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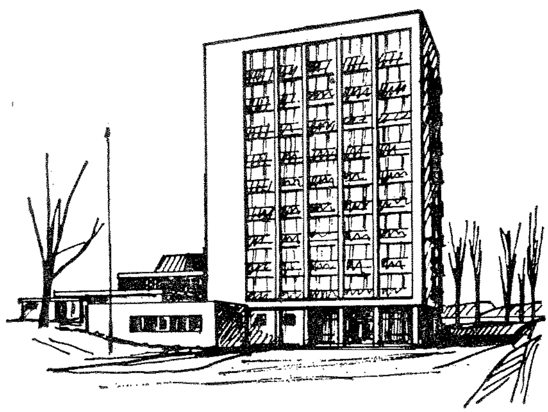

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FACTORS INFLUENCING YEAR-CLASS STRENGTH OF NORWEGIAN SPRING SPAWNING HERRING
(*Clupea harengus* Linné)

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INTRODUCTION

Short and long term variations in abundance of recruits in the Norwegian spring spawning stock of herring (subsequently referred to as Norwegian herring) have been described by several authors (HJORT 1914, LEA 1930, DEVOLD 1963, MARTI and FEDOROV 1963). MARTI (1959) compared the relative strengths of poor and rich year-classes of herring in different areas. For Baltic herring he found a ratio of 1/2–1/3, for North Sea herring, 1/8–1/10 and for Atlanto-Scandian herring, to which the Norwegian herring belong, 1/25–1/30. LEA (1930) estimated the ratio between poor and rich year-classes (with reference to the rich 1904 year-class) in the Norwegian herring stock to be about 1/94. ØSTVEDT (1963) found a ratio of 1/15 for the 1949–1950 year-classes. Thus year-class fluctuations are more pronounced for Norwegian herring than for many other herring stocks in the Northeast Atlantic. Also the time interval between the appearance of rich year-classes can be relatively long, in some periods even more than ten years (LEA 1930, MARTI and FEDOROV 1963).

The variation in year-class strength in marine fishes is a general phenomenon. The causes of the variation are not known, but the current hypotheses concentrate on possible variability of parental factors (MARTI 1959, BRIDGER 1960, 1961, CUSHING and BRIDGER 1964, CUSHING 1968) and of physical and biological conditions in the sea shortly after hatching (HJORT 1914, 1926, ROLLEFSEN 1930, LEA 1930, WALFORD 1938, 1946, SETTE 1943, CARRUTHERS *et al.* 1951, WIBORG 1957). A marked relationship between the number of eggs produced (the spawning potential of the parent stock) and the number of subsequent recruits is demonstrated for some species of fish with low fecundity, e.g. spurdog (*Squalus acanthias* Linné) (HOLDEN 1968). Similarly an indication of such a relationship is found in some relatively small stocks of Pacific herring (*Clupea pallasii* Valenciennes) in British Columbia (TAYLOR 1963) and in the Downs stock of herring in the North Sea (BURD and HOLFORD 1968), but no trend of decreasing recruitment with decreasing spawning stock has as yet been demonstrated for the other major stocks of herring in the North Sea (the Buchan and the Bank stocks) and in the Norwegian Sea (the Norwegian herring). However, within the range of population sizes for which data have been available for these stocks, a relationship between the spawning potential of the parent stock and the subsequent year-class strength is difficult to trace due to the variations in the normally high natural mortality rate of the very young stages. Most of the newly hatched larvae die, and slight changes in the mortality rate in the young stages will therefore result in pronounced variations in year-class strength.

Little is known about the causes of the natural mortality rate of the young stages of fish and whether or not there exist periods when the mortality rate is exceptionally high. HJORT (1914, 1926) expounded the concept of a critical period at the end of the yolk sac stage when the larvae begin feeding. Experiments carried out on herring (SOLEIM 1942) indicated that a critical period existed at this stage. Thus the natural conditions during the early stages of the life might determine the abundance of herring entering the exploited stock and the variations in spawning potential and its influence on subsequent year-class strength might be of minor importance when the size of the spawning stock is above a certain level.

In view of the serious decline in the yield of adult Norwegian herring during the late 1950s and early 1960s the Herring Committee of the International Council for the Exploration of the Sea (ICES) recommended that special attention should be given to the recruitment problem in this stock (PARRISH 1963). At the Institute of Marine Research, Bergen, investigations of the variation in size of the spawning stock, the location and time of spawning, the identification of possible critical stages during the early larval development and the larval drift have been emphasized. During the same period extensive investigations were conducted to register the distribution, migration, abundance and mortality of young and adolescent herring. The results of the latter investigations are presented in a separate paper (DRAGESUND 1970) while this account is confined to:

1) spawning characteristics, i.e. the structure and size of the spawning stock and the location and time of spawning;
2) larval studies during the first month after hatching.

The discussion is centred on year-class fluctuations in relation to spawning characteristics and to environmental conditions during the egg stage and early larval development.

MATERIAL AND METHODS

The major part of the material is related to the 1959–1965 year-classes, and the data are mainly obtained from:

1) samples of herring collected during the Norwegian winter herring fisheries in 1959–1968;
2) tagging experiments carried out in 1952–1964;
3) samples of herring larvae collected in 1959–1965 and in 1968;
4) larval drift experiments;
5) official fishery statistics and meteorological annals.

When it is of importance to extend the information to other year-classes, data from the literature and unpublished data from the records of the Institute of Marine Research, Bergen, are used.

The statistical methods applied are those given in text books of statistical analysis (SNEDECOR 1956, GODSKE 1966). Geographical names or area code numbers used in the text are shown in Fig. 1. The hydrographical data are from the records of the Institute of Marine Research, Bergen.

ADULT HERRING

Samples of adult herring, each usually consisting of 100 specimens, were collected from commercial catches several times each week during the Norwegian winter herring fishery. Fresh or iced material was brought to the laboratory for examination. Until January 1963 lengths were measured to the nearest half cm and after this date to the half cm below as recommended by ICES (ANON. 1963). To make the data comparable a correction factor of 0.25 cm has been added to the mean lengths of herring in samples collected after January 1963. Ages were determined from scale readings. The weight in g was recorded, and the maturity stages were classified according to the scale recommended by ICES (ANON. 1963). This maturity scale comprises eight stages including six which describe the sexual cycle of adult fish, i.e. stages III–VIII. The stages V–VII represent the pre-spawning, the spawning and the spent phases, respectively.

Stage V. Gonads fill body cavity. Eggs large, round, some are transparent. Ovaries yellowish, testes milk white. Sperm does not flow, but can be extruded by pressure.

Stage VI. Eggs transparent. Testes white. Eggs and sperm flow freely.

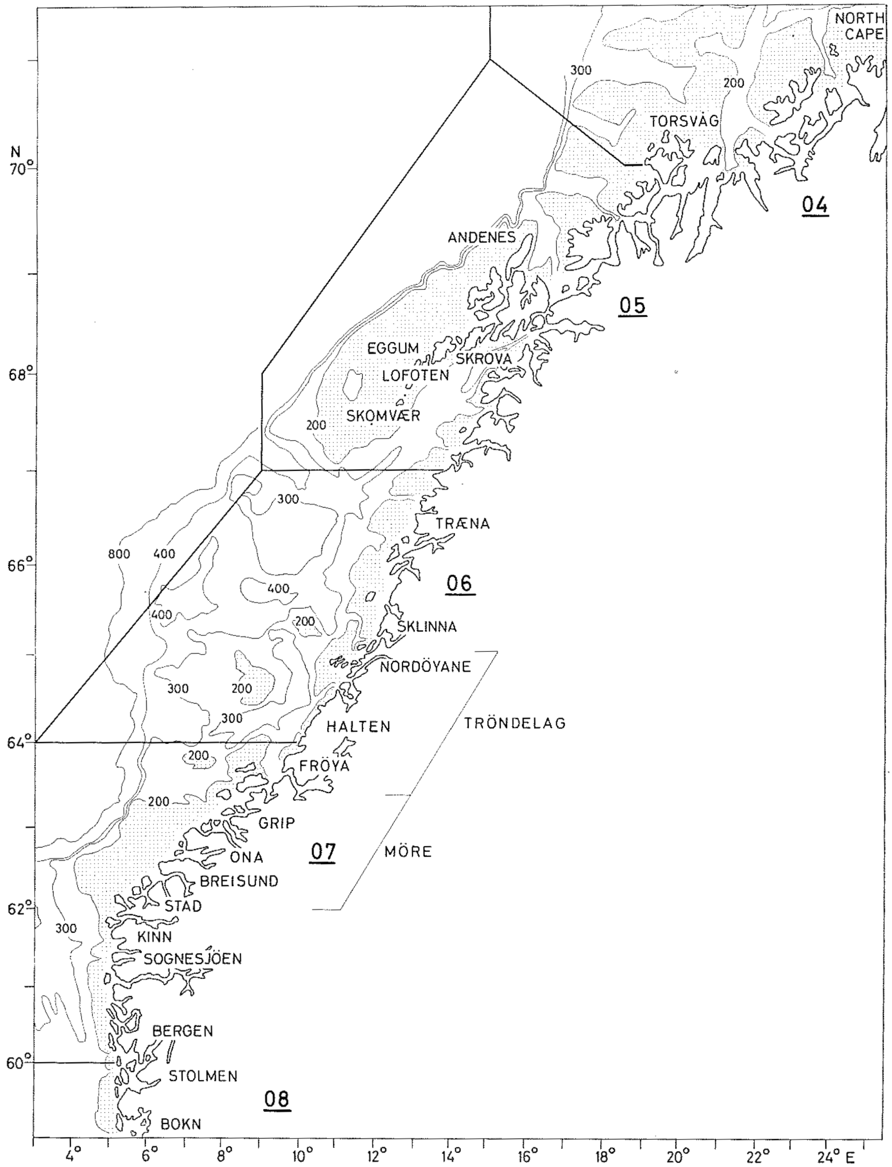

Fig. 1. Names and code numbers of areas mentioned in the text, and general bathymetric features of the coastal banks (depths in m).

Stage VII. Gonads baggy, bloodshot. The ovaries empty or containing only a few residual eggs. Testes may contain remains of sperm.

The biological data dealt with are from annual reports published by ØSTVEDT (1961, 1962, 1965, 1966), DEVOLD and ØSTVEDT (1963, 1964) and DRAGESUND (1967, 1968a, 1968b) and from unpublished records available at the Institute of Marine Research, Bergen. Statistical information on the Norwegian landings was obtained from annual reports on the Norwegian herring fisheries (ANON. 1960–1966a). The method used to estimate the adult stock size has been described by DRAGESUND and JAKOBSSON (1963), where estimates for the period 1952–1959 are also given. For the years 1964 and 1965 unpublished data are available at the Institute of Marine Research, Bergen, and the Fisheries Research Institute, Reykjavik.

LARVAL HERRING

The larvae were collected on surveys covering the Norwegian coastal banks from Stad to Lofoten (WIBORG 1960, 1961, 1962a, 1962b, DRAGESUND and WIBORG 1963, DRAGESUND 1965, DRAGESUND and HOGNESTAD 1966). The area was usually surveyed twice and the sampling was carried out from south to north and south again with one research vessel. Oblique hauls were taken with Clarke–Bumpus plankton samplers (CBPS) with a tube aperture of 13 cm diameter (CLARKE and BUMPUS 1950). The length of the nylon or silk nets used was 60 cm with a mesh size of 0.50 mm. The CBPS were equipped with flowmeters and two samplers were towed simultaneously at different depths and raised in 5 m steps. The sampling depths were 25–5 m, 50–30 m, and occasionally 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 an open position. The bias caused by this is considered to be of little importance, except when larval density in the uppermost depth interval is high compared with the depth intervals below.

In 1959 sampling with CBPS was carried out during a relatively late period (20–28 April) in the second part of the survey only. However, larvae were collected during the entire 1959 survey in vertical hauls from the bottom to the surface with a 1 m diameter Nansen net (NANSEN 1915). Sampling with Isaacs–Kidd three-foot midwater trawl (IKMT) (ARON 1962) was made at selected stations during the 1964 survey.

The larvae were preserved in diluted formalin containing 4% formaldehyde. At the laboratory they were counted and measured to the nearest mm below and classified as larvae with or without yolk sac. According to BLAXTER (1968) herring larvae shrink about 12% in length in a fixative of the type used. The shrinkage of the larvae was not taken into account when working out the length distributions, but since the larvae were preserved and measured in the same way each year the length distributions are assumed to be comparable from year to year.

To facilitate comparison between stations and from year to year, the number of larvae collected with CBPS was converted to numbers below 1 m^2 of surface by multiplying the original numbers for each station with the sampling interval and then dividing by the water volume filtered. For analysis of vertical distribution the number of larvae per 1 m^3 water was calculated. The number of larvae collected with the Nansen net was converted to numbers below 1 m^2 of surface by dividing the number of larvae caught by the area (in m^2) of the net aperture. The abundance estimates obtained by CBPS and Nansen net are not comparable.

LARVAL DRIFT

Freely floating drogues were used at several localities in 1964 and 1965 in order to study the drifting velocity of larvae. The drogue was made of two iron sheets having the dimensions of $0.2 \times 100 \times 100$ cm and fixed at right angles to each other. The drogue was suspended by a 1.6 mm thick nylon line from a plastic float to which a pole was attached. The pole was equipped with a light on the top, about 2 m above the surface. The positions of the drogues were determined by Loran and radar. In addition the larval drift pattern was deduced from wind observations and drift bottle experiments.

The wind data are from the meteorological stations Ona (N 62° 54′, E 06° 30.5′), Nordøyane (N 64° 48′, E 10° 33′) and Skomvær (N 67° 25′, E 11° 53′) as reported in Norsk Meteorologisk Årbok (ANON. 1960–1966b). Wind forces are given in Beaufort units and wind directions in twelve sectors, each covering 30°. The wind observations were transformed into monthly wind vectors. These were obtained by multiplying for each direction and month the mean wind force with the frequencies of observations of wind in the particular direction and thereafter the resultant vector was constructed from those established for each direction.

In 1961, 1963, 1964 and 1965 drift bottles were released in larval patches at various places along the coast. The bottles had an inner volume of 350 ml and weighed 530 g. A letter inside each bottle requested the finder to report the date and place of recovery.

EVALUATION OF FACTORS AFFECTING LARVAL ABUNDANCE ESTIMATES

Several methods have been employed to estimate the annual abundance of planktonic fish eggs and larvae (e.g. BUCHANAN-WOLLASTON 1926, SETTE and AHLSTROM 1948, TAFT 1960, SAVILLE 1963). ENGLISH (1963) analysed some common procedures of estimating annual abundance of planktonic fish eggs. The data used were treated by analysis of variance and he concluded that the major source of variability in estimates of annual egg abundance is the time effect. This is mainly due to the unknown fluctuations in time and location of maximum egg abundance. The number of stations was less important and duplications (paired hauls) were least important.

Reliable estimates of annual abundance of larvae are more difficult to obtain than for planktonic eggs, especially because of net avoidance and variation in diurnal behaviour of the larvae. In the present work, therefore, no attempt will be made to estimate the total abundance of herring larvae at hatching or at subsequent stages. The low number of surveys (usually two per season) and the long distance between stations (about ten nautical miles) do not allow for such estimates. Moreover, the sampling time was not always the same relative to the time of spawning. The numerical values obtained, therefore, are used only to show trends in the geographical distribution and to give some estimates of larval abundance at selected sections. The distribution charts were made by plotting the figures for each station and drawing isolines of abundance.

The haul-to-haul variation in oblique hauls with CBPS was investigated at some stations during the 1964 survey by comparing the number of larvae caught:

1) at the same station in two subsequent hauls (Table I);
2) in two samplers attached above each other, 1 m apart (Table II).

An analysis of variance was applied to these data using a log-transformation, log (x+k), where x is the number of larvae below 1 m² of surface and k=1 (CASSIE 1968). The calculations (Tables 1 and 2) show that

Table 1. Analysis of variance of the data in Table I.

Source of variation	Sums of squares	Degrees of freedom	Variance of estimate	Value of F	Probability
Between series of haul	0.036	1	0.036		
Between hauls	7.675	15	0.512		
"Residual"	0.806	15	0.054	0.667	>0.05
Total	8.517	31			

Table 2. Analysis of variance of the data in Table II.

Source of variation	Sums of squares	Degrees of freedom	Variance of estimate	Value of F	Probability
Between series of haul	0.004	1	0.004		
Between hauls	17.471	20	0.874		
"Residual"	0.628	20	0.031	0.129	>0.05
Total	18.103	41			

there was no significant difference ($P > 0.05$) in numbers between series of hauls or between catches from approximately the same depth. The results from this analysis indicated that the larvae were evenly distributed within the relatively small area sampled. The error caused by the variability in catch of replicate hauls in the same body of water is therefore assumed to be relatively small compared with that introduced by taking a sample over a small area as being representative of a much larger area.

Knowledge of the avoidance of sampling devices by planktonic organisms (including fish larvae) has been reviewed by CLUTTER and ANRAKU (1968). Even if the results are contradictory the accumulated data indicate that avoidance occurs. They reported that the catching efficiency increases with increasing speed of the net, and that larger fish larvae avoid nets towed at low speed to a greater extent than do the smaller larvae. It is assumed, therefore, that CBPS being towed at 1.5–2.0 knots will catch the fish larvae less efficiently than will high speed samplers, e.g. the Gulf III (GEHRINGER 1952).

In order to evaluate the effect of avoidance by herring larvae for CBPS, comparisons were made of the length distributions of larvae caught with IKMT and CBPS. Moreover, comparisons were made of the length distributions in catches taken by CBPS around subsurface drogues at night and during the day. The IKMT generally caught larger larvae than the CBPS (Table 3). However, no significant difference in mean length was found for the smallest larvae. Larger larvae were caught at night at drift stations 2 and 5 (off Sklinna and Frøya), whereas at drift station 4 (off Eggum) they occurred in the samples during the daytime (Table 4).

The diurnal variation in catches was analysed by sampling larvae at different depth layers around subsurface drogues every second hour during a 24-hour period at the three mentioned drift stations (Table III). At station 2 (off Sklinna) the number of larvae caught at night was significantly higher than at daytime ($P < 0.05$), whereas at stations 4 and 5 (off Eggum and Frøya) no significant difference was found (Table 5).

Although the results are somewhat ambiguous it is assumed that the net avoidance will affect both length distributions and abundance esti-

Table 3. Comparison between mean lengths ($\bar{l}$) of larvae caught with IKMT and CBPS during the 1964 survey.

Locality	Date	Hour	Gear	Depth in m	No. of larvae	$\bar{l}$ in mm	Standard deviation	Value of Student's t	Probability
Off Halten	16.4	1724–1910	IKMT	25–5	7	12.7	1.20	0.362	>0.05
			CBPS	25–5	7	12.4	1.84		
Off Sklinna	18–19.4	1920–1540	IKMT	50–30	113	14.9	1.97	0.746	>0.05
			CBPS	50–30	16	15.3	2.26		
Off Eggum	28–29.4	1455–0910	IKMT	50–30	84	12.2	2.26	0.152	>0.05
			CBPS	50–30	334	12.1	1.53		
Off Træna	1.5	0145	IKMT	50–30	159	18.2	1.95	8.257	<0.05
		0105	CBPS	50–30	27	14.7	3.74		
		0558–0820	IKMT	50–30	90	17.2	2.43	4.380	<0.05
		0524–0741	CBPS	50–30	16	14.2	3.03		
Off Sklinna	2.5	0227	IKMT	50–30	42	18.7	2.18	4.632	<0.05
		0150	CBPS	50–30	30	14.9	4.66		
Off Halten	3.5	0228	IKMT	50–30	63	21.1	1.65	3,717	<0.05
		0150	CBPS	50–30	5	18.0	3.32		
		1047	IKMT	50–30	23	16.3	2.21	0.455	>0.05
		1055	CBPS	50–30	3	15.7	1.25		
Off Grip	4.5	0543	IKMT	50–30	1	19.0	—		
		0343	CBPS	50–30	4	14.3	2.94		

Table 4. Comparison between mean lengths ($\bar{l}$) of larvae caught by night and by day in oblique hauls from 50 to 5 m with CBPS at three drift stations.

Drift station no.	Date	Time	No. of larvae	$\bar{l}$ in mm	Standard deviation	Value of Student's t	Probability
2	1964 18–19.4	Night	244	16.1	1.95	1.983	<0.05
		Day	94	15.6	2.37		
4	1964 28–29.4	Night	505	12.0	1.54	2.494	<0.05
		Day	1275	12.2	1.52		
5	1965 9–10.4	Night	157	12.2	1.49	5.359	<0.05
		Day	271	11.5	1.18		

Table 5. Analysis of variance of the data in Table III. The calculations were made on the log (x+1) transformation.

Drift station no.	Source of variation	Sums of squares	Degrees of freedom	Variance of estimate	Value of F	Probability
2	Between day and night	1.468	1	1.468		
	Within day and night	1.570	11	0.143	10.290	<0.05
	Total	3.038	12			
4	Between day and night	0.015	1	0.015		
	Within day and night	0.192	11	0.017	0.882	>0.05
	Total	0.207	12			
5	Between day and night	0.284	1	0.284		
	Within day and night	0.851	10	0.085	3.341	>0.05
	Total	1.135	11			

mates, especially when the larvae are longer than 15 mm. However, since there was no clear diurnal variation in the catches, it was not considered necessary to apply any conversion factor to make catches comparable to those taken by night.

During the 1959 and 1960 surveys sampling with CBPS was carried out only from 25 to 5 m, and to make the catches comparable with the following years a conversion factor was estimated and used to compensate for the lack of sampling in 50–30 m. The number of larvae caught at each station during the 1959 and 1960 surveys at depths of 25–5 m was multiplied by a factor of 1.7, which is the ratio between the number of larvae caught at 50–5 m and 25–5 m, respectively, during the cruises in 1961–1965. Larvae also occur below 50 m and the larval abundance is, therefore, underestimated by the present sampling procedure. However, samples are scarce from depths below 50 m, and no attempt has been made to compensate for this underestimate.

SPAWNING CHARACTERISTICS

SPAWNING STOCK

During the period 1959–1962 the spawning stock had only one component which migrated towards the coast off Møre (area 07) from the usual wintering area east of Iceland (DEVOLD 1963). The major part of the stock again approached the coast from this wintering area in 1963–1965, but a second component migrated towards the Lofoten region (area 05) from another wintering area, located off the coast between Torsvåg and North Cape (DEVOLD 1968). The herring arrived off Møre at the end of January and during February. The other component reached the Lofoten spawning grounds three to four weeks later, except in 1965.

In 1959–1963 the rich 1950 year-class dominated in the spawning stock off Møre (Table 6). In 1963 the age structure of the stock changed as recruit spawners from the 1959 year-class appeared in the catches. In 1964 and 1965 this year-class dominated in the spawning stock both off Møre (area 07) and at Lofoten (area 05), but herring of the 1960 and the 1961 year-classes were also present on the spawning grounds. In 1965 these three year-classes made up 80–85% of the total catches off Møre. The spawning stock at Lofoten consisted almost entirely of the 1959–1961 year-classes.

In 1959 recruit spawners constituted 11.7% of the herring caught off Møre and 21.3% of those caught between Bokn and Stolmen (Table 7). During the seasons in 1960–1963 the percentage of recruit spawners was considerably lower, except in 1963 at Lofoten where only recruit spawners were recorded. In 1964 and 1965 recruit spawners made up 34.4% and 35.9% respectively of the herring off Møre with the corresponding percentages for the Lofoten region being 93.7% and 76.4%.

Estimates of the absolute size of the spawning stock based on tagging experiments are available for the years 1952–1959 and 1964–1965 (DRAGESUND and JAKOBSSON 1963, ANON. 1969). Estimates obtained from combined acoustic surveys and underwater photography experiments for the years 1959 and 1962–1965 are also available (FEDOROV, TRUSKANOV and YUDANOV 1963, ANON. 1969). The results are illustrated in Fig. 2. The average figures are given for years when both methods have been used.

Table 6. Age composition (in %) of Norwegian herring caught with purse seine during the spawning seasons in 1959–1968.

Year	Area	Total no.	Year-class 1963	1962	1961	1960	1959	1958	1957	1956	1955	1954	1953	1952	1951	1950	<1950	Mean age
1959	08	553						—	—	0.4	1.3	4.0	17.4	6.0	8.0	51.8	11.1	8.4
	07	2106						—	—	—	0.7	1.1	7.1	5.7	8.4	54.1	22.9	9.5
	06	94						—	—	—	—	—	2.1	3.2	4.2	73.4	17.1	9.5
1960	07	3038					—	—	—	0.2	1.4	1.2	6.1	3.6	5.3	64.4	17.8	10.3
1961	07	666				—	—	—	0.4	0.9	3.3	2.9	7.7	4.8	6.5	59.0	14.5	10.7
1962	07	992			—	—	0.1	—	0.5	1.0	2.7	1.5	7.8	4.2	6.6	62.7	12.9	11.7
	06	80			—	—	—	—	—	—	—	1.3	11.2	2.5	7.5	73.7	3.8	11.7
1963	07	923		—	—	—	4.0	0.3	0.4	0.7	1.8	1.7	8.7	3.6	8.3	61.1	9.4	12.2
	06	314		—	—	—	13.1	0.3	—	—	—	0.3	7.3	3.2	7.3	62.5	6.0	11.6
	05	433		—	—	9.5	89.8	0.7	—	—	—	—	—	—	—	—	—	3.9
1964	07	1198	—	—	—	4.0	51.5	0.4	0.2	0.7	1.3	0.5	4.2	2.2	3.2	28.0	3.8	8.7
	05	1089	—	—	0.6	10.1	88.4	0.3	—	—	—	—	0.1	—	—	0.5	—	4.9
1965	07	1141	—	—	3.2	10.7	62.7	0.1	0.2	—	0.4	0.9	2.0	1.4	2.2	14.4	1.8	7.8
	06	96	—	—	18.8	26.0	55.2	—	—	—	—	—	—	—	—	—	—	5.4
	05	719	—	—	5.8	19.6	74.1	0.1	—	—	—	—	0.3	—	—	—	0.1	5.7
1966	07	2963	—	0.1	10.3	27.7	53.4	0.2	0.2	0.1	0.2	0.3	0.7	0.7	0.4	5.2	0.5	7.2
	06	471	—	—	3.6	25.1	60.8	—	—	0.2	—	—	0.6	0.6	0.2	8.5	0.4	7.6
	05	749	—	0.3	8.0	39.1	51.6	0.3	—	—	—	—	—	0.1	0.3	0.3	—	6.5
1967	07	2135	0.5	0.4	13.4	32.1	48.8	0.1	0.1	0.1	0.2	0.3	0.7	0.3	0.3	2.6	0.1	7.3
	06	99	1.0	—	10.1	41.4	46.5	1.0	—	—	—	—	—	—	—	—	—	7.4
1968	07	1352	0.7	1.7	13.8	34.2	46.9	0.2	—	0.1	0.2	0.2	0.7	0.3	—	1.0	—	8.5
	06	243	0.8	1.2	9.9	34.6	51.5	—	—	—	—	—	0.4	—	—	1.2	0.4	8.6

Table 7. Composition (in %) of recruit and repeat spawners of Norwegian herring during the spawning seasons in 1959–1965.

Year	Area	Region	No.	Recruit spawners	Repeat spawners
1959	08	Bokn-Stolmen	816	21.3	78.7
1959	07	Stad-Frøya	1761	11.7	88.3
1960	07	Stad-Frøya	3991	3.9	96.1
1961	07	Stad-Frøya	2610	1.0	99.0
1962	07	Stad-Frøya	2842	0.5	99.5
1963	07	Stad-Frøya	1938	5.2	94.8
1963	05	Off Lofoten	434	100.0	—
1964	07	Ona-Frøya	2097	34.4	65.6
1964	05	Off Lofoten	1176	93.7	6.3
1965	07	Ona-Grip	1270	35.9	64.1
1965	06	Off Halten	96	87.5	12.5
1965	05	Off Lofoten	643	76.4	23.6

The stock estimates for the 1952–1965 period vary between 2.5 and 20.0 million tons with the highest figures for 1952–1956. From 1957 onwards a rapid decrease in the stock took place and this continued until 1962 when it was about 2.5 million tons. In the following three years the stock increased from 2.9 million tons in 1963 to 7.3 million tons in 1965

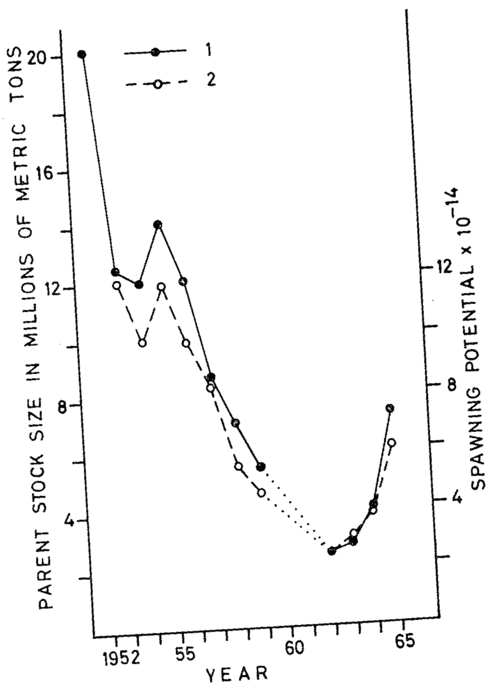

Fig. 2. Variation in, (1) parent stock size of Norwegian herring during the spawning seasons in 1952–1965 and (2) number of eggs spawned (spawning potential).

due to recruitment from the rich 1959 year-class. The estimates for 1963–1965 do not include the component spawning off Lofoten, and the total spawning stock in these years, therefore, is underestimated. Abundance indices obtained from data on catch per unit effort (ØSTVEDT 1963) indicated that the estimate of the stock size for 1952 is too high. The figures for the period 1953–1959 follow the same trend as the abundance indices given by ØSTVEDT.

The spawning potential of the stock is positively correlated to the size of the stock. However, fecundity (the number of eggs in the gonads of individual fish) increases with length and weight of the fish, and thus the spawning potential of the stock is a function both of the number and the length distribution of fish. In order to analyse the year by year variations of the spawning potential, the stock size in tons in the different years were converted to numbers of fish by length. Length and weight data of herring collected from purse seine catches were used to give stock estimates in tons for the different length groups. The estimated stock sizes in weight by length were then divided by the corresponding mean weight of herring in each length group. The sex ratio of spawning Norwegian herring is approximately 1:1 (DRAGESUND unpublished). With data on fecundity by length (PARRISH and SAVILLE 1965), the number of eggs deposited each year, therefore, could be calculated (Fig. 2). The variations in the spawning potential follow the same trend as that of the stock estimates in tons. However, in years when young individuals dominated in the spawning stock, as in 1954–1956 (ØSTVEDT 1963) and in 1964–1965, the spawning potential was relatively low compared to years when the stock consisted of old individuals, as in 1962–1963.

The following characteristic features concerning the structure and size of the spawning stock during the period 1959–1965 can be listed:

1) the mean age of the stock increased from 1959 to 1963 with the 1950 year-class predominating;
2) the 1959 year-class dominated in the stock in 1964 and 1965 and the percentage of recruit spawners was highest these years;
3) the stock size had its lowest values in 1961–1963 and its highest in 1965;
4) the stock size was on a considerably lower level in 1959–1965 than in the mid 1950s.

LOCATION AND TIME OF SPAWNING

The spawning grounds were located by studying the geographical distribution of catches of spawning and spent herring and by surveying the coastal banks for newly hatched larvae. Herring remain on the same grounds from just before spawning until they gradually migrate from the coastal banks. The distribution of catches during the spawning season, therefore, will give information on the location of spawning (Fig. 3). The occurrence of larvae with yolk sac indicates that spawning must have taken place not very far from the locality of capture. The distribution of yolk sac larvae coincided fairly well with the distribution of catches of spawning and spent herring (Fig. 3). However, in some years the larvae were found distributed slightly to the west and north of the herring catches. This could be expected since the yolk sac stage lasts for some days, about ten days at 8°C (Blaxter and Hempel 1963), and a dispersion from the spawning grounds evidently takes place during this time. In 1964 the survey was made late in relation to the main spawning season, and therefore only few yolk sac larvae were found in areas 07 and 06 that year.

Although the data are insufficient for a precise determination of the spawning grounds, it can be concluded that spawning was concentrated within four following areas:

1) area 08, between Bokn and Stolmen;
2) area 07, between Kinn and Frøya;
3) area 06, between Halten and Sklinna;
4) area 05, off the Lofoten Islands.

During the period 1959–1965 the most important spawning took place in area 07. In 1959–1962 the majority of the herring in this area tended to concentrate somewhat farther south (between Stad and Ona) than in 1963–1965, when the centre of spawning was located between Ona and Grip. Spawning in area 08 was negligible except in 1959 when spawning was observed at certain places along the coast as far south as Bokn. The spawning between Halten and Sklinna (area 06) occurred regularly and did not show any change in location. Mass spawning off the Lofoten Islands (area 05) was not recorded during the period 1959–1962. However, a few yolk sac larvae caught in this region in 1960 suggest spawning there that year. From 1963 to 1965 herring spawned regularly at Lofoten.

The distribution of relative catches of spawning and spent herring presumably give the best indication of the geographical distribution of the spawning area. In Table 8 the number of rectangles shown in Fig. 3 in which spawning and spent herring were caught, is listed. For 1960 and 1961, within area 06, the distribution of yolk sac larvae was used. The spawning was restricted to grounds with sandy or rocky bottom, and not all the grounds within the rectangles shown in Fig. 3 constitute localities for spawning. Within the two southern spawning areas (08 and 07) a restriction in the geographical distribution of the catches were found from

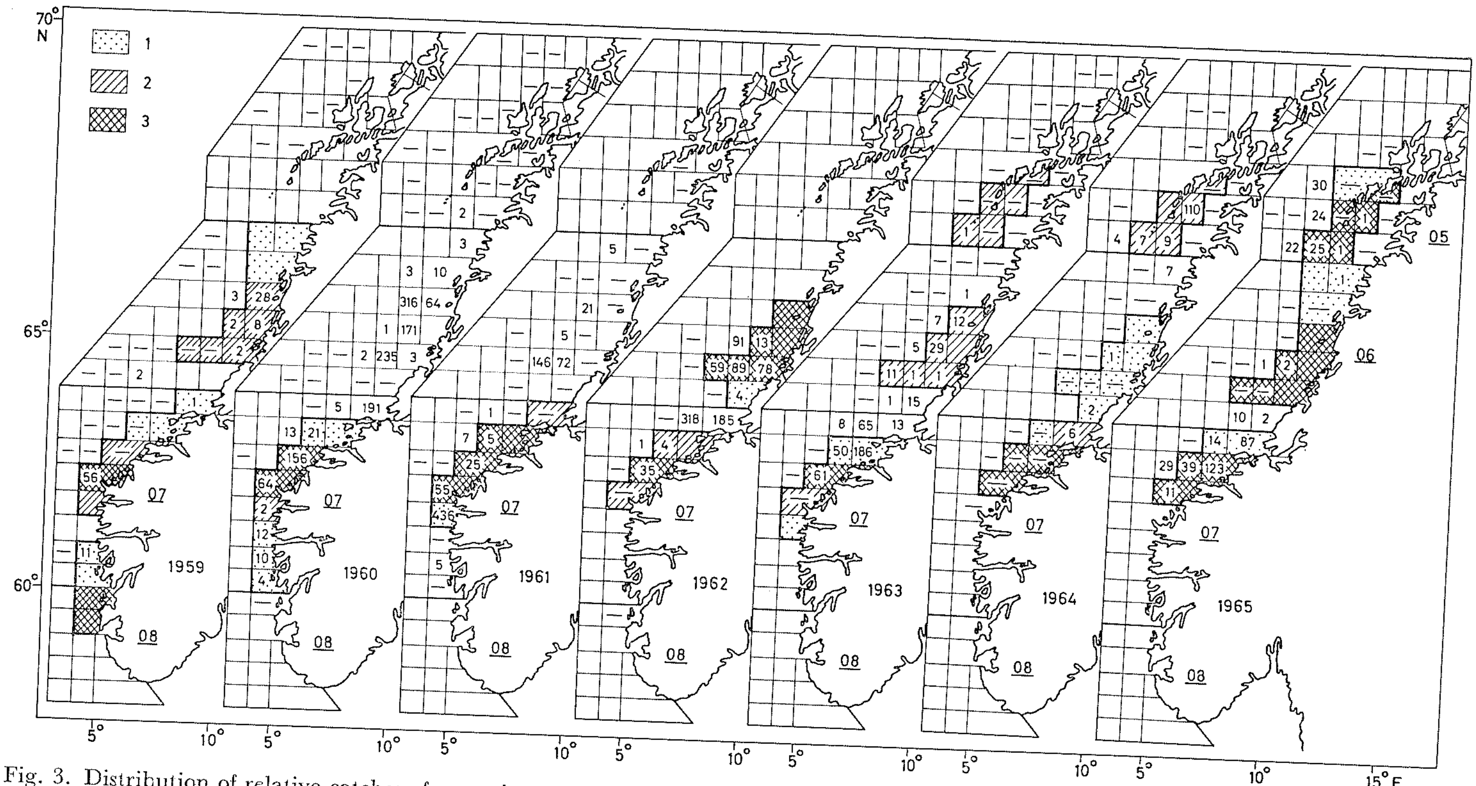

Fig. 3. Distribution of relative catches of spawning and spent herring during the Norwegian winter herring seasons in 1959–1965. Legend: (1) <5%, (2) 5–15% and (3) >15% of the total catches, respectively. The figures in the rectangles denote numbers of yolk sac larvae per station below 1 m² of surface. The horizontal lines denote hauls without larvae.

1959 to 1965, accompanied with an increase in the extension within area 05 from 1963 to 1965. The extension of the spawning area seemed to decrease with the size of the spawning stock, being most restricted in 1961 and 1962.

Table 8. Extension of spawning area indicated by number of rectangles shown in Fig. 3 in which spawning and spent herring were caught in 1959–1965.

Area	Spawning year						
	1959	1960	1961	1962	1963	1964	1965
08	2	0	0	0	0	0	0
07	8	8	6	4	5	5	5
06	9	9?	5?	7	6	7	9
05	?	?	?	?	5	5	6

Even in the same locality groups of herring which keep together will spawn at slightly different times. The time of the main spawning is estimated from the composition of the various maturity stages of herring in samples collected just prior to and during the spawning season. The duration of the spawning season is defined as the time between the first and last occurrence of herring in stage VII.

In Fig. 4 the relative frequency for the different maturity stages is plotted against time (in five-day periods). The data used in the figure are listed in Table IV. The time when the first fish were found in maturity stage VII, indicating the commencement of spawning (T_1), could be determined fairly accurately, but the time for the end of spawning (T_2) was more difficult to assess from the present material since some herring in stage V occurred in samples collected even at the end of the sampling period. These herring had to pass through stage VI before the season could be considered ended. The duration of stage VI for the individual fish is incompletely known for Norwegian herring, but this stage is the shortest (Iles 1964). To get approximate figures for the duration of stage VI, the time interval between the first occurrence of stages VII and VI (T_d) was measured. By adding T_d to the last time when herring in maturity stage V occurred, the end of the spawning season (T_2) was estimated. The time of the main spawning is defined to occur at the mid-point between T_1 and T_2 (Fig. 4).

In area 07 (off Møre) spawning commenced relatively early in 1959, 1960 and 1965, when the main spawning took place in the first week of March. In 1962 and 1963 the onset of spawning was late and the main spawning occurred 15–19 and 10–14 March, respectively. The duration of the spawning seasons in 1959–1965 was longest in 1959, 1960 and 1961,

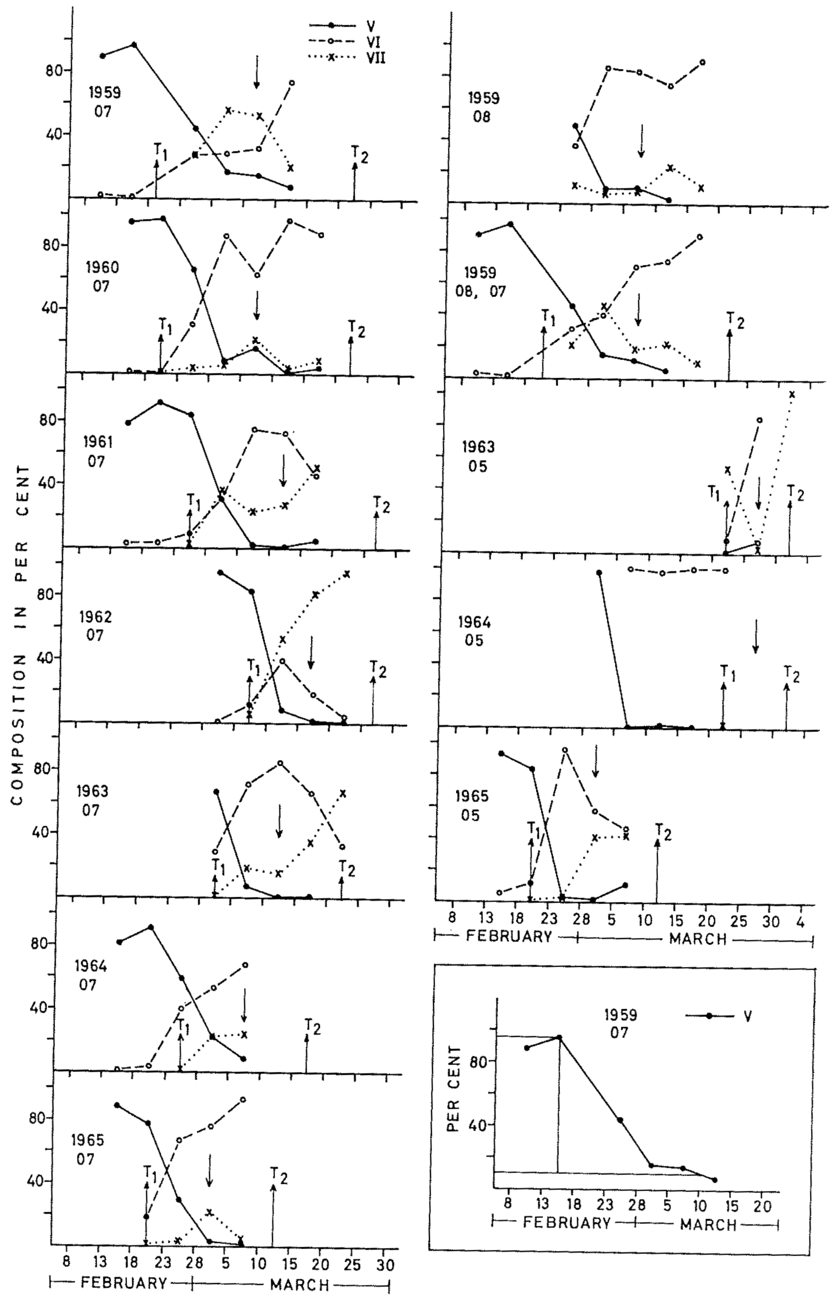

Fig. 4. Maturity composition (in %) of stages V–VII in samples of Norwegian herring collected during the spawning seasons in 1959–1965. Data for males and females are pooled and plotted against time in five-day periods. T_1 and T_2 represent the onset and end of spawning. The time of main spawning is indicated as the midpoint between T_1 and T_2 by an unlabelled arrow. The inserted illustration of the method used to estimate the spawning rate by measuring the reduction of stage V is explained in the text.

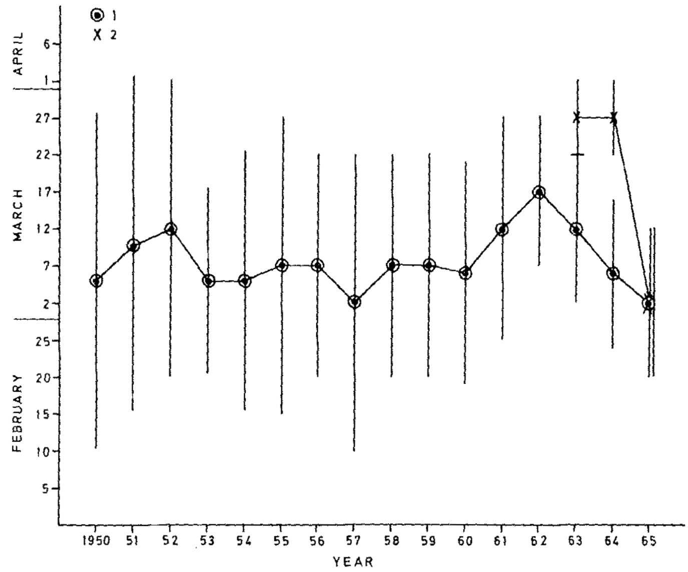

Fig. 5. Time of main spawning during the period 1950–1965, (1) within areas 07 and 08 and (2) within area 05. Vertical bars denote duration of the spawning season.

lasting for about one month. In the other years the season lasted only about three weeks.

In area 06 (between Halten and Sklinna) the duration of spawning in 1959 could not be studied in the same detail because of the limited number of samples available. Apparently, spawning occurred almost at the same time or slightly later than in area 07. Herring examined from the Halten Bank showed that spawning commenced a few days later there than elsewhere in area 06. In area 05 (off Lofoten) the onset of spawning was late in 1963 as well as in 1964, and lasted only about ten days. In 1965 the onset and duration of spawning were the same as in area 07.

In Fig. 5 the time of the main spawning and the duration of the spawning season are illustrated for the period 1959–1965, supplemented with data from the spawning seasons in 1950–1958. No special trend in time of the main spawning was found during the period 1950–1965. However, the spawning seasons lasted somewhat longer in 1950–1958 than during the period 1959–1965, probably because of the restricted spawning in the southernmost region within area 08.

In the spawning seasons of 1964 and 1965 the influx of recruits was high. A comparison between the onset of spawning for recruit and repeat spawners these years is given in Table 9. Apparently no marked difference

Table 9. Composition (in %) of the maturity stages of Norwegian herring in five-day periods during the spawning season in 1964 and 1965.

Area	Date		Recruit spawners					Repeat spawners				
			No.	Maturity stage				No.	Maturity stage			
				IV	V	VI	VII		IV	V	VI	VII
07	1964	13–17.2	137	20.4	78.8	0.8	—	228	17.1	82.9	—	—
		18–22.2	223	9.0	87.0	4.0	—	238	0.8	95.4	3.8	—
		23–27.2	208	1.4	57.7	39.4	1.5	428	0.2	59.6	39.7	0.5
		28.2–3.3	83	1.2	26.5	54.2	18.1	237	0.4	21.2	52.7	25.7
		4–8.3	71	—	14.1	71.8	14.1	224	—	7.4	65.6	27.0
05	1964	28.2–3.3	79	2.5	97.5	—	—	3	—	100.0	—	—
		4–8.3	80	—	—	100.0	—	14	—	—	100.0	—
		9–13.3	92	—	2.2	97.8	—	3	—	—	100.0	—
		14–18.3	513	—	0.2	99.8	—	27	—	—	100.0	—
		19–23.3	338	—	—	99.1	0.9	27	—	—	100.0	—
07	1965	13–17.2	115	26.1	73.9	—	—	202	3.0	97.0	—	—
		18–22.2	146	9.6	72.6	17.8	—	258	—	79.8	19.8	0.4
		23–27.2	45	2.2	33.3	57.8	6.7	203	—	29.0	68.0	3.0
		28.2–4.3	110	1.8	1.8	63.6	32.8	95	—	5.3	88.4	6.3
		5–9.3	40	—	2.5	95.0	2.5	56	—	—	92.9	7.1
06	1965	15–19.3	84	—	—	92.9	7.1	12	—	—	100.0	—
05	1965	13–17.2	70	2.9	91.4	5.7	—	25	—	96.0	4.0	—
		18–22.2	129	5.4	86.0	7.8	0.8	46	2.2	76.1	21.7	—
		23–27.2	71	—	2.8	94.4	2.8	23	—	—	100.0	—
		28.2–4.3	142	—	2.2	57.0	40.8	45	—	—	60.0	40.0
		5–9.3	79	1.3	12.7	49.6	36.4	13	—	—	30.8	69.2

was found in the onset of spawning although repeat spawners reached maturity stages VI and VII a little earlier than the recruits. This suggests that recruits spawned slightly later than the repeat spawners, especially in area 07.

The transition from the prespawning to the spawning stage was studied by estimating the rate of reduction for the maturity stage V from the maximum frequency points of the stage V curves to their 10% levels. The percentage reduction was measured (Fig. 4) and the reduction per day (defined as the spawning rate) was estimated (Table 10). The figure for 1962 (area 07) indicates mass spawning over a relatively short period, whereas in 1959 spawning took place at a considerably slower rate. The spawning in the other years occurred at a more moderate rate than in 1962. In area 05 (off Lofoten) the spawning rate was generally higher than in area 07 (off Møre), especially in 1964.

Table 10. Spawning rate of Norwegian herring indicated by the percentage reduction of the maturity stage V per day (see text for explanation).

Area	Spawning year						
	1959	1960	1961	1962	1963	1964	1965
07	3.8	5.9	6.3	8.7	—	5.3	5.3
05	—	—	—	—	—	22.0	10.3

TIME OF HATCHING

The time of main hatching can be found by adding the incubation period to the time of main spawning. Knowing the temperature on the spawning grounds, an approximate figure for the incubation period can be estimated (BLAXTER and HEMPEL 1963). The incubation period varies from about twenty-five days at 5°C to about sixteen days at 8°C. Investigations carried out off Møre (unpublished) during the spawning seasons in 1967 and 1968, showed that the spawning took place at depths less than 250 m, with the most frequent spawning depths ranging from 50 to 200 m. Therefore, the mean temperature between 50 and 200 m (or bottom) in the different regions was used in order to estimate the incubation period (Fig. 6). The stations were located on the main spawning grounds within each region. The number of stations varied between two and four. The mean temperature in the spawning region off Møre (area 07) was lowest in 1959 and 1963 resulting in a correspondingly longer incubation period than in the other years. The quartile intervals, indicat-

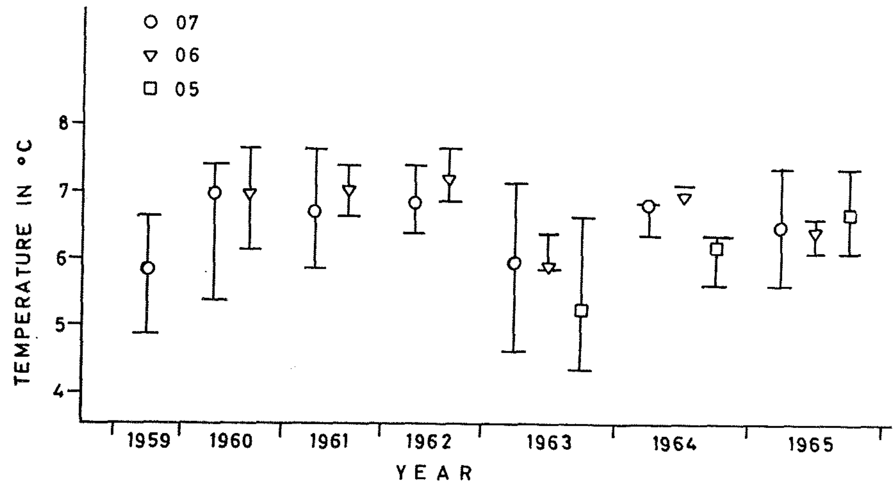

Fig. 6. Mean temperature at different spawning grounds within the main spawning regions in areas 07, 06 and 05, depth intervals from 50 to 200 m or to the bottom. The vertical bars show the quartile intervals.

ing the temperature range within the main spawning depths, were widest in 1959, 1960, 1963 and 1965 and this feature may have resulted in a variable incubation period (Fig. 7). The range was considerably more narrow in 1962 and 1964 and the time of main hatching, therefore, shorter. In the spawning regions off Halten–Sklinna and Lofoten (areas 06 and 05) the mean temperature followed the same trend as in area 07, but the quartile intervals in area 06 was not as wide as on the spawning grounds within area 07. Since the spawning occurred at different times off Møre (area 07) and Lofoten (area 05) in 1963 and 1964, the total hatching period was relatively long these years. In 1965 the spawning and hatching took place almost at the same time in the two spawning regions and the time of main hatching occurred relatively early, especially in area 05 (Fig. 7).

