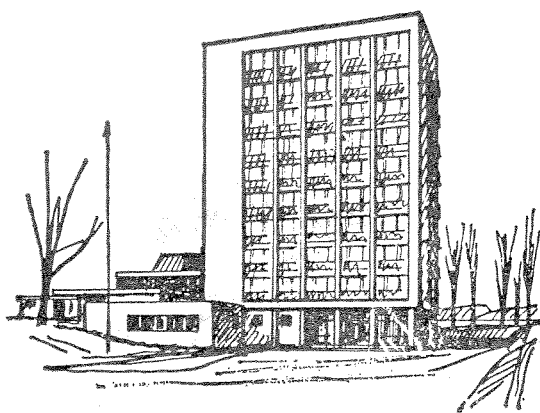


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FECUNDITY AND EGG SIZE OF SPRING SPAWNING BARENTS SEA CAPELIN

By

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ABSTRACT

GJØSÆTER, J. and MONSTAD, T. 1973. Fecundity and egg size of spring spawning Barents Sea capelin. *FiskDir. Skr. Ser. HavUnders.*, 16: 98—104.

Fecundity of Barents Sea capelin was studied in 1971 and 1972. No differences were found between these two years. The regression line

$$\log F = 3.4871 \cdot \log L - 0.2049$$

was fitted to the whole material. This is in good accordance with studies on Barents Sea capelin carried out by others and shows much lower fecundity than capelin from Newfoundland waters.

Diameters, measured on artificially fertilized eggs, ranged between 1.10 and 1.23 mm, mean 1.165 mm, and diameters of eggs from spawning beds measured between 1.10 and 1.20, mm mean 1.184 mm. Canadian and Icelandic measurements show smaller and similar sizes respectively.

INTRODUCTION

Spring spawning capelin, *Mallotus villosus* (Müller), from the Barents Sea mature at an age of 3 and 4 years and spawn from February to April along the coasts of northern Norway and Murman. Capelin are believed to be one time spawners, but parts of the stock probably survive and spawn one year later for a second time (PROKHOROV 1965). Earlier work on fecundity of the Barents Sea capelin has been reviewed by PROKHOROV (1965). Fecundity of capelin in Newfoundland waters has been studied by TEMPLEMAN (1948) and WINTERS (1971). An extensive difference in egg numbers seems to occur between these two stocks of the North-Atlantic capelin. Diameters of fertilized eggs of Newfoundland capelin have been measured by TEMPLEMAN (1948) and of Icelandic capelin by FREDRIKSSON & TIMMERMANN (1951). No comparable data is found for Barents Sea capelin, although POZDNYAKOV (1967) has measured some ripe interovarial eggs.

This paper gives data on fecundity and egg size of Barents Sea spring spawning capelin for the years 1971 and 1972. The results of the present study are compared with data from Canada, U.S.S.R. and Iceland.

METHODS

Prespawning capelin were collected by pelagic trawl off Finnmark in February 1971 and 1972. Total length of the fish, i.e. the length between the anterior end of the mandible to the posterior end of the ventral lobe of the caudal fin in natural position, was measured in 1971 on fresh material and in 1972 on frozen. To make the measurements comparable, shrinking due to freezing and thawing was adjusted for by using the equation

$$L_{\text{fresh}} = 1.01 L_{\text{frozen}} + 0.273$$

developed by MONSTAD (1971). Length measurements made by POZDNYAKOV (1957) were converted from fork length to total length by adding 8% (TEMPLEMAN 1968). The age of the fish was determined from the otoliths.

In 1971 the gonads were removed from the fresh fish and placed in 10% formalin. In 1972 the fish were frozen, and after about one week the gonads were removed and transferred to formalin. As it turned out to be quite easy to separate the eggs of capelin gonads kept in formalin, Gilson's fluid was not used.

After separating the eggs from each other, a whirling vessel (WIBORG 1951) was used to fraction the samples, and one sample of 1/10 of both gonads combined was counted from each fish. A study of egg size was carried out in 1971. Eggs were artificially fertilized and kept in glass jars with sea water at 5°C for about 12 hours. Diameters of a hundred eggs or more from each fish were measured using a Watson eyepiece micrometer. Length and age of these fish were recorded.

Diameters were also measured on live eggs from natural spawning beds situated along the Finnmark coast.

RESULTS

FECUNDITY

In 1971 eggs were counted in 48 specimens ranging between 14.1 and 18.2 cm in length. Fecundity ranged between 5800 and 19090 eggs per female (Fig. 1). The following logarithmic regression of fecundity (F) on length (L in cm) was found:

$$\log F = 3.6473 \cdot \log L - 0.4074$$

In 1972 egg counts were made from 34 capelin ranging between 14.2—18.6 cm. Fecundity ranged from 5250 to 19070 eggs per female. Accordingly the regression line

$$\log F = 3.2508 \cdot \log L + 0.0924$$

was found.

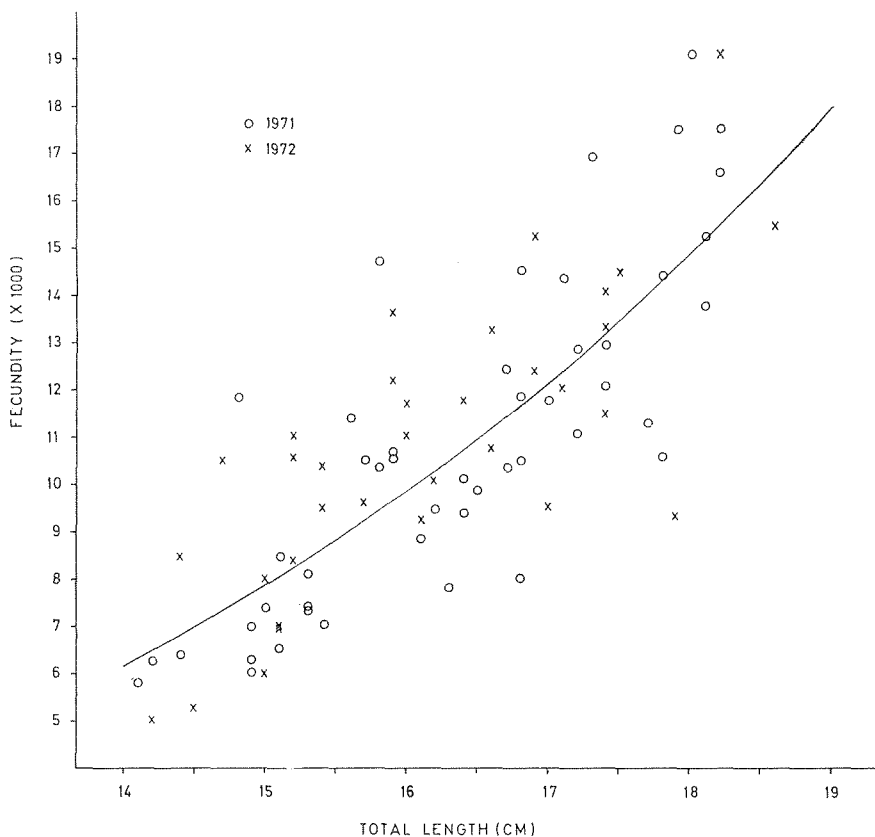


Fig. 1. Fecundity of Barents Sea capelin from 1971 and 1972 with the regression line $F = 0.3913 \cdot L^{3.4871}$

Correlation coefficients, r , variances of estimate, $S^2 \log F \log L$, regression coefficients, b , with confidence intervals, and intercepts, a , with confidence intervals are listed in Table 1. Both correlations are highly significant.

Values of t between the regression coefficients, b , and between the intercepts, a , for the years 1971 and 1972 are 0.358 and 0.040 respectively. This shows that there is no significant difference in fecundity-length relationship between the two years. Therefore the material from the two years were combined, and the regression line

$$\log F = 3.4871 \cdot \log L - 0.2049$$

was found. Some parameters for this regression are also listed in Table 1.

This equation can be converted to

$$F = 0.3913 \cdot L^{3.4871}$$

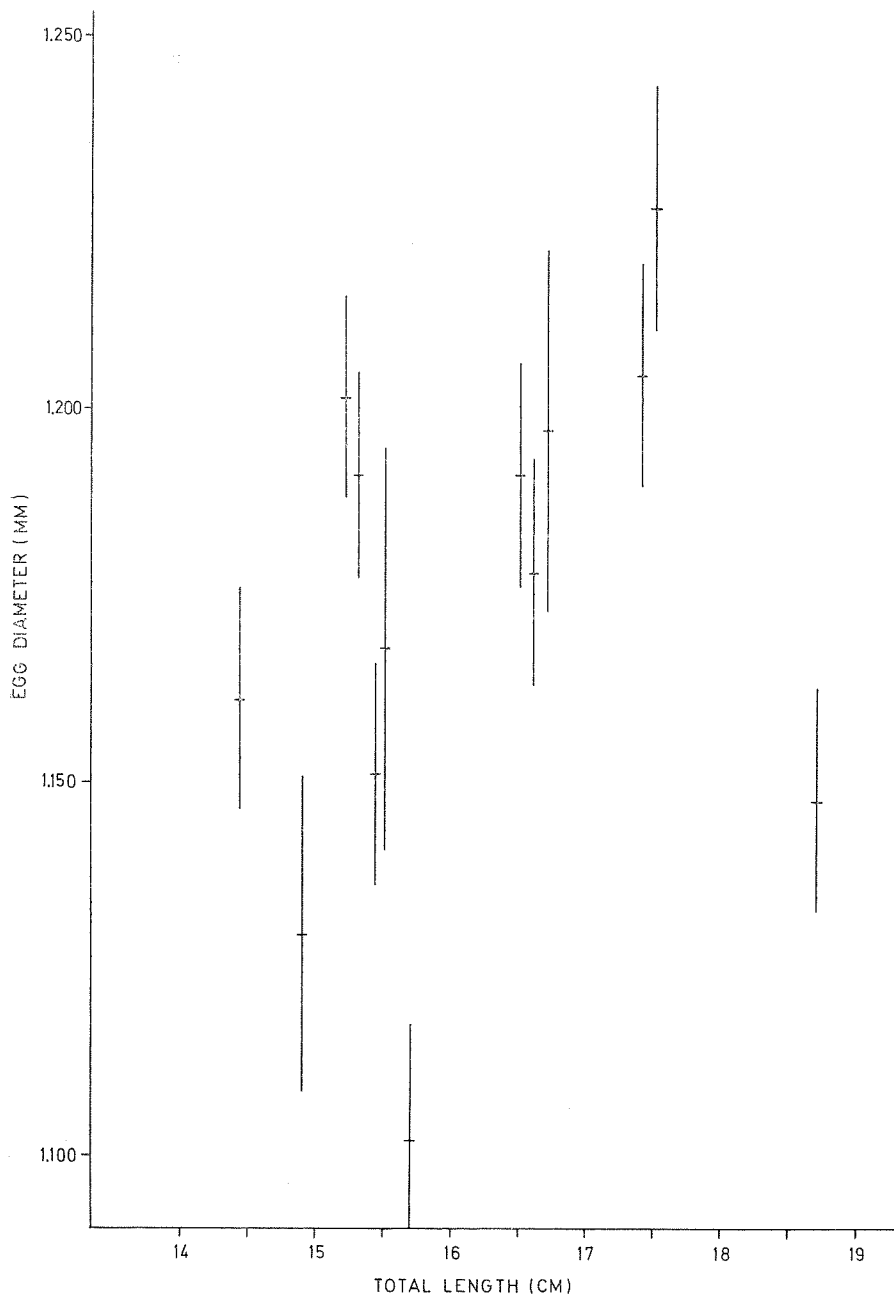


Fig. 2. Diameters of artificially fertilized eggs of Barents Sea capelin from 1971. The range of the vertical bars show two standard deviations.

Table 1. Parameters of the regression line $\log F = b \log L + a_n$ used for fecundity (F) and length (L) on Barents Sea capelin.

Year	n	$b \pm 95\% \text{ conf. lim.}$	$a \pm 95\% \text{ conf. lim.}$	r	$S^2_{\log F \log L}$
1971	48	3.6473 ± 1.4186	-0.4074 ± 1.7174	0.82	0.023
1972	34	3.2508 ± 1.6283	$+0.0924 \pm 1.9626$	0.75	0.021
Total	82	3.4871 ± 1.0420	-0.2049 ± 1.0243	0.79	0.015

MONSTAD (1971) has shown that the length-weight relationship for maturing female Barents Sea capelin taken during late winter has the form

$$W = 0.00036 \cdot L^{3.89}$$

(W = weight in g, L = length in cm).

The conclusion, therefore, is that fecundity is changing nearly linearly with weight.

In the material analysed 72 specimens were 4 years old and only 8 and 2 were 3 and 5 years respectively. It is therefore impossible to analyse the effect of age on fecundity.

The results of the egg diameter measurements are shown in Fig. 2. The size of eggs varied between 1.10 and 1.23 mm, mean 1.165 mm. The regression line

$$D = 0.081 \cdot L + 1.040$$

of mean diameter of eggs, D (mm), on fish length, L (cm), was found. The results suggest that the diameter is increasing with fish length (Fig. 2), but the correlation coefficient $r = 0.2684$ shows that the correlation is not significant ($P > 0.05$).

In addition to artificially fertilized eggs, 467 live eggs from 3 spawning areas were measured. The following mean diameters were found: West-Finnmark, 1.177 mm (N = 147); Mid-Finnmark, 1.174 mm (N = 223); East-Finnmark, 1.218 mm (N = 97). Mean for the whole area was 1.184 mm.

DISCUSSION

Fecundity of Barents Sea capelin has been studied by POZDNYAKOV (1957), who counted eggs from 128 specimens. Fecundity ranged from 4518 to 22021 with a mean of 10764 eggs, and the corresponding lengths were between 12.5 and 19.0 cm, mean 16.1 cm. No regression line was fitted but he suggested an almost linear relation between weight and fecundity.

Table 2. Mean lengths and fecundity from POZDNYAKOV (1957) compared to fecundity at same lengths from the regression line $\log F = 3.487 \cdot \log L - 0.2049$.

Length (cm)	Fecundity	
	Pozdnyakov	Authors
13,7	6 319	—
14,8	7 455	7 525
15,8	9 695	9 441
16,1	10 764	10 070
16,9	12 362	11 930
17,7	15 334	14 030
18,8	17 285	17 310

His data shows a slight, but insignificant higher fecundity than the present study (Table 2).

For Atlantic capelin in Canadian waters fecundity has been studied by TEMPLEMAN (1948) and also by WINTERS (1971) who found the regression line

$$\log F = 2.94 \log L - 4.8473$$

indicating a higher fecundity than in the Barents Sea.

In capelin from the area off British Columbia, ranging in total length between 10.7 and 12.2 cm, HART & MCHUGH (1944) found a fecundity range of 3020—6670 eggs, mean 4590.

Because of the small size at maturity, a comparison of this data to ours is very difficult.

Diameters of fertilized eggs of Atlantic capelin from Canada have been measured by TEMPLEMAN (1948). He found a mean diameter of 0.965 mm and the range from 0.901 to 1.037. His material was preserved in 10% formalin, but the developmental stage is not reported. The mean diameter of eggs from Barents Sea capelin were approximately 23% higher than this. Shrinkage of eggs in 4% formalin is about 7% (HIEMSTRA 1962) and cannot account for the total difference. It can therefore be concluded that Barents Sea capelin have bigger eggs than Atlantic Canadian capelin. This is also to be expected from the differences in fecundity-length relationship between the two stocks.

In Icelandic capelin FREDRIKSSON & TIMMERMANN (1951) found diameters ranging between 0.98 and 1.27 mm with the mean 1.12 mm in fertilized eggs taken from a spawning bed. Preservation and developmental stages are not reported. Comparison is therefore difficult, but the eggs of Icelandic capelin seems to be of similar size as eggs from Barents Sea capelin.

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ESTIMATES OF STOCK SIZE AND REPRODUCTION OF THE BARENTS SEA CAPELIN IN 1970—1972.

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ABSTRACT

DRAGESUND, O., GJØSÆTER, J. and MONSTAD, T. 1973. Estimates of stock size and reproduction of the Barents Sea capelin in 1970—1972. *FiskDir. Skr. Ser. HavUnders.*, 16: 105—139.

The distribution and migration of young and maturing capelin during the period 1969—1972 have been investigated by combined acoustic surveys and fishing experiments.

The nursery area of the capelin is extensive, but the main grounds are in the central and eastern part of the Barents Sea. The two and three year old fish are distributed farther north and northeast than the younger capelin.

Previously, the main part of the spawning stock approached the western part of the Murman coast and the Varanger peninsula, and dispersed westward along the Norwegian coast. During recent years, a major part of the stock also reached the coast of West-Finnmark and migrated farther west and south along the coast for spawning.

The capelin mainly become sexually mature when they are four years old. A very heavy postspawning mortality is observed, and most likely very few capelin survive to spawn a second time.

At present the Barents Sea capelin is the most important fish resource for the Norwegian purse seine fleet, and Norway has been responsible for more than 90% of the total catch from this resource.

Preliminary spawning stock size estimates for 1971 and 1972 are available from acoustic surveys, egg and larval surveys, and tagging experiments.

It is tentatively concluded that the spawning stock size in 1971 was at a high level, being somewhat lower both in 1970 and 1972.

So far no sign of overfishing has been observed. The increase in catch during the last six years is due to a significantly increased fishing effort, but also for a larger part attributed to a raise in the stock size.

A more detailed analysis of the location and time of spawning during the 1971 season is given. Spawning took place along the coast from Vesterålen to Varangerfjord. The major spawning west of North Cape took place during March and off the coast of eastern Finnmark in April.

Fertilization and survival of eggs were studied. On the spawning beds the fertilization seemed to be almost 100%. Egg mortality seemed to be low. The distribution of capelin larvae, during the first month after hatching, was studied. The larvae were collected on five surveys in oblique hauls with Clarke Bumpus plankton samplers.

INTRODUCTION

The annual yields of the Norwegian capelin has gradually increased during the last two decades, and at present the Barents Sea capelin is the most important fish resource for the Norwegian purse seine fleet. Previously capelin were exploited commercially mainly during winter and spring when the mature stock enters coastal waters to spawn, but since 1968 an important fishery has also developed for capelin on the feeding grounds in the Barents Sea (Fig. 1). It is apparent from the history of the fisheries that great variations in spawning time and area have occurred, and that the stock strength has fluctuated widely (OLSEN 1965, 1968). These fluctuations strongly influence the fisheries, and in 1960 the Institute of Marine Research started a programme of capelin investigations with the aim of establishing the causes of these fluctuations and if possible, making prognoses for the fishery.

Each year in February—March, and in later summer and autumn, research vessel surveys have been carried out in the Barents Sea (MØLLER og OLSEN 1962, OLSEN 1968, MONSTAD 1969, LAHN-JOHANNESSEN og MONSTAD 1970). The work has included sonar and echo sounder searching, sampling with midwater and bottom trawls, and hydrographic observations. Since the 1961 season, sampling of the commercial landings has been carried out, and records of biological data for the last decade are available.

Due to the increasing fishing effort, great attention has recently been given to the question of regulating the fisheries for the Barents Sea capelin. Thus in 1970 the Norwegian government introduced a time regulation by closing the summer season from 1 June to 15 July. In 1971 it was prohibited to land catches of capelin from 15 May to 24 July and in 1972 from 1 May to 24 July. A minimum legal size of 12 cm was set in 1971. For the 1972 season it was recommended to increase the minimum size to 14 cm, in order to utilize the growth potential of the young fish (DRAGESUND, MONSTAD og ULLTANG 1973). However, the decision was taken by the Government to increase the legal minimum size by only 1 cm.

The need for regulatory measures during the spawning season has also been discussed. The question has arisen as to whether the intensified fishery during the years 1970—1972 has endangered the future reproduction of the stock. During the winter fishery of 1972 the season was closed for a short period from 19 to 26 March west of North Cape and from 27 March to 9 April east of North Cape.

