FISKERIDIREKTORATETS SKRIFTER
Serie Havundersøkelser
(Report on Norwegian Fishery and Marine Investigations Vol. VI, No. 8)

Published by the Director of Fisheries

Quantitative Investigations on Herring Spawning and its yearly Fluctuations at the West Coast of Norway

By
SVEN RUNNSTRÖM

1 9 4 1

A.s John Griegs Boktrykkeri, Bergen

CONTENT

INTRODUCTION.

For centuries huge herring masses have immigrated to the west coast of Norway in order to spawn on the coastal banks. They appear in a very regular manner in the first month of the year and remain in the coastal region for two or three months when they again emigrate into the open sea. During the spawning time a rich spring herring fishery takes place on the coastal banks. This fishery has, however, shown great fluctuations and in the same manner as in the Bohuslen fishery periods occur when the herring fishery in the usual places has entirely failed for years. But also in periods of rich fishery there are great fluctuations from year to year.

It was natural to explain the failure in the fishery by supposing that the herring in such periods do not visit the usual fishing places but migrates to other areas, and already AXEL BOECK (1871) has discussed the question, whether the herring in certain years may spawn on the North Sea banks. The swedish investigators G. EKMAN and O. PETTERSSON (1891), who have studied the causes of the fluctuations of the Bohuslen herring fishery, came to the conclusion that the herring migrations are related to fluctuations in the current system of the sea. They found that the immigration of the winter herring into the fjords of the swedish west coast was dependent on the presence of Bank water. When the Bank water disappeared from Skagerak and was replaced by other water masses the herring also disappeared from the coast. In cooperation with the swedish investigators JOHAN HJORT started similar hydrographical observations at the west and south coast of Norway in order to study the influence of the current system upon the herring fishery and published a report on this subject in the year 1895.

When one, however, had learnt to determine the age of the common foodfishes by means of the winter rings on the scales, the norwegian program of work was mainly concentrated on the possibilities opened to utilize this discovery in a similar way as in the science of human vital statistics. In the period 1901—1914 HJORT and his colleagues SUND und LEA tried to follow up this program in the study of the stock

of cod and herring in the norwegian waters. It was found that the stocks of cod and herring include a far greater number of year classes than had been supposed, and that the relative strengths of these year classes exhibit great fluctuations from year to year. HJORT (1914) is of the opinion that the fluctuations of the year classes is to be considered as a predominating factor determining fluctuations in the fisheries, and he considered age investigations alone as sufficient to elucidate these fluctuations, at least those occurring in the period investigated. These studies have also been of great importance but on the other hand the study of the migrations of the herring based on racial investigations and on direct observations of the spawning conditions were somewhat neglected.

In the years 1931—1937, when I was in charge of the herring investigations of the Fisheries directorate in Bergen, I was interested in studying the last mentioned problems. The results of the racial investigations have been published in an earlier paper. The present report will treat biological and hydrographical observations made in the spawning areas in the years 1931—1937. Even if the great work laid down on these observations have not given new views on the problem of the relation between the spawning immigration and the hydrographical conditions, it may be of interest to give a more detailed description of what occurs on the spawning grounds and of the imposing biological phenomenon which takes place at the west coast of Norway every spring.

The investigations could be carried out due to grants from the Research Fund of the Fisheries Industries. This report is the last one based on my work at the Fisheries directorate and I therefore wish to express my thank to the Director of fisheries and to my former colleagues for a series of good working years.

THE WINER HERRING FISHERY AND ITS FLUCTUATIONS DURING THE PERIOD INVESTIGATED.

The winter herring appears at the present time at the west coast of Norway about Christmas time and the fishery then takes place during the months January, February and March. The herrings which appear in the beginning of the season have hard roe and milt and are not ready to spawn. This herring is called »large herring«. At first, in the beginning of February the roe and milt running, and this spawning herring is now called spring herring. As shown in an earlier paper one can clearly distinguish a large herring period in December-January and a spring herring season in February—March with a strong fall in the fishery in the intermediate time.

The winter herring fishery takes place at the west coast from the Trondheim fjord in the north to Lista in the south (compare fig. 1). As shown in a previous paper one can distinguish three regions along the coast: 1. The region between Trondheim and Stat which formerly was the main large herring district. The large herring fishery is now, however, reduced and the main fishery takes place in the spring herring season. 2. The region between Stat and Bergen where at present the main large herring fishery takes place while the spring herring fishery is very unimportant. 3. The region between Bergen and Lista which always has been the main spring herring district. The herring appears here immediately before the spawning begins, and a large herring fishery never takes place in the same manner as in the two other regions.

Thus the southernmost region represents the most important spawning district but spawning also takes place in the northernmost region, while no spawning of importance takes place in the intermediate area which is a pronounced large herring district. As shown in my racial studies the great masses of large herring which appear in December—January are not identical with the spring herring which spawns later in the season in the southern district. The large-herring do not spawn at all on the Norwegian coastal banks but dissappear from the coastal waters before the spawning season begins.

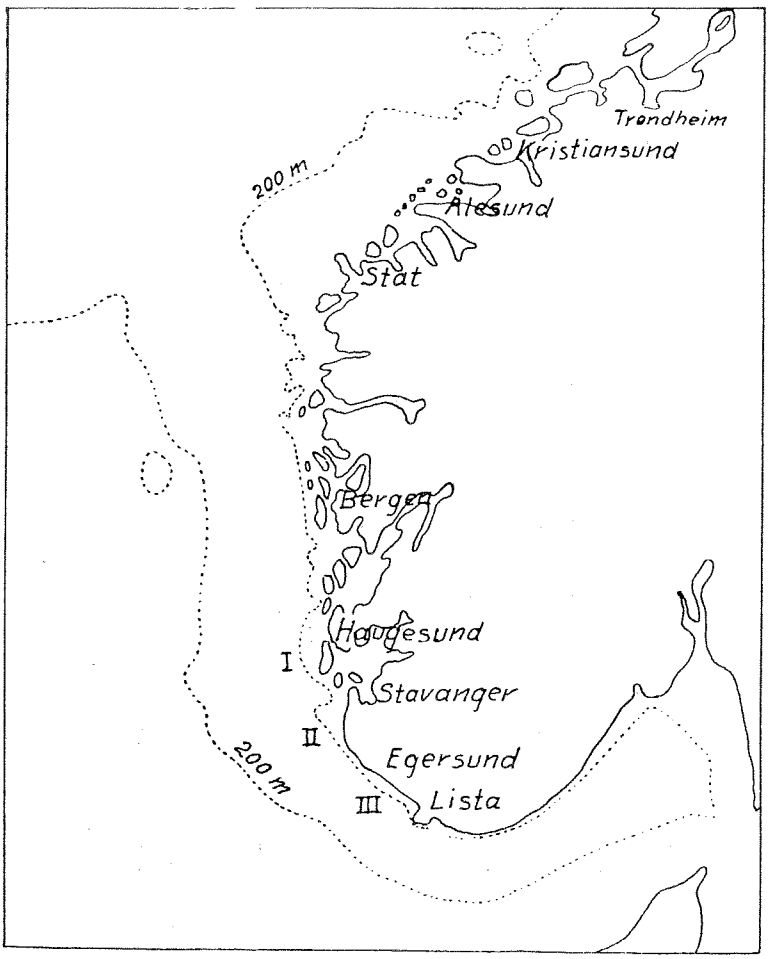

Fig. 1. Areas investigated with bottom grab, area I every year from 1931 to 1937, areas II and III from 1932 to 1937 except in 1933.

In my paper on the racial studies I have given a more detailed description of the fluctuations in the winter herring fishery during the two last great herring periods, and I will here only give a short recapitulation. In 1874 the spring herring almost entirely disappeared from the coastal waters for a serie of years. Then the spring herring gradually returned to the usual spawning grounds at the south west coast but the quantities caught in the first years were very small. In 1897 large herring suddenly appeared off the Møre coast north of Stat, and when the fishermen had learnt to catch the herring by means of drift nets in the open sea, a rich large herring fishery was developed in the northern district. Since the year 1929 very great large herring masses have visited the region

Stat—Bergen which now is the main large herring district. In Table 1 are shown the increased catches during the period 1901—1937. In the period 1901—10 the average catch was less than 1 million hl but in the two following 10-years periods more than 2 millions hl were caught and in the period 1931—37 the average catch was more than 3 millions hl. This last great increase is due to the strong development of the large herring fishery between Bergen and Stat which has in the last years reached the same average quantity as the spring herring fishery, this the last fishery predominating in earlier years.

Table 1. *Average yearly catch of winter herring (1000 hl).*

	Large herring	Spring herring	Total
1901—10	211	691	902
1911—20	699	1.510	2.209
1921—30	662	1.631	2.293
1931—37	1.680	1.780	3.460

As regards the distribution of the fishery along the west coast table 2 shows that the average catch in the period 1931—37 was 0,6 mill. hl in the district Trondheim—Stat including about 25 % large herring. In the region Stat—Bergen was caught 1,5 mill. hl including almost exclusively large herrings, while in the southern springherring district the catch was 1.3 mill. hl spring herring. Thus the main spawning apparently occurs in the southern district while the northern spawning district seems to be of far less importance.

According to the different character of the large and spring herring fishery the methods of fishing are somewhat different. The spring herring was in earlier time almost exclusively caught on the spawning grounds proper by means of bottom nets and land seines close to the coast. When the large herring appeared in the open sea off the Möre coast in the nineties they could not be caught by means of the usual fishing gears, and a drift net fishery was developed and in 1905 the purse seine also was introduced in the Norwegian winter herring fishery. Herrings on migration are thus caught by means of drift nets and purse seines, and when coming near to the shore with land seines. When the herrings have entered the spawning grounds and occur here close to the bottom,

they are caught with bottom gill nets. The last-mentioned method is therefore still predominating in the southern spring herring district while the other methods play a greater rôle in the large herring fishery as shown in table 2. The drift net and bottom net fishery are not separated in the reports but the net fishery in the southernmost district includes almost exclusively bottom nets while the drift nets are predominating in the two more northern districts.

The fluctuations in the fishery in the period 1931—37 is demonstrated in table 2. The last column contains the yearly catches from the whole winter herring fishery. With the exception of 1934 when stormy weather during long periods hindered the fishery, the yearly catches have exceeded 3 mill. hl. In 1935 the total catch increased to 4.2 mill. hl and in 1936 the greatest yearly catch in the history of the winter herring fishery (5.3 mill hl) was landed. These figures are, however, not representative for the spring herring fishery in the southern spawning district as the best spring herring fishery took place in the year 1932 when 2 mill. hl were caught while in the year 1936 the fishery in the southern district was rather ordinary and the huge total catch was due to an extraordinary rich large herring fishery in the northern districts. Thus the fluctuations of large- and spring herring fishery do not coincide which is natural as we now know that these two kinds of herring represent separate stocks.

As already mentioned in the introduction the numerical strength of the herring stock fluctuates very much owing to rich and poor broods. The variations in the number of individuals belonging to a year class of the spawning stock is determined by recruitment from the young herring stock and by death through fishery or other causes. The recruitment mainly takes place at an age of 3—6 years and in this time the increase of the stock is mostly greater than the decrease. From an age of 7 years when all the individuals of the year class have joined the spawning stock there is only decrease through death. We know the main rules for the decrease and increase of the Norwegian spawning stock due to LEA'S (1930) investigations and it is possible to estimate the relative strength of the stock from year to year. In the years 1908—10 the spring herring stock increased strongly owing to the immigration of the rich year class 1904. In the following years no important recruitment from rich year classes took place and in 1921 the stock had reached a very low level. In the years 1922—24 again a strong increase took place owing to the immigration of the year class 1918 but thereafter the stock decreased until the years 1928—29. when the rich year class 1923 appeared. Since the year 1929 the recruitment has not been large enough to compensate the loss by death, the stock gradually declining

Table 2. *Yearly catch of winter herring in the period 1931—37 (hl).*

Year	Gear	Districts			Grand Total
		Trondheim—Stat	Stat—Bergen	Bergen—Lista	
1931	Nets	529.423	61.900	695.600	
	Purse seines	235.074	920.000	252.500	
	Land seines	—	417.500	32.500	
	Total	764.497	1.399.400	980.600	3.144.497
1932	Nets	147.253	69.500	1.300.500	
	Purse seines	271.257	593.500	536.500	
	Land seines	—	409.900	169.600	
	Total	418.510	1.072.900	2.006.600	3.498.010
1933	Nets	199.153	145.500	704.500	
	Purse seines	261.740	618.000	582.000	
	Land seines	—	637.000	113.000	
	Total	460.893	1.400.500	1.399.500	3.260.893
1934	Nets	224.160	22.200	522.800	
	Purse seines	3.140	107.000	178.000	
	Land seines	—	17.100	12.900	
	Total	227.300	146.300	713.700	1.087.300
1935	Nets	337.711	162.500	1.097.500	
	Purse seines	105.018	1.283.900	489.100	
	Land seines	—	566.200	229.300	
	Total	442.729	2.012.600	1.815.900	4.271.229
1936	Nets	542.557	197.500	967.000	
	Purse seines	487.808	1.875.600	154.400	
	Land seines	362	1.119.750	7.250	
	Total	1.030.727	3.192.850	1.128.650	5.352.227
1937	Nets	661.938	316.000	1.011.000	
	Purse seines	273.542	937.400	191.600	
	Land seines	—	151.600	48.400	
	Total	935.480	1.441.000	1.251.000	3.627.480
Average 1931—1937	Nets	337.456	139.300	899.843	
	Purse seines	233.940	910.200	340.587	
	Land seines	52	474.150	87.564	
	Total	611.448	1.523.650	1.327.994	3.463.092

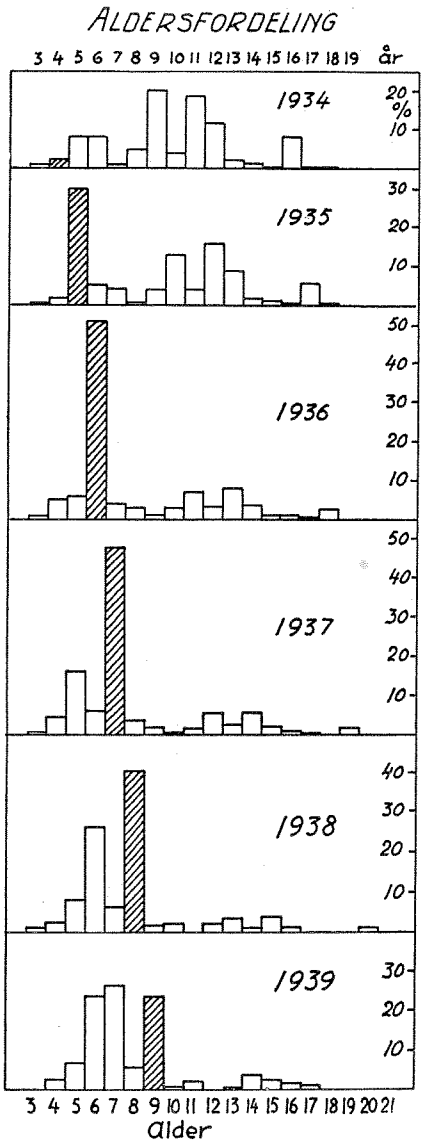

Fig. 2. Percentage age distribution of Norwegian winter herring 1934—39. (»Alder« — age).

until 1934, when the stock had reached a low level similar to that of the year 1921. In the years 1935 and 1936 however the stock was increased considerably due to the appearence of the year class 1930 as demonstrated in fig. 2. This year class is calculated to be the richest next to the year classes 1904 and 1918 and is quite predominating in the catches. Also the year class 1932 seems to be rather rich and has in the year 1937 compensated the loss from the older year classes.

When the fluctuations of the stock are compared with the yearly catches of spring herring in the southern district in 1931—37 it is found that the good spring herring fishery in 1935 may be explained by the immigration of the new rich year class 1930. The very rich fishery in the year 1932, more than twice as great as that of 1931, can, however, hardly be explained in this way as we know that the stock was decreasing until 1934. Likewise we might expect an increase in the catch from 1935 to 1936 but this did not happen. Thus the fluctuations of the stock do not entirely explain the fluctuations of the fishery.

