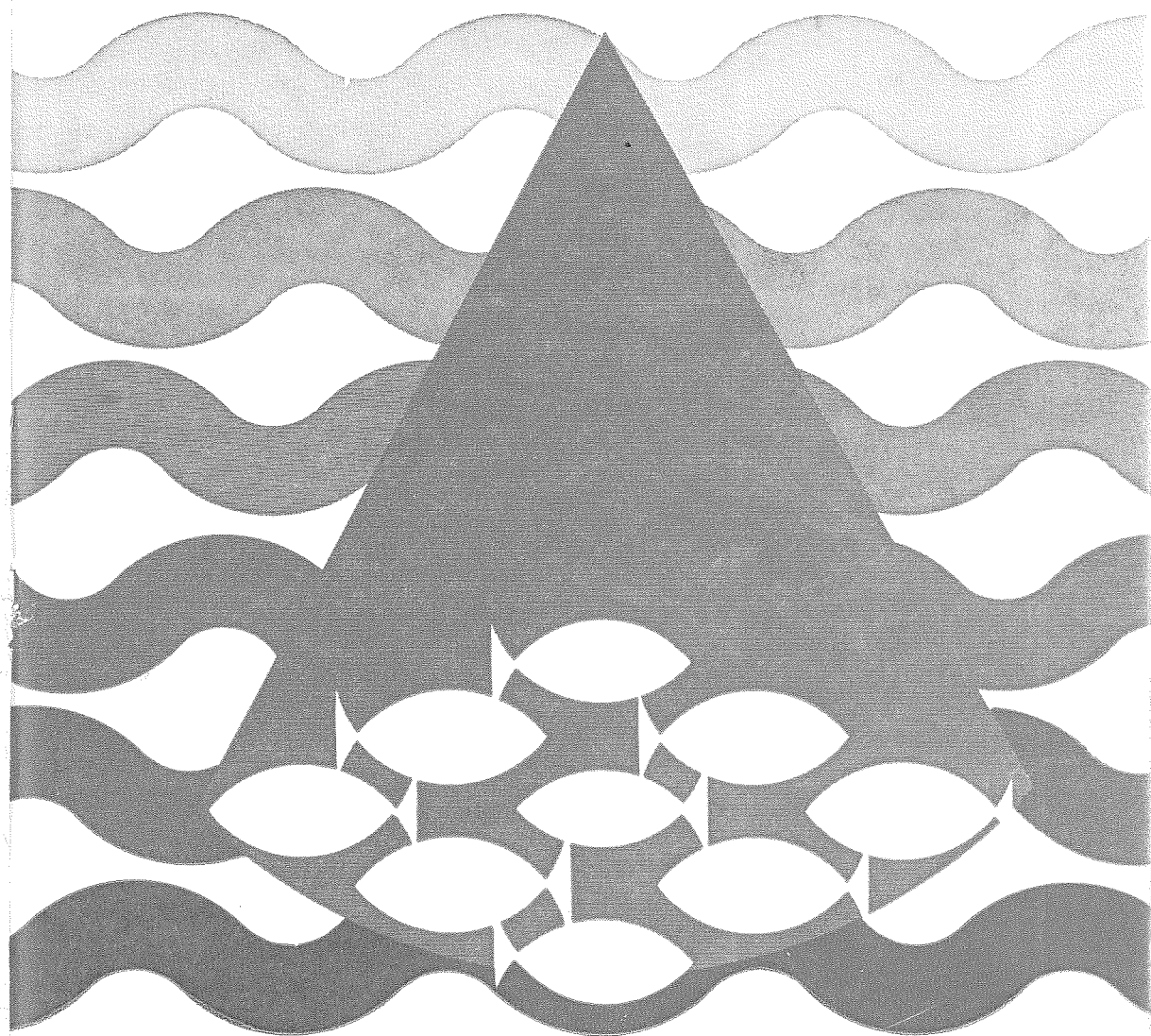


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ECOLOGICAL INVESTIGATIONS ON THE SPAWNING GROUNDS OF THE BARENTS SEA CAPELIN

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ABSTRACT

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A programme to study the reproduction of the Barents Sea capelin was conducted by the Institute of Marine Research in Bergen during the period 1971—1974. The present paper deals with the investigations on the spawning grounds along the coast of northern Norway.

During the years of investigations the spawning started between 1 and 15 March, and there was a gradual movement of the spawning area towards north and east during the observation period. The temperature during the incubation has been 1.5 and 6.5° C. The main spawning depth appears to be between 25 and 75 m. The extremes of the spawning depth observed was 12 and 280 m.

The capelin seem to prefer rather coarse substratum as gravel or cobble for spawning. The capelin eggs are mixed with the substratum to a layer up to 15 cm thick. This burying of the eggs is caused by strong current resulting in a sediment transport along the bottom.

Both diving ducks and haddock have been observed feeding on capelin eggs. This predations is probably of little importance although the haddock may consume significant egg quantities on some of the deepest spawning grounds.

INTRODUCTION

The Barents Sea capelin, *Mallotus villosus*, is one of the most important resources for the Norwegian fisheries. The catch was reaching a peak, 1.6 mill. tons, in 1972. The main fishery is based on the spawning stock approaching the coast of northern Norway and Murman during February—April. The spawning stock is dominated by one or two yearclasses and wide fluctuations in the spawning stock size may therefore be expected. Most of the capelin probably die after the spawning. There is also a spawning during summer and autumn but this seems to be of minor importance and very little data is available (ПРОКХОРОВ 1965).

Capelin has a circumpolar distribution and can be found in the northern regions of the Atlantic and the Pacific. The eggs are demersal

and stick to the bottom substratum. For spawning its preference with regard to depth, temperature and substratum seem to vary geographically, and the published accounts appear to be partly contradictory. Egg development takes 40—50 days at a temperature of 2.8 °C and 30 days at 5 °C (PITT 1958, POZDNJAKOV 1960).

A programme to study the reproduction of capelin was initiated by the Institute of Marine Research in 1971. This programme aimed to give a better understanding of the reproduction biology of capelin and to give data for the management of the fishery. It includes studies on the spawning influx, on the spawning grounds and on the larval drift.

Results from these studies have partly been published by BJØRKE, GJØSÆTER and SÆTRE (1972), GJØSÆTER and SÆTRE (1973), DRAGESUND, GJØSÆTER and MONSTAD (1973) and GJØSÆTER, HANSEN, SÆTRE and WESTERGAARD (1974). Some diving observations from the spawning grounds were presented by BAKKE and BJØRKE (1973) and observations on predation of capelin eggs by eiders by GJØSÆTER and SÆTRE (1975). A method for estimating the spawning stock size based on egg and larval data, and the application of this method on the Barents Sea capelin was described by GJØSÆTER and SÆTRE (1974).

The present paper sums up the results from the spawning grounds investigations.

BEHAVIOUR

The behaviour of capelin on the spawning grounds was observed by SCUBA divers and by using echo sounders. Echo recordings indicate that the capelin approach the spawning grounds in dense, pelagic schools (Fig. 1). These schools may contain several hundred tons. Sampling has indicated that males and females often form separate schools. As the schools reach the spawning ground, they may be recorded as settled on the bottom (Fig. 2) or as a continuous layer along the bottom as seen on the left side of Fig. 3. This is a typical spawning layer. A Petersen grab with a 0.1 m² opening caught 30 spawning capelin from such a layer. At the right side of Fig. 3 spent capelin are leaving the spawning bed.

Excluding the pelagic migratory schools, the divers observed two types of schools at the spawning grounds. The first type consisted of more or less regularly oriented capelin swimming forward or in circles (Fig. 4). The distance between the capelin was usually between 15 and 30 cm, and the size of the schools was highly variable. The schools

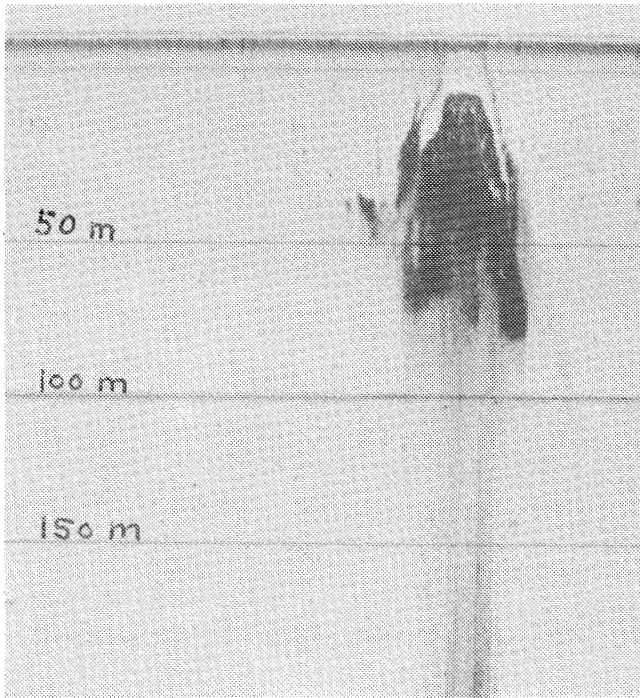


Fig. 1. Pelagic migration school of capelin.

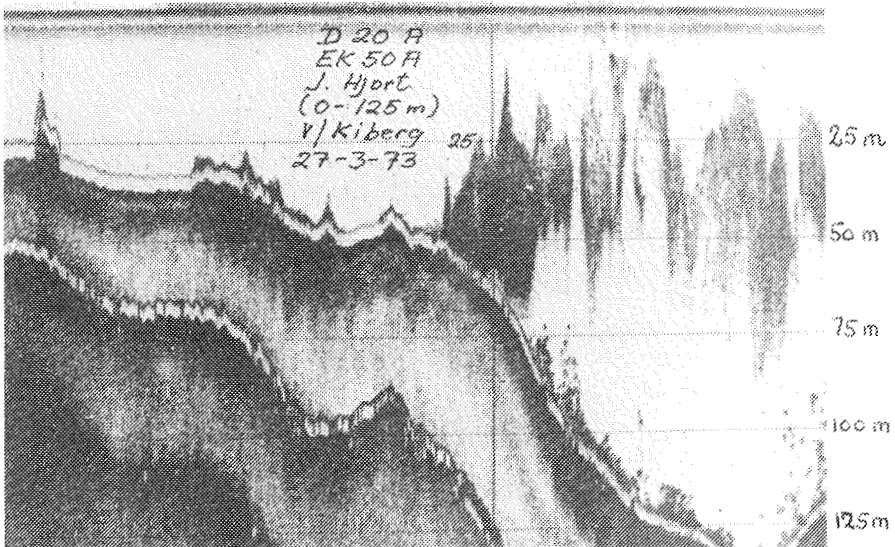


Fig. 2. Schools of capelin settling on the bottom.

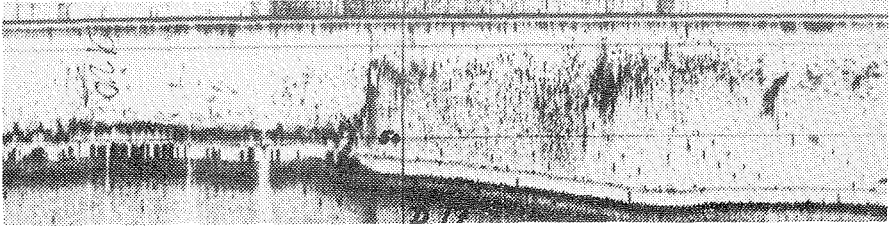


Fig. 3. Spawning capelin forming a layer along the bottom.

reacted collectively to stimuli, and they seemed to be attracted by white and shining objects. As two schools met, the capelin swam upwards in a disorderly manner but they soon gathered in separate schools again.

The second type of schools or masses was often pyramidal and consisted of irregularly oriented fish (Fig. 5). The lower part, having a diameter of about 3—5 m, was close to the bottom. The mean distance between the fishes was only 5 cm, and occasionally they were more concentrated. The activity was highest in the centre of the school.

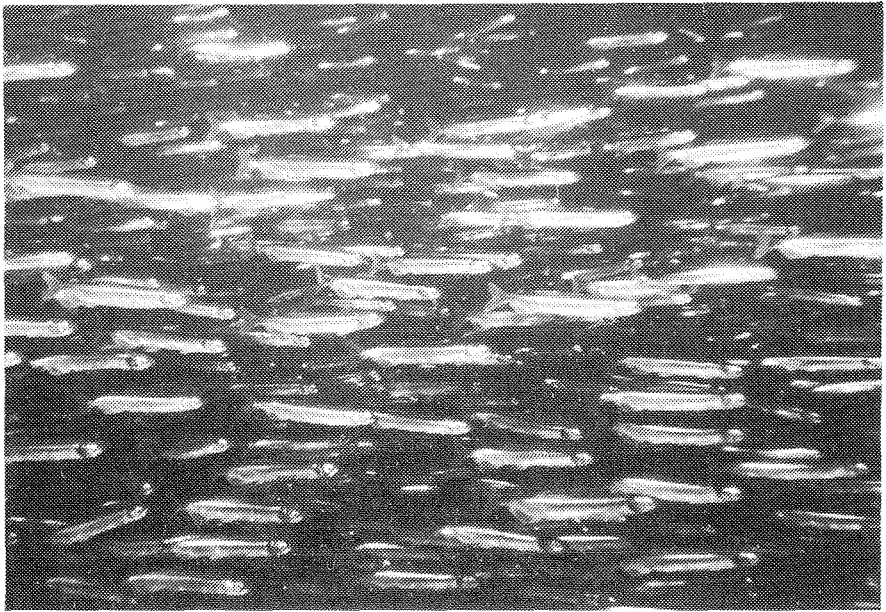


Fig. 4. School of regularly oriented capelin at the spawning ground.

Sometimes capelin from these schools were observed feeding on eggs whirled up from the bottom. Prespawning and spawning males were totally dominant in both types of schools, and females were seldom observed at the spawning grounds.

The spawning act was never observed, possibly because it mainly takes place during the night. The spawning has, however, been described for Canadian beach spawners (e.g. SLEGGs 1933). Male capelin, which had finished spawning, were occasionally observed on the spawning grounds. They seemed to be in a very bad condition. Many of these, and also the dead males found on the bottom, had a permanent deflection on the side. This malformation probably appears during the spawning act when only one male spawns with a female and has therefore to take up a strongly curved position. Spent females were very seldom observed at the spawning grounds.

The two types of schools described here probably correspond with those described by SLEGGs (1933) and BAKKE and BJØRKE (1973). Our observations indicate great variations in the swimming speed of the first type of school. These schools can probably search wide areas to find suitable spawning beds. Both our observations and those of BAKKE and BJØRKE (1973) agree that the schools reacted collectively to stimuli.