In order to give more reliable prognoses for the fishery and to collect adequate material for regulatory measures to be taken, the Norwegian

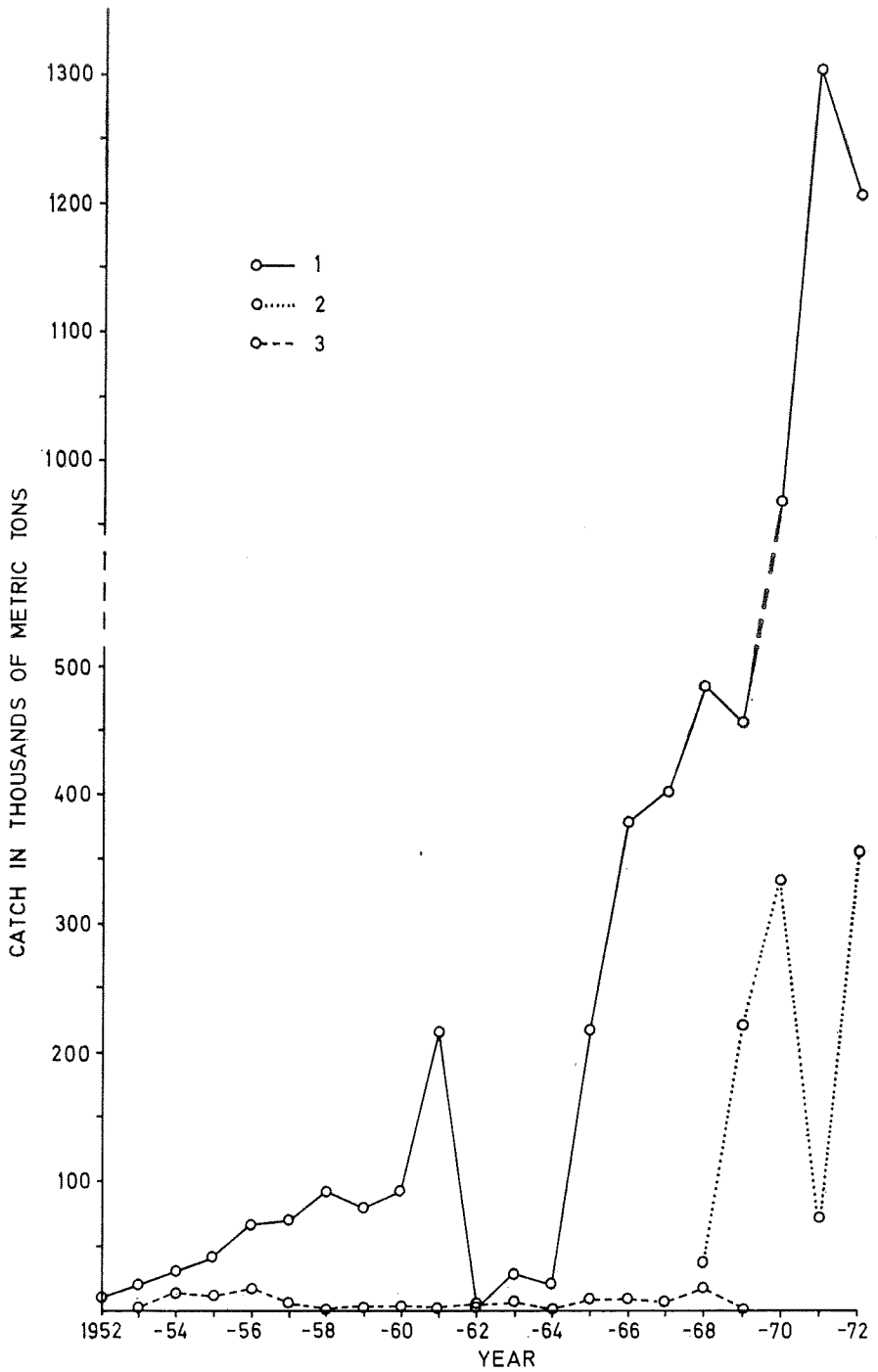


Fig. 1. Catches of Barents Sea capelin in 1950—1972. 1) Norwegian winter fishery, 2) Norwegian summer fishery, 3) Soviet winter- and summer fishery.

capelin investigations were considerably extended in 1971 by including more qualitative work on the Barents Sea capelin resource and its production of recruits.

The aim of the present paper is to report some results of the investigations carried out the last three years with emphasis on:

- 1) distribution and migration of capelin during autumn and winter;
- 2) structure and size of the spawning stock;
- 3) reproduction of the stock and the resulting year-class strength.

MATERIAL AND METHODS

Most of the material is obtained from investigations carried out during autumn and winter 1969—1970 to 1971—1972. It includes data from acoustic surveys, egg and larval surveys, tagging experiments, samples of capelin and catch statistics.

ACOUSTIC SURVEYS

Every autumn, during October to December, the distribution and abundance of adult capelin in the Barents Sea were studied from combined acoustic surveys and fishing experiments with pelagic trawl (MONSTAD 1971, JAKUPSSTOVU *et al.* 1972). Similar acoustic surveys were conducted from January to late February (LAHN-JOHANNESSEN og MONSTAD 1970, BLINDHEIM og MONSTAD 1972). In 1971 and 1972 investigations were also carried out during the spawning season from mid-March to the end of April. In order to give a more quantitative distribution of the capelin resource, special echo surveys were undertaken in August-September 1970 and 1971 (BLINDHEIM *et al.* 1971, DRAGESUND og NAKKEN 1972).

The research vessels used («Johan Hjort» and «G. O. Sars») were equipped with vertical echo sounders, echo integrators and horizontal ranging sonars, and during the surveys the acoustic instruments were operated continuously. The settings of the Simrad echo integrator and the EK 38 kHz echo sounder during the surveys in August-September 1970 and 1971 were: Output power 1/10 effect, time varied gain (TVG) 20 log R and receiver gain — 20 dB. The source level was 136 dB, receiving voltage response 7.8 and the beamwidth 5° and 5.5° along and athwartship between the 3 dB points. In order to avoid saturation of the echo integrator the gain was adjusted when necessary. Three echo integrators with six echo integrator channels were used, each covering a depth interval of 50 m. Echo integrator readings were made each

nautical mile, and average values of each five miles were plotted on maps.

When other fish species were recorded within the same depth interval, the echo abundance was divided between capelin and the other species. Both experimental fishing and analysis of the echo traces were used for diving the total echo abundance (BLINDHEIM *et al.* 1971).

A method to estimate the stock size based on acoustic surveys, is developed by MIDTTUN and NAKKEN (1971), BLINDHEIM and NAKKEN (1971) and applied by MIDTTUN and NAKKEN (1972).

The total echo abundance (T) was estimated from the equation

$$T = \int_A \rho dA \quad (1)$$

where A is the area of distribution and ρ the number of fish or fish weight per unit area.

C is calculated from the relation of MIDTTUN and NAKKEN (1971),

$$\rho = CM \quad (2)$$

where C is approximately constant for the same species in case ρ is measured in fish weight per unit area. M is the integrated echo intensity. The procedure for calculating C is described by BLINDHEIM and NAKKEN (1971).

Applying (1) and (2) $T = C \int_A M dA$ (3)

$$T = C_{T \text{ relative}} \quad (4)$$

where T_{relative} has the dimension: mm echo integrator readings \times unit surface area.

By integrating the area between the isolines on the map where the echo integrator readings are plotted, T_{relative} can be found.

EGG AND LARVAL SURVEYS

During surveys carried out in winter of 1971 and 1972, capelin eggs were collected by Pettersen grab, but were also sampled by diving and from the stomach content of haddock, cod and saithe caught by bottom trawl. A more detailed description of the diving technique used is given by BAKKE and BJØRKE (1973).

The larvae were collected in oblique hauls with Clarke—Bumpus plankton samplers (CBPS). The length of the nylon net used was 60 cm with a mesh size of 0.5 mm. The CBPS were equipped with flowmeters, and three samplers were towed simultaneously at different depths and raised in 5 m steps.

The sampling depths were 25—5, 50—30 and 75—55 m. The total towing time was 20 minutes. A weight of 28 kg was attached at the end of the 4 mm thick wire which was kept as close as possible to an angle

of 50° from the surface by keeping the towing speed between 1.5 and 2.0 knots. Because of difficulties in operating the closing mechanism of the CBPS in bad weather, this was permanently kept in open position. The number of larvae collected was converted to numbers below 1 m² sea surface.

In order to evaluate the size of the spawning stock, the total number of eggs in a locality near North Cape (Nordvågen) was estimated in 1971. One week after hatching commenced, a detailed larval survey was carried out in the area where larvae from Nordvågen were distributed. Probably some larvae had drifted out of the area, and some larvae from other spawning grounds may have drifted into it; though it is believed that the estimated number is reasonably close to the real one. The ratio, between eggs spawned in Nordvågen and the number of larvae derived from these eggs and available to the plankton gears during the given period of time, was calculated. This ratio between eggs and larvae can be applied to the whole spawning area, provided that:

- 1) the plankton samplers are taken at the same time in relation to the hatching sequence;
- 2) that hatching success and mortality of the implied larval stages are the same in all areas, or that the area selected for the detail study has conditions corresponding to an average for the other areas;
- 3) the larvae sampled are equally representative in all areas.

By this method number of eggs spawned can be computed from number of larvae taken during a larval survey, and when fecundity is known, number of fish which have spawned can be found. A more detailed discussion of this method is given by GJØSÆTER and SÆTRE (1973).

TAGGING EXPERIMENTS

During the winter seasons of 1971 and 1972 tagging experiments were carried out from the scouting vessel «M. Ytterstad», which on this occasion was equipped with purse seine. The capelin were tagged with internal steel tags measuring 14 × 3 × 0.5 mm. A tagging device, especially developed for inserting this tag, was used. After being carefully brought from the purse seine into the tank on deck, the capelin were taken out individually, immediately tagged, and were released in batches of approximately 20 individuals into the sea by means of a bucket.

Nearly all tags recovered were found at Norwegian reduction plants where magnets are installed for detecting the tags. The efficiency of the

magnets was tested during the winter seasons of 1971 and 1972. The procedure for testing the magnets, and the routine for collecting data on the catches and tags recovered at Norwegian reduction plants, are described by AASEN (1958) and by DRAGESUND and HARALDSVIK (1968).

The spawning stock (S) was estimated from the relation

$$S = \frac{S_1 \cdot N_1 + S_2 \cdot N_2 + \dots + S_n \cdot N_n}{N} \quad (5)$$

where S_1, S_2, \dots, S_n are the stock sizes estimated from each release and N_1, N_2, \dots, N_n the number of tagged fish. N is the total number of tagged fish. S_1, S_2, \dots, S_n are estimated from the relation

$$S_n = \frac{N_n \cdot C_n \cdot s}{R_n} \quad (6)$$

where C_n is the catch subsequence to the n^{th} release and R_n the number of recaptures from this release.

s is the tagging survival, taking into account both tagging mortality and shedding of tags. No decisive experiments on capelin have been carried out on tagging survival with internal steel tags. This factor certainly plays an important role in the calculations of the stock strength and has to be adjusted for. Tentatively s is set to 0.80.

CAPELIN SAMPLES AND CATCH STATISTICS

During the acoustic surveys capelin were caught with a Norwegian capelin trawl with an opening of 12×12 fathomes, mesh size (stretched) ranging from 200 mm (wings and squares) graded down to 22 mm (cod end). An ordinary Granton bottom trawl with cover net equipped with bobbins was also available.

In addition to samples collected during the acoustic surveys, capelin samples were collected throughout the winter seasons of 1970—1972 from commercial catches. The capelin were examined fresh or from frozen material.

Total length was measured to the nearest mm and grouped in half cm class intervals (GJØSÆTER and MONSTAD 1973). Otoliths, mainly taken stratified, were used for age determination, and age-length keys were established. The maturity stages were classified according to a scale used by MONSTAD (1971). The weight in g was recorded.

During surveys the volume of individual fish was measured by the displacement method, and from this the weight was estimated.

Catch statistics of the Norwegian landings were obtained from the official fishery statistics. Statistical information, on the geographical distribution of commercial catches of spawning and spent capelin in

winter 1971, was supplied from the fishermen's sales organization, Feitsildfiskernes Salgslag. Statistics of landings by USSR were derived from «Bulletin Statistique des Peches Maritimes».

DISTRIBUTION AND MIGRATION

The distribution of capelin in August—September 1970 and 1971 is illustrated in Fig. 2, 3 and 4. The survey in 1970 did not cover the area east of 40°E and north of 77°N. In the western part of the investigated area the abundance was significantly higher in 1970 (Fig. 2) than in 1971 (Fig. 3). During the second survey in 1971 (Fig. 4) the capelin were recorded somewhat farther west and north. The summer fishery on two and three years old capelin in 1969—1971 took place in this area, i. e. between 74°—78°N and 25°—45°E.

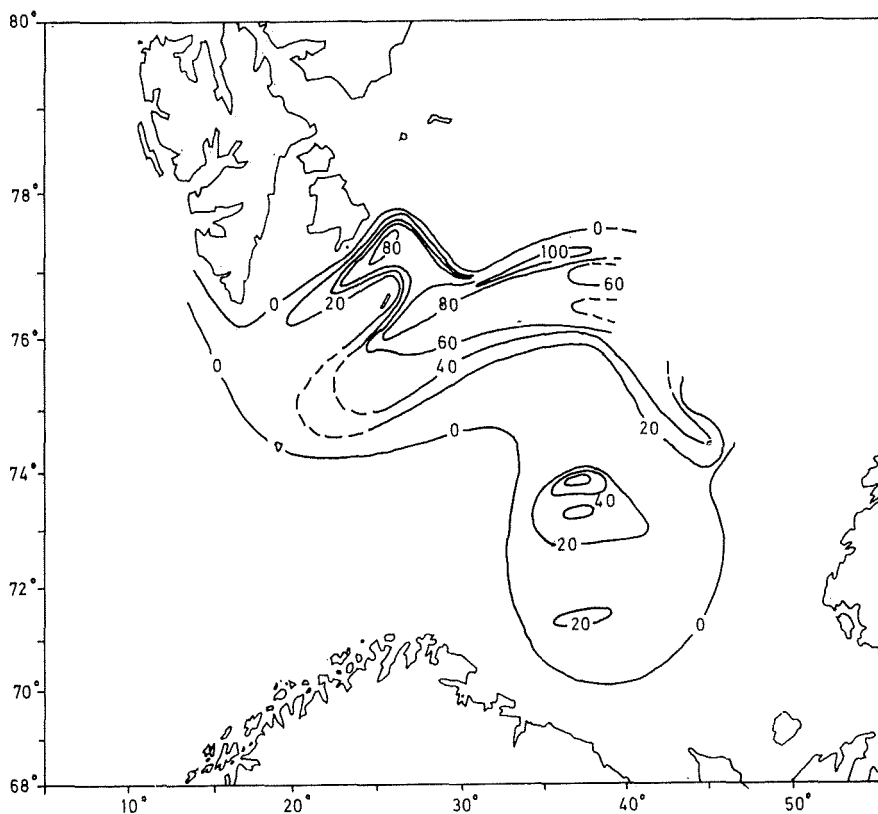


Fig. 2. Distribution of capelin 28 August—11 September 1970. Isolines and numbers are fish density as echo integtorar recordings in mm.

Fig. 5—7 show the distribution and migration during the prespawning period in 1969—1970, 1970—1971 and 1971—1972. In late autumn the maturing capelin segregate from the immature stock and gradually start their migration southward along the front between the cold and warmer water in the area from the Central Bank (75°N , 35°E) towards the Thor Iversen Bank (73°N , 35°E). From this region part of the stock moves farther south and southeast, whereas another component start migrating westward.

In previous years the main part of the spawning stock usually approached the western part of the Murman coast and the Varanger peninsula and dispersed westward along the Norwegian coast (PROKHOROV 1965, MØLLER og OLSEN 1962). During the spawning seasons in 1970—1972

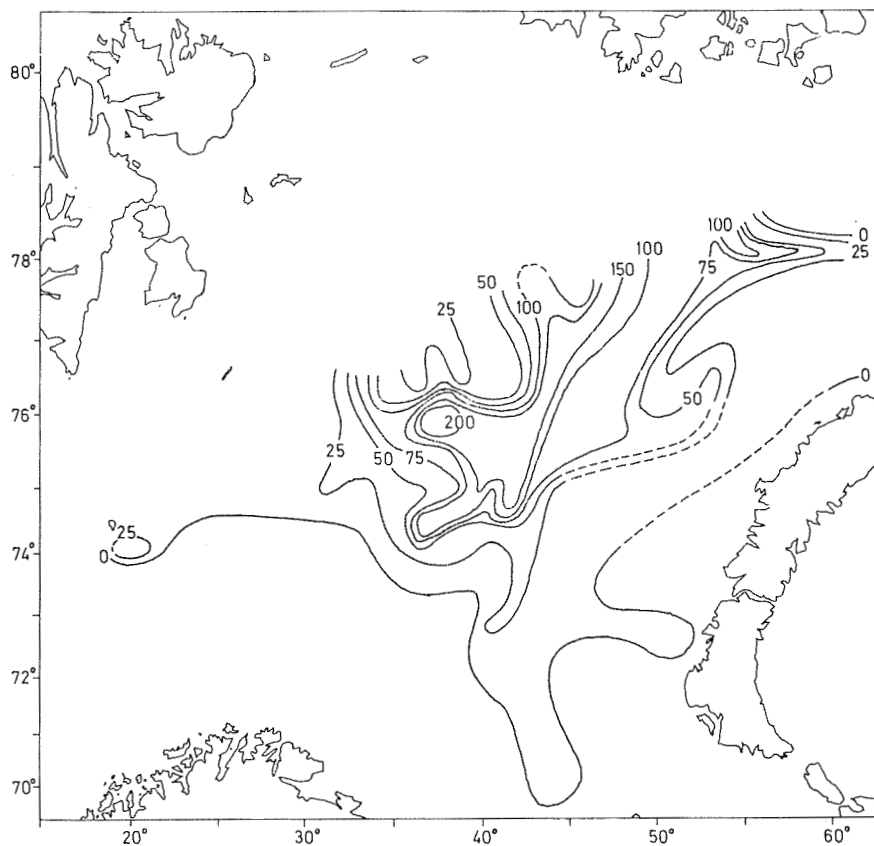


Fig. 3. Distribution of capelin 23 August—9 September 1971. Isolines and numbers are fish density as echo integrator recordings in mm.

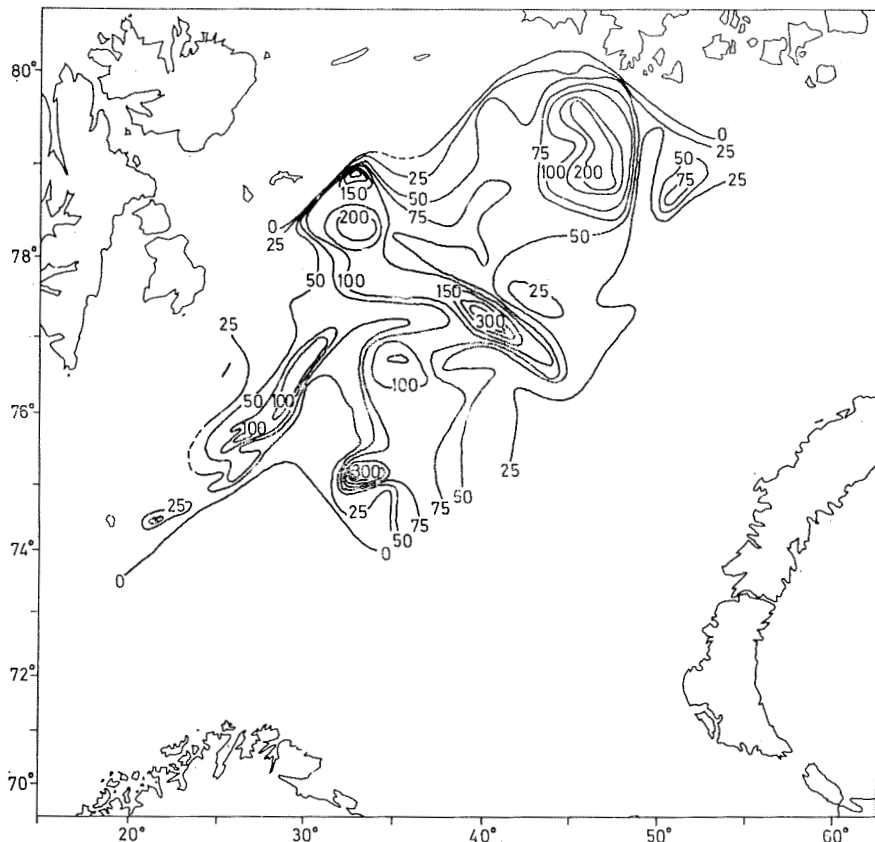


Fig. 4. Distribution of capelin 12—29 September 1971. Isolines and numbers are fish density as echo integrator recordings in mm.

as well as in 1968 and 1969 (OLSEN 1968, LAHN-JOHANNESSEN og MONSTAD 1970) part of the stock also migrated from the open sea towards the coast of West-Finmark (west of North Cape). The main part of the western stock component approached the coast between Sørøya and the North Cape during February. In 1970 the main part of the spawning stock was distributed east of North Cape where the most important fishery took place (Table 1). However, in 1971 mature capelin continuously approached the coast west of North Cape during February and March and dispersed farther west and south along the coast. In March concentrations of capelin were located off Senja and in March—April off Vesterålen. This is the most southern area of capelin catches recorded in Norwegian waters during the last two decades. Components of the stock also reached the Finnmark coast east of North Cape, but in contrast to previous years no great concentrations were observed along

the coast of eastern Finnmark in 1971, although the larval surveys indicated heavy spawning also in this area. The most important fishing took place west of North Cape, but profitable catches were also obtained east of North Cape. Also in 1972 most of the fishing took place west of North Cape, but the capelin did not move to the spawning grounds off Senja and Vesterålen.