On the other hand the quantity of herring caught does not always give a true information of the relative amount of herring really present in the spawning area. This paper will try to give a better estimate of the herring masses present on the spawning grounds according to an investigation of the quantity of roe deposited on the bottom.

THE AREA INVESTIGATED, METHODS AND MATERIAL.

As already mentioned it was of interest to get a method of estimating the real extent of the herring masses present on the spawning grounds in the different years. For that reason it was my intention to investigate the distribution and the quantity of herring roe deposited on the spawning banks. The investigation was then at first restricted to the main spawning area in the Haugesund district from Bømmelen to Kvitsøy, the area indicated by section I on the map in fig. 1. This area was investigated every year from 1931 to 1937. In the second year, 1932, the investigation was extended to include also the sections II and III, from Stavanger to Lista, and these areas were afterwards visited in the following years with exception of 1933. In the year 1932 also some preliminary observations were made in the northern spawning district north of Stat and in the years 1934 and 1935 the whole area between Stat and Kristiansund was investigated. In the year 1936 only the southern part of this area was visited.

Thus areas of very great extent were investigated, the distance from Kristiansund to Stat being about 160 km, from Bømmelen to Kvitsøy about 100 km and from Kvitsøy to Lista about 100 km, thus in all about 360 km. When however the lines along which the sampline was done are included the distances are calculated to 475, 300 and 200 km respectively, thus in all nearly 1000 km.

It was intended to cover the different spawning grounds with a net of stations as evenly distributed as possible. The places where bottom grab hauls were made are indicated in the figs. 3—5. The situation of the stations was about the same in the different years. However the number of stations varies somewhat from year to year according to the size of the area investigated as shown in table 3. On an average 320 stations were taken yearly in the southern district and about 230 stations in the northern district Stat—Kristiansund. In 1937 when the whole program was realized, 409 stations were taken in the southern district and the spawning grounds investigated had an area of about 425 km^2. Thus each station represented an area of about 1 km^2. The

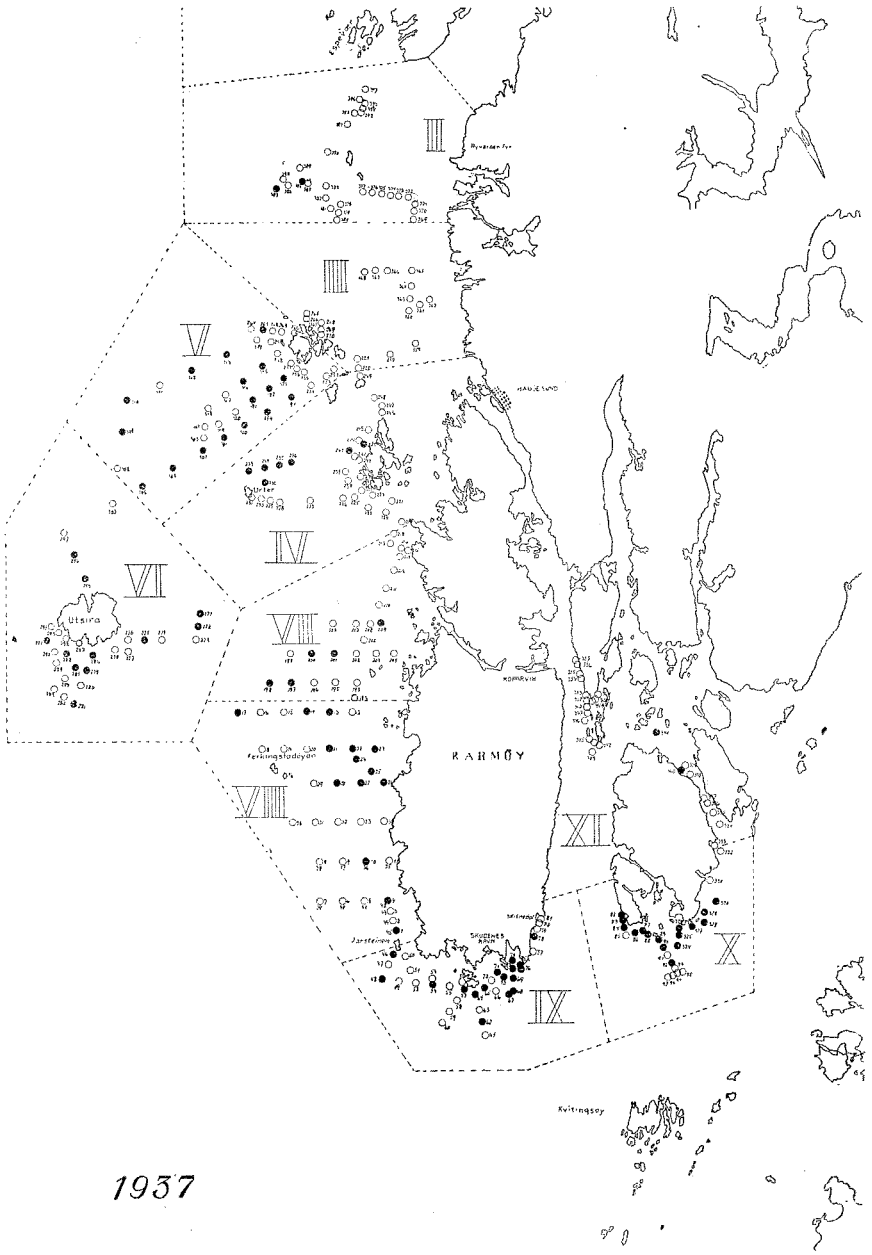

Fig. 3. Bottom-grab stations 1937 on the spawning grounds in the Karmøy—Utsira—Haugesund area. Black dots denote finds of herring roe, open circles negative hauls.

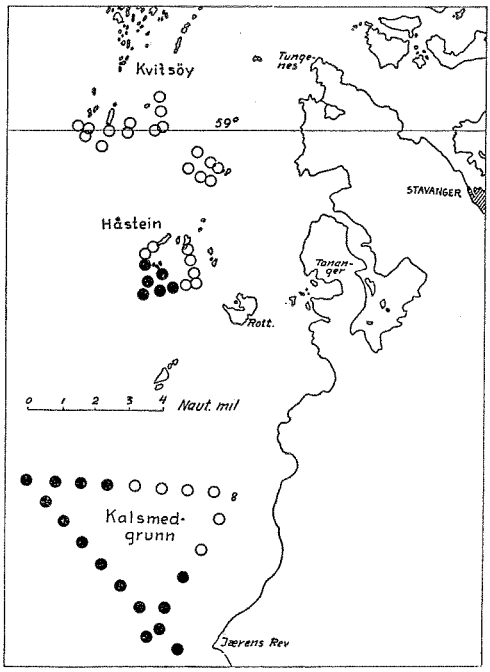

Fig. 4. Grab stations in the Kvitsøy—Jæren area (near Stavanger) in 1937. Signs as in fig. 3.

number of stations was limited by the time at disposal as the investigations had to be ended before the eggs were hatched. The number of actual working days was also often strongly restricted by the winter storms in these rather exposed areas. It might perhaps, have been more advantageous to investigate an area of less extent more thoroughly, but on the other hand it was thought to be of interest to compare the immigration to the different spawning grounds.

Already BOECK (1871) and later J. HJORT (1895) had by means of a dredge found, that herring roe may cover the bottom in thick layers. LEA made in the years 1928 and 1929 some preliminar observations on the occurrence of herring roe by means of a bottom grab. His results encouraged the following up of this line. By means of the bottom grab one gets far more exact knowledge about depth, bottom conditions and quantity of roe.

The bottom grab used was that constructed by PETERSEN with an opening of 0.1 m^2. Herring roe was obtained in a satisfactory manner on sandy as well as on hard bottom. When no roe was found in the grab the haul was commonly repeated one or two times at the same spot. On an average herring roe was taken at every third of all the

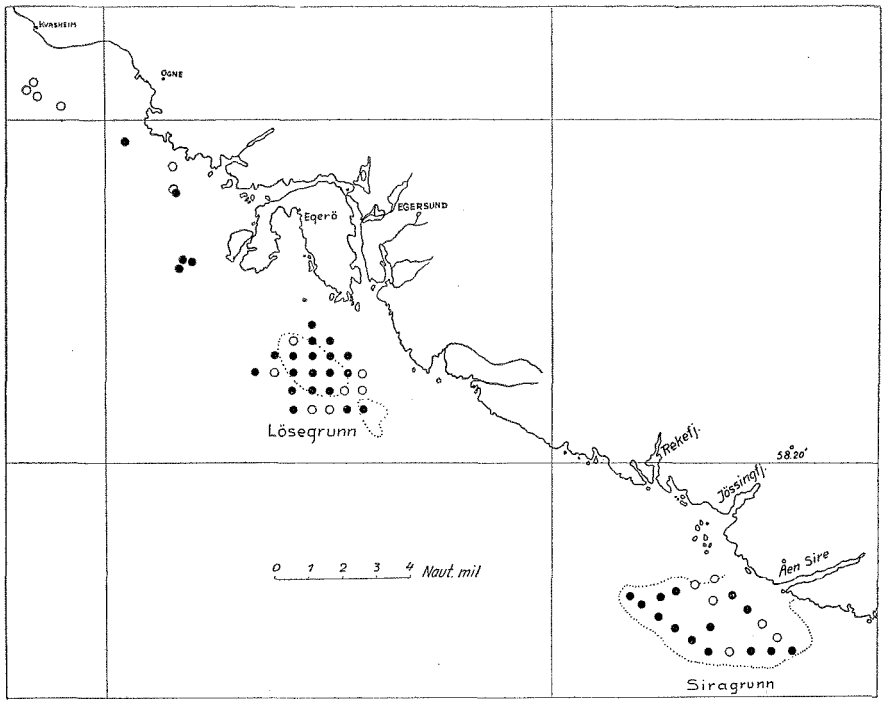

Fig. 5. Grab stations near the S limit of the Spring herring district, off the S part of Jæren. Signs as in fig. 3.

stations in the southern district while the roe occurred much more scantily in the northern district, in the year 1935 only at 29 out of 231 stations. The quantity of roe varied from a few eggs to thick flakes in the different hauls.

The herring roe from each station was put into glasses with formaline and was examined later in the laboratory. The volume (ccm) of the roe was measured in a cylinder glass, the number of dead eggs counted and the stage of development of the eggs determined according to a scheme worked out by means of hatching experiments. In this manner also the age of the eggs could be determined in days and thus also the date of the spawning. For each season the stations were plotted on a map and each station was considered to represent a rectangular area, the sides of which was determined by half the distances to the adjacent stations. As the quantity of roe pr. m^2 was known, the quantity in the whole area represented by the station could be calculated.

According to measurements a female herring contains about 20 000 eggs corresponding to a volume of 50 ccm. One liter roe thus corresponds to 20 females. As the males and females are present in about equal

Table 3. *Number of bottom grab stations.*

Area	1931		1932		1933		1934		1935		1936		1937		Total	
	whole no.	with roe	whole no.	with roe	whole no.	with roe	whole no.	with roe	whole no.	with roe	whole no.	with roe	whole no.	with roe	whole no.	with roe
I	—	—	12	2	—	—	10	—	—	—	32	9	25	6	79	17
II	19	8	20	8	17	—	28	5	28	—	28	6	29	2	159	29
III	17	8	25	9	12	—	9	3	16	1	24	6	20	0	123	27
VI	19	6	29	9	16	2	16	1	30	2	27	1	30	7	167	28
V	28	11	25	12	15	8	18	10	29	6	30	10	37	17	182	74
VI	37	15	38	7	27	17	28	8	28	11	28	3	28	11	214	72
VII	5	—	20	7	30	13	26	8	25	12	28	11	25	5	159	56
VIII	28	9	45	15	34	6	36	17	34	15	34	12	34	14	245	88
IX	39	18	33	15	52	16	30	9	36	23	36	0	36	17	262	98
X	7	2	19	14	26	10	9	2	21	14	—	—	26	16	108	58
XI	22	3	17	2	15	4	—	—	—	—	24	0	24	2	102	11
XII	—	—	47	14	—	—	—	—	51	21	36	9	49	7	183	51
XIII	—	—	17	7	—	—	9	0	37	24	31	17	26	15	120	63
XIV	—	—	31	12	—	—	37	4	20	14	21	7	20	—	129	37
Total	221	80	378	133	244	76	256	67	355	143	379	91	409	119	2232	709

numbers, one liter of roe corresponds to 40 spring herrings. In this manner the number of spawning herring present in a certain area was estimated. In order to compare the quantity of herring present in a certain area with the quantity caught in the same area, the quantity was calculated in hectoliters of herring. One hectoliter spring herring contains about 400 individuals and thus 1 liter herring roe corresponds to 0.1 hl. spring herring. The number of herring in one hl will of course to a certain degree depend on the size of the herrings and in years with a rich immigration of recruit spawners there will be a somewhat greater number in one hl. This error in the calculation will however be compensated by the fact that smaller herrings also deposit a lesser quantity of roe.

In the year 1937 the herring masses were also directly localized by means of echo sounding as will be reported in a later section.

During the spawning season a series of hydrographical sections was taken in different coastal areas and across the Norwegian Deep. Also a great number of plancton hauls were made. In the years 1935—37 the hydrographical investigations were extended to include four sections across the northern North Sea from the Norwegian coast to Scotland and Shetland. The great hydrographical material has been worked up by the hydrographical laboratory of the Directorate under the direction of Mr. J. EGGVIN, who also has published a preliminary report on the North Sea material (1937). The hydrographic sections from 1937 given in the present report in fig. 19—24 have been drawn up by Mr. KJELSTRUP OLSEN, these figures also having been used by EGGVIN in his paper on »the movement of a cold water front« (1940).

The cruises in the spawning districts and in the North Sea have been carried out with the M/S Armauer Hansen which was hired from the Geophysical Institute in Bergen. I am much indepted to captain SYNNES, the navigator on »Armauer Hansen«, for his great interest in carrying out the program of work at sea. Also Mr. P. O. SOLEIM, who assisted me in the work on board as well as in the laboratory, I thank very much for his valuable help. Mr. SOLEIM has in a report (1940) treated some of the plancton material collected on the cruises and he has also given a short report (1940) on the spawning grounds along the West Coast based on our observations.

LOCALIZATION OF THE SPAWNING GROUNDS ALONG THE WEST COAST.

As shown in fig. 1 one finds along the Norwegian coast a coastal shelf limited by the 200 m-line. Off the Møre coast (north of Stat) the coastal shelf has a great extension seawards which ends with a steep slope towards the great depths of the Norwegian Sea. At the south west coast the shelf is separated from the North Sea plateau by the Norwegian Deep. Within the sehlf one finds more or less isolated shallower banks with rocky or sandy bottom separated by deeper channels with soft bottom. These banks form favourable spawning grounds for the herring and I will in the following give a short description of the different spawning areas localized by means of grab sampling. Beginning with the southern Spring Herring District this region may be divided into 14 more or less separated spawning areas as demonstrated in the fig. 3—5.

I. *Slotterøy—Espevær* is the northernmost spawning area of importance. This area forms a continuous bank along the western coast of the Bømmeløy and is in the north limited by the Selbjørns fjord and in the south by the Bømmel fjord. Here are many small islands as Hisken, Lyngø, Holsøyerne and Nordøyerne. Herring roe has been found in depths from 30 to 145 metres but not every year. The spawning area is estimated at 20 km^2.

II. *Sletta.* There is rather open water between Espevær and Haugesund, only protected by a small group of islands. We find here a rather extensive tongue-like bank limited by the 100 m-line and separated from the northern area by a deep hollow, Gunnarskjærhullet. In the south the bank is separated from Røvær also by a deep channel. Herring roe was found in depths from 25 to 125 metres but not regularly every year. The spawning mainly takes place between the small islands and skerries and the spawning area is estimated at about 15 km^2.

III. *Bleiskjær.* At the bottom of the deep trench penetrating between the lastnamed region and Røvær one finds a spawning area around the skerries and grounds of Bleiskjær. In certain years the herring arriving along the trench also spawn on the southern slope of

this trench along the north eastern part of Røvær. Herring roe has been found in depths from 10 to 95 metres and the spawning area is about 12 km².