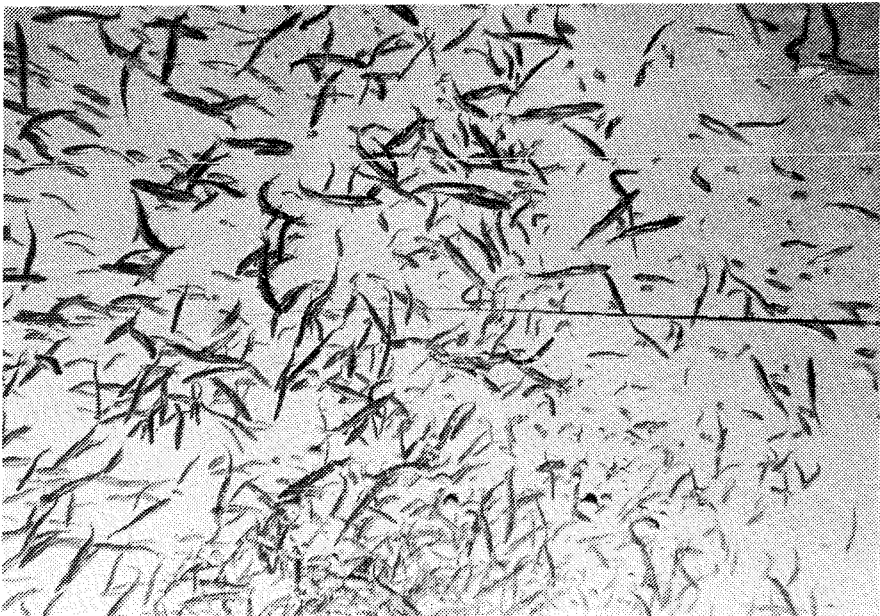


Fig. 5. Pyramidal school with irregularly oriented capelin.

The second type, described as «globular masses» by SLEGGs (1933) and as «very dense formations» by BAKKE and BJØRKE (1973), most likely represent the last stage before spawning. These schools appeared to be rather stationary. They reacted only slightly to the presence of divers, and this reaction was individual and not common for the whole school.

LOCATION AND TIME OF THE SPAWNING

The spawning grounds were located by a combination of the following methods:

- A) Monitoring the migration of the maturing capelin by echo surveys.
- B) Following the development of the fishery and reports from the fishermen.
- C) Analysing the stomach contents of demersal fishes (e.g. haddock).
- D) Recording concentrations of diving ducks.
- E) Sampling with a 0.1 m² Petersens grab.
- F) SCUBA diving.

Methods A to D were used for limitation of the most likely spawning areas and methods E and F for confirmation and detail surveying. To confirm that alle the important spawning grounds had been found, the data from the larval surveys (GJØSÆTER and SÆTRE, unpublished) were consulted.

Eggs, naturally spawned and artificially fertilized, were placed onboard in incubators for hatching at different temperatures. The results obtained, made it possible to calculate the age of the eggs (GJØSÆTER, unpublished). Based on this, the time of spawning was estimated.

Fig. 6 shows the observed spawning grounds during the period 1971—1974. In 1971 the larval distribution indicates that some spawning also occurred farther south. This year concentrations of capelin were located as far south as Vesterålen which is the most southerly area of capelin catches during the last two decades (DRAGESUND *et al.* 1973). For the remaining years all major spawning localities are assumed to be included. These are always situated at the outer part of the coast.

There seems to be a gradual movement of the spawning area towards north and east during the observation period. Except for the years 1938—1942 and 1962 the capelin has been an unfailing guest along the coast of northern Norway for at least the last hundred years (MØLLER og OLSEN 1962, OLSEN 1968). The Vardø—Kiberg area seems to be the most regular spawning locality. Spawning west and south of Loppa is considerably less frequent.

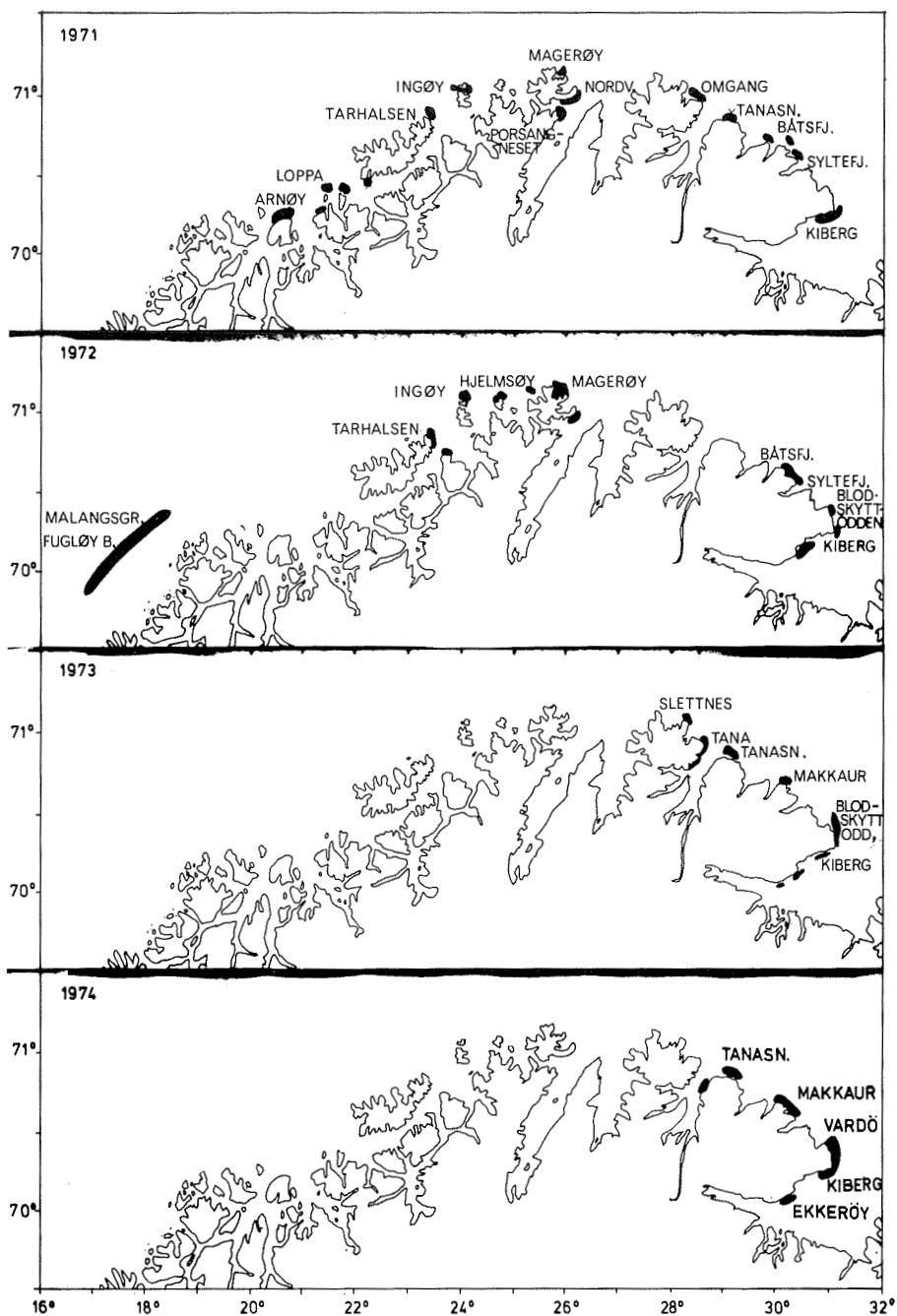


Fig. 6. Location of the observed spawning grounds.

Fig. 7 shows the time and duration of the spawning for the years 1971—1974. Usually there are several separate spawning runs at the different localities. The year 1971 appears to be somewhat anomalous in that respect. Mature capelin approached the coast in the Ingøy—Magerøy area continuously during February and March and proceeded farther west and south along the coast. (DRAGESUND *et al.* 1973). This may be due to spawning stock size which in 1971 was at a very high level. In the eastern part of the spawning area at Vardø—Kiberg only small concentrations of capelin were recorded. The spawning started in the southernmost area in the middle of March.

In 1972 two separate influxes occurred. The westernmost influx approached the coast in the Ingøy—Magerøy area from the north at the end of January. The capelin moved south and west along a route approximately 20 nautical miles from the coast (BLINDHEIM og MONSTAD 1972). The spawning started at the Fugløybank and Malangsrunden in the beginning of March. In the middle of March a second influx reached the surroundings of Vardø. This part of the spawning stock moved westward.

In 1973 the capelin influx followed the coast of Murman and reached Vardø at the end of February (JACOBSEN og NAKKEN 1973). The spawning started in this area about 10 March.

Three independent spawning runs were present in 1974. The first one approached Omgang from the north and turned eastwards along the coast. The second influx reached Vardø from the northeast, and the third followed the coast of Murman towards Kiberg (ANON. 1974). The spawning started in the Vardø—Kiberg area about 15 March.

During the last century the first spawning run has reached the Norwegian coast between the beginning of February and the end of April. An early arrival of the capelin appears to be associated with a westerly distribution (OLSEN 1968, GJØSÆTER 1972).

HYDROGRAPHIC CONDITIONS

The bottom temperature and salinity were measured throughout the whole incubation time. Current measurements with recording instruments of the Aanderaa type were carried out close to the sea floor at several spawning beds.

Table 1 shows the hydrographic conditions during the spawning seasons 1971—1974. The lowest temperature during the time of incubation was recorded in 1971 when the capelin started to spawn in water of 1.5°C. The high upper limit in 1972 is due to the spawning in more oceanic water masses at the Malangsrunden and the Fugløybank. The salinity

Table 1. Hydrographic conditions during the spawning seasons 1971—1974.

Year	t °C during incubation	S ‰ during incubation	t ₁₀₀ Ingøy	S ₁₀₀ Ingøy	Temperature anomaly	
					Loppa	Vardø
1971	1.5°—3.5°	34.1—34.4	3.72°	34.470	—1.0°	—0.9°
1972	2.5°—6.5°	34.1—34.6	4.85°	34.560	+0.5°	+0.7°
1973	2.0°—4.0°	34.4—34.6	4.82°	34.658	+0.8°	+0.9°
1974	2.5°—4.0°	34.4—34.6	4.59°	34.651	+0.2°	+0.6°

at the spawning beds during the period 1971—1974 has been between 34.1 and 34.6‰ which is about the normal salinity for the coastal waters along northern Norway.

Table 1 also shows the mean temperature and salinity for the upper 100 m at a fixed oceanographic station off Ingøy during March—April and the temperature deviations from the normal 1936—1970 for the surface layer at Loppa and at Vardø (SÆTRE 1973). It is quite obvious that 1971 is characterized by a small influence of Atlantic water masses along the coast of northern Norway and 1973 as the year of the most marked Atlantic influence.

Previous observations of the spawning temperature of the Barents Sea capelin are rather few. RASS (1933) reports spawning in about 2 °C, and OLSEN (1968) observed spawning in temperature between 2.5 and 5 °C. Listed in Table 2 are spawning temperatures of capelin reported from other areas. It appears that the temperatures at Greenland and on the Grand Banks are very similar to those observed by the present authors.

Table 2. Temperatures in some capelin spawning areas.

Area	Spawning temperature	Author
Newfoundland, beachspawners.	5.6°—10.0°	SLEGGs 1933, TEMPLEMAN 1948
Newfoundland, Grand Banks .	2.8°—4.2°	PITT 1958
British Columbia	10.0°—11.0°	HART and McHUGH 1944
Iceland	6.0°—7.0°	JESPERSEN 1920, MAGNUSSON 1966
Greenland	1.9°—6.6°	KANNEWORFF 1968

FLORA AND FAUNA ON THE SPAWNING GROUNDS

The macro flora on the spawning beds included some dispersed *Laminaria digitata*. Various corallinaceae and other red algae were also found. Some eggs were overgrown with small filamentous colonies of diatomea. This occurred only at depths between 10 and 30 m and only

Table 3. Some animals from the spawning grounds.

Phylum	
Porifera	Various species
Cnidaria	Various thecaphore hydroida
Plathyhelminthes.	Turbellaria
Nemertini	Various species
Aschelminthes .	Various nonparasitic nematoda
Arthropoda	Ostracoda
	Copepoda, mainly harpacticoida
	Cirripedia
	Cumacea
	Amphipoda
	Mycidacea
	Decapoda, e.g. <i>Hyas</i> , <i>Pagurus</i> .
Mollusca	Polyplacophora
	Gastropoda
	Bivalvia, e.g. <i>Cyprina</i> , <i>Clamys</i> , <i>Modiolus</i>
Annelida	Polychaeta
Ectoprocta	Many species
Brachiopoda . . .	Various species
Echinodermata .	Asteroidea, e.g. <i>Asterias</i>
	Ophiuroidea
	Echinoidea, e.g. <i>Strongylocentrotus</i> , <i>Spataugus</i>
	Holothuroidea
Chordata	Pisces: <i>Gadus morhua</i> , <i>Melanogrammus aeglefinus</i> , <i>Pollachius virens</i> , <i>Ammodytes sp.</i> , <i>Anarhichas lupus</i> , <i>Pleuronectes platessa</i> .

on eggs lying on the top of the substratum. Laboratory experiments suggested that these algae had no noticeable effect on the development of the eggs.

The fauna on the spawning grounds was usually sparse and the total biomass very low. No systematic collection was carried out, but some taxa, commonly observed in grab samples or by divers, are listed in Table 3. None of the invertebrates seemed to feed noticeably on eggs or significantly alternate their environment.

DEPTH AND SUBSTRATUM OF THE SPAWNING

After the location of the spawning grounds, some of the spawning beds were selected for a more detailed investigation. A Decca map in the scale of 1:5000 or 1:10000 was constructed covering the selected spawning bed. The Decca Navigator System has a high resolution in coastal waters and thus make it possible to navigate with a high relative accuracy. A detailed surveying of the spawning bed was performed using grab and SCUBA divers. The divers were equipped with sampling tubes

0 NO EGGS

1 LESS THAN 10 EGGS

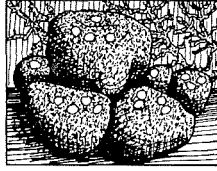
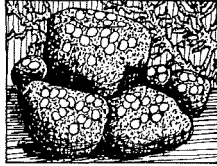
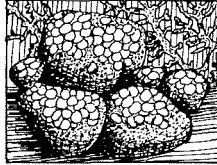
2 SOME EGGS ON
SUBSTRATA3 SUBSTRATA
PARTLY COVERED4 SUBSTRATA
DENSELY COVERED

Fig. 8. Scale for classification of egg quantity.

which enabled them to take samples where the stratification of the bottom substratum was undisturbed. The divers also filmed and photographed on the spawning beds.

The amount of eggs in the grab samples were subjectively classified from 0 to 4 according to the scale shown in Fig. 8. No eggs in the sample were denoted 0 and the highest densities of eggs designated 4. The decisive factor for the classification was the ratio between number of eggs and the quantity of bottom substratum in the sample. The order of size of the egg densities corresponding to the different egg quantities appears in Table 4.

Table 4. Corresponding values of egg quantities and egg densities.

Egg quantity	Egg density eggs/m ²
0	None
1	10 ¹ —10 ³
2	10 ³ —10 ⁵
3	10 ⁵ —10 ⁶
4	10 ⁶ —10 ⁷

The size distribution of the sediment aggregates was classified according to the Wentworth scale (WENTWORTH 1922). This scale is a geometrical one using the particle diameter in mm raised to the powers of 2 as steps between successive elements of the series. KRUMBEIN (1936) used the exponents, that is, the powers of 2 in the Wentworth series as the basis for a logarithmic scale of sediment size. He defined a unit, Φ , as the negative logarithm to the base of 2 of the particle diameter in millimeters, $\Phi = -\log_2 D$. The logarithmical scale is chosen as most of the physical properties of a sediment are found to vary as some power of sediment size rather than directly with size.