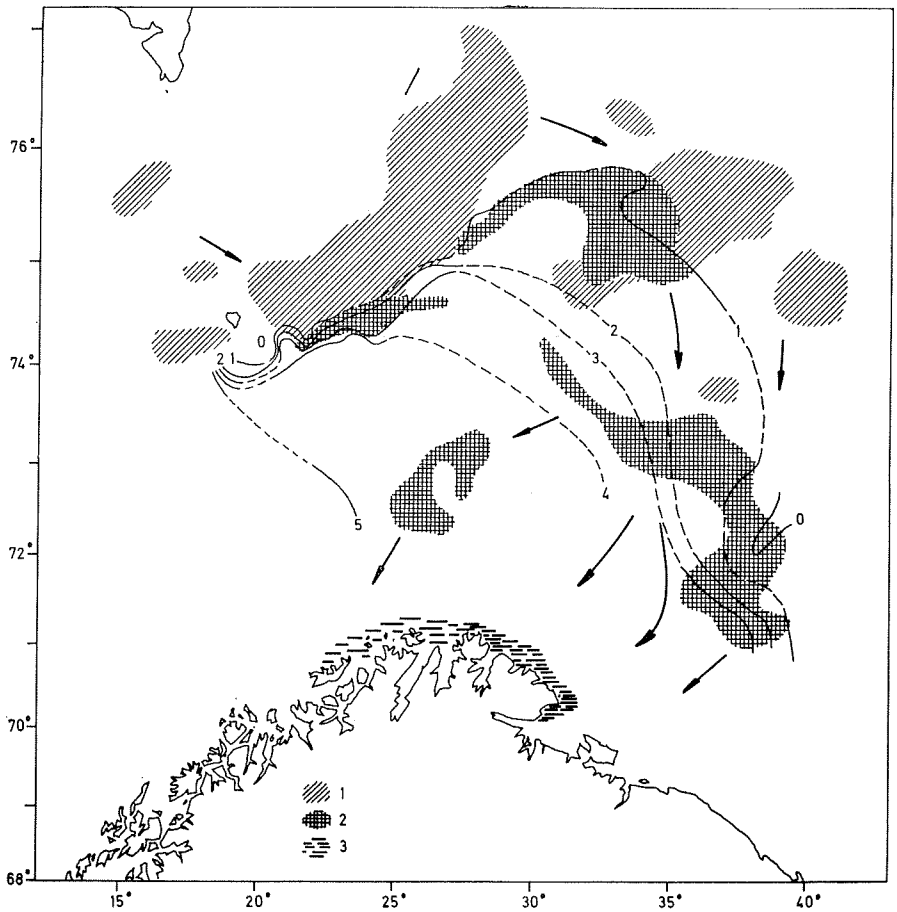


Fig. 5. Distribution of capelin during autumn and winter of 1969—1970. The temperature ($^{\circ}\text{C}$) at 50 m depth in January 1970 is also indicated. Arrows denote the main migration routes. 1) October—November 1969, 2) January 1970, 3) March—April 1970.

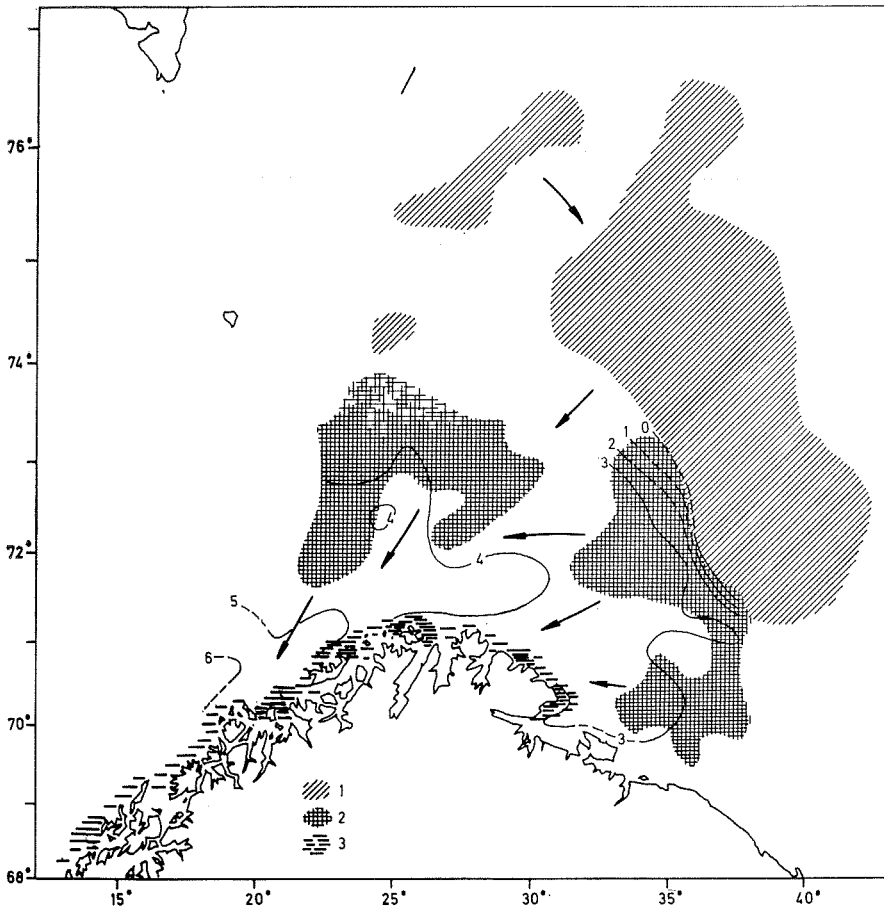


Fig. 6. Distribution of capelin during autumn and winter of 1970—1971. The temperature ($^{\circ}\text{C}$) at 50 m depth in January—February 1971 is also indicated. Arrows denote the main migration routes. 1) November—December 1970, 2) January—February 1971, 3) March—April 1971.

Table 1. Catch of capelin (in thousand tons) during the winter seasons 1970—1972, west and east of North Cape respectively.

Month	Week no.	Year					
		1970		1971		1972	
		West	East	West	East	West	East
January	3			7.035		71.630	
	4		1.451	47.193	1.410	130.600	
	5	8.859	11.167	58.647		85.565	
February	6	0.198	0.042	6.604	22.390	158.065	
	7	23.632	14.043	100.573	39.340	126.220	
	8	88.283	10.210	101.555	42.909	69.931	
	9	95.381	35.295	127.950		52.607	0.100
March	10	6.286	114.983	124.365	2.000	206.167	2.817
	11	31.065	95.023	117.710	19.010	147.240	
	12	7.949	89.701	115.100	9.100	65.316	18.546
	13	2.558	67.702	142.508	20.636		105.330
	14	0.999	96.772	112.877	22.022	1.545	
April	15		116.072	32.867	0.307		
	16		31.070	5.649	31.925		
	17		7.255		5.060		
	18		0.131				
May	19	0.023	0.544				
	20		0.136				
	21						
	22		0.013				
Total		265.233	691.610	1 100.633	216.109	1 114.886	126.793

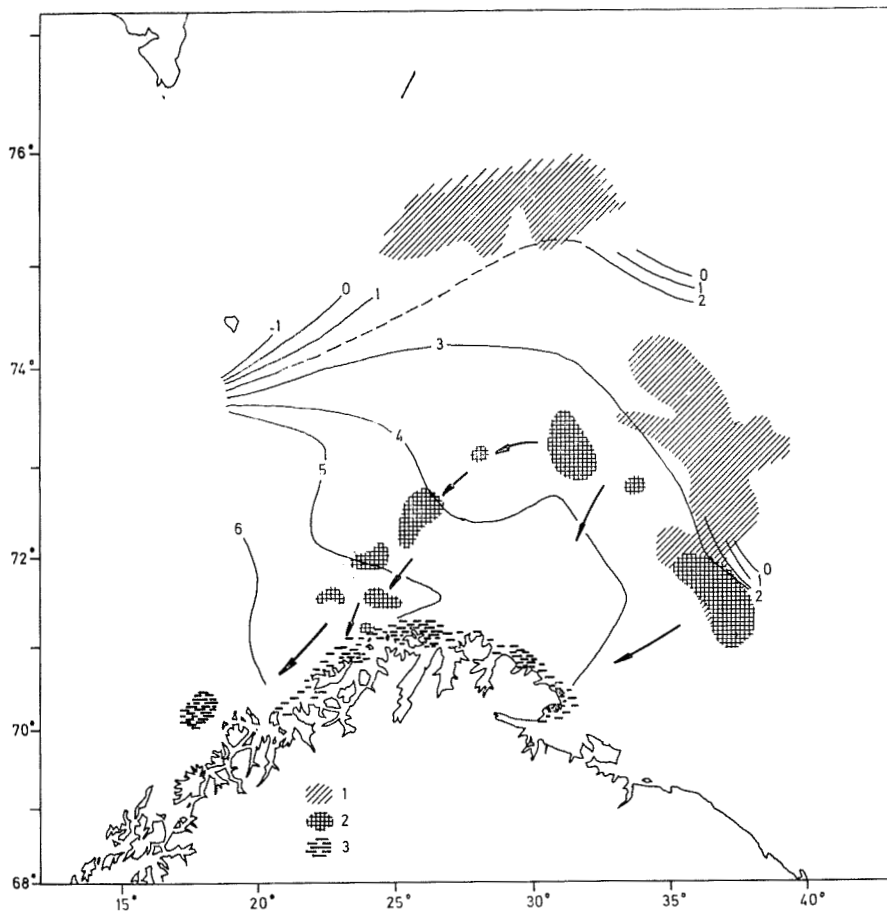


Fig. 7. Distribution of capelin during autumn and winter of 1971—1972. The temperature ($^{\circ}\text{C}$) at 50 m depth in January—February 1972 is also indicated. Arrows denote the main migration routes. 1) November—December 1971, 2) January—February 1972, 3) March—April 1972.

STRUCTURE AND SIZE OF SPAWNING STOCK

The Barents Sea capelin spawn mainly when three and four years old, and the lack of older fish strongly supports the theory of a very heavy postspawning mortality. At the end of the spawning season dead and dying capelin were observed over wide areas. Possibly some capelin do survive to spawn a second time (TEMPLEMAN 1948, PROKHOROV 1965, VILHJÁLMSSON 1968, WINTERS 1971), but it is suggested that most of them die after spawning.

According to previous investigations, the major part of a year-class spawn at an age of four years (OLSEN 1965, 1968, PROKHOROV 1965). During the winter fishery in 1970 the rich 1966 year-class dominated the catches (Fig. 8), followed by the 1967 year-class.

Investigations carried out during the summer of 1970 (BLINDHEIM *et al.* 1971) indicated that the 1967 year-class was rich, and during the winter season of 1971 this year-class showed to be very abundant and strongly dominated the catches (Fig. 9).

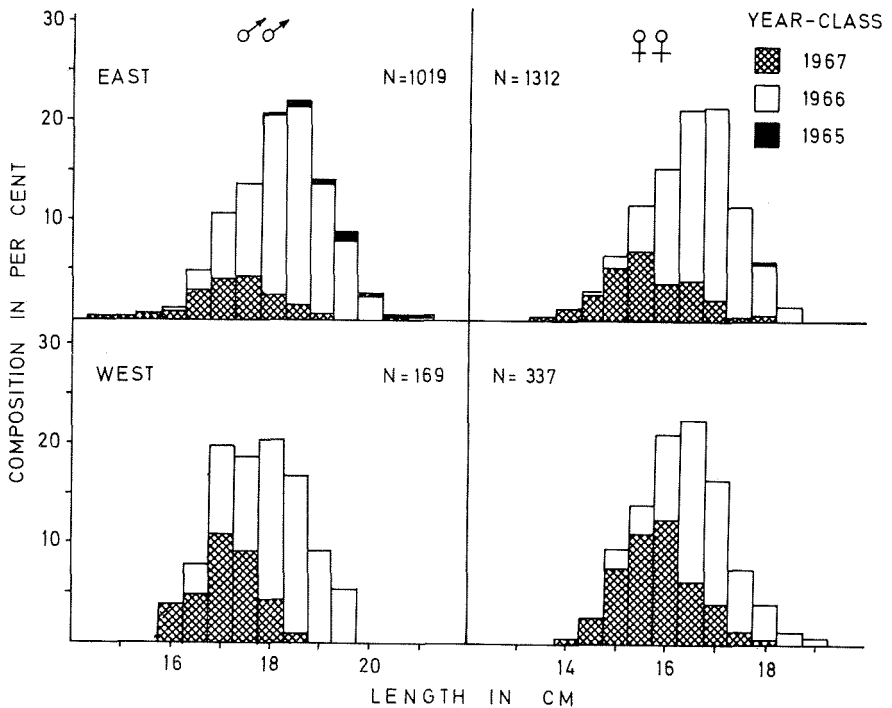


Fig. 8. Age and length composition of capelin during the winter season 1970 off eastern (East) and western (West) Finnmark.

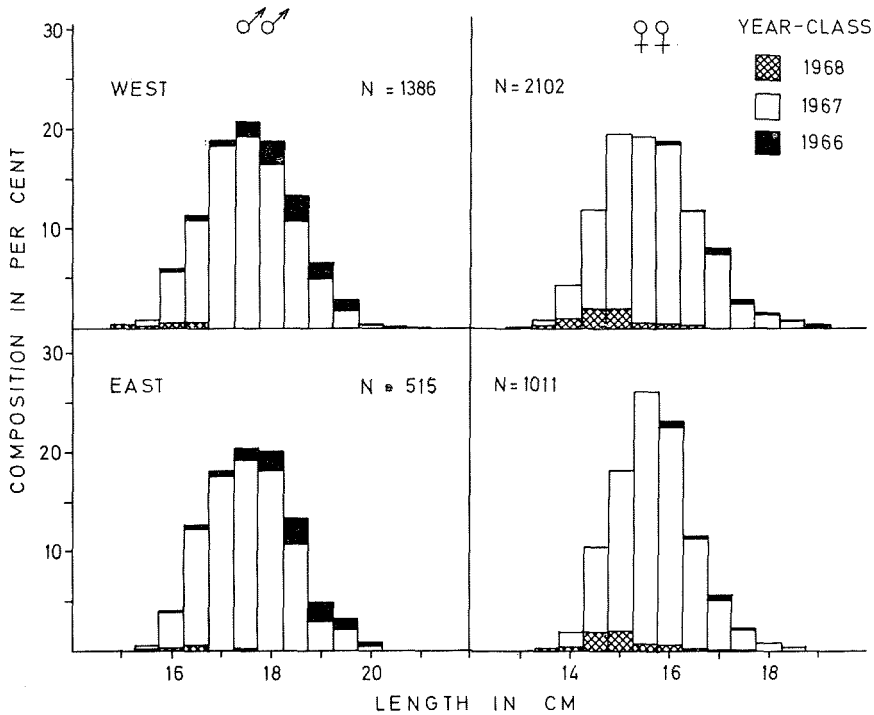


Fig. 9. Age and length composition of capelin during the winter season 1971 off western (West) and eastern (East) Finnmark.

Also, in the winter season of 1972 the four year old fish (1968 year-class) predominated (Fig. 10).

Estimates of the spawning stock size in 1971 are available from tag returns and data on egg and larval abundance and distribution, and for the 1972 season from tagging experiments and acoustic surveys. The different methods used are subject to great errors and will only give some indication of the order of magnitude of the stock size.

The tagging experiments both in 1971 and 1972 were carried out at the beginning of the winter season. The within season returns are listed in Table 2 and 3. The effective quantities of capelin processed during the season, at reduction plants equipped with tested magnets, are also given in Table 2 and 3. The effective quantity processed, subsequent to each release, was estimated according to date on weekly landings during the season (Table 1).

Applying relations (5) and (6), the stock size in 1971 was estimated to be about 5.9 mill. tons, and in 1972 to about 4.8 mill. tons. The

figures obtained from this method are overestimated and must be interpreted with caution. An estimate of the stock strength based on these data is only tentative due to lack of information on tagging survival, and because the number of returns are too low and probably not evenly distributed in the catches.

A preliminary estimate of the spawning stock size for the season of 1971 is also obtained from egg and larval surveys. On 7—9 May a detailed larval survey was carried out in the area where larvae from Nordvågen were distributed. Approximately 4×10^{10} larvae were present. Number of eggs spawned in Nordvågen was 7.5×10^{11} . Number of larvae in this period was therefore approximately 1/20 of the number of eggs.

The survey of the whole area and the detail survey should be conducted at the same time in relation to the hatching curve. This requirement is best solved if the survey between 2 and 17 June is selected (Fig. 18). This survey indicate that 1.5×10^{13} larvae were present, and

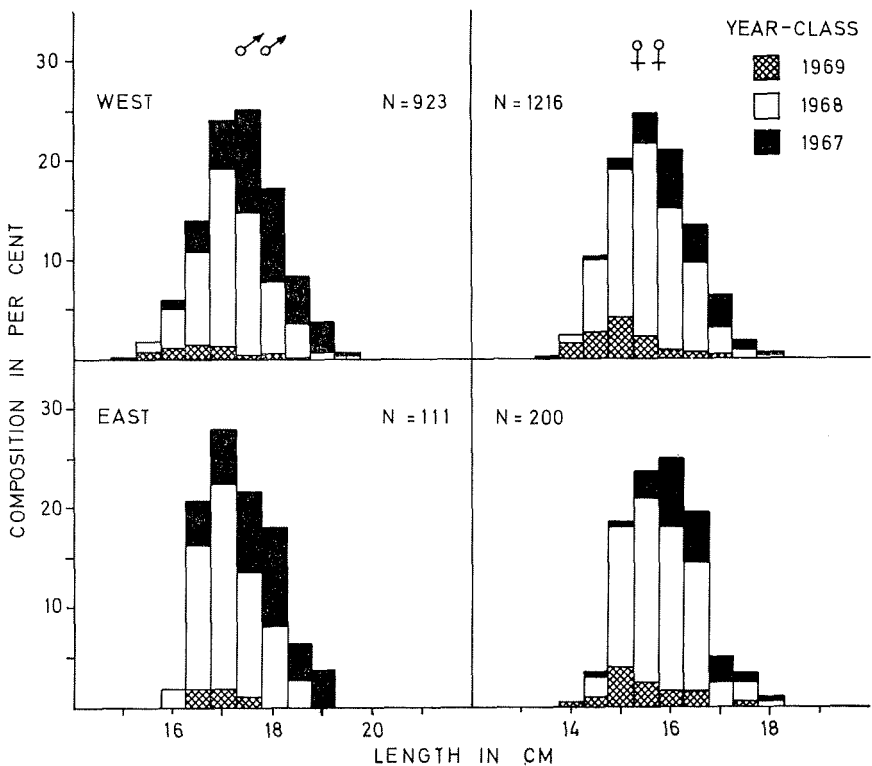


Fig. 10. Age and length composition of capelin during the winter season 1972 off western (West) and eastern (East) Finnmark.

Table 2. Quantity of processed capelin (tons) and number of returns from tagging experiments off the Finnmark coast during the winter season 1971.

Factory no.	Efficiency (e)	Quantity processed (p)	Corrected quantity (e . p)	Date and number of released capelin			
				16—18 February	24 February	11—12 March	Total
				3000	500	1500	
79.....	0.53	104 305	55 281	4	3	25	32
70.....	0.65	38 150	24 797	4		2	6
69.....	0.62	36 000	22 320	5			5
95.....	0.89	47 363	42 153	10	2	3	15
66.....	0.64	21 753	13 922	7		3	10
55.....	0.94	28 774	27 047	5		6	11
45.....	0.76	28 037	21 308	10			10
43.....	0.77	34 828	26 817	4		2	6
40.....	0.50	21 340	10 670	6			6
42.....	0.90	53 948	48 553	15		1	16
37.....	0.67	32 000	21 440	31			31
24.....	0.66	35 978	23 745	10	2	2	14
31.....	0.88	25 449	22 395	4			4
68.....	0.89	59 510	52 963	36	4	3	43
73.....	0.41	36 642	15 023			7	7
			428 434	151	11	54	216

accordingly that 3×10^{14} eggs had been laid. Assuming a mean fecundity of 10 000 eggs pr. female (GJØSÆTER and MONSTAD 1973), that males and females were present in equal proportions and that there are 3000 capelin in one hl, this corresponds to about 2.0 mill. tons of spawning capelin. Most of the capelin caught during the winter season were in the prespawning stage, and only between one and two hundred thousand tons of the total landings were spent capelin. The stock size at the beginning of the season, estimated from this method, should at least be in the order of 3.2 mill. tons.

A slightly different method, considering only number of young larvae, was applied by GJØSÆTER and SÆTRE (1973). This method indicated a spawning stock size in 1971 of 4.0 mill. tons.

The total echo abundance of capelin during the autumn of 1971 was estimated on the basis of the echo survey carried out 12—29 September (Fig. 4). Both immature and maturing capelin were distributed within the area surveyed (Fig. 11). The mean weight in the samples collected, showed that the maturing capelin made up 36% (weight) of the total stock. The total stock in the area surveyed was estimated from relations (3) and (4).

Table 3. Quantity of processed capelin (tons) and number of returns from tagging experiments off the Finnmark coast during the winter season 1972.

Factory no.	Efficiency (e)	Quantity (p)	Corrected quantity (e · p)	Date and number of released capelin				Total
				2	3	6	7	
				February 1200	February 1100	February 1500	February 300	
79	0.86	126 833	109 077	2	13	15	3	33
70	0.65	37 506	24 379	1	2	7		10
69	0.79	38 796	30 649	3	5	1		9
95	0.85	43 753	37 190	8	5	13	4	30
66	0.97	22 923	22 235	3	6	5		14
55	0.94	30 312	28 493	7	9	4	2	22
45	0.82	30 047	24 638	3	12	9	1	25
43	0.60	24 828	20 896		4	1	1	6
40	0.81	17 591	14 249	2	10	4		16
42	0.56	55 319	30 978	3	13	4	2	22
37	0.50	19 145	9 573	1	2			3
24	0.93	28 823	26 806	1	2	6	1	10
68	0.86	53 231	45 779	7	8	4	2	22
35	0.58	24 577	14 255	2		1	4	7
47	0.58	28 192	16 351	2	5	1	1	9
52	0.92	22 372	20 583	2	4	9	2	17
53	0.90	18 550	16 695	1	3	2	1	7
49	0.86	14 949	12 856	1	2	5	1	9
59	0.53	16 632	8 815		4			4
63	0.74	19 258	14 251			3	1	4
			528 748	49	109	94	26	278

$$T_{relative} = 479 \cdot 10^4 \text{ mm} \cdot (\text{nautical miles})^2$$

$$C = 2.1 \text{ tons/mm} \cdot (\text{nautical miles})^2.$$

The total stock of capelin (T) in the area was estimated to

$$T = 10.1 \cdot 10^6 \text{ tons}$$

Assuming that all the maturing capelin migrated towards the coast for spawning in 1972, the size of the maturing stock was estimated to be between 2 and 3.6 mill. tons. This is a significantly lower figure than that obtained from tag returns (4.8 mill. tons). It is tentatively concluded that the figure estimated on the basis of the acoustic surveys is the most reliable of the two. It should be noted that the C probably is too high, and consequently this will result in an overestimation of the stock size (MIDTTUN and NAKKEN 1972).