IV. *Fæøy—Urter.* South of the lastnamed area a depression with depths between 100 and 150 metres penetrates from the island Utsira towards the northern part of Karmøy. At both sides of the head of this depression spawning occurs (west of the island Fæøy and at Urter) and has taken place here every year in depths between 30 and 120 m. The spawning area is estimated at about 23 km².

V. *Røvær—Svea.* South west of the island Røvær one finds a rather extensive plateau within the 100 m line, unprotected towards the open sea with exception of the shoal Svea. On this plateau, but also to a certain degree in deeper water westwards, a regular spawning takes place in depths from 20 to 140 metres. The spawning area is about 48 km².

VI. *Utsira,* the small island situated in the open sea about 20 km west of Karmøy, has some rather important spawning grounds at the southern side and partly also at the northern side. At the western side the bottom slopes steeply into the Norwegian Deep but at the eastern side some spawning may occur in the deeper area between the Utsira and Karmøy banks. Herring roe has been found from 25 down to 150 metres. The estimated spawning area is about 26 km².

VII, VIII, IX. These areas form an extensive continuous bank along the western and southern part of Karmøy and this is the most important spawning region in the spring herring district. Herring roe has been found over wide areas in depths from 20 to 110 metres. The spawning bank covers about 145 km². In the south and south west the bank slopes rather steeply into a deep trench penetrating from the Norwegian Deep towards the Bokn fjord.

X. *Bokn—Aregrunnen.* Separated from the southern part of Karmøy by the Karmsund a spawning area is situated mainly between the south end of the island Bokn and the Aregrunn, a shoal at some distance off shore. Spawning occurs here in depths from 10 to 145 metres and the estimated spawning area is 14 km².

XI. *Karmsund.* In the inner part of Karmsund and north of Bokn spawning has been observed in certain years close to the shore in depths from 5 to 70 metres. The bottom area favourable for spawning is not very extensive and is estimated at 8 km².

XII. *Kvitsøy—Kalsmedgrunnen.* South of the Skude fjord a rather extensive bottom area is found within the 100 m line from Kvitsøy in the north to Jærens rev in the south. In the northern part of this area small groups of islands and skerries are situated and spawning

has been observed on the rocky bottom around the islands Kvitsøy and Håstein. At Kvitsøy roe was found in depths from 41 to 58 metres and at Håstein from 20 to 55 metres, in a single case also at a depth of 165 metres. The spawning areas are 12 and 15 km² respectively.

In the southern part of the area outside the coast line Feistein—Jærens rev one finds a relatively extensive spawning bank, Kalsmedgrunn, where herring roe has been found in depths between 24 and 54 metres. The area is about 40 km².

The coast south of Jærens rev is very flat and the land is only some few metres above the sea level. The Norwegian Deep runs here close to the coast and one finds only a narrow strip of shallow water with the bottom covered by fine sand. This area is not favourable for spawning and the coast is very exposed to wave action. Only outside the Ogna bight spawning is known to occur and here herring roe was found in the year 1935. In certain years the waves have driven large masses of herring roe on to the shore here as will be reported later.

XIII. *Egersund.* Only outside Egersund one finds more important spawning grounds namely Løsegrunn and Kletta-grunn as indicated in fig. 5. Herring roe was found from 30 to 95 metres depth. Area = 26 km².

XIV. *Siragrunn,* situated further south, is also a wellknown spawning place. This bank is somewhat shallower than the former ones and herring roe has only occurred in depths between 15 and 50 metres. The area is about 30 km².

In the northern district Stat—Kristiansund large areas within the 100 m-line were investigated by means of grab hauls. Compared with the great number of observations (231), herring roe was found in rather few cases (29 stations). Spawning was ascertained at Svinøy and between this island and the peninsula Stat. Further north herring roe was found at two stations on the great shallow north of Rundøy close to the island. Separated from the Rundøy area by a deep channel one finds an extensive area outside Erkna. Here herring roe was somewhat more widely distributed and 10 stations gave positive results. Farther north no roe was found over a great distance and only at the edge of the great Buagrunn in the north spawning was ascertained. Further north roe was taken at 3 out of 21 stations on Griptaren, a shallow area outside Kristiansund.

THE VERTICAL DISTRIBUTION OF HERRING ROE AND THE BOTTOM CONDITIONS ON THE SPAWNING GROUNDS.

As shown in the previous chapter the spawning grounds are mainly situated within the 100 m-line. Spawning takes, however, place to a certain degree also in deeper water. Fig. 6 shows the vertical distribution of grab hauls in the southern spring herring district taken in the years 1931—37.

Bottom samples were taken in shallow water down to a depth of 200 metres but herring roe was only found in depths between 5 and 150 metres. The number of hauls increases gradually down to the 41—50 m-zone where a maximum of nearly 500 hauls was made. At greater depths the number of hauls was less and in depths of more than 100 m the hauls were rather few. As the stations was distributed as evenly as possible over the spawning areas, the depths best represented by the hauls also are the most common in the spawning areas. The samples containing herring roe show the same vertical distribution as the total number of hauls, the relative number of samples with roe being apparently of the same order in greater depths as in shallower water.

When, however, the density of herring roe (quantity pr. m^2) is considered as in fig. 7 one finds that the richest spawning occurs in depths of 20 to 80 m; in shallower or deeper water the density is far less. At the Møre coast the greatest density also was found at a depth of 61—70 m while the vertical distribution of the roe is more limited there than in the southern district. Spawning of some importance had only taken place at depths of 40 to 90 m.

The bottom on the spawning grounds is composed of rocks, stones, gravel and sand but also to a great extent of calcareous deposits of broken shell, serpulid tubes, calcareous algae etc. forming a more or less coarse shell sand. Also brown and red algae may be found covered by roe and even free-living animals as *Hyas* and other species have been caught with herring eggs attached to the body.

Table 4 shows the various bottom conditions on the spawning grounds based on 781 bottom samples taken in the southern spring

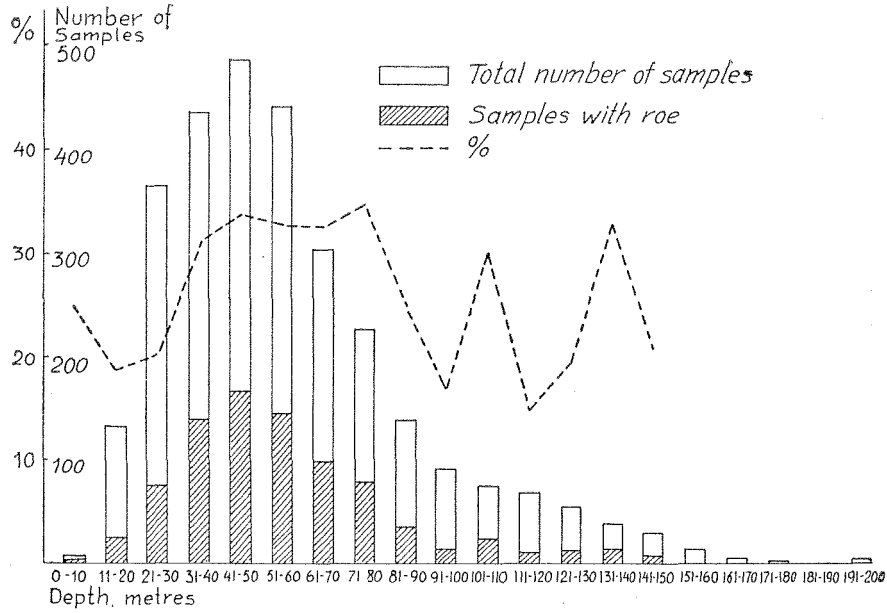

Fig. 6. All grab hauls made in the S Spring Herring district 1931—37 distributed according to depth.

herring district. In each column the total number of samples is entered to the left and the number of those with herring roe to the right. The samples are also classified according to depth. About 40 % of the samples were taken on rocky bottom and then comes shell sand in about 26 % of the hauls. Algae, stones and gravel were found in about 8 % of the samples respectively and fine sand only in 3 %, muddy bottom in 7 % of all the samples. In depths down to 100 m the rocky or sandy bottom is predominating, in greater depths muddy bottom. Herring roe was found in 35 % of all the samples. The greatest number of positive samples, or nearly 49 %, was obtained on bottom with loose stones and 41 % on rocky bottom, while 33—34 % of the samples with algae, gravel or shell sand contained herring roe. On fine sand bottom herring roe was found in only 18 % of the samples and on muddy bottom only in two of 56 samples. In the last case however the eggs were deposited on shell of dead mussels and not directly on the muddy bottom.

Thus the herring apparently prefers to spawn on stony or rocky bottom but deposites also the eggs on algae, gravel and coarse shell sand. Fine sand seems to be less favourable as spawning bottom and muddy bottom seems to be entirely avoided, as the eggs on the last mentioned bottoms would probably soon be covered by fine sand or

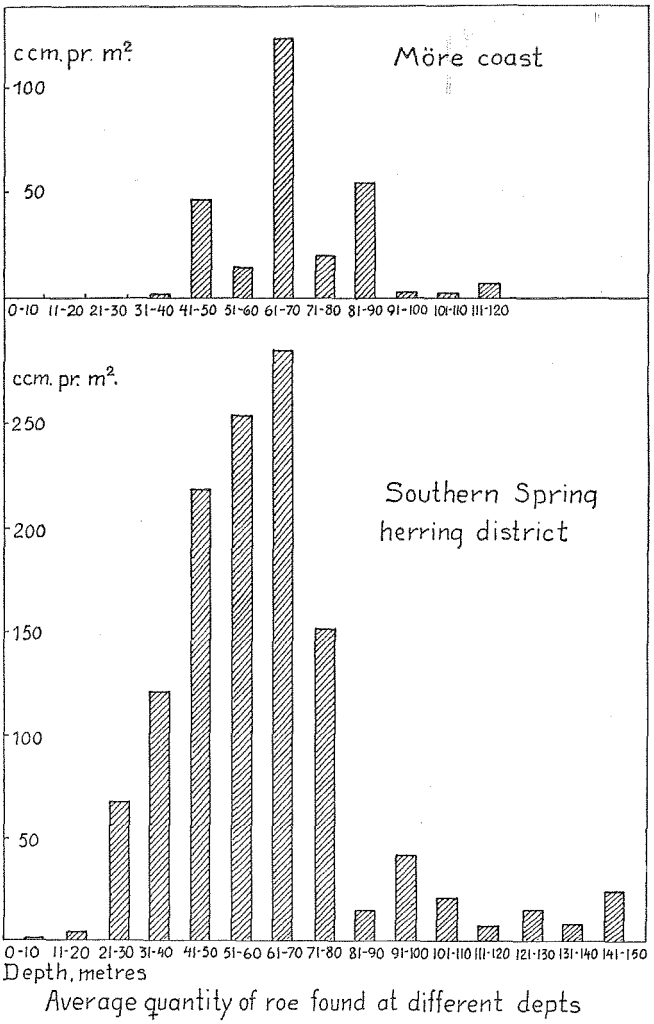

Fig. 7.

mud particles and perish. Thus the best spawning conditions are found within the 100 m-line.

At the Møre coast between Stat and Kristiansund the hard bottom is still more prevailing and areas with shell sand bottom are not so extensive as in the southern district. About 87 % of all the samples with herring roe were taken on stony or rocky bottom, about 10 % on gravel and only 3 % on shell sand.

Table 4. *Number of grab stations on different bottoms.*

Depth m	Rocky bottom		Algae on rocks		Stony bottom		Gravel		Fine sand		Shell sand		Muddy bottom		Total no. of stations	
	whole no.	with roe	whole no.	with roe	whole no.	with roe	whole no.	with roe	whole no.	with roe	whole no.	with roe	whole no.	with roe	whole no.	with roe
0—50	146	64	62	21	27	13	27	9	18	4	89	22	2	—	371	133
50—100	120	51	—	—	28	14	29	11	9	1	111	43	11	—	308	120
100—150	35	9	—	—	11	5	7	1	—	—	6	3	43	2	102	20
Total	301	124	62	21	66	32	63	21	27	5	206	68	56	2	781	273
%	39.8	45.4	8.0	7.7	8.5	11.7	8.1	7.7	3.2	1.8	26.4	24.9	7.2	0.7		

THE DENSITY OF THE HERRING ROE ON THE SPAWNING GROUNDS AND THE MORTALITY OF THE EGGS.

As far as can be seen the only workers who have attempted a quantitative estimate of the numbers of eggs deposited, of herring spawning and of the mortality of the eggs are J. LAWSON HART and ALBERT L. TESTER (1934) who carried out investigations in British Columbia in 1931 and 1932. The herring shed their eggs there chiefly on eel grass (*Zostera*) or rock weed (*Fucus*) in or just below the intertidal zone and generally the spawning beds are left dry or nearly dry at low tide which simplified the investigation very much. These investigations were apparently started at the same time as my own.

In the Norwegian spring herring district BOECK and others have reported the occurrence of inch-thick layers of herring roe on the bottom. LEA (1929, 1930) also found more or less thick layers of roe, forming up to $^1/_2$ inch thick flakes. It is therefore near at hand to suppose that the whole spawning areas are covered by a continuous more or less thick layer or »carpet« of roe. As a drastic instance of the great quantities of roe occurring on the bottom BOECK mentions that in a certain year roe was washed up on the beach at Jæren in so great masses that the farmers carted many waggon-loads on to the fields as manure and the swines were fed on roe for many days. A similar event occurred in the years when the present investigation took place. Near Ogna, Jæren, where the coast is very low and the surf can be very strong, great masses of roe were found on the beach and 400 cart-loads of Laminaria and roe in equal proportions were taken along a stretch of 80 metres of the beach. I have personally controlled this information and have calculated that about 80 000 litre of pure roe were collected by the farmers. This quantity may seem imposing but in fact the quantity only corresponds to a catch of 8000 hl of herring which is often taken in a single catch with land seine.

In order to get a better understanding of the density of the herring roe on the spawning grounds I have, in table 5, classified the samples according to the quantity of roe taken in each grab haul. As the stations

Table 5. *Distribution of the grab stations according to quantity of herring roe taken pr. haul.*

Year	Quantity of herring roe (ccm pr. m^2)														Total no. of stations
	< 1	1—10	11—25	26—50	51—100	101—250	251—500	501—750	751—1000	1001—2500	2501—5000	5001—7500	7501—10000	10001—12500	
1931	27	3	5	6	3	12	5	7	5	5	2	2	—	—	76
1932	32	24	5	9	9	8	8	6	3	10	2	1	1	2	120
1933	24	21	6	4	2	3	1	1	—	2	1	—	—	—	65
1934	25	14	1	4	2	7	3	2	2	3	3	—	—	1	67
1935	37	24	6	12	14	13	13	2	4	11	3	2	—	—	141
1936	32	20	7	3	6	9	3	6	1	2	1	—	—	—	90
1937	47	23	9	3	8	11	6	6	1	4	—	—	2	—	120
Total	218	129	39	41	44	63	39	30	16	37	12	5	3	3	679
% ...	32.1	19.0	5.7	6.0	6.5	9.3	5.7	4.4	2.4	5.4	1.8	0.7	0.4	0.4	

are rather evenly distributed over the spawning areas these figures may also serve as a rough expression of the relative distribution of the different quantities.

The table shows that 32 % of the stations gave less than 1 ccm. roe pr. m^2 while 19 % gave 1—10 ccm pr. m^2. Thus in about 50 % of all the stations less than 10 ccm roe pr. m^2 was found. About 18 % of the stations show quantities between 10 and 100 ccm, 15 % had 100—500 and about 7 % quantities between 500 and 1000 ccm pr. m^2. Only at about 9 % of the stations the quantities were greater than 1 litre pr. m^2 and only very few (0.4 %) with more than 10 litres pr. m^2.