Table 5. Depth distribution of egg quantity 0—4 in grab samples 1971—1974.

Depth in m	Egg quantity					Sum
	0	1	2	3	4	
0—24.....	221	83	32	16	15	367
25—49.....	820	171	100	52	33	1 176
50—74.....	387	69	31	5	5	497
75—99.....	170	16	9	4	1	200
100—124.....	78	5			1	84
125—149.....	51	2	1			54
150—174.....	23	3				26
175—199.....	22	1				23
200—224.....	6	1	1			8
225—249.....	2		1			3
250—350.....	9	1				10
Sum	1 789	352	175	77	55	2 448

Table 5 shows the distribution of egg quantities 0—4 at different depths for all the grab samples during the period 1971—1974. Fewer high egg densities are found (i.e. egg quantity 3 and 4) as the depth of the grab samples is increased. In 0—24 m 8.4% of the samples contained egg quantity 3 or 4, in 25—49 m 7.2% and in 50—74 m about 2%. The most shallow spawning bed observed is Nordvågen in 1971 with depths between 12 and 18 m. The deepest sample containing capelin eggs is from 280 m off Vardø in 1973. The samples from the deeper parts are few and the probability of getting a correct sample will decrease with increasing sampling depth. Although the sampling design makes the data unsuitable for statistical treatment they still indicate that the main spawning take place in the upper 75 m.

Information concerning the depth of spawning of the Barents Sea capelin is rather divergent. The suggestions that appear to be in best accordance with our observations are those by RASS (1933) (50—100m) and MOLLER and OLSEN (1962) (10—100 m).

Along the coast of Newfoundland and Labrador the beach spawning is often succeeded by spawning at increasing depth down to at least 55 m (TEMPLEMAN 1948). PRITT (1958) reported indications of spawning on the Grand Banks at depths between 46 and 80 m.

The capelin eggs observed by us in the deepest samples may have been spawned at this depth or they may have been transported there from shallower spawning beds. Bottom trawl used at about 250 m depth several times caught haddock with a stomach content of recently swallowed fertilized capelin eggs. This supports the first explanation. Though the main spawning occurs in the upper 100 m, the Barents Sea capelin seems to be able to spawn down to at least 250 m.

Table 6. Distribution of egg quantity 0—4 at different substrata in grab samples 1971—1974.

Substrata	Egg quantity					Sum
	0	1	2	3	4	
Pebble-gravel	129	39	29	19	27	243
Shell gravel	387	71	55	29	15	557
Hard bottom-cobble ...	1 036	192	62	23	12	1 325
Mineral sand	144	47	27	6	1	225
Silt-Clay	93	3	2			98
Sum	1 789	352	175	77	55	2 448

In Table 6 is listed the distribution of egg quantities 0—4 at different substrata. The table shows that gravel or pebbles is the most preferred substratum for spawning. About 19% of the samples from this bottom material contained egg quantity 3 or 4. Shell gravel also occurs as a spawning substratum. About 8% of these samples were classified as egg quantity 3 or 4. At hard bottom and mineral sand between 2.5% and 3% of the grab samples contained egg quantity 3 or 4. Eggs were rarely observed on silt and clay.

Fig. 9 shows a typical size distribution of pebble substratum at Blodskyttdoden. The size frequency distribution is represented by a cumulative percent curve of weight. The median M_d , which is the diameter size at 50% of the cumulative frequency curve, amounts to 8.25 mm. TRASK (1932) defined a sorting coefficient as $S = V \frac{Q_3}{Q_1}$ where Q_1 and Q_3 are the diameter in millimeters corresponding to the 25th and 75th percentiles, respectively, of the cumulative curve. S in the distribution shown in Fig. 9 is 1.55 which indicates a well sorted sediment.

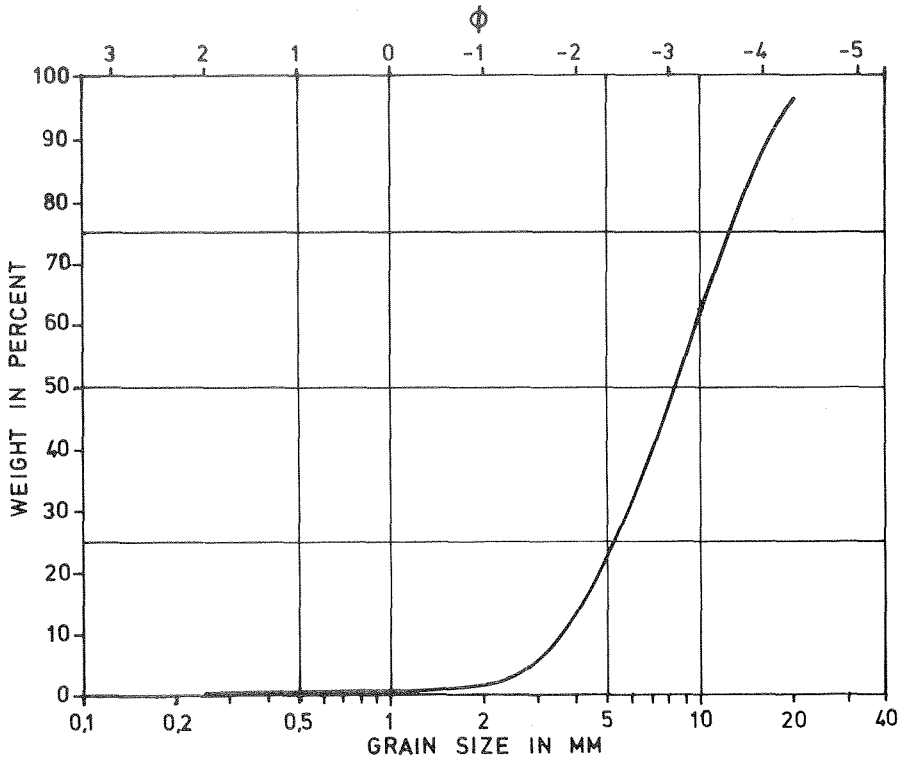


Fig. 9. Typical grain size distribution of pebble substratum from a spawning bed. For explanation see text.

The median of the pebble or gravel substratum where spawning occurred varied between 5 and 15 mm and the sorting coefficient between 1.3 and 1.6. On cobble spawning was observed on substratum up to a size of 60 mm in diameter.

The capelin seem to prefer rather coarse material for spawning. SLEGGs (1933) states that the Newfoundland beach spawning capelin prefer to spawn on gravel beach. TEMPLEMAN (1948) confirms this and observed a grain size from 2.5 to 15 mm to be especially favourable for spawning. For the deeper spawning grounds PITT (1958) reports spawning at a grain size from 0.5 to 2.2 mm at Grand Bank. PROKHOROV (1965) also believes the spawning of the Barents Sea capelin to take place on sandy grounds with shell fragments. The observations of the last two authors are based on recordings of the stomach content of haddock and capelin where swallowed substratum particles were found together with capelin eggs. It is not believed that this method shows representative measure of the grain size at the spawning beds. As shown in Fig. 9 the gravel or pebble substratum also contains particles belonging to the sand fraction. From our investigation it appears that the haddock selects

the eggs attached to the smallest particles (GJØSÆTER and SÆTRE, unpublished). We therefore question the statements of an offshore spawning on a sandy bottom. We have indeed observed high egg densities in grab samples consisting mainly of sand (Table 6). This seems to be due to patches of sand in a substratum of coarser materials.

DISTRIBUTION OF EGGS ON AND IN THE SUBSTRATUM

The methods used for these investigations are the same as those described in the section on depth and substratum of the spawning.

As indicated by Table 6, the preferred spawning substratum is gravel, pebble, shell gravel and cobble. Fig. 10 shows egg quantity 4 on gravel



Fig. 10. Eggs at gravel bottom (Egg quantity 4).

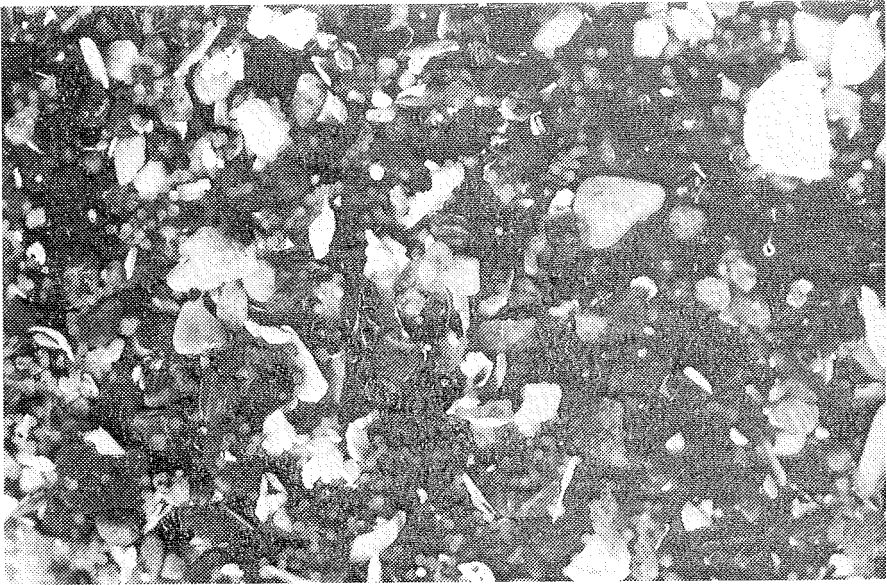


Fig. 11. Eggs at gravel bottom with shell fragments (Egg quantity 3).

bottom. A more detailed picture is shown in Fig. 11. Fig. 12 shows eggs on bottom consisting of shell gravel. A conspicuous feature of the egg distribution on these substrata is that the eggs are attached to the single particles. The layer of bottom substratum with eggs can reach a thickness of 15 cm, but 5—7 cm is the most usual.



Fig. 12. Eggs at shell gravel.



Fig. 13. Layers of eggs at cobble.

On cobble the eggs are less mixed with the substratum and more attached to each other. Fig. 13 shows eggs on such a bottom together with empty shells. Fig. 14 gives a more detailed picture of the egg distribution. The egg layer of the cobble rarely exceeds 3 cm. The egg distribution is usually homogenous within a spawning bed. An abrupt change in egg density corresponds with a transition of the bottom substratum.



Fig. 14. Eggs and fauna from hard bottom.

The capelin eggs, found in gravel and shell gravel, are mixed with the substratum to a layer up to 15 cm thick. Although the capelin may be capable of doing some active burying, they certainly are not able to bury them to this depth. On most of the gravel and shell gravel spawnings beds the SCUBA divers observed periodic undulation in the bedding plane (Fig. 16). These so-called ripple marks are commonly observed in sand, but appear to be rather seldom in coarser materials (ALLEN 1968). The ripple marks observed had a wave length of 1.0—2.0 m and an amplitude of 0.2—0.5 m. According to the classification of ALLEN (1970) they are called dunes. The gravel dunes were longcrested and usually elongated transversely to the dominant current directions. The current is the generating force of these dunes, and they will move with the water flow. Due to erosion the material on the crests is coarser than in the troughs. The lighter material, such as eggs, is accumulated in the troughs which are therefore visual as light parts in Fig. 11. Along the coast of northern Norway there is a rather strong and alternating tidal current approximately parallel to the coast. The dunes thereby will move back and forth and thus mix the eggs into the substratum.

Though the mechanism governing the formations of ripples and dunes is still not fully understood, the appearance of these is evidence of sedimentary displacement along the bottom.



Fig. 16. Ripple marks on a gravel spawning bed.

The mean egg density at egg quantity 4 is calculated within 95% confidence limits to $4 \cdot 10^6 \pm 1 \cdot 10^6$ eggs/m². If a fecundity of 10^4 eggs (GJØSÆTER and MONSTAD 1973) and a sex ratio of 1 : 1 are assumed, this will correspond to approximately 800 spawning capelin per square meter. The egg density expressed in eggs/cm³ substratum, will decrease with depth in the mixture of eggs and substratum. Typical examples of vertical distributions are shown in Fig. 15.

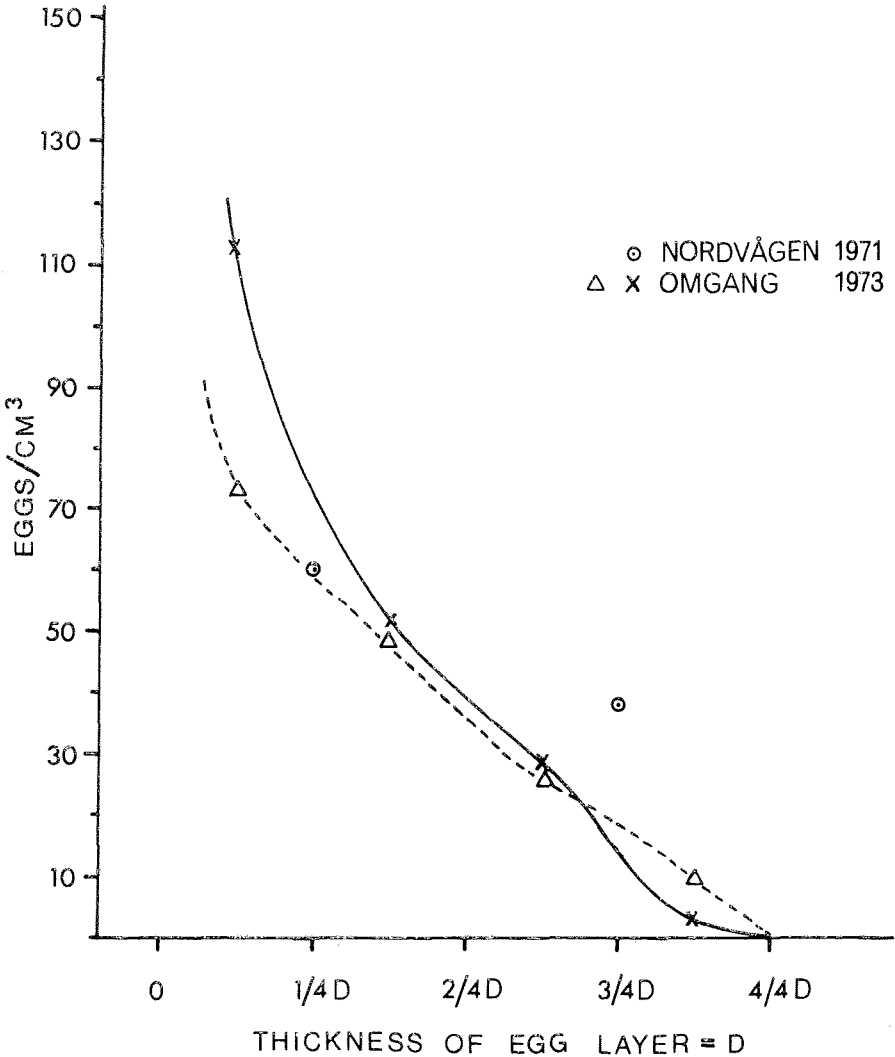


Fig. 15. Vertical distribution of eggs in the substratum.