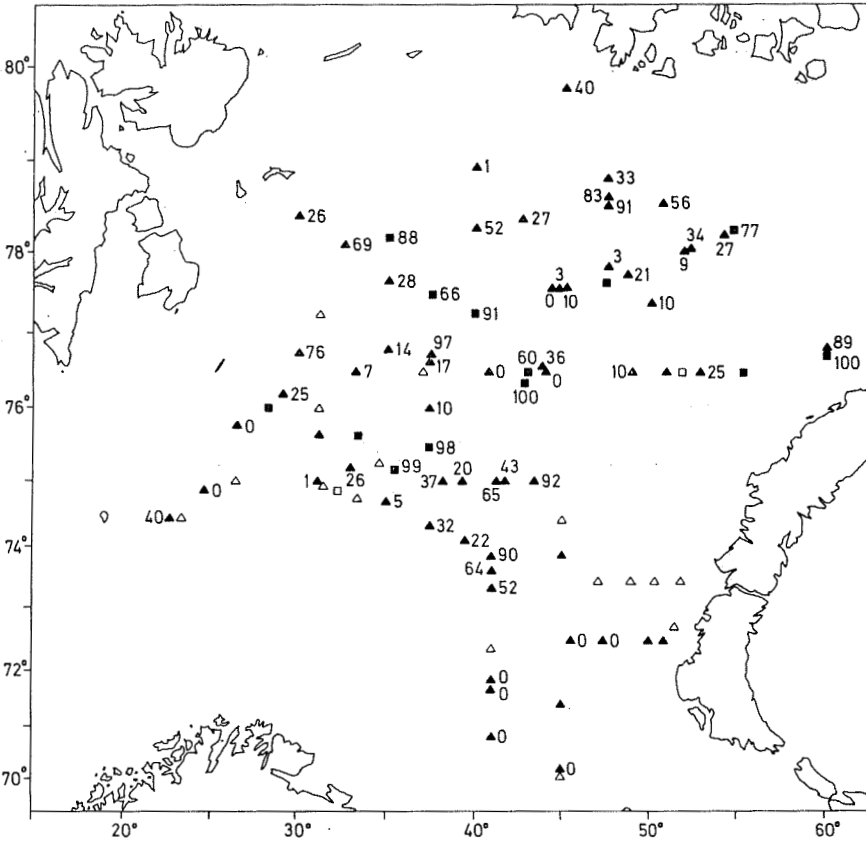


Fig. 11. Weight percentage of capelin ≥ 14 cm at each trawl station August—September 1971. Open symbols indicate no catch. At stations where the symbols are filled and no figure is given, only a few fish were caught, and no percentage is given. Triangles indicate pelagic — and squares bottom trawl stations.

REPRODUCTION AND RESULTING YEAR-CLASS STRENGTH

LOCATION AND TIME SPAWNING

To locate spawning concentrations of capelin in 1971 an echo survey was carried out during the second half of March (Fig. 12). The geographical distribution of commercial catches of spawning and spent capelin were compared with the echo integrator readings, and from these data a series of possible spawning places were found.

To verify the spawning, a grab station survey was carried out. Most of the stations were made in areas where capelin had been recorded. In some cases, divers were also used to locate spawning places (BAKKE and BJORKE 1973). Eggs were found at 55 out of 227 grab stations. At 33 of these, eggs only occurred in numbers between 1 and 10 in each sample, indicating that the main spawning beds were surrounded by relatively large areas with small concentrations of eggs. This feature was also confirmed by the divers.

It is therefore suggested that, in areas where concentrations of eggs were sparse, mass spawning had taken place in a nearby area. The spawning places, found by grab or divers or both, are shown in Fig. 12.

The bottom substratum and number of eggs in the grab samples are shown in Table 4. Gravel was by far the most preferred substratum, and only few eggs were found on other substrata. The gravel on most spawning grounds had a grain size between 0.5 and 1.5 cm. Depth distribution of the eggs is shown in Table 5. Great concentrations of eggs were found to a depth of 65 m, while small numbers were observed

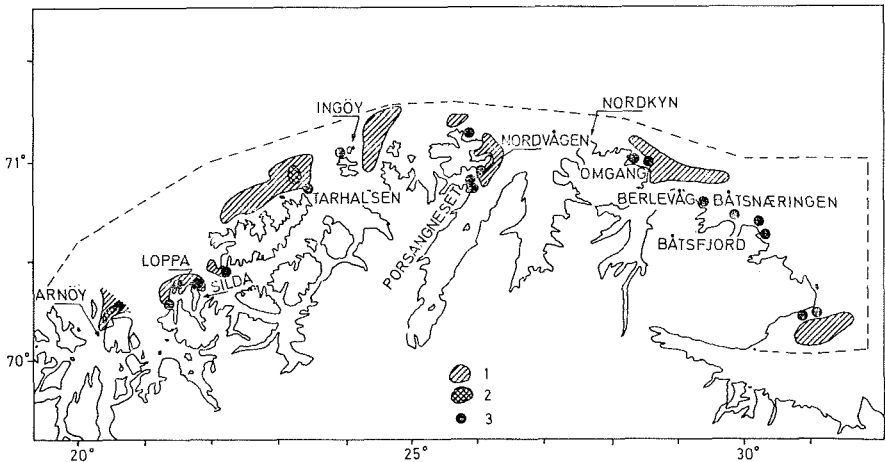


Fig. 12. Distribution of capelin 19—31 March 1971 and observed spawning places. 1) 1—10 integrator units, 2) > 10 integrator units, 3) spawning places.

Table 4. Substratum and egg density on the grab stations.

Substratum	Number of stations	No eggs	Scattered	Dense	Very dense
Gravel	28	11	2	10	5
Shell sand, shell fragments.....	44	29	10	4	1
Mineral sand	33	21	11	1	
Rocks, algae	117	106	10	1	
Silt, clay	5	5			

Table 5. Depth (in m) and egg density on the grab stations.

Depth	Number of stations	No eggs	Scattered	Dense	Very dense
10—19.....	36	19	5	9	3
20—29.....	45	34	9	2	
30—39.....	60	50	7	2	1
40—49.....	33	22	8	2	1
50—59.....	19	16	3		
60—69.....	9	8			1
70—79.....	9	7	1	1	
80—89.....	3	3			
90—99.....	4	4			
> 100.....	9	9			

to 75 m depth. The most shallow spawning beds were found at 12—15 m depth. Probably the bottom substratum is a more important factor for the location of spawning than the depth.

Both direct observations and study of the character of the substratum indicate a strong current at most of the spawning grounds.

The greatest concentrations of eggs were found at Loppa, Nordvågen and Båtsnæringen (Fig. 12). At Nordvågen egg densities of up to 8 mill. per m² were recorded in a local patch. However, most samples indicated egg densities between 1 and 3 mill. eggs per m². Similar great densities might also have been situated in other areas where only samples from the fringe or the surroundings of the spawning beds were taken.

Nordvågen was selected for a more detailed study. For this area a Decca map in scale 1:10 000 was made by reading the values of the decca meters. Simultaneously the position was determined by taking the bearing of selected land points (Fig. 13). The area was surveyed by grabbing, and all stations were plotted on the map. These stations were

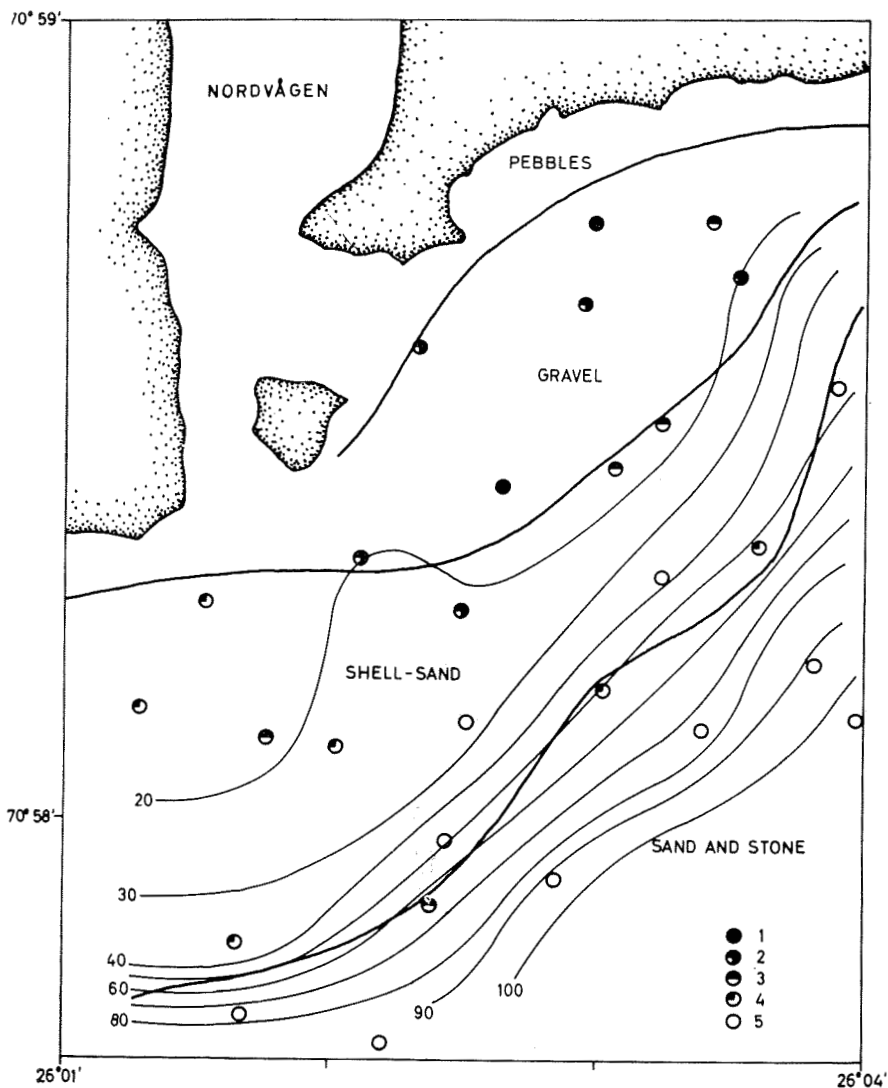


Fig. 13. Depth, bottom substratum and distribution of capelin eggs in Nordvågen 26 April 1971. 1) very dense, 2) dense, 3) scattered, 4) very scattered, 5) none.

later used for determining the area of the spawning bed. Divers were also used in this surveying.

The extension of the spawning bed in Nordvågen was about 0.2 km². This turned out to be very similar to the extension of the area with gravel bottom. Within this area a mean egg density of 2.5 mill. per m² was observed. A total of 7.5×10^{11} eggs had therefore been spawned

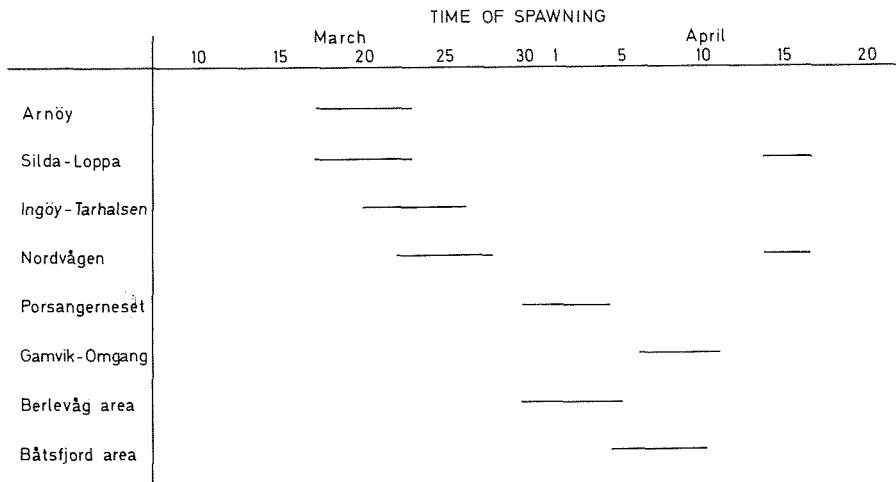


Fig.14. Time of main spawning in different areas, 1971.

Table 6. Maturing of capelin (%) in weekly samples from northern Norway during the spawning season 1971.

Date		West of Nordkyn				East of Nordkyn			
		Maturing	Spawning	Spent	Number in samples	Maturing	Spawning	Spent	Number in samples
17	— 23 January	100.0	—	—	97	—	—	—	—
24	— 30 January	100.0	—	—	248	100.0	—	—	119
31 Jan.	— 6 February	100.0	—	—	125	100.0	—	—	146
7	— 13 February	100.0	—	—	123	100.0	—	—	273
14	— 20 February	100.0	—	—	119	100.0	—	—	195
21	— 27 February	100.0	—	—	245	100.0	—	—	110
28 Febr.	— 6 March	99.0	1.0	—	103	100.0	—	—	131
7	— 13 March	—	—	—	—	100.0	—	—	99
14	— 20 March	32.9	32.9	34.2	365	—	—	—	—
21	— 27 March	—	27.8	72.2	36	57.5	42.0	0.5	200
28 March	— 3 April	2.8	45.8	51.4	216	—	—	—	—
4	— 10 April	—	—	—	—	42.9	30.0	27.1	140

in Nordvågen. If it is presumed that males and females were present in equal numbers, this implies that approximately 5000 tons of capelin had spawned.

From the grab samples, the developmental stages of eggs were designated, by comparison with artificially fertilized eggs kept in the laboratory. Thus, approximate dates of spawning were found for the different areas (Fig. 14). At Arnøy, Loppa, Silda, Ingøy and Tarhalsen spawning probably took place between the 15 and 25 March. Spawning at Nordvågen occurred between the 20 and 30 March. At Porsangneset and in the Berlevåg areas spawning most likely occurred about 1 April, in Omgang and Båtsfjord areas one week later. At Loppa and in Nordvågen a new spawning occurred in the middle of April, but in Nordvågen this spawning was of little significance compared to the first one. These spawning times are in accordance with the development of the gonad condition of the capelin (Table 6).

The exact temperature at the time of spawning is not known. In Nordvågen temperature at the bottom was measured on 30 March and 14 April, and was then 1.5° and 3.0° C respectively. An other spawning grounds which were visited two or three weeks after spawning, the temperature varied between 2° and 3°C.

Spawning in 1972 was studied by BJØRKE, GJØSÆTER and SÆTRE (1972). Both spawning area and spawning time differed from the conditions in 1971. Spawning depth also showed some difference, especially in the western part of the area. In 1972 the most extensive spawning took place off East Finnmark. Farther to the west, spawning was observed at Magerøy, Hjelmøy, Tarhalsen and Malangsgrunnen—Fugløybanken. At all these localities the spawning depth was greater and the temperature considerably higher than in 1971. At Malangsgrunnen spawning took place at about a 150 m where the temperature was about 6°C. Spawning in 1972 started about 1 March and lasted until the end of March.

In the eastern part of the spawning area, spawning was later than in the western part.

FERTILIZATION AND SURVIVAL OF EGGS

On the spawning beds the fertilization seemed to be almost 100 per cent, while fertilization rates down to about 50 per cent were sometimes observed among eggs brought up by grab or divers. Between 2.5 and 5.0 per cent were mechanically destroyed. It is not known whether this was a result of the sampling or a natural phenomenon. Apart from this, mortality seemed to be very low. Generally, greater mortality was observed where only a few eggs were found than on the proper spawning

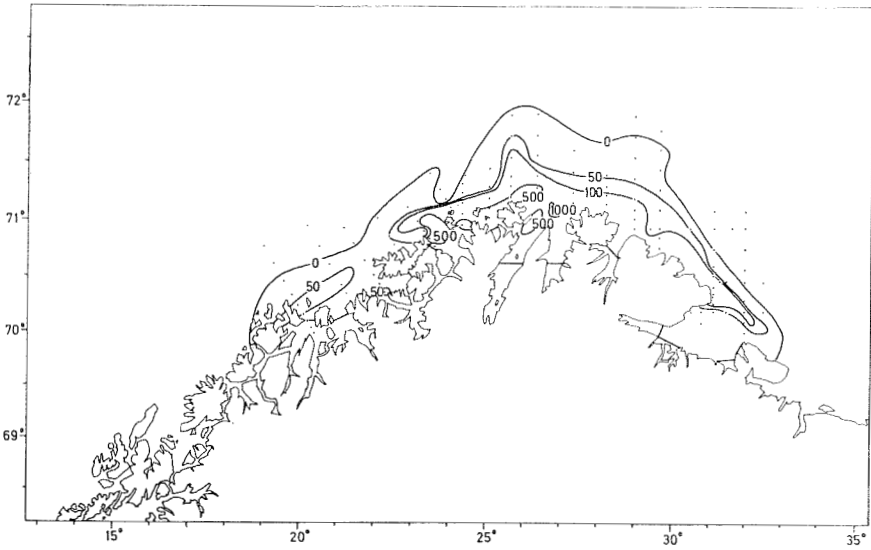


Fig. 15. Distribution of capelin larvae 1—15 May 1971. Isolines indicate the number of larvae below 1 square m surface. Stations are plotted as dots.

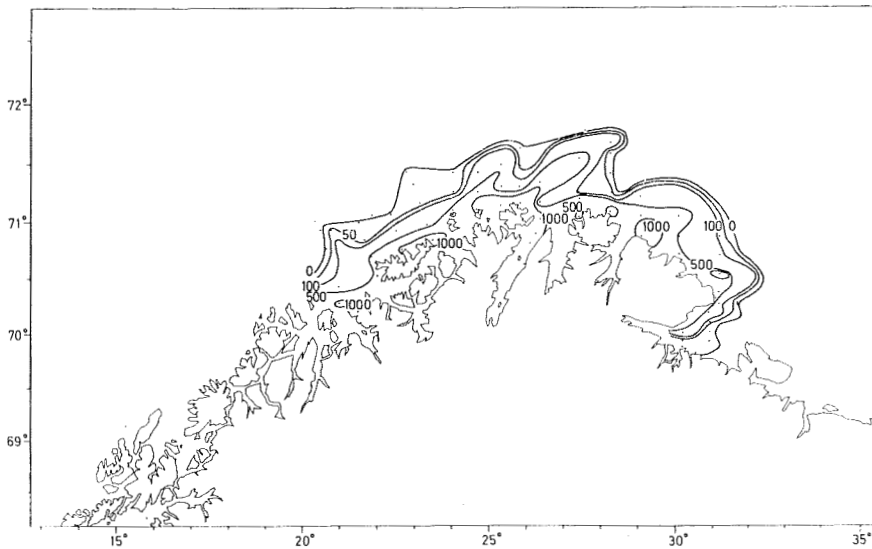


Fig. 16. Distribution of capelin larvae 19—25 May 1971. Isolines indicate the number of larvae below 1 square m surface. Stations are plotted as dots.

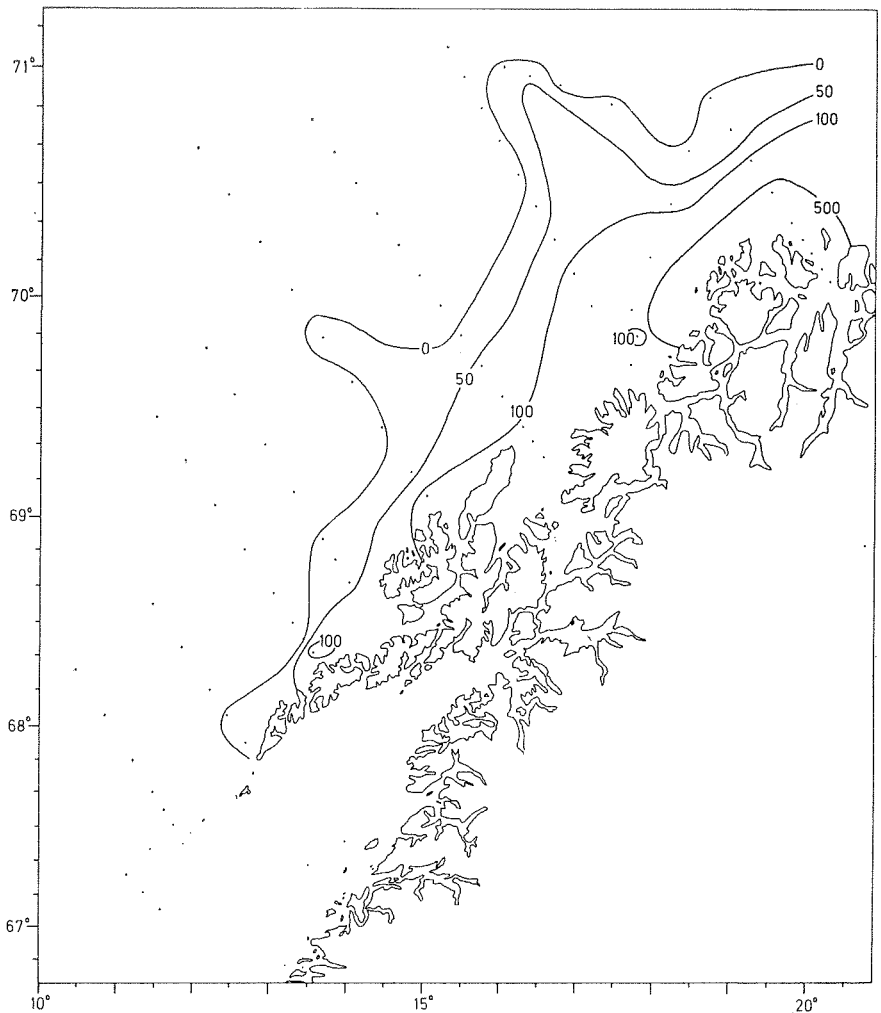


Fig. 17. Distribution of capelin larvae 20—28 May 1971. Isolines indicate the number of larvae below 1 square m surface. Stations are plotted as dots.

beds. An exception was observed at Loppa, where mortalities up to 19 per cent were found in samples with very dense concentrations of eggs. On some of the spawning grounds many eggs were overgrown with small filamentous algae, but this did not seem to cause any retardation of the development or any increase in the mortality rate.