What do these quantities of roe really mean? When an area of 1 m^2 is covered by a single layer of eggs lying as strings of pearls on the bottom we may calculate the number of eggs to about 440 000 (eggdiameter 1.5 mm). A quantity of 1 ccm measured in a glass cylinder contains about 400 eggs and thus a single layer of eggs over an area of 1 m^2 corresponds to about 1 litre of roe. Thus we find that only in 9 % of the stations the bottom was covered by one or more continuous layers of eggs. 1 ccm roe pr. m^2 corresponds to a density of 1 egg pr. 25 cm^2 and 10 ccm pr. m to 1 egg pr. 2.5 cm^2 if the eggs were evenly distributed over the bottom. This is not the case, however, the roe being commonly found in small lumps owing to the circumstance that the eggs, which are deposited as pearl stringes of pearls, stick together in the water.

The largest quantity of roe found by me, 13 liter pr. m^2, corresponds to an about 1.3 cm thick compact flake of roe, and at a few other stations I got 1/2 to 1 cm thick flakes corresponding to 5—10 liter pr. m^2. In one case a fragment of a 2.5 cm thick flake corresponding to 25 liter pr. m^2, was found. The volume of the fragment was only 1.1 liter which shows that the grab did not always work quite well.

The investigations by means of bottom grab have also shown that the herring does not spawn all over the banks. Table 6 shows the total bank area of the southern spring herring district investigated each year and the portion covered by roe (in km^2) in the different years. On an average an area of 369 km^2 was investigated but roe was found only over an area of 107 km^2 or 29 % of the whole area. We must therefore conclude that the herring masses do not cover the whole bank area but immigrate in greater or smaller shoals in the shape of streams which also agrees with the observations by means of echo sounding.

We know that a single female contains about 20 000 eggs corresponding to a volume of 50 ccm. At about 63 % of the stations less than 50 ccm roe pr. m^2 was found and it is therefore apparent that the females do not deposite all the eggs at the same time. When, however, such

Table 6. *Spawning area and quantity of roe covering the area*

Year	Area investigated	Area covered by roe		Quantity of roe on the area	Average quantity pr. m²
	km²	km²	%	litres	ccm
1931	281.8	62.9	22.3	27.384.315	435
1932	385.8	86.4	22.4	54.094.445	626
1933	281.8	70.4	25.0	6.753.730	96
1934	339.6	75.9	22.4	38.312.805	504
1935	417.6	169.8	40.7	53.165.359	313
1936	425.8	112.7	26.5	16.893.147	150
1937	446.8	170.0	38.0	32.208.202	190
Total	2.579.2	748.1	29.0	228.812.003	
Average	368.5	106.9	29.0	32.687.429	306

great quantities as 5—10 litres of roe pr. m² are found, the concentration of herring must have been considerable in these places. These quantities corresponds to at least 100—200 females pr. m² and probably a similar number of males are present. The largest quantity observed, 25 litres pr. m², córresponds thus to 1 000 herrings spawning over an area of 1 m². The herring masses seem to immigrate to the spawning grounds from the sea as large streams, the females at first only little by little depositing their eggs, but gradually the shoals get more concentrated and the spawning culminates, after which the shoals leave the spawning grounds and emigrate to the open sea.

Even if the quantities of herring roe present on the spawning grounds have been somewhat overestimated by the previous more sporadic observations we may suppose that considerable masses of roe must occur on the bottom. In table 6 is given the total quantity of roe in the areas investigated in the different years, estimated according to the methods previously mentioned. As seen in the lowest horisontal row the average quantity for the whole period was 34 million litres over an average area of about 107 km². The quantity varies, however, very much from year to year with a maximum of 53—54 mill. litres in 1935 and 1932 and a minimum of only 7 mill litres in 1933.

The average quantity, 34 mill. litres, corresponds to about 13 600 milliards of eggs and to 1 360 million fish or 3.4 million hl packed herring. The average yearly catch with bottom gill nets on the spawning grounds in the district investigated in the period 1931—37 was 890 000 hl which means that 26 % of the estimated quantity were caught. LEA (1930) who has studied the mortality in the tribe of Norwegian herring, has estimated that the stock every year is reduced by 20 % due to fishing and death by other causes. HJORT (1914) has estimated from marking experiments that about 27 % of the Lofoten cod are caught by fishing gear while ROLLEFSEN (1934) estimated the mortality in the tribe of Lofoten cod to at least 40 %. Thus the value calculated by me, 26 %, does not seem improbable and one may consider the estimated quantities as fairly representative of the actual conditions.

In his studies on the »mortality in the tribe of the Norwegian herring« LEA (1930) writes: »while nearly all the eggs in the thick flakes of herring roe found had been fertilized and had commenced hatching only the embryos in the uppermost eggs were alive and could be brought to liberate themselves. The eggs in the deeper layers, necessarily deposited earlier than the eggs in the superficial layers, contained embryos at very different stages of development, while the bottom layers were found in a state of putrefaction«. From this discovery LEA concluded »that the number of fry hatched on the spawning grounds must be relatively independent of the *number* of eggs deposited and more dependent on the *area* covered by eggs. In addition it seems to give a partial explanation of the fact that the numerical strength of a herring brood is comparatively independent of the number of parent herring«.

I can confirm the observation made by LEA: that often a very high mortality is observed in the thick flakes of roe. In $^1/_2$ to 1 cm thick flakes a mortality of 43—70 %, and 80 % in a flake of 2.5 cm was noted. The mortality is, however, dependent on the stage of development of the eggs. In flakes with eggs in early stages a mortality of only 1—2 % has been observed, but even at this stage the eggs in the bottom layers are retarded in development and apparently die later on. In a flake containing in all 70 % dead eggs the mortality in the bottom layer was 96 %, in the surface layer only 39 %. In another flake with 80 % of all the eggs dead the lower layers were wholly devoid of life.

As already mentioned the thick flakes of roe do not, however, play as great role in the nature as formerly supposed. Table 7 shows the average mortality of herring roe at varying densities. There is no clear increase of the mortality with increasing density except for the large quantities between 10 000 and 12 500 ccm pr. m^2. The average mortality of the whole material is 12.1 % and apparently the high

Table 7. *Average mortality of the eggs.*

	Quantity of her ing roe (ccm) pr. m²											
	> 10	11— 50	51— 100	101— 250	251— 500	501— 750	751— 1000	1001— 2500	2501— 5000	5001— 7500	7501— 10000	10001— 12500
Nr. of samples investigated	37	80	44	53	46	30	19	38	14	4	2	3
Mortality %	11.6	10.5	9.1	15.5	11.7	10.4	15.9	16.2	9.4	3.5	6.5	31.0

mortality in the thick flakes does not influence the average value in any great degree. HART and TESTER (1934) have found that the dead eggs on the spawning beds constituted from 1.4 to 10.5 %

LEA concluded that the number of fry hatched on the spawning grounds must be relatively independent of the number of eggs deposited and more dependent on the area covered by eggs. He considers it more favourable for the hatching when small quantities of roe are distributed over a great area than the contrary. This is of course theoretically true but as we have seen the thick layers with a very high mortality only infrequently occur to such an extent that they can play any great rôle in nature. As seen in table 6 the area covered by roe varies strongly from year to year. In the year 1932 when the spawning was very rich, the area covered by roe was only 22 % of the area investigated. The average density of the roe was also the highest observed in the period, or 629 ccm pr. m². In the next year there was a very poor spawning over about the same area while the density was only 97 ccm pr. m². In the year 1935 the spawning was of about the same richness as in the year 1932 but the roe was distributed over an area twice as large as in the year 1932, the density being only the half, or 313 ccm pr. m². According to LEA the conclusion would be that the hatching in 1932 was much less favourable than in 1935 and that the numerical strength of the year class 1932 should be comparatively poor. Fig. 2 shows, however, that the year-class 1932 plays a rather predominant rôle in the spawning shoals during recent years, 1937—39*), along with the unusually rich year-class 1930. The brood from the year 1931, when the density of roe was less than in the year 1932, is of far less importance in the spawning shoals. The year class 1933 seems, however, to be somewhat richer and was fairly numerous in the year 1939, at an age of six years. It is still to early to say anything about the year class 1935. This brood appeared 1939 in the spawning shoals as four years old spring herring but in relatively smaller numbers than the year-class 1932 at the same age in the year 1936. Thus no close relation is apparent between the area covered by roe and the density of the eggs on the one hand and the numerical strength of the year broods on the other hand.

If all the surviving eggs of the roe masses (88 % on an average) found on the spawning grounds, grew up to maturity, the spawning stock would increase yearly by 30 milliards hl. The number of herring yearly present in the investigated area was on an average estimated at 3.4 million hl. As LEA has calculated the yearly decrease of the spawning stock at 20 %, a yearly increase of only 680 000 hl is needed to make up for the loss. It is thus apparent that an egg-mortality of

*) As well as in 1940 and 1941.

12 % is of no importance for the numerical strength of the year broods and that the mortality must be much greater at a later stage. HART and TESTER have come to the same conclusion.

As J. HJORT (1914) has pointed out the critical stage probably is reached when the larvae have absorbed the yolc-sack and begin to feed on small plancton organisms. By hatching experiments with herring eggs I succeeded to keep the free-swimming larvae alive for 6 weeks without any great mortality, feeding them on plancton algae. Always, however, when they had reached a certain stage, they all died in a short time. SOLEIM (1940) who has continued these experiments in 1940, made the interesting observation that the herring larvae feed very well on nauplii of *Balanus*. The larvae passed the critical stage and grew up very well, but the experiments were unfortunately interrupted on April 9th. It seems to be of great importance that the larvae get enough of the right food at the right time.

THE SPAWNING TIME IN THE DIFFERENT SPAWNING AREAS.

According to LEA (1929) the Norwegian spring herring must consist of two contingents of herring on their way to the spawning grounds. The one contingent, which is regulary noticed to be the first and most abundant, contains the older spawners. The second contingent are the recruit spawners which become ready to spawn later in the season than the bulk of older spawners. I have also, in my racial investigations, demonstrated that the younger individuals reach maturity later in the season than the older spawners. TH. RASMUSSEN (1939), who has studied the mean degree of sexual development of the spring herring, has clearly established that the average state of maturity observed in successive catches decreases during the spawning season, which implies the advent of fresh shoals. I have further demonstrated that we have to do with several separate shoals immigrating into the different areas. They can be distinguished by differences in the mean number of vertebrae. The different shoals do not, however, appear at the same time over the whole spawning district, but immigrate gradually to the different grounds. Consequently the bottom gill-net fishery moves in a fairly regular manner from area to area throughout the season.

Fig. 8 shows the periods of bottom gill-net fishery in the different areas in the years 1931—37 in the southern spring herring district. The areas are indicated by I—XIV as in the maps fig. 3—5. It is seen that the fishery starts in the first days of February at the west and south coast of Karmøy (VII—IX) and then somewhat later at Bokn and Karmsund (X, XI, inside Karmøy). Some days after fishing has started at Karmøy a fishery begins in the Jæren and Egersund areas in the south (XII—XIV). The fishery here at first generally starts at Kalsmedgrunnen and then gradually at Egersund and Siragrunn in the south and lastly at Kvitsøy in the north. The fishery in all these areas is in most years finished at the end of February. In the northern areas (II—V) the fishing begins only in the later part of February and closes in the first part of March. In the northernmost area (I) no fishery takes place

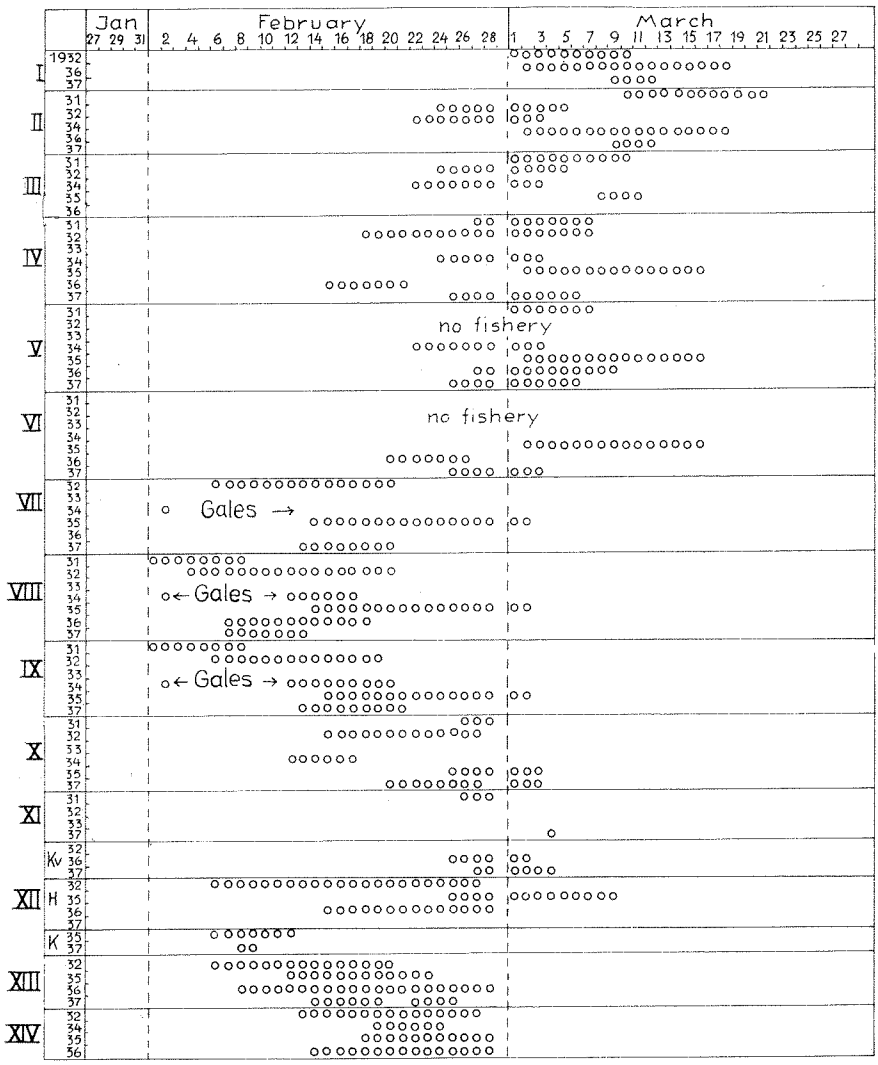

Fig. 8. Periods of bottom gill-net fishery on the spawning grounds in the years 1931—37. The grounds are indicated by roman numerals refering to fig. 3 (I—XI), to fig. 4 (XII, subdivided thus: Kv — Kvitsøy grounds, H — Håstein grounds and K — Kalsmedgrunnen) and to fig. 5 (XIII, Løsegrunnen etc. and XIV, Siragrunnen).