HJULSTRØM (1939) has constructed a diagram to predict the critical conditions for the beginning of sediment movement as a function of current velocity. According to his diagram particles of size 5 mm are transported at a current of 40 cm/sec and particles of size 10 mm at 70 cm/sec. Current measurements on the spawning beds confirm that these values quite often are exceeded. It is obvious that the critical conditions for the commencement of the sediment transport cannot be deduced entirely from the grain size. The critical water velocity also varies with the excess density ($\rho_s - \rho$) of the grain where ρ_s is the density of the solid grain and ρ is the density of the water. Shell fragments therefore demand a lower velocity to move than pebbles of the same size. Eggs attached to the particles will reduce their density. This effect will increase with decreasing particle size. Therefore, to move a particle covered with eggs the strength of the current will be less than that deduced by the diagram of HJULSTRØM (1939), and this discrepancy will increase as the grain size is reduced.

The eggs of the Newfoundland beach spawning capelin are also mixed with the gravel. The thickness of this mixture can exceed 30 cm (SLEGG 1933). In this case it is the wave action which is the causal factor governing the burying.

At the spawning beds with egg layers thicker than approximately 5 cm there was a retardation in the development of the eggs from the deepest layers. This retardation became more pronounced during the incubation period. This is probably due to decreased availability of oxygen in the deepest layer. However, the viability did not appear to be influenced by this.

EGG MORTALITY

The reduction in number of eggs at the spawning grounds can be attributed to factors as rate of fertilization, drift of eggs and predation.

The rate of fertilization seems to be very close to 100% both in natural environment and in the laboratory. Outside the main spawning beds lower rates of fertilization were sometimes observed. Very little is known about the fate of the eggs that drift away from the spawning beds. LILLELUND (1961) has, however, shown that eggs of the closely related *Osmerus eperlanus* usually survive although they drift freely in the water masses. BAKKE and BJØRKE (1973) observed a reduction in egg density on the surface of the substratum in Nordvågen in 1971, and they believed this to be due to drift of eggs. Later investigations indicate, however, that drift of eggs is usually of little significance, and the observed reduction

in egg density on the surface was probably due to the eggs being buried in the gravel.

Water from the fish pumps used onboard the fishing ships often contains large number of eggs. Samples from this water, which go back to the sea, contained fertilized eggs. These eggs had retained their ability to stick to other objects. Most of them survived till the experiment was concluded at the blastula stage.

Predation by fish is often the most significant cause of mortality in demersal eggs. The most important predator is haddock.

In 1971 spawning was mainly observed in shallow water (less than 80 m), and only an insignificant number of haddock and other fish were found at the spawning grounds.

In 1972 part of the spawning took place in deeper waters, and at spawning grounds deeper than 150 m haddock was abundant. Seventy percent of the haddock caught at Malangsgrunnen contained capelin eggs. The number of eggs in each stomach ranged between 5000 and 10 000. Saithe and cod were also observed on the spawning grounds, but they did not feed on eggs. In trawl catches in the Malangsgrunnen area there were more haddock compared to saithe and cod at stations where capelin eggs were found. The mean length of haddock was lower and the degree of filling of their stomachs higher at stations with eggs than at stations without. The material available is too sparse to decide whether the haddock, and especially the small haddock, concentrates at the spawning grounds.

In 1973 and 1974 predation by haddock was also recorded at the deeper spawning grounds, but the predation was less than in 1972. It is not possible to assess the quanta of capelin eggs consumed by haddock, but it may be a significant part of the eggs spawned in water deeper than 100—150 m.

Haddock feeding on capelin eggs have been observed both in the Barents Sea and in Canadian waters, and it is supposed to constitute an important part of the haddock's diet during the capelin spawning season (ZENKEVITZH 1963, TEMPLEMAN 1965). TEMPLEMAN (1965) observed haddock feeding on capelin eggs at spawning beds lying as shallow as 40 m.

At spawning beds shallower than approximately 50 m flocks of ducks were observed feeding on capelin eggs. In 1972 the flocks consisted of about 3/4 king eiders (*Somateria spectabilis*) and 1/4 common eider (*Somateria mollissima*) and long-tailed duck (*Clangula hyemalis*).

In 1973 and 1974 king eiders were even more dominating and long-tailed ducks very sparse.

The ducks concentrated over the spawning beds as soon as the spawning started, and they disappeared during the hatching period. Although

the ducks were numerous, calculations indicate that the quanta of eggs consumed were less than 2—3% of the total egg production (GJØSÆTER and SÆTRE 1975).

Common eiders have also been observed feeding on herring eggs (SOLEIM 1942, CANTIN, BEDARD and MILNE 1974).

Capelin have often fertilized capelin eggs in the stomach, and in 1974 the divers saw capelin feeding on eggs. This predation is, however, probably of little importance.

Table 7. Mortality of capelin eggs at different egg quantities.

Mortality %	Egg quantity				Sum
	1	2	3	4	
<5%.....	10	19	14	13	55
5<10%.....	2	10	10	8	31
10<20%.....	7	3	4	1	15
20<50%.....	6	8	—	—	15
≥50%.....	12	2	3	—	17
Sum	37	43	32	21	133

The percentage of dead eggs was recorded in 132 samples from various parts of the spawning area (Table 7). In general the mortality was lowest where the egg density was highest. Even where the mixture of egg and gravel was as thick as 15 cm, no vertical gradient in mortality could be observed. Many of the eggs recorded as dead were mechanically destroyed. Parts of these eggs were probably destroyed by the sampling process.

Eggs which had completed approximately 2/3 of their developmental time (embryo with pigmented eyes and capable of strong movements), showed no increase in mechanical destruction, but slightly reduced viability when trawl bobbins were towed through the spawning beds (BAKKE and BJØRKE 1973, DRAGESUND *et al.* 1973).

Laboratory experiments (unpublished) also indicate that the eggs can endure fairly strong mechanical stress. The experiments indicate, however, that the susceptibility to mortality varies with the age. It seems to be high until the closure of the blastophore, then it decreases, but it apparently increases again during the last period before hatching. Comparable development in the vitality has also been observed for other species (e.g. RILEY 1974, POMMERANZ 1974).

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INVESTIGATIONS ON DIEL VERTICAL MIGRATION OF 0-GROUP FISH IN THE BARENTS SEA

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ABSTRACT

BELTESTAD, A. K., NAKKEN, O. and SMEDSTAD, O. M. 1975. Investigations on diel vertical migration of 0-group fish in the Barents Sea. *FiskDir.Skr.Ser.HavUnders.*, 16: 000—000.

In August—September diel vertical migration of 0-group fish was studied in the Barents Sea. Redfish and capelin had different vertical migration patterns. 0-group redfish were found at the surface at dark and spread in the upper 50 m during the daylight period while the unpigmented 0-group capelin stayed in small schools close to the surface by daylight and dispersed into a weak scattering layer at the depth of the thermocline (20—30 m) at dark. This behaviour might introduce large errors to the abundance indices of 0-group capelin.

Comparative fishing with a pelagic trawl and a purse seine were carried out. The samples showed no significant differences in the length distributions of each species of 0-group fish caught with the two gears.

INTRODUCTION

During late summer and early autumn fish fry of many species occur pelagically in the Barents Sea. Since 1965 joint international surveys have been carried out annually in this area during 12—15 days in late August and early September. The primary aim of these surveys has been to map the geographical distribution and to obtain estimates of yearclass strength of the different species of 0-group fish. Preliminary results have each year been reported to the International Council for the Exploration of the Sea (ANON. 1965—1974 a).

The distribution and density of the pelagic layers of 0-group fish have been observed with echo sounders, echo integrators and small meshed pelagic trawls. Details of the technique applied are given in DRAGESUND, MIDTTUN and OLSEN (1970), and a thorough description and discussion of the method was made by ANON. (1974b).

The main results from these surveys are indices of yearclass strength (HAUG and NAKKEN 1973). These indices might be influenced both by the sampling efficiency of the pelagic trawls and by the behaviour of the

fish. The vertical migration of the different species may thus effect observations both with echo sounders and pelagic trawls.

Diel vertical migration is a well known feature of the behaviour of most pelagic fishes. WOODHEAD (1966) and BLAXTER (1970) have reviewed the literature on the subject. Normally, pelagic fishes are found at intermediate depths during the day, they move towards the surface at dusk and descend at dawn. This general pattern will probably vary with fish size, species and environmental factors. Although a few investigations have been carried out on redfish larvae (KELLY and BAKER 1961 a, KELLY and BAKER 1961 b, MAGNUSSON, MAGNUSSON and HALLGRIMSSON 1965), the diel vertical migration pattern of the 0-group fish in the Barents Sea was considered to be insufficiently known. During the survey in 1974 experimental work was therefore conducted to study this subject, and the results from the experiments are reported here.

MATERIAL AND METHODS

The investigations were carried out with the 600 tons purse seiner «Havdrøn» which is also fitted for pelagic trawling and equipped with Scientific sounder, EK 38, two echo integrators, QM, and a net sonde. Observations were collected in three different localities (Fig. 1). The periods of observations were as follows:

Area 1: 27—29 August Area 2: 1— 3 September

Area 3: 4— 5 September

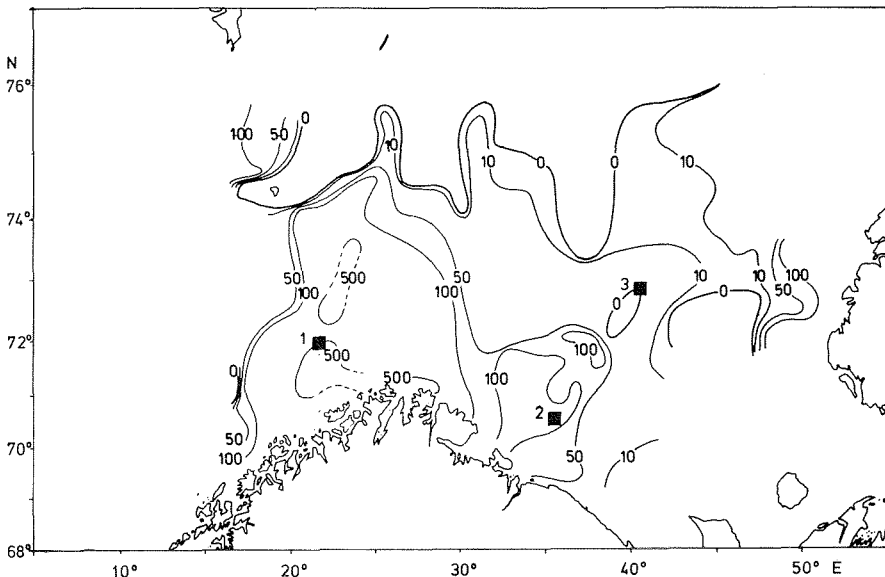


Fig. 1. Localities where diel vertical migration pattern of 0-group fish were studied in August—September 1974. 1) Area 1, 2) area 2, 3) area 3. Isolines indicate the echo integrator deflections observed during the international 0-group survey.

The selection of the areas were made on basis of information from the other vessels which participated in the survey. A standardized sampling procedure was followed in all three areas. An anchored bouy was used as a fixed position. Another bouy, attached to a free floating drogue in 25 m depth, was used as the point of reference for a small scale survey (Fig. 2). The grid of the small scale survey was continuously adjusted to keep the drogue at point A (Fig. 2). The arrows in Fig. 2 indicate «Havdrøn»s courses, and during one small scale survey the ship sailed 32 nautical miles. Between each completed survey one trawlhaul, one hydrographic station, one plankton haul and one series of light measurements were taken (Fig. 2). In each of the areas 1 and 2 ten small scale surveys were carried out while five completed surveys were found to give sufficient information in area 3.

When the weather conditions permitted, the 0-group fish scattering layer was observed by scuba divers. The divers observed the water column from 0 to 30 meters once by daylight and once at dark in area 2, and once at dark in area 3.

The four echo integrator channels were continuously monitoring the following depth intervals: 6—15 m, 15—30 m, 30—60 m, 60—200 m.

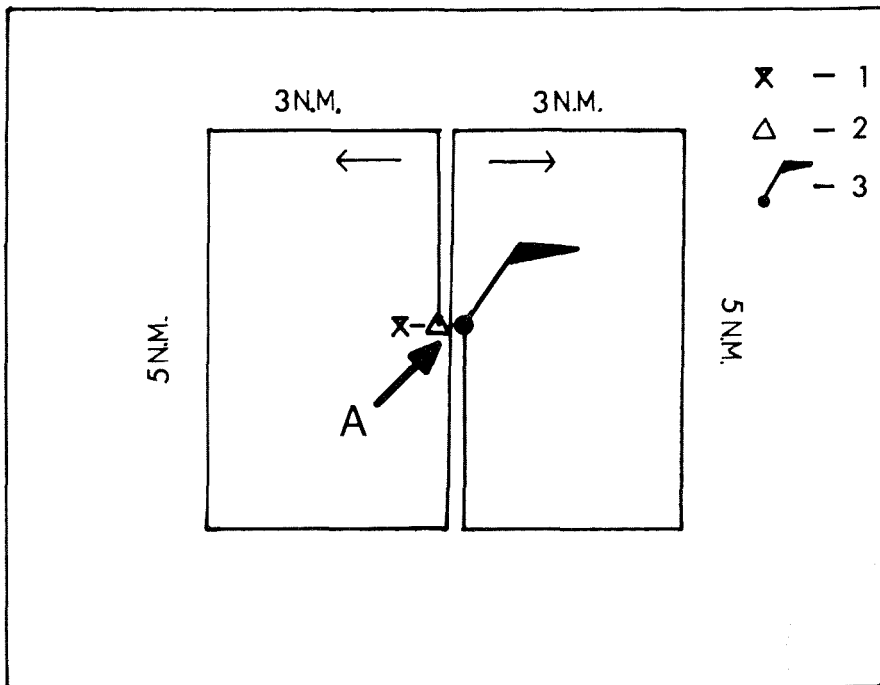


Fig. 2. The small scale survey conducted in the three areas. A) Start and end. 1) Hydrography and plankton station, 2) pelagic trawl and purse seine station, 3) drogue.

Their outputs were read for each nautical mile and then averaged for each half completed small scale survey. The values were converted to R.V. «G. O. Sars» values in order to be directly comparable to the figures in Fig. 1 (BUZETA *et al.* 1974).

The fishing gears, which were used, were of commercial sizes with minor modifications for sampling of 0-group fish. The purse seine was a capelin net 470 meter long and 112 meter deep with a mesh size of 20 mm. In the very end of the bunt a piece of webbing, 28 meter long with mesh size 5 mm, was inserted to prevent the smallest fishes to escape. The pelagic trawl was a capelin trawl, 1000 meshes in circumference with a mesh size of 400 mm, giving an approximate vertical opening of 10—14 meters at 3.5—2.5 knots towing speed. An inner net of mesh size of 12 mm was used in the codend.

The hydrographic stations were worked with Nansen bottles and bathythermograph. Plankton samples were collected with a 180 μ Juday net, hauled vertically from 50 meter to the surface. The light measurements were made at 1 m depth.