The commencement of the Norwegian winter herring fishery, coinciding in time with the arrival of spawners to the coast, the estimated time of the main spawning and hatching and the first and second periods of larval sampling are also plotted on the time scale in Fig. 7. On the Møre coast (area 07) the time of arrival of the herring, the spawning and the subsequent hatching all occurred progressively later during the period 1959–1962, whereas the opposite trend was found from 1963 to 1965.

Fig. 7. Time of, (1) commencement of the Norwegian winter herring fishery, (2) main spawning, (3) main hatching, (4) and (5) first and second annual periods of larval sampling.

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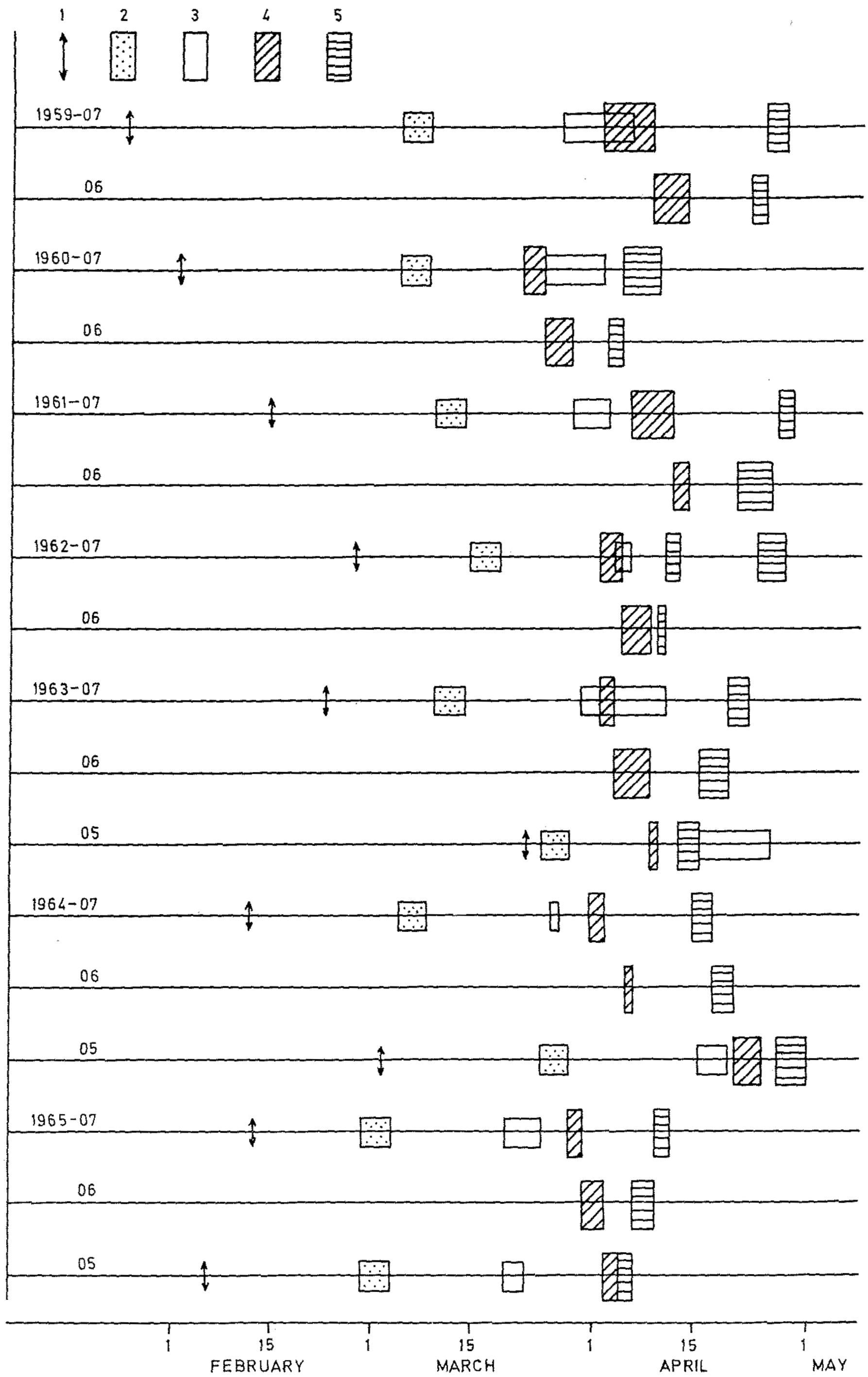
1
2
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THE LARVAE

LARVAL DISTRIBUTION AND ABUNDANCE IN RELATION TO SPAWNING CHARACTERISTICS AND WATER CURRENTS

Soon after hatching the major part of the larvae rise into the upper water layers (50–0 m). Observations made at drift stations off Sklinna and Eggum indicated a vertical migration of the larvae (Fig. 8). During the dark, larvae were most abundant in the upper 20 m and by day they concentrated at a depth between 20 and 40 m. However, a higher net avoidance during the day might to some extent account for the variation in vertical distribution within the upper 40 m. Nevertheless the majority of the larvae did occur within the upper 50 m and were scarce in the depth range from 50 to 70 m.

The larvae are transported northwards mainly in coastal water, i.e. water with salinity less than 35‰ (HELLAND-HANSEN and NANSEN 1909). This water moves as a coastal current from the Skagerak to the Barents Sea, whereas Atlantic water (with salinity above 35‰) moves northward farther offshore with the core just outside the edge of the continental shelf. The main bulk of coastal water seems to be deflected northward off Stad (Fig. 9), and outside Møre the current has its maximum northward velocity at the edge of the shelf, whereas over the Møre plateau the current is weaker and on some occasions vortex movements of the water masses occur (HELLAND-HANSEN and NANSEN 1909, LJØEN and NAKKEN 1969). The branch of the coastal water which follows the slope northwards from about N 63°15′, E 5°40′ is mixed with salter and warmer water masses and will relatively soon lose its original characteristics (LJØEN and NAKKEN 1969). The main bulk of coastal water flows to the east off Ona–Grip and follows the coast northwards from Grip (Fig. 9).

The velocity of the coastal current varies greatly (HELLAND-HANSEN and NANSEN 1909, EGGVIN 1940, LJØEN 1962). The subsurface drogue

Table 11. Subsurface drogue measurements in larval patches during the surveys in 1963–1965 and 1967.

Date		Drift station no.	Position	Duration of experiment in hours	Drifting velocity parallel to the coast in knots
1963	20–21.4	1	N 63° 44′, E 07° 52′	24	0.75
1964	18–19.4	2	N 65° 26′, E 10° 45′	24	1.08
	30.4	3	N 66° 33′, E 12° 02′	12	0.36
	28–29.4	4	N 68° 20′, E 13° 14′	24	0.29
1965	9–10.4	5	N 64° 20′, E 09° 32′	24	1.00
1967	3– 9.4	6	N 63° 06′, E 05° 51′	138	0.10 clockwise drift

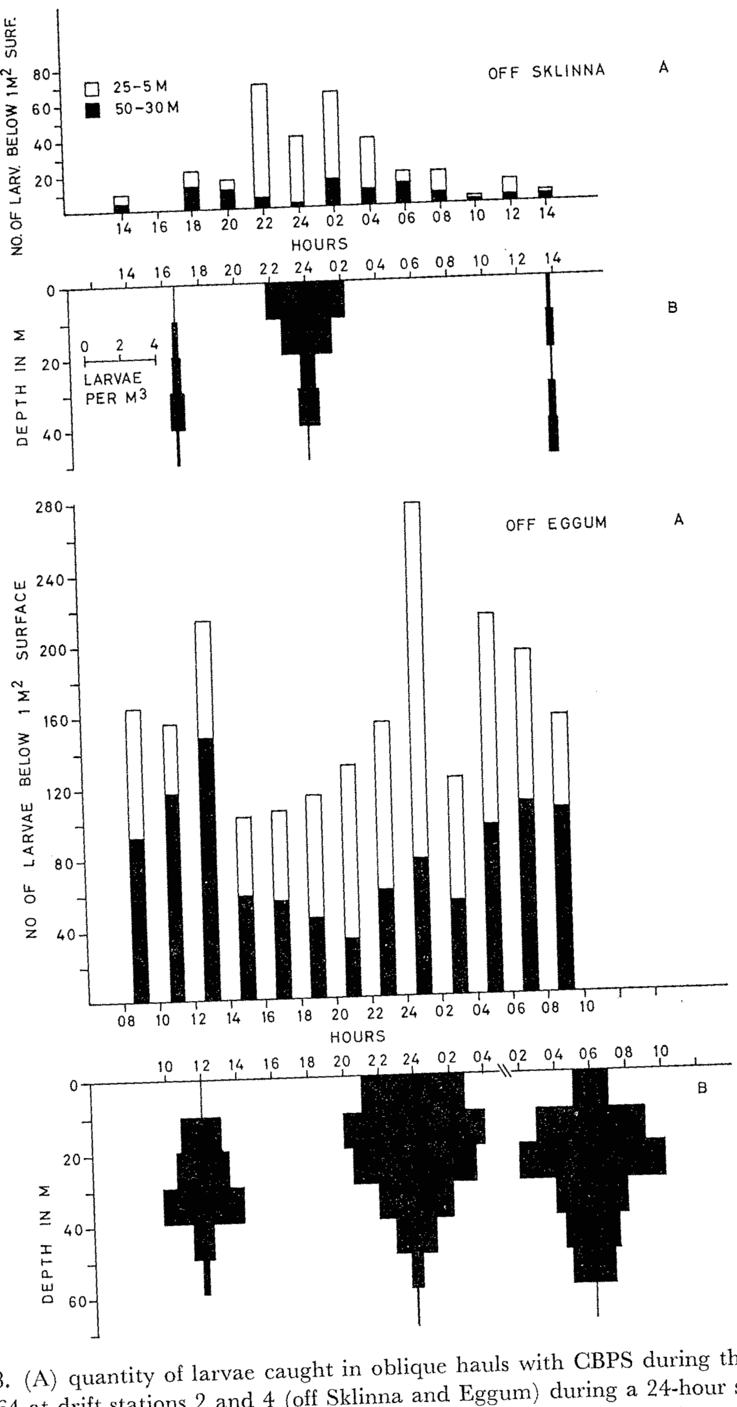

Fig. 8. (A) quantity of larvae caught in oblique hauls with CBPS during the survey in 1964 at drift stations 2 and 4 (off Sklinna and Eggum) during a 24-hour sampling period and (B) vertical distribution of larvae at the same stations.

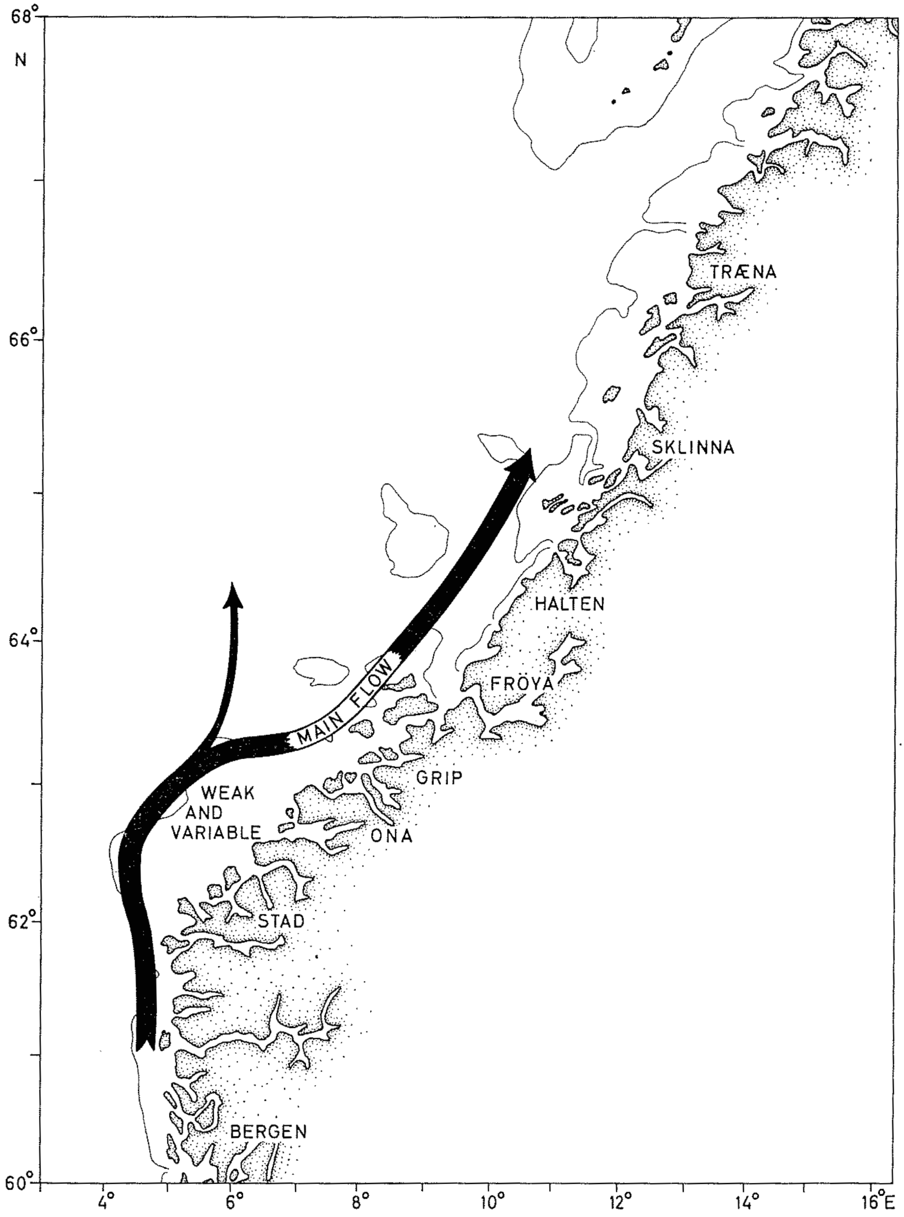

Fig. 9. Main flow of coastal water off Møre and Trøndelag (reconstructed from LJØEN and NAKKEN 1969).

measurements carried out at different places along the coast (Table 11) showed relatively high velocities off Frøya and Sklinna (stations 1, 2 and 5) and lower velocities farther north off Træna and Eggum (stations 3 and

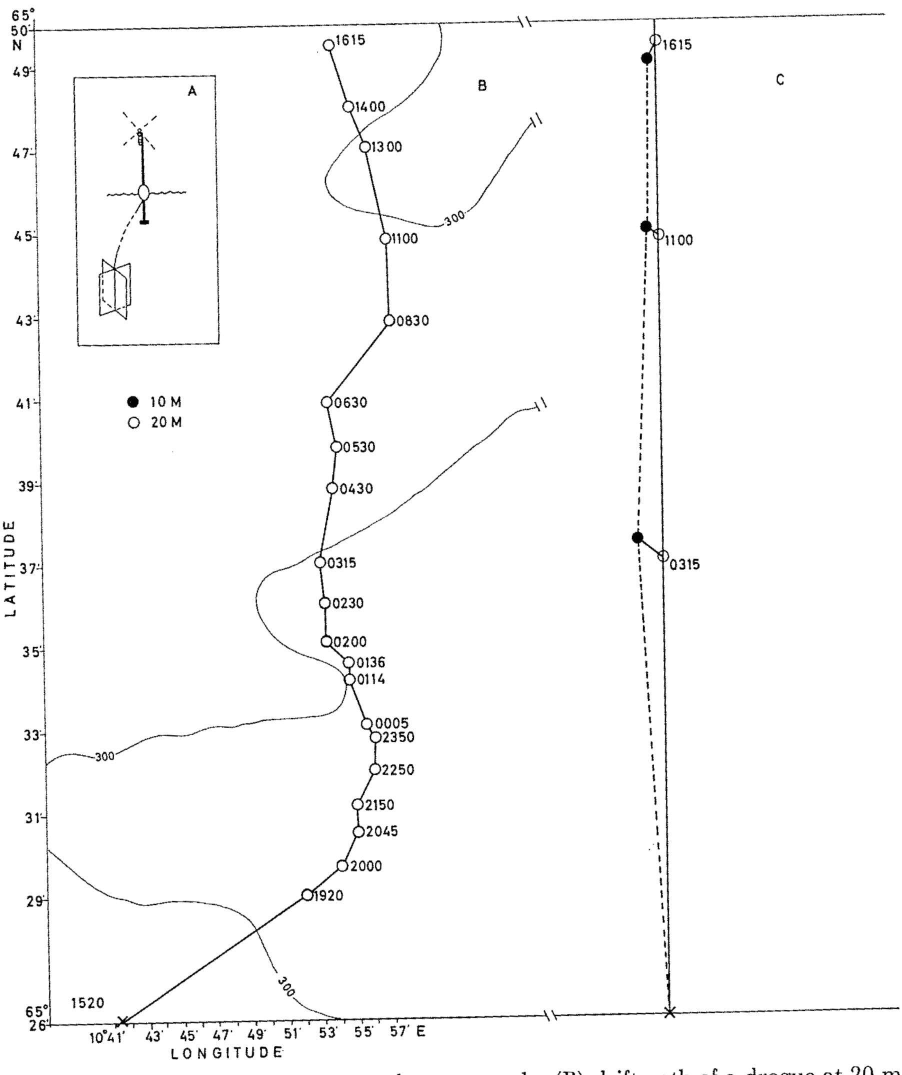

Fig. 10. (A) subsurface drogue, not drawn to scale, (B) drift path of a drogue at 20 m depth off Sklinna in 1964, from 18 April at 1520 hours to 19 April at 1615 hours (local time) and (C) positions of the drogue at 20 m depth compared with positions of drogue at 10 m depth.

4). On the shelf off Ona (station 6) a vortex movement took place during an experiment in 1967 (DRAGESUND and NAKKEN 1968). Thus the larval distribution and drift will vary depending on the location of spawning.

No important difference in the direction and velocity of the current was found between 10 and 20 m during the 1964 experiments (Fig. 10), and none was found between 10 and 40 m in an experiment carried out in 1965 (DRAGESUND and HOGNESTAD 1966).

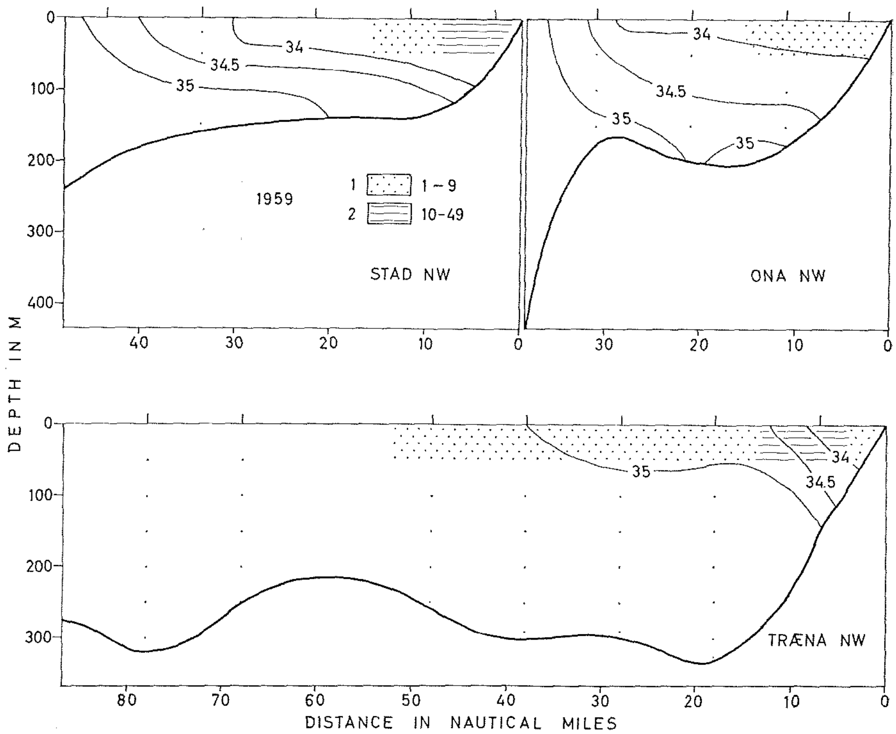

Fig. 11. Distribution of salinity (‰) in three vertical sections seaward from Stad, Ona and Træna, (1) and (2) number of larvae below 1 m² surface.

The seaward extent of larval distribution in 1959 in relation to the salinity distribution is shown in Fig. 11. All larvae in the two southernmost sections (off Stad and Ona) were found in coastal water, whereas farther north (off Træna) they were more dispersed and found also in Atlantic water. However, the most dense concentrations were observed in the core of coastal water where the main transport of larvae took place. The 35‰ isohaline at 0 m in relation to the larval distribution on the shelf between Stad and Lofoten is shown in Fig. 12.

Figs. 12–18 show the larval distribution in 1959–1965 during successive periods. The first survey in 1960 is not included as it was carried out prior to the time of main hatching (Fig. 7). In 1964 the first survey was omitted because sampling was made only at a few stations. The second survey of that year covered a relatively late period in relation to hatching in areas 07 and 06, but about the same period as in other years in area 05.

During the first annual survey period (Figs. 12–18A) the main larval concentrations from the spawning grounds in areas 07 and 06 were found between Stad and Sklinna, extending to the southernmost part of area

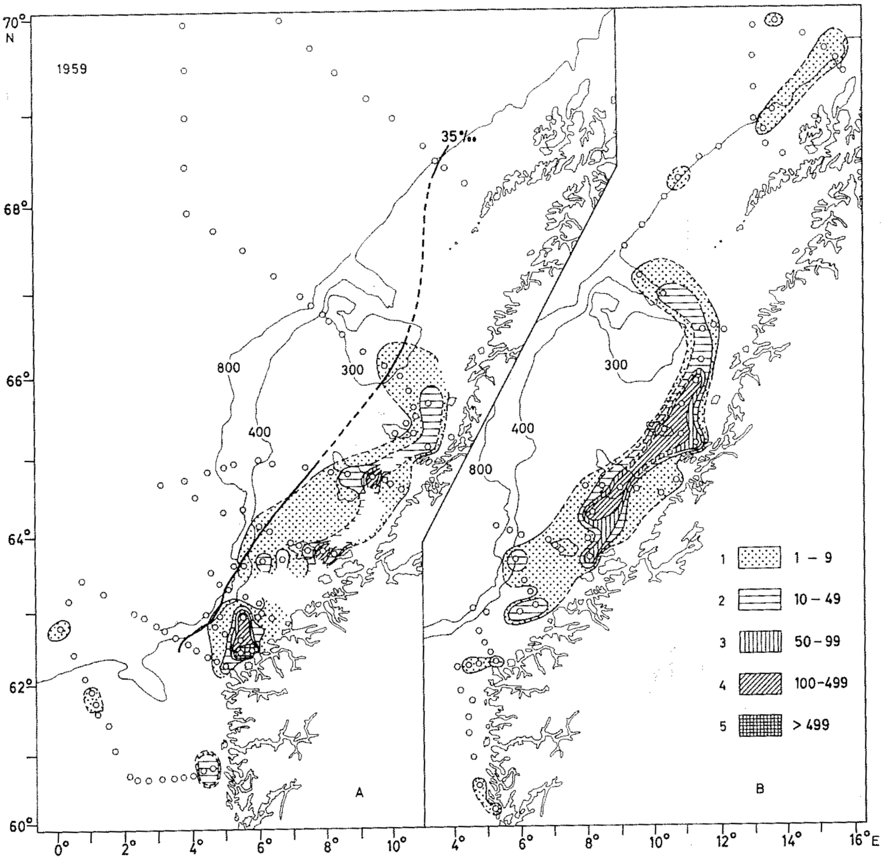

Fig. 12. Distribution of herring larvae in 1959, (A) all length groups (caught with Nansen net), 2–13 April, and the 35‰ isohaline at 0 m, (B) larvae $\geq$12 mm (caught with CBPS), 20–28 April. (1) to (5) number of larvae below 1 m^2 surface. Stations are plotted as circles.

07 in 1959–1961. In 1959, 1961, 1963 and 1964 the distribution in areas 07 and 06 was somewhat more wide than in 1962 and 1965. The distribution pattern was characterized by high larval concentrations near the coast, decreasing seaward and almost no larvae were found outside the edge of the shelf. In the years 1962–1965 larvae were scarce south of Ona, a result of the restricted spawning on the southern grounds.

In 1964 and 1965 the distribution was characterized by two main centres, one off the Møre–Trøndelag coast and the other off the coast between Træna and Eggum. In 1964 larvae from the spawning grounds off Møre (area 07) and Trøndelag (area 06) had already mixed with those from the Lofoten spawning grounds (area 05) when the survey was carried out, whereas in 1965 the larvae from the spawning off Møre–

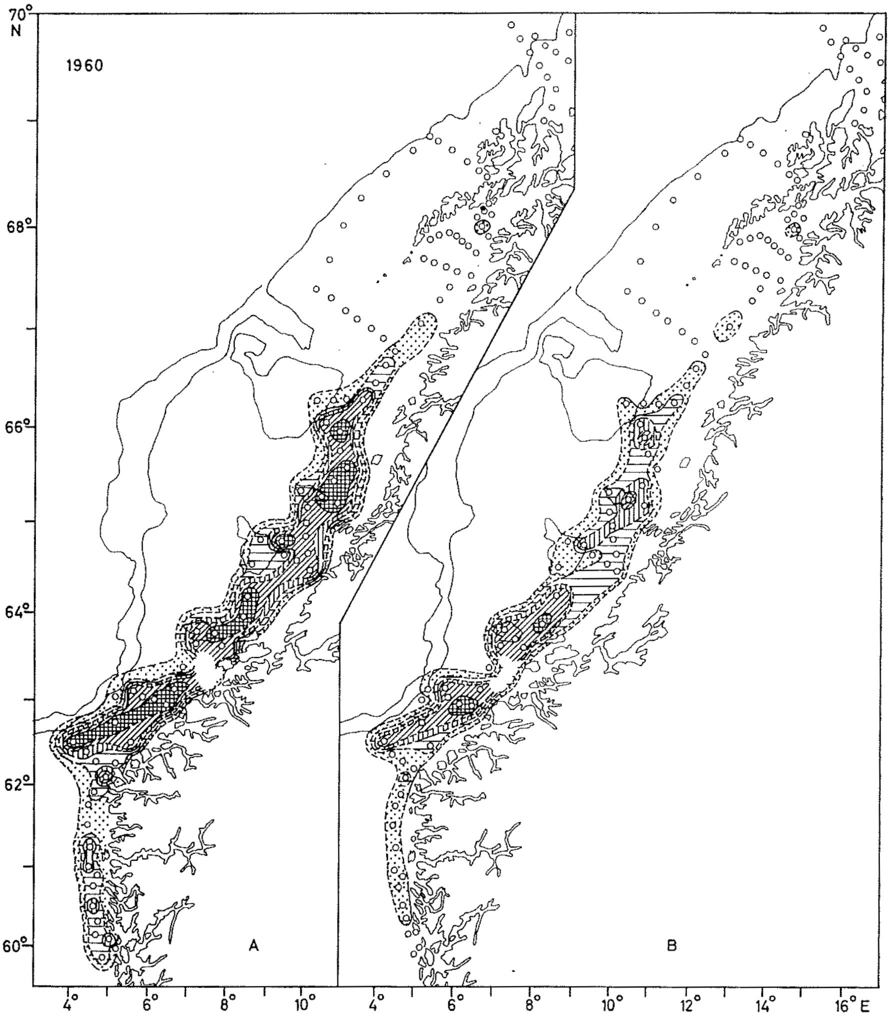

Fig. 13. Distribution of herring larvae 31 March–9 April 1960, (A) all length groups and (B) ≥ 12 mm. Legend as in Fig. 12.

Trøndelag were separated from those hatched at Lofoten. During April of 1964 and 1965 the major part of the larval population was located farther north than at the same time in earlier years (1959–1961), mainly because of the spawning at Lofoten.

In general the abundance of larvae was high during or immediately after the time of the main hatching, especially in 1960 (Fig. 19A). In 1962 and 1965 high catches were restricted to a limited region off Frøya, whereas in 1963 and 1964 relatively low catches were obtained at all sections (1959 is omitted due to lack of data with CBPS). In 1967 evidence

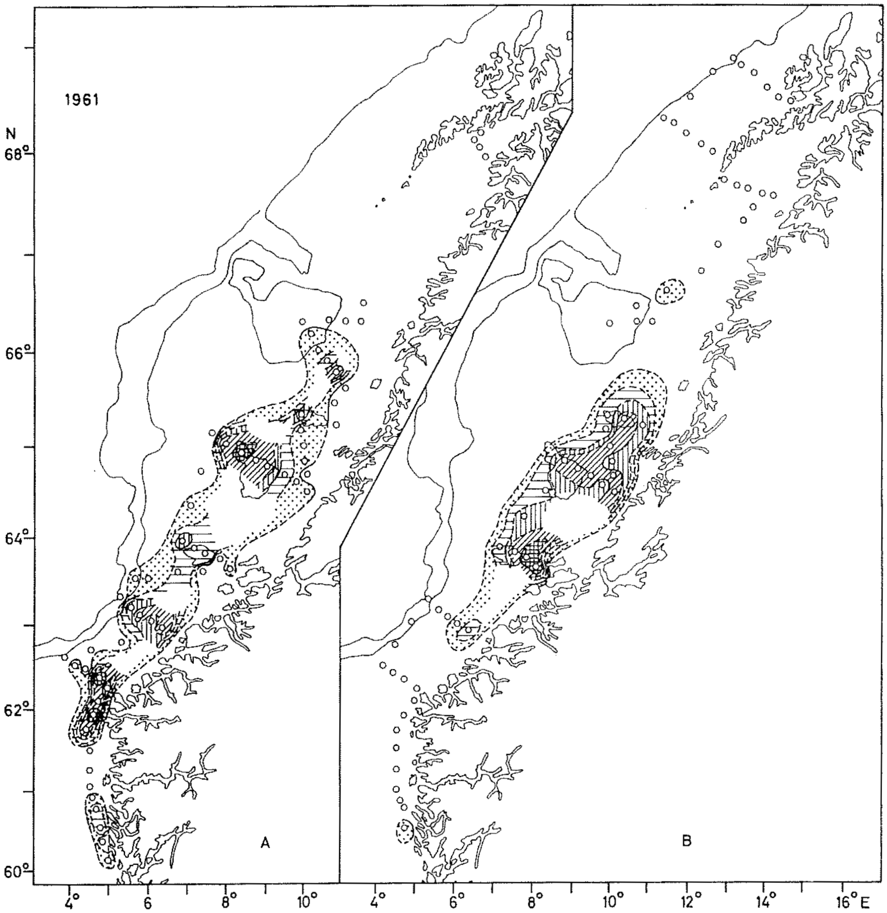

Fig. 14. Distribution of herring larvae in 1961, (A) all length groups, 6–19 April and (B) $\geq$12 mm, 20–29 April. Legend as in Fig. 12.

of a mass mortality of larvae off Møre soon after hatching (i.e. during the growth period between 10 and 12 mm of length) was found by DRAGESUND and NAKKEN (1968). When comparing the distribution and abundance of larvae in relation to subsequent year-class strength, therefore, those having passed the yolk sac stage (i.e. larvae $\geq$12 mm) should be considered separately.

In Figs. 12–18B the distribution of these larvae are shown during the second annual survey period. In 1961, 1962 and 1965 the post yolk sac larvae were concentrated off Frøya and were considerably less abundant south and north of this region. In 1961 larvae also were numerous off Halten. In 1959, 1960, 1963 and 1964 the larvae were more widely distributed. Because of the variable sampling time in relation to hatching, it

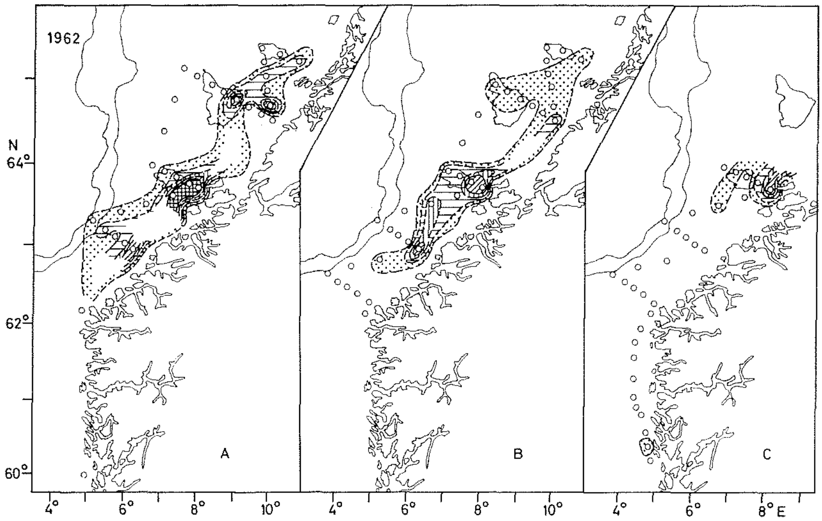

Fig. 15. Distribution of herring larvae in 1962, (A) all length groups, 2–9 April, (B) ≥12 mm, 6–13 April and (C) ≥12 mm, 24–28 April. Legend as in Fig. 12.

is difficult to make a quantitative comparison of the abundance estimates between years. Table 12 shows the percentage of larvae ≥12 mm and of larvae ≥15 mm during the second period of sampling. In 1959 96.3% of the larvae were ≥12 mm, whereas the corresponding figures for the following years were considerably lower, particularly in 1960. Larvae hatched off Lofoten were mainly below 12 mm in length at the time of sampling.

Table 12. Percentage of larvae ≥12 mm and ≥15 mm during the second annual sampling period for each of the years 1959–1965.

Date		Area	No. of stations	Total no. of larvae below 1 m^2 surface	≥12 mm	≥15 mm
1959	23–28.4	07 and 06	30	1435	96.3	53.0
	20–23.4	05	8	31	87.1	45.2
1960	2– 8.4	07 and 06	59	26445	21.9	0.0
	28.3– 2.4	05	2	9	0.0	0.0
1961	21–29.4	07 and 06	22	4824	84.1	13.6
1962	24–27.4	07 and 06	8	1047	32.9	2.7
1963	16–23.4	07 and 06	38	1809	66.1	2.5
	13–16.4	05	3	18	16.7	16.7
1964	13–20.4	07 and 06	34	1224	59.2	30.4
	20–30.4	05	51	3375	29.4	7.1
1965	7–12.4	07 and 06	27	2127	57.3	5.6
	4– 7.4	05	15	443	24.4	0.0

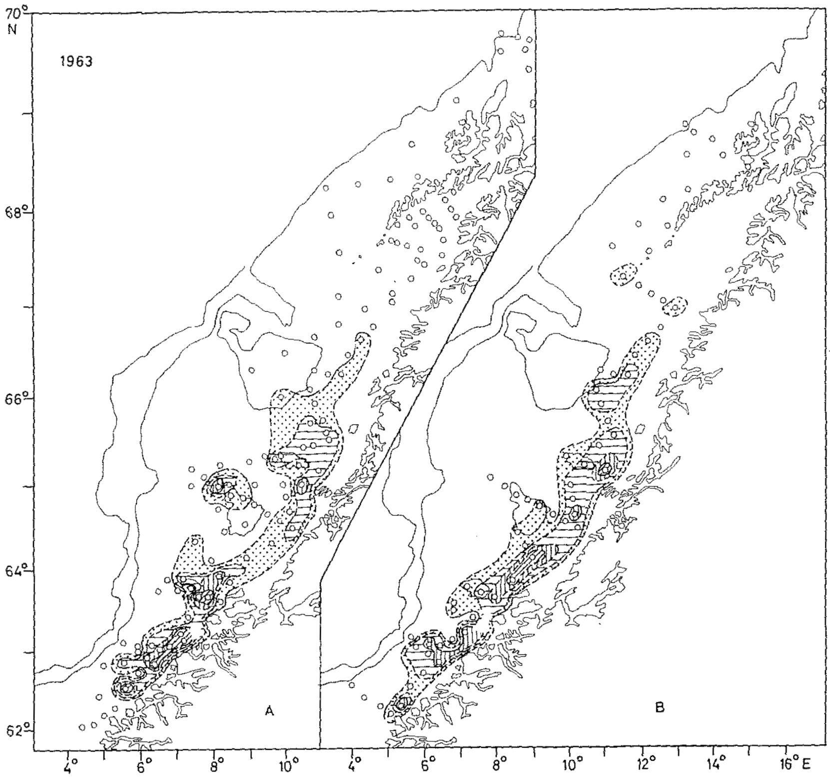

Fig. 16. Distribution of herring larvae in 1963, (A) all length groups, 2–10 April and (B) ≥12 mm, 13–23 April. Legend as in Fig. 12.

The number of larvae ≥12 mm and ≥15 mm per station at the sections off Stad, Ona, Frøya, Halten, Sklinna and Træna is illustrated in Fig. 19B (1960 is omitted). Less variable values were found at the different sections for post yolk sac larvae ≥12 mm in 1959, 1963 and 1964 than in 1962 and 1965. In 1961 a marked displacement northward had taken place between the two sampling periods, and the larvae were evidently more concentrated during the second than during the first period of sampling. The abundance off Frøya and Halten in 1961 was markedly higher than in the other years. The number of larvae ≥15 mm was low except for 1959 and 1961. More than 50% of the larvae caught in 1959 were ≥15 mm. This may have resulted in an underestimate of the abundance of the 1959 larvae compared with other years as the catching efficiency of CBPS is lower for larger than smaller larvae. Mortality from hatching up to the sampling stage adds also to this underestimate.

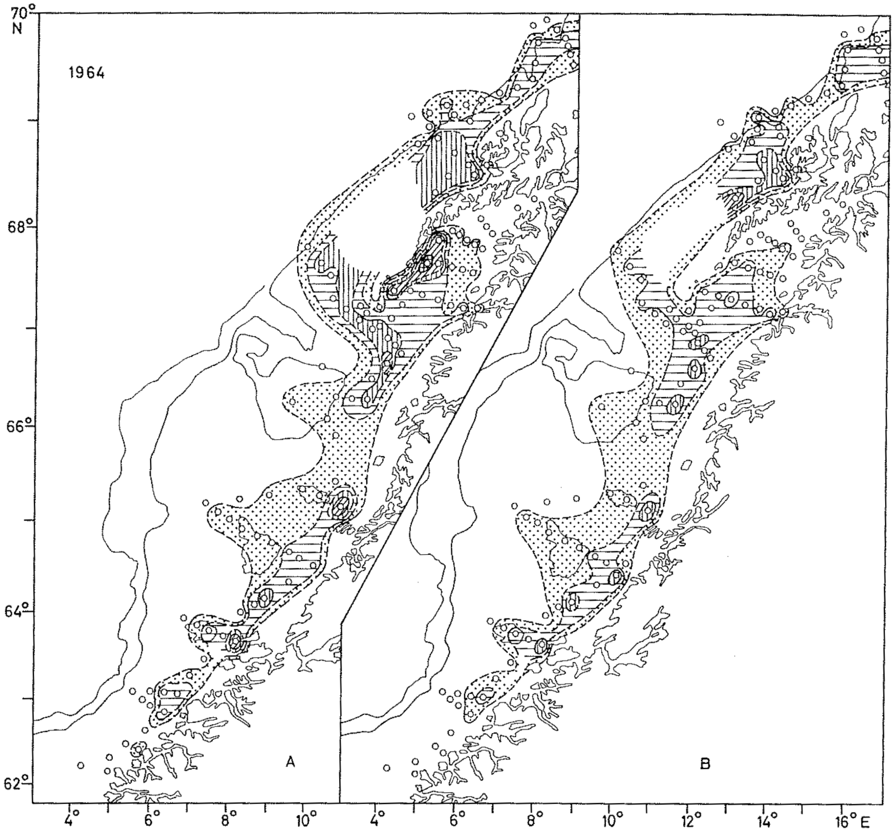

Fig. 17. Distribution of herring larvae 13–18 April 1964, (A) all length groups and (B) $\geq$12 mm. Legend as in Fig. 12.

The following characteristic features of the distribution and abundance of the larvae can be listed:

1) the abundance was relatively high during the post yolk sac stage in 1959;

2) the highest abundance just after hatching was found in 1960, and the exceptionally high figures found at all sections that year indicated a high hatching success over a wide spawning area;

3) the 1961 larvae were also numerous after hatching and throughout the post yolk sac stage, though more marked concentrated during the second than during the first period of sampling;

4) the 1962 and 1965 larvae were more concentrated and had a more patchy distribution than in other years;

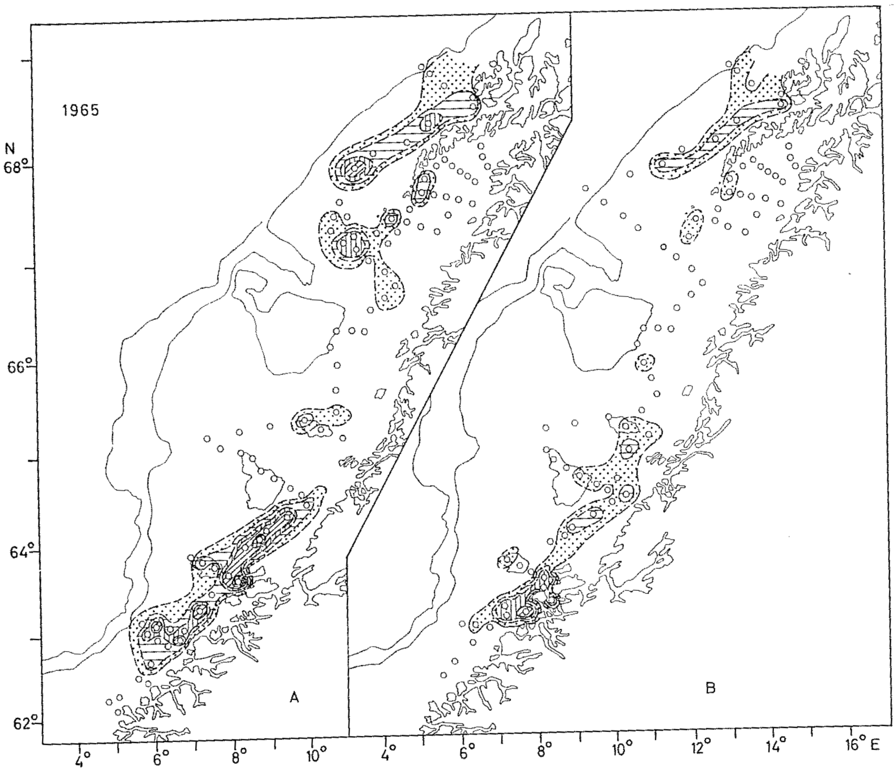

Fig. 18. Distribution of herring larvae in 1965, (A) all length groups, 29 March–6 April and (B) ≥12 mm, 4–12 April. Legend as in Fig. 12.

5) the distribution in 1963 and 1964 was widespread, particularly during the second period of sampling, but the abundance at the different sections were low;

6) the abundance estimates at the different sections between Stad and Træna suggest that the variation in the size of the spawning stock was reflected in the larval abundance figures obtained in the period just after hatching.

As indicated by the distribution charts (Figs. 12–18) a northward displacement of the larval concentrations in the southern part of the survey area was observed in most of the years. In the northern part of the area time intervals between surveys were too short to allow any marked northward drift to be recorded. However, in 1959 a displacement northward off Træna was traced. To illustrate the drift from a known spawning site near Grip, the larval distributions during two successive periods of the survey in 1968 are shown (Fig. 20). The spawning site was located on

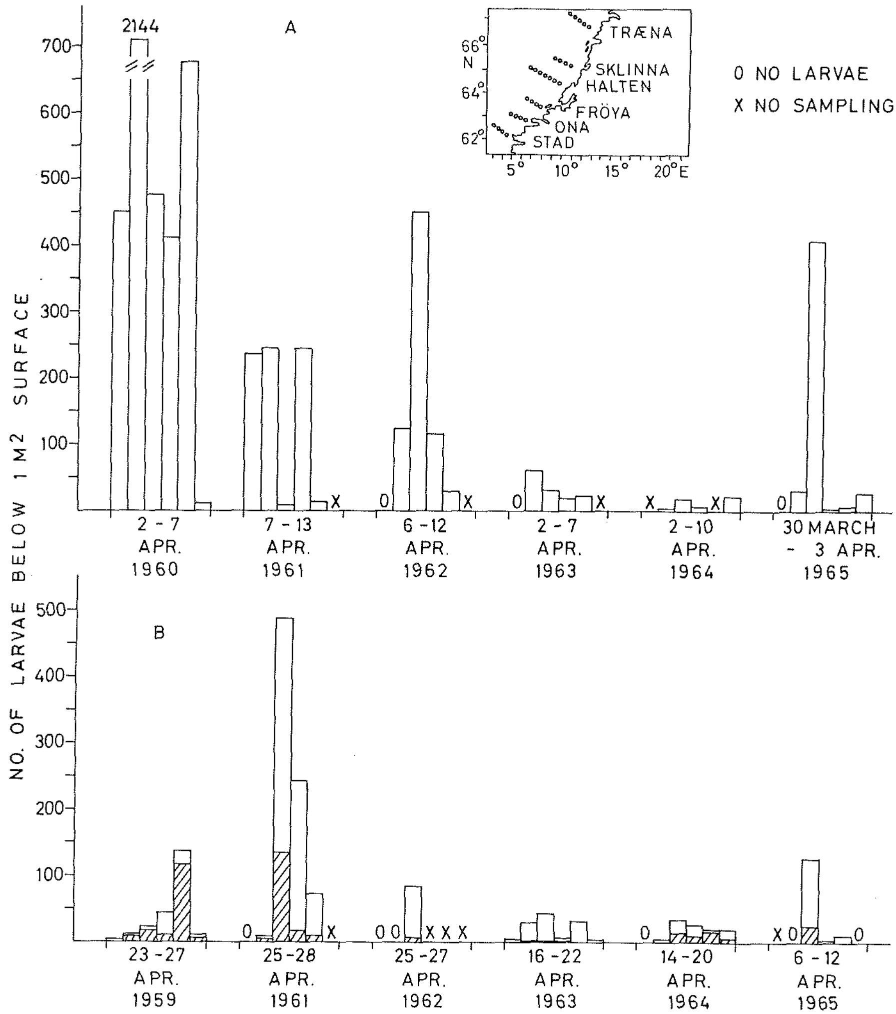

Fig. 19. Number of larvae below 1 m² of surface per station at six sections, from left to right: Stad, Ona, Frøya, Halten, Sklinna and Træna, (A) larvae of all length groups, (B) of larvae ≥ 12 mm and ≥ 15 mm (diagonal shading).

23 March when eggs were collected with dredge. Adult herring were recorded near the bottom some days earlier at the same locality. The eggs were examined and fertilization was estimated to have taken place from 5 to 10 March. Further inspections were carried out from 25 to 31 March, and the larvae were now nearly at the hatching stage. A detailed sampling programme was started, and during the following few days larvae were numerous just north of the spawning site. Assuming that the majority of the larvae were derived from this spawning site, the drift was

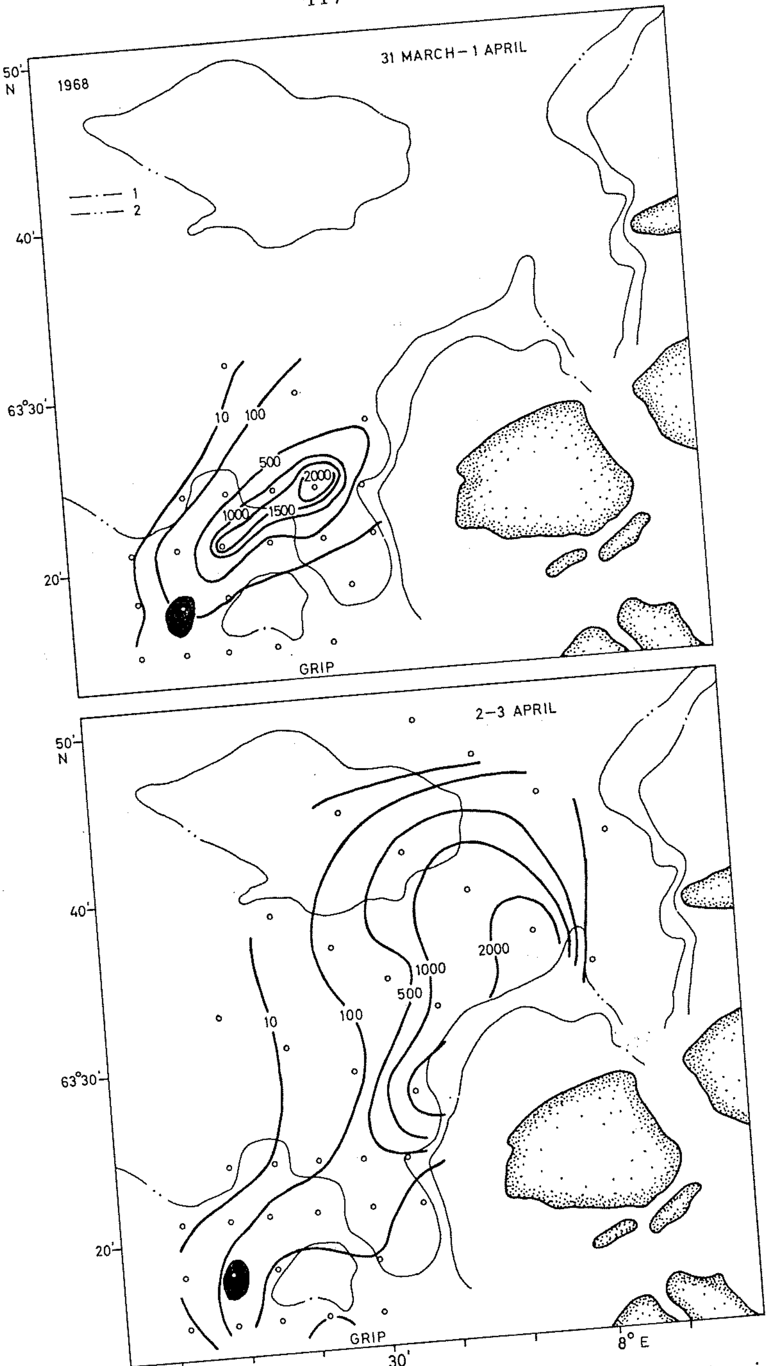

Fig. 20. Larval dispersion from a spawning site (black) off Grip. Isolines indicate the number of larvae below 1 m² of surface, (1) and (2) are the 100 and 200 m contour lines, respectively.

estimated to 0.67 knots by measuring the distance between the centres of concentrations in two successive sampling periods. The estimated drifting velocity was slightly lower than indicated by the subsurface drogue measurements farther north off Frøya and Sklinna in 1963–1965 (Table 11).