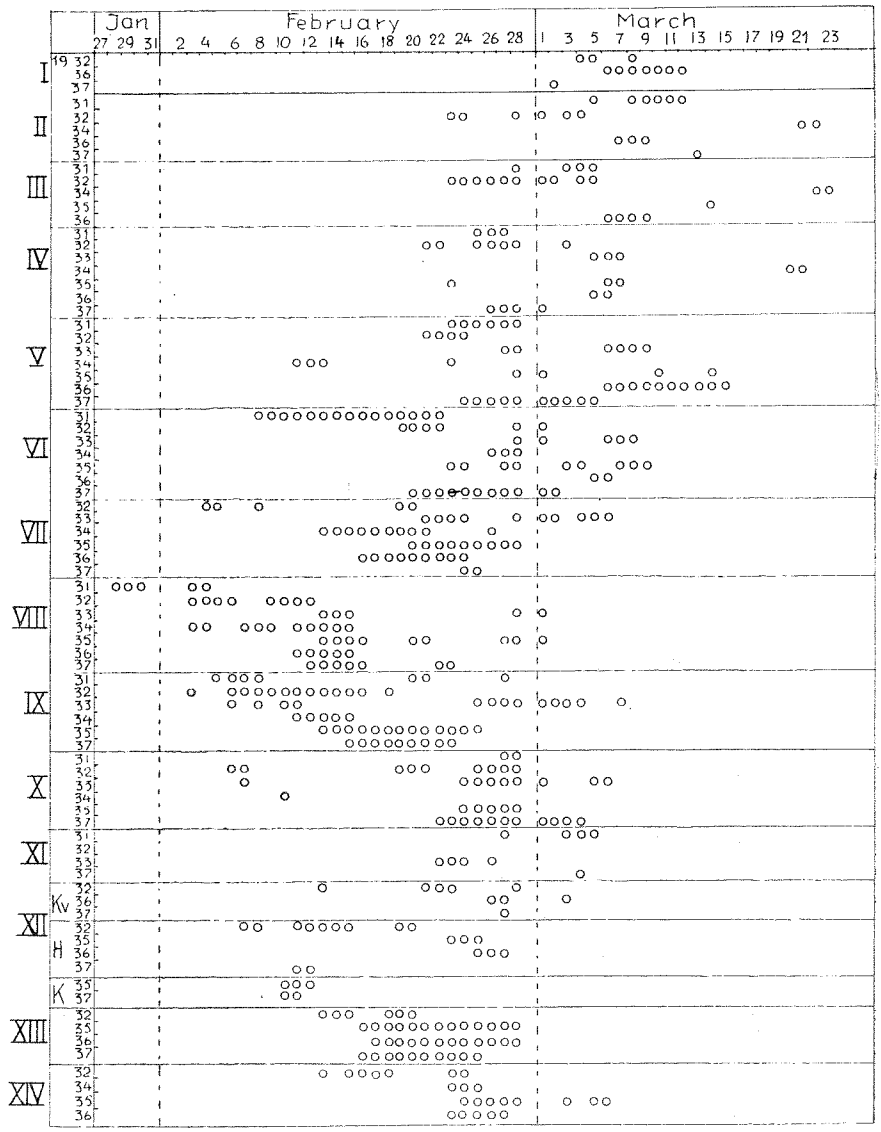

Fig. 9. Spawning periods on the various grounds estimated from age of spawn obtained by means of bottom grab. Compare this fig. with fig. 8, and text p. 38.

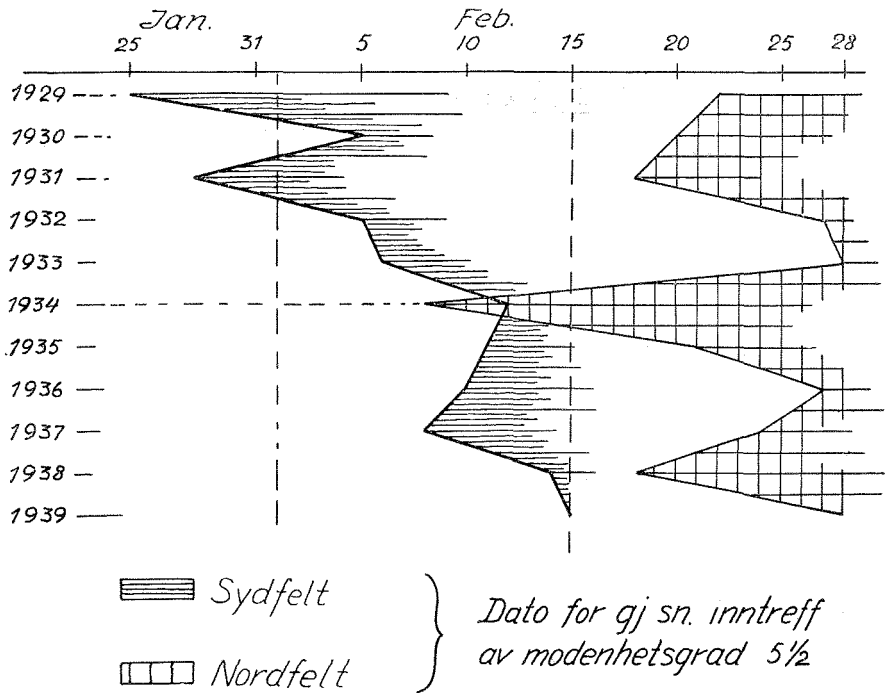

Fig. 10. Date when average maturity stage $5^1/_2$ was observed.

before the first days of March and the fishery is finished at the middle of the month. This lastnamed area is mainly visited by recruit spawners.

The spawning time was determined in the manner that the age of the eggs found on the spawning places was estimated according to a scheme based on the studies of the development in the laboratory. The hatching of the eggs takes about three weeks in a temperature of 5° C. corresponding to the water temperature at the spawning places. The stage of development for each day was drawn up and in that way we got a scheme in order to determine the age of the eggs in number of days. The results of these estimations is given for the areas I—XIV in fig. 9. A close relation is found between the periods of bottom net fishery and the spawning time in the different areas. The only difference is that the spawning at Utsira and Røvær (VI and V) in certain years may begin earlier than the fishery and this is due to the circumstance that stormy weather often delays the fishery in these exposed areas.

As already discussed in a previous chapter all the eggs are not deposited at once. As seen in fig. 9 the spawning in one and the same area is generally extended over one or two weeks and it may also happen

that the spawning is interrupted for some days. When the spawning is finished the herring disappear from the ground and the fishery is also ended. The fishermen say that when the water get milky no more fishing can be done. This observation may mean that the males deposite the milt only at the end of the spawning period, It is, however, perhaps more probable that the spawning ends with a great culmination which also was supposed when discussing the varying density of the roe.

As seen in fig. 9 the spawning started rather early in the year 1931 while later the spawning shows a tendency to be delayed from year to year. This phenomenon is also demonstrated by TH. RASMUSSEN (1940) by studying the stage of maturity of the spring herring. In fig. 10 which is reproduced from the paper by RASMUSSEN, he has shown graphically the dates when herring samples with more than 50 % spawning individuals were taken in the southern and northern spawning districts during the period 1929—39. In the southern district the spawning started already at the end of January, in the same manner as I have shown, but later the date of maturity seems to be continually postponed. It is further shown that the spawning starts later in the northern district than in the southern as I also have demonstrated in my racial studies.

REGISTRATION OF THE SPAWNING SHOALS BY MEANS OF ECHO SOUNDING.

As O. SUND had obtained good results in registration of cod shoals at Lofoten with the echo sounder installed in the M/S Johan Hjort I made some preliminary investigations in the herring districts in the year 1936. In the succeeding season I then tried to make a more thorough investigation in order to chart the distribution of the herring shoals in the spawning districts. These attempts have already been related in my report on the herring investigations in the year 1937 but it may be of interest to discuss the results in connection with the present studies.

The first of these cruises with the »Johan Hjort« was made to the large-herring district north of Bergen in the period January 6—16th. Already the first day a herring shoal was registrated in the Hjelte fjord, about 30 km north of Bergen. The echogram is shown in fig. 11. The thick horisontal line at the top of the figure represents the surface of the sea, and the irregular line indicates the bottom. Between the surface- and bottom lines a horisontal dark shadow is seen which was supposed to represent a herring shoal. The distances between the thin vertical lines is one nautical mile and the distance from the surfaceline to the lower edge of the echogram corresponds to a depth of some 200 metres. By cruising on different courses the shadow was found over an area of 1×3 naut. miles and the thickness of the shadow on the paper corresponded to about 40 metres. No fishing fleet was present except a purse-seine steamer on the way to Bergen which was hailed. The herring fishermen have great experience in localizing herring shoals by means of a thin brass line with lead estimating the density of the shoals from the frequency of shocks felt on the line touching the herring bodies. The head fisherman found in this way that herring were present and estimated that they could make a catch of 1 000 hl with the purse seine fairly ordinary catch. Due to strong current the catch, however, turned out a failure as they got only about 50 hl, still sufficient proof that it really was a herring shoal which had been indicated by the echo gear and we had also got an estimation of the density of the shoal. By

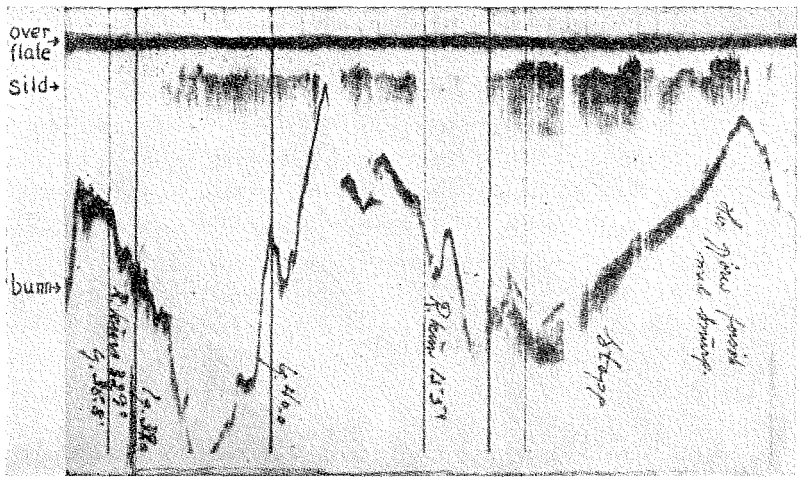

Fig. 11. Echogram showing herring shoal in the Hjeltefjord (about 30 km N of Bergen) 7. Jan. 1937. The heavy, horizontal streak along the upper edge represents the surface (»overflate«), the bottom contour is indicated by »bunn«. The herring shoal is shown as smudges in the mid-water space. The max. depth shown is about 220 m, hence the upper limit of the shoal is seen to be about 12—20 m from the surface, the lower 30—50 m. The horizontal scale is about 25 times less than the vertical, each cm in the fig. representing a distance of about 1000 m. The writing to the right means: »here purse seines go to action«.

calculating the volume of the water masses enclosed by a purse seine I found that a catch of 1 000 hl corresponds to about 2 herrings pr. cub. m of water (if evenly dispersed).

On February 7th a hydrographical section was made from Feie and 40 naut. miles westwards across the Norwegian Deep towards the Viking Bank. Returning to the coast a somewhat more northerly course was taken, namely towards Holmengrå outside the Sognesjø. Halfway to the coast the echo sounder began to indicate herring and over a distance of 20 naut. miles across the Norwegian Deep a continuous herring mass was found, reaching to the coastal slope. A section straight across the herring mass showed that the shoal had a width of 2 naut. miles and a vertical thickness of about 30 metres. Within the skerries of the Sognesjø also a smaller shoal was observed which apparently had been separated from the chief mass present in the open sea. Supposing a density of 2 herrings pr. cub. m the registered herring mass was calculated to consist of at least 15 million hl. The total catch within the large herring district between Bergen and Stat was in that year 1.5 million hl. No fishery took place on this shoal registered in the open sea, and within the skerries, where the main fishery took place, no shoals of a corresponding size

were registered. The huge herring shoal had the shape of a very long and narrow streak with the length directed straight against the coast.

The ordinary cruise to the southern spring herring district in the »Armauer Hansen« was started on january 26th. The echo sounder was always in function when working with the bottom grab on the spawning banks but herring was never registered on the banks in the day time. But also special cruises were made outside the banks in order to localize herring shoals, the courses steered being indicated on the charts in figs. 12 and 13. The shaded course lines denote the presence of herring.

Fig. 12 shows the situation in February in the Espevær—Kvitsøy area. At least three separate herring masses were found within this district, namely south of Karmøy, south west of Utsira and west of Røvær. Further occurrence of herring was noted early in February on the line from Slotterøy to Rogøy (north of Espevær) about 4—5 nautical miles off the coast. The greatest herring masses undoubtedly occurred at Røvær and Utsira. The herring ar Røvær were registered already on February 2nd but these courses are not drawn up on the chart. On February 11—12th this area was again investigated and herring was found over a great area as shown in fig. 12 (unbroken lines). The herring mass occurred outside the 100 m-line west of the great spawning bank situated between Røvær and Svea (V) but on the bank proper no herring was found. On February 17th, however, streaks of herrings moved in over the bank (broken course lines). Also north of Røvær now a small shoal was found moving along the deep towards the spawning grounds at Røvær—Bleiskjær (III). The next time this area was investigated, on March 4th, the herring mass had moved northwards and was localized outside Sletta (area II) as shown in fig. 13 (unbroken line). But already the next day when the same area was visited (broken course lines) the herring had disappeared and only two small shoals were present at the edge of the spawning grounds at Sletta. The spawning at Røvær began only on February 24th but already on February 2nd the herring was present outside the spawning bank.

At Utsira a small herring shoal was for the first time registered at the western edge of the spawning ground south of the island on Feb. 12th and on the same day also great herring masses were found about 10 km SW of Utsira. These shoals were found again on Feb. 17th and further, smaller, shoals at the E side of Utsira and along the deep hollow running towards the spawning grounds at Fæøy—Urter (IV). It is probable that the herring which have spawned in the areas IV and VI and probably also in the area VII at the end of February, have been small offshoots from the great herring mass found SW of Utsira. When this area again was investigated on March 3rd the herring had entirely disappeared.

The herring shoal south of Karmøy was registered on Feb. 12th and then again on Feb. 15th when herring also was registered W of Kvitsøy. Early in March no more herring was observed in this area. This herring have apparently spawned at the south west and south coast of Karmøy (areas VIII—IX) where spawning took place on Feb. 12—21th Probably offshoots also have spawned at Bokn (X) and Karmsund (XI) where spawning occurred at the end of February and early in March.

It is also of interest to notice that herring were registered in the western part of the Norwegian Deep early in February. On Feb. 3rd a hydrographical section was made from Utsira and 40 naut. miles westward, across the Norwegian Deep towards the North Sea plateau. In the western part of this section herring were registered over a distance of several naut. miles and the shoal ended near the slope of the North Sea plateau. As herring were observed at Røvær a day before, it is probable that the herring mass in the Norwegian Deep had nothing to do with the shoals present in the spring herring district the herring apparently moving towards the edge of the North Sea plateau, where also bottom conditions favourable for spawning are found.

From the investigation by echo sounding one gets the impression that only small detachments of the herring masses present in the open sea outside Røvær and Utsira immigrated to the shallower spawning grounds proper, while the herring at the south end of Karmøy were found close in to land.

It would be of interest to get a rough estimate of the quantity of herring registered and to compare these values with those estimated from the quantities of roe found on the grounds. The lines along which herring was registered by echo-sounding represented a total distance of 65 km at Røvær, 57 km at Utsira and 21 km south of Karmøy. The waterlayer inhabited by herring was not very thick, on an average about 10 m. According to the experience from the northern district one may suppose that the herring masses had a breadth of at least 1 km.