Eggs, together with bottom sediment, were found in the stomachs of capelin and haddock. At the spawning beds investigated, few haddocks were present. Therefore the predation on eggs was not very

intensive and had no serious effect. In 1972 an extensively larger predation by haddock was observed, but only at spawning grounds deeper than 150 m (BJØRKE, GJØSÆTER og SÆTRE 1972). According to ZENKEVITCH (1963) capelin eggs form an important part of the haddock's diet.

Predation on eggs by ducks (*Somateria spectabilis*, *S. mollissima* and *Clangula hyemalis*) was observed at shallow spawning grounds (GJØSÆTER, SÆTRE og BJØRKE 1972), but the quantities consumed are probably of little significance.

Eggs from the upper bottom strata showed a faster development than those laying deeper in the substratum. No difference in mortality was observed at the egg stage, but preliminary results indicate a higher hatching success among eggs from the upper strata.

To evaluate the effects of using fishing gears on the spawning beds, trawl bobbins were towed through one of them (BJØRKE and BAKKE 1973). No increase in mechanical destruction could be observed, but eggs whirled up from the bottom showed mortalities between 6.0 and 10.2 per cent after being kept in glass jars in the laboratory, while eggs taken from the bottom of untouched spawning beds showed mortalities between 0 and 2.1 per cent when kept in a similar way. This experiment was carried out when the eggs had finished about 2/3 of the developmental time. Studies of eggs in the laboratory suggest that susceptibility to mortality is higher in earlier stages of development and possibly also in the latest. These results, therefore, might not be representative for eggs in other stages.

LARVAL DISTRIBUTION

Five larval surveys were carried out during 1 May to 22 June 1971. The distribution of larvae in each survey is shown in Fig. 15—19. In the first surveys the larvae were distributed close to the shore. During the surveys in June smaller quantities of larvae had drifted from land. Near the shore both newly hatched and older larvae were found, while offshore only older larvae were found. This indicates that spawning in 1971 only occurred in the near shore area.

During the first surveys highest larval concentrations were observed off Troms and West Finnmark, while the latest surveys showed highest concentrations at the coast of eastern Finnmark. This is due to later spawning and lower temperatures in the eastern area.

Number of larvae was determined for each survey by means of an area integration. The following results were obtained:

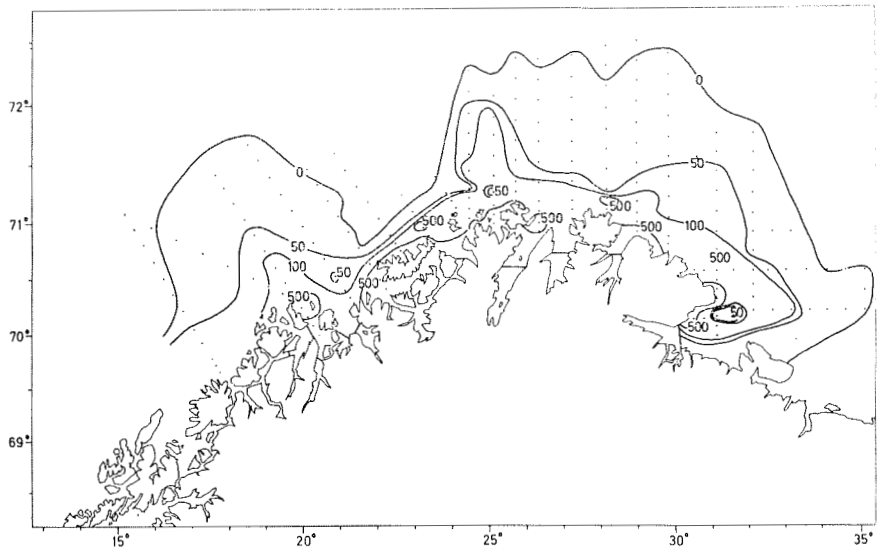


Fig. 18. Distribution of capelin larvae 2—17 June 1971. Isolines indicate the number of larvae below 1 square m surface. Stations are plotted as dots.

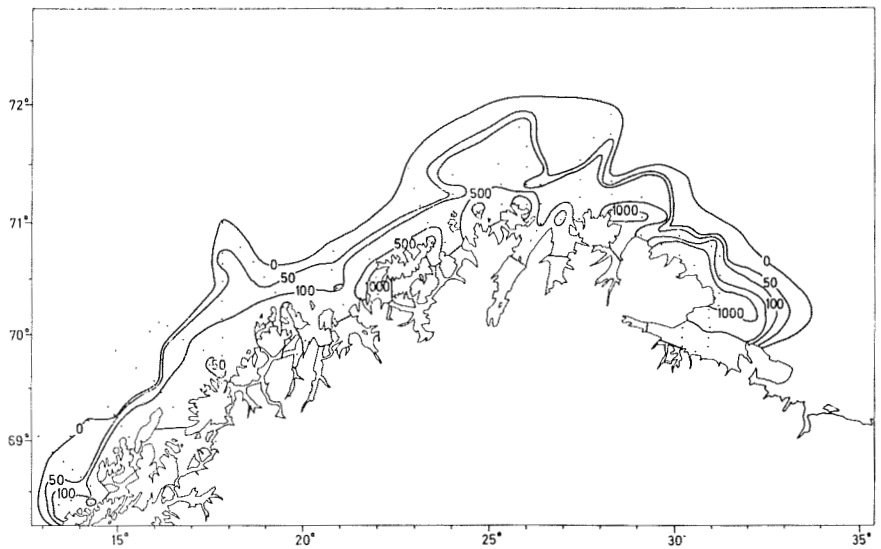


Fig. 19. Distribution of capelin larvae 7—22 June 1971. Isolines indicate the number of larvae below 1 square m surface. Stations are plotted as dots.

- 1—15 May: $2.8 \cdot 10^{12}$
 19—25 May: $1.4 \cdot 10^{13}$
 2—17 June: $1.5 \cdot 10^{13}$
 7—22 June: $1.6 \cdot 10^{13}$

Although the larval material for 1972 is not completed, preliminary results seem to indicate a more eastern distribution than in 1971.

0- AND I-GROUP ABUNDANCE

During the larval and postlarval stages a drift migration takes place into the central part of the Barents Sea. The younger capelin (0- and I-group fish) are distributed farther south than the two and three year olds. The nursery area of the capelin is extensive, but the main grounds are in the central and eastern part of the Barents Sea. The abundance indices of 0-group fish, obtained from acoustic surveys, give a fairly good estimate of year-class strength (DRAGESUND 1971).

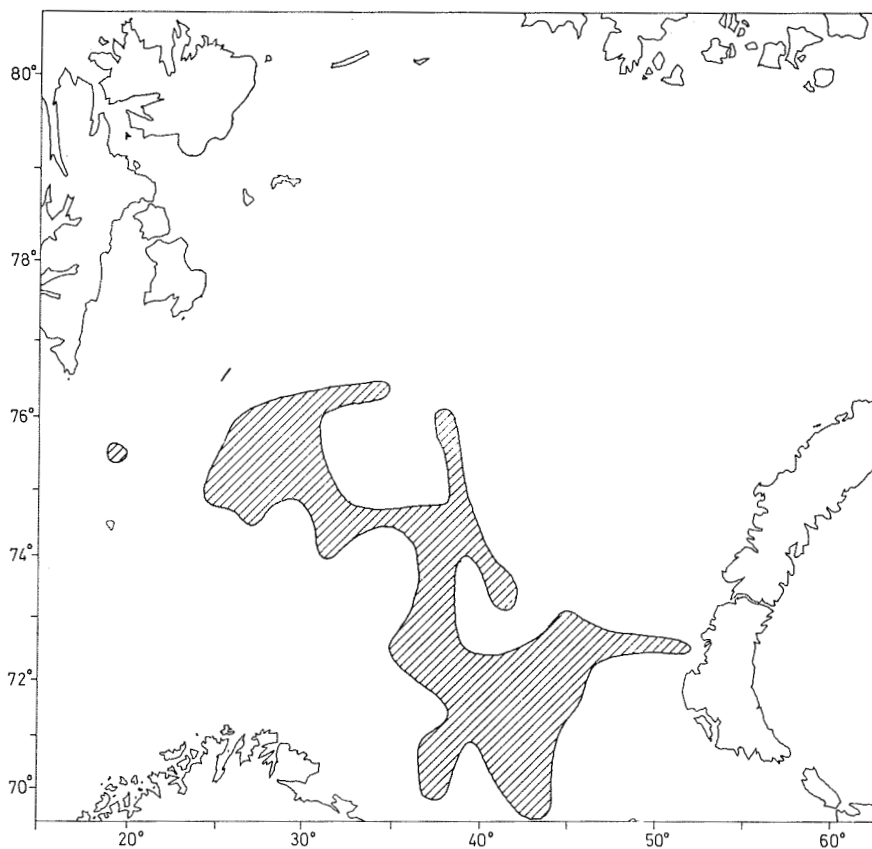


Fig. 20. Distribution of I-group capelin 23 August—9 September 1971.

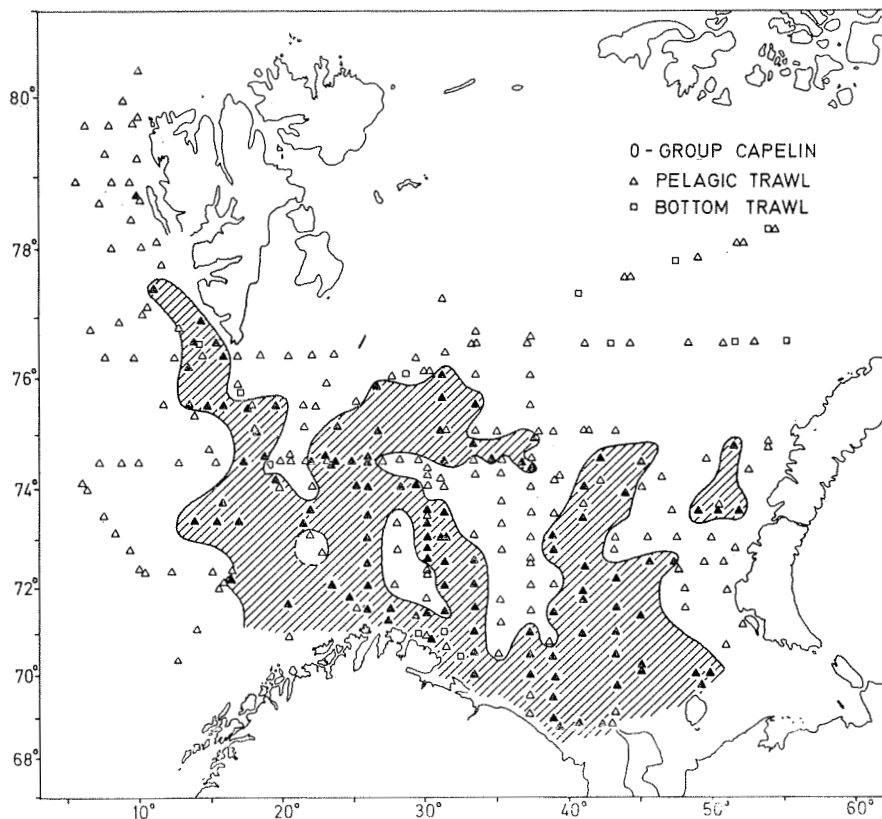


Fig. 21. Distribution of 0-group capelin 23 August—9 September 1971.

In 1970, 0-group capelin were limited to a small area, mainly along the Finnmark and Murman coast and in the eastern Barents Sea (ANON. 1970). The concentrations were rather low, indicating a weak 1970 year-class. However, later investigations showed that the I-group capelin were distributed over a fairly wide area (Fig. 20), and, although the 1970 year-class is relatively weak, it is suggested that the year-class is somewhat stronger than indicated from the 0-group survey. In 1971 the abundance of 0-group capelin was not so high as that observed in the years 1967 and 1969 (BENKO *et al.* 1970), but was considerably higher than in 1970 (Fig. 21), and the indication is that the 1971 year-class is abundant. The 1972 year-class also seem to be strong (Fig. 22), probably of the same order as that of 1971.

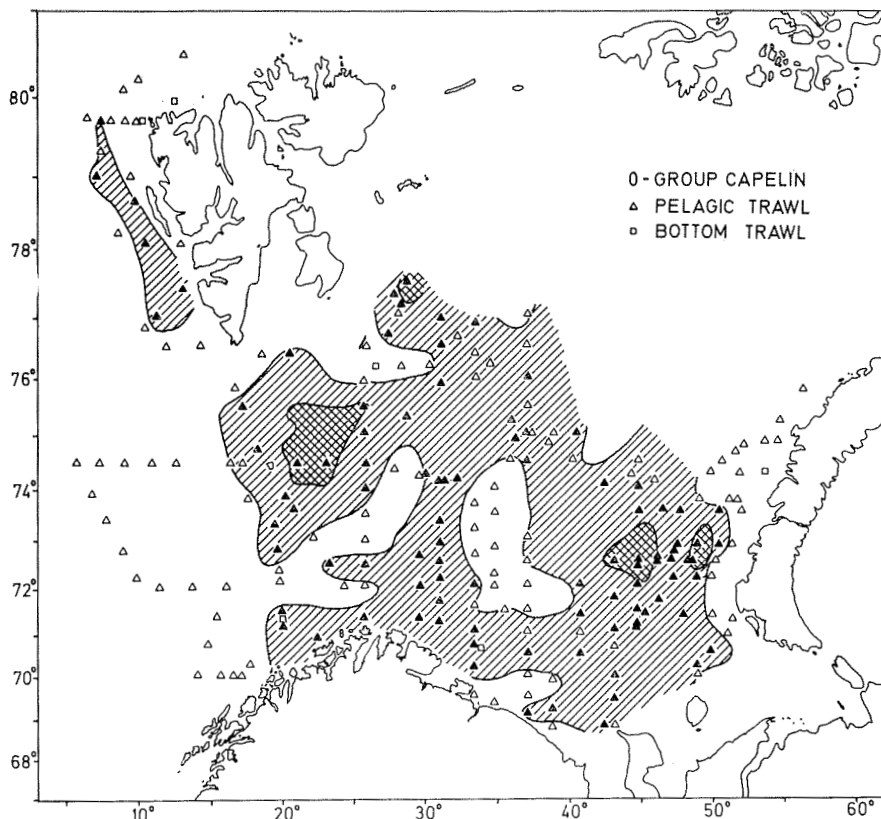


Fig. 22. Distribution of 0-group capelin 27 August—11 September 1972.

DISCUSSION

The availability of capelin was good during the winter seasons 1970—1972. Capelin were distributed over wide areas, the seasons lasted relatively long, and the weather conditions were good. A relatively small part of the stock reached the Murman coast for spawning (SELIVERSTOV, verbal information), and most of the capelin spawned in Norwegian territorial waters in 1971 and 1972.

Table 7. Summary of results of stock size estimates (mill. tons) in 1971 and 1972.

Year	Method		
	Tagging experiments	Egg and larval surveys	Acoustic surveys
1971.....	5.8	3.2	—
1972.....	4.8	—	2-3.6

The steady increase in the total catch of capelin since 1965 is due to a significantly increased fishing effort (BAKKEN and DRAGESUND 1971), but is also for a large part attributed to a raise in stock size. Some indication of the relative variation in the size of the spawning stock in 1969—1972 might be obtained from year-class strength estimates at the 0-group stage (ANON. 1969, BENKO *et al.* 1970).

These estimates indicated that the 1966, 1967 and 1968 year-classes exceeded the year-class of 1965. The ranking of the 1966, 1967 and 1968 year-classes were difficult to assess from the 0-group fish surveys. However, later information from catch statistics and echo surveys, suggests that the 1967 year-class was significantly stronger than those of 1966 and 1968. Since four year old fish predominated in the spawning stocks in 1969—1972, it is likely that the spawning stock was higher in 1970 than in 1969, and again the stock strength was greater in 1971 than in 1970 and 1972.

Although the stock size estimates for 1971 and 1972 must be interpreted with caution, they indicate that the spawning stock in 1971 was greater than in 1972 (Table 7).

With the fragmentary knowledge of stock size and of the relationship between stock size and reproduction of capelin, it is difficult to state that the exploitation rate is too high. A study of capelin reproduction during the period 1951 to 1961 indicated, however, that although the stock size probably was much lower than now, there were no clear correlation between parent stock size and subsequent recruitment (GJØSÆTER 1972). This, and the investigations carried out during the last two years, indicate that no immediate further steps are needed to secure a high spawning potential. On the other hand, it is possible that the intensive fishing during the prespawning and spawning period may have unfortunate influence on spawning behaviour.

The spawning stock was at a very high level in 1971 and fairly high in 1972. The resulting year-classes measured at the 0-group stage seemed to be abundant. The 1969 year-class is also estimated to be strong (ANON. 1969). The relatively low production in 1970 was most likely due to environmental factors and not to small spawning stock, and so far no sign of overfishing has been observed.

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DIVING OBSERVATIONS ON BARENTS SEA CAPELIN AT THE SPAWNING GROUNDS OFF NORTHERN NORWAY

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ABSTRACT

BAKKE, S. and BJØRKE, H. 1973, Diving observations on Barents Sea capelin at the spawning grounds off northern Norway. *FiskDir. Skr. Ser. HavUnders.*, 16: 140—147.

During the spring of 1971 divers made observations at the spawning grounds of the Barents Sea capelin.

Large masses of capelin eggs were found at two localities: Loppa, (35—70 m depth) and Nordvågen (12—18 m depth). The eggs were mixed down to a depth of 5 cm with fine gravel (0.5—1.5 cm diameter).

Two behaviour patterns of the capelin were observed: Loosely packed schools in the upper layers and dense circulating schools close to the bottom. The latter are believed to be males waiting for ripe females.

Egg mortality caused by trawlers was experimentally investigated by dragging trawl bobbins along the egg beds. Eggs stirred up by the bobbins showed higher mortality (up to 10.2% after ten days incubation) than undisturbed eggs and eggs from bobbin tracks (up to 2.5% mortality after ten days incubation). Less than 1% of the eggs on the investigated spawning grounds is believed to be damaged by trawlers.

Divers estimated a 5—10% decrease in the number of eggs on the spawning grounds over a four week period. This was due to a drift of eggs largely caused by wave action and water currents.

No predation of the capelin eggs was observed.

INTRODUCTION

The aim of this investigation was to obtain information about the spawning grounds of the Barents Sea capelin, the fishes' behaviour and the egg mortality on these grounds. The observations were made in spring 1971.

The spawning behaviour and the morphology of the spawning grounds have been described for the Newfoundland capelin. TEMPLEMAN (1968) reports both beach spawning and spawning down to at least 55 m. A substrate of fine gravel from 0.25 to 1.50 cm in diameter seemed to be especially favourable for capelin spawning (TEMPLEMAN 1948). On the offshore spawning grounds the bottom substrate was somewhat finer, from 0.5 to 2.2 mm in diameter (PIRT 1958).

Spawning behaviour and spawning grounds of the capelin in the northeastern Atlantic have not been well investigated. COLLETT (1903) reports that the capelin search along the shores of bays and fjords for suitable spawning grounds. He mentions that spawning mostly takes place on sandy bottoms, sometimes at depths of only a few metres, but

more often at depths of 70 to 90 m. PROKHOROV (1965) refers to Russian authors who unanimously state that spawning takes place on sandy grounds with an admixture of fine shell gravel. He concludes that a depth range of 50 to 100 m at the spawning places is most usual while MØLLER og OLSEN (1962) suggest that spawning takes place at depths of 10 to 100 m.

MATERIAL AND METHODS

Capelin were found all along the coast of Finmark by using echo sounders. Schools were also observed by divers at three different localities: Hasvik, Trollstund and Nordvågen. (Fig.1) Photographs and films were taken of the fish as close as 0.4 m.

The diving was carried out from the R.V. «Johan Hjort» during the period 15 March — 29 April 1971. The sampling gear included a stainless steel box designed by the authors to take 0.1 m² samples from sand and gravel bottoms and two frames of 1.0m² and 0.1m² for sampling algae and stones from specific areas. At least two bottom samples were taken at each diving locality. Temperatures were measured on the bottom and in the sediment, and the speed and direction of the current was determined. The diving equipment used is described by BAKKE and BJØRKE (1971).

Grab samples were also taken at various localities along the coast to check for the presence of eggs. A total of 46 dives were made.