Since the larvae are mainly found in the upper 50 m, it may be assumed that the force and direction of the wind play an important role in determining the distribution pattern of larvae. Although the coastal current is directed northward, the surface water may be turned in various directions by the wind force. In periods with southerly winds the larvae will be transported northwards relatively quickly, whereas the drift will be hampered when winds from north prevails as the wind produces not only a pure wind current to the right of the wind direction, but also a relative current that runs parallel to the coast (EKMAN 1923, SVERDRUP, JOHNSON and FLEMING 1946). Therefore, wind data from the meteorological stations Ona, Nordøyane and Skomvær have been analysed (Fig. 21).

The wind distribution in 1961 presumably resulted in a rather strong northward flow of water in the southern area but a weak northward flow in the northern area. In 1962 the same trend was found, although the wind vectors were smaller. In these years the wind distribution thus may have hampered the northward drift of the larvae from the spawning region in area 06, and may also partly have accounted for the high concentrations of larvae found between Frøya and Halten. For 1959, 1960, 1963 and 1964 the wind vectors indicate a prevailing strong northward flow of water resulting in more widespread north–south distribution of larvae.

The larval drift also may be studied in relation to the distribution of recovered drift bottles released in larval patches at various places during the surveys in 1961 and 1963–1965 (Fig. 22). All the bottles recovered in 1961 were found within thirty days after release in the coastal belt, and the high frequency of returns indicates that they were transported northwards close to shore. The 1963 recoveries showed a quite different distribution. None of the bottles released was recaptured within thirty days, and all the returns are from areas farther north (areas 05, 04 and 03). This distribution indicates that the bottles drifted northwards at some distance from the coast during the first period after release. Bottles released in 1964 and 1965 in area 07 were frequently recovered in areas 07 and 06, indicating a drift nearer to the coast in those years. Bottles recovered within sixty days in 1964 were distributed somewhat farther north than in 1965, indicating a faster drift in 1964. The drift of bottles along the coast from Møre to Finnmark was clearly demonstrated, and it is likely that larvae hatched off Møre are transported to this area.

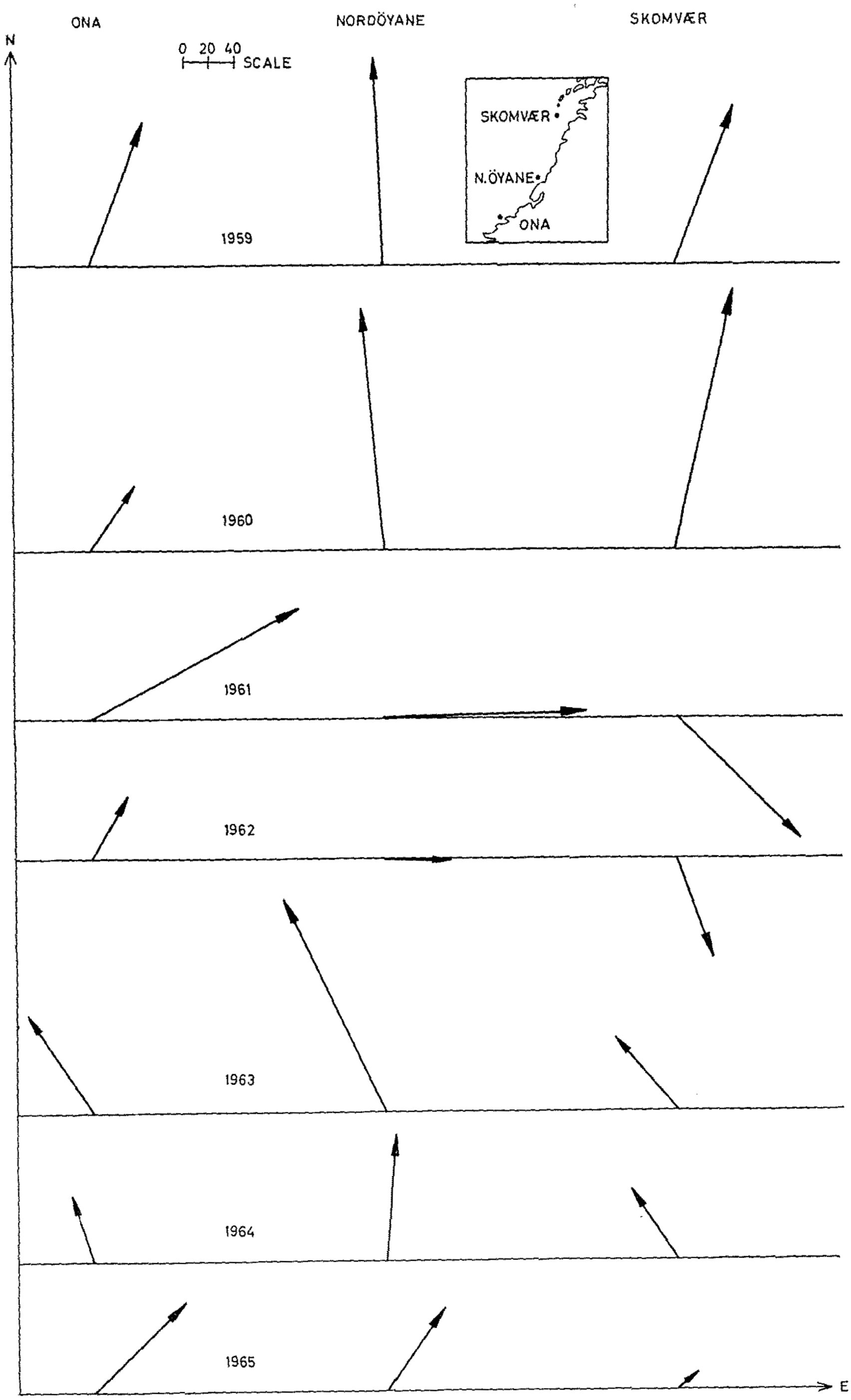

Fig. 21. Average resultant wind vectors for the period March–April in 1959–1965.

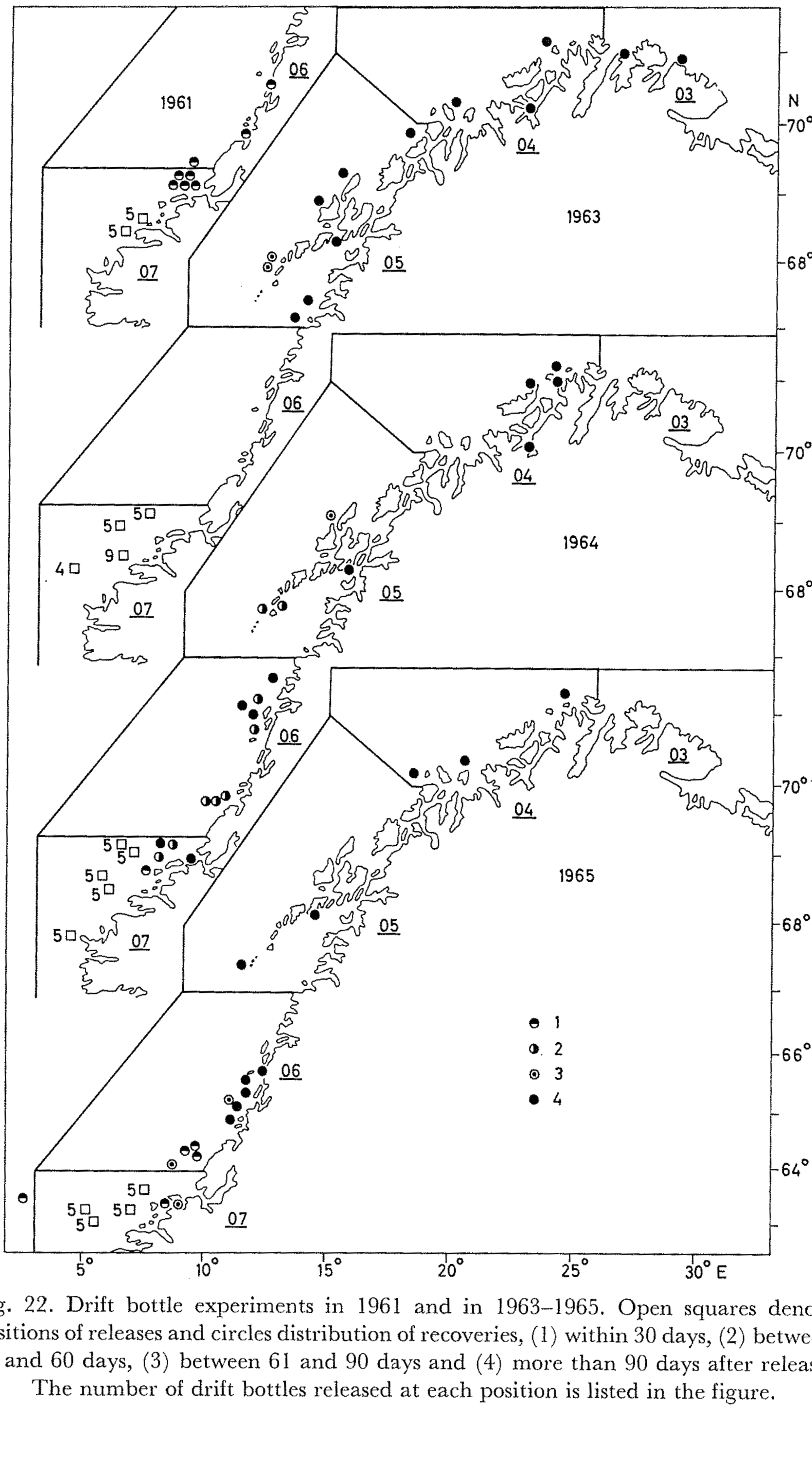

Fig. 22. Drift bottle experiments in 1961 and in 1963–1965. Open squares denote positions of releases and circles distribution of recoveries, (1) within 30 days, (2) between 31 and 60 days, (3) between 61 and 90 days and (4) more than 90 days after release. The number of drift bottles released at each position is listed in the figure.

The general drift pattern of larvae can be summarized as follows:

1) an extensive northward drift of larvae takes place from all the spawning grounds along the coast;
2) larvae hatched south of Stad will probably be transported northward near the coast, but a more offshore distribution is possible when they pass the region off Møre;
3) larvae drifting northward along the coast may follow a vortex movement over the southern part of the Møre plateau;
4) larvae being transported offshore will most likely be deflected towards the coast again off Grip–Frøya where the northward flow is relatively rapid before it slows down again off the coast between Træna and Lofoten;
5) during the northward drift part of the total larval population will accumulate at the entrance of the fjords along the Norwegian coast, and this part is probably greatest when the spawning takes place in the southernmost region (within area 08).

LARVAL LENGTH IN RELATION TO TIME OF SPAWNING

The length distribution of larvae in different regions between Bergen and Andenes is shown in Figs. 23 and 24. During the first period of sampling in 1959–1961 larger modal lengths were found between Stad–Ona and Grip–Frøya than south and north of these regions. It is assumed, therefore, that spawning started in the central part of the main spawning district (i.e. between Stad and Ona), and that the onset of spawning occurred slightly later to the south and north of this area. In 1962–1964 the largest modal lengths were found off Grip–Frøya, indicating that spawning started first between Ona and Grip. However, in 1962 only small differences in lengths were found in relation to both region and time. The late onset and the restricted duration of spawning that year presumably led to a mass spawning over a relatively short period resulting in smaller variations in lengths. Similarly, no marked trends were found in the length distributions of larvae between Stad and Halten in 1965. This suggests simultaneously hatching on all spawning grounds.

Table 13 lists the coefficients of variation (v) for the different length distributions

$$v = \frac{s}{\bar{l}} 100$$

where s is the standard deviation and $\bar{l}$ the mean length.

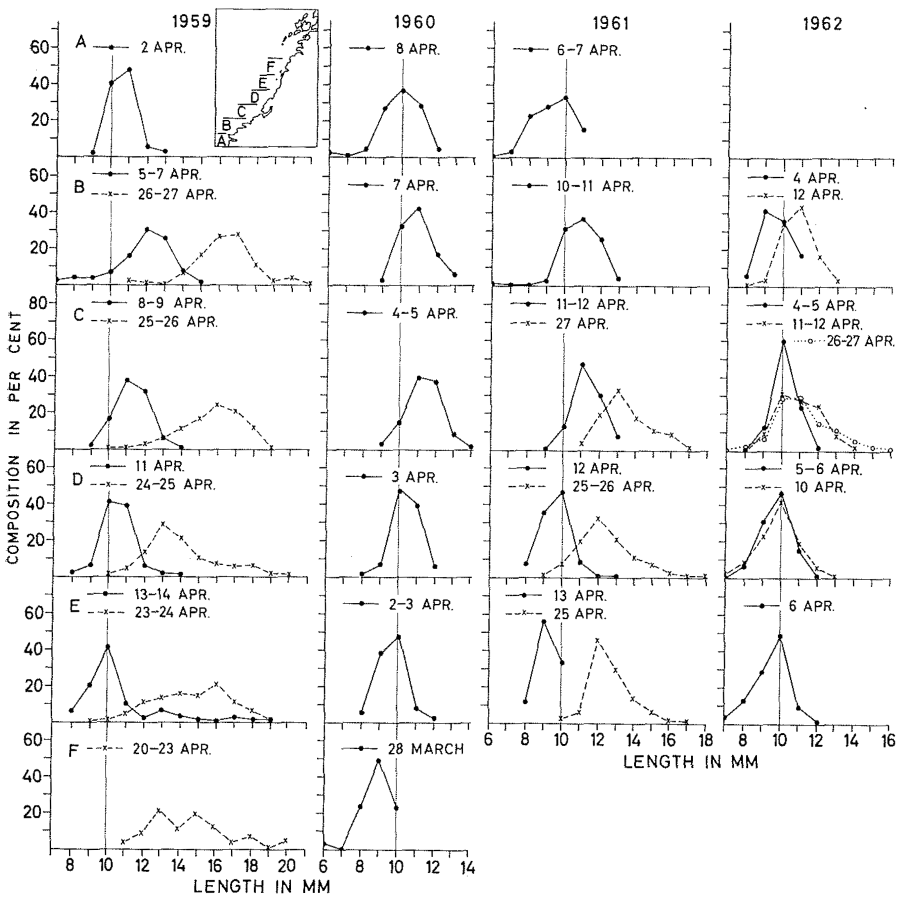

Fig. 23. Length distribution of larvae caught with CBPS in 1959–1962, (A) Bergen-Kinn, (B) Stad-Ona, (C) Grip-Frøya, (D) Halten, (E) Sklinna and (F) Træna. Data on larval lengths from CBPS and Nansen net are pooled for the second part of the 1959 survey (20–27 April). Prior to this period the larvae were caught with Nansen net.

The coefficients were relatively high in 1959, reflecting the long duration and low rate of spawning (Table 10). Although the spawning seasons were long, the coefficients of variation for 1960 and 1961 were lower than for 1959, suggesting that the main hatching was concentrated over a shorter period these years. This is also supported by the relatively high spawning rate and the high numbers of larvae per station in 1960 and 1961 (Fig. 19).

In 1964 the length distributions were bimodal in most of the regions during the second period of sampling, probably because of the difference in spawning time between the spawning regions off Møre–Trøndelag and off Lofoten and also within the Møre–Trøndelag spawning regions. The

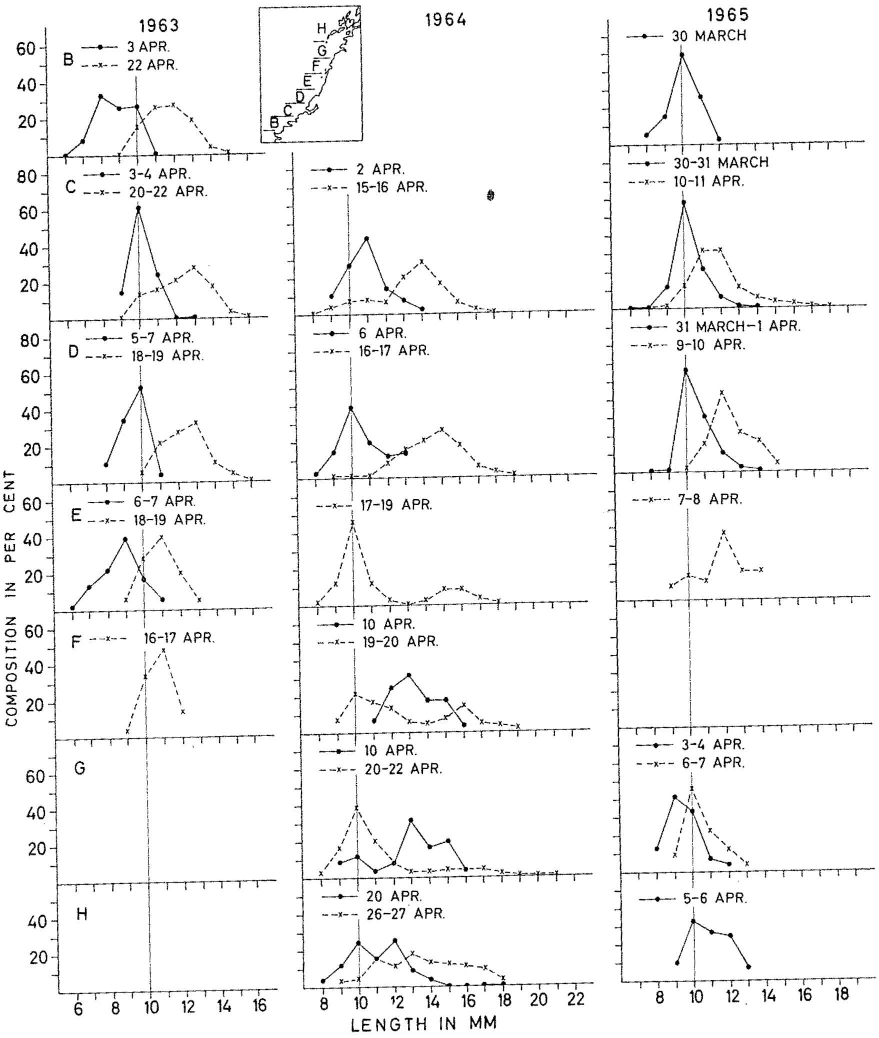

Fig. 24. Length distribution of larvae caught with CBPS in 1963–1965, (B) Stad-Ona, (C) Grip-Frøya, (D) Halten, (E) Sklinna, (F) Træna, (G) Lofoten and (H) Eggum-Andenes.

age composition of the spawners may explain the differences in spawning time between and within the regions, the recruits spawning later in the season than repeat spawners. The largest larvae found in area 06 may have been produced by old fish which spawned relatively early in the season, whereas the smaller larvae probably originated from recruits which spawned slightly later. The larger larvae caught between Lofoten and Andenes were most likely transported from spawning grounds south of this region.

Table 13. Coefficients of variation (v) for larvae caught in different regions between Bergen and Andenes during the larval surveys in 1959–1965.

Region	1959			1960			1961		
	Date	No.	v	Date	No.	v	Date	No.	v
Bergen-Kinn	2.4	39	7.1	8.4	122	9.8	6–7.4	129	11.6
	28.4	8	14.3	—	—	—	—	—	—
Stad-Ona	5–7.4	443	14.1	23.3	114	13.1	10–11.4	245	8.6
	26–27.4	101	10.7	7.4	499	7.8	28.4	22	6.1
Grip-Frøya	8–9.4	141	8.6	23.3	294	8.8	11–12.4	383	7.5
	25–26.4	139	10.8	4–5.4	400	7.5	27.4	630	10.0
Halten	11.4	120	9.7	24.3	38	—	12.4	254	8.0
	24–25.4	133	14.4	3.4	148	7.0	25–26.4	1074	12.0
Sklinna	13–14.4	65	22.4	25.3	123	7.7	13.4	142	6.7
	23–24.4	450	14.0	2–3.4	400	6.9	25.4	344	8.4
Træna	20–23.4	65	14.8	28.3	55	9.1	—	—	—
	1962			1963					
Stad-Ona	4.4	53	8.8	3.4	175	11.4			
	12.4	378	8.2	8.4	29	7.3			
	—	—	—	22.4	161	10.3			
Grip-Frøya	4–5.4	1339	6.5	3–4.4	271	6.1			
	11–12.4	1129	11.1	7–8.4	266	7.6			
	26–27.4	674	13.4	20–22.4	341	11.8			
Halten	5–6.4	509	9.1	5–7.4	50	7.7			
	10.4	480	10.9	18–19.4	190	9.8			
Sklinna	6.4	277	9.7	6–7.4	139	11.3			
	—	—	—	18–19.4	139	8.2			
Træna	—	—	—	16–17.4	56	6.6			
	1964			1965					
Stad-Ona	—	—	—	30.3	38	8.7			
	—	—	—	—	—	—			
	—	—	—	—	—	—			
Grip-Frøya	2.4	46	10.1	30–31.3	1419	7.7			
	15–16.4	110	14.6	10–11.4	756	12.1			
Halten	6.4	42	12.3	31.3–1.4	835	7.6			
	16–17.4	107	6.3	9–10.4	56	9.0			
Sklinna	17–19.4	144	22.5	2.4	14	3.0			
	2.5	45	27.5	7–8.4	38	12.4			
Træna	10.4	29	9.9	—	—	—			
	19–20.4	185	21.2	—	—	—			
Lofoten	10.4	37	15.2	3–4.4	132	10.2			
	20–22.4	503	21.1	6–7.4	103	9.6			
	29–30.4	104	23.0	—	—	—			
Eggum-Andenes	20.4	84	18.0	5–6.4	110	10.2			
	26–27.4	78	16.4	—	—	—			
	27–29.4	290	13.2	—	—	—			

Also the mixture of relatively young recruit spawners and old repeat spawners (off Møre and Trøndelag) may have contributed to the expanded bimodal length distribution of larvae. According to BLAXTER and HEMPEL (1963) and HEMPEL and BLAXTER (1967) young recruit spawners produce slightly smaller eggs and hence smaller larvae. The difference in egg weight between the youngest recruit spawners and the next age group in Norwegian herring was about 10–14%, so the difference in egg size and spawning date worked in the same direction and contributed to the bimodal length distribution of larvae.

No such bimodality in the length distribution was found in 1965 when both young recruits and old repeat spawners were present on the southern spawning grounds off Møre. However, the old fish made up only 15–20% of the stock in this region. In 1965 both the duration and the time of main spawning were nearly the same over the entire spawning area from Ona to Lofoten. This resulted in smaller length variations compared with 1964.

DISCUSSION

SPAWNING CHARACTERISTICS

The relationship between year-class strength and the following factors will be discussed:

1) age structure and size of the parent stock;
2) location of spawning;
3) duration and time of spawning.

The effect of the age structure of the parent stock on the year-class strength has been discussed by MARTI (1959) and BRIDGER (1961). They suggested that older herring produce bigger eggs resulting in stronger larvae with better yolk reserves. BLAXTER and HEMPEL (1963) found that the egg size and survival time on yolk reserves depend little on the age structure of the parent stock, although very young recruits produce slightly smaller eggs and larvae. Thus, in years when the stock consists mainly of very young spawners, the viability of the progeny may be reduced. During the 1950s young recruits were relatively abundant in 1954 (ØSTVEDT 1963). In the period 1959–1965 the influx of young recruit spawners was highest in 1964 and 1965, but also in 1963 recruits of the 1959 year-class appeared on the spawning grounds in significant numbers. The 1963 and 1964 year-classes were of average strength, whereas those of 1954 and 1965 were very poor (Fig. 25). From 1955 to 1962 repeat spawners and relatively old recruits dominated in the stock, and in most of these years poor year-classes were produced. Accordingly no apparent relationship can be established between the age structure of the parent stock and subsequent year-class strength.

In Fig. 25A the absolute size of the parent stocks for the period 1947–1962 is plotted against subsequent year-class strengths at six years of age. The absolute size of the spawning stocks during the period 1947–1952 has been derived from data given by ØSTVEDT (1963). The abundance indices showed that stock size remained at about the same level during this period, and was somewhat lower than that which occurred in the mid-1950s. The average abundance figure for the stock size during the period 1947–1952 was about 83% of the average figure for the years 1954–1956.

Estimates of year-class strength for adults are complicated by the wide range of ages over which individuals of a given year-class attain sexual maturity. However, knowing the size of the spawning stock, an estimate of year-class strength can be obtained by calculating the abundance of the year-class at an age when most of the year-class has entered the adult stock. According to ØSTVEDT (1958) the mean age at first spawning for herring of northern growth type (slowly growing herring) varies between 5.1 and 7.5 years, and for herring of southern growth type (rapidly growing herring) between 4.1 and 4.5 years. The strength of a year-class as adults, therefore, has been estimated at an age of six years (Fig. 25A).

During the period 1947–1962, two exceptionally rich year-classes were spawned, those of 1950 and 1959. The 1959 year-class was spawned when the adult stock was about half the size of that in 1950. During the period 1947–1956 the spawning stock was two to three times larger than in 1959, without producing any rich year-classes. In 1957 and 1958 the stock was also more abundant than in 1959, and again very poor year-classes occurred. The survival of the herring spawned in 1959 must have been relatively high since a rich year-class was spawned by a much smaller spawning stock than the stock which was present during the previous eight years. Similarly the survival was relatively high for herring spawned in 1960, although markedly lower than for those spawned in 1959. The 1962 year-class was very poor, being of the same magnitude as the year-classes spawned during the 1954–1958 period. The 1963–1965 year-classes had not reached the adult stage in 1968 and cannot be compared with the previous year-classes in the adult stock. Investigations carried out during the 0-group stage (DRAGESUND 1970) indicated that the 1963 and 1964 year-classes were slightly more abundant than that of 1961, whereas the 1965 year-class was very poor and probably less abundant than that of 1962 (Fig. 25B).

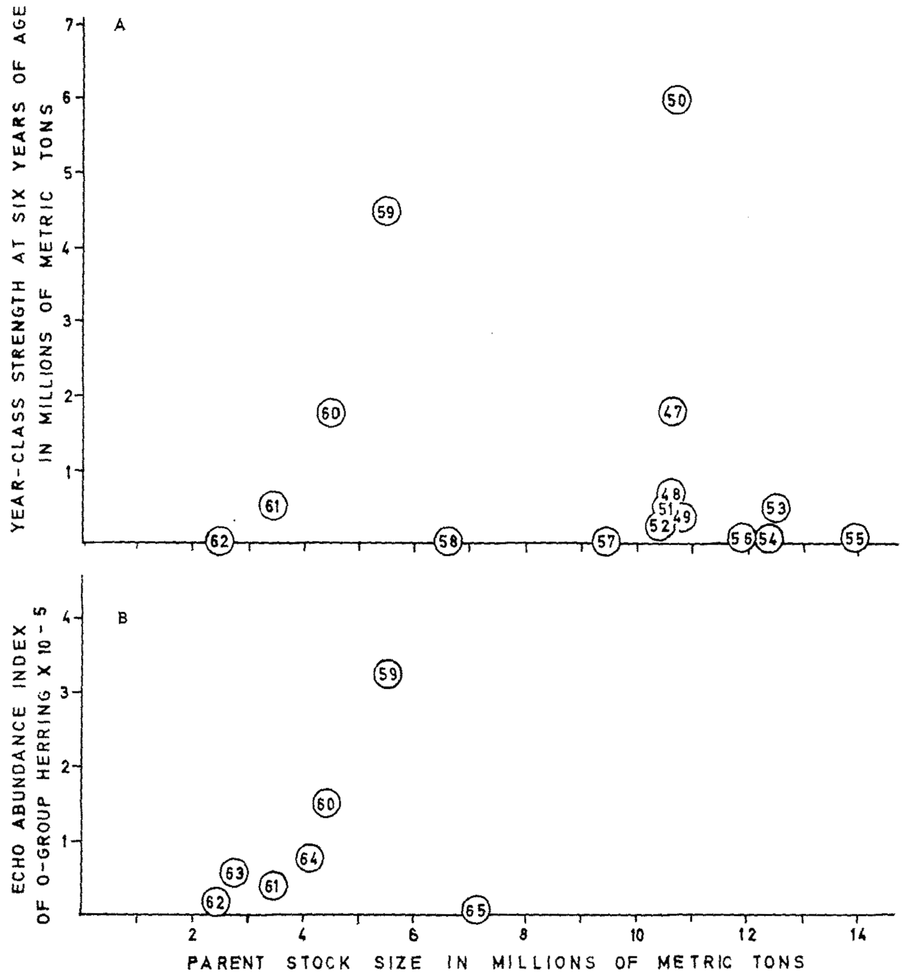

Fig. 25. Relationship between the parent stock size and the subsequent year-class strength, (A) at six years of age for the 1947–1962 year-classes and (B) at about six months of age for the 1959–1965 year-classes. The respective year-classes are indicated inside each circle.

The correlation diagram suggests that within the period considered, a relationship existed between the stock and the abundance of the resulting year-class when conditions for the progeny were favourable. However, in most of the years year-class strength was determined by other factors which completely ruled out the effect of the size of the parent stock. Thus, in at least twelve of the nineteen years during the period 1947–1965, the size of the parent stock has apparently not been the primary factor controlling subsequent year-class strength. In the years when numerous year-classes were produced as in 1950 and 1959 other factors (as for instance a more widespread distribution of the spawning grounds and a longer duration of spawning) may have given rise to favourable conditions for the progeny.

In the years 1948–1959 the main spawning took place gradually farther north (DEVOLD 1963) and in 1959–1965 the most important spawning centre was concentrated within area 07 between Stad and Grip. The main spawning grounds within area 06 were located off Halten–Sklinna, and no change in location could be recorded in this area during the period of investigation. In the 1950s spawning off Halten–Sklinna was observed by WIBORG (1954, 1956) and YUDANOV (1962). The locations of spawning off Møre–Trøndelag given by YUDANOV for the period 1959–1965 agree fairly well with the results of the present investigation. Spawning in the area 05 took place mainly during the period 1963–1965. YUDANOV (1962, 1964, 1966) found insignificant spawning in the Lofoten region in 1959, 1961 and 1962, whereas in 1960 a major spawning was found on the banks between Lofoten and Andenes. Spawning in this region has also occurred in previous years as pointed out by RUNNSTRØM (1934), AWERINZEW (1935), RASS (1939) and MARTI (1956).

In the 1930s spawning was found at certain places along the entire coast from Lindesnes to Vesterålen (RUNNSTRØM 1934, 1941a), i.e. off the southwest coast between Lindesnes and Bergen, off the Møre coast and on the banks off Lofoten. The most important spawning region during this period, however, was located within area 08 off the southwestern coast of Norway. Thus, a general restriction of the spawning area has taken place during the 1950s and 1960s, especially in the southernmost spawning region (within area 08) at the same time as the main spawning centre moved farther north. The probability is that the spawning area is more extensive when the spawning stock is large than when the stock size is small. Also the age structure of the spawning stock may have an effect on the extension of the spawning area. However, the change and restriction in spawning area found in 1959–1962 could not only be attributed to the decrease in the size of the spawning stock but also to a real shift in the spawning migration.

DEVOLD (1963) demonstrated that the stock arrived at the coast in area 07 increasingly farther north during the period 1950–1962. During the early 1950s a major part of the stock migrated southward along the coast for spawning, but this did not occur after 1959. The fact that herring shift from one spawning ground to another during their life span is also supported by tagging experiments (DRAGESUND 1961, 1962). Herring tagged on the spawning grounds between Bokn and Stolmen in 1957 and 1958, migrated to the spawning grounds off Møre–Trøndelag the following years. Moreover, the stock component spawning off Lofoten during the period 1963–1966 did not appear on these spawning grounds the following two years, but mixed with the component migrating towards the spawning grounds off Møre–Trøndelag (Devold 1968, Jakobsson 1968). This change in location of maximum spawning may have resulted in a simultaneous change in the time of spawning.

To investigate the relationship between the duration of the main spawning period and subsequent year-class strength, the spawning rate has been plotted against year-class strength at six years (Fig. 26A) and at six months (Fig. 26B). The diagrams suggest that high spawning rates resulted in poor year-classes, whereas in years when the main spawning was prolonged stronger year-classes were produced. However, this did not fit in for all year-classes, e.g. those of 1951 and 1953–1955. Long spawning periods often result in prolonged hatching, and it is possible that a larger number of larvae can find suitable and abundant food when they are hatched over a long period than when hatching is restricted in time.

Within the period 1950–1965 the time of main spawning varied (Fig. 5), but no special trend in variation was found. However, in general the main spawning occurred later than it had previously in this century (Aasen 1962, Devold 1963). Between 1904 and 1920 the adult herring arrived at the coast already in October to December, and the main spawning, which took place within area 08, probably commenced earlier than at present time. During the period from 1929 to 1959 the spawning time changed markedly in the spawning region within area 08 (Fig. 27). From 1929 to 1932 the main spawning took place at the beginning of February, and from 1933 to 1939 it occurred in the second half of February. The main spawning time for the period 1929–1939 has been derived from data of Rasmussen (1940) by adding ten days to the onset of spawning given in his paper. During the 1950–1959 period the spawning in area 08 occurred during the first half of March. In area 07 (i.e. between Kinn and Grip) no marked change could be found, although the spawning in 1961–1963 took place somewhat later than in the previous years.

During the last three decades the main spawning time thus changed simultaneously with a progressively northward displacement of the main spawning centre. The change in location of maximum spawning and the variations described in spawning time may have resulted in variations in the environmental conditions for the larvae during the period just after hatching. The most striking change is the absence of spawning on the southernmost grounds, between Bokn and Stad, since 1959. In the 1930s and 1940s when the main spawning took place in this region, rich year-classes occurred more frequently (Marti and Fedorov 1963, Devold 1963). On the other hand, in the period 1904–1920 when spawning also

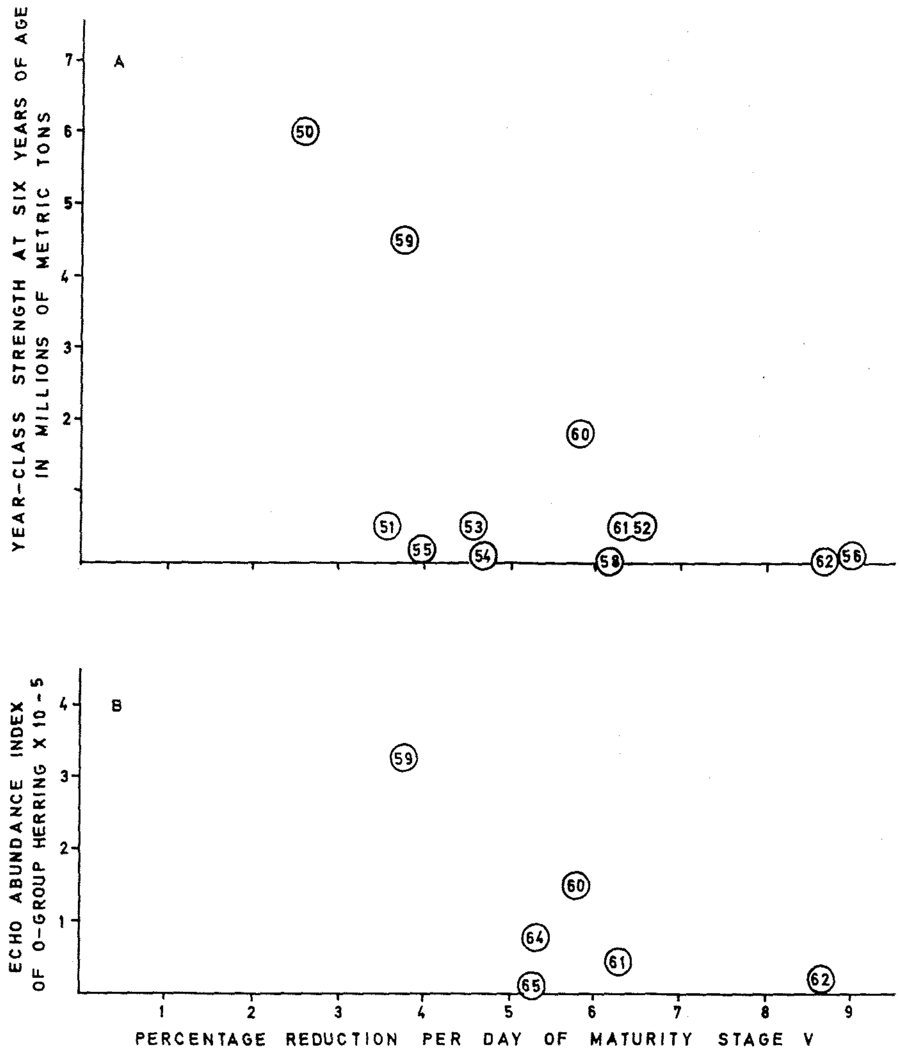

Fig. 26. Relationship between the spawning rate (percentage reduction per day of maturity stage V) within areas 08 and 07 during the spawning seasons in 1950–1965 and subsequent year-class strength, (A) at six years of age for the 1950–1962 year-classes and (B) at about six months of age for the 1959–1965 year-classes. The 1957 and 1963 year-classes are omitted due to insufficient data. The respective year-classes are indicated inside each circle.

took place in the same region, only two rich year-classes were spawned, those of 1904 and 1918. However, during this period the spawning most likely occurred somewhat earlier than in the 1930s (Runnstrøm 1934, Devold 1963), and this feature may have accounted for the long intervals between the appearance of rich year-classes.

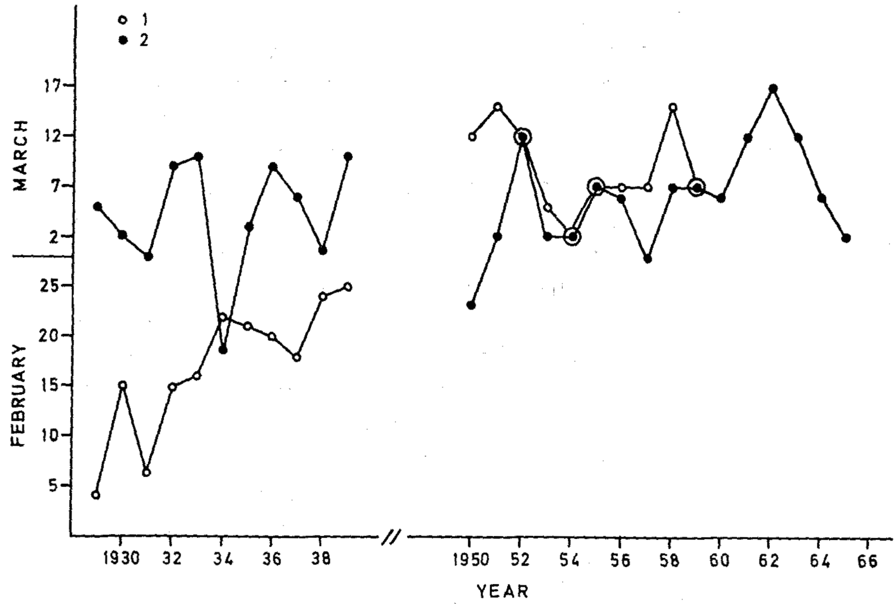

Fig. 27. Time of main spawning during the periods 1929–1939 and 1950–1965, (1) within area 08 and (2) within area 07.

ENVIRONMENTAL CONDITIONS DURING THE EGG STAGE AND EARLY LARVAL DEVELOPMENT

Considerations of environmental factors and their effects on developing eggs and larvae have mainly been concerned with the temperature and thickness of the egg layers. More recently, attention has also been drawn to other factors, as for instance predator effect, pollution and mechanical forces.

Postuma (1968) showed a relationship between the temperature on the spawning bed and year-class strength for Downs and Bank autumn spawning herring and suggested that optimum conditions existed at around 12 °C. In the 1930s, when the main spawning of Norwegian herring took place in the southern spawning region (area 08), the most frequent bottom temperature during the spawning season was between 5 and 6 °C (Runnstrøm 1941b). During the period 1959–1965, when maximum spawning took place farther north, the temperature varied between 5.5 and 7.5 °C on the spawning grounds between Møre and Lofoten. The temperature on the main spawning grounds during the incubation period did not vary markedly from one year to another and cannot be associated with the year-class strength variations during the period 1959–1965.

Lea (1930) showed that thick egg layers on the Norwegian spawning grounds resulted in a high mortality since eggs in the deepest layers were subjected to oxygen deficiency. RUNNSTRØM (1941b) did not find a distinct increase in mortality with increasing density of eggs, except in extremely thick egg layers (10,000 to 12,500 cm^3 per m^2 of sea bed), and the average mortality for the total egg material collected was 12.1%. In the Firth of Clyde, PARRISH *et al.* (1959) showed that only very few dead and unfertilized eggs occurred in the samples, but the stage of development varied through the egg layer. Recent investigations in same area by BAXTER (1968) showed average figures of 3–6% for dead eggs, and there was little indication of higher mortality in the lower layers. For North Sea herring mortality rates of 0–11% (average 4%) were found by HEMPEL and HEMPEL (1968). DRAGESUND and NAKKEN (unpublished) also observed few dead and unfertilized eggs on a spawning site near Grip in 1968. None of these results include mortality at the hatching stage, and mortality during the egg stage seems to be relatively low.

However, gadoid fish feeding on herring eggs have frequently been recorded on the spawning grounds both in the North Sea and along the Norwegian coast. Nothing is known about the frequency of stomach fillings per fish during the spawning season or of the number of fish feeding on herring spawn. The stomach of an adult haddock normally can contain at least the annual egg production of one herring per filling (HEMPEL and HEMPEL 1968, DRAGESUND and NAKKEN unpublished). Therefore, the predator effect may be of some importance.

A second phase of mortality occurs during the hatching period. Experiments carried out on Pacific herring (GALKINA 1968, TAYLOR 1968) indicated that in dense concentrations of eggs the hatching success is rather low. The experiments by TAYLOR showed that the production of viable larvae per unit area often was lower when eggs were packed in eight than when only in four layers. It is not known if these results are applicable for larger stocks of herring reproducing in the open sea. However, LEA (1930) believed that conditions were more favourable for hatching when small quantities of eggs were distributed over a large area than when the spawning was concentrated in a limited region. The present material cannot be used for an analysis of egg concentration in relation to year-class strength. However, heavy packing of eggs is most likely to occur when a large stock spawns during a short period in a restricted area. During the period 1959–1965 the spawning within areas 08, 07 and 06 was more extensive and prolonged in 1959 than in 1962 (Table 14).

The hypothesis of critical periods during early larval development expounded by HJORT (1914, 1926) has been discussed by several authors (e.g. MARR 1956, WIBORG 1957, FARRIS 1960, BEVERTON 1962, GULLAND 1964, HEMPEL 1965). MARR concluded that although catastrophical mortality rates will always remain as a possibility, evidence points towards survival at a constant rate or at a constantly increasing rate, rather than towards the existence of critical periods. GULLAND suggested that mortality is very high just after hatching, and that this is common to all year-classes. Then there is a density-dependent phase in which mortality is higher for year-classes with an initially high number of eggs than for one with an initially low number of eggs. According to GULLAND there is then a phase during which the strength of a year-class is determined, i.e. the phase during which the mortality of an ultimately poor year-class is higher than that of an ultimately rich year-class. Investigations by SOLEIM (1942) indicated a heavy mortality of larvae when the yolk was resorbed. DRAGESUND and NAKKEN (1968) estimated a larval mortality of 94% between a size of 10 mm and a size of 12 mm in 1967. It is likely that such a high mortality at this stage affected the abundance of 0-group herring observed in autumn of 1967 (ANON. 1967). However, comparable larval mortality data for other years are not available. Therefore, it is not possible to estimate the influence of early larval mortality on variations in year-class strength.

The extremes among the year-classes of Norwegian herring spawned during the period 1959–1965 were the rich one of 1959 and the poor ones of 1962 and 1965. Investigations carried out during the 0-group stage (DRAGESUND 1970) showed a considerably higher abundance of the 1959 year-class than of those produced in 1962 and 1965. These results suggest that the mortality of the progeny during the first six months of life may have been considerably higher for the two latter year-classes than for that of 1959. Indication was found that the variation in the size of the spawning stock was reflected in the larval abundance estimates just after hatching (Fig. 19A) and it is, therefore, unlikely that any marked difference in mortality existed before hatching of these year-classes.

When the larvae have resorbed their yolk sacs, suitable food must be available if mass mortality is not to occur. Larvae with poor swimming performance and small field of vision can only search a small volume of water (ROSENTHAL and HEMPEL 1968). For larvae with better vision and better swimming performance, which again is a function of the length of larvae, the volume of water searched every day is far greater. This factor may cause serious competition among larvae during a period of low abundance of food. ROSENTHAL and HEMPEL concluded that the very young larvae are more endangered by malnutrition than somewhat older and larger larvae because they require a higher abundance of food. This feature is in line with the hypothesis of a critical phase of starvation after the yolk stage, and supports the assumption that a restricted and concentrated distribution of larvae just after hatching is disadvantageous.

Advantageous conditions for a high survival of larvae, therefore, should exist when the larvae are dispersed in areas of abundant food supply.

According to BJØRKE (1968) eggs of *Calanus finmarchicus* constituted 93% of the number of particles in the gut content of larvae investigated in 1967 off Møre during a three-week period from the time of hatching. LIE (1965) found that spawning of *Calanus finmarchicus* at Sognesjøen started in the first half of March in 1959, whereas the spawning in 1962 started later, probably in early April. Thus, the spawning of *Calanus* occurred earlier in relation to the hatching of herring larvae in 1959 than in 1962 (Fig. 28). The spring spawning of *Calanus* is followed by an increase in the zooplankton biomass. In 1962 the mean total volume of zooplankton at Sognesjøen in April and May was considerably lower than in 1959, indicating less available food for herring in 1962. On the other hand, no such differences either in time of spawning or in total plankton volume were found between the two seasons at the Skrova and Eggum stations in the Lofoten region (LIE 1965). However, these stations are located farther north of the areas where the main concentrations of herring larvae at yolk resorption were observed than Sognesjøen is located south of these areas. In 1965 the spawning of *Calanus* took place in February–March at the Sognesjøen station (LIE 1966) and the hatching of herring larvae off Møre occurred during the second half of March (Fig. 28). The hatching of herring larvae off Lofoten occurred relatively early in 1965 (about 20 March). The spawning of *Calanus* took place in March–April (LIE 1966) and it is possible that the coincidence in time between the *Calanus* spawning and hatching of herring larvae in 1965 may have been unfavourable.

The importance of abiotic factors, as for instance wind direction and force influencing year-class strength, have been stressed by several authors (SETTE 1943, CARRUTHERS *et al.* 1951, HILL and LEE 1957, BAKKEN 1966). HILL and LEE suggested that there was a positive correlation between rich year-classes of Arctic-Norwegian cod and strong southerly wind during the period when the larvae drift from the Lofoten spawning grounds to the Bear Island area. A similar relationship was found for herring larvae. The northward drift of larvae is hampered in years with relatively weak winds or prevailing westerly and northerly winds. This feature has probably added to the effect of a concentrated spawning in 1961 and 1962, resulting in a relatively restricted distribution. In 1961 a rather rapid northward drift took place on the southern spawning grounds just after hatching, whereas farther north the wind had a diminishing effect on the northward larval drift and led to a concentrated distribution. In 1959, 1960, 1963 and 1964, spawning took place over a wider area and the prevailing southerly winds during and just after hatching resulted in a

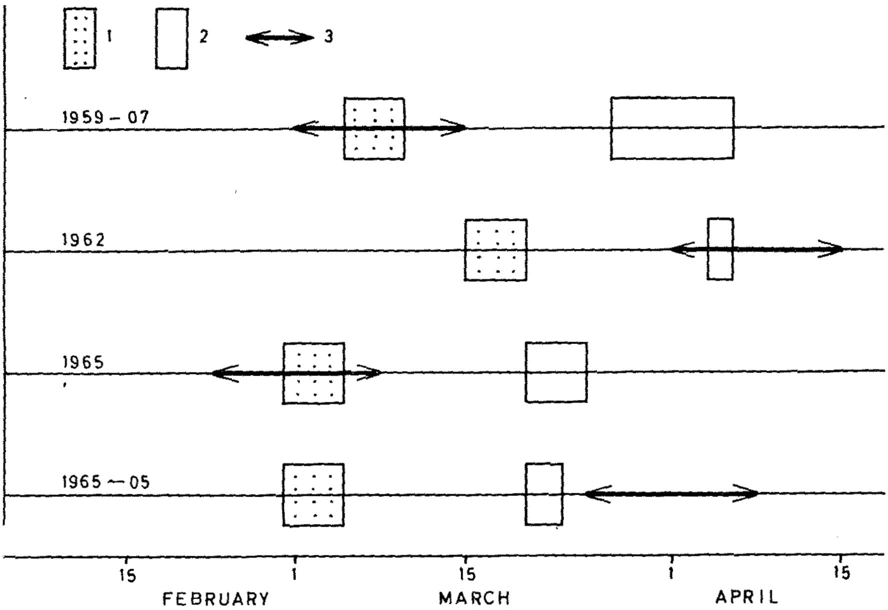

Fig. 28. Time of, (1) main spawning and (2) main hatching of herring compared with (3) time of the first spawning of *Calanus finmarchicus* at Sognesjøen (area 07) and off Eggum (area 05) in 1959, 1962 and 1965.

rapid dispersion of larvae from the spawning grounds. Also, the long duration of the spawning in these years added to the effect of southerly winds and resulted in a dispersed distribution.

BENKO and SELIVERSTOV (1968) and POSTUMA (1968) concluded that the water temperature during the larval and postlarval periods is an important factor controlling the success or failure of recruitment. BENKO and SELIVERSTOV found a positive correlation between the surface temperature during the larval stage and the year-class strength of Norwegian herring for the period 1948–1965. The underlying mechanism of the effects of temperature on larval mortality is complex. Temperature affects metabolic rate, i.e. incubation time, rate of growth, rate of resorption of the body reserves, swimming speed, food demand, etc. (BEVERTON and HOLT 1957, HEMPEL 1965). It also affects the abundance and species composition of food plankton and predators. If the larvae are distributed in water with a relatively high temperature immediately following hatching, they may pass rapidly through critical stages. NAKKEN (1966) has shown a positive correlation between high temperatures in the coastal water and the current velocity. The relatively high temperatures found off Ona, Sula (near Nordøyane) and Myken (near Træna) in March and April 1959 and 1960 and partly in 1961, 1963 and 1965 (BENKO and

Table 14. Summary of factors considered to be of importance in determining year-class strength of Norwegian herring compared with abundance estimates obtained at the 0-group stage and at six years of age for the 1959–1965 year-classes.