Thus one may estimate the volume of water inhabited by herrings at Røvær to 1 300 mill. cub. m and with a density of 2 herrings pr. cub. m this corresponds to 2 600 mill. herring or 6.5 mill. hl. At Utsira and S of Karmøy the corresponding figures are 5.7 and 2.1 mill. hl respectively. It is, however, inprobable that the main masses of herring are composed of separate streams of herring. At Røvær herring was registered in all directions within an area of about 10×15 km and we had probably to do with a continuous herring mass covering an area of 150 km^2. In the latter case the herring mass may be calculated at 7.5 mill. hl. We will, however, in the following prefer the smaller values. Thus the

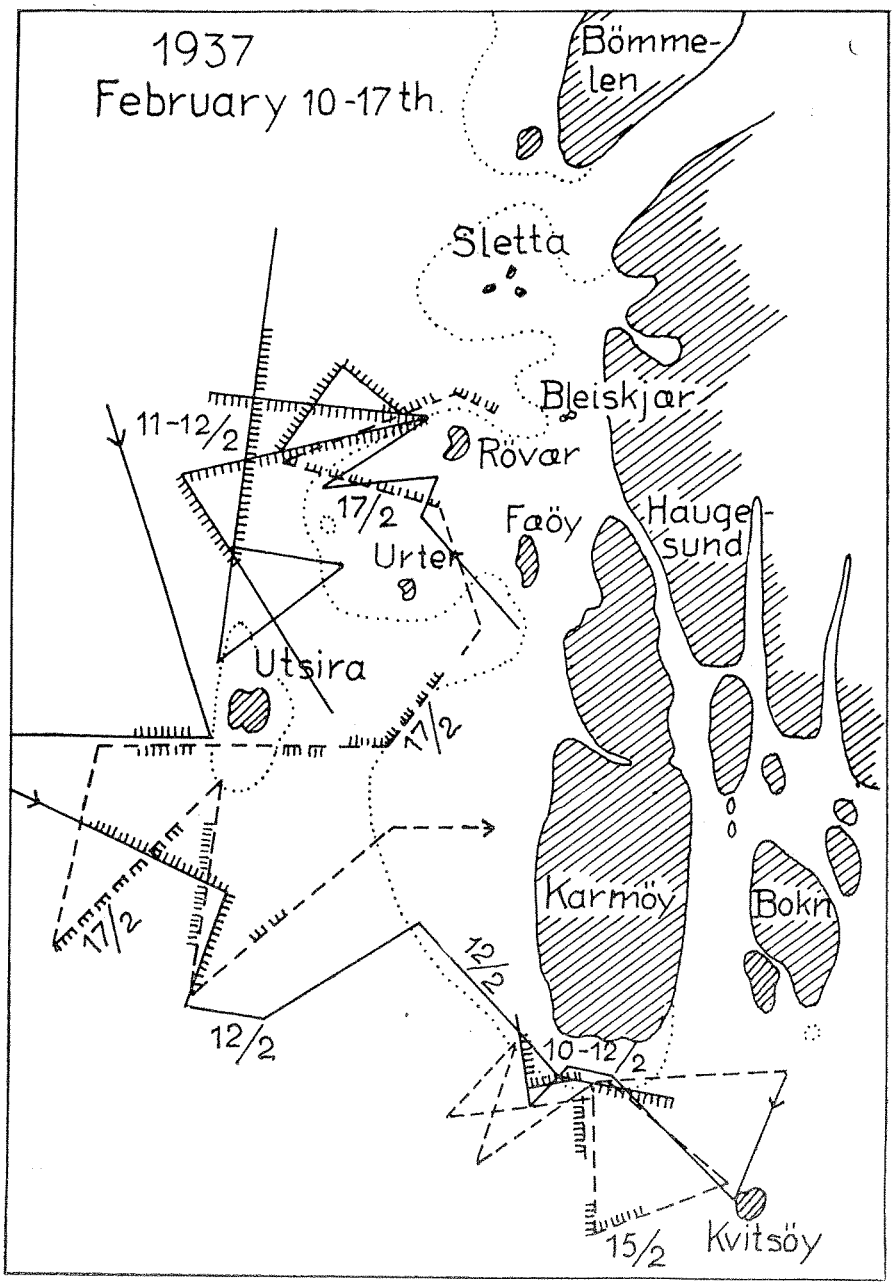

Fig. 12. Echo search for herring in the Karmøy—Utsira area in Feb. 1937. Courses showing herring hatched.

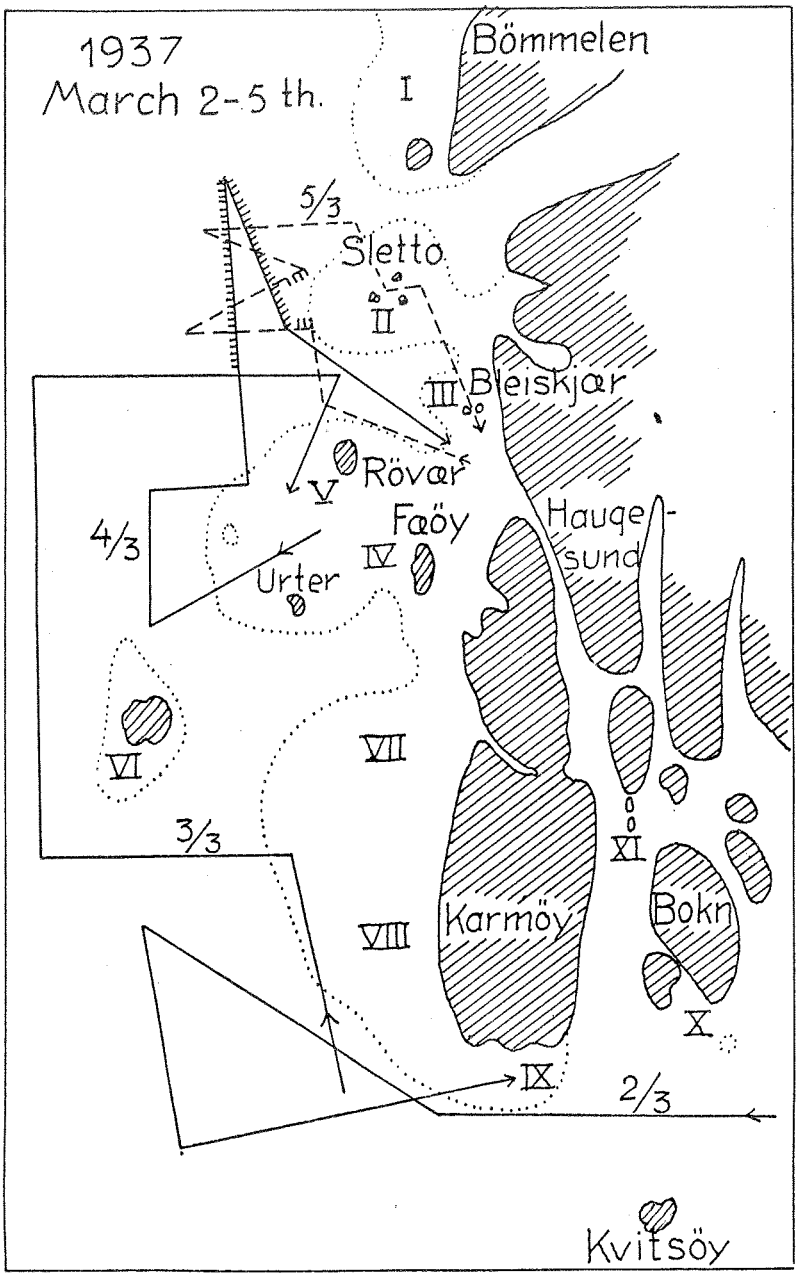

Fig. 13. Echo search for herring in Mar. 1937. Compare fig. 12.

entire quantity of herring registered in the investigated areas is calculated at 14 mill. hl or about the same figure as that estimated for the shoal registered N of Bergen at the end of January. The racial investigations have, however, shown that there is no relation between the large herring north of Bergen and the spring herring in the southern district.

Table 8 contains the quantities of herring present in the different areas estimated by means of echo sounding and also according to the quantities of roe found on the banks. Further the quantities caught by the fishermen are given. It looks as if all the herrings registered at Karmøy have also spawned here. At Utsira and Røvær, however, only an unimportant portion of the herring masses registered has spawned in these areas. Also the fishery has mainly been concentrated to the southern part of Karmøy where about 25—30 % of the estimated quantities were caught. At Utsira and Røvær the fishery was a great failure in spite of the great herring masses present outside the banks. In all about 1.3 mill. hl were caught in the whole district, thus constituting less than 10 % of the quantity registered by echo sounding. The greatest quantity or about 1 mill. hl was caught by bottom nets which is about 30 % of the quantity estimated of herring to spawn on the banks. The purse seine and land seine fisheries were a great failure because the herring occurred in too deep water for the purse seines and too far from the shore for the land seines.

The echograms also illustrate the fact that the herring occurred in deep water. In the day-time the herring was always found at a depth of 150 metres, but in the gloaming the herring rose to lesser depths. This phenomenon is seen in fig. 14 which is a continuous record made west of Røvær throughout the evening. At about 18 o'clock the herring mass began to rise and at 19 o'clock it had risen to about 50 m below the surface.

The occurrence of the great herring masses at Utsira and Røvær was reported to the fishermen by radio and some purse seine boats tried to fish there but the current was too strong and the herring stayed in too deep water. In the night when the herring rose to reasonable depths, the purse seines are not allowed to be used. In the daytime they could only reach the herring when small lots were driven to the surface by whales or coalfish. In the upper row of the echogram in fig. 14 is seen recorded such a small lot of herring rising to the surface in the daytime. To the left of the place, where the bottom is rising towards the Røvær bank one notices a small »mountain« of herring rising above the common level of the mass. Over the shallowest part of the bottom the ship has turned and runs then in the opposite direction along the

Table 8. *Quantity of spring herring estimated to be present in the southern spring herring district and output of the fishery in the year 1937.*

	Røvær area II, III, V	Utsira area IV, VI, VII	Karmøy area VIII, IX, X, XI	Jæren XII	Egersund XIII	Siragrunn XIV	Whole district
	hl	hl	hl	hl	hl	hl	hl
Quantity estimated by echo sounding	6.500.000	5.700.000	2.100.000	?	?	?	14.300.000
Quantity of herring spawning, estimated from bottom grab results	26.776	146.275	2.793.629	725	235.080	—	3.202.485
Quantity caught by:							
Bottom nets	57.000	99.850	480.900	69.600	275.900	26.000	1.009.250
Purse seines	14.350	5.650	165.800	1.500	—	—	187.300
Land seines	1.565	—	45.550	—	—	—	47.115
Total, all gear	72.915	105.500	692.250	71.100	275.900	26.000	1.243.665

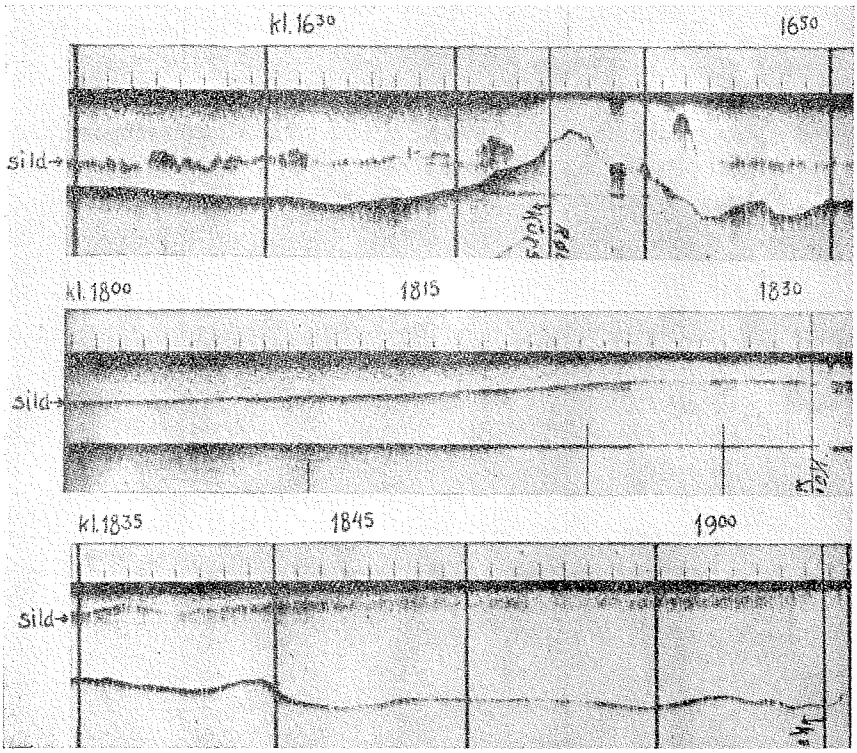

Fig. 14. Three sections of echogram obtained off Røvær (see fig. 12) in the afternoon of Feb. 11, 1937. It is, i. a., seen how the shoal rises towards evening from about 150 m. The short verticals along the upper edge are minute marks, the heavy verticals are supplied automatically by the ships log and are spaced one n. mile apart. See p. 46.

same line and to the right of the ground the same small isolated shoal reappears but now much nearer to the surface, while the main body of the herring mass remains at a depth of 150 m.

Summarizing the results we have by means of echo sounding made the interesting observation that in spite of the occurrense of very great herring masses at the open sea the spawning immigration to the shallower coastal banks may be rather unimportant and the fishery therefore also a failure. In the last chapter will be discussed the causes of this phenomenon. The recording of herring shoals by means of echo sounding may also become of great practical importance and it is apparently possible for a research ship to chart the distribution of the shoals in order to give informations to the fishermen.

THE YEARLY FLUCTUATIONS OF THE SPAWNING IN THE SOUTHERN SPRING HERRING DISTRICT IN THE PERIOD 1931—37.

As already mentioned the output of the fishery is influenced by many factors as weather conditions, number of fishermen taking part in the fishery and so on. By estimating the quantity of herring roe one therefore gets a better approximation to the quantity herring present on the spawning grounds. In fig. 15 shows the quantity of herring (shaded columns) estimated to spawn in the southern spring herring district in each of the years 1931—37. In order to compare these values with the catches taken by bottom nets, also shown in the figure (dotted columns), the quantities are calculated as hl.

The catches in the different years de not always show a direct proportion to the quantity estimated to be present on the spawning grounds. Thus in the years 1932 and 1935 about 20 % of the spawning herring was caught. In the year 1937, however, the corresponding value was 28 % and in the year 1936 about 45 %. In the year 1934, when the fishery was hindered by much stormy weather only about 12 % were caught. In the year 1933 the estimated quantity of roe is probably somewhat too low, because the bottom grab did not work satisfactorily during a shorter period due to a damage.

As the figure illustrates, the fluctuations are rather irregular and do not show any close relation to the fluctuations in the numerical strength of the spring herring stock estimated according to the recruitment from poor or rich year classes. For instance the herring mass spawning on the banks in the year 1932 was quite as great as in the year 1935 when the stock was strongly increased by the immigration of the rich year class 1930, as already discussed in a previous chapter. As it was observed in the year 1937 the main herring masses may remain in the open sea while only small offshoots spawn on the coastal banks. In this way only a poor fishery may take place in spite of the presence of huge herring masses outside the banks.

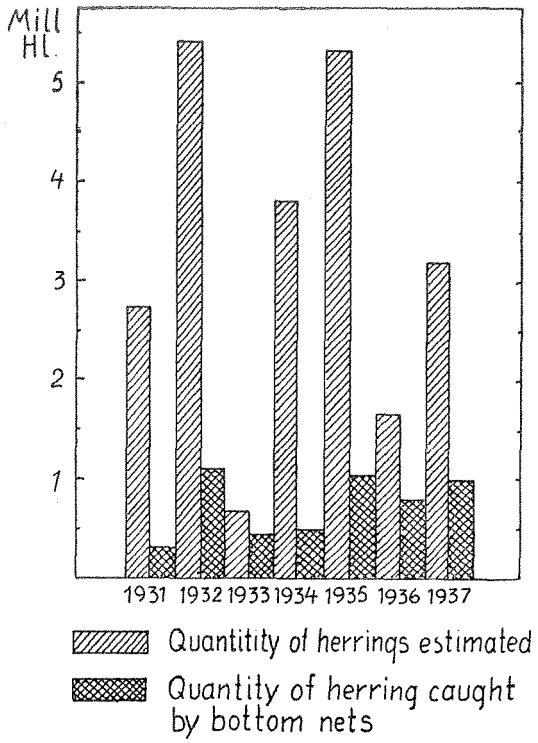

Fig. 15. Comparison of quantities of herring present on the grounds within the entire Southern Spring Herring district as estimated from observations on roe deposited, with amount of herring caught in bottom gill-nets.

In fig. 16 is given the estimated quantities of spawning herring and the quantities caught by bottom nets in the different spawning areas during the period of investigations.

In the year 1931 the main spawning took place at Røvær (V) and Utsira (VI) which areas are situated farthest from the coast. At Utsira, where great herring masses were present, no fishery took place. The spawning on the banks at the S and W of Karmøy (VIII—IX) and inside Karmøy (X—XI) was very unimportant, but in the more northern areas (II—IV) a somewhat more intensive spawning took place. The Egersund district no investigations were made but the fishery was not very rich here. It seems that the herring mostly remained on the outer grounds and that no important immigration near to the shore took place. The land seine fishery was also unusually poor. The fishermen could localize the herring with the lead line but only in deep water, and even in the night the herring did not rise to the upper layers. Owing

to this no great catches were taken by purse seines and most of grab hauls with herring roe (67 %) were made at depths of 50—150 m and only 33 % of the hauls at depths less than 50 m.

In 1932 the situation was quite different. A rich spawning took place on all the inner banks especially at the SW of Karmøy while the spawning at Utsira and Røvær was very unimportant and the fishery at the latter places was a great failure. Also at Egersund the spawning was good. In all the quantity of roe found in the year 1932 was twice as great as in the year 1931 and also the bottom net fishery was twice as productive (1.2 and 0.6 mill. hl respectively). The purse seine fishery was very rich. Due to the great quantities of spring herring landed and the difficulties in disposing of the catches, the fishermen were recommended to stop the fishery at the end of February. The herring roe was deposited in shallower water in 1932 than in 1931 and 60 % of all the stations with roe were situated within the 50 m-line.