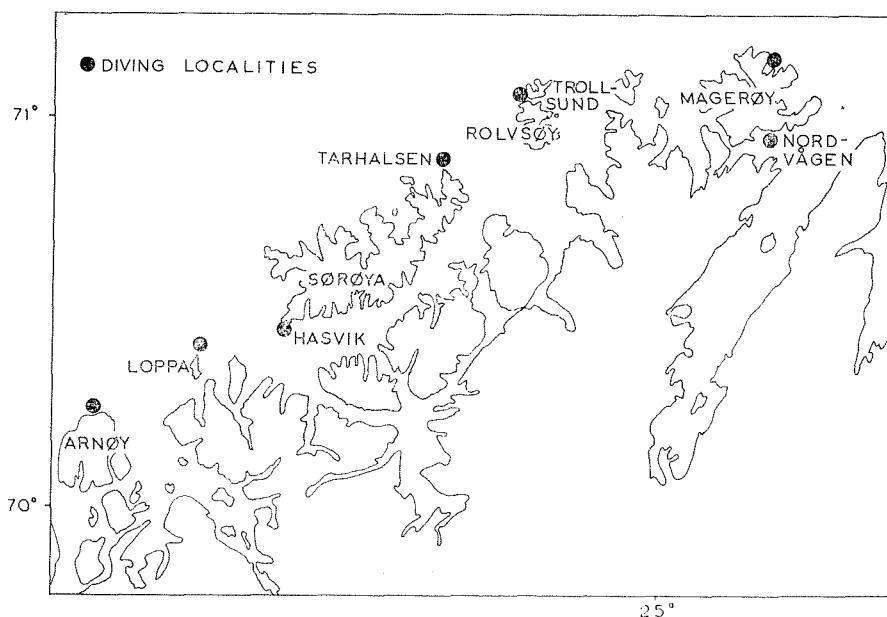


Fig. 1. Diving localities in the investigated area.

RESULTS

OBSERVATION ON CAPELIN SCHOOLS

Two different behaviour patterns of the schools could be distinguished. Firstly, and most commonly, the schools could be at least 100 m in length and 20 m in width and depth. The fish swam slowly, well above the bottom at depths between 5 and 20 m and were about 40 to 80 cm apart. Initially they reacted simultaneously to movement by the divers, but this reaction eventually ceased as they became accustomed to the divers' presence. The schools changed course several times while observed; they often made a wide circular movement, but whether this was due to the presence of the diver or not, is unknown.

Secondly, the schools swam close to the bottom (20 m) in a very dense formation with the fish less than 10 cm apart. The schools were sharply delineated in all directions and were less than 2 m in depth. The school was most dense nearest the bottom with the fish head to tail and their sides nearly touching. The movement of the school was still circular, but within a very small radius. These schools did not react to the presence of the divers and pictures could be taken from as near as 0.4 m with the school in effect circulating around the divers. The pictures indicate that such schools consisted mainly of males (Fig. 2).

Individuals were frequently seen to lag behind the schools. Such

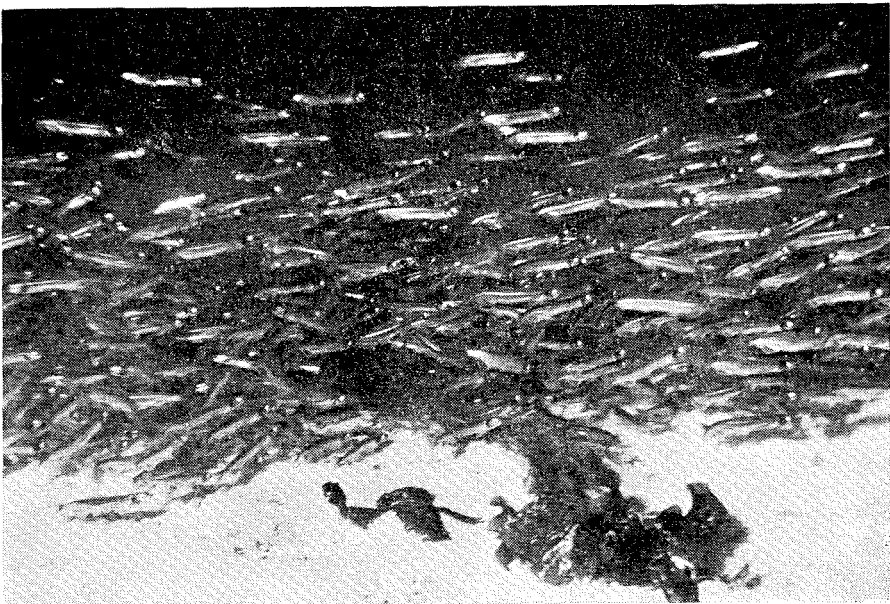


Fig. 2. Male capelin circulating around the photographer at Nordvågen.

fish were found either close to the bottom or near the surface; sometimes they even swam upside down. These individuals did not show any external signs of abnormality other than the often bloodshot and swollen base of the male anal fin.

At Nordvågen (Fig. 1) where extensive trawling took place, large masses of dead capelin were seen on the bottom. Whether this high mortality was the result of spawning or fishing by trawlers, is not known. Dead fish were seen at all diving localities, but it must be concluded that the dead capelin seen at Hasvik died a natural death as no fishing had taken place there. All samples of dead fish consisted of spent males.

OBSERVATIONS AT THE SPAWNING GROUNDS

At Loppa and Nordvågen (Fig. 1), where the greatest egg masses were found, the substrate changed progressively with increasing depth, starting with rocks and boulders just below the surface and ending with fine sand. This sequence did not occur at the other six localities where only small numbers of eggs were found attached to algae and stones.

The main spawning ground at Loppa was much more exposed to wave action than the ground at Nordvågen. The shallowest edge of the spawning bed at Loppa was at 35 m where coarse gravel was succeeded by finer gravel with a grain size of 0.5—1.5 cm. Grab samples revealed that the gravel and egg mixture extended to at least 70 m water depth. The concentration of eggs on this ground was the highest observed; and numerous clumps consisting only of eggs were seen.

The other more closely observed spawning locality was just outside Nordvågen (Fig. 3). This relatively sheltered area had fine gravel from 12 to 18 m in depth with coarse gravel at lesser and sand at greater depths. Divers surveyed the main spawning ground and found it to be about 180 000 m². No eggs were found closer than 250 m to the shore. The ground consisted of fine black gravel and was bordered either by coarser gravel with stones or by sand (Fig. 3). Grab samples which covered a greater area, later confirmed these observations and showed that the main spawning ground lay within the area of the fine gravel (DRAGESUND, GJØSÆTER and MONSTAD 1971). Eggs were found in the substrate to a depth of about 4 cm in the centre of the main spawning ground, but penetrated less deeply towards the borders. Samples from the centre indicated a density of about 3×10^6 eggs per square m. On one occasion, a diver's sample taken from fine sand at greater depths showed densities of up to 4×10^5 about 100 m from the main spawning ground.

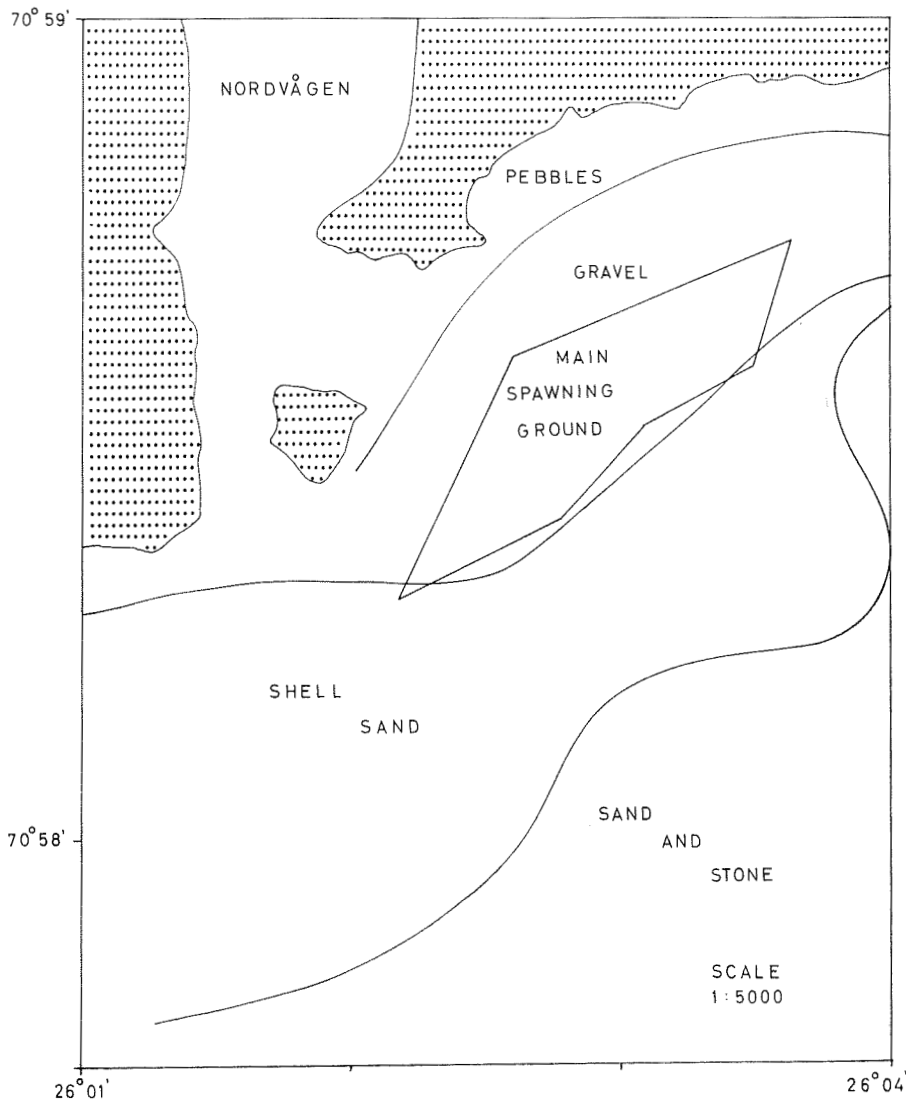


Fig. 3. The spawning ground at Nordvågen. The lines separate different bottom substrata.

The ground at Nordvågen was examined three times, from 29 to 31 March, from 14 to 16 April and on 25 April. During this time the sea temperature near the bottom rose from 1.5°C to 3.2°C. During dives on 14 April the temperature was measured at intervals of 40 m across the spawning area just above the egg layer and at about 5 cm down into the substrate. The water temperature ranged from 3.2°C offshore to

2.8°C nearest the shore. The bottom substrate was consistently slightly cooler than the water above. The current direction at 5 m above the bottom, measured over a 29 hour period, was mainly northnortheast, and the current speed varied from 13 to 46 cm per sec.

From 14 to 16 April and on 25 April, brown patches caused by a filamentous algae that settled on both the stones and the eggs, were observed on the beds. They seemed to have no effect on the eggs since samples of eggs with algae kept in jars did not show a higher mortality than eggs without attached algae (DRAGESUND, GJØSÆTER and MONSTAD 1971). Only a few laminarians and starfishes were found at the spawning ground, and capelin were the only fish observed.

Between 29 March and 25 April a marked decrease was noted in the number of eggs on the surface of the substrate. Below the surface, however, the concentration of eggs remained high during the entire investigation. Drifting eggs were observed at both the Nordvågen and the Loppa grounds except during calm weather. The total decrease in eggs at Nordvågen was probably between 1×10^5 and 4×10^5 eggs per square m.

DAMAGE TO CAPELIN EGGS BY TRAWLERS

Norwegian fishermen have suggested that the lower doors of pelagic trawls may damage capelin eggs if dragged along the spawning beds. Tracks made by trawl doors were observed at the spawning grounds in Nordvågen. These drag marks were about 0.5 m wide and usually more than 40 m long with ridges of an egg and gravel mixture about 10 cm high on one side of the tracks. Altogether, such tracks covered less than 1% of the spawning area.

Several samples were taken from the middle of the tracks and from the top and bottom of the ridges. The proportion of damaged eggs (2.5—5.0%) in these samples was similar to that in samples taken outside the tracks.

An experiment was carried out in Nordvågen to study the effects of mechanical disturbance of the eggs. Three trawl bobbins were hauled along the spawning beds while a diver observed the effect. The bobbins stirred up the eggs and bottom substrate and made tracks on the bottom similar to those made by trawl doors. Egg samples were taken from the tracks and from an undisturbed area nearby, while a plankton net, placed behind and above the bobbins, sampled the eggs which were stirred up. There was no difference in the proportion of damaged eggs, or their subsequent mortality, between the samples taken from the tracks and those from undisturbed areas. Whereas the mortality of

both these types of samples, kept for 12 days in glass jars, was between 0 and 2.1% (DRAGESUND, GJØSÆTER and MONSTAD 1971), the mortality of eggs caught in the plankton net ranged between 6.0 and 10.2%.

DISCUSSION AND CONCLUSIONS

The behaviour patterns observed on the spawning grounds in northern Norway resemble observations made by SLEGGS (1933) in Canada where the schools of mature capelin formed either a dense globular mass or an elongated streak of swimming fish. TEMPLEMAN's statement (1948) also supported this when he described capelin schools prior to spawning and observed that these schools, as in the case of the Barents Sea capelin, consisted entirely of males. In addition, he stated that male capelin are mature when they approach the shore for spawning, and that they are in constant attendance at the beaches. Schools of immature females stay in shallow water, away from the immediate neighbourhood of the beach, and as they reach maturity, swim in groups to the beach to spawn.

The indication in the present results, that greater numbers of eggs are found where there is fine gravel, agrees with observations from the main spawning grounds in Canada (TEMPLEMAN 1948). Only once, at Nordvågen, were large number of eggs found in fine sand close to the main spawning ground. Although sand seems to be a less suitable substrate, it is possible that mass spawning can occur there when the best ground is occupied or when the spawning pressure is great (TEMPLEMAN 1948).

TEMPLEMAN (1948) and SLEGGS (1933) found that spawning movements could bury the eggs to some extent, but most of the burying, to a depth of one foot, was the result of wave action. This did not seem to be the case on the spawning grounds observed in this investigation, since the depth of 35 to 70 m at Loppa and the sheltered conditions in Nordvågen probably prevented strong wave action. It was noticed, however, that the egg and gravel mixture could be stirred up by slight water movements made by the diver's hand just above it due to the extra buoyancy of the gravel with eggs stuck to it. Thus, eggs can be buried more easily when repeated spawning occurs on the same ground. When the egg and gravel mixture reached a maximum thickness of 5 cm, as at Loppa, clumps of eggs were formed after additional spawning.

DRAGESUND, GJØSÆTER and MONSTAD (1971) reported that both the natural egg mortality of the spawning grounds and the mortality of the disturbed eggs was low. However, BURD and WALLACE (1968) carried out laboratory experiments on mechanically disturbed herring eggs and

found that trawling at the spawning grounds might induce a reduction in larval viability. During the investigation, intensive trawling at or near the Nordvågen spawning ground yielded 7300 tons of capelin. In spite of this, less than 1% of the spawning ground was disturbed by the trawl doors. Even if all the disturbed eggs did die, this would affect less than 1% of the eggs at Nordvågen. Pelagic trawling at the spawning grounds therefore seems to have little influence on overall egg mortality.

At Nordvågen, a decrease of 5 to 10% in egg numbers due to drift was observed over a four week period. Since a similar drift of eggs was also observed at Loppa, this may well be the greatest source of loss there and in other areas.

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AN INTRODUCTION TO A STUDY OF THE MARINE ECOSYSTEM AND THE LOCAL HERRING STOCK IN LINDÅSPOLLENE

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ABSTRACT

DAHL, O., ØSTVEDT, O. J. and LIE, U. 1973. An introduction to a study of the marine ecosystem and the local herring stock in Lindåspollene. *FiskDir. Skr. Ser. HavUnders.*, 16: 148—158.

A study of the marine ecosystem in a landlocked fjord (Lindåspollene) with a self-contained herring stock has been initiated. On the basis of preliminary investigation a brief description of topography, hydrography and general biological features of the Lindåspollene is given. The plans for the projected long term research are described and discussed.

INTRODUCTION

At the 1961 symposium on «Herring population studies», arranged by the International council for the exploration of the sea, (ICES), the following recommendation was adopted (ANON. 1969):

«In view of the size and great complexity of the biological, ecological and other processes governing the population dynamics of the herring stocks, and of the extent and complexity of scientific problems involved in understanding them, the Symposium recognizes the need for setting up intensive and comprehensive studies on a small, self-contained, easily accessible herring population. It further recognizes that such populations are known to exist in at least one member country. It therefore recommends that the Herring Committee of ICES should explore the possibilities of such investigations being initiated».

As a result of this recommendation a special working group was set up to study various localities, particularly within the Norwegian fjord systems which might meet the requirements for these studies.

The working group studied three localities near Bergen: Heiamarkpollen 36 km south of Bergen, Fjellspollen 18 km southwest of Bergen and Lindåspollene 36 km north of Bergen (ANON. 1969). The only really

self-contained stock was found in Lindåspollene, but the working group agreed that the herring in Fjellspollen was of greater interest as it contained both spring and autumn spawning populations.

For various reasons the ICES did not find it possible to embark on the proposed research programme, but recommended that national laboratories started such investigations either individually or on a bilateral basis.

The Institute of Marine Research, Directorate of Fisheries, decided to follow up the Council's recommendations on a national basis. Lindåspollene were selected for the study because the herring stock there is largely self-contained and only slightly influenced by herring stocks in the surrounding fjord sytsem (ANON. 1969). As important parameters of the herring population are intimately related to chemical, physical and biological conditions in the environment, it was felt that a comprehensive study of the entire ecosystem would be desirable. In order to undertake such a study it was necessary to engage other marine laboratories, and in 1970 a cooperative research programme for the study of herring and its environment in Lindåspollene was initiated with the Biological station, Espegrend, University of Bergen.

In 1971 a large industrial complex was planned at Mongstad, which is located about 15 km north of Lindåspollene. In connection with this development a housing project for about 200 persons is under construction near Lindås (Fig. 1), and for a period of four years sewage from these houses will be discharged into Lindåspollene. As further urbanization of the area must be expected, a study of the effect of sewage pollution on the dynamics of the ecosystem will be one of the important aspects of the investigation.

The purpose of the present paper is to give a preliminary description of the environmental and biological features of the Lindåspollene ecosystem, and to present the objectives and long term plans for the investigations.

GENERAL DESCRIPTION OF LINDÅSPOLLENE

TOPOGRAPHY

Lindåspollene consist of three major basins separated by shallow sills (Fig. 1). The outermost basin, Straumsosen, with adjacent inlets has a surface area of $2.205 \times 10^6 \text{ m}^2$, and it has access to the Lurefjord through three narrow channels. The maximum depth in Straumsosen is about 60 m, and the sill depth between Straumsosen and the middle basin, Spjeldnesosen, is 5–10 m. Spjeldnesosen is the deepest and largest of the basins with a surface area of $3.782 \times 10^6 \text{ m}^2$ and a maximum

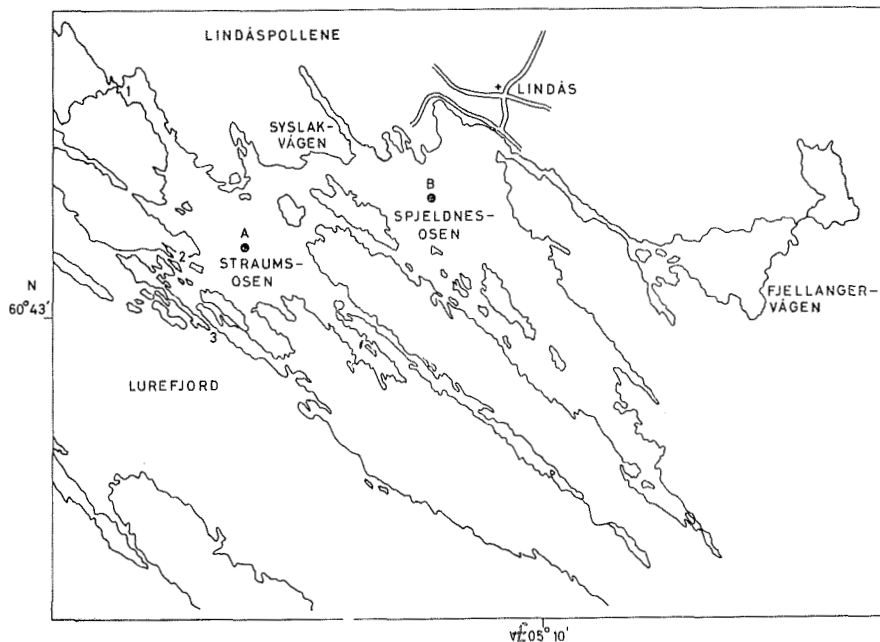


Fig. 1. Lindåspollene. A and B) Hydrographical stations, 1, 2 and 3) outlets to Lurefjord.

depth of about 90 m. A narrow channel about 2 km long leads into Fjellangervågen, the smallest of the three basins, with a surface area of $0.885 \times 10^6 \text{ m}^2$ and a maximum depth of about 80 m.

The shores around Lindåspollene are generally rocky and steep, but at the heads of the inlets there are beaches with bottom types ranging from gravel to soft mud. The sediments of the bottom deeper than about 25 m in the major parts of Fjellangervågen and Spjeldnesosen consist of a very soft, black ooze whereas in Straumsosen they consist of a mixture of mud, sand, gravel and shell-fragments.

The landscape surrounding Straumsosen is rocky and barren which is characteristic of the outer West-Norwegian coastline. Fjellangervågen and the southern half of Spjeldnesosen are surrounded by farmland and pine forest. In general the area is sparsely populated, and there is very little industry. The district of Lindås (Fig. 1) has a population of about 300, and about the same number of people inhabit the farms in the surrounding area.