RESULTS

HYDROGRAPHY

Fig. 3 shows the drift of the current cross in area 1 and 2. The average velocity of the drogue was 0.1 knot in both areas. In area 3 the displacement of the drogue was less than the error of the positioning.

Fig. 4 shows the vertical temperature distribution in the three areas. In all areas there was a thermocline between 25 and 40 meters, the vertical temperature gradient being more pronounced in area 3 than further west.

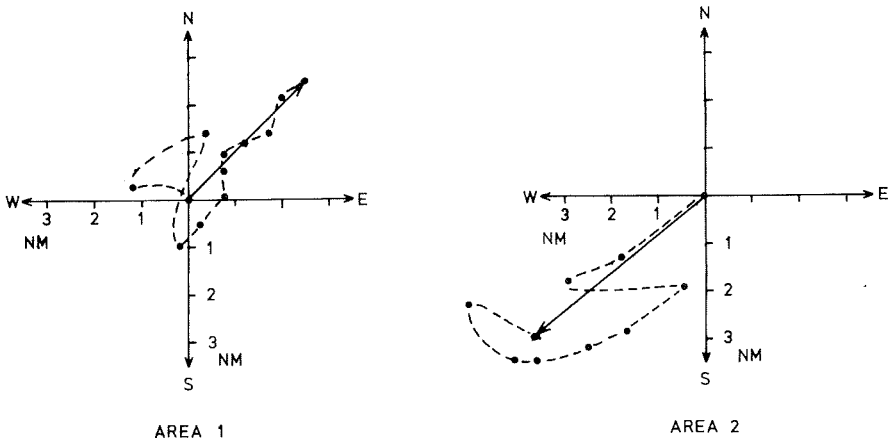


Fig. 3. Drift of drogues during the period of the small scale survey.

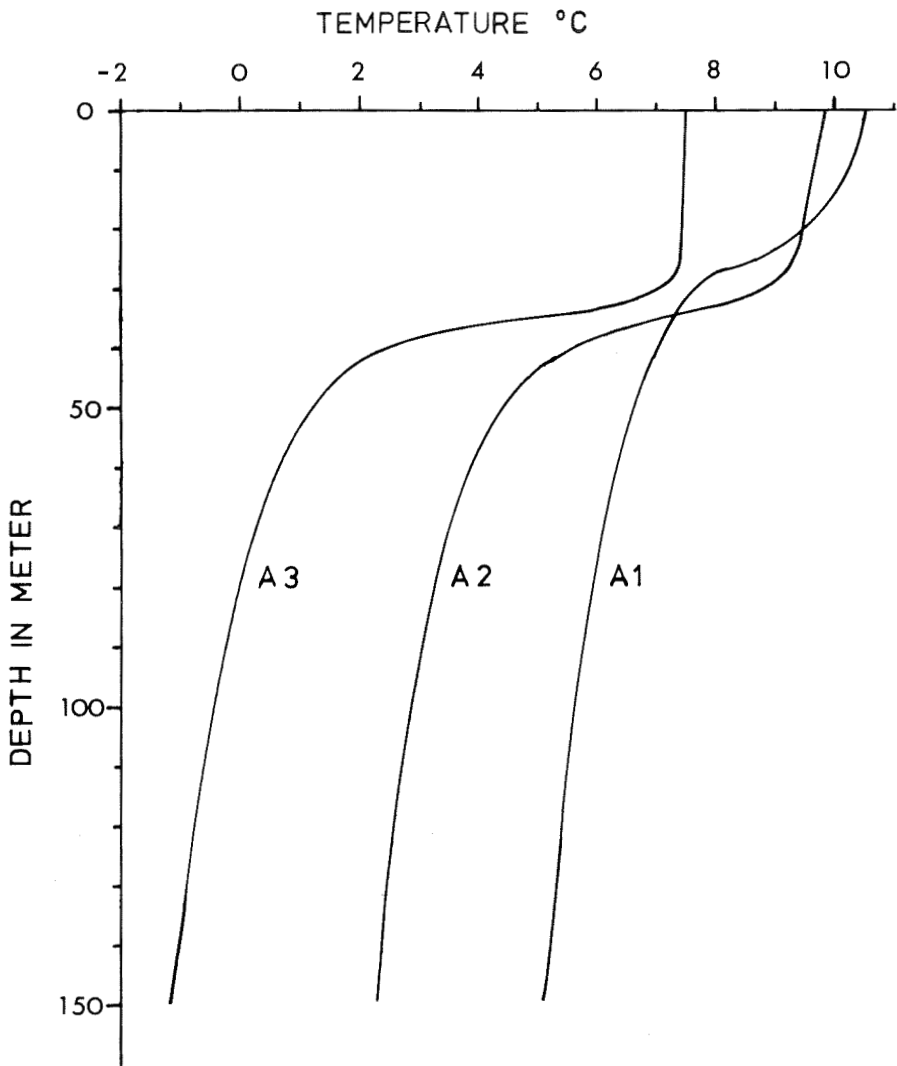


Fig. 4. Vertical distribution of temperature in the three areas.

DISTRIBUTION OF 0-GROUP FISH

The composition of species in the catches are given in Table 1, 2 and 3. According to these tables the distribution of 0-group fish in the three areas can be characterized as follows:

Area 1 was a «pure» redfish area. In area 2 redfish and capelin were mixed while area 3 was a «pure» capelin area. The contribution from other species was quite low compared to the contribution from capelin and redfish.

Table 1. Composition of trawl and purse seine (PS) catches of 0-group fishes in area 1.

St. No.	Date	Hrs. (GMT)	Depth Meters	Redfish		Haddock		Cod		Long Rough Dab		Mackerel	
				No.	%	No.	%	No.	%	No.	%	No.	%
1	27 Aug.	1930	35-48	8 000	100	3	+	2	+	—	—	—	—
2	28 »	0040	25-38	3 000	100	6	+	—	—	—	—	—	—
3	28 »	0547	22-34	1 300	98	9	1	6	+	2	+	14	1
4	28 »	1014	10-22	13 750	100	42	+	5	+	—	—	1	+
5	28 »	1510	25-38	6 000	100	1	+	—	—	—	—	—	—
6	28 »	2108	10-40	1 000	99	8	1	—	—	2	+	—	—
7	29 »	0300	20-40	4 300	100	6	+	—	—	1	+	—	—
8	29 »	0754	10-40	5 600	99	30	1	—	—	—	—	11	+
PS 1	29 »	1814	0-60	25 800	99	181	1	4	+	—	—	—	—
PS 2	29 »	2055	0-60	52 000	99	460	1	20	+	—	—	—	—

Table 2. Composition of trawl and purse seine (PS) catches of 0-group fishes in area 2.

St. No.	Date	Hrs. (GMT)	Depth Meters	Redfish		Capelin (Unpigmented)		Capelin (Pigmented)		Haddock		Cod		Long Rough Dab	
				No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
11	31 Aug.	2045	25—37	91	+	46 300	99	337	1	6	+	52	+	2	+
12	1 Sep.	0027	22—42	850	3	28 800	97	102	+	5	+	16	+	6	+
13	1 »	0316	15—37	190	95	—	—	—	—	1	+	2	1	6	3
14	1 »	1509	25—42	125	51	110	45	—	—	—	—	1	+	8	3
15	1 »	1919	22—40	135	+	122 400	99	780	1	8	+	24	+	1	+
16	1-2 »	0003	30—42	73	+	71 250	95	3 900	5	2	+	10	+	4	+
17	2 »	0410	10—32	260	22	600	51	271	23	10	1	37	3	1	+
18	2 »	0848	10—25	450	59	—	—	267	35	5	1	35	5	—	—
19	2 »	0957	0—12	—	—	5 000	100	36	+	—	—	1	—	—	—
20	2 »	1544	30—42	7	12	8	14	40	70	1	2	—	—	1	2
21	2 »	2217	10—40	445	+	127 500	99	170	+	3	+	21	+	—	—
22	3 »	0220	30—42	9	45	—	—	—	—	5	25	6	30	—	—
23	3 »	0312	0—12	8 100	45	10 000	56	1	+	4	+	2	+	—	—
PS 3	3 »	1305	0—60	4 200	92	176	4	135	3	34	1	4	+	—	—
PS 4	3 »	1612	0—60	8 700	99	—	—	—	—	41	+	18	+	—	—
PS 5	3 »	2250	0—60	2 700	72	1 000	27	6	+	47	1	17	+	—	—

Table 3. Composition of trawl catches of 0-group fishes in area 3.

St. No.	Date	Hrs. (GMT)	Depth	Capelin (Unpigmented)		Capelin (Pigmented)		Cod		Long Rough Dab	
				No.	%	No.	%	No.	%	No.	%
24	5 Sept.	1526	0—12	49 000	100	151	+	—	—	—	—
25	5 Sept.	1919	0—12	10 000	100	33	+	—	—	—	—
26	5 Sept.	2255	20—35	13 800	86	2 120	13	100	1	2	+

Fig. 5 shows selected typical echograms from the areas. It appears from the paper record that the redfish in area 1 had a rather wide spread vertical distribution in daylight, but concentrated in the upper layer at dark. This is also clearly demonstrated in Fig. 6 where the contributions from the different echo integrator channels are presented as a function of time. During the dark 80—100% of the reflecting scatterers were observed in the upper channel, 6—15 m. The total echo abundance showed no significant diel variation.

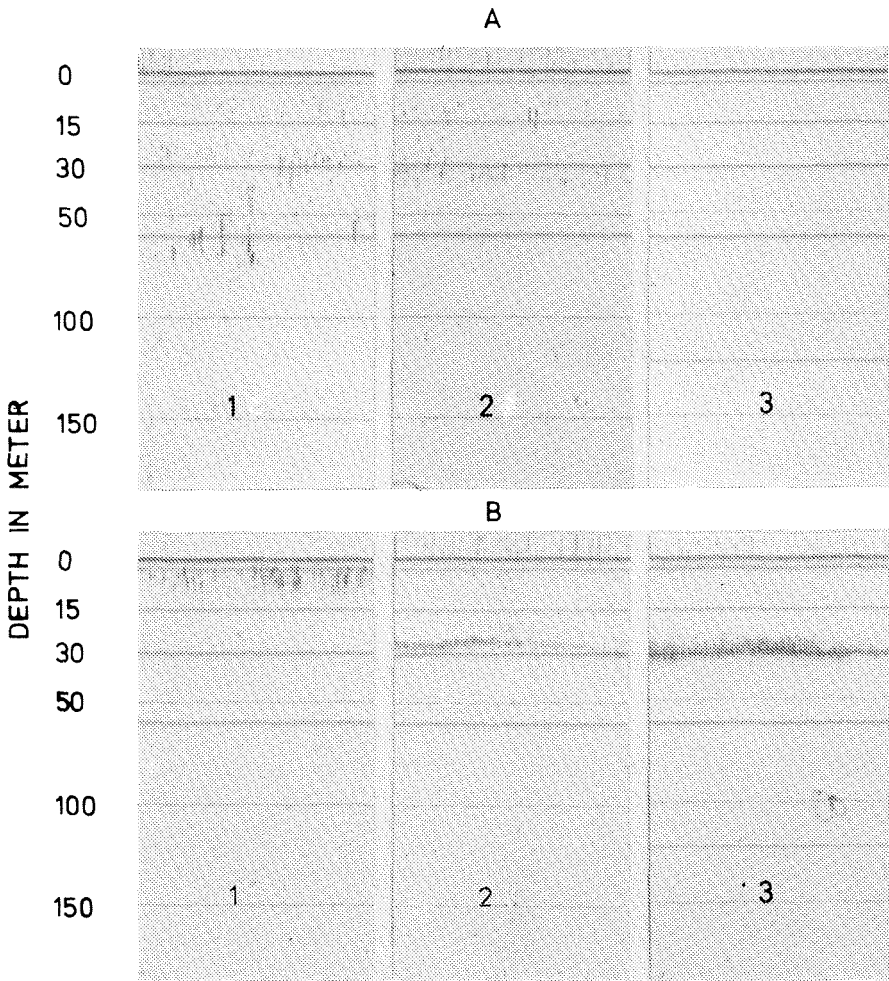


Fig. 5. Typical echo recordings from the three areas. A) Daylight, B) at dark. 1) Area 1, 2) area 2, 3) area 3.

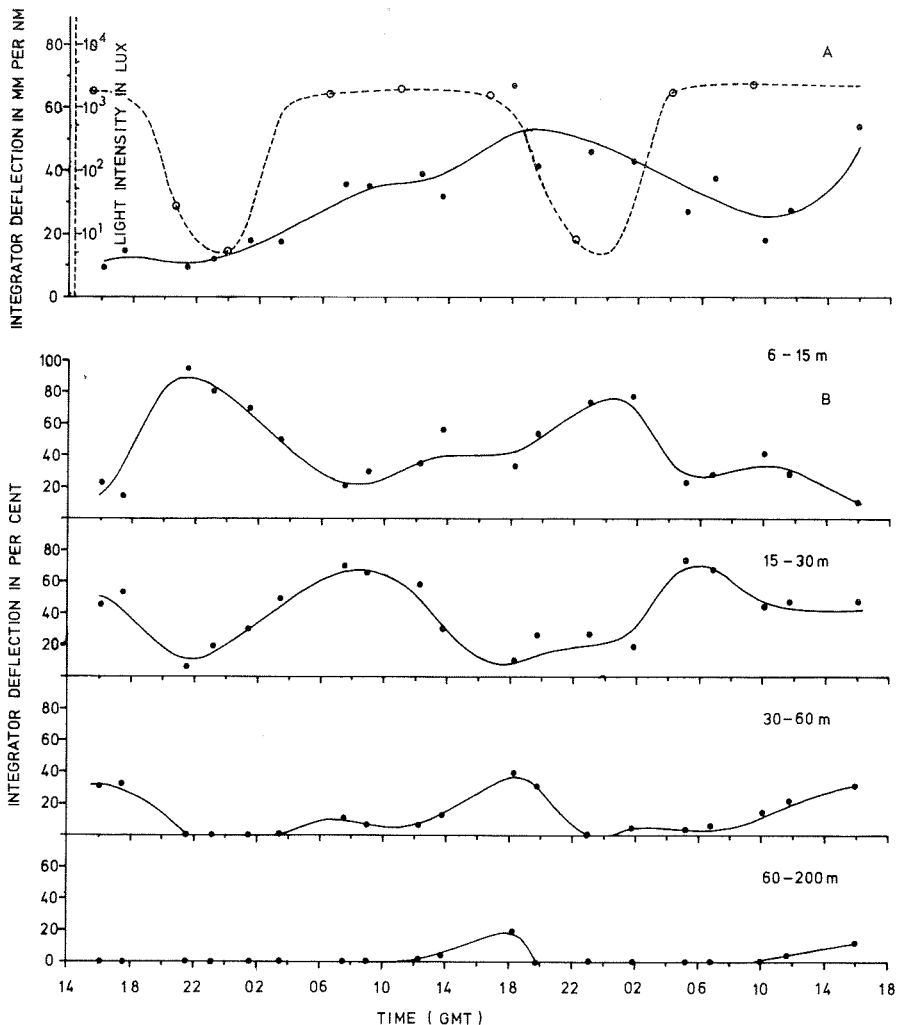


Fig. 6. A) Total echo abundance and light intensity according to time in area 1. B) The contribution to the total echo abundance from various depths according to time.