Factor	Area	Spawning year						
		1959	1960	1961	1962	1963	1964	1965
Spawning stock size in mill. tons (Fig. 2)	07 06	5.5	4.5?	3.5?	2.5	2.9	4.2	7.3
Mean age of spawning stock (Table 6)	07	9.5	10.3	10.7	11.7	12.2	8.7	7.8
	06	9.5	—	—	11.7	11.6	—	5.4
	05	—	—	—	—	3.9	4.9	5.7
Extension of spawning area, indicated by number of rectangles, where herring in spawning and spent condition were caught (Table 8)	08	2	0	0	0	0	0	0
	07	8	8	6	4	5	5	5
	06	9	9?	5?	7	6	7	9
	05	?	?	?	?	5	5	6
Approximate northward displacement (in nautical miles) of spawning centres, reference year 1959 (Fig. 3)	07	Centre: Off Stad	30	60	60	70	90	90
	06	Halten-Sklinna	0	0	0	0	0	0
Duration of spawning season in days (Fig. 4)	07	30	30	30	20	20	20	20
	05	—	—	—	—	10	10	20
Date of main spawning (Fig. 4)	07	5–9.3	5–9.3	10–14.3	15–19.3	10–14.3	5–9.3	28.2–4.3
	05	—	—	—	—	25–29.3	25–29.3	28.2–4.3
Spawning rate (Table 10)	07	3.8	5.9	6.3	8.7	?	5.3	5.3
	05	—	—	—	—	?	22.0	10.3
Date of main hatching (Fig. 7)	07	26.3–5.4	23–31.3	29.3–3.4	4–6.4	30.3–11.4	25–26.3	20–25.3
	05	—	—	—	—	16–26.4	15–19.4	20–23.3

Direction and relative strength of the mean wind vectors for March–April (Fig. 21)	07	20°	34°	62°	29°	325°	342°	45°
		120	60	180	50	85	55	90
	06	357°	354°	88°	91°	334°	50°	35°
		160	190	160	50	180	100	75
	05	20°	12°	135°	160°	310°	326°	5°
		130	200	130	80	75	60	20
First spawning period of *Calanus finmarchicus* (LIE 1965, 1966)	Sognesjøen	1–15.3	1–15.3	1–15.3	1–15.4	Feb.–March	Feb.–March	Feb.–March
	Eggum	—	1–15.4	1–15.4	1–15.4	April	April	April
Year-class strength at six months of age, echo abundance index $\times 10^{-3}$ (DRAGESUND 1970)		325.8	147.4	37.5	14.8	53.6	75.0	9.1
Year-class strength at six years of age (in mill. tons)		4.5	1.8	0.5	0.03	—	—	—

SELIVERSTOV 1968) also may have been associated with higher velocity of the coastal current those years than in 1962 and 1965 when lower temperatures were found at these stations.

Table 14 compiles information from preceding chapters on factors to be of importance in determining year-class strength of herring during the period 1959–1965. The data indicate that within the range of observed stock size a relationship might exist between the parent stock and abundance of the resulting year-classes when favourable conditions occurred. However, in most of the years during the period 1947–1965, year-class strength was determined by a complex of other factors which completely ruled out the effect of the parent stock size. The following factors are considered to be most important in determining year-class strength:

1) the extent of the spawning area;
2) the duration of the main spawning season;
3) the rate of dispersion of larvae from the spawning grounds;
4) the coincidence in time between the availability of suitable food and hatching of herring larvae.

In 1959, 1960, 1963 and 1964, spawning was extensive and prolonged with a rapid dispersion of larvae from the different spawning grounds. The opposite conditions existed in 1962. In 1965 spawning was extensive and in 1961 relatively prolonged, but the conditions for transport of the larvae during the period after hatching resulted in a concentrated distribution. The gradual northward displacement of the main spawning centre during the last two decades probably has increased the importance of the timing factor, since only two definitely numerous year-classes occurred during the period 1950–1965, namely those of 1950 and 1959.

SUMMARY

1. Variation in year-class strength of Norwegian spring spawning herring is analysed in relation to the structure and the size of the spawning stock, the location and the time of spawning and environmental conditions during the egg stage and the early larval development with special reference to the 1959–1965 year-classes.

2. Stock size estimates were obtained from tagging experiments, and the number of eggs spawned in each year was calculated from fecundity data in the literature. The highest figure for the stock size (7.3 million tons) was found in 1965. The stock size had its lowest figure in 1962 when it was about 2.5 million tons.

3. The location of spawning was determined from the distribution of catches of spawning and spent herring and from the distribution of newly

hatched larvae. During the period 1959–1965 the most important spawning took place off Møre, i.e. on the shelf between Stad and Grip, and mainly in depths of less than 200 m. Spawning south of Bergen was negligible except in 1959. During the entire period spawning took place off Halten and Sklinna, whereas spawning at Lofoten was more sporadic.

4. The duration of the spawning season was determined from the maturity composition of herring collected several times a week during the spawning season. Off Møre spawning was late in 1962 (15–19 March) and early in 1965 (28 February–4 March). In 1963 spawning off Lofoten occurred about two weeks later than off Møre, and in 1964 three weeks later, whereas in 1965 spawning took place about simultaneously in the two regions.

5. The time of main hatching was estimated by adding an incubation period of generally 18–24 days (depending on the temperature) to the time of main spawning. Approximate figures for the incubation periods were obtained from the literature.

6. The distribution of herring larvae during the first month after hatching was analysed for the period 1959–1965. The larvae were collected with Clarke-Bumpus plankton samplers in oblique hauls during regular surveys covering the coastal banks between Stad and Lofoten. Factors affecting larval abundance estimates are discussed, and a general description of the vertical distribution and diurnal migration of herring larvae is given. The geographical distribution of larvae was analysed in relation to the spawning grounds. The drift of larvae was inferred from subsurface drogue experiments, wind observations and drift bottle experiments. Larval length was analysed in relation to the time of spawning. During the first month after hatching the larvae were concentrated near the coast, and almost no larvae were found outside the edge of the shelf. A more concentrated distribution of larvae was observed in 1961, 1962 and 1965 than in the other years considered. The larvae are transported northward in coastal water and the force and direction of the wind play an important role in determining the distribution pattern of larvae.

7. The results indicated that within the range of observed stock sizes a relationship may exist between the parent stock and abundance of the resulting year-classes when favourable conditions occurred. However, it is likely that the year-class strength was determined by a complex of other factors which completely ruled out the effect of parent stock size in most of the years. Conditions assumed to be advantageous for the development of strong year-classes were inferred from the present and other investigations. Strong year-classes seemed to occur when a combination of the following conditions existed:

1) widespread distribution of spawning;
2) long duration of the spawning period;
3) a rapid dispersion of larvae from the spawning grounds.

In 1959, 1960, 1963 and 1964, spawning was extensive and prolonged and with a rapid northward dispersion of larvae from the different spawning grounds. In 1962 the opposite conditions existed. Spawning was extensive in 1965 and prolonged in 1961, but the transport conditions during and after the yolk sac stage resulted in a concentrated distribution pattern.

8. The coincidence in time between the occurrence of suitable food and hatching of herring larvae is assumed to be the most important environmental factor controlling year-class strength during the early larval development. The gradual northward displacement of the main spawning centre during the last decades probably has increased the importance of the timing factor, since only two definitely rich year-classes occurred during the period 1947–1965, namely those of 1950 and 1959.

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TABLES

Table I. Number of larvae below 1 m^2 of surface caught with Clarke–Bumpus plankton samplers in two subsequent pairs of oblique hauls off Halten in 1964.

Date	Series 1				Series 2			
	Hour	25–5 m	50–30 m	Total	Hour	25–5 m	50–30 m	Total
16.4	1730	5	0	5	1800	0	0	0
	1937	2	0	2	2005	0	0	0
16–17.4	2350	37	16	53	0020	45	30	75
17.4	0152	18	11	29	0225	27	7	34
	0400	9	4	13	0428	2	2	4
	0605	4	0	4	0730	10	0	10
	0840	3	2	5	0910	3	2	5
	1503	0	4	4	1530	2	2	4

Table II. Number of larvae below 1 m^2 of surface caught in oblique hauls with pairs of Clarke–Bumpus plankton samplers attached 1 m apart, off Eggum (23–29 April) and off Træna (30 April–1 May) in 1964.

Date	Series 1			Series 2		
	Hour	24–4 m	25–5 m	Hour	49–29 m	50–30 m
23.4	0115	162	290	0320	338	280
	—	—	—	0505	348	263
28.4	1105	27	50	1315	135	161
	1455	43	47	1715	67	42
	1900	69	70	2110	43	23
28–29.4	2310	69	120	0110	106	49
29.4	0310	76	64	0508	132	58
	0705	87	85	0910	134	82
30.4–1.5	2345	31	29	0105	12	11
1.5	0300	2	10	0524	0	0
	0741	10	23	0940	2	0

Table III. Number of larvae below 1 m² of surface caught in oblique hauls with Clarke–Bumpus plankton samplers close to subsurface drogues at drift station 2 off Sklinna (18–19 April, 1964), at drift station 4 off Eggum (28–29 April, 1964) and at drift station 5 off Frøya (9–10 April, 1965).

Date		Hour	25–5 m	50–30 m	75–55 m	Total
1964	18.4	1340	5	5		10
		1600	0	0		0
		1820	9	13		22
		2005	6	12		18
		2205	64	7		71
	19.4	0015	39	2		41
		0213	49	16		65
		0420	29	9		38
		0605	6	12		18
		0805	13	6		19
		1000	2	2		4
		1205	9	4		13
		1400	2	4		6
1964	28.4	0920	74	91		165
		1105	50	117		167
		1315	66	161		227
		1455	47	58		105
		1715	52	42		94
		1920	70	45		115
		2110	94	23		117
		2310	120	60		180
	29.4	0110	199	49		248
		0310	64	53		117
		0508	120	58		178
		0705	85	108		193
		0910	53	82		135
1965	9.4	1415	18	34	21	73
		1617	21	71	24	116
		1829	9	94	42	145
		2020	115	43	16	174
		2220	53	77	7	137
	10.4	0035	18	18	0	36
		0210	121	29	2	152
		0414	60	18	3	81
		0624	15	69	0	84
		0820	0	23	2	25
		1015	0	17	4	21
		1120	0	30	7	37

Table IV. Composition (in %) of the maturity stages of Norwegian herring in five-day periods during the spawning seasons in 1959–1965.

Area		Date	No.	Maturity stage			
				IV	V	VI	VII
08	1959	23–27.2	177	4.0	48.6	36.1	11.3
		28.2–4.3	89	—	9.0	85.4	5.6
		5–9.3	272	—	9.9	83.5	6.6
		10–14.3	188	—	2.1	74.5	23.4
		15–19.3	90	—	—	90.0	10.0
07	1959	8–12.2	640	8.6	89.4	2.0	—
		13–17.2	217	2.3	96.3	1.4	—
		23–27.2	264	0.8	43.8	27.7	27.7
		28.2–4.3	364	0.3	16.2	28.3	55.2
		5–9.3	90	—	15.6	32.2	52.2
		10–14.3	186	—	7.0	73.1	19.9
08 and 07	1959	8–12.2	640	8.6	89.4	2.0	—
		13–17.2	217	2.3	96.3	1.4	—
		23–27.2	441	2.0	45.8	31.1	21.1
		28.2–4.3	453	0.2	14.8	39.5	45.5
		5–9.3	362	—	11.3	70.7	18.0
		10–14.3	374	—	4.5	73.8	21.7
		15–19.3	90	—	—	90.0	10.0
07	1960	13–17.2	1182	4.8	94.9	0.3	—
		18–22.2	1039	2.1	96.9	0.9	0.1
		23–27.2	703	—	65.7	30.9	3.4
		28.2–3.3	280	—	7.9	86.8	5.3
		4–8.3	345	—	16.2	62.3	21.5
		9–13.3	308	—	0.7	96.1	3.2
		14–18.3	134	—	3.7	88.1	8.2
07	1961	13–17.2	404	18.6	78.5	2.7	0.2
		18–22.2	531	5.3	91.9	2.8	—
		23–27.2	704	4.7	83.8	9.2	2.3
		28.2–4.3	516	0.2	33.0	30.8	36.0
		5–9.3	227	—	2.7	75.3	22.0
		10–14.3	182	—	1.1	72.5	26.4
		15–19.3	46	—	4.3	45.7	50.0
07	1962	28.2–4.3	1052	5.3	94.2	0.5	—
		5–9.3	888	0.8	82.3	11.3	5.6
		10–14.3	662	—	8.0	39.6	52.4
		15–19.3	128	—	1.6	18.0	80.4
		20–24.3	112	—	0.9	4.5	94.6

Table IV (*continued*)

Area	Date		No.	Maturity stage			
				IV	V	VI	VII
07	1963	28.2–4.3	430	3.3	66.7	29.3	0.7
		5–9.3	214	2.8	7.0	71.5	18.7
		10–14.3	116	—	—	85.3	14.7
		15–19.3	974	—	0.4	65.5	34.1
		20–24.3	204	—	—	32.8	67.2
05	1963	20–24.3	77	37.7	—	9.1	53.2
		25–29.3	264	5.3	7.2	85.2	2.3
		30.3–3.4	93	—	—	—	100.0
07	1964	13–17.2	365	18.4	81.3	0.3	—
		18–22.2	461	4.8	91.3	3.9	—
		23–27.2	636	0.6	59.0	39.6	0.8
		28.2–3.3	320	0.6	22.5	53.1	23.8
		4–8.3	315	—	8.9	67.0	24.1
05	1964	28.2–3.3	82	2.4	97.6	—	—
		4–8.3	94	—	—	100.0	—
		9–13.3	95	—	2.1	97.9	—
		14–18.3	540	—	0.2	99.8	—
		19–23.3	365	—	—	99.2	0.8
07	1965	13–17.2	317	11.4	88.6	—	—
		18–22.2	404	3.5	77.2	19.1	0.2
		23–27.2	248	0.4	29.9	66.1	3.6
		28.2–4.3	205	1.0	3.4	75.1	20.5
		5–9.3	96	—	1.0	93.8	5.2
05	1965	13–17.2	95	2.1	92.6	5.3	—
		18–22.2	175	4.6	83.4	11.4	0.6
		23–27.2	94	—	2.1	95.8	2.1
		28.2–4.3	187	—	1.6	57.8	40.6
		5–9.3	92	1.1	10.9	46.7	41.3

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DISTRIBUTION, ABUNDANCE AND MORTALITY OF YOUNG AND ADOLESCENT NORWEGIAN SPRING SPAWNING HERRING (*Clupea harengus* Linné) IN RELATION TO SUBSEQUENT YEAR-CLASS STRENGTH

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INTRODUCTION

Doubts regarding the reasons for a decreasing yield of the herring fisheries in the southern North Sea and in the Norwegian Sea during the 1950s and early 1960s have caused fishery biologists to pay close attention to problems concerned with recruitment to the fishable stocks of herring. Nursery areas have been identified, and variations in distribution and abundance of young herring in relation to subsequent year-class strength in the adult stock have been studied (e.g. BERTELSEN and POPP MADSEN, 1956, 1957, DRAGESUND and OLSEN 1965, SAVILLE 1968, WOOD 1968). Growth and migration of adolescent herring in relation to recruitment to the adult stock were investigated by CUSHING (1962), ZIJLSTRA (1963), PARRISH and SAVILLE (1965) and ØSTVEDT (1965), and the fisheries for young herring and their effects on subsequent yield of the adolescent and adult herring fisheries have been analysed by DEVOLD (1953, unpublished), CUSHING (1959), MARTI and FEDOROV (1963) and PARRISH and SAVILLE (1967).

Until recently little was known about the biology of the early stages of Norwegian spring spawning herring, subsequently referred to as Norwegian herring. LEA (1929) was of the opinion that most of the 0-group herring entered the fjords of western and northern Norway and were distributed in coastal waters, but at that time no attempt had been made to search for 0-group herring in the open sea. DEVOLD (1950) showed that 0-group herring of the rich 1950 year-class were distributed far offshore in the northeastern part of the Norwegian Sea, and he suggested that only a small part of the total 0-group population entered the Norwegian fjords. This view was not shared by MARTI (1956), who held that most of the 0-group herring were to be found along the coast and in the fjords of Norway.

LEA (1929) held the opinion that 0-group herring entering the fjords emigrated during the fat-herring stage (at an age of two to three years).

He demonstrated that the development from the immature fat-herring to the adult herring took place through an intermediate oceanic stage. The fat-herring which migrated from the fjords of northern Norway did not appear on the spawning grounds the following year but arrived two to four years later, having remained in the open sea during this period.

From more recent investigations (DRAGESUND and HOGNESTAD 1960, DRAGESUND and OLSEN 1965, DEVOLD 1968, JAKOBSSON 1968, ANON. 1969) it can be stated that the distribution of young and adolescent Norwegian herring is widespread and ranges from the fjords of northern Norway to the open ocean of the Norwegian Sea and the Barents Sea and varies with the different year-classes.

A fishery which is of considerable importance to the population dynamics is carried out on young and adolescent herring in Norwegian coastal waters. This fishery can be divided into two components, (1) that based on the small-herring (småsild), i.e. mainly 0- and I-group fish with the former predominating, and (2) that based on the fat-herring (feitsild), i.e. I- to IV-group herring with the II- to III- group predominating. Since the industrial small-herring fishery started in the 1910–1914 period, great attention has been paid to the effects this fishery may have on the recruitment to the older age groups. Although LEA (1924) and DEVOLD (1953) did not find any connection between the catch of small-herring and the subsequent yield of the fat-herring fishery and could not recommend any regulation of the 0- and I-group herring fishery, many Norwegian fishermen have maintained that the exploitation of small-herring affected both the fat-herring fishery and the fishery for adult herring.

Soviet scientists have seen the low recruitment to the adult stock during the late 1950s and early 1960s as a consequence of the industrial fishery on small-herring in the Norwegian fjords (MARTI and FEDOROV 1963). DEVOLD (1963), however, argued that the decline of the Norwegian winter herring fishery was caused by a series of poor year-classes, which were the results of changes in environmental factors and the migration pattern and subsequent changes in the time and area of spawning. Since no clear relationship has been found between the exploitation of 0- and I-group herring and subsequent year-class strength in the adolescent and adult stocks, the Norwegian Government has so far not introduced any rigid regulation of the small-herring fishery. However, since 1963 it has been prohibited to land catches of small-herring from 1 February to 30 April consisting of more than 50% of herring below a total length of 15 cm (north of 64° N) or 16.5 cm (south of 64° N).

Comprehensive investigations of distribution, abundance and mortality of young and adolescent herring in coastal and offshore waters of northern Norway were initiated in the autumn of 1959 by the Institute of Marine Research, Bergen, in order to examine whether the exploitation of 0- and I-group herring in the Norwegian fjords has any primary impact on subsequent year-class strength in the adult stock. In a previous paper (DRAGESUND 1970) spawning characteristics and environmental conditions during early larval development were analysed as factors which may have influenced the strengths of the 1959–1965 year-classes of Norwegian herring.

The aim of the present paper is to:

1) describe the distribution of the 1959–1965 year-classes during the young and adolescent phases;
2) determine when the 0-group herring, which enter the fjords in autumn, migrate from the fjords, and investigate whether 0-group herring occurring far north and east off northern Norway migrate as adults to the spawning grounds off Møre;
3) study the variations in abundance of young and adolescent herring, i.e. small- and fat-herring;
4) estimate the mortality rates of 0- and I-group herring in the Norwegian fjords.

These items are discussed in relation to subsequent year-class strength in the adult stock.

MATERIAL AND METHODS

The material includes data from acoustic surveys, tagging experiments, herring samples and catch statistics. The statistical methods applied are those given in text books of statistical analysis (SNEDECOR 1956, GODSKE 1966). Geographical names and code numbers for areas appearing in the text are shown in Fig. 1.

ACOUSTIC SURVEYS

Every autumn during the period 1959–1965 the distribution and abundance of young and adolescent herring in the coastal and offshore waters of northern Norway were studied from combined acoustic surveys and fishing experiments with pelagic trawl and purse seine (MIDTTUN 1959, DRAGESUND 1959, 1961, 1962, 1964, DRAGESUND and HOGNESTAD 1962, HOGNESTAD 1963a, OLSEN 1960, ANON. 1965a). More detailed investigations during the same period were carried out in the fjords of northern Norway in collaboration with the Marine Biological Station, Tromsø. Special attention was paid to the Hamarfjord–Ullsfjord–Lyngen-

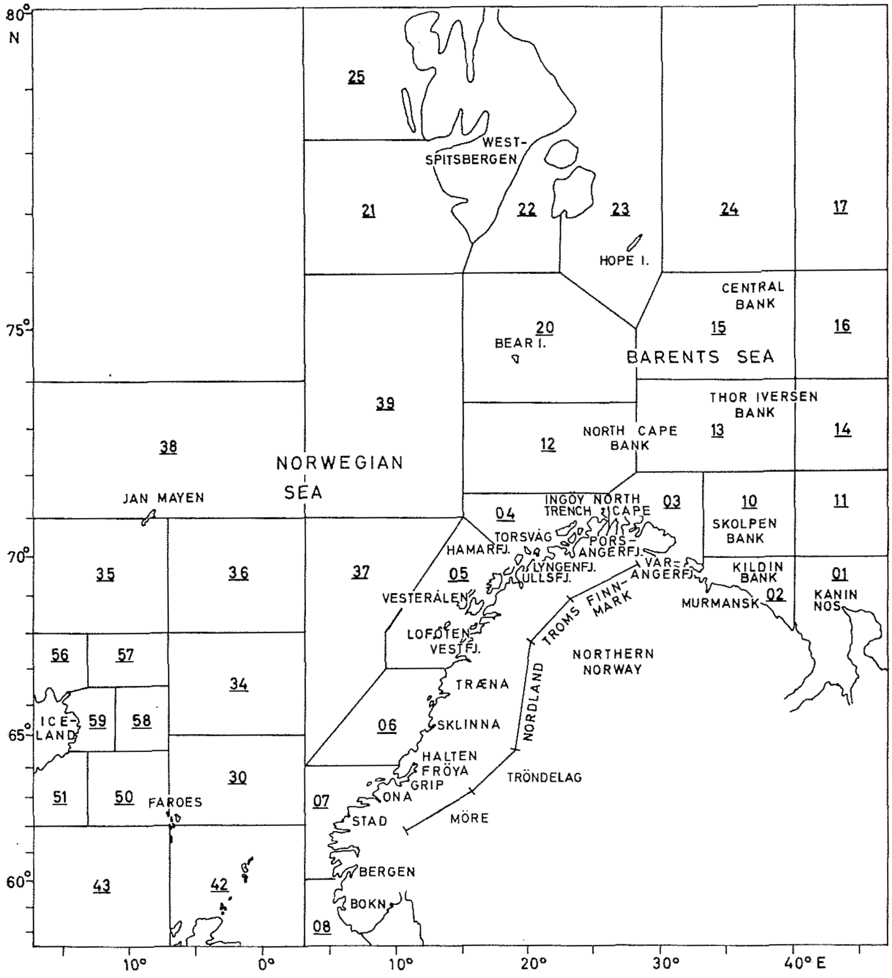

Fig. 1. Names and code numbers of areas mentioned in the text.

fjord complex and to the Porsangerfjord, and usually these fjords were investigated twice a month from September to May (HOGNESTAD 1960, 1961, 1962, 1963b, 1964). In 1962 and 1963 observations were also made during early summer in limited regions off Troms and Finnmark, and for the years 1960–1963 information is available from acoustic surveys carried out in winter and early spring off Finnmark and in the Barents Sea (MIDTTUN 1960, 1961, MØLLER *et al.* 1961, MØLLER 1963).

All the ships were equipped with vertical echo sounders and horizontal ranging sonars, and during the surveys the acoustic instruments were operated continuously. Except on the cruise in early summer of 1963, when the ship was equipped with a Kelvin Hughes echo sounder (MS 29, 30 kHz) and sonar (Mk2, 48 kHz), Simrad echo sounders (513–1, 38.5 kHz and 513–5, 18 kHz) and sonar (580–1, 30 kHz) were used. The sensitivity control of the Simrad echo sounders is regulated in steps from 1 to 10 and during all surveys the 38.5 kHz echo sounder was set at step 7 and the 18 kHz echo sounder mainly at step 4. In 1962 the Norwegian research vessels "G. O. Sars" and "Johan Hjort" were equipped with Simrad Research Sonar (580–10, 11 kHz), and from that year onwards a third echo sounder working on 30 kHz (580–10) was also used. However, the 38.5 kHz echo sounder has been used as standard equipment, and all the recordings have been graded according to observations made with this machine.

For every five nautical miles steamed, the echo traces of 0-group herring were plotted according to the following density classification (Fig. 2):

1) very scattered (barely visible on the recording paper);
2) scattered (the middle stages between black and white paper);
3) dense (recording paper nearly black, but with no indication of "white-line effect", which occurs when the density of the scatterers is especially high);
4) very dense (recording paper black with "white-line effect").

The most favourable conditions for estimating the abundance of herring exist during darkness when the fish are dispersed (Fig. 2, A to D) and occur as a continuous series of traces (scattering layer) on the recording paper. However, the shoaling concentrations recorded during the day (Fig. 2, E and F) were converted to night time abundance values. By frequently surveying the same area both by day and by night, factors to convert the day recordings to night time abundance values were established.

During the surveys herring were caught either with Isaacs–Kidd ten foot midwater trawl (IKMT) (Isaacs and Kidd 1953) or a larger pelagic trawl (modified capelin trawl) with headline and footline of 18.3 m, sidelines of 15.3 m and mesh size from 100 mm (wings and square) graded down to 8 mm (cod end). On some cruises a commercial herring purse seine of 8 mm mesh size was also used. Table I gives more details of the fishing experiments conducted during the surveys. In order to establish the relationship between wire angle and depth of trawling, an echo sounder transducer was attached to the depressor of the IKMT during some of the cruises, and a depth-time recorder was used on the larger pelagic trawl. The towing speed of the IKMT was usually 5–6

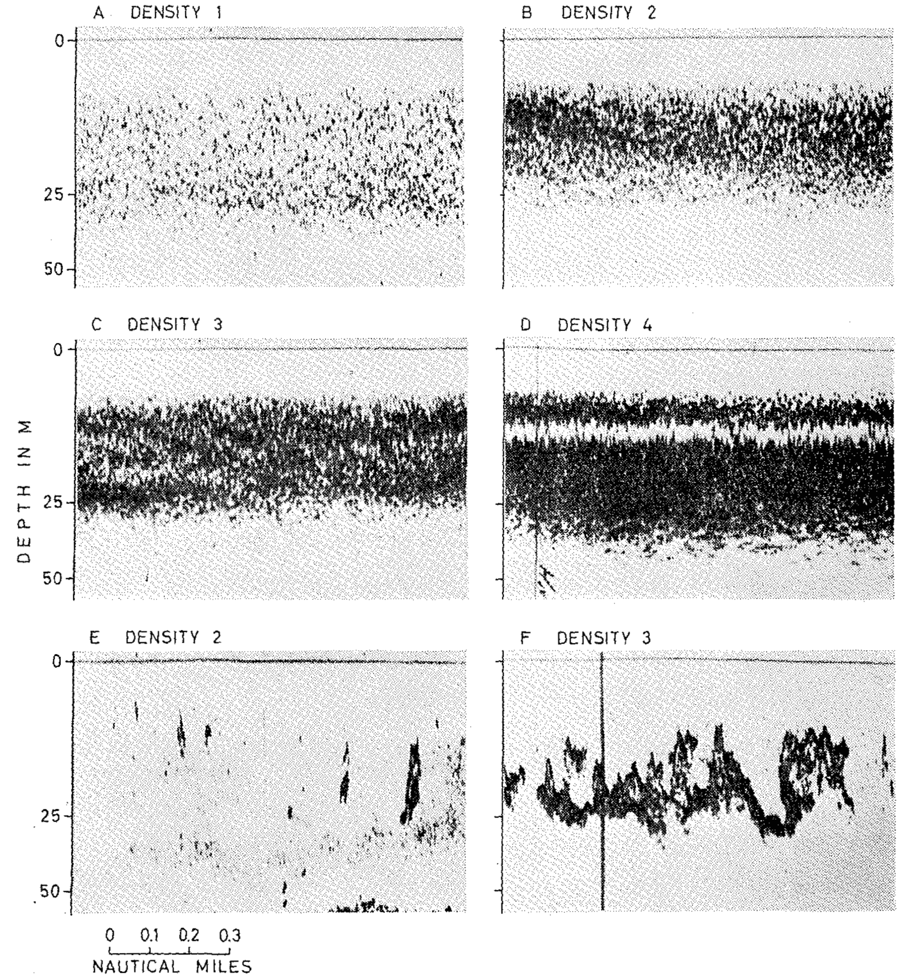

Fig. 2. Echo recordings (Simrad echo sounder 38.5 kHz set at step 7) of sound scatterers identified as 0-group herring, by night (A) to (D) and by day (E) and (F). The densities of recordings (E) and (F) are comparable with those of (B) and (C), respectively.

knots, and the larger pelagic trawl was towed at 3–4 knots. The dimensions of the pelagic trawl used by the research vessel of Marine Biological Station, Tromsø, were: Headline, 15.0 m, footline, 19.0 m, and sidelines, 4.0 m with mesh sizes graded from 50 mm to 8 mm.

IDENTIFICATION OF SOUND SCATTERERS

During the 1950s sound scatterers were frequently recorded in the top layers of water in the Barents Sea, and some success was achieved in identifying them by underwater photography (MIDTTUN and SÆTERSDAL

1959). However, no systematic routine programme of identification was developed until 1959. From material collected during the present surveys it has been demonstrated (DRAGESUND and OLSEN 1965) that during late summer and early autumn 0-group fishes of different species, such as herring, cod (*Gadus morhua* Linné), haddock (*Melanogrammus aeglefinus* Linné), redfish (*Sebastes marinus* Linné), capelin (*Mallotus villosus* Müller), and long rough dab (*Hippoglossoides platessoides* Fabricius) occurred pelagically as scattering layers in the upper 100 m of water in the Barents Sea and adjacent waters.

The 0-group herring generally were found in the upper 50 m of water. During daytime they were found at depths from 25 to 50 m, while at night they came closer to the surface, dispersed and appeared as a continuous layer on the recording paper. In the daytime the herring clustered in shoals (Figs. 2 and 3). Both experimental fishing and analysis of the echo traces as well as underwater photography have been used to identify the sound scatterers during the acoustic surveys for 0-group fish. Comparisons between the IKMT and the larger pelagic trawl catches showed that the former trawl was not catching 0-group herring efficiently during the daytime and that older age groups were caught only occasionally. At night, however, when 0-group herring were distributed in typical scattering layers, they were caught frequently with IKMT. The 0-group herring were easily caught with the larger pelagic trawl both at night and day whenever they were present. The larger trawl was not reliable for catching fat-herring when these occurred in daytime shoals, but when the herring dispersed at night they could be caught with this gear. The purse seine was definitely the most reliable gear for identification of the sound scatterers, but because of the rather complicated fishing procedure involved, it was not found suitable for routine sampling. It was found necessary to identify the scatterers rather frequently, and therefore the larger pelagic trawl was chosen as the most convenient sampling gear, supplemented with the purse seine at selected stations.

When bad weather prevented fishing, identification was made from the echo traces, showing the shoaling behaviour of the fish and the difference in target strengths of the various species. By comparing the echo traces at the fishing stations with the catches obtained, it was found that 0-group capelin and long rough dab had a lower target strength than 0-group herring, redfish, cod and haddock. The four latter species, however, were difficult to separate on the basis of target strength alone. The 0-group cod and haddock were usually found somewhat deeper than the herring, and during daytime they showed a different shoaling pattern (Fig. 3, A and B). The 0-group herring formed shoals of somewhat denser concentrations and could easily be distinguished by sonar also

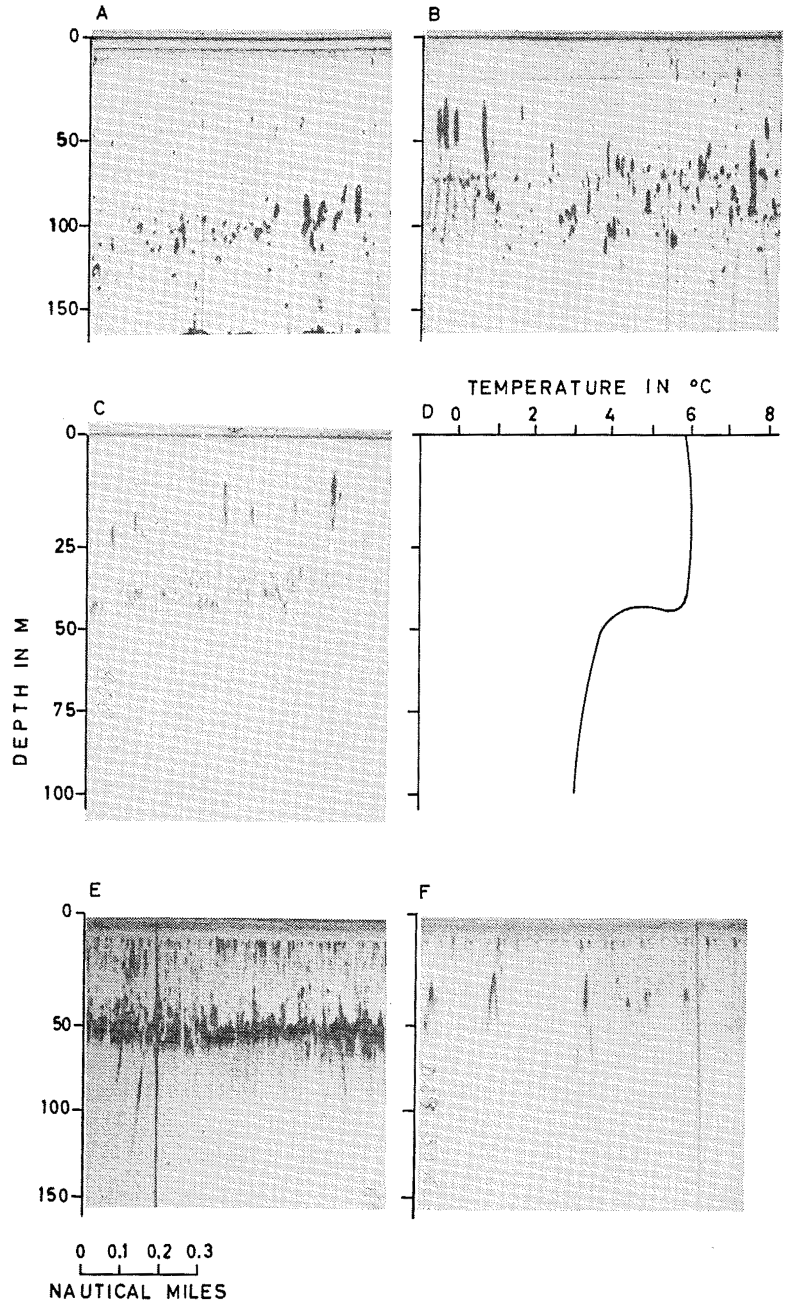

Fig. 3. Echo recordings of 0-group fish by day, (A) cod or haddock or both and (B) herring (top left) and cod or haddock (Simrad research echo sounder 30 kHz set at step—18db), (C) herring recorded above the thermocline (Simrad echo sounder 38.5 kHz set at step 7), (D) bathythermogram from the same region, (E) herring and redfish and (F) herring (Simrad research echo sounder 30 kHz set at step—18db).

when they occurred in the scattering layer together with other 0-group fishes, e.g. redfish (Fig. 3, E and F).

The shoal pattern of older age groups of herring is very characteristic and could usually be identified on the echo recordings, except in the western part of the investigated area where shoals of adult herring sometimes were difficult to distinguish from blue whiting (*Micromesistius poutassou* Risso). In such cases a distinction was made possible by increasing the resolution of the sounder by decreasing the pulse length. During early autumn fat-herring and adult capelin were rarely encountered in the same areas, while during winter and early spring fat-herring and adult capelin frequently occurred together, especially off the Finnmark coast. In this period echo recording analysis together with fishing experiments were necessary to identify the sound scatterers.

Only on a few occasions during the Barents Sea surveys was underwater photography used for identification (MIDTTUN 1959, HOGNESTAD 1963a, OLSEN 1966), mainly because the equipment was technically inadequate for routine use. Fishing experiments combined with analysis of echo trace pattern thus have been used as principle methods for identification of the sound scatterers.

TAGGING EXPERIMENTS

Most of the tagging experiments were carried out during acoustic surveys with the R/V. "G. O. Sars", which on these occasions was equipped for purse seine fishing. The herring were tagged with internal steel tags which measured $15 \times 2 \times 0.5$ mm for 0-group herring and $20 \times 3 \times 1$ mm for adolescent herring. A special tagging device was developed for the small tags (DRAGESUND and HOGNESTAD 1960). The large tags were inserted by means of Aasen's tagging gun (FRIDRIKSSON and AASEN 1952). The fish were taken individually from the purse seine and released into the open sea immediately after tagging. The fat-herring tagged in 1963 were obtained from commercial purse seiners, the herring being transferred to a depository net before tagging. The number of herring tagged in the different localities are listed in Table II.

Although experiments on I-group and older herring tagged with internal steel tags show relatively low tagging mortality and low shedding of tags (FRIDRIKSSON and AASEN 1950, 1952, DRAGESUND and HARALDSVIK 1968), these factors are the most important causes of loss of tagged herring. No decisive experiments have been carried out on 0-group herring, but the experiments performed with I-group herring in tanks (DRAGESUND and HARALDSVIK 1968) showed a tagging mortality of 10.1% and a shedding of tags of 5.1%. These figures are used in this analysis to calculate the number of effectively tagged herring.

Nearly all tags were recovered at Norwegian reduction plants where magnets are installed for detecting the tags. The magnets were tested every autumn. The efficiency of the magnet at each factory multiplied by the quantity of herring processed gives the effective quantity of herring processed. The procedure for testing the magnets and the routine for collecting data on the catches reduced and tags recovered at Norwegian plants are described by AASEN (1958) and DRAGESUND and HARALDSVIK (1968).

HERRING SAMPLES

In addition to samples collected during the acoustic surveys, herring samples, generally consisting of 100 specimens, were collected throughout the year from commercial catches. The herring were examined fresh, or frozen material was brought to the laboratory for examination. The weight was recorded in g. Total length was measured to the nearest half cm until January 1963. After this date, following a recommendation by the International Council for the Exploration of the Sea (ANON. 1963), the length was measured to the half cm below. A correction of 0.25 cm has therefore been added to the mean lengths of herring in samples collected after this date to make the mean lengths comparable with earlier recordings. No correction can be made for comparisons of the length frequency distributions and lengths of individual fish. The discrepancy, however, is of minor importance in the present study. Frozen herring showed a total length shrinkage of about 1.5% when compared with fresh specimens. No correction has been applied to compensate for this shrinkage.

Scales were used for age determination, and estimates of l_1, $l_2 \ldots l_n$ (the total length of a fish at the formation of the first, second, etc. winter ring) were obtained from scale measurements by using the simple proportional growth formula

$$l_n = \frac{s_n}{S} L$$

where s_n refers to measurements on the scale from the basal line to the n^{th} winter ring, S to the edge of the scale, and L is the total length of the fish (LEA 1910, ANON. 1963). Because the method of measuring the total length was changed, there is a bias in $l_1 \ldots l_n$ for samples collected after January 1963 compared with those collected prior to this date. However, back-calculations were based on the 1959 year-class, and the bias in mean annual increments for this year-class is relatively small because the mean length of the scales ($\bar{S}$) is large compared with the mean annual increment on the scales ($\bar{s}_n - \bar{s}_{n-1}$) from 1963 onwards. Therefore,

$$\Delta \bar{t} = \frac{\bar{s}_n - \bar{s}_{n-1}}{\bar{S}} \Delta \bar{L}$$

may be almost negligible. $\Delta \bar{L} = 0.25$ cm, which is the difference between means of total lengths measured before and after January 1963.

CATCH STATISTICS

Catch statistics of small- and fat-herring of the Norwegian landings were obtained from the official fishery statistics (ANON. 1961–1962, ANON. 1963–1969). Statistics for landings by foreign vessels were derived from a report of the Atlanto-Scandian herring working group (ANON. 1969). Supplementary catch data were also recorded at reduction plants by inspectors who classified every landing of small- and fat-herring into size groups according to the number of fish per kg. Statistics on catch and participation of vessels in the small- and fat-herring fisheries also were supplied from the fishermen's sales organization, Feitsildfiskernes Salgslag.

DISTRIBUTION AND MIGRATION

RECORDS FROM ACOUSTIC SURVEYS

Young herring

The 1959 observations were the first in the present series, and the research programme had not been fully established at that time. Additional observations on the 0-group herring distribution, therefore, were procured from catch data and echo recordings of other fish surveys in the areas around Bear Island and on the western banks off West-Spitsbergen (G. SÆTERSDAL personal communication, J. CORLETT personal communication).

In the autumn of 1959 0-group herring were observed over large areas and in dense concentrations (Fig. 4). The distribution this year, therefore, is of particular interest. The concentrations of herring along the coast were generally scattered south of Vestfjord. Dense concentrations were observed particularly in the outer part of the Vestfjord, off Vesterålen and at the entrance of the fjords between Hamarfjord and Varangerfjord. At the time of the surveys only scattered shoals were found in the inner parts of the fjords of northern Norway. The records clearly demonstrated that the 0-group herring had a wide oceanic distribution with the densest concentrations in the southern part of the Barents Sea, but that they were also numerous in the northern part of the Barents Sea and towards the edge of the shelf off Bear Island.

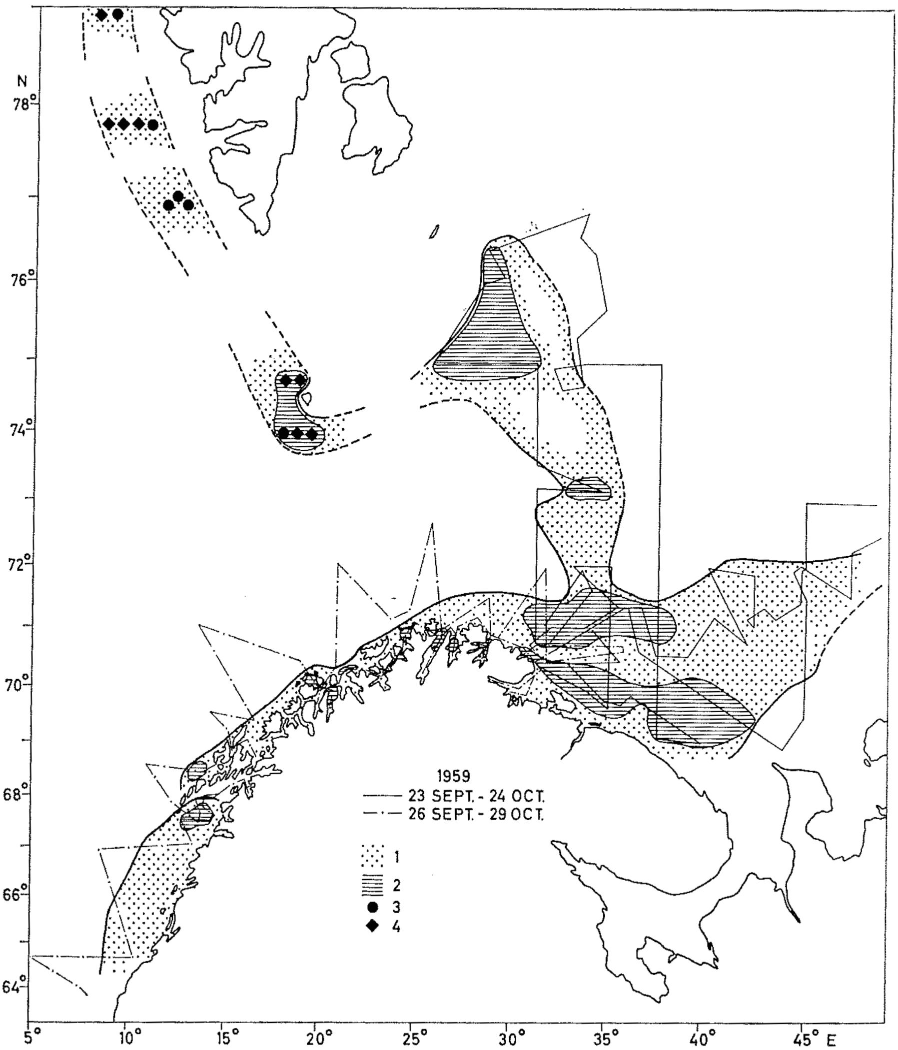

Fig. 4. Survey routes and distribution of 0-group herring in the autumn of 1959, (1) very scattered and scattered, (2) dense and very dense concentrations, (3) 0-group herring caught by bottom trawl with cover net and (4) 0-group herring identified from stomach contents of cod.

A similar pattern was found in 1960 and 1964 (Figs. 5 and 9) and partly also in 1963 (Fig. 8), whereas in 1961 and 1962 (Figs. 6 and 7) the 0-group herring were more restricted to the coastal belt. In 1965 herring were observed in two separated small regions in the open sea, i.e. between Bear Island and the Norwegian coast and along the edge of the continental shelf towards northwest of Bear Island to the southern part of West-

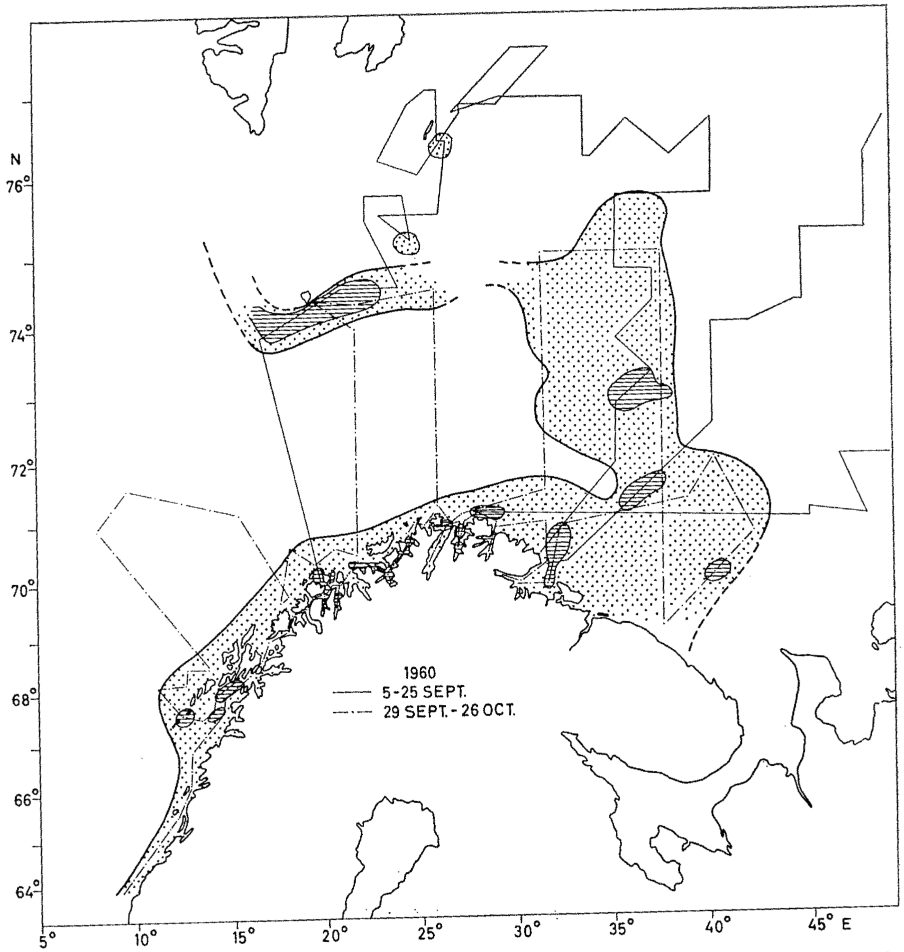

Fig. 5. Survey routes and distribution of 0-group herring in the autumn of 1960. Legend as in Fig. 4.

Spitsbergen (Fig. 10). In all the years concentrations of 0-group herring were observed along the coast, particularly at the entrances to the fjords. Between the coast of northern Norway and Bear Island 0-group herring were recorded in 1964 and 1965, but in these years the surveys were carried out somewhat earlier than in the previous years, and the herring would have moved farther east at a later date. The densest concentrations were observed in 1959, but dense concentrations were also recorded in 1960. In 1962 and 1965 the concentrations were very small.