HYDROGRAPHY

The tidal range measured on 8—9 December 1970 was 35 cm, but according to local residents the average range is about 50 cm. With a total surface area of $6.872 \times 10^6 \text{ m}^2$ and a total volume of $153.313 \times$

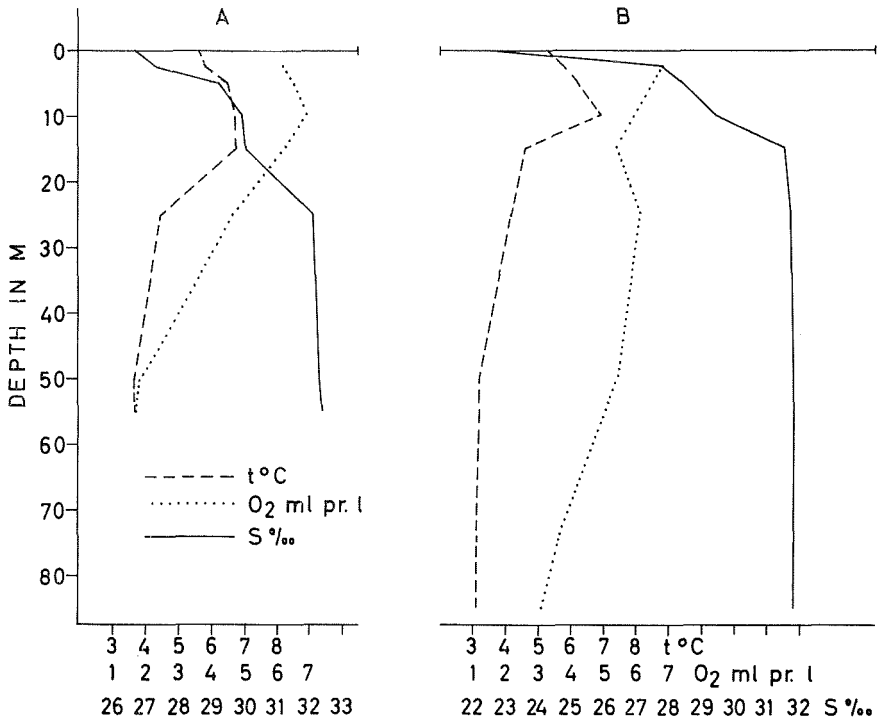


Fig. 2. Vertical distribution of temperature, salinity and oxygen at station A in Straumsosen and station B in Spjeldnesosen, 8 December 1970.

10^6 m³ the exchange of water during a tidal cycle would be about 3.436×10^6 m³ or about 2% of the total volume.

Fjellangervågen, the southern half of Spjeldnesosen and the inlets adjacent to Straumsosen are as a rule covered by ice about 2—3 months each winter.

A small lock used to be in operation in one of the entrances to Lindåspollene (2 in Fig. 1), but because of a decline in shipping in the area the lock gates have been permanently open since 1964. According to local residents this has had a marked effect on the water masses in Lindåspollene as evidenced by a distinct reduction in ice cover. An additional effect may be increased immigration and emigration of fish.

Preliminary investigations carried out during 1964 showed that Fjellangervågen differed from the rest of Lindåspollene in having hydrogen sulphide in the water at depths in excess of about 25 m. Partly for this reason and partly because of the long ice cover in the area, Fjellangervågen will not be studied during the first part of the investigations in Lindåspollene.

Fig. 2 shows the vertical distribution of three hydrographic para-

meters in the centre of Straumsosen (A) and Spjeldnesosen (B) on 8 December 1970. The watermasses below 25 m in Straumsosen and below 15 m in Spjeldnesosen were rather homogeneous in salinity and temperature, whereas the oxygen values showed a sharp decline with depth in Straumsosen. The surface salinity was considerably lower in Spjeldnesosen than in Straumsosen, and in the deeper layers the salinity at the former station was about 0.5‰ lower than at corresponding depths in Straumsosen. The temperatures of the watermasses deeper than about 25 m ranged from 3.1 to 4.5°C, which is 2—3°C lower than the bottom temperatures of West-Norwegian fjords (AASEN 1952, SÆLEN 1962).

GENERAL BIOLOGICAL FEATURES IN LINDÅSPOLLENE

The benthic macrovegetation in the area is sparse and largely limited to Straumsosen and the northern part of Spjeldnesosen. Large parts of the shore are too steep for macrovegetation to be successful, but where it is a convenient slope there is some growth of *Ascophyllum nodosum*, *Fucus vesiculosus* and *F. serratus*. At depths of 5—8 m dense concentrations of calcareous algae, (*Lithothamnium fornicatum*), have been observed, and at depths of 1—3 m some *Laminaria saccharina* also occurs (SVENDSEN, verbal information). On bottoms of sandy mud at the head of the inlets are small concentrations of eel-grass (*Zostera marina*).

The zooplankton studied during December 1970 revealed a very low species diversity, but an extreme dominance of *Pseudocalanus elongatus* in the uppermost 50 m. In the deeper layers of Spjeldnesosen the zooplankton was dominated by copepodite stage V of *Calanus finmarchicus*. Other abundant forms were *Oithona* spp., *Oncaea* spp., and small chaetognaths. The zooplankton biomass measured as displacement volume was about 0.1 ml/m³ in the 0—25 m layer, about 0.2 ml/m³ in the 25—50 m layer, and in the deepest parts of Spjeldnesosen (50—85 m) it was about 1.0 ml/m³.

Qualitative samples of the benthos collected by an epibenthic dredge with a net of 0.5 mm mesh size revealed significant differences between the two basins. In Spjeldnesosen the net was full of a black, evil smelling ooze, and no animals were found after sieving with 1.0 mm mesh size. In Straumsosen the dredge contained a mixture of mud and sand with only a faint smell of hydrogen sulphide. The fauna was dominated by the cumacean *Diastylis rathkei*, the polychaetes *Chone dumeri*, species of the family Aphroditidae and the brittle-stars *Ophiura albida*, *O. affinis*, and *O. sarsi*. A few specimens of the cumacean *Leucon nasicus* and the mysid *Mysis mixta* also occurred in the samples. The latter species has not previously been recorded south of Trondheimsfjorden.

Observations made by SCUBA-divers supported the impression of a low species diversity in the area (SAMUELSEN and HØISÆTER, verbal information). The muddy bottoms deeper than about 30 m in Spjeldnesosen were dominated by the polychaete *Chone duneri*, and the rocky bottoms at depths between 20 and 30 m by sedentary polychaetes, particularly *Placotegus tridentatus*. In the latter zone large individuals of the Iceland scallop, *Chlamys islandica* were observed.

In Straumsosen the fauna appeared more diverse, but largely the same species dominated as in similar habitats in Spjeldnesosen. *Chlamys islandica*, however, did not occur in Straumsosen. The tunicate *Ciona intestinalis* was very abundant at depths from 3 to 15 m and completely dominated the benthos on hard bottoms. This species was also observed along the rocky shores of Spjeldnesosen.

In Straumsosen an individual of the mysid *Heteromysis formosa* was found. Only one specimen of this species has previously been recorded in Norwegian waters (BRATTEGARD, verbal information).

Oysters (*Ostrea edulis*) were previously grown commercially in inlets adjacent to Straumsosen, but the oyster industry tapered off during the years following World War II and is presently nonexistent (SOLHEIM, verbal information).

Herring has been caught commercially in Lindåspollene for centuries and sold locally or on the Bergen fish market. Gill nets were the traditional gear, but beach seines and in recent years purse seines have also been used. Estimates of the fishing effort and annual catch are only available for recent years. Gill nets are used by local inhabitants particularly during the spawning season, and during August—September a few small purse seiners using artificial light have operated in the area. The estimated gill net catch is less than five tons per year, and the purse seine fishery yielded about 15 tons. Assuming 20 tons as the maximum sustainable yield and five years as the turn-over time (Fig. 3), the minimum standing stock would be about 100 tons. This stock size would satisfy the requirements defined by the ICES working group (ANON. 1969).

Investigations of herring samples taken during 1963—64 showed that the population was a spring spawning one, differing from the oceanic stocks in racial characters such as vertebral counts and growth rate. The mean length of the herring at the end of the fourth year of life was 24.5 cm. A similar slow growth of herring has been found in other land-locked fjords such as Lusterfjorden (AASEN 1952).

Bimodality in the length distribution (Fig. 3) indicated a small degree of mixing with other stocks (ANON. 1964). The two components in the samples were easily distinguished by growth rate and vertebral counts. The component with relatively slow growth and a low vertebral

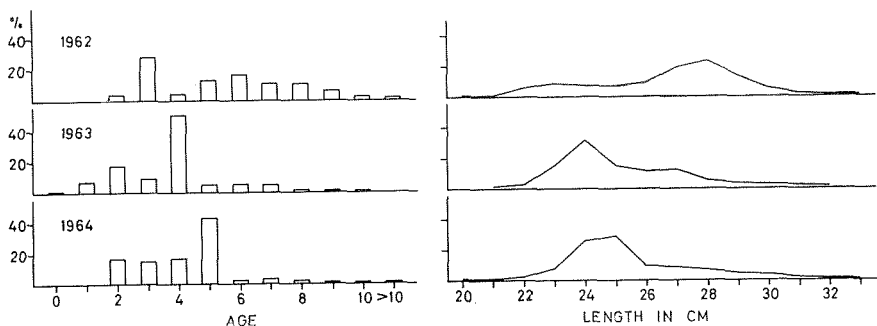


Fig. 3. Age and length distribution of herring from gill net catches in Lindåspollene during 1962—64.

count was overwhelmingly dominant during 1962—64. This group consisted of herring up to 14 years old, but the 1959 year-class was the most abundant. Tagging experiments carried out in November 1962 have shown that some herring migrate out of Lindåspollene, but it is not clear to which component of the population the recaptured fish belonged.

According to information received from the local people, the herring spawn particularly in a small area of Syslakvågen at depths from 0—5 m. In some years scattered spawning has also occurred in other areas near Syslakvågen.

The period of spawning is in the second half of March. The maturity stage distribution in samples collected during 1962—64 confirm that March is the main spawning period, but occasional individuals in spawning condition were recorded until early May.

In autumn the purse seiners also catch sprat (*Clupea sprattus*) together with herring in Straumsosen. There are no reports of spawning sprat from Lindåspollene, and they are most likely immigrants from the outside fjord system.

Other fish species such as mackerel (*Scomber scombrus*), cod (*Gadus morhua*) and pollock (*Pollachius pollachius*) are caught by local fishermen, but none of these species is sufficiently abundant to be of any commercial value.

Species of Cottidae, Labridae and Gobiidae occur along the shores everywhere in Lindåspollene. The Gobiidae particularly are sufficiently abundant to play a significant role in the energy budget of the ecosystem.

PROJECTED LONG TERM RESEARCH

THE ECOSYSTEM

The ultimate aim of the ecosystem studies in Lindåspollene is to build a dynamic mathematical model of the energy flow through and

the cycling of matter in the ecosystem. By model simulation and optimization (WATT 1968) it is hoped to gain sufficient insight into the intricacies of the biological situation to be able to manipulate the system for the benefit of man. Optimal management of the system would involve attempts to increase the yield of the herring fishery, to cultivate marine molluscs and crustaceans and to guarantee continued recreational use of the area.

As no information is available at present about either the biotic or the abiotic properties of the ecosystem, it is felt that it is premature to think in terms of a model at an advanced level of sophistication. Rather, the immediate aim is to gather pertinent information on which to build a crude box model of energy transfer in accordance with the concept of trophic levels (LINDEMAN 1942). The box model will be the basis for further modelling of the entire ecosystem or sub-sets thereof.

In order to understand the observed temporal and spatial variability in biological properties one must be able to monitor the important hydrographic parameters, i.e. the vertical and horizontal movement of the water masses, and the heat and salt budgets. Eventually, attempts will be made to build a mathematical model for the water circulation in Lindåspollene.

The projected immediate (a) and long term (b) research of the Lindåspollene ecosystem is summarized below.

Hydrography

a) Annual cycles in major parameters such as temperature, salinity, density and oxygen in the water column in Straumsosen and Spjeldnesosen.

b) Horizontal and vertical movements of the water masses, the salt budget, the heat budget, mathematical modelling of circulation.

Botany

a) Primary production and standing crop of phytoplankton and benthic diatoms, standing crop of macrovegetation.

b) Modelling of primary production in relation to environmental parameters such as light, nutrients and physical properties of the water masses.

Zooplankton

a) Quantitative composition, diversity, seasonal fluctuations, trophic groupings, standing crop.

b) Energy flow through populations of dominant species, modelling the «interrelationships» between phytoplankton and zooplankton.

Zoobenthos

- a) Distribution and species composition of benthic communities, standing crop, trophic groupings.
- b) Energy flow through populations of dominant species in the infauna and epifauna, quantitative studies of meiofauna, total oxygen consumption by the sea bed.

Fishes (other than herring)

- a) Energy flow through populations of gobiid fishes, particularly *Gobius flavescens*.

Microbiology

- a) Rate of decomposition of organic matter and regeneration of nutrients in the water masses and in the sediments.

Systems analysis

- a) Introductory box models of energy transfer, efficiencies between trophic levels.
- b) Dynamic modelling, simulation experiments.

The research listed as a) above is presently under way or near completion except for the microbiological aspects. The most efficient way of carrying out large scale ecosystem analyses would be to engage experts in the various disciplines. As neither the funding nor the qualified manpower available permit this, the policy is to engage graduate students in oceanography, fisheries and marine biology in addition to permanent research staff at the Institute of marine research and the Biological station, Espesrend. Projects for the students have been selected with the aim of providing pertinent data for the initial modelling. This approach has the added advantage of training students in team efforts and integrated research.

THE HERRING INVESTIGATIONS

The vertical and horizontal distribution of the herring will be investigated by echo surveying. This programme will be performed by monthly or fortnightly surveys along permanent transects in the area. Particular studies of stock assessment using acoustic methods will be made at selected times of the year when the herring distribution is most suitable for such studies.

Sampling with gill nets of various mesh sizes will be performed monthly, and the material will be analysed in order to monitor the maturation cycle of the stock and to estimate individual growth.

Mesh selection in gill net catches prevents true estimates of the age composition of the stock and therefore some purse seining will be done in summer or autumn. Commercial fishing has shown that during this season the herring is particularly susceptible to purse seining, especially if combined with the use of artificial light.

As the herring in Lindåspollene spawns in shallow water in well defined areas, the stock is particularly suited for studies of spawning behaviour and estimation of the spawning stock. Attempts will be made to estimate the spawning intensity by mapping the spawning area and counting the abundance of eggs per unit area. Variation in spawning time from year to year in relation to chemical and physical properties of the environment will be studied. Hatching time can be estimated by frequent larval surveys on the spawning grounds, and the dispersal and survival of larvae will be investigated in the period following hatching. In this connection it is of particular interest to test the efficiency of various types of sampling gear.

Estimates of the rates of survival of the herring in Lindåspollene can probably only be obtained from tagging experiments. Tagging with Lea's external tags in 1962 resulted in extremely high numbers of returns because the externally tagged fish were highly vulnerable to gill nets. On the other hand, returns from internally tagged fish will be severely underestimated because the herring is used exclusively for human consumption, and such tags are only occasionally observed when the fish are gutted. Recent developments in tagging techniques (GUNDERSEN 1960) combine the advantages of external and internal tagging, and these methods may be suitable for tagging experiments in Lindåspollene. As no regular commercial fishing takes place in the area, the tagging operations will have to be followed up by an extensive fishing effort.

When the various parameters of the herring population have been estimated with reasonable confidence intervals, an attempt will be made to build computer models of the population dynamics which may be amenable to simulation experiments aimed at suggesting refinements of the model.

The herring stock in Lindåspollene is well suited for short term biological and experimental studies as recommended by the ICES Working Group (ANON. 1969). Such studies include behavioural studies, genetical studies, experiments with tagging techniques, and experiments with sonar equipment for estimating fish abundance, target strength etc.

THE POLLUTION STUDIES

A research programme has been started to measure the possible effect of the sewage discharge into Lindåspollene on the production of phytoplankton and on the steady state conditions generally. Primary production measurements by ^{14}C -technique, chlorophyll estimates, and estimates of total organic matter in the water masses will be carried out throughout the year, and physical and chemical parameters such as light, temperatures, salinity, oxygen, nitrates, nitrites, ammonium, silicate, phosphate, and pH will be measured simultaneously.

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AGE DETERMINATION AND THE GROWTH AND
AGE DISTRIBUTION FROM CEMENTUM GROWTH
LAYERS OF BEARDED SEALS AT SVALBARD

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ABSTRACT

BENJAMINSEN, T. 1973. Age determination and the growth and age distribution from cementum growth layers of bearded seals at Svalbard. *FiskDir. Skr. Ser. HavUnders.*, 16: 159—170.

Material for this study was collected from 177 bearded seals on a sealer at Svalbard in 1968 and from 18 seals studied by biologists at Svalbard and in the Barents Sea in 1968 and 1970.

Bearded seal teeth degenerate and are lost at an early age, but canines in the upper jaw remain, apparently throughout life. They wear down at a linear rate. Dentine cannot be used for age determination, but cementum growth layers are added annually and permit age determinations also of adult seals. Growth layers in claws wear off after about 10 years. Bearded seals grow to a mean adult length of 225 cm at about 10 years. Females are slightly, but not significantly, larger than males. At Svalbard age-groups are fully recruited at 9 years and live to an age of about 31 years. A total annual mortality of 0.14 has provisionally been estimated for adult bearded seals at Svalbard.

INTRODUCTION

The circumpolar boreoarctic bearded seal, *Erignathus barbatus* (Erxleben, 1777), is found as far south as to the White Sea and the Gulf of St. Lawrence in the Atlantic and to the Sea of Okhotsk, even to Sakhalin and Hokkaido, in the Pacific. Occasional stragglers go further south, but the main distribution is at the pack ice in areas with moderate water depths. It moves seasonally with the edge of the ice, but does not perform regular migrations in open water (SCHEFFER 1958, KING 1964). According to POTELOV (1966) the bearded seal has been seen close to the North Pole.

Evidence for segregation between age groups has been found by POTELOV (1966) and by BURNS (1967) who suggests that the tendency to remain near the ice is more fixed in adults than in juveniles.

Two slightly different geographical forms are recognized. These forms have been given the rank of subspecies: *E.b. barbatus* in the Atlantic and *E. b. nauticus* in the Pacific (SCHEFFER 1958). However, a recent comparative study of more than four hundred crania from the White,

Kara, Barents, Okhotsk and Bering Seas showed no significant differences in growth rates of cranial bones between the different populations (KOSYGIN and POTELOV 1971).

The bearded seal is not a very abundant species, but it is hunted by aborigines all around the Arctic and is quite important in the economy of local communities. World wide catch statistics have not been compiled.

Norwegian sealers have on the average taken some 1 600 bearded seals per year in North Atlantic waters since 1945. About two thirds of these seals were caught by small ships hunting in Svalbard waters and in the northern Barents Sea during summer. However, prices for bearded seal skins have decreased, and in the last few years only occasional catches, mostly taken by expeditions, have been landed.

Annual zones in the cementum and the dentine have been used for age determination in several species of mammals since the technique was described in the early 1950-ies (LAWS 1962). In studies of seals a lower canine tooth usually has been selected for ageing, but the method was found to be inapplicable for bearded seals in the Arctic America because the teeth in this species are degenerated and often missing (McLAREN 1958, BURNS 1967). In those studies the growth ridges on the claws were used for age determination. By this method only a minimum age can be obtained for older seals because wear at the tip of the claw eliminates the first growth ridges after 9 to 16 years (McLAREN 1958). However, POTELOV (1964) points out that the cementum layers in the upper canines of the bearded seal are useful for age determinations because these teeth have more cementum than lower canines and are not so often missing.

In this paper methods for age determination are studied and data on growth, age distribution, longevity and mortality of bearded seals at Svalbard are presented. Age determinations are based on growth layers in the cementum of the upper canines.

MATERIAL AND METHODS

This study is based mainly on data from 177 bearded seals caught by a sealing vessel in the pack ice of eastern Svalbard waters in May and June 1968. The material was collected by a sealer trained by a technician from the Institute of Marine Research on a previous sealing voyage.

For each animal sex was recorded, the upper jaw collected and the standard length measured along a straight line from tip of nose to end of tail with the animal lying on it's back on a flat surface. Material from 8 and 10 bearded seals collected by biologists in the Barents Sea in the spring of 1968 and at Svalbard in July 1970 has also been examined.

Both the jaw and a claw from the middle digit of one of the fore flippers was collected from 16 of these seals.

Jaws and claws were stored in brine. After boiling for about 30 minutes in water the teeth could be extracted without damage. Inspection of a few longitudinal tooth sections showed that all cementum layers were represented and well defined at about 1 cm from the basal end of the root, and therefore the teeth were cut in transverse sections, 0.1—0.3 mm thick, at this position. The claws were cut in 0.5—0.8 mm thick longitudinal sections. Sections were washed in 96% alcohol, dried and permanently mounted on glass slides with Eukitt (Heinrich Vogel, Giessen).

Cementum layers were most easily counted in a phase microscope, but a binocular microscope could also be used. Growth layers in the claws could be counted by the naked eye.

The annual mortality was calculated by the equation

$$Z = 1 - x / (1 + \bar{x} - 1/n)$$

where

Z = annual mortality

\bar{x} = mean age, beginning with age of full recruitment as zero.

n = number of animals in the fully recruited age groups in the sample,

(CHAPMAN and ROBSON, 1960).