In area 2 a significant diel variation in echo abundance was observed (Fig. 7). The integrator deflection was significantly higher at dark than in daylight. There was also a periodic variation in species composition in the catches from the 10—30 m depth layer (Table 2, Fig. 8). In this layer the redfish were caught in daylight while at dark the catches consisted of capelin and krill. Capelin were also caught at the very surface (0—12 m) in daylight. The observations made by the scuba divers verified these observations. At dark they found a scattering layer of krill and capelin in 20—30 m while the redfish were observed very close to the surface, 0—2 m. In daylight they saw no 0-group fish at all.

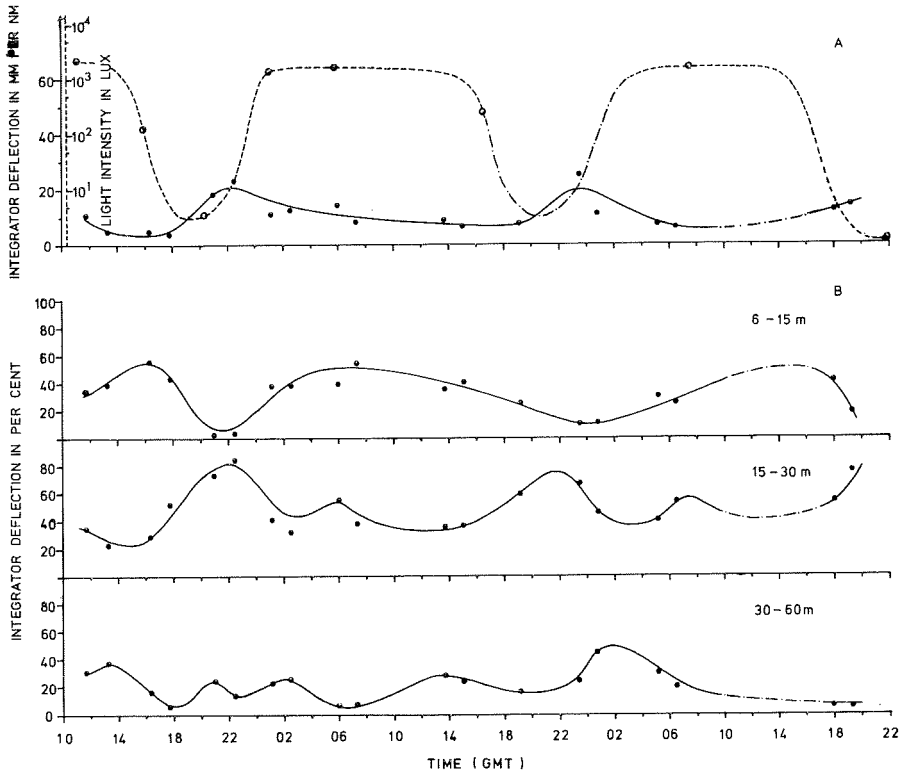


Fig. 7. A) Total echo abundance and light intensity according to time in area 2. B) The contribution to the total echo abundance from various depths according to time.

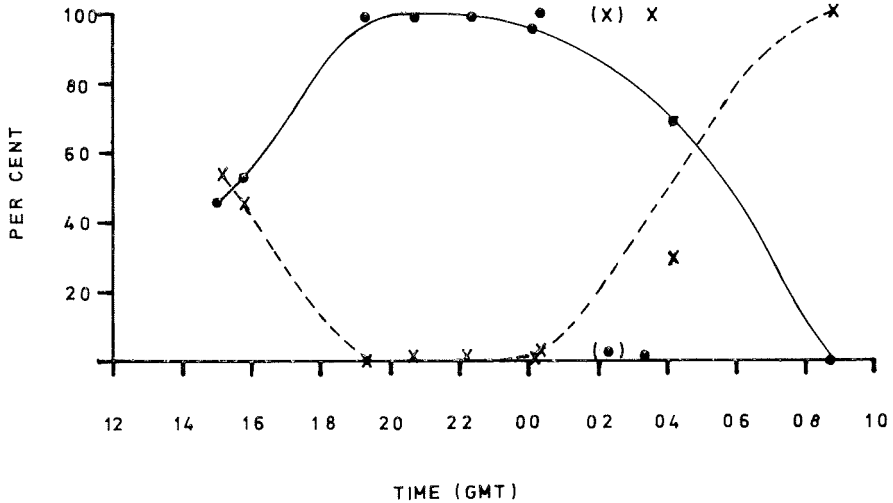


Fig. 8. The fish composition of trawl catches from 10 to 30 m depth in area 2. Solid line) capelin, broken line) redfish.

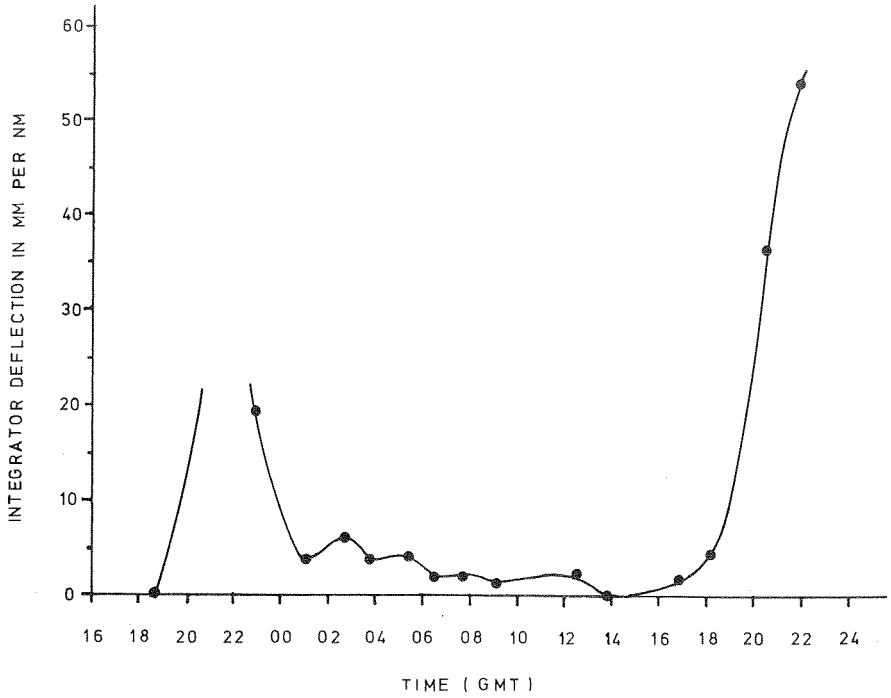


Fig. 9. Total echo abundance according to time in area 3.

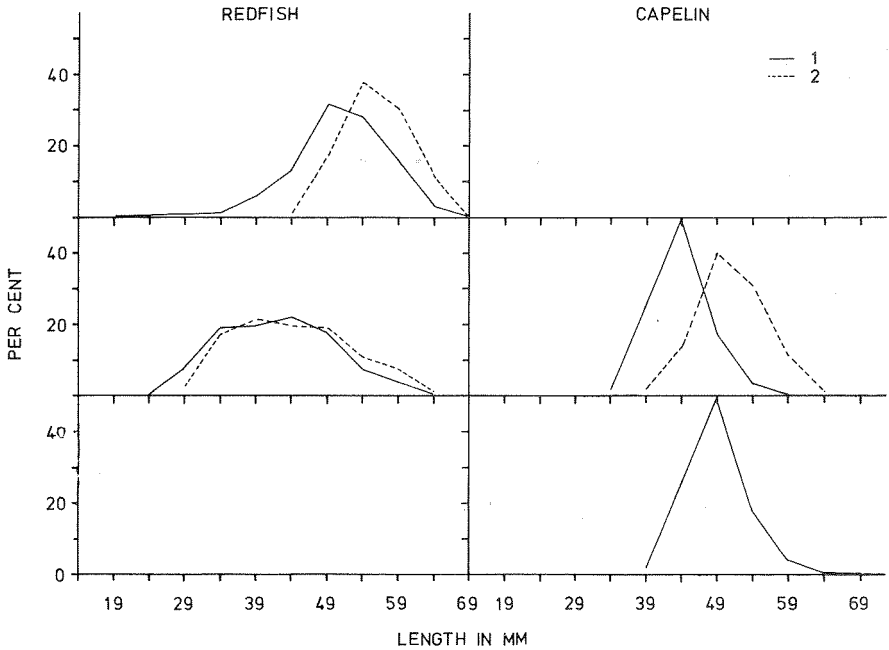


Fig. 10. Length distributions of 0-group redfish and capelin in the different areas.
1) Pelagic trawl, 2) purse seine.

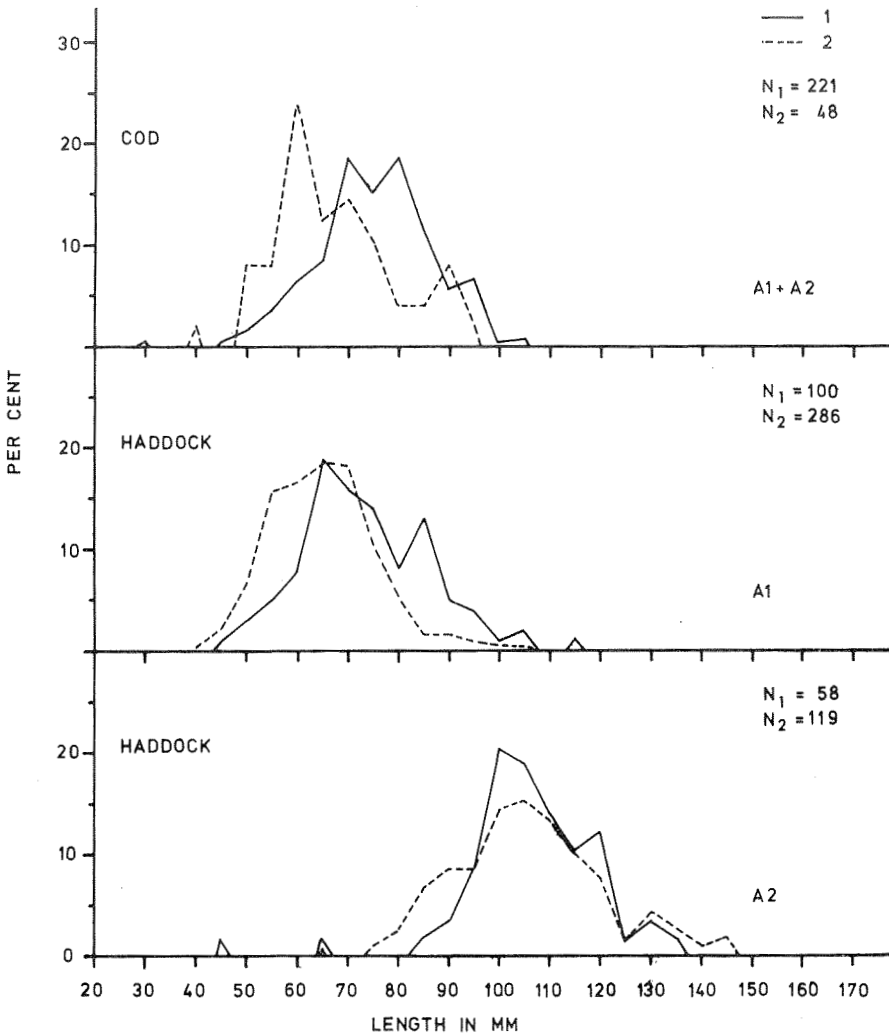


Fig. 11. Length distributions of 0-group cod and haddock in the different areas. 1) Pelagic trawl, 2) purse seine.

In area 3 there was practically no contribution to the echo abundance in daylight (Fig. 9), but great numbers of 0-group capelin were caught in surface hauls (Table 3). At dark the scattering layer in 20—30 m depth consisted of capelin and krill (Fig. 5.3 and Fig. 9) which was sampled with pelagic trawl and observed by scuba divers.

Nearly all the observed 0-group capelin were unpigmented while the 0-group redfish, cod and haddock were pigmented. Fig. 10 and 11 show the length distributions of these four species according to area and gear.

The krill, mainly *Thysanoessa* sp., were only caught at dark in the pelagic trawl, sometimes in quantities up to 80 kg per haul in area 2. It had an average length of about 2 cm.

DISCUSSION

Table 1, 2 and 3 show that 0-group redfish and capelin dominated the catches completely. Fig. 5, 7 and 8 show that 0-group redfish and unpigmented 0-group capelin had a different vertical migration pattern. The redfish showed a normal diel vertical migration and were found in the surface layer at dark while the capelin stayed in the surface layer during the daylight period and descended to deeper water at dark. According to BREDER (1962) the light radiation in the upper water layers may have deleterious effects on pigmented organisms while unpigmented organisms to some extent are protected against the light radiation. This may explain why capelin was found at the very surface in broad daylight. By staying in the uppermost water layer the unpigmented larvae can feed almost undisturbed by fish predators during most of the daylight period. However, the radiation theory cannot explain why the capelin descended and concentrated at the thermocline at dark (Figs. 4 and 8). A possible explanation may be that in the dark period, when feeding is difficult, the larvae save energy by staying in layers of higher water density. This behaviour will also be of advantage if the predators migrate to the surface layer at dark. It is known that 0-group cod feed on capelin larvae, and it is also likely that 0-group haddock do so, but the data at hand on the diel vertical migration of the two latter species are insufficient.

The observations of krill indicated that it stayed in depths below 40 m in daylight while it mixed with the 0-group capelin in the thermocline at dark (Fig. 5.3). The higher integrator deflection at dark in area 2 and 3 (Figs. 7 and 9) are thus caused by this mixture.

Although the observations on the horizontal distribution pattern (patchiness) of 0-group redfish and capelin are limited, some main features were found. Fig. 5 shows that 0-group redfish gathered in small groups during the daylight period. Some observations indicated a similar grouping of 0-group capelin. A lot of small sonar echoes in the uppermost water layer in daylight and the fact that the scuba divers did not observe 0-group capelin, in daylight supports this view. When the fishes form schools, the probability of detecting them with echo sounders is less than when they are evenly distributed, and dispersed distributions at dark are therefore easier to detect than dense schools in daylight. At dark the capelin dispersed in 20—30 m depth. The redfish, which at dark were observed by eye in the surface layer, appeared also to be dispersed although

Fig. 5.1 indicates that a certain grouping was maintained even in the most dark period. The differences in fish length between purse seine and trawl catches, which occur in Fig. 10 and Fig. 11, are not significant. From the present investigation we must thus conclude that the trawl catches were representative samples of the length distributions of 0-group fish.

The 0-group capelin, which in broad daylight is found above the depth of the hull mounted transducers, will not be recorded by the echo sounder (Fig. 5.3). Neither will it be representatively fished by a pelagic trawl unless special care is taken to haul the trawl at the very surface. Therefore errors of unknown magnitude might be introduced to the indices of abundance for 0-group capelin.