In 1933 the spawning was rather poor over the whole district and no spawning seems to have taken place on the more northern grounds, on Sletta (II, III). The Egersund district was not investigated. The estimated values from this year are as already mentioned, however, perhaps not quite reliable. The bottom net fishery was not very rich but the purse seine fishery was rather good.

Also in 1934 no, or a very unimportant, spawning took place on the northernmost grounds I—IV. The spawning at Røvær and Utsira (V, VI) was somewhat richer than in the year 1932 but the main spawning took place W and S of Karmøy (VII—IX), and especially off Åkrehavn (VII) great herring masses were present. In the more southern areas, Kvitsøy—Egersund, no spawning took place and only on the Siragrunn some roe was found. The quantity of herring caught was the smallest for many years and this was mainly due to stormy weather. As we have seen rather great herring masses were present but especially concentrated to the area VII and at a time when strong gales hindered the fishery. The fishermen thought, however, that the herring also occurred in too deep water. In any case the fishery with purse seines was a failure in spite of these nets being up to 40 fathoms deep.

In 1935 a very rich fishery took place and great herring masses were present not only at Karmøy but also at Utsira. In the same manner as in the previous year the most intensive spawning occurred in the Åkra area (VII), but stormy weather hindered the fishery there. Also at Utsira no great quantities were caught in spite of much herring being present. Due to the bad fishery at the Egersund district in the previous year the fishermen was of the opinion that the herring was disappearing from this district. However a rather intensive spawning took place

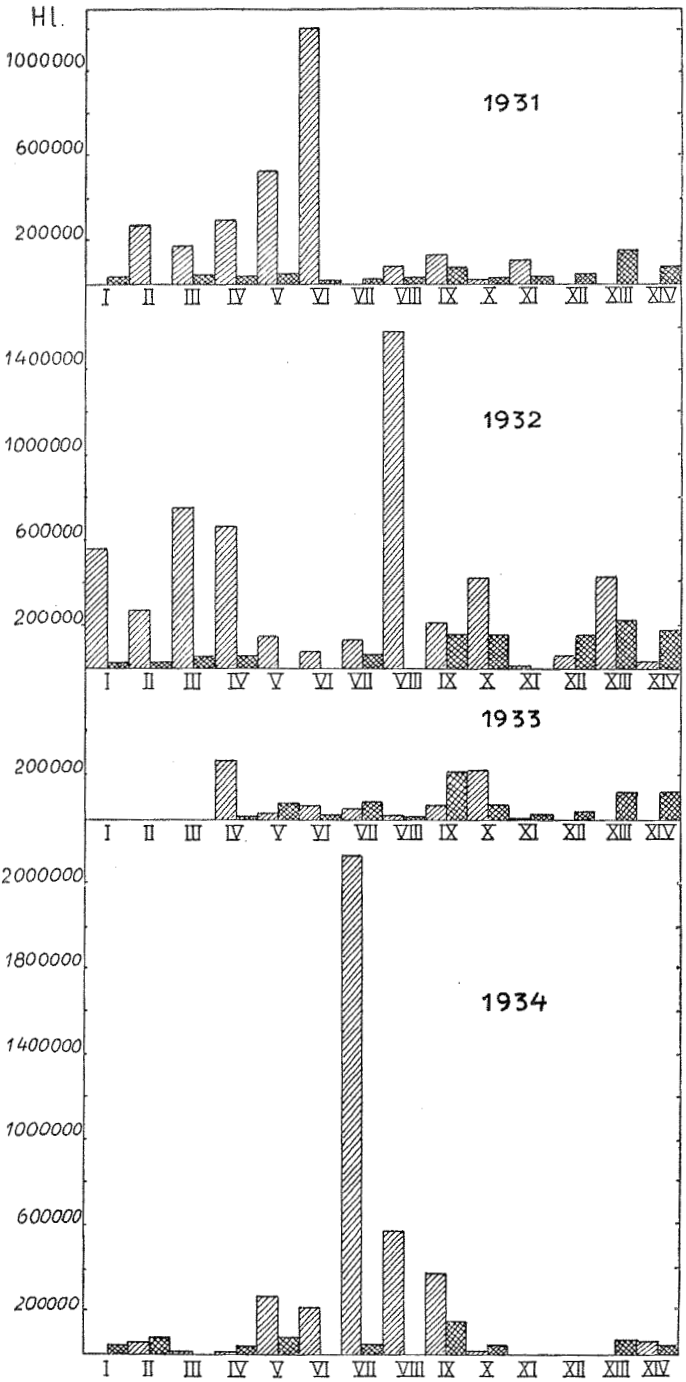

Fig. 16, a & b. As fig. 15 and specified for each spawning ground (roman numerals refer to fig. 3. See text under fig. 8.

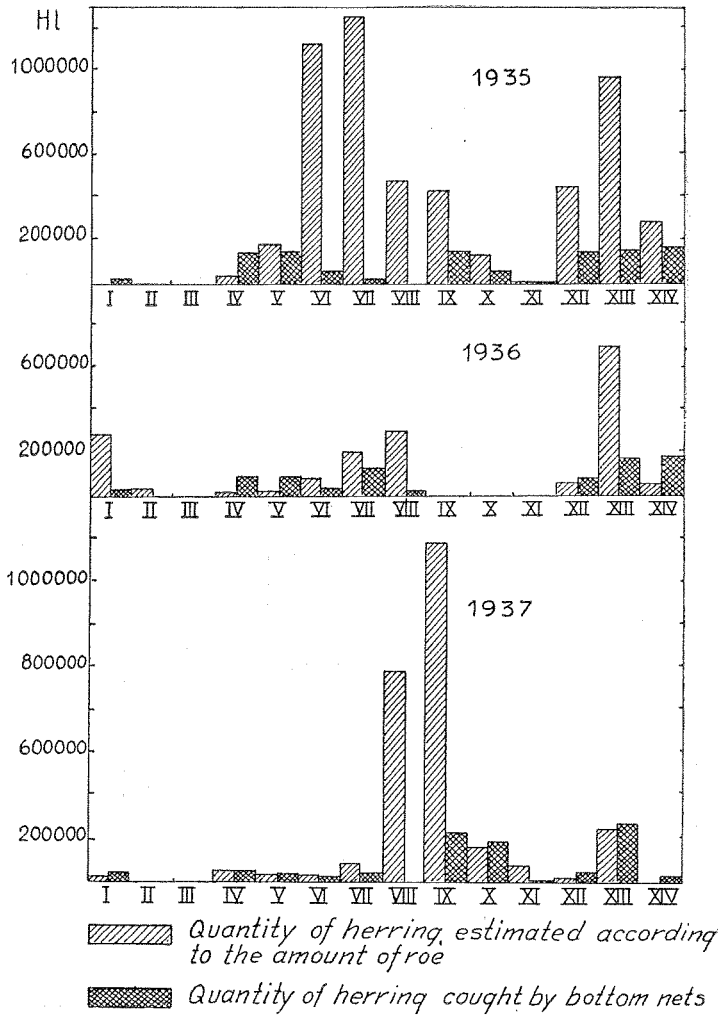

Fig. 16 b.

on the banks from Håstein to Siragrunn (XII—XIV). Also the greatest bottom nets catches, or about 50 % of the whole quantity, was taken in these southern areas. On the northern grounds I—IV no or only an unimportant spawning took place in the same manner as in the two previous years. This phenomenon is remarkable as we know that a great immigration of recruit spawners took place in the year 1935. However after the main fishing had ended an unexpected rich land seine fishery again began at the end of March and lasted to the middle of April. This fishery mainly took place in more northern areas off

Table 9. *Estimated quantity of Spring herring and quantity caught district in the years*

Area	1931		1932		1933	
	estimated	caught	estimated	caught	estimated	caught
I	—	(29.000)	565.000	13.000	—	(15.000)
II	281.225	600	268.203	7.000	0	0
III	181.256	36.500	744.480	44.000	0	0
IV	203.655	30.000	666.088	38.000	269.500	3.500
V	529.800	36.500	150.014	0	7.310	64.500
VI	1.215.603	7.500	87.205	0	61.837	14.000
VII	0	0	126.957	62.000	41.256	85.000
VIII	86.400	24.500	1.593.805	158.000	13.142	0
IX	138.640	85.000	203.549		62.142	217.000
X	6.500	20.000	421.542	146.000	220.062	56.000
XI	106.212	25.000	15	0	126	19.000
XII	—	(33.500)	44.161	243.000	—	(26.000)
XIII	—	(152.000)	525.000	220.000	—	(120.000)
XIV	—	(80.000)	13.300	185.000	—	(120.000)
Total	2.749.291	294.600 (560.100)	5.409.319	1.116.000	675.375	459.000 (740.000)

and N of Bergen. Apparently the recruit spawners arrived later and to more northern areas than usual.

The winter herring fishery in the year 1936 was the richest ever noted. This was, however, due to a very rich large-herring fishery while the spring herring fishery was rather unsuccessful. This was partly caused by the exceptional phenomenon that no spawning took place on the usual fishing grounds at the south end of Karmøy (IX) and at Bokn (X) as shown in fig. 16 and where the bottom net fishery was complete failure. Also at the west coast of Karmøy (VII—VIII)

by bottom nets on the different spawning grounds of the southern 1931—37 (in hektolitres).

1934		1935		1936		1937	
estimated	caught	estimated	caught	estimated	caught	estimated	caught
0	32.500	0	8.500	293.787	16.000	18.335	29.200
4.148	77.000	0	0	24.519	0	141	0
22	0	0	0	608	0	0	0
4	9.500	18.240	135.000	2.800	88.000	39.905	42.800
272.184	70.000	176.898	150.000	5.053	92.000	26.635	27.800
210.978	0	1.126.071	47.200	79.005	18.000	26.207	11.000
2.331.555	20.000	1.255.049	8.100	200.265	120.000	80.163	35.500
584.446	0	479.721	0	298.339		974.542	
382.774	140.000	434.112	138.500	0	9.000	1.584.578	225.000
2.003	28.000	125.322	53.500	—	0	162.476	195.000
—	0	—	0	0	0	72.033	0
—	0	446.076	138.500	47.184	72.600	725	44.000
0	60.000	965.821	209.000	697.449	170.000	235.080	272.800
43.167	32.000	289.313	168.000	40.307	186.000	0	26.000
3.831.281	469.000	5.316.535	1.056.300	1.689.316	771.600	3.220.820	909.100

no important spawning took place. The same was the case at Utsira, and on the more northern grounds practically no spawning took place with exception of the northernmost area (I) where recruit spawners appeared at the end of the season. In the southern part of the spring herring district, however, a rather rich spawning took place and the main bottom net fishery was done from Kalsmedgrunn to Siragrunn in the same manner as in the previous year. The purse seine fishery in the spring herring district was also very bad and the land seine fishery gave the smallest quantity on record for many years. The fishermen assumed

that rather great quantities of herring were present but occurring in too deep water and too far from land.

The situation in the year 1937 has already been discussed in the previous chapter. Only at Karmøy a fairly rich spawning took place, while the great herring masses registered by echo sounding at Utsira and Røvær remained in deep water outside the spawning banks. At Egersund smaller quantities of roe were found than in the two previous years and at Siragrunn no spawning took place at all.

The quantitative investigations on the spawning grounds thus have demonstrated that the spawning on the different coastal banks may fluctuate very much from year to year independently of the size of the herring stock. In certain years there may be a very rich spawning on the shallow banks while in other years the spawning may be poor or the herring entirely fail to appear on certain grounds in spite of the presence of great herring masses outside the banks. In the latter case the herring mainly remain in deep water and farther from land. This was apparently more or less the case in the years 1931, 1934, 1936 and 1937 while in the years 1932 and 1935 a rich immigration to the coastal banks took place.

It is apparent that the changing habits of the herring in the different years must have a great influence on the yield of the fishery. The bottom net fishery, which is the most important in the southern spring herring district, is dependent on the immigration of the herring to the habitual coastal banks as for the land-seine fishery it is of importance that the herring come close to the shore. When the herring occurs in too deep water the purse seines are also unable to catch the herring. In former days, when bottom nets and land seines were the only implements used, the fishery must have been still more dependent on the herring approaching close to the shore.

THE RELATION BETWEEN THE SPAWNING IMMIGRATION AND THE HYDROGRAPHICAL CONDITIONS IN THE SPRING HERRING DISTRICT.

As already mentioned in the introduction the swedish investigators EKMAN and PETTERSSON (1891) have shown that the migration of herring to the Bohuslen coast in winter was dependent on the occurrence of Bank water with a salinity of 33—34 %: when the Bank water was replaced by the cold and less saline Baltic water (salinity below 30 ‰) the herring indeed disappeared from the coastal areas.

As regards the spring-herring fishery on the west coast of Norway is is an old experience of the fishermen that the spring-herring avoids very cold water. This has also been confirmed by observations made by JENSEN (1881) and BUCH (1883). In the same manner as the swedish investigators J. HJORT (1895) also concludes that the Baltic current seems to drive the herring away from the coast.

With exception of the more sporadic observations made by the authors cited above, no regular hydrographic observations have, however, been made in the spring-herring district during an extended period. In the years 1931—37 therefore a number of hydrographic sections were made in the spring-herring district during the spawning season. The sections made in the different years were mainly the same as indicated for the year 1937 in fig. 17. With exception of the year 1931 an additional, more southern, section was made, starting near Egersund. In certain years sections were also made across the Norwegian Deep and in the years 1935—37 also across the northern North Sea. Some of the sections in 1937 have already been utilized by EGGVIN (1940) in a paper on »The movement of a cold water front«. He has here in an excellent manner given a detailed description of the movement of the Baltic water along the Norwegian West coast in the year 1937 by means of combined research methods including surface water samples and thermograms taken on board the coastal mail steamers, weekly observations in all depths at a selected place, the Sognesjø (entrance of the Sognefjord) and oceanographic sections in the spring-herring district. These investi-

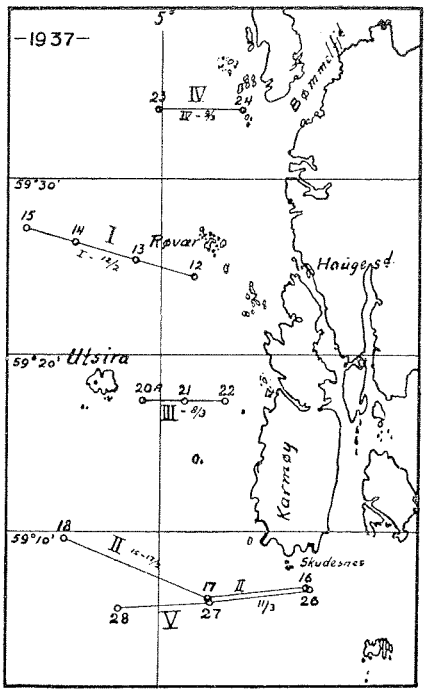

Fig. 17. Oceanographical sections executed in the spring of 1937. (Approximately the same program was carried through in the years 1931—36).

gations have been a valuable help to me and I will therefore in the first instance discuss the situation in 1937.

As a summary of the situation in 1937 EGGVIN writes: »The continuous south-easterly gales along the west coast were certain to bring about a strong wind-drift of the upper layers, with one component directed off-shore, and another in a northerly direction. This naturally resulted in great masses of coast water being conveyed out from land and then urged northwards upon this being replaced by the deeper, more saline and warmer water, the compensatory current in the depths would take on a component directed towards land towards the south. Consequently, in the month of February a comparatively very high salinity was present in the upper layers, which was succeeded by an unnormally low salinity in March and April. This occurred when the poorly saline, cold Baltic water, whose movement the same south-easterly winds had accelerated, reached in to the west coast«.