RESULTS

AGE DETERMINATION

Jaws collected for this study confirm earlier findings by other workers that bearded seal teeth are worn down, degenerate and fall out before the animals are very old. However, the roots of the canine teeth in the upper jaw apparently remain throughout most of the seal's life. Only one out of 194 upper jaws examined, had lost the canine roots.

Because of wear at the tip, length growth of the upper canines stops when the seal is a couple of years old. Canine tooth lengths (straight line distance from tip of crown to tip of root) are shown in relation to age in Fig. 1. A linear rate of tooth wear is suggested although individual differences are clearly indicated.

Dentine deposited in the upper canines during the first year nearly closes the basal opening of the pulp cavity. In the next few years new dentine is added inside the dentine of the first year and does not contribute to the growth of the tooth. The basal opening is closed, the pulp cavity filled, and no more dentine is deposited after the bearded seal

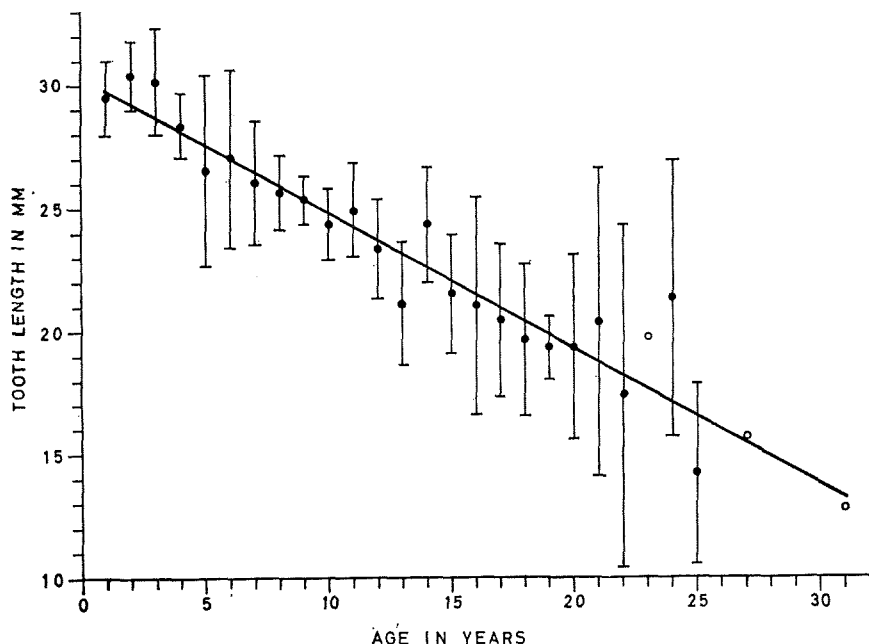


Fig. 1. Lengths of upper canine teeth of bearded seals in relation to age as determined from cementum growth layers. Means and 95 per cent confidence intervals, open circles indicate single measurements. The regression line: $y = -0.55x + 30.3$.

is about four years old. Secondary lamination within the annual dentine layers also complicate the interpretation of the layers. Dentine growth layers therefore are not satisfactory as a basis for age determinations.

However, laminated cementum is deposited on the outside of the roots of the teeth as long as they remain in the jaw. The cementum lamina on the upper canines are parallel to the long axis of the tooth, but varying in thickness both around the root and along its length. Lamina can not be distinguished at the basal end of the root.

The cementum of a standard transverse section from an upper canine tooth as it appears in transmitted light is shown in Fig. 2. Alternating translucent and opaque lamina appear as light and dark bands. One light and one dark band together are interpreted as one annual growth layer. Cementum layers usually are sufficiently distinct to be easily counted, but diffuse lamina impeded an exact age determination in about 10 per cent of the sections.

In claws the laminated structure in a longitudinal section is oriented as indicated in Fig. 3.

New lamina are formed underneath and behind the old ones and push the claw forwards while old lamina are removed by wear at the

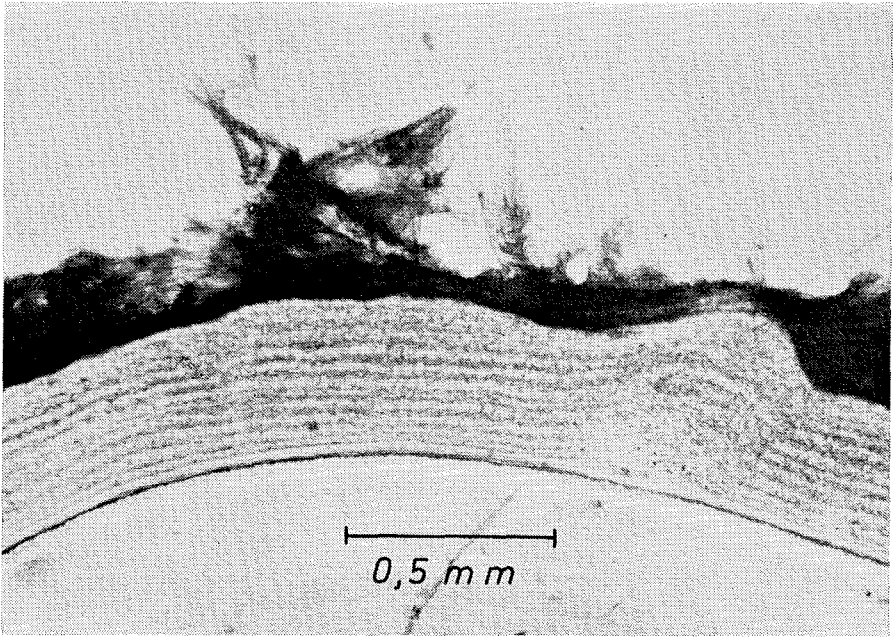


Fig. 2. The laminated structure of cementum in a transverse section from a bearded seal upper canine tooth shown by transmitted light.

tip of the claw as the seal grows older. Part of a longitudinal claw section is shown by transmitted light in Fig. 4. The lamination appears as alternating dark and light bands, one dark and one light band together forming one annual growth layer.

All material used in this study was collected in the spring and summer so the formation of layers in the teeth and the claws could not be followed through the year. However, the relative position of lamina suggests that the light bands in the claws and the opaque lamina in the cementum are deposited during the summer season, and the dark bands and translucent lamina during winter and spring.

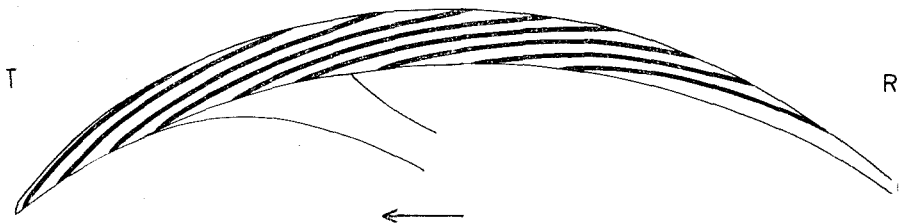


Fig. 3. The orientation of the laminated structure in a longitudinal section of a claw from a bearded seal fore flipper. R)root and T)tip of the claw. Arrow shows direction of growth.

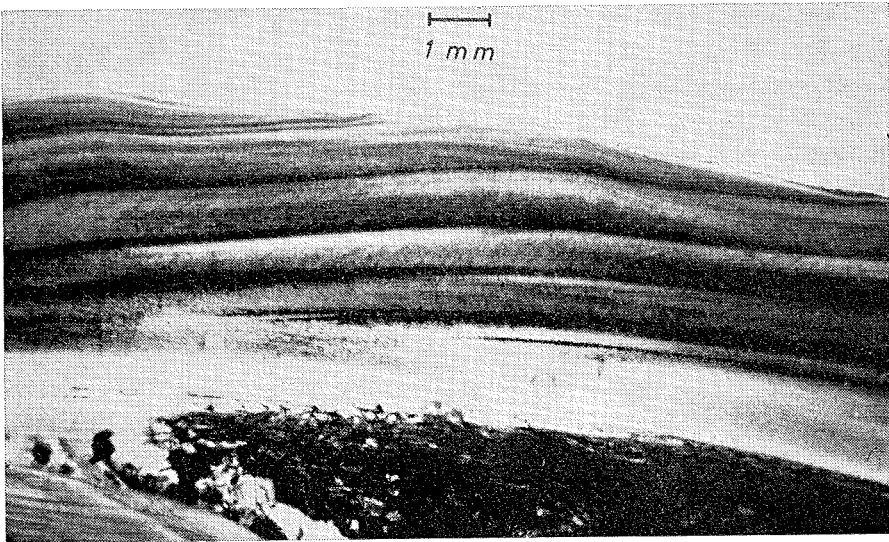


Fig. 4. The laminated structure in a longitudinal section of a claw from a bearded seal fore flipper shown in transmitted light.

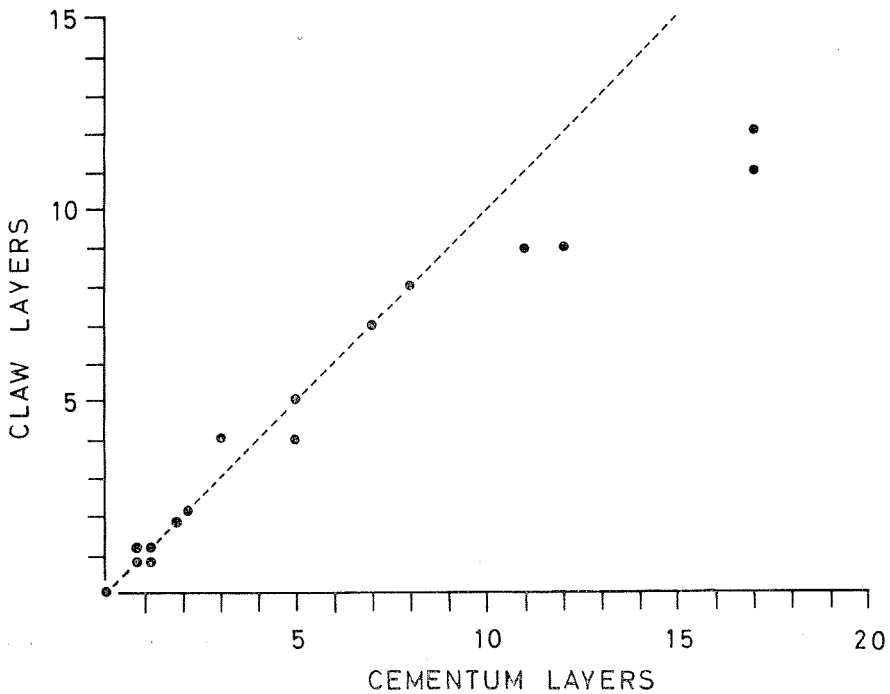


Fig. 5. The number of annual growth layers in the cementum of the upper canine teeth compared to the number of annual layers in claws from 16 bearded seals sampled at Svalbard and in the Barents Sea. The 1:1 relationship is indicated by a broken line.

Age determinations from cementum and claw layers are compared for 16 bearded seals in Fig. 5. Up to an age of about 8 years there is a good correlation between the number of layers in cementum and claws. Two animals — 3 and 5 years old from cementum layers — are exceptions from this rule. In both cases the deviation is explained by obscure bands in the claws. Wear has removed growth layers at the tip of the claw in four 11 years old and older seals.

GROWTH

The relationship between age and standard length for 191 bearded seals is shown in Fig. 6. The mean length at birth (131.3 cm) given by BURNS (1967) has been used as a starting point for the growth curve. A mean adult length of 224.7 cm (standard deviation 14.5 cm) is reached at an age of about 10 years. For adult seals 10 years old and older the standard lengths range from 180 cm to 252 cm.

The mean lengths of adult females and males were 226.6 cm and 222.5 cm respectively. A t-test showed that this difference between the sexes was not significant at the 5 per cent level ($t = 1.48, 0.1 < p < 0.2$).

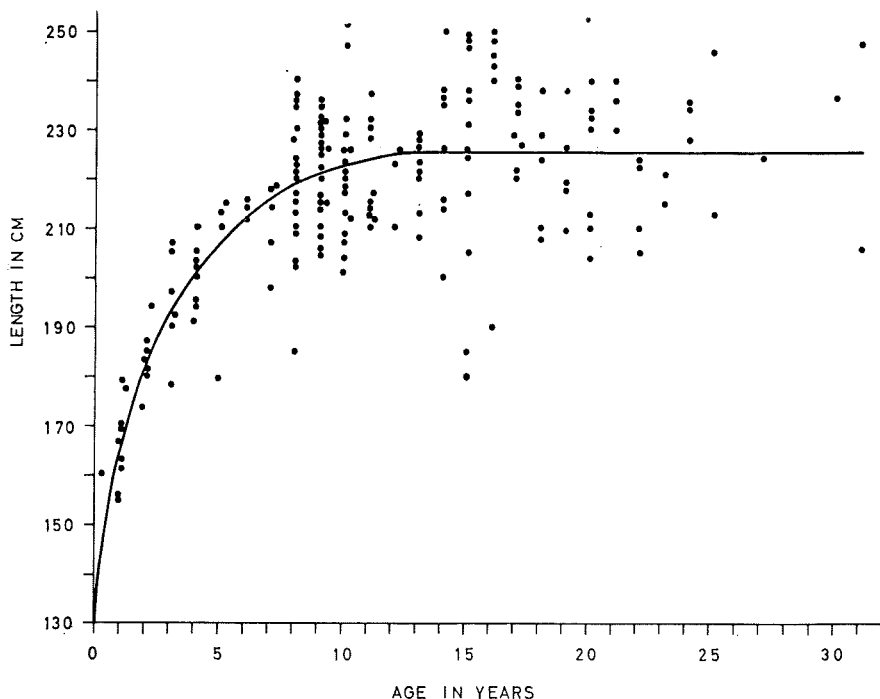


Fig. 6. The growth of bearded seals at Svalbard and in the Barents Sea based on standard length measurements and age determinations from cementum growth layers.

AGE DISTRIBUTION AND MORTALITY

The age distribution as determined from cementum growth layers of 175 bearded seals, all caught in eastern Svalbard waters in May and June 1968, is given in Fig. 7. In this sample age groups are not fully recruited until they are 8 or 9 years old. The oldest male and the oldest female in the sample were 25 and 31 years old respectively.

When 9 years is taken as the age of full recruitment, the total annual mortality rate for 9 years old and older bearded seals in the sample as calculated from the equation

$$Z = 1 - \bar{x} / (1 + \bar{x} - \frac{1}{n})$$

is 0.14.

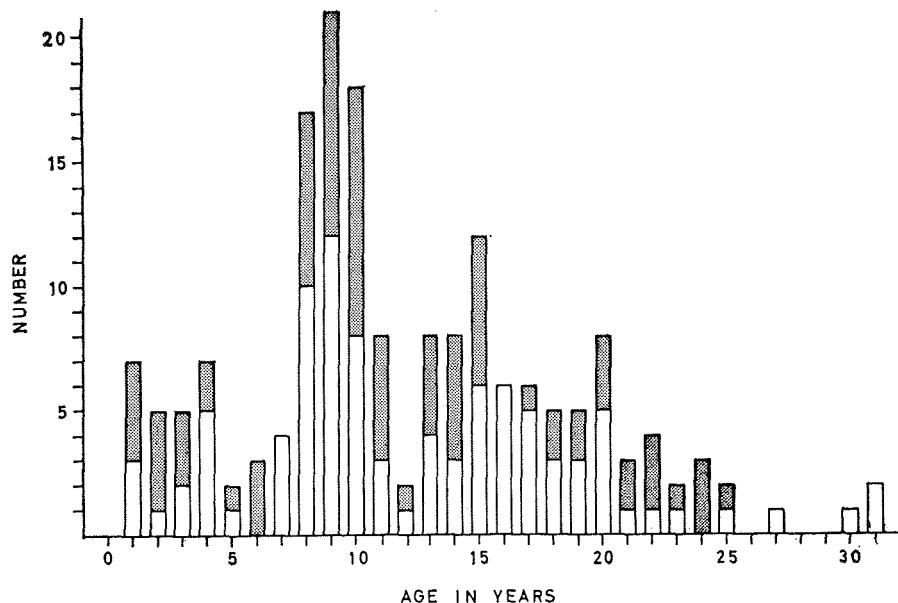


Fig. 7. The age distribution of 175 bearded seals caught in eastern Svalbard waters in May—June 1968. Open columns are females, hatched columns are males.

DISCUSSION

AGE DETERMINATION

The rapid wear and loss of the teeth in bearded seals has been attributed to evolutionary degeneration in tooth structure and to the perhaps conflicting fact that the species is feeding on abrasive benthic invertebrates like clams and crabs as well as ingesting quantities of sand (POTELOV 1964, BURNS 1967). The discovery that the upper canine

teeth can be used for age determination was first published by POTELOV (1964) who concluded that the number of cementum growth layers in these teeth reflects the age of the bearded seal.

Evidence in this study for the annual formation of the cementum growth layers may be found in the close structural resemblance to annual cementum layers in other species (LAWS 1962), in the fairly good fit of length data to a normal growth curve (Fig. 6) and in the age distribution of adult seals (Fig. 7).

The growth layers in the claws were found to be deposited annually in bearded seals in Arctic America by McLAREN (1958) and BURNS (1967) who both studied the surface structure of the claws and found the same pattern of band deposition as indicated by this study. Even if few data are available, the close correlation between the number of growth layers in the claw and in the cementum in young and subadult animals (Fig. 5) therefore gives additional evidence that the cementum growth layers are formed annually.

The deviation between cementum and claw layers in the few adult seals examined (Fig. 5), strongly suggests that studies of age distribution and mortality, perhaps also studies of growth and maturity, should be based on age determinations from cementum growth layers rather than from growth layers in the claws.

GROWTH

McLAREN (1968) and BURNS (1967) found that the mean length of adult bearded seals in the American Arctic was about 235 cm and 233.7 cm respectively. It is not clearly stated how their measurements were taken, and if zoological lengths were used (measured over curvature of body from tip of nose to end of tail), their data are not strictly comparable to the growth data from this study. A t-test also shows that their mean adult lengths differ significantly from the mean standard length of adults (224.7 cm) found in this study ($t = 2.78$, $p < 0.01$).

In Fig. 6 the lengths plotted for four animals are so much shorter than all others in their age groups that *rigor mortis* contractions may be suspected (one 8 years old male 185 cm, two 15 years old males 180 and 185 cm and one 16 years old female 190 cm). If these animals are omitted from the calculations, the mean standard length of adults changes to 225.8 cm and the range of adult lengths changes to 200 cm—252 cm, but the difference between this mean length and the American Arctic means is still significant at the 5 per cent level ($t = 2.53$, $0.02 < p < 0.03$).

A slightly longer length of adult females than of males (3.1 per cent) was also found by BURNS (1967). Omitting the four animals mentioned

above, the mean lengths in this study are 227.3 cm for adult females and 224.1 cm for adult males. The difference is still not significant at the 5 per cent level ($t = 1.23$, $0.2 < p < 0.3$).

AGE DISTRIBUTION AND MORTALITY

The poor representation of age groups from 0 to 7 years in the Svalbard area (Fig. 7) may be explained by a segregation between mature and immature seals in summer. According to BURNS (1967) and POTELOV (1972 b) female and male bearded seals attain sexual maturity at about five and six years of age respectively. POTELOV (1972 a) suggests that bearded seals in the Barents, White and Kara Seas all belong to one population which concentrates in the southern parts of the Barents Sea and the northern White Sea during winter. In summer and autumn the mature seals move north while the immatures and a very few adults remain in the south. A similar pattern of distribution during summer has been demonstrated for bearded seals in the Bering and Chukchi Seas by BURNS (1967) who also found a peak at 8—9 years in the age distribution in the Bering Strait during the spring hunting season.

Mortality estimates from the equation used here are based on the following assumptions: 1) Reproduction occurs every year, 2) the number of young born in any year balances the number of seals of all age groups that have died during the previous year, i.e. the population is at equilibrium, 3) the age distribution of fully recruited age groups in the sample represents the age distribution in the population, and 4) the mortality rate is constant in all fully recruited age groups (CHAPMAN and ROBSON 1960).

Although it has been suggested that females which have recently given birth may forego ovulation until after the mating season and thus establish a two year cycle (McLAREN 1958). BURNS (1967) found a pregnancy rate of 83—85 per cent among bearded seals in Alaska. A regular one year cycle of reproduction therefore seems likely, and all investigators have found a definite breeding season in late spring (BURNS 1967, POTELOV 1972 b). The exact timing may differ, but there is a general agreement that young are produced annually.

The other assumptions may be more doubtful. Norwegian catches in the Svalbard area have varied between nil (1967) and 3600 (1951) since 1945 with corresponding changes in hunting mortality. No attempt has been made to assess the influence of hunting on the total mortality of bearded seals at Svalbard or in the Barents Sea, but Norwegian catches have not exceeded 600 animals since 1965. It therefore seems

possible that the population nearly was at equilibrium when the sample was collected.

However, there is no reason to believe that natural mortality has changed through the years. Changes in hunting mortality therefore may have influenced the total annual mortality in the population in earlier years.

The small number of specimens in the age sample also makes estimates of mortality somewhat dubious, but most age-groups older than 8 years seem to be fairly well represented. Even with the reservations above which mean that 0.14 can only be used as a provisional estimate of annual mortality, this estimate is called for. Particularly so because, no other estimates of mortality are yet available for bearded seals.

It might also be mentioned that decreasing catches at Svalbard and a protection of bearded seals in the southeastern Barents Sea since 1970 (Norwegian—Soviet Sealing Commission) may have produced an increasing survival and a lowered adult mortality in the most recent years.

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