The redfish, which is spread in the water column during the daylight period, will be detected by echo sounders most of the time (Fig. 5.1). Although there might be areas where this species is not seen by echo sounders during a small part of the dark period, like area 2, it is felt that the error introduced to the abundance indices are negligible in comparison with the 0-group capelin.

To get a better understanding of the observed vertical diel migration pattern of 0-group capelin more detailed information is needed both on the distribution of plankton and the distribution and stomach contents of fishes in the upper 50 m depth layer in the Barents Sea.

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ABUNDANCE ESTIMATES OF THE SPAWNING STOCK OF
BLUE WHITING (*MICROMESISTIUS POUTASSOU* (RISSE, 1810))
IN THE AREA WEST OF THE BRITISH ISLES IN 1972—1974

By

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ABSTRACT

BUZETA, R. and NAKKEN, O. 1975. Abundance estimates of the spawning stock of blue whiting (*Micromesistius poutassou* (Risso, 1810)) in the area west of the British Isles in 1972—1974. *FiskDir.Skr.Ser.HavUnders.*, 16: 000—000.

An analysis is made on the blue whiting data from the echo surveys conducted during 1972—1974 for assessment of the spawning stock west of the British Isles.

Acoustic data are evaluated using a length dependent density coefficient.

Area and time coverage are discussed for each survey. Mean density and total abundance are calculated for the three years in the investigated area, and a stock size of approximately 6 million tons is suggested for the spawning stock.

INTRODUCTION

The stock of blue whiting has been surveyed for the last three years during the spawning period using the research vessel «G. O. Sars» (JAKUPSTOVU og MIDTTUN 1972, MIDTTUN and NAKKEN 1973, BUZETA *et al.* 1974). The survey grid, trawl stations and fish distribution are shown in Fig. 1—3. The technique applied is described by FORBES and NAKKEN (1972), MIDTTUN and NAKKEN (1973) and DOMMASNES and NAKKEN (1975). The concentrations of spawning blue whiting have been surveyed twice each year — from the Shetland area and southward to 52° N and then northward again. Abundance estimates based on echo integrator data have been worked out for each survey (MIDTTUN and NAKKEN 1973, BUZETA *et al.* 1974). These estimates are listed in Table 1. The figures show large variation, both within and between years. They are, however, based on the assumption that the scattering cross section of blue whiting is proportional to its weight, a rather rough approximation. Both the area and time coverage of the survey have varied from year to year. The time of maturing and accordingly the amount of fish on the spawning grounds may have varied from survey to survey, and the estimates should therefore be considered as fractions of the total spawning stock. In the present paper the acoustic and biological material from the cruises are analyzed in more detail, and some of the factors affecting the fluctuation of the abundance estimates are discussed.

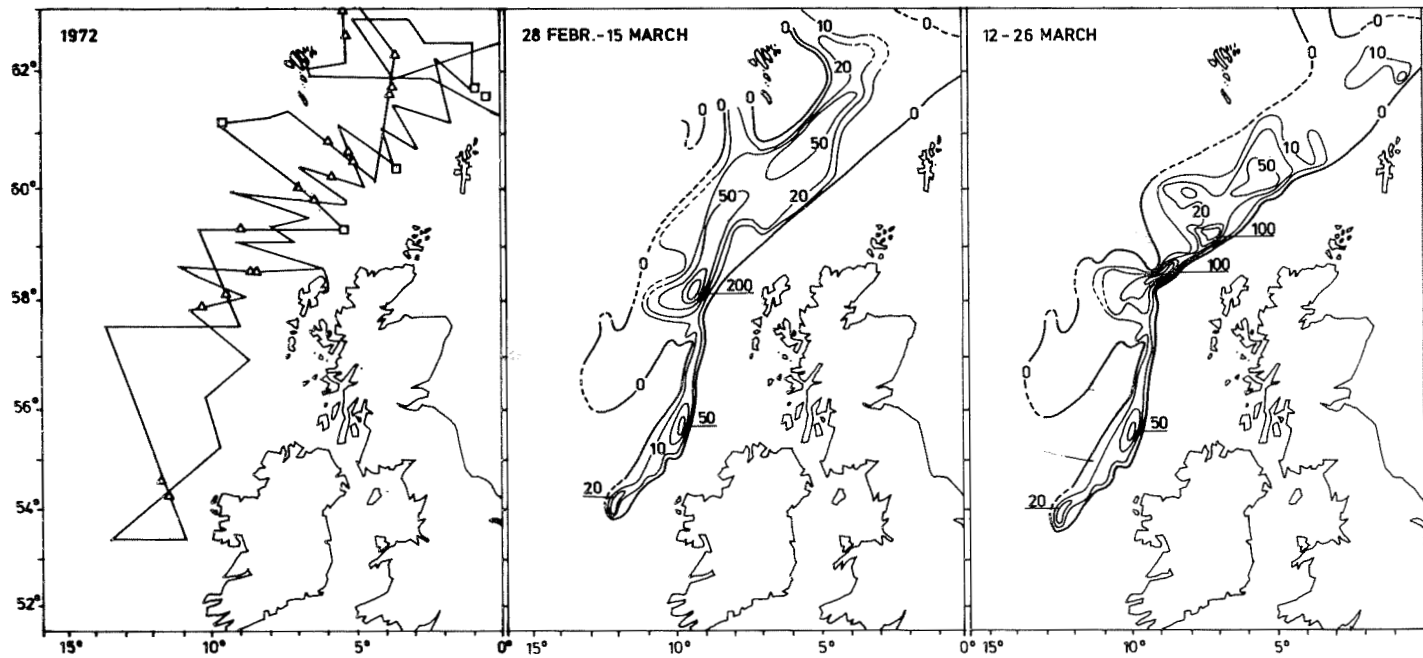


Fig. 1. Survey grid, trawl stations and distribution of integrated echo intensity (mm deflection) in 1972.

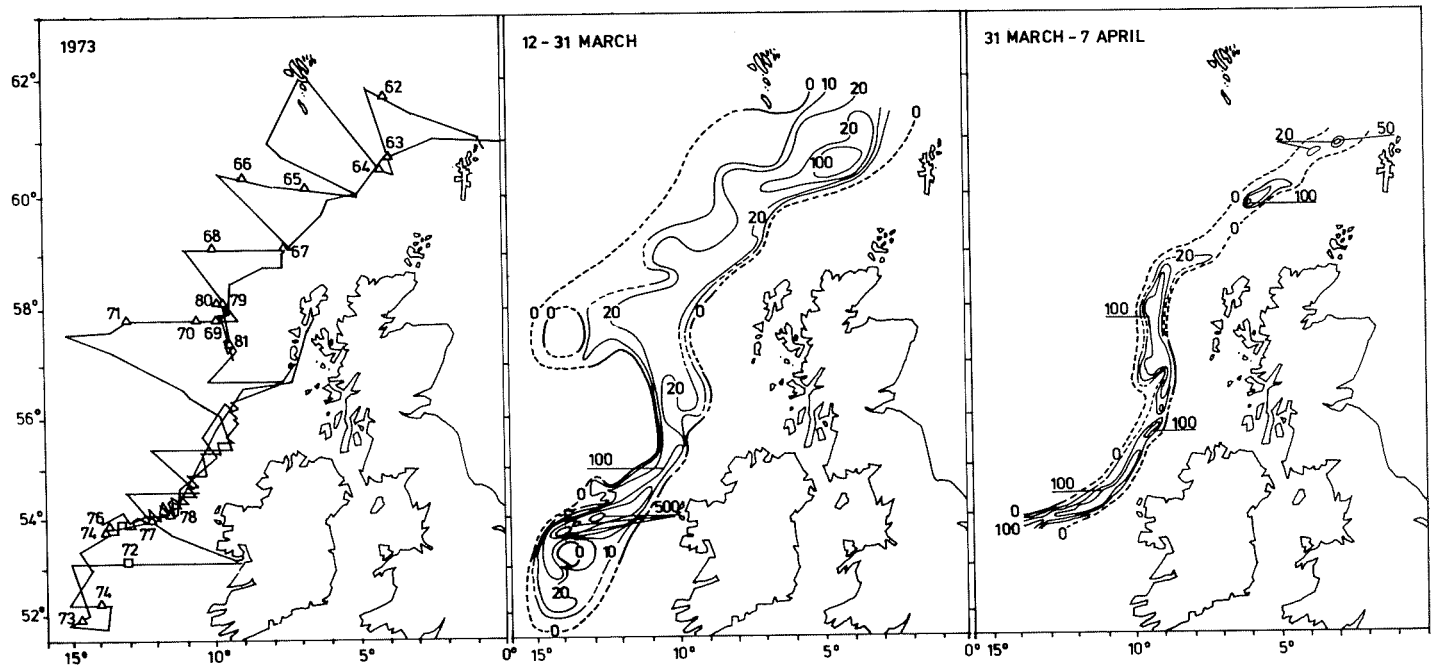


Fig. 2. Survey grid, trawl stations (numbered) and distribution of integrated echo intensity in 1973.

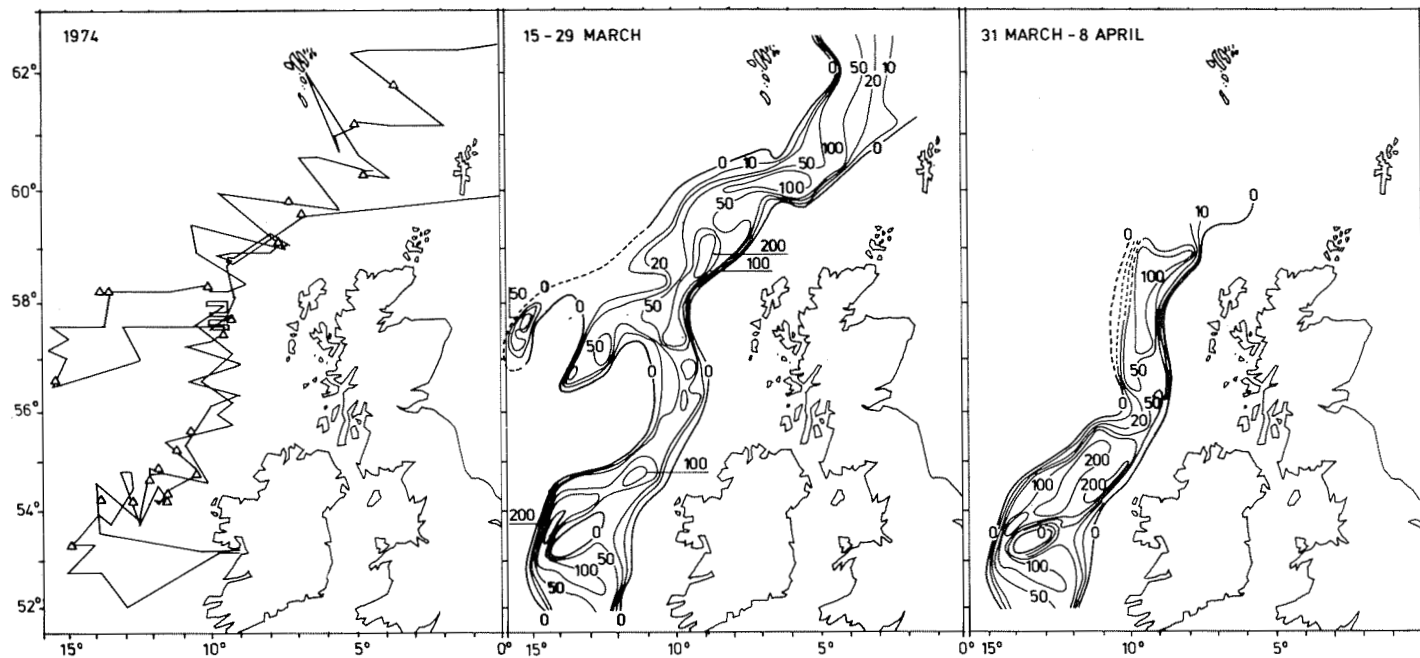


Fig. 3. Survey grid, trawl stations and distribution of integrated echo intensity in 1974.

MATERIAL AND METHOD

The method applied during the acoustic surveys is described by FORBES and NAKKEN (1972) and MIDTTUN and NAKKEN (1973). More details are given by CRAIG (1973) and DOMMASNES and NAKKEN (1975). The relation between fish density, ρ_A , and integrated echo intensity, M , is:

$$\rho_A = C \cdot M + b \quad (\text{I})$$

where ρ_A is the number of fish per unit area and M is the integrated echo intensity. The density coefficient C represents the density of fish causing 1 mm deflection on the echo integrator, and it is a constant as long as fish specie and size remains constant. The constant b is a threshold density. Below this there is no contribution to the integrated echo intensity.

When three size groups of fish contribute to M , the following expressions for the density of fish within each size group are valid (DOMMASNES and NAKKEN 1975):

$$\begin{aligned} \rho_{A1} &= k_1 \cdot K \cdot M \\ \rho_{A2} &= k_2 \cdot K \cdot M \\ \rho_{A3} &= k_3 \cdot K \cdot M \end{aligned} \quad (\text{II})$$

and

$$K = \frac{C_1 \cdot C_2 \cdot C_3}{k_1 \cdot C_2 \cdot C_3 + k_2 \cdot C_1 \cdot C_3 + k_3 \cdot C_1 \cdot C_2}$$

where k_i is the percentage of the i -th sizegroup in the catches, and C_i is the value of C for the length L_i . The numerical values of the density coefficient, C_i , are found from a $L-C$ cruve (Fig. 4).

The total number of fish in the i -th sizegroup within an area A is given by

$$N_i = \int_A \rho_A da = \overline{k_i \cdot K} \int_A M \cdot dA \quad (\text{III})$$

where the bar denotes the average over the area A . Finally, the total weight of each sizegroup is found by applying a weight—length relationship. Due to the relative low number of trawl stations, length data from the whole area were pooled each year, and consequently k_i and C_i were averaged over the whole investigated area.

RESULTS

The abundance estimates, which are given in Table 1, were recalculated according to the procedure outlined above. The relation between the density coefficient and the length of blue whiting is shown in Fig. 4.

Table 1. Estimates of abundance and mean density from the different surveys (MIDTTUN and NAKKEN 1973, BUZETA *et al.* 1974).

Year	Survey	Period	Trawl station	Area (NM ²)	Abundance (Ton)	Density (Ton/NM ²)
1972.....	1 (S)	28.2—15.3	20	41 940	4.4×10^6	104.9
	2 (N)	12.3—26.3	11	33 090	2.7×10^6	81.6
1973.....	3 (S)	12.3—30.3	17	94 500	10.7×10^6	113.2
	4 (N)	31.3— 7.4	3	12 960	4.0×10^6	208.6
1974.....	5 (S)	15.3—29.3	16	67 500	1.8×10^6	36.6
	6 (N)	31.3— 8.4	8	34 950	1.8×10^6	51.5

(S) Southward crossing.

(N) Northward crossing.

NM Nautical mile.

The curve is based on the target strength—length relationship reported by NAKKEN and OLSEN (1973) and on the values of the density coefficient arrived at by MIDTTUN and NAKKEN (1973) and BUZETA *et al.* (1974). The change in the ordinate scale from 1973 to 1974 is caused by a change in the settings of the echo sounder onboard the «G. O. Sars».