The distribution of 0-group herring indicates that postlarval fish are transported along the path of the most important water currents off northern Norway and in the Barents Sea (Fig. 11). The herring larvae

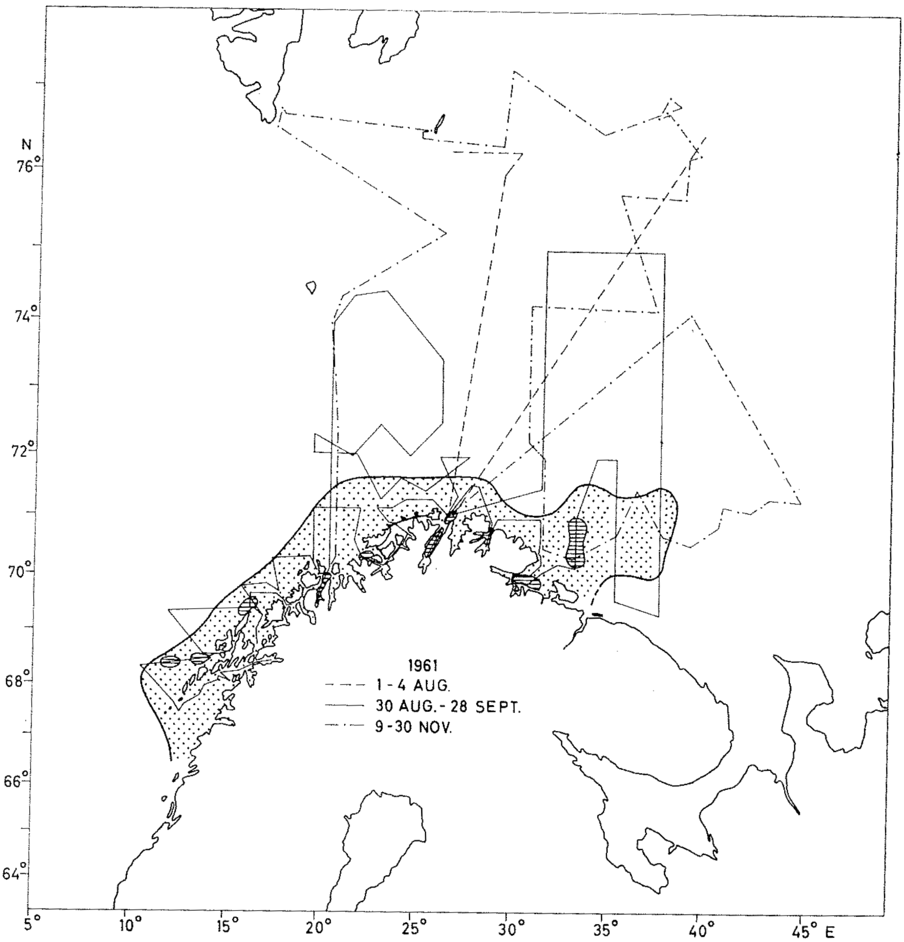

Fig. 6. Survey routes and distribution of 0-group herring in the autumn of 1961. Legend as in Fig. 4.

are transported northwards by the coastal current during the first few months after hatching (DRAGESUND 1970). When passing the banks off Troms, the drift of the larvae becomes more influenced by Atlantic water which in this area is intensively mixed with the coastal water (LJØEN 1962). At the entrance of the Barents Sea the water masses split into several branches (Fig. 11). One branch proceeds northwards to form The West-Spitsbergen Current, and two eastward branches separate off Torsvåg (N 70° 30′) where the shelf is wide. One of these flows along the coast of West-Finnmark (The North Cape Current) and the other continues towards the northern Barents Sea (Central Bank). The North Cape Current again splits into two branches, one along the southern and

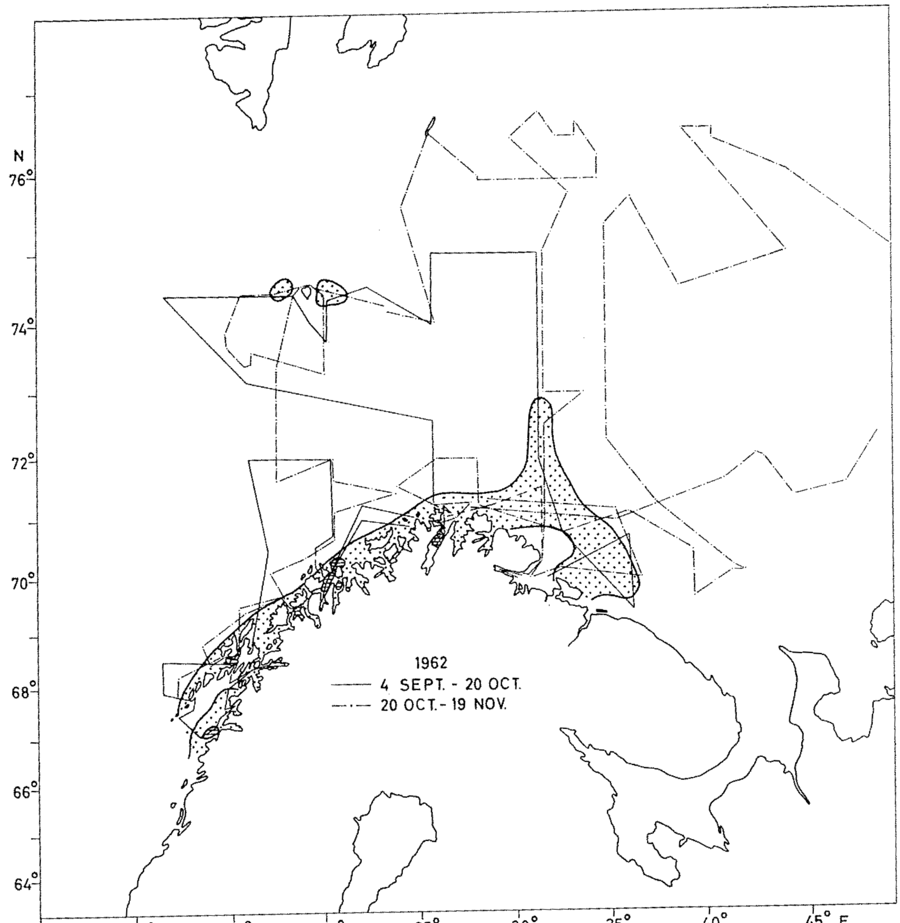

Fig. 7. Survey routes and distribution of 0-group herring in the autumn of 1962. Legend as in Fig. 4.

northern slopes of Goose Bank and the other passing near the Murman coast. Therefore, 0-group herring are always found along the coast. When the main spawning grounds are located as far north as off Møre, 0-group herring are generally more abundant on the northern than on the western coast of Norway. It cannot be determined from the present material whether the difference in distribution found between the different years was caused by hydrographic conditions during the postlarval drift phase. However, evidence was found that larvae were more widely dispersed in 1959, 1960 and 1964 than in 1961 and 1962 (Dragesund 1970). This may explain why subsequent northward drift resulted in a wide oceanic distribution in 1959, 1960 and 1964. The particularly dense concentra-

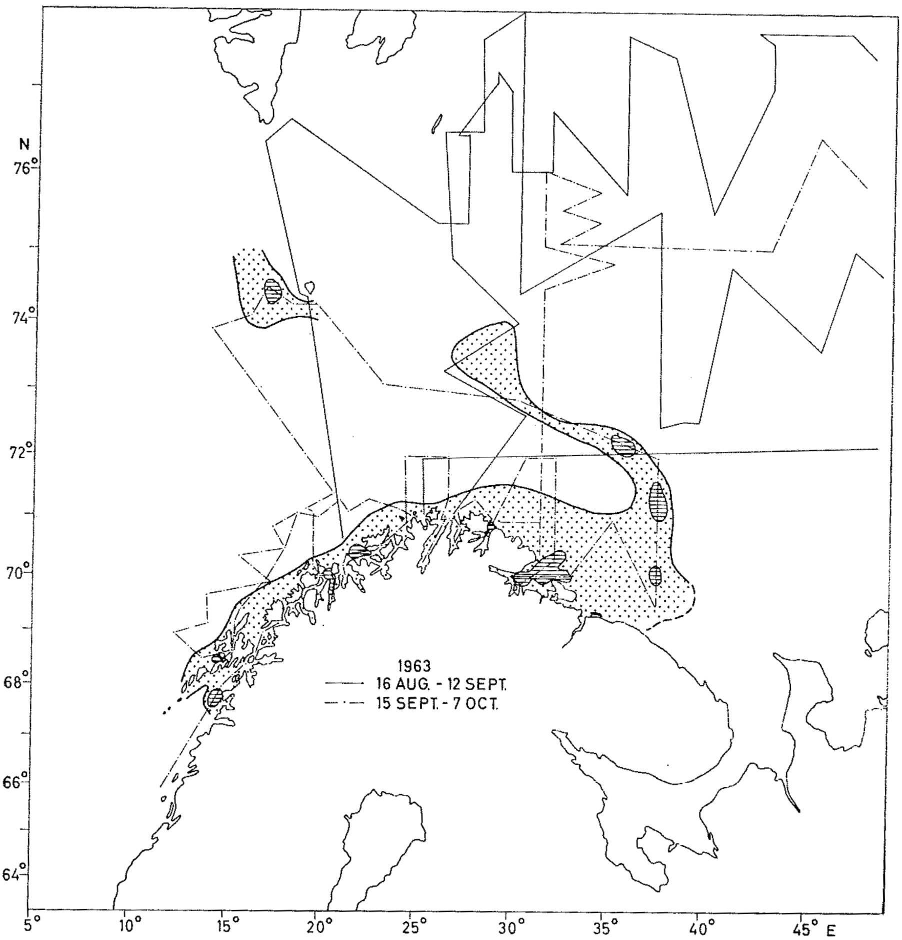

Fig. 8. Survey routes and distribution of 0-group herring in the autumn of 1963. Legend as in Fig. 4.

tions of 0-group herring in 1959 and 1960 indicated that the survival during the larval and postlarval phases was relatively high.

In late autumn a major part of the 0-group herring in offshore waters is concentrated along the fronts between the cold arctic water and the warmer water masses which cover the area west of Spitsbergen–Bear Island and the central and southeastern parts of the Barents Sea. Herring in this area will generally live in colder water during the late 0-group and early I-group stages than those accumulating along the coast and in the fjords, especially west and south of North Cape. The distribution of 0-group herring in relation to temperature is shown for the two extreme years 1959 and 1961 (Fig. 12).

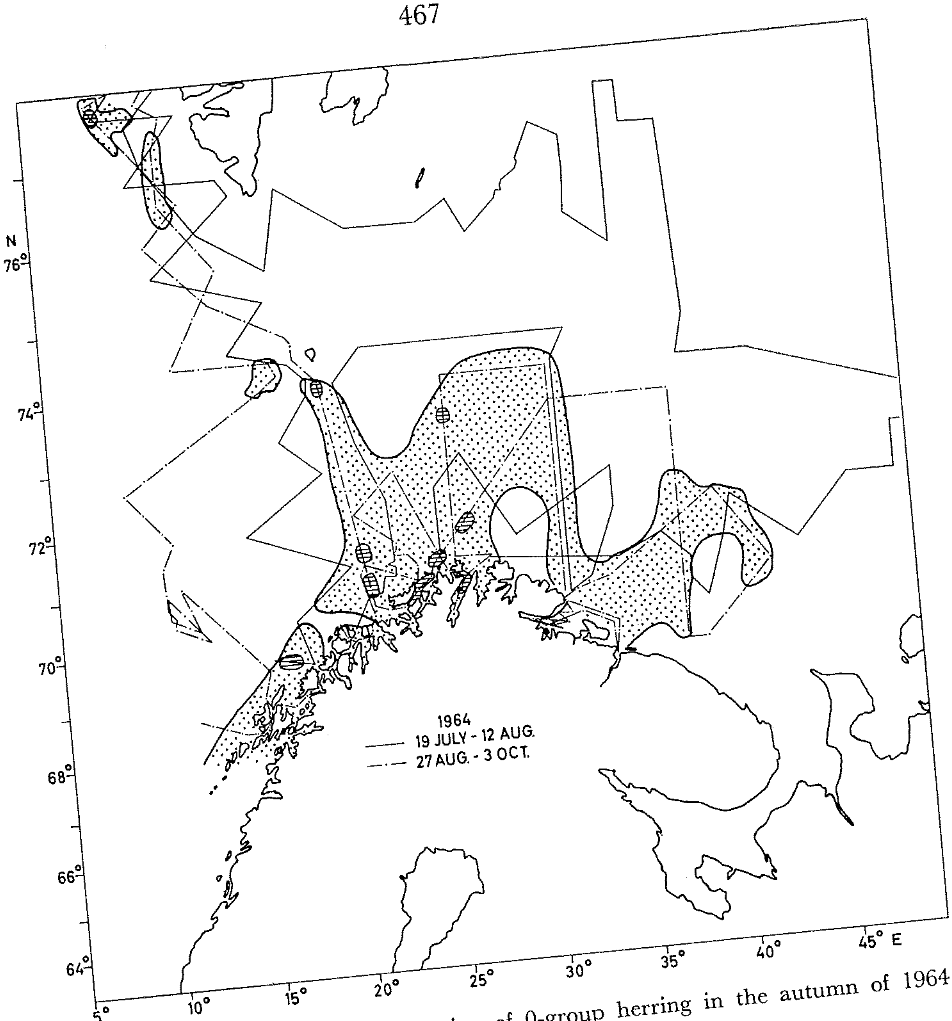

Fig. 9. Survey routes and distribution of 0-group herring in the autumn of 1964. Legend as in Fig. 4.

The herring in the northern part of the Barents Sea are mainly found in water of 1 to 4°C. In 1959 some of the herring were also found in water with a temperature as low as 0°C. In the southern part of the Barents Sea and along the coast of Finnmark, herring are mainly observed in water of 5 to 7°C. In 1961 when no herring were observed in the northern and eastern parts of the Barents Sea, the herring lived in a more uniform environment with considerably warmer water during the late 0-group stage than in 1959. This feature which may have caused a more variable growth pattern for the 1959 year-class than for the 1961 year-class, will be discussed further in a later section.

The herring accumulating at the entrances to the fjords during early

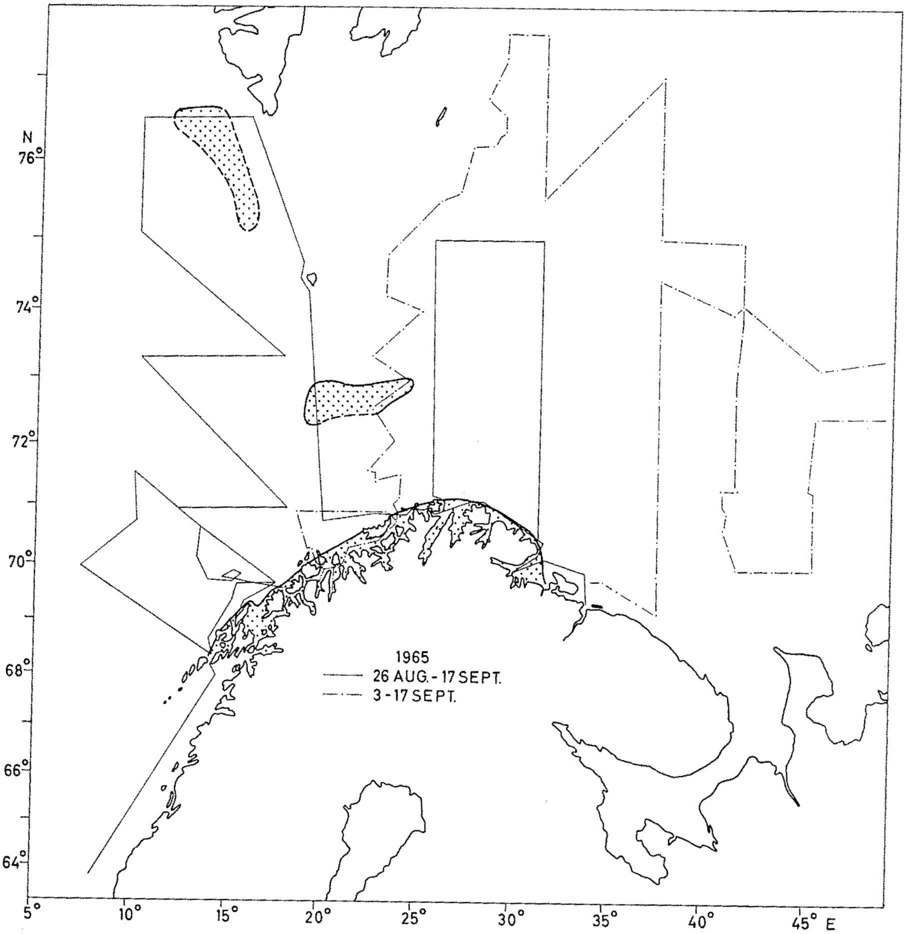

Fig. 10. Survey routes and distribution of 0-group herring in the autumn of 1965. Legend as in Fig. 4.

autumn migrate farther into the fjords later in the autumn. The situation in 1959 has been chosen to illustrate the characteristic distribution of 0-group herring during the immigration period (Fig. 13). Investigations carried out in northern Norway, mainly in the Ullsfjord region (Hamarfjord, Ullsfjord and Lyngenfjord) and in the Porsangerfjord, demonstrated that the 0-group herring remained in the fjords throughout the autumn and as I-group the following winter, i.e. the wintering period. A gradual emigration took place from March to May.

This general distribution pattern was also found in many other fjords along the coast of northern Norway. Slight variations in the behaviour during the immigration and wintering periods were found between fjords

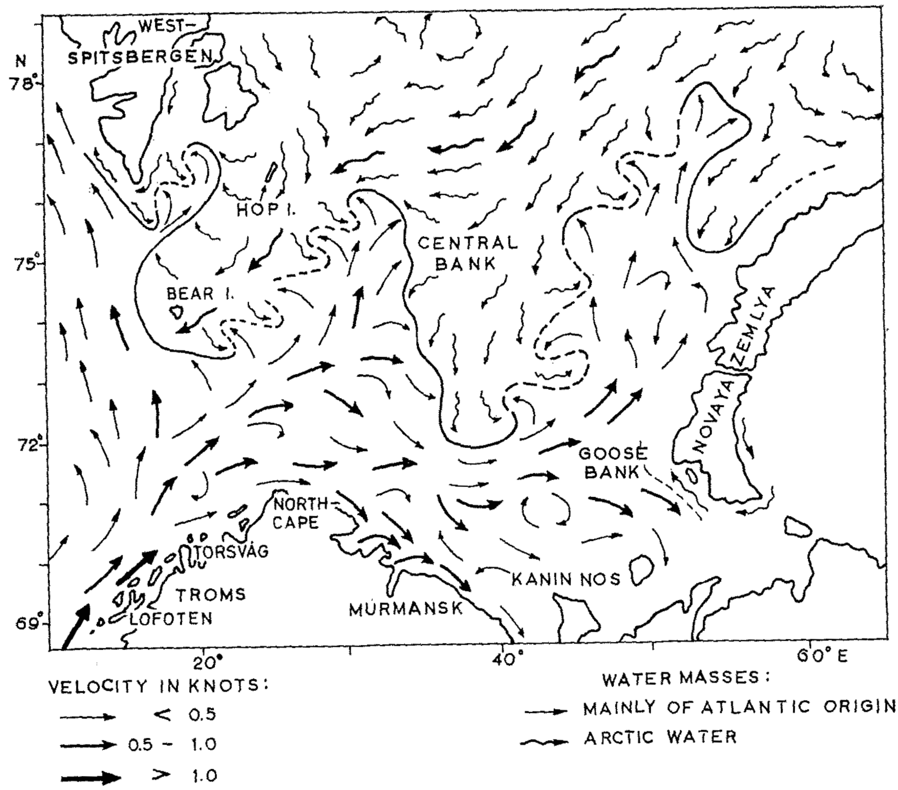

Fig. 11. General system of water currents off northern Norway and in the Barents Sea (modified from TANTSURA 1959).

and from one year to another. The Ullsfjord region in Troms and the Porsangerfjord in Finnmark were selected to study these variations. A description is given only for the wintering period from the autumn of 1959 to the spring of 1960 as this is assumed to represent the normal conditions.

In early October dense concentrations of herring were located just inside the entrance of Hamarfjord, while in Ullsfjord only few and scattered shoals were observed (Fig. 14A). During the following two weeks a further immigration took place, and in late October dense concentrations were recorded from the entrance to the central part of Ullsfjord (Fig. 14A and B). During the migration from Hamarfjord to Ullsfjord the herring were distributed at depths of 10–40 m. At night the herring dispersed, and in the day the fish clustered more closely together. During immigration, the temperature in the surface water in Ullsfjord was uniform except for a slightly lower temperature in the upper 20 m in the innermost part of the fjord (Fig. 14C).

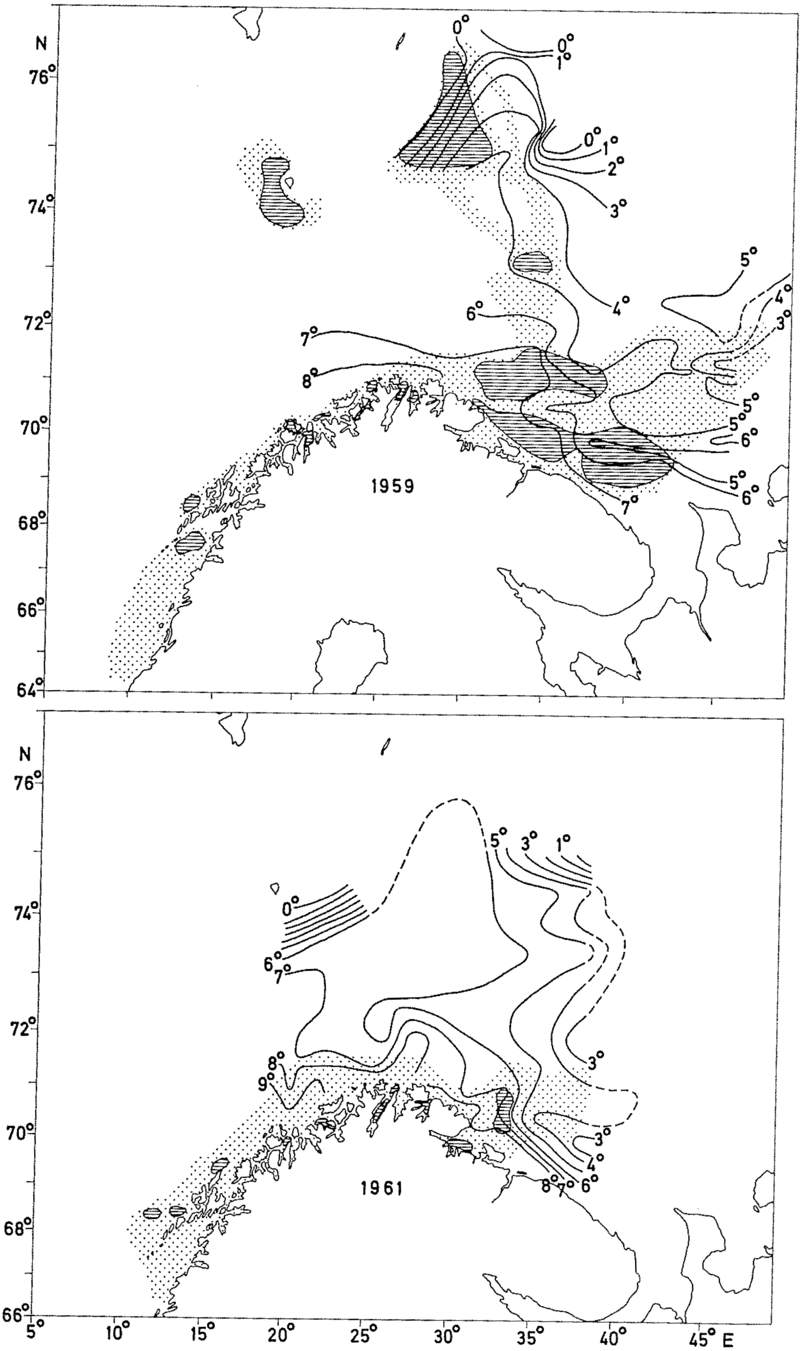

Fig. 12. Distribution of 0-group herring in relation to temperature (°C) at 50 m depth in the autumn of 1959 and 1961.

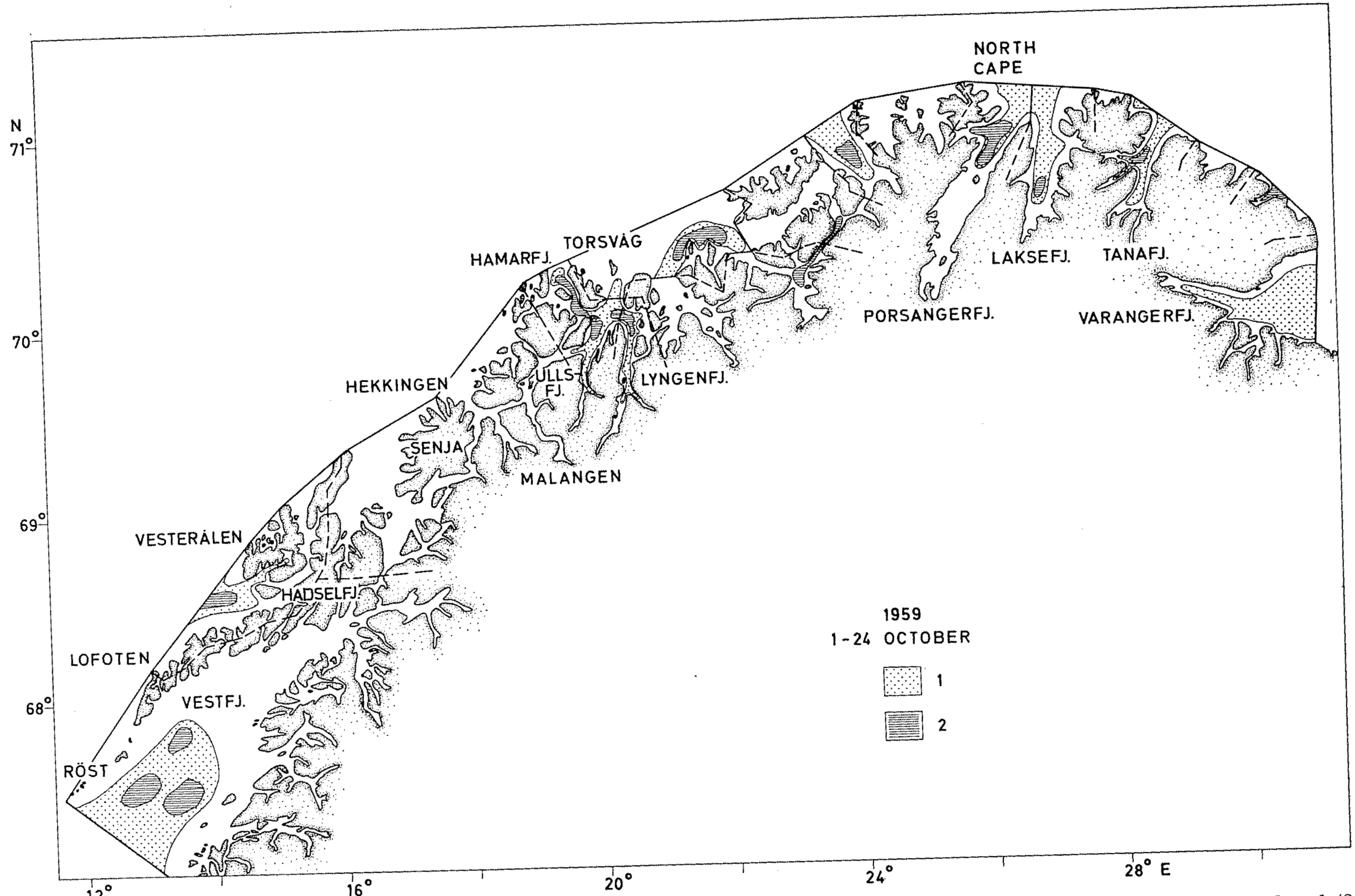

Fig. 13. Distribution of 0-group herring during the period of immigration to the fjords of northern Norway in 1959, (1) scattered and (2) dense concentrations. Herring observed inside the line drawn along the coast are later in the year subject to fishing.

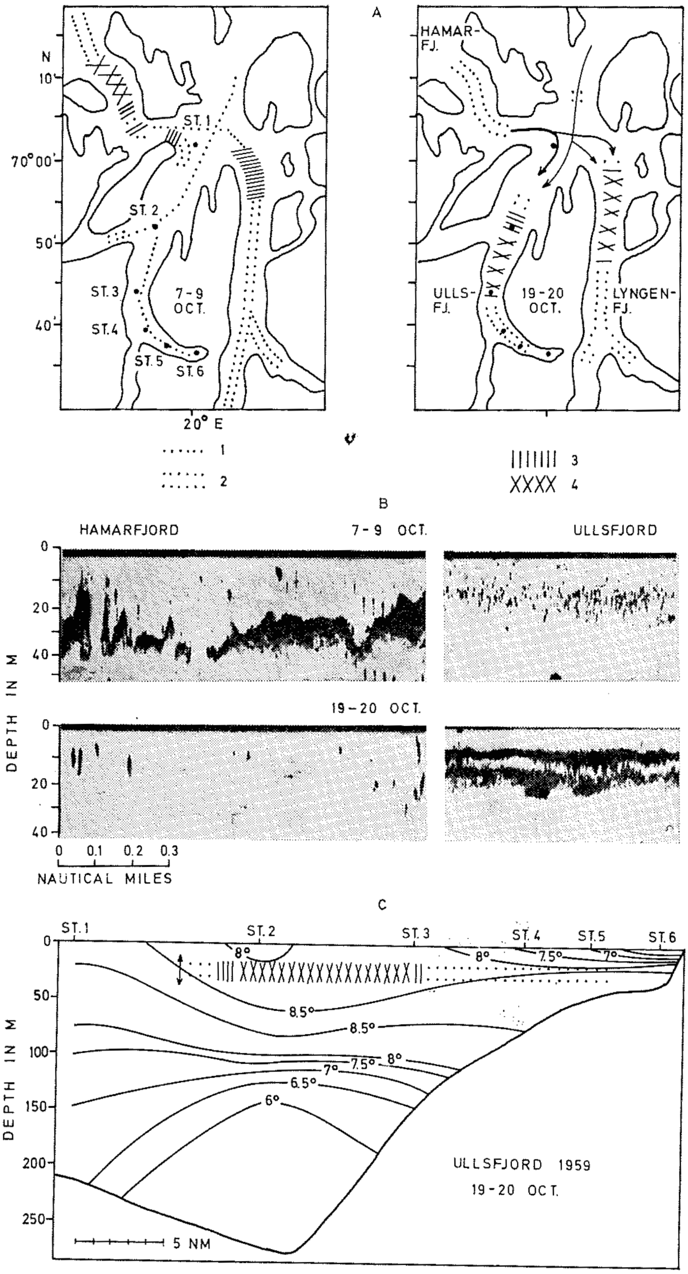

Fig. 14. Distribution of 0-group herring in the autumn of 1959, (A) in the Ullsfjord region, (1) very scattered, (2) scattered, (3) dense and (4) very dense concentrations, (B) echo recordings in Hamarfjord and Ullsfjord and (C) distribution of 0-group herring in relation to temperature (°C) in the Ullsfjord. Double pointed arrow denotes vertical extension of the distribution. Legend as in (A).

On 10 November (Fig. 15A) herring were concentrated in the inner part of Ullsfjord, and no herring were observed in Hamarfjord or off the entrance to this fjord. From October to November the fish moved from water of higher to slightly lower temperature. However, when the autumn and winter cooling started, the herring gradually moved into the central part of the fjord, where the water temperature was highest (Fig. 15B). The extent of the diurnal vertical migration increased during this period. The herring were observed near the surface at night and down to depths of 100–120 m in the daytime. In January no herring were observed in the innermost part of Ullsfjord, but herring were recorded near the surface farther out in the fjord. In February the herring were found mainly along the eastern side of the fjord and somewhat farther out. From the end of March the herring gradually migrated from the fjord, and in May the main concentrations had left the Ullsfjord region (Fig. 15C).

The migration from the entrance of Porsangerfjord and farther into the fjord started at the end of October, i.e. slightly later than in the Ullsfjord region. At that time only scattered concentrations of herring were observed outside the Porsangerfjord and in the inner parts of the fjord. The herring entered the fjord along its western shore (Fig. 16A), and from the end of November to mid-December most of the herring moved into the innermost branch of the fjord (Austerbotn), i.e. into water masses of lower temperature than those found farther out. In late autumn and throughout winter the temperature in Austerbotn was below zero, and from the end of December 1959 until April of 1960 the surface was covered with ice. The herring were found in Austerbotn when the ice broke up, and therefore probably remained in the cold water throughout winter (Fig. 16C). The emigration started in May, and the herring left the fjord within about three weeks.

A similar distribution and behaviour pattern was found for the other year-classes. The densest concentrations were observed in the autumn of 1959 and 1960, followed by 1961 and 1963. In 1962, 1964 and particularly in 1965 (Figs. 17 and 18), 0-group herring were few and scattered. In September 1965 insignificant numbers of 0-group herring were detected in the Ullsfjord region and in the Porsangerfjord. During the following two months, some small shoals migrated into the fjords. The herring concentrations were, however, more scattered than in any other year since the investigations started in the autumn of 1959.

Throughout the investigated period the immigration of 0-group herring was completed somewhat earlier in Ullsfjord than in Porsangerfjord, i.e. during the first and second half of October, respectively. In Ullsfjord the herring usually migrated to the central part of the fjord during winter, and when the winter cooling started, the extension of the

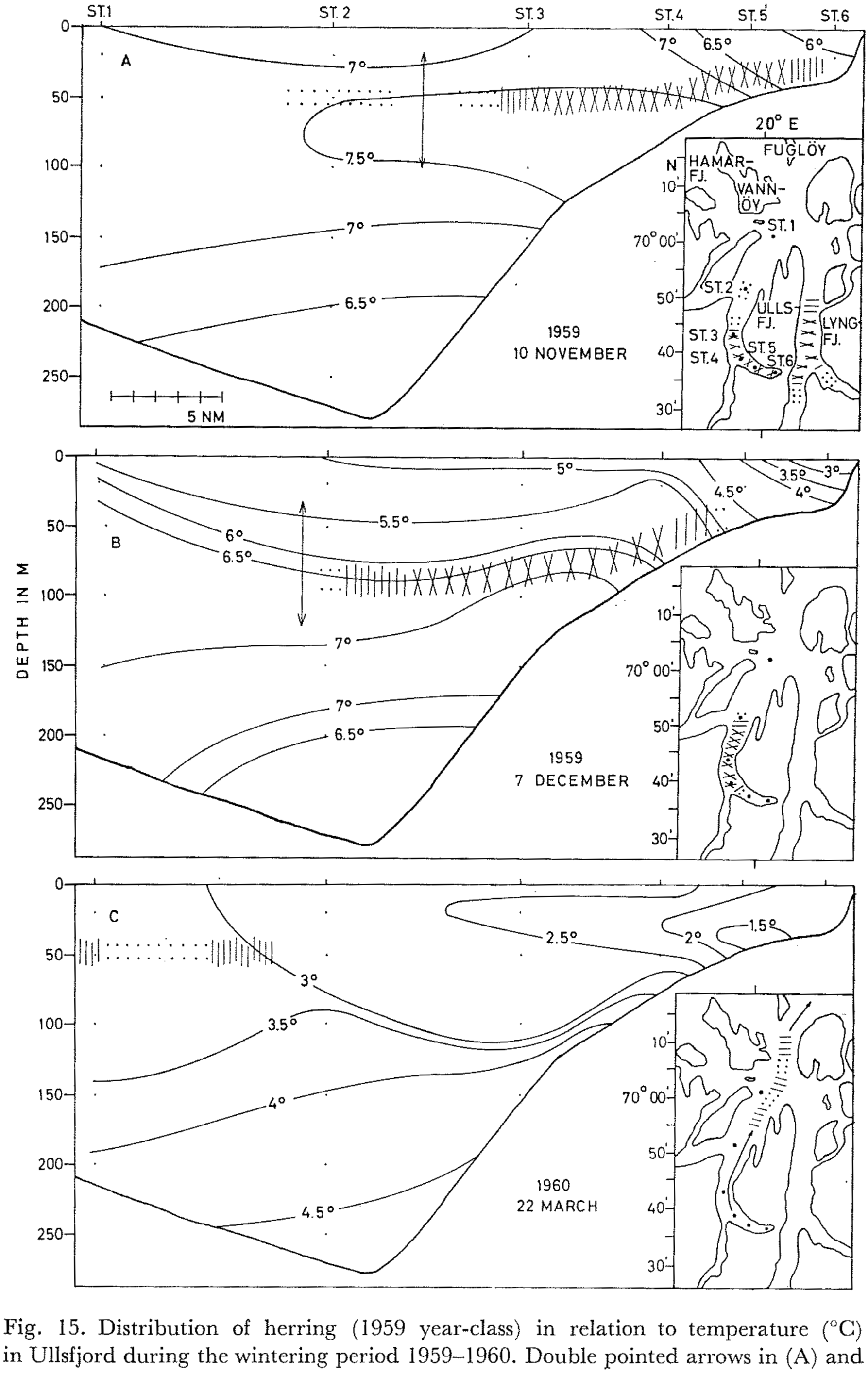

Fig. 15. Distribution of herring (1959 year-class) in relation to temperature (°C) in Ullsfjord during the wintering period 1959–1960. Double pointed arrows in (A) and (B) denote vertical extension of the distribution. Legend as in Fig. 14A.

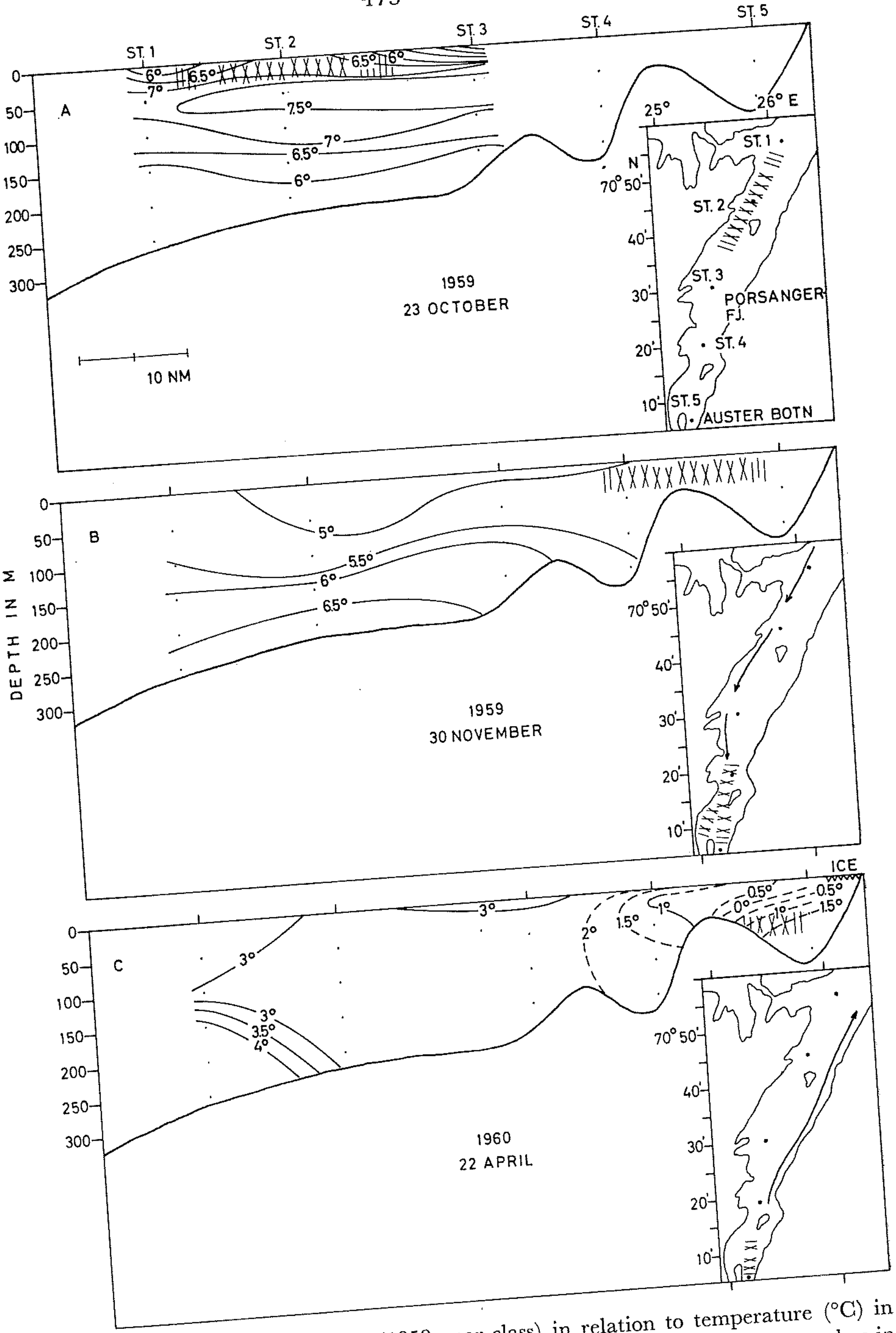

Fig. 16. Distribution of herring (1959 year-class) in relation to temperature (°C) in Porsangerfjord during the immigration and wintering period 1959–1960. Legend as in Fig. 14A.

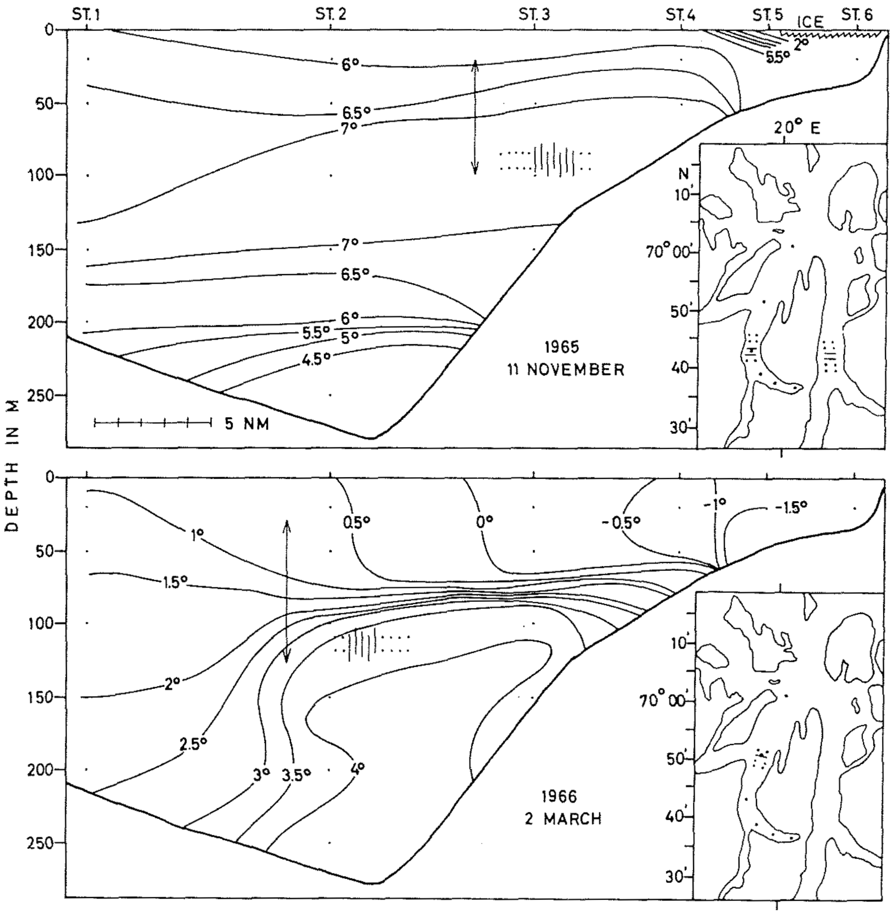

Fig. 17. Distribution of herring (1965 year-class) in relation to temperature (°C) in Ullsfjord during the wintering period 1965–1966. Double pointed arrows denote vertical extension of the distribution. Legend as in Fig. 14A.

vertical migration increased. From late afternoon to the following morning the herring were found close to the surface, i.e. above 50 m depth, whereas during the day the herring remained in the intermediate warm water layer at depths varying from 50 to 120 m. The emigration started in March when this layer disappeared, and the herring usually migrated from water of lower to higher temperature. In Porsangerfjord the herring stayed in cold water, probably near the bottom in water of temperature below 0 °C, throughout the winter until May when the herring ascended and gradually started migrating from the fjord.

The fishery on 0-group herring starts with the immigration and is continued throughout the wintering period. The concentrations of 0-group herring migrating into the fjords appeared to be most dense in

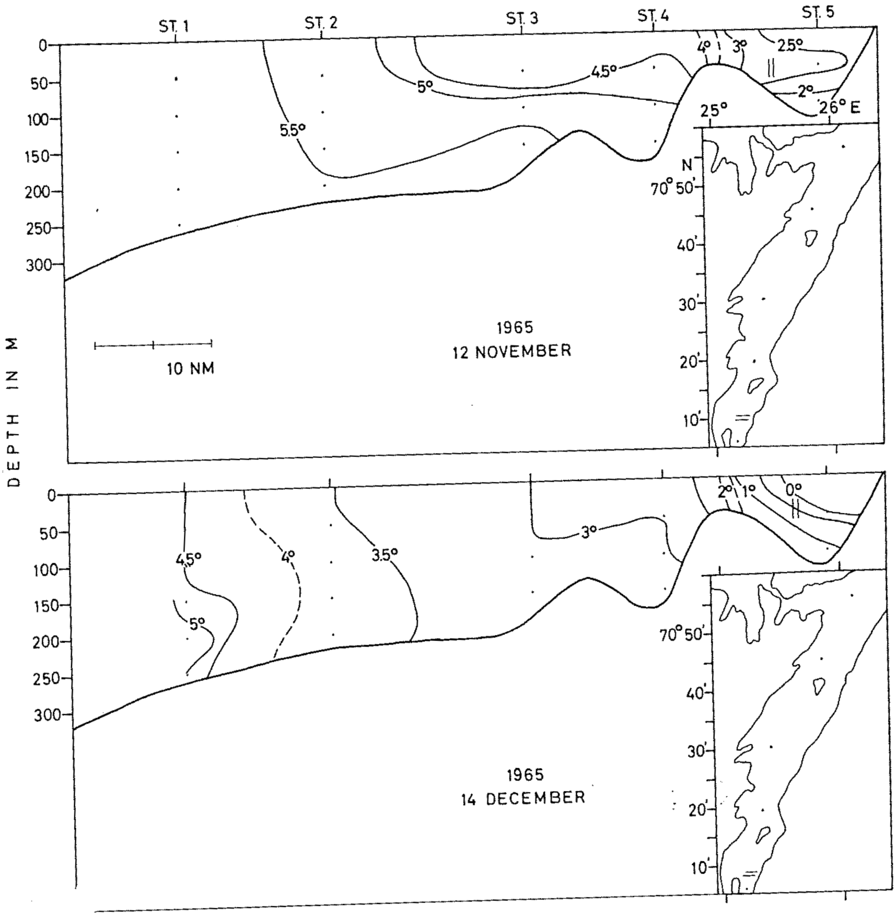

Fig. 18. Distribution of herring (1965 year-class) in relation to temperature (°C) in Porsangerfjord in November–December 1965. Legend as in Fig. 14A.

years when rich year-classes occurred, but other factors will also have an influence on the proportion of 0-group herring migrating into the fjords, e.g. the drift and distribution pattern during the larval and post-larval stages. In 1959–1960, 1960–1961 and 1961–1962 a productive small-herring fishery took place, whereas in the other years in question the fishery was rather poor, especially in 1965–1966.

Adolescent herring

The distribution and migration of the 1959 year-class during 1960 is illustrated in Fig. 19A. During winter and spring the year-class was recorded as I-group in the fjords and offshore from the banks of eastern Finnmark into the northern, central and southern parts of the Barents Sea. In Sep-

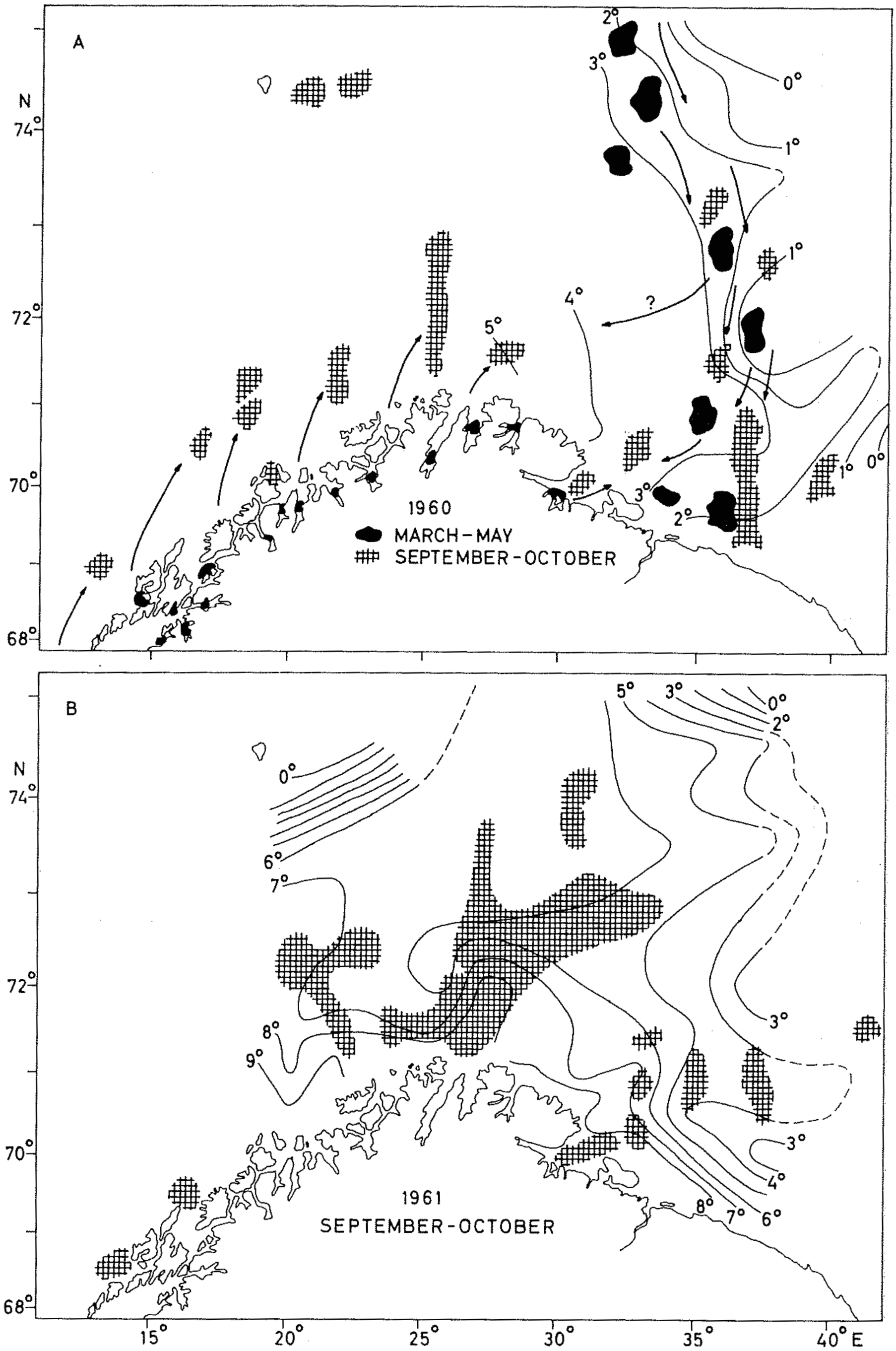

Fig. 19. Distribution of adolescent herring, mainly of the 1959 year-class in relation to temperature (°C) at 50 m depth, (A) in 1960 and (B) 1961. Temperatures in (A) refer to April—May and arrows denote the main migration routes of herring during the summer of 1960.

