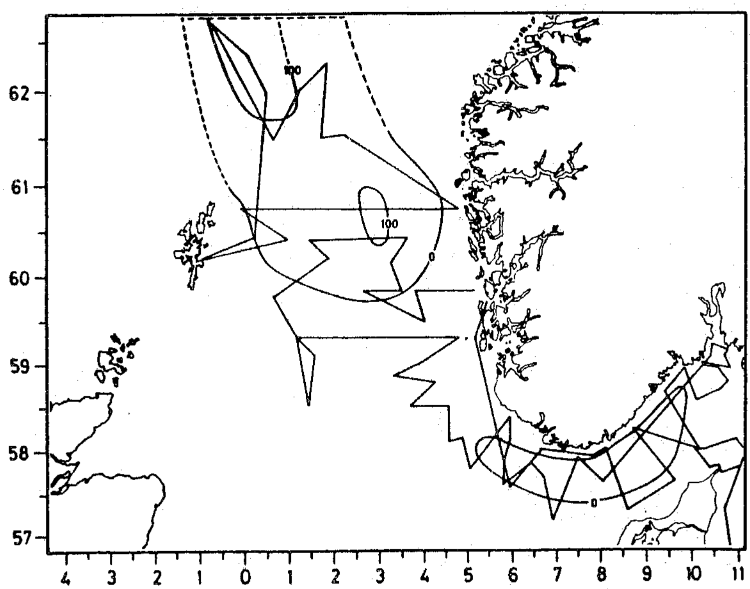

Fig. 16. Integrated echo intensities (mm deflection) of mesopelagic fish in November-December 1976. the survey routes are indicated.

DISCUSSION

An abundance assessment of the type used in the present study has many serious sources of error. Some of the problems involved in the use of acoustical methods for estimating abundance of mesopelagic fish is discussed by Gjøsæter (1981c) and Aglen et al. (1982).Probably the most important ones are the difficulties in segregating echoes of mesopelagic fish from other organisms and to establish a density coefficient for the echo recordings.

In the areas studied, mesopelagic fish often occurred together with krill. To separate them, recordings from the 38 kHz echo sounders were compared to those from the 120 kHz sounders, and the trawl catches were studied. Probably the separations were not always very accurate; krill, however, give much less echo than fish of comparable biomass (Beamish 1971).

In the present study the conversions of integrated echo abundance to fish biomass may be the most important source of error. When fish length is much larger than wave length, a relationship is established (e.g. Nakken and Olsen 1977), but there is doubt about what happens when fish length approaches wave length (approximately 4 cm for 38 kHz). The present calculations assume that the equation $P_a = CM + d$ is applicable to all length groups considered. The density coefficient (C) for mesopelagic fish is not known and therefore that for capelin (*Mallotus villosus*) has been used. This may be acceptable for *Maurolicus meulleri* but it may lead to an underestimation of the quantity of *Notoscopelus kroeyeri* since the latter species has fat in the swimbladder and therefore is believed to reflect less sound energy.

The density coefficient is also dependent on the size of the fish concerned, but the variations in size of one of the most important fish, *Maurolicus muelleri*, is not sufficiently known to compensate for this. Therefore, a constant mean length was used for this species.

As the density coefficient changed during the period of investigation (Table 2), the integrated echo intensities and the isolines shown in Fig. 1-5 and 7-16 are not directly comparable. The abundance of fish corresponding to a given isoline will be about five times higher in 1971 and 1972 than in 1974.

West of the British Isles all the cruises were carried out during spring and nothing is therefore known about the seasonal variation in abundance. *Notoscopelus kroeyeri*, which seems to be the most abundant mesopelagic fish during the cruises, appears to be expatriated, but it is not known from where the population is recruited (Gjøsæter 1981a).

Off western Norway five cruises were carried out during the period April-July, and five during October-December. The variance within a season was larger than the difference between seasons and there was no consistent trend in the differences.

The data available do not suggest any seasonal migration pattern. The distribution of eggs and larvae also suggests that *M. muelleri* spawns over wide areas and has no special spawning migration (Gjøsæter 1981b).

Mesopelagic fish are also present outside the zero isolines shown on the maps. The lowest echo intensity recorded was 1 mm/n.mile, and for *M. muelleri* this corresponds to about 0.03 fish/m^2 in 1974, 0.06 fish/m^2 in 1973 and about 0.2 fish/m^2 in the other years. For *N. kroeyeri* the values will be about four times lower, but this is still higher than the density commonly observed in deep scattering layers in the open ocean (Batzler and Pickwell 1971).

Generally, the fish densities observed during the present investigations were lower than those observed in the highly productive areas in the Arabian Sea (Gjøsæter 1984) and off north-west Africa (Gjøsæter and Blindheim 1982). However, the densities were sometimes high enough to be interesting from a fisheries point of view.

In March 1972 Olsen (1972) did some exploratory fishing for *M. muelleri* in an area about 61°N 2°E, but the catches were small (maximum one tonne/3 hrs.) as the mesh size of the trawl was too large. Exploratory fishing for *M. muelleri* off Australia has been characterized as promising, although the catches so far have been low (Anon. 1977).

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