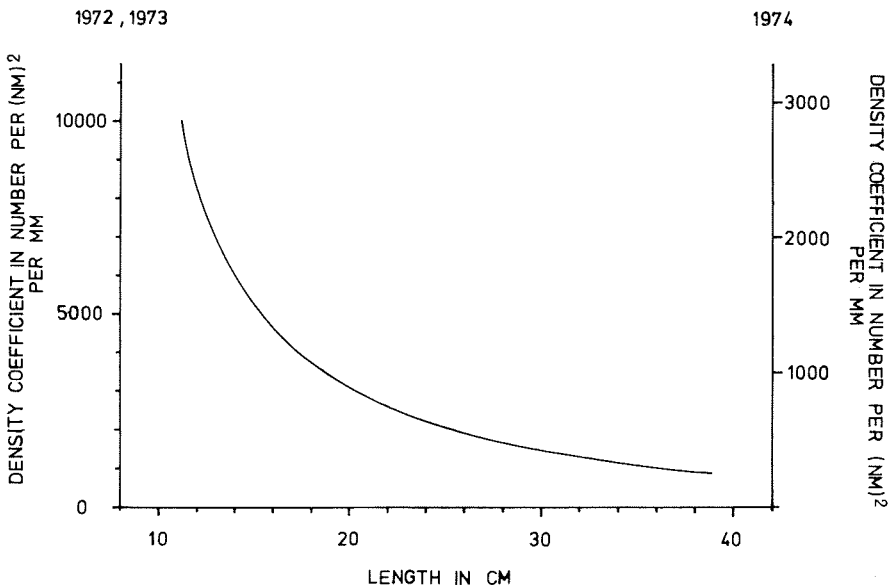


Fig. 4. The density coefficient C as a function of length for blue whiting the different years.

The length distributions of the blue whiting are given in Fig. 5. In these distributions the three modal groups were selected as size-groups, and C -values corresponding to the modal lengths were found in Fig. 4. The values of k were also found from the length distributions in Fig. 5 by accumulation of the percentages within each modal group. The age of the fish within each of the three modal length groups was found from Fig. 6. This figure shows the age—length relationship for blue whiting as per available literature.

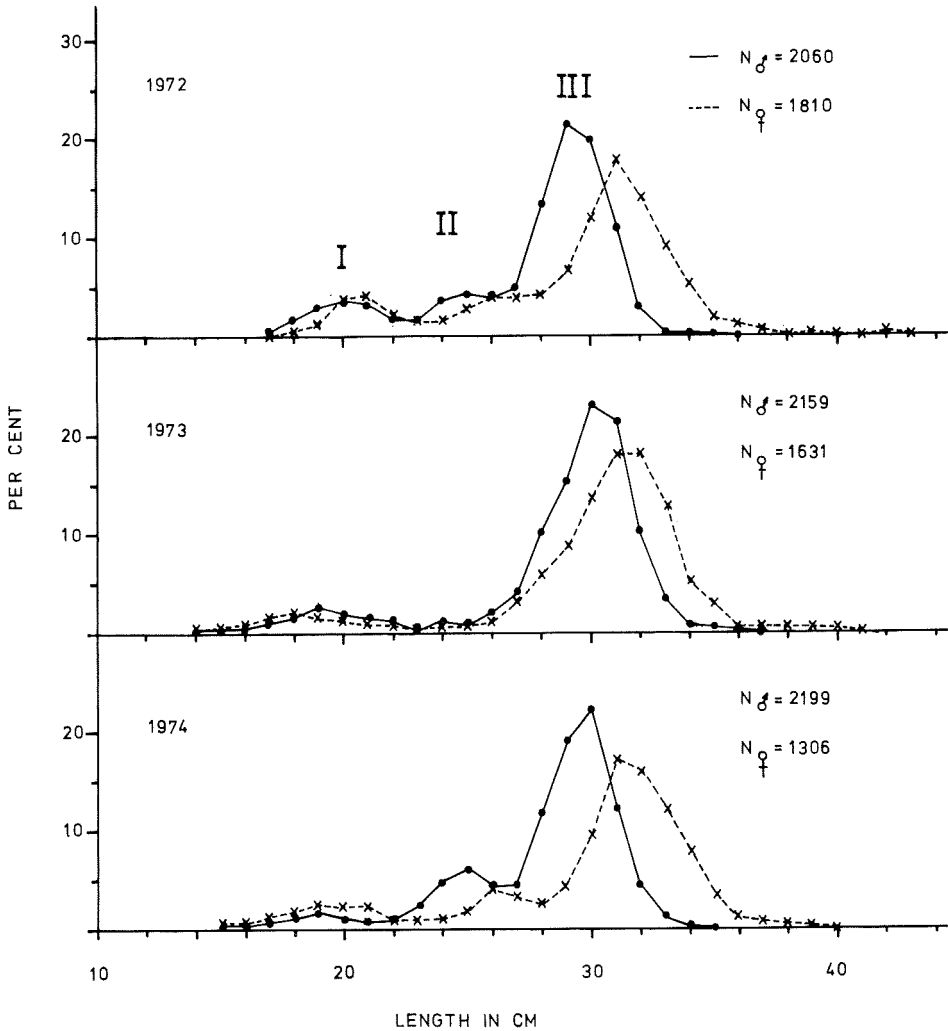


Fig. 5. Length distribution of blue whiting in the samples. (I, II and III are modal lengths).

Table 2. Estimated weights (gr) of blue whiting according to length the different years.

Year	Length (cm)													Weight-length relationship and correlation coefficient
	14	16	18	20	22	24	26	28	30	32	34	36	38	
1972			33	46	63	82	106	134	166	203	246	295	349	$W = 0.0037 L^{3.15} r = 0.99$
1973	14	22	32	45	61	81	105	134	167	206	250	301	359	$W = 0.0028 L^{3.24} r = 0.99$
1974		23	33	46	61	80	102	128	159	194	233	278	329	$W = 0.0045 L^{3.08} r = 0.99$

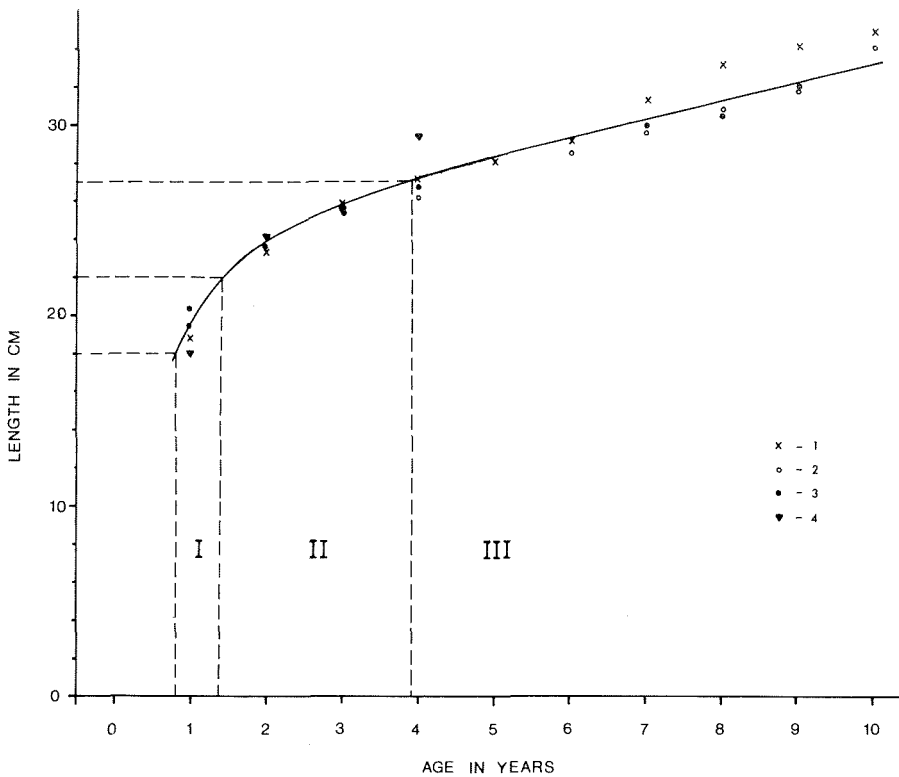


Fig. 6. Blue whiting growth curve (Data in RAITT 1968).

- 1) The western coast of Scotland (RAITT 1966),
- 2) the Færoes (RAITT 1966),
- 3) Iceland (RAITT 1966),
- 4) Iceland (SÆMUNDSSON 1929).

I, II and III are modal lengths according to length distribution in the samples.

The weight—length relationship of blue whiting for the three years are shown in Table 2. The figures in the table are estimated weights using the length-weight equation.

In Table 3 are listed the observed values of the different parameters used in the calculations and the estimates of abundance for each size-group and year.

Table 4 gives the total abundance in number and tons, the sampled area and the average density in tons per unit area for the three years. The percentages of fish in the different maturity stages are also shown in Table 4. From the correlative changes in percentage from mature to spent fish between the first and the second part of the cruise the top of the spawning season is indicated.

Table 3. Corresponding values of modal length (L), density coefficient (C), calculated weight (W), length frequency (k) and relative and absolute abundance in each modal length group the different years.

Year	L (cm)	C (n/mm/ (nm) ²)	W (gr)	k %	Relative abundance (mm.(nm) ²)	Absolute abundance	
						(number)	(tons)
1972...	20	3 200	46	13	11 . 10 ⁶	2.2 . 10 ⁹	0.10 . 10 ⁶
	25	2 100	93	9		1.7 . 10 ⁹	0.16 . 10 ⁶
	30	1 500	166	78		14.3 . 10 ⁹	2.37 . 10 ⁶
1973...	18	3 700	32	10	26 . 10 ⁶	4.1 . 10 ⁹	0.13 . 10 ⁶
	30	1 570	167	90		38.9 . 10 ⁹	6.49 . 10 ⁶
1974...	19	1 133	39	9	31 . 10 ⁶	1.5 . 10 ⁹	0.06 . 10 ⁶
	25	700	91	18		3.1 . 10 ⁹	0.28 . 10 ⁶
	30	500	159	73		12.4 . 10 ⁹	1.97 . 10 ⁶

Table 4. Calculated abundance, density and observed maturity of sampled fish in per cent on the different cruises.

Year	Survey	Sampled area (nm ²)	Abundance (Tons)	Density (Ton/nm ²)	Maturity		
					I	M	S
1972.....	1 (S)	41 940	2.6 × 10 ⁶	62.6	19	75	6
	2 (N)	33 090	1.6 × 10 ⁶	49.1	36	46	18
1973.....	3 (S)	94 500	6.6 × 10 ⁶	70.1	75	22	3
	4 (N)	12 960	2.4 × 10 ⁶	190.4	1	77	22
1974.....	5 (S)	67 500	2.3 × 10 ⁶	34.4	67	29	4
	6 (N)	34 950	2.3 × 10 ⁶	66.0	8	64	28

(S) Southward crossing, (N) Northward crossing, I = Immature, M = Mature, S = Spent.

Table 5. Maturity distribution (%) and mean length (cm) in the samples from cruise 3 and 4 (1973). Area south of 59 °N.

Maturity	Cruise 3 Trawl Station 69—71		Cruise 4 Trawl Station 72—80	
	%	cm	%	cm
	Immature*	43.3	31	0.8
Matur	56.7	30	76.6	29
Spent			22.2	30

* Juveniles (<22 cm) disregarded.

In 1973 the maturing process was investigated in details. Table 5 shows the percentages and mean lengths of fish at each maturity stage in different periods of time. It appears that the fish changes from the prespawning stage into the stages spawning and spent within a very short period (time difference between St. 71 and 72 is one week). There were no significant differences in mean lengths between prespawning, spawning and spent fish.

DISCUSSION

The estimates of abundance, calculated here, tend to be lower than the previous. The main reason for this is that the previous estimates were obtained under the assumption that all fishes were reflecting as if they were 30 cm in length. As the smaller fish will contribute more per unit weight to the echo integrator output than the larger one, the estimates will be reduced when a length dependent density coefficient is used. The variation from survey to survey is still present to a considerable extent, and in the following some possible reasons for this variation are discussed.

In the introduction the grid coverage is mentioned as a possible source to large variances. To assess the blue whiting spawning stock abundance, the best procedure will be to cover most of the spawning grounds during the period when most of the spawning stock is present on these grounds.

There is no doubt that the cruises satisfactory cover large parts of the spawning area at least for some of the surveys. This is evident from maps of larvae distribution (BAINBRIDGE and COOPER 1973) which show that Rockall and Porcupine banks and the continental margin of the south-western Celtic Sea are the main spawning grounds for blue whiting. It can, however, be questioned whether both the area and time coverage are sufficient for any of the surveys.

Table 1 shows the sampled areas on each cruise. According to this table the widest coverage were made during cruise number 3 (1973) and cruise number 5 (1974). Although the main spawning areas were covered in 1972, the coverage of the Rockall and Porcupine banks was very poor that year.

To find which survey has the best time coverage, it is necessary to analyse the maturity distribution in the samples. The highest percentage of mature fish will be an indication of the peak of the spawning, and table 4 shows that the higher percentage of mature fish coincide with the higher density values.

It is difficult to say whether the spawning takes place massively or by consecutive groups of spawners entering the spawning ground. A short

duration of the spawning period is suggested as some of the cruises have missed by days the peak of the spawning season (BUZETA *et al.* 1974) and also because of the quick maturing process during cruise 3 and 4 (1973). This indicates a massive spawning.

Cruises 1, 4 and 6 seem to have the best time coverage as most of the fish were in a spawning stage, which would mean that most of the spawning stock was present at the time of the investigation. With the exception of cruise number 4 the mean densities are also similar. Cruise 4 (1973) has a much higher density owing to a selection of course lines through the most dense concentrations. A high percentage of immature fish is present in the samples on cruise 3 (Table 4). The size distribution of these fish was investigated to see if the mature fish in the 2nd part was different from these immature fish. Table 5 shows that it is the same group of fishes. Cruise 3 (1973) is therefore chosen as the best abundance estimate assuming that during this survey, when most of the spawning ground was covered, the major part of the spawning stock was already present.

Although there is a small amount of juvenile fishes in the samples, most of the fish entering the area are spawners. When the size distribution of the fish (Fig. 5) is compared with the age-length curve in Fig. 6, mode I represents fishes of 1 year which are not spawning and thus are not quantitatively well represented in the samples. Modal size II representing fish of 2—3 years, which is the approximate age of first maturity (RAITT 1968), is also poorly represented in the spawning area. (Fig. 5). Thus the bulk of the spawning stock is represented by fish of ≥ 4 years (mode III). This fish spawn on the continental slope west of the British Isles and on the Porcupine, Rockall and Rose Mary banks, an area representing roughly 90,000 square nautical miles. The mean density, attained by the fish on the peak of the spawning season, is around 70 ton per square nautical miles which means that the size of the spawning stock is of the order of 6 million tons.

The fluctuation of the total spawning stock abundance between years should be studied in the light of the strength of the age groups of spawners since the age composition of the spawning stock may vary between years, i.e. scarce amount of 2—3 years spawners in 1973 (Fig. 5).

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