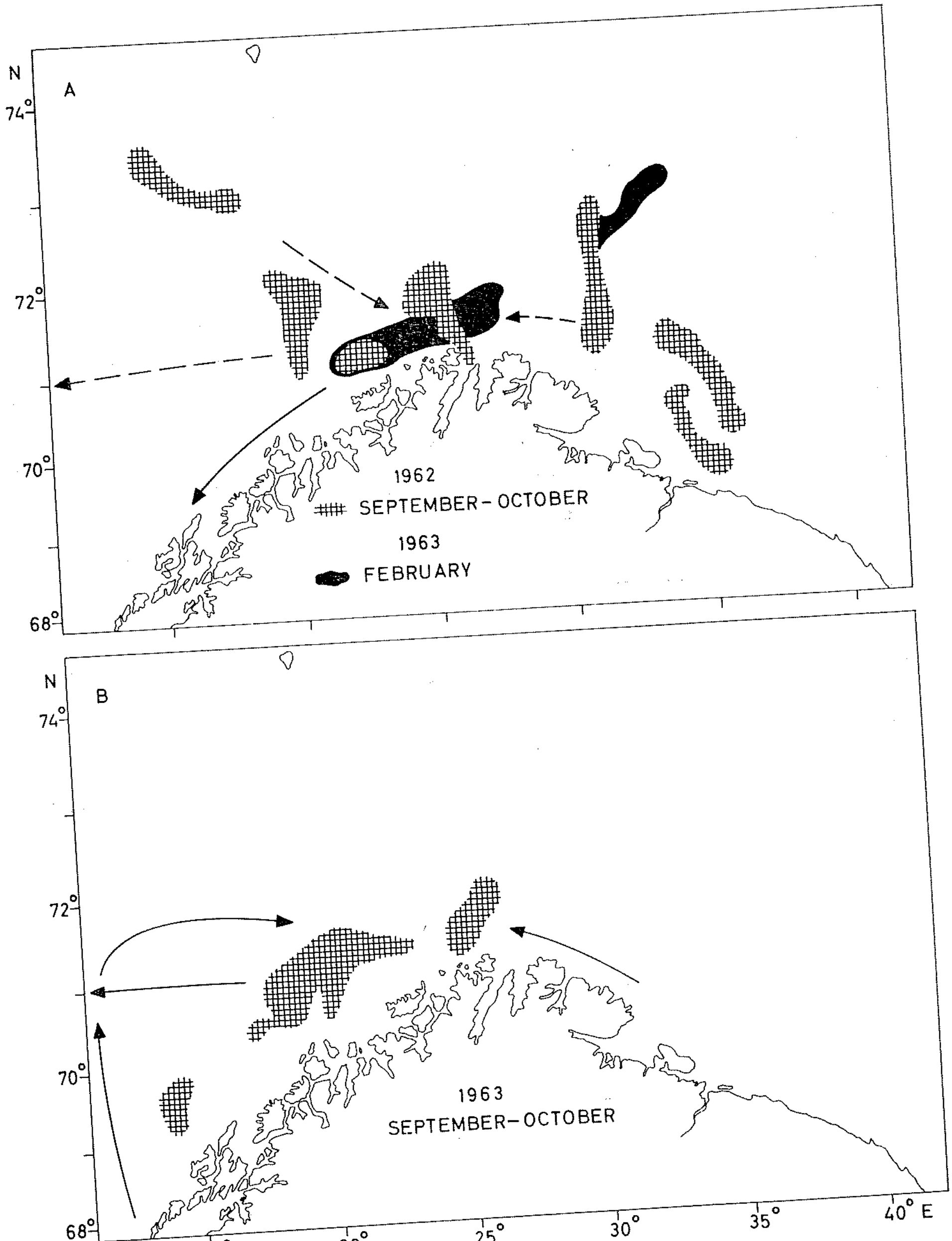

Fig. 20. Distribution of adolescent herring, mainly of the 1959 year-class, (A) in the autumn and winter of 1962 and 1963 and (B) in the autumn of 1963. Arrows indicate migration routes, broken ones summer and autumn 1962 to winter 1963, the fully drawn ones spring and summer 1963.

tember–October of 1960 the main concentrations as I-group were recorded from the North Cape Bank and eastward into the central and southern parts of the Barents Sea. During the summer of 1960 the open sea concentrations of this year-class gradually moved southward along the front between the cold and warmer water in the area from the Central Bank towards the Thor Iversen Bank. At the same time its members, which had wintered in the fjords of northern Norway, migrated from the coast. Members of this year-class also occurred on the banks around Bear Island in the autumn of 1960. Some of these herring could have wintered in this area, and others probably had migrated from the region south of Hope Island, although the majority of the herring observed south of Hope Island in the previous autumn presumably migrated southwards over the Central Bank and Thor Iversen Bank. In the winter and spring of 1961 the 1959 year-class was found in almost the same areas although the distribution was more restricted to the central and southern parts of the Barents Sea.

In the autumn of 1961 (Fig. 19B) the 1960 year-class had mixed with that of the 1959, and it was not possible to distinguish exactly between the distribution of these year-classes. However, the 1959 year-class, which was then in its third year of life (II-group), had moved farther west although it was also found in the central and southern parts of the Barents Sea. During the winter of 1962 the 1959 year-class was still observed off the coast of Finnmark and in the southern part of the Barents Sea (areas 03 and 02). The following summer dense concentrations in which the 1959 year-class predominated, were observed off Finnmark in areas 03 and 10 (Table 1).

In the autumn of 1962 (Fig. 20A) large concentrations mainly of the 1959 year-class were recorded off Torsvåg (areas 04 and 12), while other concentrations were also observed farther east. During the summer of 1962 members of the 1959 year-class migrated westwards into the Norwegian Sea, but most of the herring remained in the areas off Torsvåg. From the autumn of 1962 to February 1963 herring mainly of the 1959 year-class concentrated off western Finnmark. Some of these herring became mature and migrated later in the winter of 1963 towards Lofoten for spawning (Devold 1968). In the autumn of 1963 (Fig. 20B) most of the 1959 year-class had left the central parts of the Barents Sea and the Finnmark coast and had concentrated off Torsvåg together with herring which spawned at Lofoten in 1963.

The 1960 year-class dominated among the herring recorded off eastern Finnmark in spring and summer 1963 (Table 1). The 1963 and 1964 year-classes remained off eastern Finnmark during the entire adolescent phase (up to the end of 1968), and no westward migration could be discovered during this period (Table 1).

Table 1. Age composition (in %) of adolescent herring caught with purse seine (PS) and pelagic trawl (PT) in some of the main fishing areas in 1961–1968.

Date		Area	Gear	No.	Year-class				
					1959	1960	1961	1963	1964
1961	11–22.9	03 and 12	PS	215	90.7	9.3			
	20.9	03 and 10	PS	97	29.9	70.1			
1962	28.2–7.3	03 and 02	PT	102	41.2	58.8			
	1.7–2.8	03 and 10	PS	973	90.6	9.4	—		
	13.9	03	PT	76	57.9	42.1	—		
	14–18.9	04 and 12	PT and PS	112	77.7	21.4	0.9		
1963	6.2	04	PT	49	67.3	28.6	4.1		
	2.2–5.4	03 and 13	PT	255	27.5	60.4	12.1		
	4.6–25.7	03	PS	358	7.5	81.3	11.2		
	1.10–28.11	04	PT and PS	725	43.2	42.2	14.6		
1965	30–31.8	03	PT and PS	302	—	—	—	41.7	58.3
1966	4–24.8	03	PT and PS	305	—	—	—	44.3	55.7
1967	11.8	03	PS	50	—	—	—	36.0	64.0
1968	8.4–8.5	03	PS	537	—	—	—	41.9	58.1

Almost all the adolescent herring found along the coast were recorded outside the entrances to the fjords. The main fat-herring fishery, therefore, took place offshore and most intensively off eastern Finnmark (area 03) and off Vesterålen and Lofoten (area 05). However, almost no fishing took place on the dense offshore concentrations recorded in the autumn of 1962 and 1963 between Torsvåg and North Cape (areas 04 and 12). During the period 1965–1968 a productive fat-herring fishery occurred off eastern Finnmark on the 1963 and 1964 year-classes which were concentrated within a relatively limited area.

LENGTH AND GROWTH STUDIES

The present investigations have shown that herring, which have wintered in the fjords during the late 0-group and early I-group stages, move into the open sea and join those which have spent their first year of life there. With increasing age more extensive migrations occur, extending into the central and western parts of the Norwegian Sea. To investigate the effect of growth on the timing of migration from the nursery areas the length and growth in different areas are compared.

Length distributions of 0-group herring are given in Table III. An analysis of variance showed in most cases significant differences in lengths of 0-group herring between areas along the coast (Table IV). However, the differences between the northernmost areas 05, 04 and 03 were not consistently significant. Mean lengths of 0-group herring in different areas

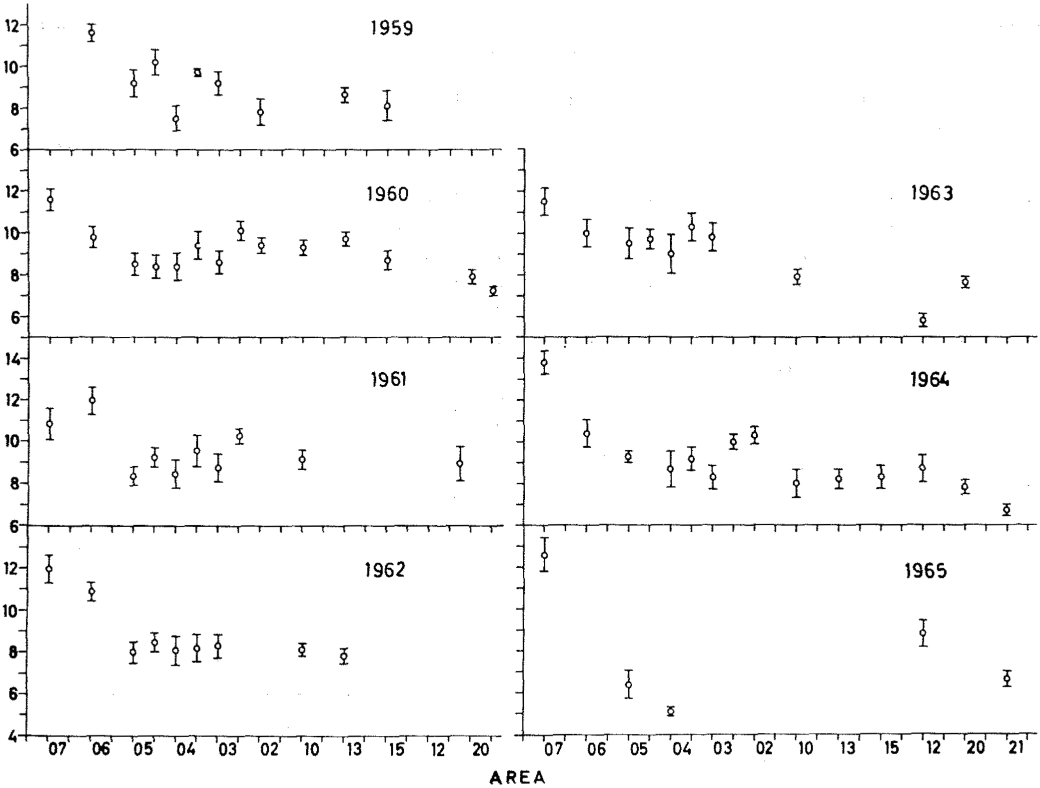

Fig. 21. Mean length of 0-group herring of the 1959–1965 year-classes in different areas. The vertical bars show the standard deviation. Samples collected with IKMT are omitted in the figure.

are listed in Table V and illustrated in Fig. 21. The mean lengths were larger for 0-group herring caught south of Lofoten (in areas 07 and 06) than for those caught north of this region. Herring collected in coastal and offshore waters north of Lofoten had variable mean lengths, but no clear decreasing trend in length was found from south to north.

Length distributions of adolescent herring of the 1959 year-class collected after the main growth seasons are shown in Fig. 22. Decreasing lengths were found from south to north. Both fast and slow growing herring were caught off Torsvåg (in areas 04 and 12). The length distribution of $3\frac{1}{2}$-year-old herring caught off Iceland (areas 56, 57, 58, 59) shows that these herring had grown more rapidly than herring of the same year-class occurring off Torsvåg at the same time. The appearance of slow growing herring off Torsvåg in the autumn of 1962 ($3\frac{1}{2}$-year-old) gave evidence of an immigration of the 1959 year-class from the eastern part of the Finnmark coast and from the Barents Sea (Fig. 22C and E).

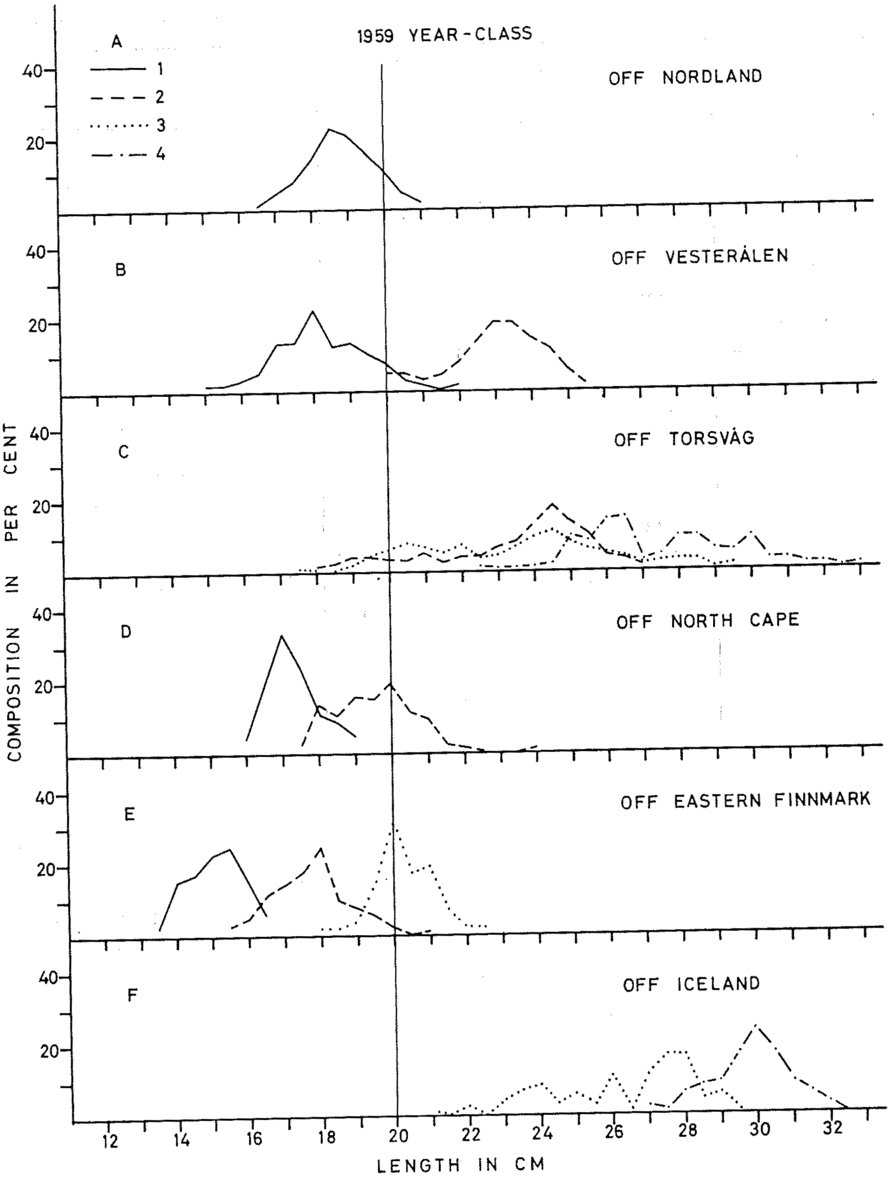

Fig. 22. Length distribution of adolescent herring of the 1959 year-class in different regions. Legend:

(1) $1\frac{1}{2}$-year-old, (A) No. = 401, (B) No. = 88, (D) No. = 49, (E) No. = 54;
(2) $2\frac{1}{2}$-year-old, (B) No. = 130, (C) No. = 176, (D) No. = 89, (E) No. = 108;
(3) $3\frac{1}{2}$-year-old, (C) No. = 244, (E) No. = 60, (F) No. = 75;
(4) $4\frac{1}{2}$-year-old, (C) No. = 142, (F) No. = 102.

Table 2. Composition (in %) of southern (S) and northern (N) growth types of the 1959 and 1961 year-classes in different regions during 1961–1967. Data on the herring off Iceland are from JAKOBSSON (1964, 1965, 1966, 1967).

Year	Region	1959 year-class				1961 year-class			
		No.	N	S	Un-certain	No.	N	S	Un-certain
1961	Off eastern Finnmark	99	88.9	—	11.1				
	Off Torsvåg	100	47.0	24.0	29.0				
1962	Off eastern Finnmark	728	96.2	0.1	3.7				
	Off Torsvåg	95	91.6	—	8.4				
	Off Iceland	407	56.5	43.5	—				
1963	Off eastern Finnmark	27	100.0	—	—	40	95.0	—	5.0
	Off Torsvåg	309	83.2	14.9	1.9	71	31.0	47.9	21.1
	Off Iceland	722	54.8	45.2	—	8	—	100.0	—
1964	Off Iceland	1630	65.3	34.5	0.2	122	24.6	70.5	4.9
1965	Off Møre	1045	64.9	29.5	5.6	300	2.3	33.3	64.4
	Off Lofoten	632	82.8	12.8	4.4	51	7.8	90.2	2.0
	Off Iceland	2130	69.9	30.1	—	241	32.4	66.0	1.6
1966	Off Møre	2101	76.5	20.6	2.9	378	13.2	81.8	5.0
	Off Lofoten	457	85.8	12.9	1.3	84	27.4	66.7	5.9
1967	Off Møre	1354	80.7	17.3	2.0	374	22.7	71.4	5.9

Also, the relative abundance between the fast growing southern (S) and the slow growing northern (N) growth types (LEA 1929) in different regions indicates that the fastest growing members of a year-class started their westward migration towards the feeding areas in the Norwegian Sea earlier than those with a slower growth (Table 2). The 1961 year-class, which had a higher proportion of S-type herring than the year-class of 1959, showed up in catches off Iceland already in 1963 when they were 2½-year-old.

Further knowledge of the migration pattern during the adolescent and maturing phases has been obtained from studies of annual length increments, $t_n = (l_n - l_{n-1})$. For this purpose scales from the herring of the 1959 year-class were analysed to investigate some of the characteristics of herring participating in the westward migration from the Barents Sea and the migration from the coast of northern Norway. The mean annual length increments are listed in Table VI, and the frequency distributions are illustrated in Fig. 23.

In the autumn of 1961 the main concentrations of adolescent herring were found off northern Norway, from the Vesterålen region and eastward towards the Skolpen Bank. The t_1 and t_2 distributions of herring

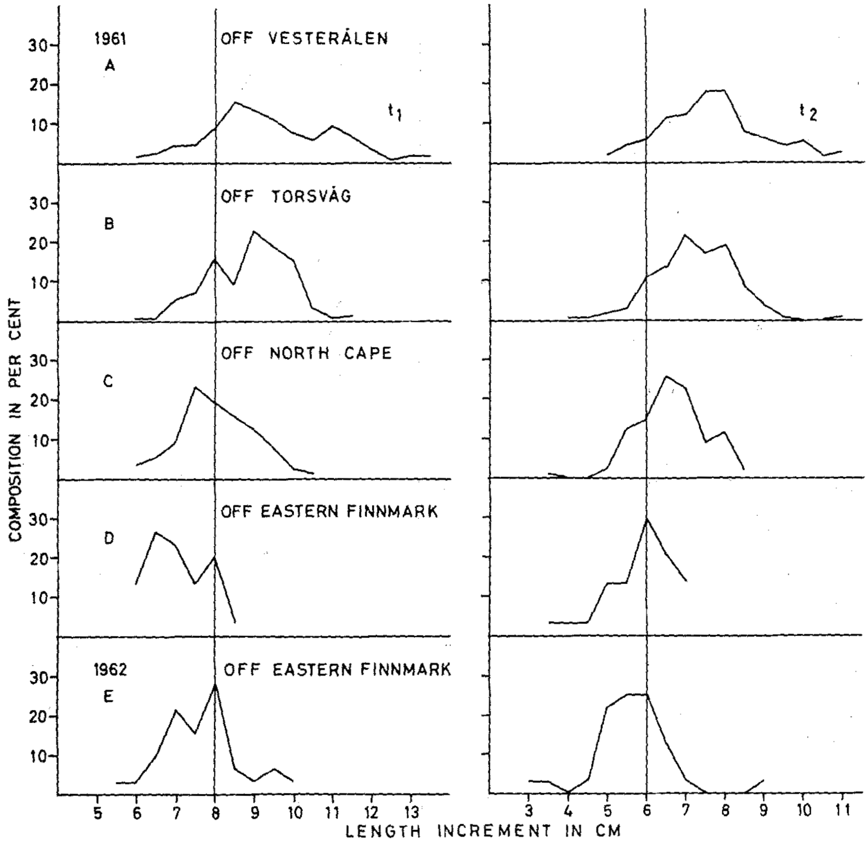

Fig. 23. Annual length increments of the first (t_1) and the second (t_2) year of life of adolescent herring of the 1959 year-class collected in the autumn and winter of 1961 and 1962.

caught in the westernmost region (Fig. 23A) show somewhat larger length increments than those off eastern Finnmark in areas 03, 02 and 10 (Fig. 23D), whereas herring collected off North Cape in area 12 and off Torsvåg show intermediate t_1 and t_2 values (Fig. 23B and C).

As indicated in Table 2 herring of the 1959 year-class appeared on the fishing grounds off Iceland during the summer of 1962. The t_1 and t_2 distributions (Fig. 24A) resemble those found off the Norwegian coast the year before (Fig. 23A), and indicate an extensive migration across the Norwegian Sea of the faster growing herring. Herring with a growth pattern similar to that found off eastern Finnmark in 1961 did not appear off Iceland in 1962.

A comparison of the t_1, t_2 and t_3 distributions of herring caught in September 1962 off Torsvåg (Fig. 24B) with those found in July farther east (Fig. 24C) suggests that herring located off Finnmark in the summer

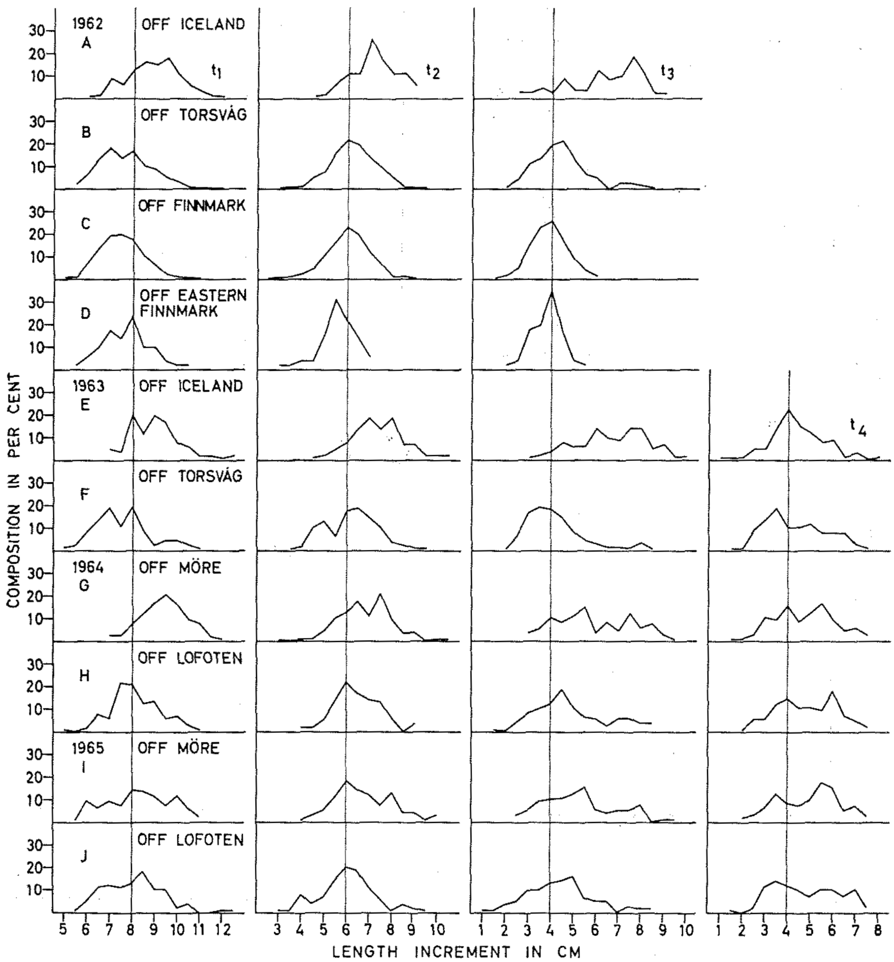

Fig. 24. Annual length increments of the first (t_1), second (t_2), third (t_3) and fourth (t_4) year of life of adolescent and adult herring of the 1959 year-class collected in 1962–1965, (A) to (F) during late summer and autumn, (G) to (J) during winter.

of 1962 migrated westward during the following months and appeared off Torsvåg in September of the same year. The length increments of herring found off Iceland in the summer of 1963 were significantly larger than those for herring caught off Torsvåg in September of the year before and in 1963 (Fig. 24B, E and F). This suggests that a westward migration into the Norwegian Sea did not take place to the same extent in 1963 as in 1962. The t_1, t_2 and t_3 distributions of herring caught off Lofoten in the winter of 1964 were similar to those found off Torsvåg in the autumn of 1962 (Fig. 24H and B), and partly also to those found off Torsvåg in 1963 (Fig. 24H and F). Herring caught off Møre in the winter of 1964 showed almost the same length increment distributions as those caught off Iceland in 1962 and 1963 (Fig. 24G, A and E). The distribution of the annual length increments also was different for herring caught off Møre and herring caught off Lofoten during the winter herring season in 1965, although this difference, especially between the t_1 distributions, was not as pronounced as in 1964 (Fig. 24I and J, G and H).

The results of the length and growth studies show that the migration from the nursery areas is largely size determined, a feature which again probably is related to environmental conditions during the adolescent phase. The westward migration of herring spending their first year of life in the Barents Sea and off the eastern Finnmark coast was somewhat delayed, although the length distribution of the 0-group herring may be similar to that of 0-group herring spending their life farther west and south along the coast (areas 04 and 05). When the herring in these latter areas and in area 06 migrated from the coast early in the I-group stage, they joined the faster growing herring from the nursery areas in the open sea. These herring entered the feeding area in the Norwegian Sea earlier than the slower growing herring from the coastal areas and the Barents Sea.

Slower growing herring of the 1959–1961 year-classes gradually aggregated at the entrance of the Barents Sea, i.e. off Torsvåg in areas 04 and 12, during the summer of 1961, 1962 and 1963. These herring originated mainly from the fjords of Finnmark and the central and eastern parts of the Barents Sea, but also faster growing herring from the coastal areas farther south migrated to the accumulation area off Torsvåg. The fastest growing herring in this area gradually segregated from the population and migrated westwards to the central part of the Norwegian Sea and the areas off Iceland. However, some of the more slow growing herring remained in the eastern part of the Norwegian Sea throughout the summer of 1962 and 1963.

ANALYSIS OF TAG RETURNS

The migrations of herring tagged off northern Norway in 1961 and 1962 are shown in Fig. 25, and migrations of herring tagged in 1963 in Fig. 26. Both in 1961 and 1962 most of the tagged herring belonged to the 1959 year-class, in autumn 1963 the major part belonged to the year-classes of 1959 and 1960 (Table 3). Tagged herring from these experiments were recovered off Lofoten–Vesterålen and in waters off Iceland the following year. Herring tagged in 1962 and in autumn 1963 were found in catches on the spawning grounds off Møre two years after tagging, whereas herring from the tagging in 1961 did not

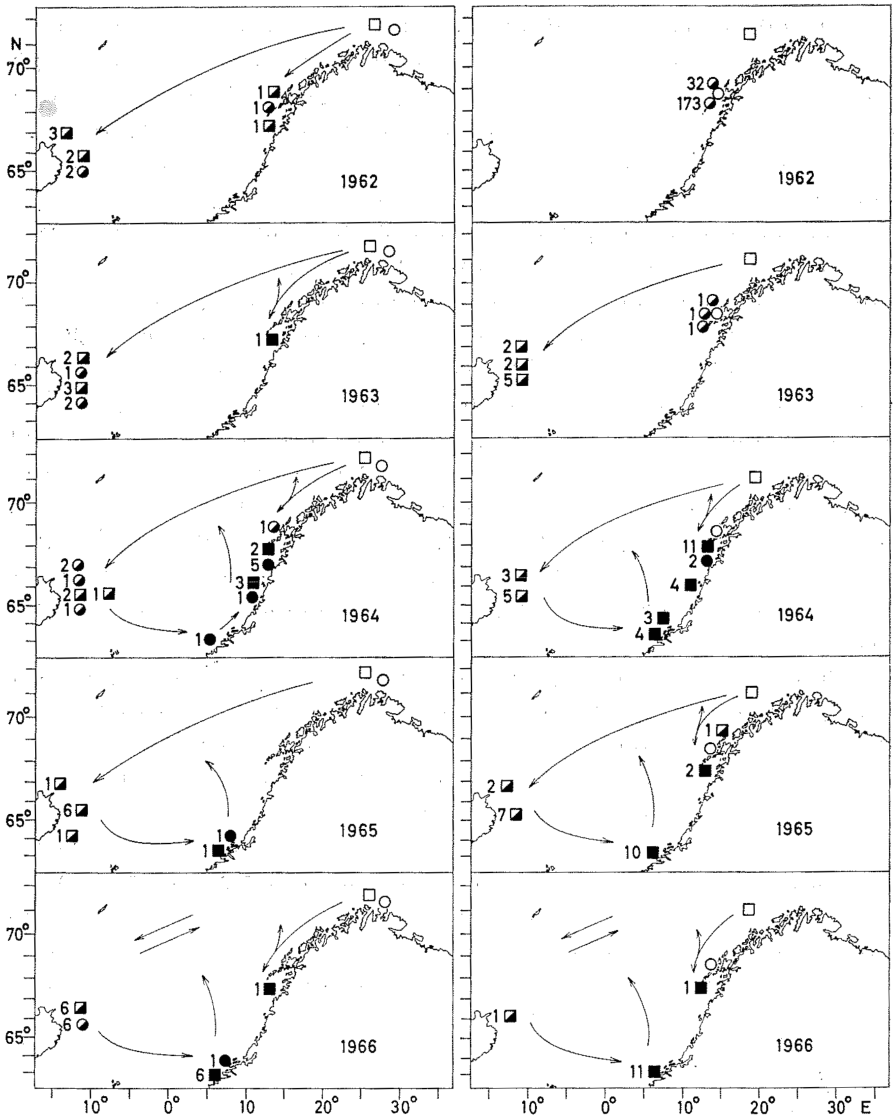

Fig. 25. Migration of herring tagged in 1961 (left column) and 1962 (right column). Open symbols indicate the tagging localities. Tags recovered during the summer fishing seasons 1962–1966 are given by half-filled symbols, recoveries during the Norwegian winter herring seasons 1963–1966, by filled symbols. The number of tags recovered is listed in the figure. Arrows indicate migration routes during the respective years.

reach these spawning grounds until three years after they were released. However, they showed up after two years in catches on the spawning grounds off Lofoten. None of the herring tagged off Varangerfjord in June 1963 has as yet (1968) been recaptured on the spawning grounds off

Table 3. Age composition (in %) of catches from which herring were taken for tagging.

Date		Tagging locality	No.	Year-class		
				1959	1960	1961
1961	12.3	Off North Cape	83	97.6	2.4	—
	22.9	Off North Cape, NE	74	94.6	5.4	—
1962	18.9	Off Torsvåg	99	83.8	12.1	4.1
	21.9	Off Vesterålen	100	1.0	3.0	96.0
1963	5.6	Off Varangerfjord	96	—	90.6	9.4
	10.6	Off Varangerfjord	99	18.2	73.7	8.1
	19.6	Off Varangerfjord	99	—	18.2	81.8
	25.6	Off Vesterålen	92	13.0	81.5	5.5
	1.10	Off Torsvåg	197	67.0	21.3	11.7

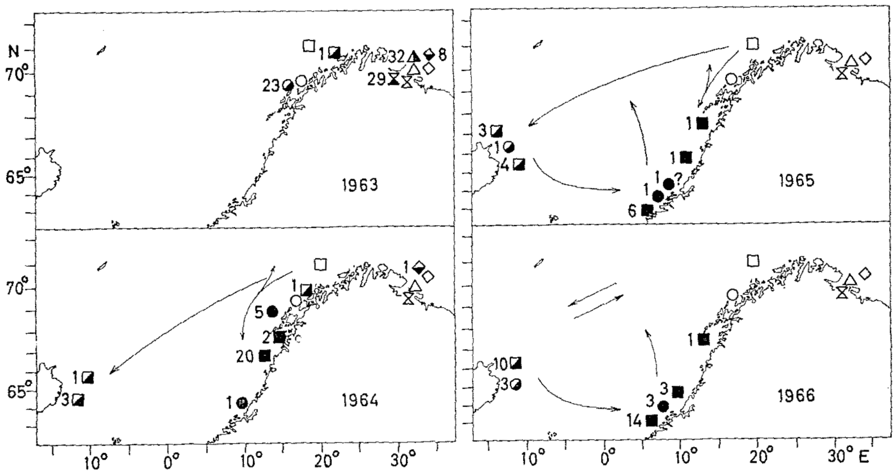

Fig. 26. Migration of herring tagged in 1963. Open symbols indicate the tagging localities. Tags recovered during the summer fishing seasons 1963–1966 are given by half-filled symbols, recoveries during the Norwegian winter herring seasons 1964–1966, by filled symbols. The number of tags recovered is listed in the figure. Arrows indicate migration routes during the respective years.

Møre or at Lofoten, but herring of the 1959 year-class tagged in autumn 1960 off eastern Finnmark (Table II) were recaptured at Lofoten in 1964 and 1966 and off Iceland in 1965.

These results indicate that recruits to the spawning grounds in the Møre region migrated via the feeding areas off Iceland through the traditional wintering area northwest of the Faroe Islands, whereas herring spawning off Lofoten remained in the northeastern part of the Norwegian Sea and moved to the Lofoten shelf from an area located off the coast of northern Norway. A more detailed description of the migration routes for this northern component spawning off Lofoten during the period 1963–1966 has been given by DEVOLD (1968) and JAKOBSSON (1968). They found that during the summer of 1966 the northern component joined the main component spawning off the Møre–Trøndelag coast, and that in 1967 and 1968 no major spawning took place off Lofoten.

It is concluded from the present investigations that herring, which in the 0-group stage were distributed far north and east off northern Norway, as adults migrated to the spawning grounds off Møre. However, this migration phase lasted longer for the herring from the northern nursery areas than for those growing up farther south. Herring from the southernmost nursery areas usually had higher growth rates and reached maturity earlier than did those spending their first years of life in the northern, central and southern parts of the Barents Sea. Accordingly, herring from these nursery areas might appear as recruit spawners from one to four years later than those from areas farther south. Taking into account the mortality during the migration phase, herring from the Barents Sea will be considerably more reduced in numbers before they reach the spawning grounds off Møre than those spending the 0-group stage along the coast south of Lofoten.

ABUNDANCE

ESTIMATES FROM ACOUSTIC SURVEYS

The distribution of 0-group herring together with the density of the echo recordings (the echo abundance) have been used to study the variation in abundance from one year to another. The surveys did not cover all the fjords. In order to obtain an estimate of abundance valid for the total distribution in inshore waters, the ratio between the area covered by the 0-group herring and the surface area in fjords which were investigated, also was applied to the fjords which had not been surveyed. In area 05 ratios for Hadselfjord and Vestfjord were used, in area 04 mainly ratios for Ullsfjord and Lyngenfjord, and in area 03 ratios for Porsangerfjord, Laksefjord, Tanafjord and Varangerfjord (Fig. 13). The total geographical distribution of scattered and dense concentrations in areas north of 67 °N was estimated for the surveys illustrated in Figs. 4–10. The estimated areas of distribution are listed in Table 4.

Fishing experiments with purse seine (two in 1960 and five in 1963) in scattering layers above 30 m depth at night were carried out to establish a conversion factor between scattered and dense echo recordings (Fig. 27). The ratio between the catches in litres taken in scattering layers (0–30 m depth) with density 1 to 2 (scattered) and density 3 to 4 (dense) was about

Table 4. Area of distribution (in square nautical miles) of scattered and dense 0-group herring concentrations and indices of echo abundance for 0-group herring in offshore and inshore areas in the autumn of 1959–1965.

Year-class	Offshore			Inshore			Total		
	Scattered	Dense	Abundance index	Scattered	Dense	Abundance index	Scattered	Dense	Aundance index
1959	62250	25318	315430	2520	784	10360	64770	26102	325790
1960	70144	7017	140314	3599	344	7039	73743	7361	147353
1961	23044	852	31564	3034	293	5964	26078	1145	37528
1962	12249	—	12249	1203	132	2523	13452	132	14772
1963	28312	2023	48542	2989	204	5029	31301	2227	53571
1964	58700	1263	71330	2845	78	3625	61545	1341	74955
1965	8400	—	8400	739	—	739	9139	—	9139

1:10. Indices of total echo abundance, therefore, were estimated by multiplying dense recordings by a factor of 10 (Table 4). The vertical extension of the scattering layers was not taken into account in these estimates.

The abundance indices for the total 0-group stock are by far the highest for the 1959 and 1960 year-classes, followed by those of 1964, 1963 and 1961. The estimates for the 1962 and especially for the 1965 year-classes are by far the lowest.

Estimates of the abundance of 0-group herring in the open sea (offshore) compared with that recorded in the fjords (inshore) have also been made for each year-class (Table 4). Not all of the 0-group herring observed along the coast migrated into the fjords. This was indicated by the low frequency of returns of 0-group herring tagged just outside the coast or at the entrances to the fjords, e.g. off Vesterålen in 1959 (Table 6). None of the 0-group herring tagged in 1960 off Bear Island and off eastern Finnmark has been recaptured in inshore areas. To separate the offshore from the inshore population, half of the area with recordings outside the border line drawn in Fig. 13 between Røst and North Cape was classified as offshore and the other half classified as inshore. Herring observed outside the fjords off eastern Finnmark are assumed not to migrate into the fjords and are included in the offshore distribution.

From Table 4 it appears that a relatively small part of the total 0-group population was distributed in the fjords in the autumn of 1959, 1960, 1963, 1964 and 1965 (3–10%). However, in 1961 and 1962 a somewhat higher percentage (15–20%) of the total 0-group population was found inshore. The results indicate that the proportion of 0-group herring entering the fjords is inversely related to the total abundance of the

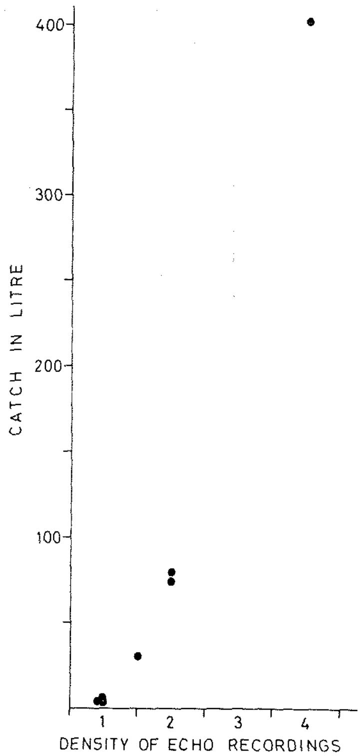

Fig. 27. Relationship between the density of the scattering layer recorded by echo sounder and the catch of the sound scatterers sampled with purse seine. The catches consisted almost entirely of 0-group herring.

0-group stock. In years when the herring are mainly restricted to the coastal belt, a relatively higher percentage of the population is found inshore.

CATCH AND CATCH PER UNIT EFFORT

Catch and effort statistics from the small- and fat-herring fishery can also be used to analyse the variations in year-class strength. The total catch of small- and fat-herring landed during the period 1930–1968 (Fig. 28), shows that considerable fluctuations have occurred. The most important small-herring fishery occurs in the fjords from late autumn to early spring, with the late autumn period being the most important. The period in the early spring coincides with the migration from the fjords. The fat-herring are usually caught at the entrances or outside the fjords, and the fishery starts in early summer and has its peak in the summer or early autumn.

In the Norwegian catch statistics herring weighing ≤ 50 g, corresponding to a total length up to 18–20 cm, are grouped as small-herring

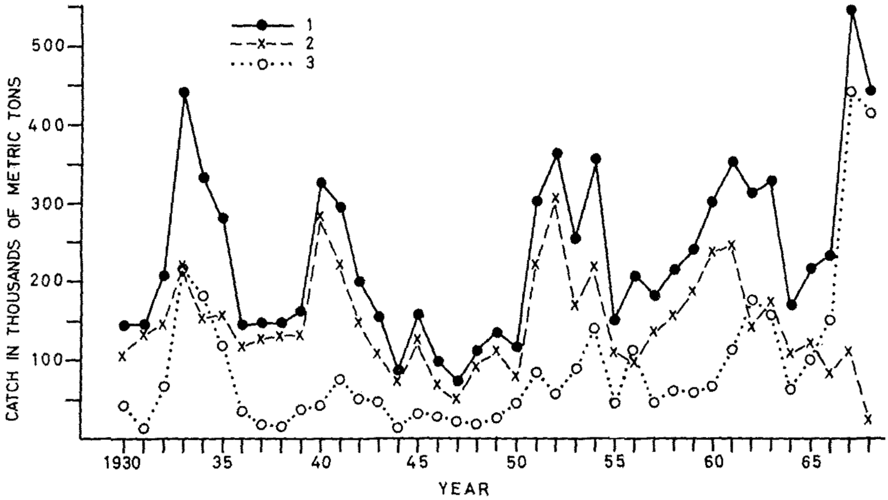

Fig. 28. Norwegian and Soviet catches of young and adolescent herring in 1930–1968, (1) total catch, (2) small-herring and (3) fat-herring.

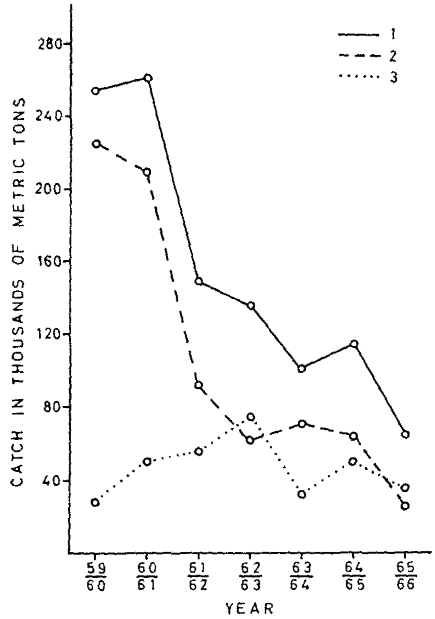

Fig. 29. Catches of small-herring landed from 1959–1960 to 1965–1966, (1) total catch, (2) 0- and I-group and (3) I- and II-group herring. Catches landed in 1959–1960 are due to the 1959 and 1958 year-classes, respectively, in 1960–1961 to the 1960 and 1959 year-classes, etc.

and fish weighing ≥ 51 g are listed as fat-herring. The small-herring subject to fishing in the autumn are mainly 0-group fish. During the following summer when these are in the I-group stage, the fastest growing herring appear in the fat-herring catches. This is especially true in areas 07, 06 and 05. The I-group herring in the northernmost areas 04 and 03, and those with lower growth rates in areas 07, 06 and 05 are still found in the small-herring catches throughout the second year until the summer of the third year of life when they, as II-group herring, gradually appear in the fat-herring catches. With a new 0-group entering the fishery every autumn, three different year-classes are represented in the small-herring catches during a calendar year. However, during the period from 1 September to 31 August the next year the catches consist mostly of two year-classes. The catches were separated on year-class by analysing the samples collected by the inspectors at the various reduction plants along the coast (Fig. 29). During 1959–1966, the 1959 and 1960 year-classes yielded the highest catches followed by the year-classes of 1961, 1963, 1964, 1962 and 1965.

Since the small-herring are mixed with the fat-herring in the catches, it is difficult to collect samples which give a representative age composition of the fat-herring landed. However, small-herring were avoided in the samples by excluding herring weighing ≤ 50 g, corresponding to lengths less than 18–20 cm. Fig. 30 shows the age composition of fat-herring in the different areas. Most of the samples were taken during the summer and autumn. Samples collected in areas 07 and 06 during the first half of the year (1 April to 31 May) were grouped separately, and in these samples I-group fish were excluded. These herring, usually called "forfangstsild", are a mixture of young recruit spawners and fat-herring. During the period 1959–1968 the yield of the fat-herring fishery was highest in 1961–1963, when the 1959 and 1960 year-classes dominated and in 1966–1968 when the year-classes of 1963 and 1964 were dominant, with a maximum yield in 1968. Herring older than five years were only rarely found in the fat-herring catches, except during the "forfangstsild" season.

In Table 5 catches of fat-herring are separated on year-class and area. The 1964 year-class has yielded the highest catch followed by those of 1959, 1963, 1960, 1961 and 1962. An evaluation of the 1965 year-class is omitted because catch data still are incomplete. The ranking of year-classes by catch is different from that found in the small-herring catches and the exploitation rate of the 1963 and 1964 year-classes obviously has increased. A further discussion of this feature will be given in a later section.

Almost all the catches of small- and fat-herring are taken with purse seine, and the fishing fleet which is equipped with echo sounder and sonar, usually moves from one fjord to another searching for herring. Prior to 1964 the purse seine was shot from two dorries, but from 1964 onwards the power block was introduced and the purse seine, which was then shot from the vessel, was gradually made deeper. Accordingly, the

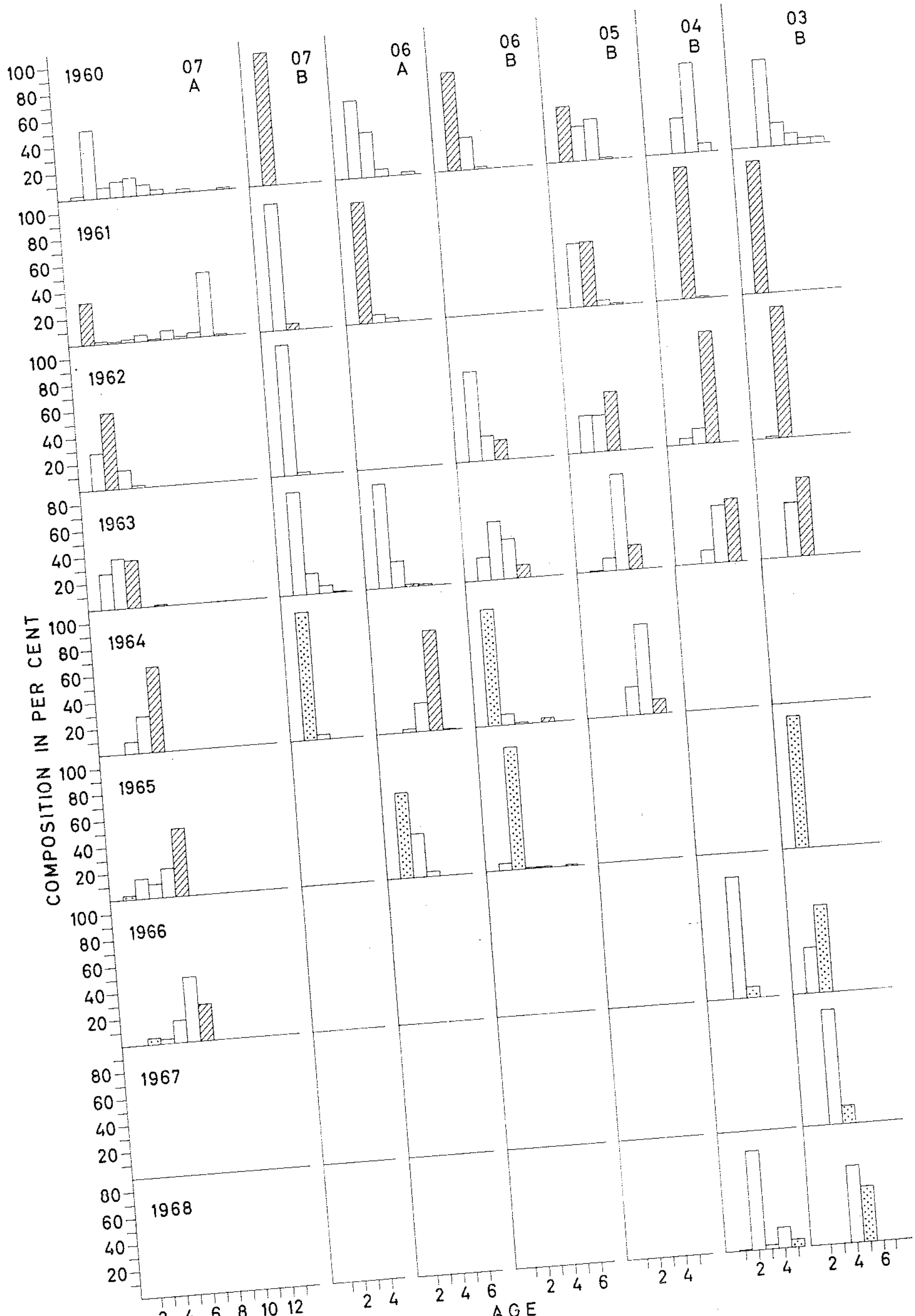

Fig. 30. Age composition (in %) of fat-herring in different areas in 1960–1968, (A) during April–May and (B) during June–December.

Table 5. Yield (in thousands of metric tons) of the 1959–1964 year-classes according to area during the Norwegian fat-herring fishery in 1960–1968.

Year-class	Area 07	06	05	04	03	Total
1959	49.558	35.127	65.583	4.108	119.676	274.052
1960	26.652	18.253	97.039	1.571	7.520	151.035
1961	15.660	29.682	25.571	0.368	—	71.281
1962	9.706	8.323	0.273	—	—	18.302
1963*	8.160	22.793	45.123	2.407	189.361	267.844
1964*		0.448	116.890	18.424	268.213	403.975

* Data still incomplete.

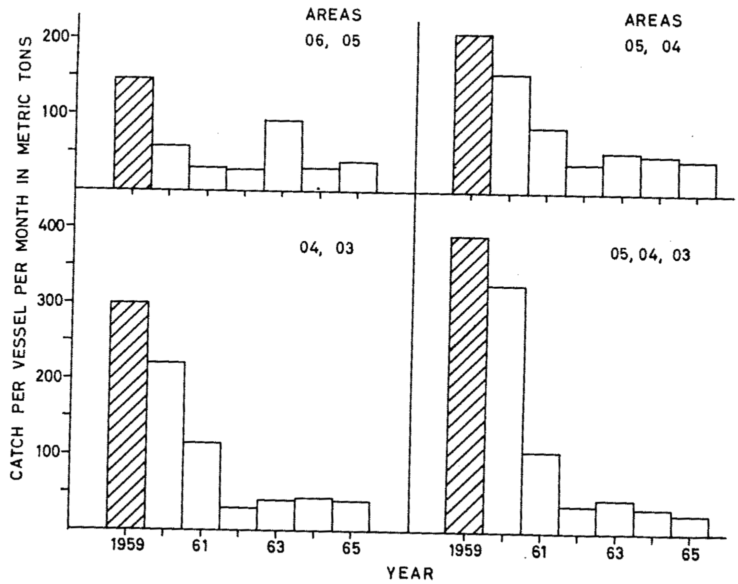

Fig. 31. Average catch of 0-group herring per vessel per month during the autumn fishery (October–December) in 1959–1965.

fleet was more efficient in 1965–1968 than during the previous period when the efficiency was considered to be fairly constant. The more modern sonar equipment introduced during the period 1964–1967 also added to the increase in efficiency of the fleet.

The fat-herring fishery, especially off the Finnmark coast, mainly takes place in the open sea or at the entrances to the large fjords. For this reason and because the availability of fat-herring varies greatly, the abundance estimates for fat-herring are more variable than those for 0-group herring. The abundance estimates for fat-herring, therefore, have been omitted here. One of the chief problems encountered when dealing with effort statistics from purse seine catches concerns the integration of searching time in the unit of fishing effort. Information concerning the time spent on the fishing grounds or number of shots with and without catch is not available. However, the average catch per vessel operating is likely to give a reasonably reliable indication of the abundance of herring in the different districts.

The average catch of 0-group herring per vessel per month during the autumn fishery from October to December in the different areas is illustrated in Fig. 31. The abundance estimates for areas 05, 04 and 03 combined are higher than those for areas 04 and 03, and 05 and 04 in 1959 and 1960. The reason for the average catch per vessel being higher for areas 05, 04 and 03 combined is due to the larger and more efficient vessels operating in all the three areas. Those operating in areas 04 and 03, 05 and 04 or 06 and 05 are smaller vessels, and the abundance indices for these areas are comparable. The catches per vessel were highest in 1959 followed by 1960 and 1961. In 1962 and 1965 the catches per vessel were lowest in most of the areas.

ESTIMATES FROM TAG RETURNS

Abundance estimates from tag returns are mainly based on taggings of 0-group herring in the Ullsfjord region. For tagging experiments at other localities (Table II) the number of recaptures is too low to permit abundance estimates. Only tags recovered in plants which were equipped with tested magnets have been dealt with quantitatively, and experiments giving less than ten recaptures are excluded in Table 6. The frequencies of returns from 0-group taggings in the fjords were relatively low in 1959–1960, 1960–1961, 1961–1962 and 1963–1964, indicating high abundances of the 1959, 1960, 1963 and 1961 year-classes compared with those of 1962 and 1964. In the autumn of 1965 no 0-group herring were tagged.

Herring catches from different fishing localities were sometimes mixed at the reduction plants before the processing started, and therefore the location of some recaptures could not be determined with certainty. In spite of this limitation the present material indicates that almost all returns during the first months after release were derived from the fjord complex where the tagging took place. This feature was clearest for tagging experiments carried out inside the entrances to the fjords and confirms the findings from acoustic surveys that 0-group herring entering the fjords in autumn stay there the following winter.

A summary of the estimates of year-class strengths at the 0-group stage obtained by the three different methods applied is given in Table 7.

Table 6. Recaptures from taggings of 0-group herring (1959–1964 year-classes) three to seven months after release and catches of the same year-classes processed at reduction plants. The catches are from the region of recapture.

Date of tagging		Region of recapture	No. of effectively tagged herring	Effective quantity processed (in tons)	Time from tagging to capture (in months)	No. of recaptures	Percentage recaptures per 100 tons (inverse value in brackets)
1959	2.10	Vesterålen	853	1283	4	10	0.09 (10.94)
	8.10	Hamarfj.–Ullsfj.–Lyngenfj.	1706	12167	5	237	0.11 (8.76)
	19.10	Varangerfj.	512	11370	7	63	0.11 (9.24)
1960	3.10	Hamarfj.–Ullsfj.–Lyngenfj.	1706	30534	6	253	0.05 (20.59)
	21.10	Varangerfj.	853	10812	6	156	0.17 (5.91)
1961	28.9	Hamarfj.–Ullsfj.–Lyngenfj.	1706	4970	3	187	0.22 (4.53)
1962	21.9	Hadselfj.–Vesterålen	1109	45	3	52	10.42 (0.10)
	27.9	Malangen	512	196	3	58	5.78 (0.17)
	28.9	Hamarfj.–Ullsfj.–Lyngenfj.	1024	1737	3	203	1.14 (0.88)
1963	27.9	Hamarfj.–Ullsfj.–Lyngenfj.	1706	2795	4	51	0.11 (9.35)
1964	29.9	Hamarfj.–Ullsfj.–Lyngenfj.	1706	212	3	128	3.54 (0.28)

Table 7. Summary showing the results of the abundance estimates of 0-group herring for the 1959–1965 year-classes.

Year-class	Echo abundance index $\times 10^{-3}$		Catch per vessel (in tons) in areas 05, 04, 03 combined	Mean inverse value of percentage recaptures per 100 tons
	Total	Inshore		
1959	325.8	10.4	391.6	9.65
1960	147.4	7.0	325.9	13.25
1961	37.5	6.0	105.0	4.53
1962	14.8	2.5	35.4	0.38
1963	53.6	5.0	44.8	9.35
1964	75.0	3.6	33.6	0.28
1965	9.1	0.7	25.5	—

The results are only comparable for the inshore part of the 0-group population. The inshore abundance estimates obtained from acoustic surveys and those obtained from catch per vessel show the same ranking of the respective year-classes except for those of 1962 and 1964. However, the discrepancy in the values of the abundance estimates is pronounced for some of the year-classes, especially those of 1962, 1963 and 1964. Because taggings were made in few localities, the abundance estimates obtained from these experiments do not give representative values for year-class strength of the inshore 0-group population.

The estimates of the total 0-group stock obtained from the acoustic surveys indicate that the 1959 year-class was about twice as abundant as the 1960 year-class and this again about twice as abundant as that of 1964. The difference between the 1961 and 1963 year-classes probably was small although the latter year-class was somewhat more abundant. The 1962 and 1965 year-classes definitely were the poorest ones.

MORTALITY

Mortality estimates of herring during the late 0-group and early I-group stages in some Norwegian fjords can be obtained from data on catch per unit of effort and from taggings. The total instantaneous mortality coefficient ($Z = F+M$) for the 1959 and 1960 year-classes was estimated according to the equation of BEVERTON and HOLT (1957)

$$N_t = N_0 e^{-(F+M)t} \qquad (1)$$

where N_0 is the number of fish at the time t_0 and N_t the number of fish at the time t. F and M are the instantaneous fishing and natural mortality coefficients, respectively.

The catch per unit of effort is taken to be proportional to N_0 at the time t_0 and N_t at the time t. During the migration into the fjords the herring are found in many small shoals, and the availability usually is lower than in the wintering period. Because of this the catch per vessel was relatively low in October, and November had to be chosen as the commencement of the fishing season in 1959 and December in 1960. By plotting the logarithms of monthly catches per vessel for November to April in 1959–1960 and for December to April in 1960–1961 and calculating the regression lines to the points, the monthly apparent total mortality ($Z = F+X$) could be estimated (Fig. 32) where F is the monthly fishing mortality and X is a combination of natural mortality and the effect of emigration.

The estimates are given in Table 8, and the basic material used for estimating the catch per vessel is given in Table VII. The values for Z is considerably greater than those obtained for adult herring in the late 1950s and in the 1960s (DRAGESUND and JAKOBSSON 1963, ANON. 1969). The monthly instantaneous mortality coefficients are of the same magni-

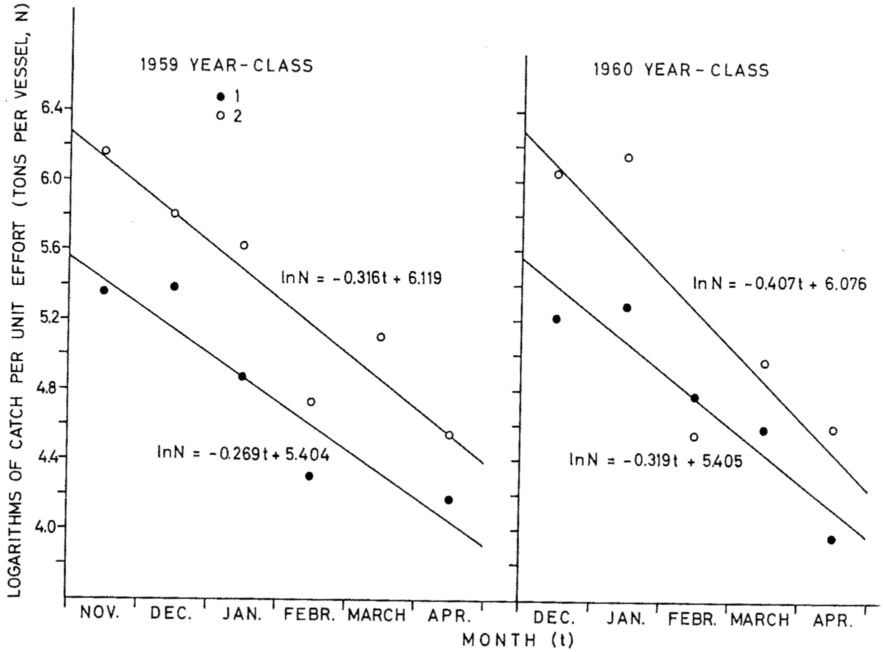

Fig. 32. Calculated regression lines fitted to months and logarithms of catch per vessel, (1) areas 05 and 04, (2) areas 05, 04 and 03.

tude as those of the annual instantaneous mortality coefficients of adult herring.

The exploitation rate (E) defined as

$$E = \frac{F}{F + M} \tag{2}$$

can also be estimated approximately from tag returns by the expression

$$E = \frac{n_r}{N_0 - N_t} = \frac{F}{F + X} \tag{3}$$

where n_r is the estimated number of tagged herring recaptured during the period from t_0 to t, N_0 the number of effectively tagged herring present at the time t_0 and

$$N_t = N_0 e^{-Z(t-t_0)} \tag{4}$$

the number of tagged herring present at the time t. The Z values (F+X) obtained for areas 05, 04 and 03 (Table 8) were used to calculate N_t, and the estimated values for E and Z were used to solve equation (3) for F. The values for N_0, N_t and n_r are listed in Table 9. The estimates

Table 8. Estimates of monthly instantaneous total mortality coefficient (Z) during the late 0-group and early I-group stages covering the period from November to the following April.

Year-class	Area	Z
1959	05 and 04	0.28
	05, 04 and 03	0.32
1960	05 and 04	0.32
	05, 04 and 03	0.41

Table 9. Estimates of number of effectively tagged 0-group herring present (N_0) at the time t_0, number of tagged herring present (N_t) at the time t and number of herring recaptured (n_r) during the period from t_0 to t.

Year-class	Vesterålen			Ullsfjord-Lyngenfjord			Varangerfjord		
	N_0	N_t	n_r	N_0	N_t	n_r	N_0	N_t	n_r
1959	853	237	37	1706	344	382	512	55	84
1960	—	—	—	1706	146	312	853	73	216

Table 10. Estimates of the exploitation rate (E) during the late 0-group and early I-group stages and the monthly instantaneous mortality coefficients F and X, covering the period from November to the following April.

Year-class	Region	E	F	X
1959	Vesterålen	0.060	0.019	0.301
	Hamarfjord–Ullsfjord–Lyngenfjord	0.280	0.090	0.230
	Varangerfjord	0.184	0.059	0.261
1960	Hamarfjord–Ullsfjord–Lyngenfjord	0.200	0.082	0.328
	Varangerfjord	0.277	0.114	0.296

of E, F and X for herring during the late 0-group and early I-group stages from November to April in some of the fjords of northern Norway are given in Table 10.

Another approach for estimating the fishing mortality during the 0- and I-group stages can be obtained from the ratio between catch and stock size of herring wintering in the Ullsfjord region. The stock size was estimated from tag returns by a modification of the Petersen method (AASEN *et al.* 1961, DRAGESUND and HARALDSVIK 1968). The number of tags returned each month during the period from November to April at factories equipped with tested magnets were plotted against the effective quantity processed at the same factories in that month (Fig. 33), and the regression lines were calculated. The stock size was estimated by multi-

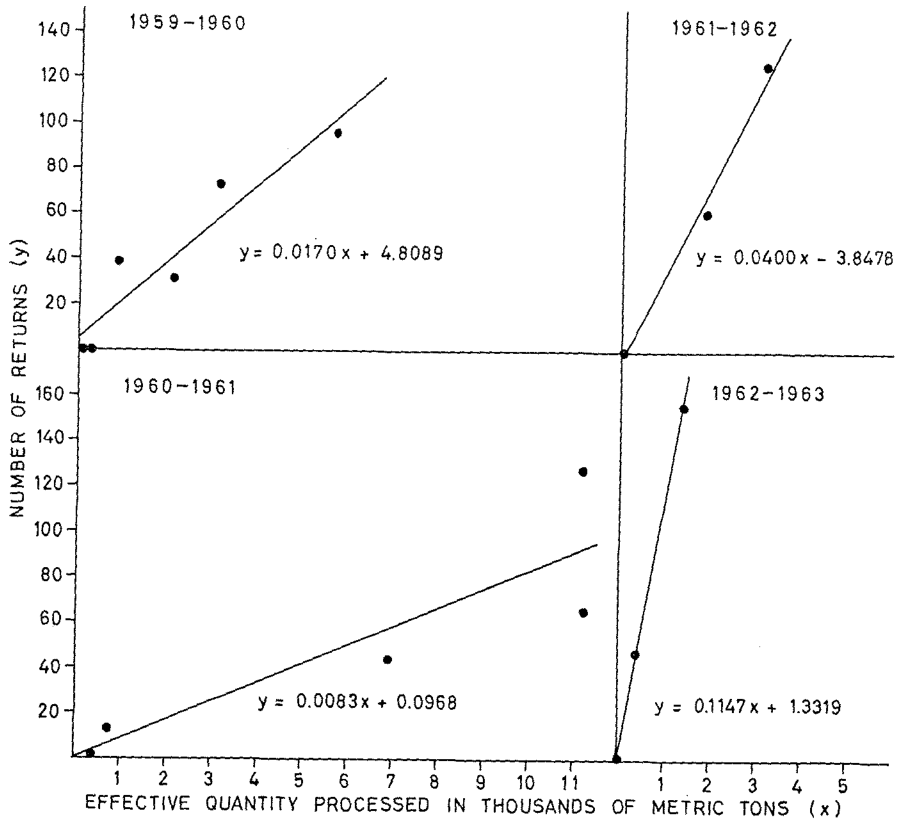

Fig. 33. Calculated regression lines fitted to the monthly catch of 0- and I-group herring processed at factories equipped with magnets and the monthly number of returns.

plying the number of effectively tagged herring present at the beginning of the period by the ratio of the effective quantity processed and the number of returns. This ratio was obtained from Fig. 33.

F was estimated according to the equation of BEVERTON and HOLT (1957)

$$\frac{C}{S} = \frac{F}{Z} (1 - e^{-Zt}) \tag{5}$$

where C is the catch of herring in numbers and S the stock size in numbers. The Z values for areas 05, 04 and 03 given in Table 8 for the 1959 and 1960 year-classes were used to solve equation (5) for F. To estimate F for the year-classes of 1961 and 1962 the mean of the Z values was used. The results are listed in Table 11.

Although the values for F listed in Tables 10 and 11 are slightly different, they are considerably higher than those obtained from tagging

Table 11. Catch (C), estimated stock size (S) of 0- and I-group herring and estimated monthly instantaneous mortality coefficient (F) during the late 0-group and early I-group stages in the Ullsfjord region for the 1959–1962 year-classes.

Year-class	C		S		F
	Tons	No.	Tons	No.	
1959	19500	279×10^7	91700	1310×10^7	0.085
1960	37600	537×10^7	204700	2924×10^7	0.082
1961	6400	91×10^7	41300	590×10^7	0.085
1962	2900	41×10^7	8800	126×10^7	0.181

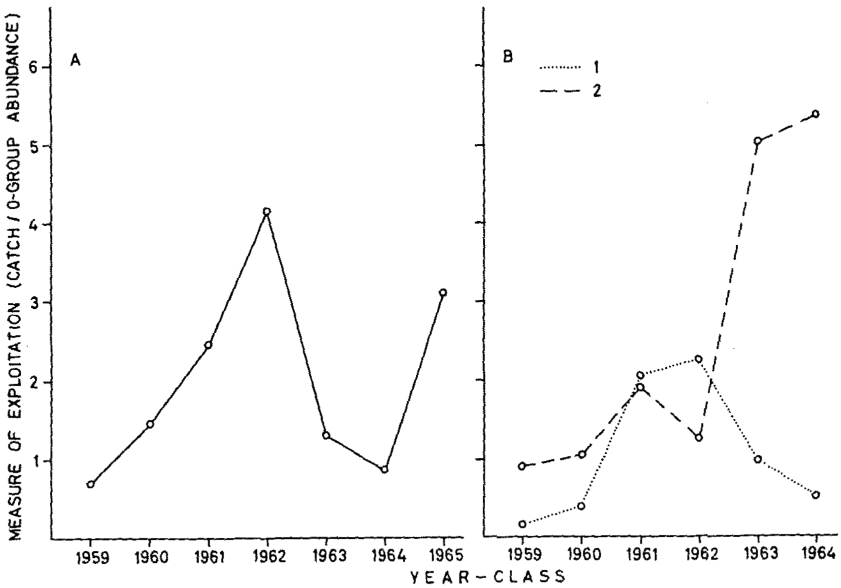

Fig. 34. Measure of exploitation, (A) during the late 0-group and early I-group stages indicated by the ratio of catch in tons/0-group echo abundance for the year-classes 1959–1965 and (B) at later stages for the year-classes 1959–1964, (1) as catch in tons of I- and II-group herring/total 0-group echo abundance and (2) as catch of fat-herring in tons/total 0-group echo abundance.

experiments during the adult stage (Dragesund and Jakobsson 1963, Anon. 1969). The monthly instantaneous fishing mortality coefficients during the late 0-group and early I-group stages are somewhat lower than those of the annual instantaneous mortality coefficients of the adult herring. However, the natural mortality was high for 0- and I-group herring, and accordingly the exploitation rate was lower than for the adult herring in the mid-1960s (Anon. 1969).

Another measure of the exploitation is obtained by taking the ratio between the total catch at different stages of the year-classes 1959–1965 and the total echo abundance index (Fig. 34). It is clearly demonstrated that poor year-classes were more heavily exploited than the rich ones during the late 0-group and early I-group stages (Fig. 34A). Also during the late I-group and early II-group stages the poor year-classes were more heavily fished than the richer ones (Fig. 34B).

The yield of the fat-herring fishery increased considerably from 1965 to 1968. This resulted in an increase of the exploitation of the 1963 and 1964 year-classes by five to six times compared with that of the 1959 and 1960 year-classes. The high exploitation of the 1963 and 1964 year-classes, which appeared to be fairly abundant during the 0-group stage, has most likely resulted in a considerable reduction of these year-classes before they entered the adult stock.

DISCUSSION

DISTRIBUTION OF 0-GROUP HERRING IN RELATION TO SPAWNING GROUNDS OF THE PARENT STOCK

During 1959–1965 the main spawning centre was located off Møre, i.e. on the shelf between Stad and Grip (Dragesund 1970). In 1959–1961 the majority of the ripe herring tended to concentrate farther south than in 1962–1965, when the centre of the spawning was located between Ona and Grip. In the southernmost region (area 08) spawning was negligible except in 1959, when spawning was observed as far south as Bokn. The second important spawning district was located off Halten–Sklinna. Within this region the location of spawning did not change. Except in 1960 (Yudanov 1962) mass spawning at Lofoten was not recorded during 1959–1962, whereas herring spawned regularly in that area in 1963–1965. During 1959–1965 Norwegian herring also spawned on the Faroe plateau (Yudanov 1962, 1964, 1966).

The origin of 0-group herring recorded off northern Norway is difficult to determine. The drift pattern of the larvae from the Faroe spawning grounds is not known, but the international 0-group fish surveys carried out in the Barents Sea and in the northeastern part of the Norwegian Sea in 1966 and 1967 (Anon. 1966, 1967) suggested that the majority of the 0-group fish recorded in the Barents Sea were derived from spawning grounds along the Norwegian coast. Also, the larval survey in 1959 (Wiborg 1959) showed that herring larvae were scarce off the continental shelf in the eastern part of the Norwegian Sea. It is concluded, therefore, that the major part of the herring observed along the coast of northern Norway and in the Barents Sea were hatched off the Norwegian coast between Stad and Grip, off Halten–Sklinna and in 1963–1965 also at the Lofoten spawning grounds.

It also may be concluded that larvae hatched off Møre–Trøndelag drifted far into the Barents Sea. This was indicated by the 0-group distribution in 1959 when no major spawning took place in the Lofoten region. Moreover, in 1959–1961 the 0-group herring were more abundant off Troms and Finnmark (areas 04 and 03) than farther south in areas 06 and 05 (Fig. 31), confirming the hypothesis of a long northward transport of larvae from the spawning grounds off Møre (Dragesund 1970). This indicates that the northward extension of concentrations of 0-group herring does not depend only on the location of spawning, but also on the conditions for transport of larvae from the spawning grounds.

GROWTH AND MIGRATION IN RELATION TO MECHANISM OF RECRUITMENT

The 0-group herring within areas 05, 04 and 03 had fairly uniform lengths. This was to be expected since larvae hatched on the spawning grounds off Møre–Trøndelag are transported northwards in the same water masses and live under rather similar environmental conditions during their first five–six months of life. However, larvae which accumulate at the entrances to the fjords in areas 07 and 06 (off Møre–Trøndelag and the southern part of Nordland) and later enter the fjords in these areas, will live in warmer water and will have a faster growth than those transported farther north.

Herring located off eastern Finnmark were found to have a markedly slower growth during the adolescent phase than those found farther west and south along the coast (Figs. 22 and 23). Herring of the 1959 year-class which stayed in the southern part of the coastal waters of northern Norway (areas 06 and 05) during the 0-group stage, migrated northwards during the second and third years of life, i.e. in 1960 and 1961, and joined the fastest growing herring farther north in an accumulation area off Torsvåg (Figs. 19, 23A and B). These herring started their westward migration into the Norwegian Sea some time during late 1961 or early 1962 and showed up on the feeding grounds off Iceland as early as in the summer of 1962. Herring with slightly smaller annual length increments (1959 year-class) remained in the accumulation area off Torsvåg during the summer and autumn of 1962.

Off Finnmark, slowly growing herring of the 1959 year-class reached an age of three–four years before they disappeared from the fat-herring catches and migrated westward to the accumulation area off Torsvåg from where they later joined the spawning stock. A similar migration pattern was found for the 1960 and 1961 year-classes. Thus, the higher growth rate of herring in the southern part of the coast of northern Norway led to an earlier migration to and from the accumulation area off Torsvåg than for herring spending their nursery period farther north and east in coastal and offshore waters off northern Norway. Accordingly, fat-herring in areas 06 and 05 were younger than those off Finnmark (area 03), and in the catches south of Vesterålen fat-herring older than three years were scarce, except during the "forfangstsild" season in April–May.

The 1963 and 1964 year-classes showed a different migration pattern compared with those of 1959–1961. During the entire fat-herring stage, i.e. up to an age of four–five years, the 1963 and 1964 year-classes were mainly recorded off eastern Finnmark. Migrations over short distances were observed back and forth between the eastern part of the Finnmark coast and the Murman coast, and in contrast to the 1959–1961 year-classes those of 1963 and 1964 did not concentrate in any detectable shoals off western Finnmark or off Troms during the second to fourth years of life. Their migration from the nursery areas off eastern Finnmark was at least one year delayed compared with the migrations of the 1959–1961 year-classes.

Variations in the occurrence of fat-herring in coastal waters off northern Norway have been discussed by LEA (1929), and variations off the Murman coast by GLEBOV (1938). According to LEA the large fat-herring (oceanic herring) occur in offshore waters where the herring adopt an oceanic mode of life. Lea concluded that large yields of fat-herring in the fjords were caused by an immigration of oceanic herring. Such immigrations were sporadic and might occur when the oceanic herring were driven towards the coast by unknown causes. GLEBOV distinguished between two types of immigrations to the fjords, one in May–July consisting mainly of I- and II-group herring, and the other consisting of mainly III- and IV-group herring approaching the coast during the autumn from August onwards. GLEBOV also found that the immigration was irregular and not always associated with strong year-classes, but was related to hydrographic conditions in coastal and offshore waters. The migration into the fjords was most frequent in years with pronounced horizontal temperature gradients. In the summer the immigration of I- and II-group herring took place when the temperature gradient increased from the open sea into the fjords, whereas in the autumn an immigration of III- and IV-group herring occurred when the temperature gradient decreased from the open sea and into the fjords.

The present investigations showed that the migration of 0-group herring into the fjords was regular and occurred almost at the same time every autumn. It cannot be stated whether the mechanism of the migration from the open sea into the fjords is a response to environmental conditions followed by an orientated active migration or if it is a passive migration resulting from drift (HARDEN JONES 1968). In Porsangerfjord the herring moved from water masses of higher to lower temperature, whereas in Ullsfjord this feature was not so clear. No distinct immigration of fat-herring (oceanic herring) to the fjords was recorded. In the years when great concentrations accumulated off northern Norway, mainly in 1961–1963, the fat-herring did not enter the fjords on their migrations from the nursery areas into the Norwegian Sea. With the material at hand no further interpretation can be given of the sporadic immigrations of fat-herring to the fjords of northern Norway. However, in years when the fat-herring stock is large, numerous shoals often occur close to the coast, and it is likely that such shoals may move into the fjords.

When studying the growth of herring, LEA (1929) observed that winter rings of scales from young and adolescent herring caught in northern Norway were more distinct (N-type) than winter rings of herring scales from the coastal area farther south (S-type). RUNNSTRØM (1936) has given further information on the geographical distribution of the two types. On the Finnmark coast, 100% of the young herring had the northern scale type. In the intermediate region, between Finnmark and the coast of Møre, the N- and S-types were mixed. On the southwest coast about 90% of the young herring had rings of the S-type. From this evidence RUNNSTRØM concluded that the northern type of winter rings is formed in coastal waters off northern Norway and that the southern type is formed at the southern part of the west coast, thus supporting LEA's theory. According to LEA more diffuse winter rings (oceanic rings) are formed during the adolescent period of transition from immature to mature herring when the herring have moved into the central part of the Norwegian Sea. However, DEVOLD (1963) suggested that the distinct winter rings (N-type) are formed when the young herring live under arctic and subarctic conditions in the Barents Sea. The more diffuse oceanic rings are formed after the westward migration into areas with boreal conditions.

This hypothesis seems to be in agreement with the distribution of 0-group herring of the 1959 and 1961 year-classes and the characteristics of their winter rings. In 1961 relatively few 0-group herring were found in the northern and eastern parts of the Barents Sea, and eventually only a small percentage of the year-class was found to have N-type winter rings. In 1959 the major part of the 0-group stock was distributed in the Barents Sea and on the shelf between Bear Island and West-Spitsbergen. In accordance with this, high percentage of distinct N-type winter rings were found for the 1959 year-class.

According to ØSTVEDT (1958) the relative abundance of N- and S-types in the spawning shoals seemed to be related to year-class strength, high frequencies of N-type herring being correlated with rich year-classes.

The major part of the 1959 year-class had N-type winter rings, whereas the 1961 year-class showed a lower percentage of this growth type both in the adolescent and adult shoals (Table 2). The correlation between rich year-classes and relatively high frequencies of N-type herring may therefore be explained as a result of strong northward transport and high abundance during the larval and postlarval stages.

OTTESTAD (1934) argued that only part of the fat-herring occurring off northern Norway might later migrate to the spawning grounds off southern Norway (area 08) and the winter herring district off Møre. The majority of fat-herring after becoming mature probably spawned farther north off Lofoten and Vesterålen. According to LEA (1929) the duration of the oceanic stage varies with the individual history of the herring. Some individuals mature after one year, others after two or three years. Each year the maturing herring, which will spawn the following spring, split off from the stock of oceanic herring. In the years 1962–1964 adolescent herring, predominately of the 1959 and 1960 year-classes, were located off Torsvåg during the autumn. Some of these herring matured and migrated to the Lofoten spawning grounds for the first time in 1963 (DEVOLD 1968), whereas others migrated westwards to the feeding areas off Iceland (JAKOBSSON 1968).

Herring approaching the Lofoten region for spawning in 1963–1966 stayed off northern Norway and in the Barents Sea during the young and adolescent phases. This component, which was separated from the main stock of adult herring both during spawning and on the wintering grounds, did not appear on the Lofoten spawning grounds in the winter of 1967 and 1968 (DEVOLD 1968). In the summer and the autumn of 1966 the two groups had mixed and formed one stock with a spawning migration towards the Møre coast. After this admixture adolescent herring in waters off Troms and Finnmark and in the Barents Sea therefore will appear on the spawning grounds off Møre somewhat later than those from the nursery areas farther south.

SELIVERSTOVA (1968) tried to estimate the abundance of the 1950 year-class which stayed in the Barents Sea during the adolescent phase and to determine the recruitment from the Barents Sea to the adult stock of the 1950 year-class in the Norwegian Sea. A relatively small percentage (1–3%) was found in the adult stock when the year-class was four to five years old, but the percentage increased to about 13–14% at an age of seven and eight years.

No other specific recruitment pattern or mechanism can be discovered from the present data, but it can be concluded that variations in growth may influence the migration pattern and the duration of the adolescent phase. Growth, on the other hand, is determined by the distribution during the 0-group stage and the 0-group distribution consequently plays an important role in recruitment mechanism. The year by year northward displacement of the main spawning centre, with a corresponding northward displacement of the 0-group population may have been the primary cause for the extended duration of the adolescent phase of the herring of the 1963 and 1964 year-classes.

ABUNDANCE OF 0-GROUP HERRING COMPARED WITH YEAR-CLASS STRENGTH IN THE ADOLESCENT AND ADULT STOCKS

The abundance estimates of 0-group herring show great variations from one year to another. The 1959 and 1960 year-classes were particularly numerous during the 0-group stage. These year-classes also were abundant throughout the adolescent phase and showed up as rich year-classes in the adult stock both on the feeding and spawning grounds (DEVOLD 1968, DRAGESUND 1970). Similarly, year-classes with low abundance during the 0-group stage, such as that of 1962, appeared to be weak during all the subsequent stages. The 1961, 1963 and 1964 year-classes were considerably more abundant as 0-group herring than those of 1962 and 1965, though clearly less abundant than those of 1959 and 1960.

In Fig. 35 the echo abundance of 0-group herring for the 1959–1962 year-classes is plotted against year-class strength in the adult stock. The values for adult year-class strength (at six years of age) are those obtained from tagging experiments and combined acoustic surveys and underwater photography (ANON. 1969). A very close correlation is found between the two independent estimates of year-class strength, and it is concluded, therefore, that the abundance indices of 0-group herring obtained from the acoustic surveys give a fairly good estimate of year-class strength.

An indication of the relative strengths of the 1959–1965 year-classes in the adolescent and adult stocks can also be obtained from their frequencies in samples collected in different fisheries. These frequencies are compared with estimates of 0-group abundances in Table 12. Samples collected during the different seasons in 1963–1968 clearly demonstrated that the 1959 year-class predominated over the year-class of 1960. In 1964 and 1965 none of the 1962 year-class and only a relatively small part of the 1960 and 1961 year-classes had reached maturity, and consequently the relative strength of the 1959 year-class as indicated by the age distribution was overestimated compared with those of 1960 and 1961. In 1966–1968 the strengths of the 1960 and 1961 year-classes probably were overestimated in relation to the 1959 year-class as mortality had reduced the latter to a greater extent. The age compositions in Table 12 indicate that the relative strength of the 1959 year-class during the adolescent and adult phases was about twice that of 1960 and at least six times that

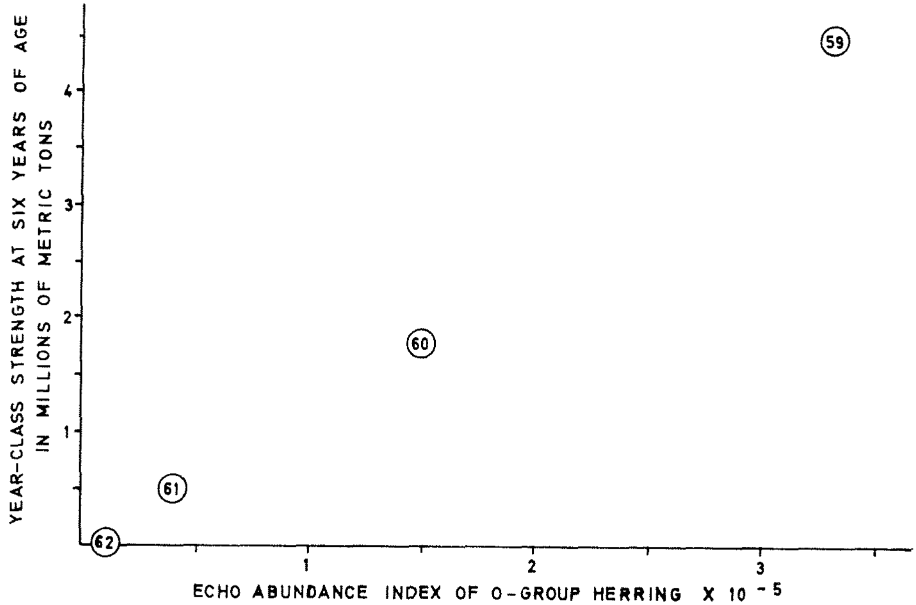

Fig. 35. Relationship between year-class strength at the 0-group stage and at six years of the 1959–1962 year-classes.

of 1961. This conclusion agrees fairly well with the estimates of 0-group abundance obtained from the acoustic surveys (Table 12).

In 1965–1968 none of the 1959–1962 year-classes was found in the fat-herring catches off Finnmark, and it is concluded, therefore, that the majority of these year-classes had migrated from the Barents Sea and the coastal areas off northern Norway. In these years the 1963 and 1964 year-classes dominated in catches off Finnmark (Table 12). Up to 1968 the 1963 and 1964 year-classes had not joined the stock on the spawning grounds in significant numbers. However, in the fat-herring catches (1966–1968) they occurred in about the same ratio as during the 0-group stage. Due to the long adolescent phase the abundance of these herring will be considerably reduced when they reach the adult stage. In addition to the high exploitation of the 1963 and 1964 year-classes, this probably is the primary cause for the absence of these year-classes in the spawning stock in 1968.

EFFECT OF THE NORWEGIAN SMALL- AND FAT-HERRING FISHERIES ON RECRUITMENT TO THE ADULT STOCK

The stock size of adult Norwegian herring increased markedly from 1963 to 1965, primarily because of recruits of the rich year-classes of 1959 and 1960. From 1966 to 1968 a rapid decrease in stock size took place

Table 12. Echo abundance estimates of 0-group herring and age composition of adolescent and adult herring of the 1959–1965 year-classes in different regions in 1963–1968.

Year	Month	Region	Year-class							
			1959	1960	1961	1962	1963	1964	1965	Others
			Total 0-group echo abundance $\times 10^{-3}$							
1959–1965	Sept.–Oct.	Off northern Norway	325.8	147.4	37.5	14.8	53.6	75.0	9.1	—
			Age composition in %							
1963	Febr.	Ingøy Trench	67.3	28.6	4.1	—				—
	March–April	Off Lofoten	90.9	8.6	—	—				0.5
	June–July	Off eastern Finnmark	7.5	81.3	11.2	—				—
	July–Aug.	Off Iceland	22.9	2.3	0.3	—				74.5
	Oct.–Nov.	Off Torsvåg	43.0	42.1	14.6	—				0.3
1964	Febr.	Off Møre	51.5	4.0	—	—	—			44.5
		Off Lofoten	88.4	10.1	0.6	—	—			0.9
	July–Aug.	Off Iceland	46.8	10.1	4.0	0.1	—			39.0
	Aug.–Sept.	Area 37	70.6	21.2	7.9	—	—			0.3
1965	Febr.–March	Off Møre	62.7	10.7	3.2	—	—	—		23.4
		Off Lofoten	74.1	19.6	5.8	—	—	—		0.5
	July–Aug.	Off Iceland	42.3	12.7	5.8	0.4	1.5	—		37.3
	Aug.	Off Finnmark	—	—	—	—	64.4	35.6		—
1966	Febr.–March	Off Møre	53.4	27.7	10.3	0.1	—	—	—	8.5
		Off Lofoten	51.6	39.1	8.0	0.3	—	—	—	1.0
	July–Aug.	Off Iceland	49.8	18.7	7.9	0.8	2.7	—	—	20.1
	Aug.	Off Finnmark	—	—	—	—	29.6	52.5	17.9	--
1967	Febr.–March	Off Møre	48.8	32.1	13.4	0.4	0.5	—	—	4.8
	June–Aug.	Off Finnmark	—	—	—	—	33.9	66.1	—	—
	July–Aug.	Off Iceland	50.3	31.8	11.6	1.1	1.2	0.1	—	3.9
1968	Febr.–March	Off Møre	46.9	34.2	13.8	1.7	0.7	—	—	2.7
	April–May	Off Finnmark	—	—	—	—	41.9	58.1	—	—
		Off Iceland	47.2	31.4	13.0	2.1	2.4	0.2	0.1	3.6

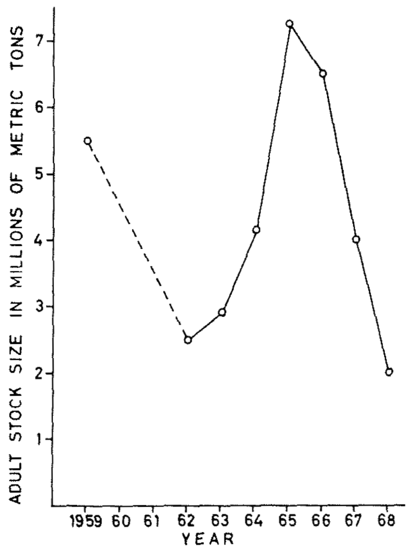

Fig. 36. Stock size of adult Norwegian herring in 1959–1968 (ANON. 1969).

(Fig. 36). During this period the stock should have been recruited from the 1962–1964 year-classes. Although the exploitation during the late 0-group and early I-group stages was nearly the same for these year-classes as for those of 1959–1961 (Fig. 34), they did not show up in significant numbers in the adult stock. The ratios of the yield of the separate year-classes of 1959–1965 in the small-herring fisheries and the echo abundance of 0-group herring (inshore) show that the exploitation of 0- and I-group herring in the fjords generally has fluctuated in accordance with the abundance of herring (Fig. 37). It is concluded, therefore, that the variations in recruitment to the adult stock during the 1960s cannot be attributed to the fishery on 0- and I-group herring.

FEDOROV, TRUSKANOV and YUDANOV (1963) pointed out that for adults the ratio between the strengths of weak and strong year-classes on the basis of catches was 1/8–1/14, while the ratio of the same year-classes in the small-herring catches was only 1/2–1/3. They take this to support their claim that the fishery on small-herring was an important factor determining recruitment during the late 1950s and early 1960s. MARTI (1959), dealing with year-classes prior to those of 1959–1965, held the opinion that year-classes which were heavily fished as young, gave relatively smaller catches as adults than those which were lightly fished prior to recuitment to the adult stock.

Fig. 38 shows the ratios between year-class strength of the 1959–1963 year-classes at the 0-group stage and at six years. Adult year-class strength for that of 1963 is based on a spawning stock size in 1969 of 1.3 million tons. This stock size was estimated from data in the report of the Atlanto-

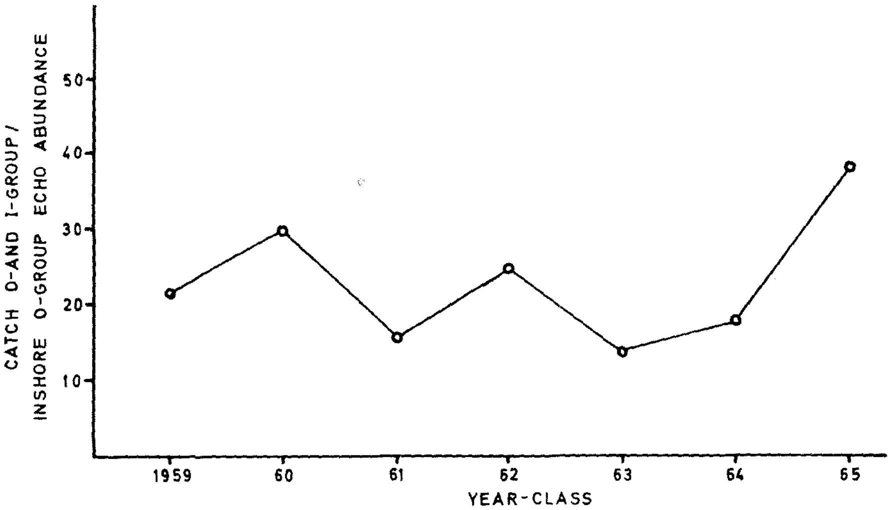

Fig. 37. Ratio between catch (in tons) of 0- and I-group herring in Norwegian fjords and inshore echo abundance of 0-group herring of the 1959–1965 year-classes.

Scandian Herring Working Group (ANON. 1969) applying a total annual mortality coefficient of $Z = 0.44$. For the 1964 and 1965 year-classes no adult abundance indices can be given.

There is no marked difference in the ratios between year-class strengths in the 0-group and the adult stocks of the 1959–1961 year-classes. However, the ratios of the 1962 and especially the 1963 year-classes were relatively higher. This indicates that these year-classes have been more reduced in numbers during the young and adolescent phases than the 1959–1961 year-classes. The exploitation of the 1962 year-class was higher during the 0- and I-group stages than that of 1963 (Fig. 34). The same was the case for the 1961 year-class compared with that of 1963, but the effect of this could not be measured in the adult stock. It is difficult, therefore, to verify whether the relative abundance of poor year-classes decreased markedly compared with the rich ones because of exploitation during the late 0-group and early I-group stages in the Norwegian fjords. However, the high natural mortality rate during these stages and the relatively low percentage of the 0-group stock present in the fjords suggest that the small-herring fishery was not a determining factor for the total mortality of year-classes up to 1965 before they were recruited into the adult stock.

The exploitation of the 1963 and 1964 year-classes during the fat-herring stage was five to six times higher than for the 1959 and 1960 year-classes, and this is assumed to have reduced the number of recruits of the 1963–1964 year-classes markedly. Since the fat-herring are exploited in

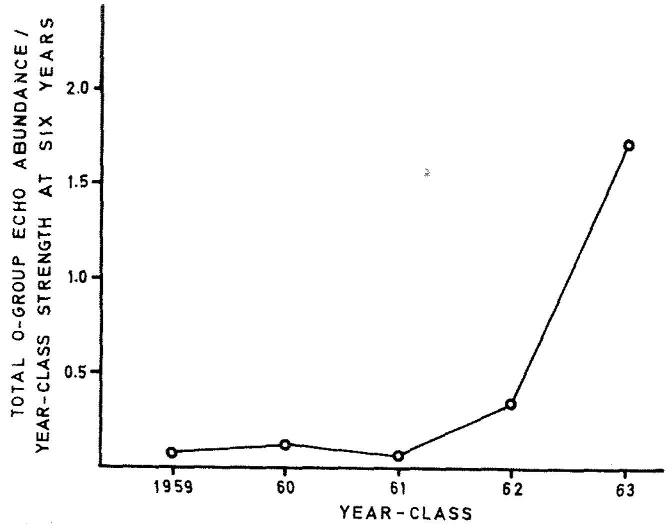

Fig. 38. Ratio between total 0-group echo abundance and year-class strength at six years (in tons) of the 1959–1963 year-classes.

offshore waters and natural mortality is most likely considerably lower than for 0- and I-group herring, the fat-herring fishery may be expected to have a relatively greater effect on recruitment to the adult stock than the small-herring fishery on 0- and I-group herring in the Norwegian fjords. No exact estimate can be made of the impact of the Norwegian small- and fat-herring fisheries on subsequent recruitment to the adult stock for the year-classes of 1959–1965. However, tentative estimates have been made for the strong year-class of 1959 and the weaker year-class of 1963 to study the possible reduction of year-class strength at six years caused by the fishery on young and adolescent herring using alternative values of natural mortalities.

The catches of 0- to III-group herring by month and district are listed in Tables VIII and IX. The catches were converted to numbers and reduced according to the equation

$$N_t = N_0 e^{-Mt} \tag{6}$$

where N_0 is the number of herring at the time t_0 and N_t at the time t. M is the instantaneous natural mortality coefficient.

Little is known about natural mortality of young and adolescent herring except for the late 0- and early I-group stages (Table 10). Because data on loss of tags are uncertain and the emigration of herring may have affected the estimates, fishing mortality is most likely underestimated. Consequently, the natural mortality may have been overestimated, and therefore the lowest monthly apparent natural mortality ($X = 0.23$) was used for the wintering period (October to April) of 0- and I-group herring in the fjords. This value corresponds to an annual M_1 of 2.76 (Table 13).

It may be assumed that natural mortality is considerably reduced after the second growth season when most of the herring have nearly doubled their lengths (Table VI). Swimming speeds increase with the lengths. BLAXTER and DICKSON (1959) found that captive herring ranging from 1–25 cm swam at speeds (for distances at least ten times their body length) of 3–175 cm/sec. Herring 20–25 cm long could swim at nearly maximum speed for 1100 lengths. It is likely, therefore, that the predator effect will decrease with length and that the natural mortality is inversely related to length. When the herring have moved from the coast and the central parts of the Barents Sea, they have relatively few predators, and in the late adolescent phase the annual natural mortality may be of the same magnitude as in the adult phase, i.e. $M = 0.16$ (ANON. 1965).

Tentatively, the monthly instantaneous natural mortality coefficient during the late I- and early II-group stages has been graded down to one fourth, one half and three quarters of that in the late 0- and early I-group stages, i.e. to 0.0575, 0.115 and 0.173, respectively, corresponding to annual instantaneous mortality coefficients (M_2) of 0.69, 1.38 and 2.07 (Table 13). These three alternative M_2 values were used to calculate the reduction from May in the I-group stage to April in the II-group stage. For the period from May in the II-group stage to 1 January in the VI-group stage the annual instantaneous mortality coefficients (M_3, M_4, M_5, M_6) are assumed to be equal, and two different values (0.16 and 0.24) were used. The estimated number of herring at the VI-group stage (by 1 January) was converted to tons by applying average weights of 217 and 232 g for herring from nursery areas in Troms–Finnmark and Møre–Trøndelag–Nordland, respectively (W_1, Table 13).

In order to evaluate the loss due to fishing on 0- to III-group herring, catches at subsequent stages (up to age six by 1 January) were estimated. The catches in numbers for the 1959 and 1963 year-classes in the adult fisheries are taken from the report of the Atlanto-Scandian Herring Working Group (ANON. 1969). The yield from the pre-recruit fisheries (fat-herring and "forfangstsild") in Norwegian coastal waters after age of three years (by April) are given in Tables X and XI. The total catches were reduced according to the alternative M_3, M_4, M_5, M_6 values listed in Table 13 and converted to tons (W_2). The loss due to catches of young and adolescent herring can be found from the expression

$$\frac{W_1}{W_1+W_2+S_6}\,100 \tag{7}$$

Table 13. Estimates of percentage loss to year-class strength at six years due to the catches of young and adolescent herring of the 1959 and 1963 year-classes. Catches and year-class strengths are given in thousands of metric tons.

Year-class	Alternative values of annual natural mortality M_1	M_2	$M_3 \ldots M_6$	Loss due to catches of 0- to III-group W_1	III- to V-group W_2	Year-class strength at six years S_6	Percentage loss $\frac{W_1 \cdot 100}{W_1+W_2+S_6}$	Loss due to catches of 0- to I-group w_1	Percentage loss $\frac{w_1 \cdot 100}{W_1+W_2+S_6}$	Loss due to catches of I- to II-group w_2	Percentage loss $\frac{w_2 \cdot 100}{W_1+W_2+S_6}$	Loss due to catches of II- to III-group w_3	Percentage loss $\frac{w_3 \cdot 100}{W_1+W_2+S_6}$
1959	2.76	0.69	0.16	1345	809	4501	20.2	682	10.2	402	6.0	261	3.9
	2.76	1.38	0.16	873	809	4501	14.1	342	5.5	270	4.4	261	4.2
	2.76	2.07	0.16	622	809	4501	10.5	172	2.9	189	3.2	261	4.4
	2.76	0.69	0.24	1006	728	4501	16.1	508	8.1	300	4.8	198	3.2
	2.76	1.38	0.24	654	728	4501	11.1	255	4.3	201	3.4	198	3.4
	2.76	2.07	0.24	467	728	4501	8.2	128	2.2	141	2.5	198	3.5
1963	2.76	0.69	0.16	529	537	31	48.2	111	10.1	101	9.2	317	28.9
	2.76	1.38	0.16	442	537	31	43.8	55	5.4	70	6.9	317	31.4
	2.76	2.07	0.16	394	537	31	41.0	27	2.8	50	5.2	317	33.0
	2.76	0.69	0.24	397	473	31	44.1	82	9.1	75	8.3	240	26.6
	2.76	1.38	0.24	333	473	31	39.8	41	4.9	52	6.2	240	28.7
	2.76	2.07	0.24	298	473	31	37.2	21	2.6	37	4.6	240	29.9

where S_6 is the estimated size in tons of the year-class at six years assuming full recruitment at this age.

The estimates show that the catches of 0- to III-group herring may have reduced the 1959 year-class at six years by 8.2–20.2% and the 1963 year-class by 37.2–48.2%. This again shows that the exploitation of the 1963 year-class during the young and adolescent phases was considerably higher than for the 1959 year-class, and taking into account the subsequent catches (up to age six) nearly all the herring of the 1963 year-class were caught before recruitment into the adult stock.

The effect of fishing on the different age groups can be analysed by splitting the loss (W_1) on 0- and I-group (w_1), I- and II-group (w_2) and II- and III-group (w_3) herring (Table 13). The loss due to catches of 0- and I-group herring may have reduced the 1959 and 1963 year-classes by 2.2–10.2%. Taking into account that the fjord population of the 1959 year-class was only about 3% of the 0-group population and about 10% of the 1963 year-class, it may be assumed that the higher estimates in Table 13 represent an overestimate of the loss due to fishing on 0- and I-group herring.

Further calculations have been made to estimate the yields which might have been obtained from the loss due to the catches of 0- to III-group herring if exploitation had started by 1 January at six years of age and continued throughout the lifespan up to an age of eighteen years. The number of fish by 1 January at six years of age is denoted by N_6. When estimating N_6 the two highest and lowest values of M_2 were excluded. The number by 1 January the following year (N_7) can be estimated from the expression

$$N_7 = N_6 e^{-Z} \tag{8}$$

where $Z = (F+M)$ is the total annual instantaneous mortality coefficient.

The catch in numbers from age six to seven is given by

$$C_6 = \frac{F}{F+M}(N_6 - N_7) = \frac{F}{F+M} N_6 (1 - e^{-(F+M)}) \tag{9}$$

and from age seven to eight by

$$C_7 = \frac{F}{F+M} N_7 (1 - e^{-(F+M)})$$

etc. to

$$C_{18} = \frac{F}{F+M} N_{18} (1 - e^{-(F+M)})$$

It has been assumed that

$$E = \frac{F}{F+M} \text{ and } Z = (F+M)$$

do not change for age groups from six to eighteen years. Average values of exploitation rate ($E = 0.64$) and total annual instantaneous mortality coefficient ($Z = 0.44$) for the 1959–1961 year-classes, which were obtained from the report of the Atlanto-Scandian Herring Working Group (ANON. 1969), have therefore been used in the estimates (Table XII). The annual catches in numbers have been converted to tons and compared with the actual catches of 0- to III-group herring (Table 14). The estimates show that about the same yield in weight would have been obtained already at the end of the third year of exploitation (starting the fishery at six years of age), and the total yield over the life-span (from six to eighteen years) would have been considerably higher.

The tentative estimates are based on too few exact observations on natural mortality during the young and adolescent phases, and unknown factors may change the results completely. Nevertheless, they indicate that the fishery for young and adolescent herring may effect the subsequent recruitment to the adult stock considerably. The high exploitation of the 1963 year-class during the fat-herring stage thus probably resulted in a marked reduction of this year-class before it entered the adult stock.

Table 14. Catches of 0- to III-group herring of the 1959 and 1963 year-classes, and estimates of yield which might have been obtained by refraining from these catches and by starting the exploitation at six years of age. The catches are given in thousands of metric tons. See Table XII for further information.

Year-class	Category	Catch	Estimated yield		
			Year	Alternative 1	Alternative 2
1959	0- and I-group	176	1965	203	152
	I- and II-group	109	1966	141	105
	II- and III-group	93	1967	110	82
	0- to III-group	378	1965–1967	454	339
			1968–1977	215	162
			1965–1977	669	501
1963	0- and I-group	45	1969	102	78
	I- and II-group	36	1970	71	54
	II- and III-group	114	1971	55	42
	0- to III-group	195	1969–1971	228	174
			1972–1981	108	83
			1969–1981	336	257

Both the small- and fat-herring fisheries fluctuate according to variations in year-class strength, but other biological factors, such as distribution, growth and migration also influence the yield of these fisheries. The decline in the catches of Norwegian winter herring in the late 1950s and early 1960s, the increase in the mid-1960s and the decrease in 1967–1968 were primarily associated with variations in year-class strength and not with the Norwegian small-herring fishery in the fjords. However, an extension of the 0-group herring fishery to the open sea, and a high exploitation rate of fat-herring will result in an appreciable reduction in the subsequent abundance in the adult stock. Environmental factors presumably play a major role in determining the reproductive success of the stock (DRAGESUND 1970). However, with the spawning stock size at a relatively low level an intensified fishery may endanger the prospects for future reproduction of the stock of Norwegian herring. Any increase in the fishing rate should be avoided, and a reduction of the fisheries on young and adolescent herring should be considered to improve the abundance of adult herring.

SUMMARY

1. The distribution of young and adolescent herring in coastal and offshore waters of northern Norway has been investigated for the 1959–1965 year-classes by combined acoustic surveys and fishing experiments.

2. In the autumn (August–October) 0-group herring occur pelagically in the upper 50 m of water together with the 0-group of several other species, such as cod, haddock, redfish, capelin and others. This complicates the charting and identification of the sound scatterers, but detailed studies of the echo recordings and frequent sampling in the scattering layer made it possible to determine the distribution of 0-group herring.

3. In 1959, 1960, 1964 and to some extent in 1963 and 1965, 0-group herring had an oceanic distribution, and only a minor part of the 0-group population entered the fjords of northern Norway. In 1961 and 1962 the distribution was more restricted to the coastal areas, and a greater proportion of the total 0-group population was present in the fjords. Herring entering the fjords at the 0-group stage in the autumn emigrate during the I-group stage from March to May.

4. Herring in the northern and eastern Barents Sea had slower growth rates and consequently a longer phase of migration to the spawning areas than did those distributed farther south and west. Herring from nursery grounds in the Barents Sea, therefore, are considerably more reduced in numbers before they reach the spawning grounds off Møre than those

which have spent their 0-group stage in the southern nursery areas in Norwegian coastal waters. The growth rate, therefore, may influence the migration pattern and the duration of the adolescent phase. Growth on the other hand is determined by the distribution during the 0-group stage, and the 0-group distribution consequently plays an important role in recruitment mechanism.

5. Abundance estimates of 0-group herring were obtained from three independent sources, i.e. acoustic surveys, catch and effort statistics and tagging experiments. The 1959 year-class, but also that of 1960, were numerous during the 0-group stage and remained abundant throughout the adolescent phase and in the adult stock. Year-classes of low abundance at the 0-group stage, such as the 1962 year-class, remained weak throughout the subsequent stages. The 1963 year-class, which was fairly abundant as 0-group, did not show up in significant numbers in the adult stock in 1968 and 1969. The 1964 and 1965 year-classes have not been studied in their adult phase because they had not attained maturity when the material was compiled. The year-classes of 1963 and 1964 showed about the same relative strengths during the adolescent phase as at the 0-group stage.

6. Mortality estimates obtained from catch and effort data and tagging experiments indicate that the fishing mortality of 0- and I-group herring in Norwegian fjords was relatively high, but because natural mortality was much higher, the exploitation rate was relatively low. Taking into account that the fjord population is only part of the total 0-group population, it is concluded that the fishing mortality generated by the 0- and I-group fishery in Norwegian fjords was too small to be the primary cause of the failure of recruitment to the adult stock.

7. A considerable increase in the exploitation of fat-herring, i.e. I- to IV-group herring took place from 1965 to 1968. The increase in exploitation during the adolescent phase of the 1963 and 1964 year-classes compared with those of the 1959–1961, and a long duration of the migration of the former year-classes from the nursery areas to the spawning grounds may explain why the year-classes of 1963 and 1964 tended to be relatively weak in the adult stock.

8. With the relatively low level of the spawning stock size an intensified fishery on the Norwegian herring should be avoided. An extension of the small- and fat-herring fisheries into the open sea may result in an appreciable reduction in the subsequent abundance in the adult stock, and a reduction of the fishery on young and adolescent herring should be considered to improve the abundance of adult herring.

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TABLES

Table I. Records of fishing experiments with pelagic trawl (PT), purse seine (PS), bottom trawl (BT) and Isaacs–Kidd ten foot mid water trawl (IKMT) for identification of echo traces during the surveys in 1959–1965.

Area	Date	Gear	No. of hauls, shots or samples	No. of fish per nautical mile towed or per purse seine shot				
				Year-class of herring				Other species
	1959			1959	1958	1957	1956	
06	27.9	PT	1	611	—	—	—	Not identified
05	30.9–2.10	PS	3	18438	—	—	—	Not identified
	6.10	PT	1	213	—	—	—	Not identified
04	9.10	PT	1	8520	—	—	—	Not identified
	8.10	PS	1	685000	—	—	—	Not identified
03	18–20.10	PS	3	35032	—	—	—	Not identified
	22.10	PS	1	A few hl				
	20.10	PS	1	Ca. 100 hl, mainly of 1957, 1958 year-classes				
02 and 10	15–16.10	Stomach content	2	8	—	—	—	Not identified
13	8.10	Stomach content	1	15	—	—	—	Not identified
15	12.10	Stomach content	1	24	—	—	—	Not identified
20	3.9	Stomach content	1	10	—	—	—	Not identified
	3.9–20.10	Stomach content	2	Many/some	—	—	—	Not identified
	20.10	BT with cover	1	200	—	—	—	Not identified
21	9–16.10	BT with cover	4	8	—	—	—	Not identified
	9.10	Stomach content	3	Some	—	—	—	Not identified
25	10.10	Stomach content	1	Some	—	—	—	Not identified
	12.10	BT with cover	1	1	—	—	—	Not identified
23	10.10	Und. wat. photogr.	1	Identified as 0-gr. herring, 1959 year-class				

Table I (*continued*)

1960				1960	1959	1958	1957	
05	28.9–2.10	IKMT	8	45	—	—	—	12
	29.9–2.10	PT	2	15	—	—	—	1
	29.9	PS	1	266	—	—	—	8
04	2–23.10	IKMT	4	4	—	—	—	—
	2–23.10	PT	2	2649	3	—	—	6
	3–24.10	PS	3	298259	80	—	—	—
03	10.10	IKMT	1	7	—	—	—	1
	21–22.10	PT	2	824	A few	—	—	—
	19–21.10	PS	3	1064	2	—	—	17
03 and 10	13.9–11.10	IKMT	4	11	—	—	—	14
02 and 10	13.9–14.10	PS	3	Ca. 1300	46	—	—	54
04 and 12	23.9–8.10	IKMT	4	1	1	—	—	3
12	8.10	PT	1	—	2326	24	24	1
13	15.9–13.10	IKMT	3	2	—	—	—	2
	13.10	PT	1	25	11	—	—	49
15 and 23	16.9–12.10	IKMT	4	7	—	—	—	523
15	12.10	PT	1	13	—	—	—	53
20	21.9–8.10	IKMT	8	139	1	—	—	4
	22.9–5.10	PT	3	371	—	—	—	28
	7.10	PS	1	Ca. 40000	—	—	—	—

Table I (*continued*)

Area	Date	Gear	No. of hauls, shots or samples	No. of fish per nautical mile towed or per purse seine shot				
				Year-class of herring				Other species
	1961			1961	1960	1959	1958	
05	4.9	IKMT	1	2	—	—	—	39
	3–28.9	PT	6	82	—	—	—	5
	6–27.9	PS	2	26540	60	—	—	—
04	23–26.9	PT	7	83	1	—	—	26
	25.9	PS	1	4808	—	—	—	—
03	21–23.9	PT	5	70	1	1	—	13
	20.9	PS	1	7370	1211	519	—	—
03 and 10	17–20.9	PT	5	19	1	1	—	44
03	22.9	PS	2	15	2	25762	—	—
04 and 12	9–12.9	PT	2	4	1	—	—	23
12	11–12.9	PS	2	3	34	1008	—	—
11	23.11	PT	1	—	4	4	—	—
13	1.8–20.11	PT	2	Ca. 80 1 mixture of I- and II-group herring 1959–1960 year-classes and 0-group cod and haddock.				
20	9.9	PS	1	3	—	—	—	721
	1962			1962	1961	1960	1959	
05	21–23.9	PT	3	40023	5	—	—	1
	21–27.9	PS	4	577066	25705	803	268	—
04	17.9	PT	2	1630	17	—	—	49
	28–29.9	PS	3	15188	700	2	—	—
03	13.9	IKMT	1	2	—	—	—	—
	13.9	PT	2	22	29	147	107	—
03 and 10	5–7.9	IKMT	2	4	—	—	—	1
	6.9–5.11	PT	7	135	82	253	198	—
04 and 12	12.9–16.11	PT	3	1	1	4	5	5
	18–29.9	PS	2	—	1326	3583	25023	—
13	8.9	PT	1	166	—	—	—	14

Table I (*continued*)

1963				1963	1962	1961	1960	
05	3.10	IKMT	1	1	—	—	—	1
	4.10	PT	1	280	—	—	—	—
	4.10	PS	1	13424	—	—	—	—
04	2.10	IKMT	1	1	—	—	—	35
	30.9–6.10	PT	2	96	—	3	14	—
	27.9–1.10	PS	6	35024	—	865	1575	—
03	30.8–17.9	IKMT	4	11	—	—	—	14
	18–20.9	PT	2	552	—	—	—	2
10	20–21.9	IKMT	2	3	—	—	—	30
	20.9	PT	1	39	—	—	—	2 litres
13	11.9	IKMT	1	18	—	—	—	33
14	4.9	IKMT	1	3	—	—	—	5
20	11.9	IKMT	1	8	—	—	—	11
	24.9	PT	1	126	—	—	—	6
1964				**1964**	**1963**	**1962**	**1961**	
05	12.8–1.10	PT	2	2362	1	—	—	3
04	10.9	IKMT	1	2	—	—	—	—
	10–28.9	PT	2	10769	—	—	—	1
	29.9	PS	2	16870	—	—	—	1
03	15–21.9	PT	2	204	15	—	—	129
	16–25.9	PS	2	10939	340	—	—	20
10	15.9	IKMT	1	2	—	—	—	65
02 and 10	13–14.9	PT	4	169	1	—	—	—
12	11.9	IKMT	1	2	—	—	—	24

Table I (*continued*)

Area	Date	Gear	No. of hauls, shots or samples	No. of fish per nautical mile towed or per purse seine shot				
				Year-class of herring				Other species
	1964			1964	1963	1962	1961	
04 and 12	10.8–26.9	PT	9	312	1	—	—	—
13	13.9	IKMT	1	5	—	—	—	3
	11–23.9	PT	3	95	—	—	—	—
15	23.9	PT	1	20	—	—	—	404
20	8.9	IKMT	1	4	—	—	—	161
	2–23.9	PT	2	14	—	—	—	222
21	23.7–6.9	PT	5	130	—	—	—	—
37	31.8–1.9	PT	2	—	—	—	—	24
	1965			1965	1964	1963	1962	
05	25–27.8	PT	3	38	—	—	—	—
04	30.8	PT	2	192	—	—	—	4
03	31.8	PT	2	—	1697	2128	—	3
12	9–14.9	PT	2	16	—	—	—	257
21	10–11.9	PT	2	25	—	—	—	862

Table II. Tagging experiments with internal steel tags on young and adolescent herring in coastal and offshore waters of northern Norway in 1959–1964.

Date		Position	Category of herring	No. of herring tagged
1959	1.10	N 67° 50′, E 14° 10′	0-group	600
	2.10	N 68° 40′, E 12° 45′	0-group	1000
	8.10	N 70° 10′, E 19° 30′	0-group	2000
	19.10	N 69° 50′, E 30° 30′	0-group	600
1960	3.10	N 70° 10′, E 19° 30′	0-group	2000
	7.10	N 74° 30′, E 19° 30′	0 group	2000
	14.10	N 70° 20′, E 36° 30′	0-group	1500
	14.10	N 69° 20′, E 37° 20′	I-group	1000
	21.10	N 70° 03′, E 29° 50′	0-group	1000
	23.10	N 70° 50′, E 26° 00′	0-group	300
1961	6. 9	N 69° 20′, E 17° 00′	0-group	1000
	20. 9	N 69° 50′, E 30° 30′	0-group	1000
	20. 9	N 69° 50′, E 30° 30′	I-group	200
	25. 9	N 70° 10′, E 19° 30′	0-group	2000
	27. 9	N 69° 35′, E 17° 25′	0-group	500
	12. 9	N 71° 35′, E 25° 35′	Fat-herring	950
	22. 9	N 71° 35′, E 27° 45′	Fat-herring	500
1962	21. 9	N 68° 30′, E 15° 00′	0-group	1300
	25. 9	N 67° 10′, E 13° 50′	0-group	600
	27. 9	N 69° 18′, E 18° 40′	0-group	600
	28. 9	N 69° 35′, E 19° 40′	0-group	1200
	18. 9	N 71° 40′, E 19° 35′	Fat-herring	1900
	21. 9	N 68° 30′, E 15° 00′	Fat-herring	800
1963	27. 9	N 69° 35′, E 19° 40′	0-group	2000
	4.10	N 68° 30′, E 15° 00′	0-group	1000
	17. 6	N 69° 50′, E 30° 30′	I-group	300
	19. 6	N 70° 15′, E 34° 00′	I-group	900
	5. 6	N 70° 10′, E 32° 30′	Fat-herring	600
	10. 6	N 70° 10′, E 32° 30′	Fat-herring	400
	19. 6	N 70° 15′, E 34° 00′	Fat-herring	100
	25. 6	N 69° 10′, E 16° 30′	Fat-herring	400
	1.10	N 71° 10′, E 20° 00′	Fat-herring	1000
1964	16. 9	N 70° 03′, E 29° 50′	0-group	1000
	25. 9	N 70° 50′, E 26° 00′	0-group	1000
	29. 9	N 69° 35′, E 19° 35′	0-group	2000

Table III. Length distribution (in cm) of 0-group herring of the 1959–

Year-class	Area	Date	Gear	No.	6.0	6.5	7.0	7.5	8.0	8.5
1959	05	1.10	PS	648						6
		2.10	PS	456						
		16.11	PS	608			18	33	37	54
	04	8.10	PS	685				3	9	33
		19.10	PS	793			8	26	78	130
		19.10	PS	661		3	—	23	52	76
		30.10	PS	613		2	12	18	42	70
		10.11	PS	617	1	—	3	—	5	11
		17.11	PS	764				9	19	87
		20.11	PS	570			1	3	12	45
		20.11	PS	833		1	3	22	59	129
		21.11	PS	712		3	18	38	55	108
		21.11	PS	838				18	55	118
		22.11	PS	577				5	7	52
		23.11	PS	459					2	5
		23.11	PS	789				9	35	106
		23.11	PS	649			4	6	25	64
		23.11	PS	729			26	103	159	150
		24.11	PS	772				4	18	47
		2.12	PS	868			3	19	54	89
		2.12	PS	886			10	26	59	108
		8.12	PS	723			9	15	29	53
		8.12	PS	824			22	51	76	117
	03	18.10	PS	1176				8	318	427
		19.10	PS	1384			24	210	431	277
		20.10	PS	725			19	22	23	43
		22.10	PS	814					12	95
		26.10	PS	774			1	3	16	71
		23.11	PS	531			4	23	52	76
		24.11	PS	583			12	32	65	88
		24.11	PS	836			26	57	104	117
		27.11	PS	885			5	33	157	200
		1.12	PS	880			1	48	151	193
		1.12	PS	956			16	101	180	176

1965 year-classes caught with purse seine (PS) and pelagic trawl (PT).

9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0
182	245	147	45	15	5	3				
9	18	46	64	102	108	68	33	7	—	1
61	65	82	46	80	47	32	34	19		
109	173	161	103	53	34	5	2			
114	104	71	84	94	52	30	2			
82	59	65	65	98	81	41	13	2	1	
99	70	68	67	78	55	27	5			
41	64	106	97	122	78	64	16	9		
168	174	181	72	31	14	8	—	—	1	
86	109	109	62	73	41					
239	180	114	46	29	7	3	—	1		
153	110	89	47	53	29	9				
228	195	140	45	24	10	4	1			
124	157	116	49	52	14	1				
25	42	65	75	79	80	68	13	5		
176	167	128	71	50	26	17	3	1		
108	148	151	61	47	21	11	1	1	1	
120	66	49	26	18	7	3	2			
128	147	194	80	87	36	27	3	1		
177	178	179	75	56	28	9	1			
177	172	148	88	65	19	11	3			
91	108	112	92	90	69	31	20	4		
145	111	96	50	65	48	34	8	—	1	
258	96	50	14	5						
189	116	73	40	18	6					
113	168	128	102	67	26	14				
196	220	176	82	23	10					
158	187	143	101	44	25	11	5	6	3	
133	83	77	35	24	12	4	4	3	1	
113	84	97	43	29	9	4	5	2		
149	122	138	57	32	18	10	3	2	1	
189	121	85	37	27	13	4	5	7	2	
179	124	83	34	34	12	11	4	5	1	
174	130	92	37	21	9	12	3	2	3	

Table III (*continued*)

Year-class	Area	Date	Gear	No.	5.5	6.0	6.5	7.0	7.5	8.0	8.5
1960	07	12.11	PS	100							
		14.11	PS	100							
		18.11	PS	100							
	05	29.9	PS	266				9	48	62	51
		20.10	PS	100		1	5	25	19	16	14
		20.10	PS	1050			24	106	269	202	159
		30.10	PS	63					1	12	18
	04	3.10	PS	126							
		23.10	PS	100				20	22	22	18
		24.10	PS	97				1	2	16	17
		24.10	PS	100					3	7	14
		7.11	PS	1091				45	250	275	193
		16.11	PS	200				8	22	35	41
		28.11	PS	100			1	6	6	8	16
		29.11	PS	100					3	7	8
		6.12	PS	100				1	2	1	7
		14.12	PS	100				3	14	11	12
	03	19.10	PS	131						8	23
		21.10	PS	71							
		21.10	PS	100							
1961	07	31.1.62	PS	100							6
		23.1.62	PS	100							
	06	16.12	PS	234							
		15.1.62	PS	90						1	—
	05	4.9	PS	99					4	23	28
		6.9	PS	100						5	22
		27.9	PS	99							2
	04	25.9	PS	100							
		25.10	PS	100						4	10
		22.11	PS	95	1	4	9	11	14	13	7
	03	20.9	PS	100							2
		22.9	PS	30							

9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
2	8	9	14	22	16	18	6	2	2	1		
		2	7	9	16	20	18	15	9	3	1	
	1	3	16	15	21	22	12	6	1	3		
37	25	21	11	2								
6	3	3	3	4	1							
122	55	45	32	19	8	8	1					
13	5	9	4	1								
3	7	22	43	35	11	3	1	1				
12	4	1	1									
24	13	8	6	6	4							
18	24	14	7	6	5	1	1					
113	55	60	36	34	20	10						
29	18	18	9	9	7	3	—	—	1			
15	11	14	14	7	2							
13	7	8	14	20	13	4	3					
7	16	32	23	11								
13	13	3	8	12	8	2	1					
43	38	10	6	2	1							
		5	20	26	19	—	—	—	1			
3	12	39	27	13	6							
22	26	18	13	7	6	1	1					
		3	12	17	21	12	6	9	13	6	1	
	1	22	27	17	18	33	59	29	13	7	4	4
3	4	6	1	9	7	17	15	17	7	3		
29	10	4	1									
54	14	3	2									
6	18	19	24	19	10	1						
	8	24	32	26	9	1						
21	17	18	7	9	5	5	2	—	2			
6	10	10	4	3	3							
7	13	30	24	14	6	4						
2	4	6	11	4	2	1						

Table III *(continued)*

Year-class	Area	Date	Gear	No.	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
1962	07	10.11	PS	100										
		20.11	PS	100										
		10.12	PS	318										
		12.12	PS	290										
		16.1.63	PS	100										1
		24.1.63	PS	100										
	05	21.9	PS	200					1	3	20	30	35	35
		25.9	PS	162						1	25	70	47	14
		27.9	PS	200				4	7	14	32	48	46	27
	04	28.9	PS	210				18	63	87	25	8	3	1
		29.9	PS	224				3	5	6	17	20	30	40
		29.9	PS	186				5	7	10	22	22	28	21
	05	17.9	PT	55		1	8	13	16	4	5	6	1	1
		21.9	PT	102					3	4	6	11	22	33
		23.9	PT	102				2	6	13	30	29	14	4
		22.10	PT	101					1	3	15	26	30	18
	04	17.9	PT	100		1	3	16	20	24	18	14	3	—
		17.9	PT	109		4	19	42	31	9	3	—	—	1
		2.10	PT	102			1	4	5	15	19	21	16	8
		2.10	PT	99				3	3	11	14	11	11	11
		3.10	PT	103	1	1	2	14	18	23	14	8	8	6
		3.10	PT	64		1	5	15	11	7	4	5	11	4
		11.10	PT	100				4	6	5	9	15	17	9
		25.10	PT	100				1	1	9	17	15	15	17
		26.10	PT	104						1	1	6	14	16
		30.10	PT	100					3	9	7	17	19	14
		31.10	PT	100			1	4	21	18	26	11	11	4
		8.11	PT	100						4	9	14	16	24
		22.11	PT	101				3	5	8	10	12	13	13
		23.11	PT	107			2	—	6	10	11	19	18	22
		5.12	PT	103				2	5	10	19	20	13	13
	03	7.9	PT	54					3	5	6	12	25	2
		13.9	PT	52					1	2	4	9	21	11
		5.10	PT	101				3	9	22	34	14	10	6
		5.10	PT	101			1	1	7	25	27	23	12	3
		5.10	PT	87						2	1	4	15	29
		8.10	PT	22				1	—	2	9	4	4	2
		2.11	PT	80				1	5	8	19	9	21	11
		3.11	PT	19							4	4	2	4
		1.12	PT	81							1	2	6	7

9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0
4	17	17	14	6	4	4	17	11	4	2			
	2	4	6	14	19	13	17	11	10	3	1		
		6	14	19	35	54	73	60	38	11	3	3	2
	5	9	27	33	37	42	47	48	28	10	3	1	
2	3	2	7	6	15	17	24	12	9	2			
		4	13	13	13	27	16	8	2	2	1	1	
27	22	19	7	1									
1	1	1	2										
13	7	1	1										
2	2	1											
38	42	21	2										
25	28	16	1	1									
17	5	1											
2	2												
8													
—	1												
4	4	4	1										
15	11	7	2										
4	2	1	1										
1													
15	9	7	4										
10	8	3	4										
18	20	20	8										
13	8	6	3	1									
1	1	2											
16	11	1	4	1									
13	9	7	5	1	1	1							
10	6	1	2										
6	4	4	4	2	1								
1													
4													
2	1												
1	1												
25	6	5											
3	3												
3	2												
21	18	13	5	5	2	1							

Table III (*continued*)

Year-class	Area	Date	Gear	No.	4.5	5.0	5.5	6.0	6.5	7.0	7.5
1963	05	5.9	PT	30						1	6
		4.10	PT	100							
		16.11	PT	101			1	5	4	6	11
	04	9.9	PT	100				1	—	5	7
		9.9	PT	84						2	7
		9.9	PT	109						3	6
		10.9	PT	101	1	38	40	17	3	—	1
		20.9	PT	106		1	14	42	21	12	12
		20.9	PT	75		4	3	11	7	2	3
		25.9	PT	34							
		26.9	PT	101					6	6	4
		12.10	PT	11							
		30.10	PT	50						3	2
		8.11	PT	102					2	11	9
		14.11	PT	97							
		15.11	PT	100					1	5	3
		20.11	PT	100					7	5	12
		4.12	PT	103				1	3	10	12
	03	18.9	PT	100							
		18.9	PT	51			3	4	4	4	2
		20.9	PT	100							
		15.10	PT	65					3	9	11
		11.12	PT	101						1	4

8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5
13	4	2	3	1							
	1	5	16	35	19	11	7	3	3		
22	14	11	8	9	2	3	3	1	1		
18	14	21	15	14	3	2					
8	11	27	15	11	2	1					
18	18	34	23	6	1						
—	1										
2	1	—	—	—	1						
5	11	9	8	4	4	2	2				
			1	3	12	12	3	3			
4	5	7	13	14	19	15	5	2	1		
		1	—	1	1	3	4	1			
5	2	5	4	8	5	6	6	2	1	1	
9	7	8	12	23	10	7	3	1			
	3	2	9	9	13	28	18	11	3	1	
1	5	13	15	21	16	13	5	2			
12	13	11	12	11	7	5	3	2			
10	9	6	6	10	11	11	7	5	1	1	
		6	29	30	28	7					
2	3	11	6	7	4	1					
10	22	24	27	15	2						
5	—	1	—	2	8	9	7	6	3	1	
2	3	4	14	20	19	18	8	5	2	1	

Table III (*continued*)

Year-class	Area	Date	Gear	No.	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
1964	04	9.9	PT	100				2	10	24	19	14
		10.9	PT	100			1	4	28	31	19	9
		21.9	PT	100					3	8	31	36
		21.9	PT	101				1	8	13	25	26
		27.9	PT	96				1	—	6	23	26
		28.9	PT	100					1	5	16	60
		9.10	PT	101	1	—	—	—	—	1	1	7
		9.10	PT	65								
		22.10	PT	52	1	6	1	1	2	7	10	14
		10.11	PT	53								
		12.11	PT	34							1	2
		18.11	PT	100			1	1	2	17	39	17
		18.11	PT	100					2	11	20	26
		18.11	PT	100							3	5
		20.11	PT	103								14
		10.12	PT	101			1	1	—	5	9	13
		11.12	PT	12								
		18.12	PT	100								2
	03	15.9	PT	100						6	23	26
		15.9	PT	100						7	25	17
		18.9	PT	101							5	26
		18.9	PT	101			1	2	7	20	23	21
		21–22.9	PT	100							4	6
		19.11	PT	22			1	—	—	—	—	3
		9.12	PT	102						2	14	32
	02	21.9	PT	29								
	10	13.9	PT	103					4	3	1	1
		14.9	PT	102				2	16	43	27	10
	13	11.9	PT	60						1	5	12
		22.9	PT	100					2	13	14	20
		23.9	PT	68					1	4	7	11
	12	9.9	PT	53					2	3	5	7
		10.9	PT	101							1	1
		23.9	PT	100			1	3	3	5	7	14
		24.9	PT	108					2	3	7	20
		26.9	PT	100				3	10	17	18	19

8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5
13	9	5	2	1	1						
4	2	1	—	—	1						
13	5	1	2	1							
13	8	5	1	1							
15	16	2	6	—	—	1					
17	1										
16	16	15	8	12	10	11	2	1			
1	1	2	1	7	10	20	13	9	1		
5	2	2	1								
	2	3	1	4	12	15	12	3	1		
3	1	1	4	4	3	8	4	3			
9	11	3									
16	14	3	4	3	1						
5	9	20	25	17	2	4	5	3	2		
20	16	14	5	12	8	6	7	—	1		
14	16	8	6	4	1	6	5	4	4	4	
					1	2	2	4	1	1	1
3	—	3	3	12	19	23	19	8	4	4	
14	7	8	9	3	4						
13	9	13	8	3	4	1					
41	15	7	4	2	1						
17	6	2	2								
14	24	12	21	10	5	3	1				
4	6	5	3								
24	8	7	4	2	3	2	1	1	1	1	
1	1	2	6	8	6	3	2				
4	26	32	19	8	4	1					
2	1	1									
29	13										
27	6	9	4	3	2						
15	12	8	2	3	4	—	—	1			
14	7	6	4	3	2						
1	7	15	27	24	22	3					
13	3	11	15	14	6	3	2				
29	13	12	10	8	3	1					
20	6	3	2	1	1						

Table IV. Analysis of variance of the data in Table III.

Area	Gear	Source of variation	Sums of squares	Degrees of freedom	Variance of estimate	F	Probability
					1959 year-class		
05, 04 and 03	PS	Between areas	10631.302	2	5315.651 (s^2_B)		
		Within areas	122725.400	25615	4.791 (s^2_W)		
		Between samples	19181.219	31	618.749 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	103544.181	25584	4.047 (s^2_w)		
		Total	133356.702	25617		$\frac{s^2_B}{s^2_b}$	<0.05
					1960 year-class		
05, 04 and 03	PS	Between areas	3024.802	2	1512.401 (s^2_B)		
		Within areas	21462.832	3892	5.515 (s^2_W)		
		Between samples	4563.484	14	325.963 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	16899.348	3878	4.358 (s^2_w)		
		Total	24487.634	3894		$\frac{s^2_B}{s^2_b}$	<0.05
07, 05, 04 and 03	PS	Between areas	12068.346	3	4022.782 (s^2_B)		
		Within areas	22768.419	4191	5.433 (s^2_W)		
		Between samples	4761.771	16	297.611 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	18006.648	4175	4.312 (s^2_w)		
		Total	34836.765	4194		$\frac{s^2_B}{s^2_b}$	<0.05
					1961 year-class		
05, 04 and 03	PS	Between areas	341.263	2	170.632 (s^2_B)		
		Within areas	3852.209	720	5.350 (s^2_W)		
		Between samples	1589.416	5	317.883 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	2262.793	715	3.165 (s^2_w)		
		Total	4193.472	722		$\frac{s^2_B}{s^2_b}$	>0.05

					1961 year-class		
07, 06, 05, 04 and 03	PS	Between areas	5563.961	4	1390.990 (s^2_B)		
		Within areas	7530.480	1242	6.063 (s^2_W)		
		Between samples	2486.318	7	355.188 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	5044.162	1235	4.084 (s^2_w)		
		Total	13094.441	1246		$\frac{s^2_b}{s^2_B}$	>0.05
					1962 year-class		
05 and 04	PS	Between areas	75.579	1	75.579 (s^2_B)		
		Within areas	6567.199	1180	5.565 (s^2_W)		
		Between samples	2373.214	4	593.304 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	4193.985	1176	3.566 (s^2_w)		
		Total	6642.778	1181		$\frac{s^2_B}{s^2_b}$	>0.05
05, 04 and 03	PT	Between areas	130.997	2	65.499 (s^2_B)		
		Within areas	16210.148	2446	6.627 (s^2_W)		
		Between samples	6826.211	25	273.048 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	9383.937	2421	3.876 (s^2_w)		
		Total	16341.145	2448		$\frac{s^2_B}{s^2_b}$	>0.05
07, 05 and 04	PS	Between areas	38258.607	2	19129.303 (s^2_B)		
		Within areas	11960.318	2187	5.469 (s^2_W)		
		Between samples	2908.844	9	323.205 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	9051.474	2178	4.156 (s^2_w)		
		Total	50218.925	2189		$\frac{s^2_B}{s^2_b}$	<0.05

Table IV (*continued*)

Area	Gear	Source of variation	Sums of squares	Degrees of freedom	Variance of estimate	F	Probability
					1963 year-class		
05, 04 and 03	PT	Between areas	858.072	2	429.036 (s^2_B)		
		Within areas	22565.678	1918	11.765 (s^2_W)		
		Between samples	11912.946	20	595.647 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	10652.732	1898	5.613 (s^2_w)		
		Total	23423.750	1920		$\frac{s^2_B}{s^2_b}$	>0.05
					1964 year-class		
04 and 03	PT	Between areas	205.966	1	205.966 (s^2_B)		
		Within areas	21332.571	2142	9.959 (s^2_W)		
		Between samples	12011.093	23	522.221 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	9321.478	2119	4.399 (s^2_w)		
		Total	21538.537	2143		$\frac{s^2_B}{s^2_b}$	>0.05
04, 03, 02, 10, 13 and 12	PT	Between areas	400.601	4	100.150 (s^2_B)		
		Within areas	27509.570	3063	8.981 (s^2_W)		
		Between samples	14636.416	31	472.142 (s^2_b)	$\frac{s^2_b}{s^2_w}$	<0.05
		Within samples	12873.154	3032	4.246 (s^2_w)		
		Total	27910.171	3067		$\frac{s^2_B}{s^2_b}$	>0.05

Table V. Mean length of 0-group herring of the 1959–1965 year-classes caught with pelagic trawl (PT), purse seine (PS) and Isaacs–Kidd ten foot midwater trawl (IKMT).

Year-class	Date of sampling	Area	Gear	No. of samples	No. of fish	Mean length in cm.	Standard deviation	Standard error
1959	28.9	06	PT	1	101	11.6	0.86	0.09
	6.10	05	PT	1	102	9.2	1.28	0.13
	1.10–16.11	05	PS	3	300	10.2	1.15	0.07
	13.10–27.11	04	PT	5	441	7.5	1.23	0.06
	8.10–2.12	04	PS	20	1993	9.7	0.35	0.01
	18.10–1.12	03	PS	11	1104	9.2	1.04	0.03
	16.10	02	Stomach content	1	9	7.8	1.25	0.42
	8.10	13	Stomach content	1	15	8.6	0.71	0.18
	12.10	15	Stomach content	2	24	8.1	1.42	0.29
1960	12–18.11	07	PS	3	300	11.6	1.04	0.06
	18–29.11	06	PS	2	106	9.8	1.01	0.10
	29.9–2.10	05	PT	2	56	8.5	1.04	0.14
	28–29.9	05	IKMT	5	359	7.3	0.70	0.04
	29.9–30.10	05	PS	4	362	8.4	1.08	0.06
	2.10–30.11	04	PT	5	217	8.4	1.28	0.09
	3.10–14.12	04	PS	10	1001	9.4	1.29	0.04
	10.10–11.11	03	PT	4	371	8.6	1.08	0.06
	19–21.10	03	PS	3	273	10.1	0.93	0.06
	14.10	02	PS	1	100	9.4	0.77	0.08
	13.10	10	PS	1	100	9.3	0.70	0.09
	13.10	13	PT	1	59	9.7	0.62	0.08
	12.10	15	PT	1	53	8.7	0.89	0.12
	22.9–5.10	20	PT	3	301	7.9	0.65	0.04
	21.9–8.10	20	IKMT	4	285	7.5	0.80	0.05
	7.10	20	PS	1	100	7.2	0.42	0.04

Table V (*continued*)

Year-class	Date of sampling	Area	Gear	No. of samples	No. of fish	Mean length in cm.	Standard deviation	Standard error
1961	13–23.1.62	07	PS	2	200	10.9	1.47	0.10
	16.12.61–15.1.62	06	PS	2	190	12.0	1.26	0.09
	4–27.9	05	PT	4	329	8.4	0.87	0.05
	4–27.9	05	PS	3	298	9.3	0.94	0.03
	24.9–21.11	04	PT	13	1229	8.5	1.34	0.04
	25.9–22.11	04	PS	3	295	9.6	1.46	0.08
	21.9–10.12	03	PT	8	726	8.8	1.33	0.05
	20–22.9	03	PS	2	130	10.3	0.75	0.07
	17–20.9	10	PT	4	101	9.2	0.90	0.09
	9–10.9	12 and 20	PT and PS	2	10	9.0	1.62	0.51
1962	10.11.62–16.1.63	07	PS	2	200	12.0	1.36	0.10
	21.12	06	PS	1	98	10.9	0.87	0.09
	17.9–22.10	05	PT	4	360	8.0	1.03	0.05
	21–27.9	05	PS	3	308	8.5	0.95	0.05
	17.9–5.12	04	PT	15	1492	8.1	1.40	0.04
	28–29.9	04	PS	3	302	8.2	1.37	0.08
	7.9–1.12	03	PT	9	597	8.3	1.12	0.05
	7.9	10	PT	2	108	8.1	0.59	0.06
	8.9	13	PT	1	99	7.8	0.75	0.08
1963	24.10–10.12	07	PS	3	302	11.5	1.27	0.07
	15.12	06	PT	1	99	10.0	1.29	0.13
	5.9–16.11	05	PT	3	231	9.5	1.44	0.09
	4.10	05	PS	1	100	9.7	0.96	0.10
	9.9–4.12	04	PT	15	1273	9.0	1.87	0.05

1963	27.9–13.11	04	PS	3	301	10.3	1.34	0.08
	18.9–11.12	03	PT	5	417	9.8	1.34	0.07
	20.9	10	PT	1	79	7.9	0.75	0.08
	5.8	12	PT	1	102	5.8	0.65	0.06
	24.9	20	PT	1	100	7.6	0.51	0.05
1964	7.12	07	PS	1	101	13.8	1.11	0.11
	30.10–3.12	06	PS	2	200	10.4	1.28	0.09
	1.10	05	PT	1	100	9.3	0.52	0.05
	9.9–18.12	04	PT	18	1518	8.7	1.73	0.04
	29.9	04	PS	2	200	9.2	1.06	0.07
	15.9–29.12	03	PT	7	626	8.3	1.11	0.05
	16–25.9	03	PS	2	200	10.0	0.72	0.05
	21.9	02	PT	1	29	10.3	0.82	0.15
	13–14.9	10	PT	2	205	8.0	1.34	0.09
	11–23.9	13	PT	3	228	8.2	0.95	0.06
	23.9	15	PT	1	20	8.3	1.05	0.23
	9–26.9	12	PT	5	462	8.7	1.34	0.06
	2.9	20	PT	1	46	7.8	0.64	0.09
	4–6.9	21	PT	2	40	6.7	0.57	0.09
1965	14.10–16.11	07	PS	3	298	12.6	1.62	0.09
	25–27.8	05	PT	2	161	6.4	1.35	0.11
	30.8	04	PT	2	258	5.1	0.39	0.02
	9–14.9	12	PT	2	47	8.8	1.24	0.18
	10–11.9	21	PT	2	96	6.6	0.76	0.08

Table VI. Mean annual length increments ($\bar{t}$ in cm) of herring (1959 year-class) collected in different regions in 1961–1965, s = standard deviation and $s/\sqrt{n}$ = standard error.

Region	Date		n	$\bar{t}_1$	s_1	$s_1/\sqrt{n}$	$\bar{t}_2$	s_2	$s_2/\sqrt{n}$	$\bar{t}_3$	s_3	$s_3/\sqrt{n}$	$\bar{t}_4$	s_4	$s_4/\sqrt{n}$
Off Vesterålen	1961	24.8–6.9	116	9.44	1.62	0.15	7.71	1.34	0.12						
Off Torsvåg		12–22.9	166	8.88	1.00	0.08	7.21	1.01	0.08						
Off North Cape		11–22.9	89	8.03	0.97	0.10	6.63	0.86	0.09						
Off eastern Finnmark		20.9	30	7.05	0.72	0.13	5.83	0.89	0.16						
Off eastern Finnmark	1962	18.2–6.3	32	7.64	1.00	0.18	5.63	1.02	0.18						
Off Iceland		21.7–14.9	100	8.82	1.30	0.13	7.11	1.01	0.10						
Off Torsvåg		18–29.9	237	7.69	1.20	0.08	6.22	0.98	0.06	4.38	1.19	0.08			
Off Finnmark		1.7–2.8	391	7.53	0.96	0.05	5.99	0.98	0.05	3.86	0.80	0.04			
Off eastern Finnmark		13.9–5.11	51	7.74	1.08	0.15	5.57	0.83	0.12	3.77	0.70	0.10			
Off Iceland	1963	29.7–14.8	102	9.16	1.41	0.14	7.39	1.18	0.12	6.66	1.54	0.15	4.40	1.21	0.12
Off Torsvåg		1–30.10	130	7.58	1.24	0.11	6.21	1.15	0.10	4.18	1.31	0.11	4.33	1.33	0.12
Off Møre	1964	17–20.2	107	9.46	1.15	0.11	6.84	1.19	0.12	5.92	1.68	0.16	4.75	1.33	0.13
Off Lofoten		2–4.3	106	8.17	1.10	0.11	6.46	1.02	0.10	4.94	1.64	0.16	4.81	1.31	0.13
Off Møre	1965	15.2	96	8.30	1.41	0.14	6.79	1.31	0.13	5.32	1.59	0.16	4.99	1.41	0.14
Off Lofoten		18–20.2	99	8.10	1.32	0.13	6.06	1.20	0.12	4.47	1.53	0.15	4.87	1.51	0.15

Table VII. Catch of 0- and I-group herring of the 1959 and 1960 year-classes landed by purse seiners in different areas.

Year-class	Month	Area	Catch in tons	No. of vessels
1959	November	05 and 04	6178	29
	December	05 and 04	5699	26
	January	05 and 04	2466	19
	February	05 and 04	887	12
	March	05 and 04	4	1
	April	05 and 04	262	4
	November	05, 04 and 03	6636	14
	December	05, 04 and 03	4330	13
	January	05, 04 and 03	4403	16
	February	05, 04 and 03	685	6
	March	05, 04 and 03	1647	10
	April	05, 04 and 03	1041	11
1960	December	05 and 04	7556	41
	January	05 and 04	6742	34
	February	05 and 04	2256	19
	March	05 and 04	689	7
	April	05 and 04	264	5
	December	05, 04 and 03	9728	23
	January	05, 04 and 03	11647	25
	February	05, 04 and 03	1612	17
	March	05, 04 and 03	580	4
	April	05, 04 and 03	1786	18

Table VIII. Catch and average weight of young and adolescent herring (1959 year-class) according to month and district.

Month	Møre and Romsdal, Trøndelag		Nordland		Troms		Finnmark	
	Catch in tons	Weight in g	Catch in tons	Weight in g	Catch in tons	Weight in g	Catch in tons	Weight in g
				0- and I-group				
October	11979	11	13982	9	1963	7	2310	5
November	14579	11	19275	9	5289	7	20108	5
December	303	11	10123	9	10946	7	14527	5
January	313	11	3595	9	10072	7	15173	5
February	—	—	237	9	3155	7	1567	5
March	44	13	59	9	487	7	9072	5
April	1373	16	458	11	424	9	4487	6
				I- and II-group				
May	9693	22	2744	15	3395	13	4797	7
June	7045	32	1962	23	399	18	2816	9
July	1280	43	1148	34	716	24	8698	11
August	8986	57	764	46	59	34	1447	16
September	3667	63	1088	48	3	40	—	—
October	2552	66	3987	49	146	43	—	—
November	3437	67	1990	49	1309	44	3795	21
December	1324	67	495	49	1401	44	8075	21
January	937	67	2141	49	1453	44	7616	21
February	56	67	776	49	556	44	1898	21
March	1	68	104	49	109	44	1137	21
April	345	73	296	50	270	44	2052	22
				II- and III-group				
May	3429	82	309	53	573	45	947	24
June	3523	91	395	63	749	47	14702	29
July	1798	101	176	77	368	57	35997	34
August	1800	112	4421	93	309	76	38	41
September	526	123	3263	98	69	90	50	47
October	759	132	6393	99	1682	96	18	51
November	749	138	2943	100	1013	99	46	53
December	961	140	1444	100	514	100	13	54
January	161	140	1621	100	340	100	—	—
February	15	140	254	100	37	100	—	—
March	22	140	28	100	—	—	—	—
April	60	140	5	100	—	—	—	—

Table IX. Catch and average weight of young and adolescent herring (1963 year-class) according to month and district.

Month	Møre and Romsdal, Trøndelag		Nordland		Troms		Finnmark	
	Catch in tons	Weight in g	Catch in tons	Weight in g	Catch in tons	Weight in g	Catch in tons	Weight in g
				0- and I-group				
October	6220	11	1673	9	1316	7	449	5
November	4248	11	11031	9	9051	7	1770	5
December	1303	11	1606	9	374	7	386	5
January	563	11	4018	9	261	7	7	5
February	—	—	—	—	—	—	—	—
March	—	—	—	—	—	—	—	—
April	—	—	161	11	—	—	—	—
				I- and II-group				
May	1199	22	934	15	1039	13	506	7
June	2103	32	1120	23	837	18	235	9
July	1300	43	583	34	204	24	8	11
August	1071	57	726	46	11	34	—	—
September	854	63	1374	48	3	40	—	—
October	1120	66	4552	49	322	43	—	—
November	1429	67	3868	49	856	44	1409	21
December	524	67	834	49	261	44	2814	21
January	173	67	338	49	171	44	2663	21
February	35	67	—	—	—	—	—	—
March	222	68	—	—	—	—	—	—
April	259	73	44	50	1	44	—	—
				II- and III-group				
May	6664	82	1486	53	1019	45	615	24
June	1898	91	1482	63	711	47	5315	29
July	1787	101	4714	77	1150	57	38480	34
August	1716	112	7934	93	832	76	19154	41
September	718	123	3535	98	2664	90	5953	47
October	1106	132	1162	99	108	96	1346	51
November	563	138	825	100	11	99	363	53
December	219	140	162	100	—	—	23	54
January	—	—	—	—	—	—	—	—
February	—	—	—	—	—	—	—	—
March	—	—	—	—	—	—	—	—
April	47	140	2	100	—	—	—	—

Table X. Catch and average weight of young and adolescent herring (1959 year-class) according to month and district.

Month	Møre and Romsdal, Trøndelag		Nordland		Troms		Finnmark	
	Catch in tons	Weight in g	Catch in tons	Weight in g	Catch in tons	Weight in g	Catch in tons	Weight in g
				III- and IV-group				
May	57	141	357	100	—	—	—	—
June	57	143	2439	101	141	101	8059	55
July	21	147	232	103	227	102	58948	56
August	27	157	9955	108	235	104	3543	62
September	11	172	7852	113	1173	107	—	—
October	11	199	9606	123	954	112	—	—
November	60	199	2974	131	391	117	—	—
December	14	199	1858	131	8	117	—	—
January	—	—	904	131	—	—	—	—
February	—	—	303	131	—	—	—	—
March	—	—	149	131	—	—	—	—
April	8	199	859	131	—	—	—	—
				IV- and V-group				
May	45	199	999	140	13	123	—	—
June	99	200	643	155	6312	135	7426	85
July	74	200	6277	180	1506	160	9245	90
August	113	200	3751	200	13	180	275	100
September	48	200	238	200	22	200	11	120
October	43	200	356	200	655	200	1121	140
November	39	200	332	200	—	—	60	140
December	19	200	20	200	18	200	—	—
January	3	200	12	200	—	—	44	140
February	—	—	—	—	—	—	—	—
March	—	—	—	—	—	—	—	—
April	249	200	2951	200	—	—	—	—
				V-group				
May	—	—	33	200	7	200	—	—
June	—	—	49	200	4	200	—	—
July	—	—	67	200	1	200	—	—
August	—	—	79	200	2	200	—	—
September	—	—	—	—	—	—	—	—
October	—	—	—	—	—	—	—	—
November	—	—	—	—	—	—	—	—
December	45	225	305	200	155	200	—	—

Table XI. Catch and average weight of young and adolescent herring (1963 year-class) according to month and district.

Month	Møre and Romsdal, Trøndelag*		Nordland*		Troms		Finnmark	
	Catch in tons	Weight in g	Catch in tons	Weight in g	Catch in tons	Weight in g	Catch in tons	Weight in g
				III- and IV-group				
May	195	141	8	100	—	—	660	54
June	97	143	29	101	—	—	9972	55
July	24	147	37	103	1	102	34656	56
August	26	157	18	108	8	104	27557	62
September	14	172	16	113	3	107	16943	72
October	16	199	27	123	12	112	6	79
November	24	199	7	131	—	—	—	—
December	5	199	—	—	—	—	—	—
January	—	—	—	—	26	117	12	81
February	—	—	—	—	—	—	—	—
March	—	—	—	—	—	—	—	—
April	—	—	—	—	—	—	19778	81
				IV- and V-group				
May					2	123	3046	83
June					22	135	7998	85
July					6	160	10312	90
August					11	180	8655	100
September					431	200	1426	120
October					520	200	606	140
November					207	200	323	140
December					20	200	105	140
January					—	—	—	—
February					—	—	—	—
March					—	—	—	—
April					—	—	—	—
				V-group				
May					—	—	8380	140
June					—	—	41900	140
July					—	—	41900	140
August					6	200	29330	140
September					30	200	—	—
October					30	200	—	—
November					—	—	—	—
December					—	—	—	—

* Data incomplete.

Table XII. Estimated annual yields which might have been obtained from the 1959 and 1963 year-classes by refraining from fishing 0- to III-group herring, and by starting the exploitation at six years of age (calculated from 1 January). $M_1 = 2.76$, $M_2 = 1.38$ and two alternative values of $M_3 = M_4 = M_5 = M_6$, i.e. 0.16 and 0.24 have been used to estimate N_6. Average values of $E = 0.64$ and $Z = 0.44$ are used for the period of exploitation (ANON. 1969).

Year	Average weight in g	Alternative 1			Alternative 2		
		No. by 1 Jan. $\times 10^{-6}$ N_n	Catch in no. $\times 10^{-6}$ C_n	Catch in thousands of metric tons	No. by 1 Jan. $\times 10^{-6}$ N_n	Catch in no. $\times 10^{-6}$ C_n	Catch in thousands of metric tons
1965	225	3959	902	203	2970	677	152
1966	242	2550	581	141	1912	436	105
1967	293	1642	374	110	1232	281	82
1968	302	1058	241	73	793	181	55
1969	317	681	155	49	511	116	37
1970	321	439	100	32	329	75	24
1971	334	282	64	21	212	51	17
1972	341	182	41	14	136	31	11
1973	364	117	27	10	88	20	7
1974	388	75	17	7	57	13	5
1975	388	49	11	4	36	8	3
1976	388	31	7	3	23	5	2
1977	388	20	5	2	15	3	1
Total		11085	2525	669	8314	1897	501
1969	225	1998	455	102	1514	345	78
1970	242	1287	293	71	975	222	54
1971	293	829	189	55	628	143	42
1972	302	534	122	37	404	92	28
1973	317	344	78	25	260	59	19
1974	321	221	50	16	168	38	12
1975	334	143	32	11	108	25	8
1976	341	92	21	7	70	16	5
1977	364	59	13	5	45	10	4
1978	388	38	9	3	29	7	3
1979	388	25	6	2	19	4	2
1980	388	16	4	1	12	3	1
1981	388	10	2	1	8	2	1
Total		5596	1274	336	4240	966	257