Two sections across the Norwegian Deep given in figs. 18 and 19 show the hydrographic conditions off the large-herring and spring-herring districts after the first radical change (mentioned by EGGVIN)

had taken place in January. The section in fig. 18 was made on Jan. 27th from Feie (north of Bergen) and about 40 nautical miles westwards. One finds the coastal water with salinities below 35 $^0/_{00}$ as a small triangular strip close to the coast while the deep channel is filled up with Atlantic water with salinities above 35 $^0/_{00}$. According to EGGVIN there was only 7 % coastal water in the section, the remainder being Atlantic water. Quite another situation was met with in a section made along the same course on Jan. 7th prior to the gales setting in. At that time there was 46 % coastal and 54 % Atlantic water which did not, however, reach the surface at any place along the section, at the coast being reached only at a depth of 180 m. On Jan. 27th Atlantic water was found right up to the surface only 12 naut. miles off Feie, while close to the coast it was met with at a depth of 85 m. Thus the wind-drift had caused an exchange of great water masses.

The section given in fig. 19 shows the hydrographical situation off the spring herring district at the beginning of the spawning season. The section was made on Feb. 3rd from Utsira and 40 naut. miles westwards. The day before herring had been observed at Røvær by means of echo sounding. It is seen that the Atlantic water has a much smaller extension than in the Feie section taken some days before, and it does not reach the surface at any place along the section. At the western part Atlantic water is met with at a depth of about 60 m, in the eastern part, close to Utsira, at a depth of 140 m. The mayor portion of the coastal water consists of North Sea water with a salinity of 34—35 $^0/_{00}$ and a temperature of 6—7° C. A wedge-shaped strip of bank water with a salinity of 33—34 $^0/_{00}$ and a temperature of 5—5.5° C is met with close to the coast and also as a thin surface layer in the western part of the Norwegian Channel. We have no observations from this area earlier in the season but probably also here changes have taken place due to wind action. The Bank water met with in the open sea probably represents coastal water driven westwards by the wind. The changes have not, however, been so radical as in the more northern area. In my paper on racial investigations I have also pointed out that the pre-spawning immigration of large-herring to the coast is apparently related to the inflow of more saline water to the large herring district.

As detailed in a previous chapter herring masses were recorded by echo sounding at Røvær, Utsira and at the south end of Karmøy (Skudefjord). Contemporaneously with the recording of herring shoals some hydrographical sections were made in these areas as shown in fig. 17. Section I given in fig. 20 was made on Feb. 12th from Røvær and about 26 km westwards. It is seen that the spawning ground within the 100 m-line was covered by Bank water with a salinity of 33—34 $^0/_{00}$

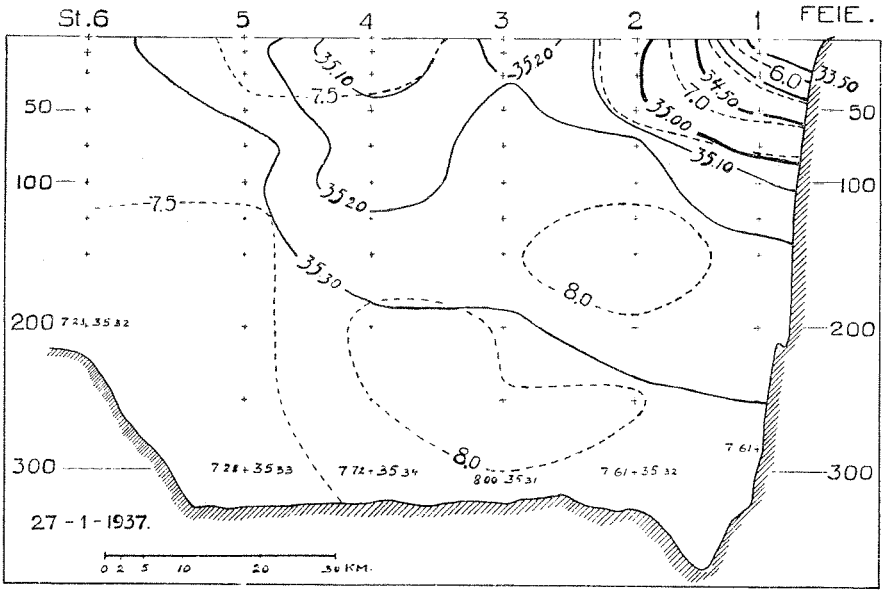

Fig. 18. Temperature and salinity in a section from Feie on Jan. 27th 1937 across the Norwegian Deep.

and a temperature of about 4—5° C. The slope of the deep channel was covered by North Sea water down to a depth of 200 m where Atlantic water was found. From station 13 and 11 km westwards to the outermost station herring was registered at a depth of 150 m, which is indicated by a hatched line. Further west no herring was found. The herring occurred in North Sea water, one edge of the shoal close to the slope, the other at the 35 $^0/_{00}$ isohaline, no herring being found in Atlantic water. As previously mentioned the herring shoal rose to a depth of 50 m at nightfall and at the same time moved along the slope of the bank as indicated by the upper shaded line. The spawning thus mainly takes place in Bank water (33—34 $^0/_{00}$).

Section II given in fig. 22 was made on Feb. 15—17th from the south end of Karmøy and about 25 km westwards. The innermost station 16 is situated on the spawning ground south of Karmøy and the two other stations, 17 and 18, are taken in the deep channel west of the spawning bank. At the innermost station Atlantic water is found below a depth of 200 m in the same manner as in the Røvær section. The North Sea water does not reach the spawning ground proper within the 100 m-line which is covered by Bank water. In contrast to the Røvær section one finds here a surface layer down to a depth of 40 m consisting of colder and less saline water (30—32) covering the Bank water. Further

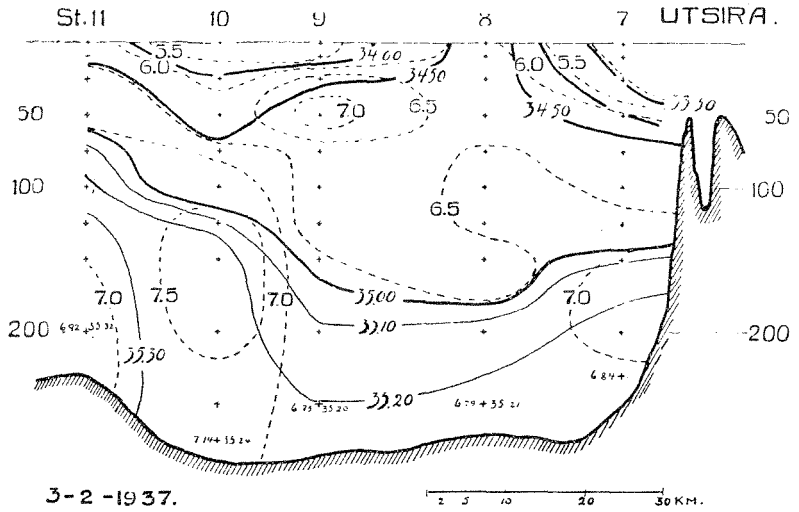

Fig. 19. Temperature and salinity on Feb. 3rd in a section from Utsira across the Norwegian Deep.

westwards, however, this layer is very thin. It is probable that we here have to do with poorly saline fjord water driven out from the great Boknfjord. As EGGVIN has stated the thermograph often shows a fall of the temperature when passing a fjord-mouth. In the year 1937 the thermograms indicated that cold water was transported out of the Boknfjord when the mail steamer was crossing the fjord on Jan. 16th and 22nd. In this section herring was recorded at a depth of 150 m somewhat west of the innermost station and at the outermost station, 18, we arrived at the edge of the great herring shoal recorded on Feb. 11th and 17th SW of Utsira (compare fig. 12). It is seen that the herring here also occurred in North Sea water, but when rising to the spawning grounds in the night they find Bank water within the 100 m-line where the main spawning occurs. Within the 40 m-line in the Karmøy area, however, the herring encounters less saline and colder fjordwater. The most intensive spawning accordingly took place here in depths between 40 and 60 m.

At the end of February and in the beginning of March the cold and poorly saline Baltic water reached the spring herring district as shown in fig. 24. In the upper part of the figure the salinity and temperature at the stations previously mentioned are given, in the lower part observations are given from stations at Egersund, Skudefjord and Røvær later in the season. One finds at Egersund already on Feb. 26th a surface layer, about 30 m thick, with salinities between 26 and 30 $^0/_{00}$. The sur-

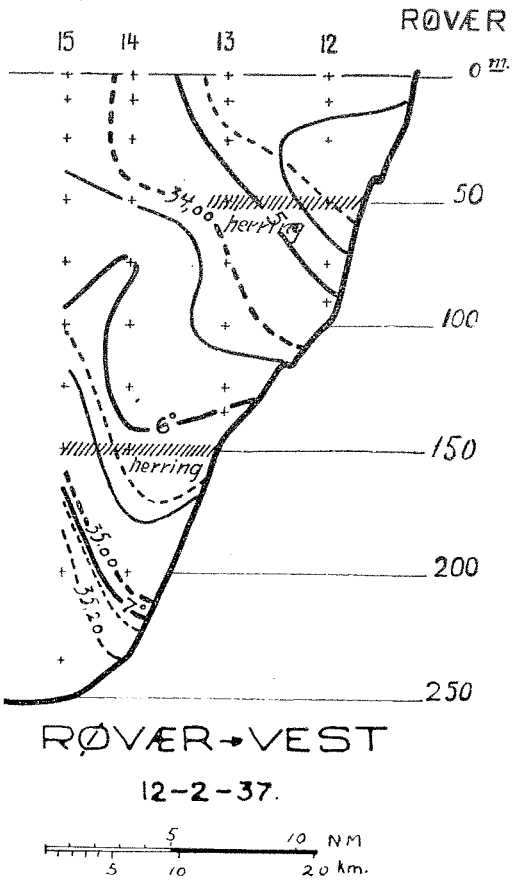

Fig. 20. Temperature and salinity off Røvær. Position and extent of herring shoal during day-time and in the evening shown. See p. 60.

face temperature was only 0.2° C. On March 10th and 11th the Baltic current had also reached the Skudefjord and Røvær where surface temperatures of 0.3 and 1.26° C respectively were noted. At the same time the Atlantic and North Sea waters have risen nearer to the surface, best seen in the Skudefjord section taken on March 11th (fig. 23). One sees that the Atlantic water close to the innermost station has risen from 200 to 150 m and the North Sea water has moved inwards to the spawning ground and is found at a depth of 60 m at the innermost station. Consequently the Bank water is reduced to a rather thin layer between the Baltic water and the North Sea water. Apparently most of the Bank water has been driven away from the spring-herring district and has been replaced by Baltic water at the same time as the more

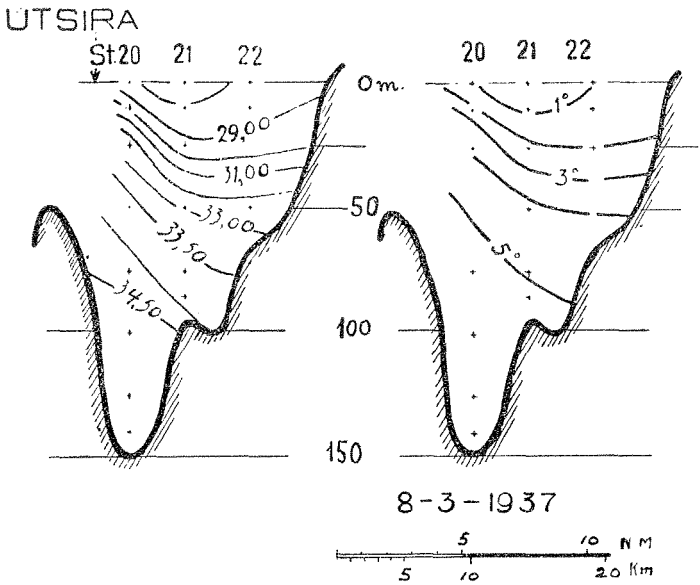

Fig. 21. Salinity and temperature in the waters between Utsira and Karmøy on Mar. 8th 1937.

saline deep-water has risen nearer to the surface. This process normally occurs in early summer but due to the SE gales the movement of the Baltic current has been highly accelerated. As the main spawning seems to occur in the more saline layers of the Bank water, these changes must be supposed to have an unfavourable effect on the spawning in the later part of the spawning season.

EGGVIN has by means of the various research methods already mentioned been able to follow the movement of the cold Baltic current along the coast. By means of the observations on the spawning time and the density of spawning in the different areas shown in figs. 11 and 16 I shall in the following discuss the effect on the spawning of the cold water front.

The cold water front reached Egersund already on Feb. 17th. According to EGGVIN it may be supposed that the thickness of the cold water layer was slight to begin with, but increased as time went on. On Feb. 26th the thickness of the layer was about 30—40 m. The average velocity of the current was about 12 naut. miles pr. day. The spawning on the grounds off Egersund began on Feb. 16th and was finished on Feb. 24th. The herring roe was deposited at depths from 44 to 75 m or just over the bottom area which according to the hydrographical station 19 in fig. 24 was covered with Bank water of 33—34 $^{0}/_{00}$.

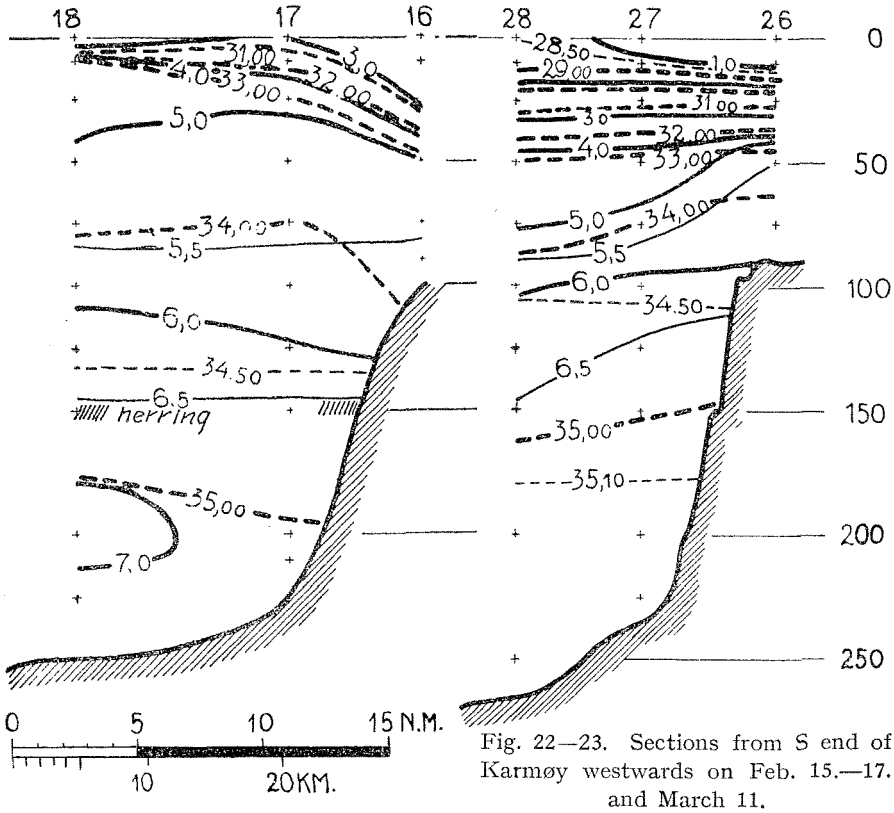

Fig. 22—23. Sections from S end of Karmøy westwards on Feb. 15.—17. and March 11.

salinity and a temperature of 4.5—5.5° C. Thus the spawning on these grounds was not entirely hindered by the cold water layer but the spawning was much less intensive than in the two previous years and it is possible that the herring disappeared from the grounds before all the eggs were deposited. On the more southern Siragrunn with depths less than 50 metres, however, no spawning at all took place, and the fishery entirely failed. According to the report of the fishery inspector herring roe, however, was found in deeper water during the succeeding saithe fishery.

On Feb. 25th the cold water front reached the south end of Karmøy. At this time however the spawning was finished south and west of the island and a very rich spawning had taken place in the period Feb. 7th to 20th.

Already on Feb. 26th the cold water was recorded on the thermograms across Sletta (north of Haugesund) and as shown by the hydrographic observations made at Utsira and Røvær on Feb. 8th to 10th a rather thick layer of Baltic water was present also at these outermost

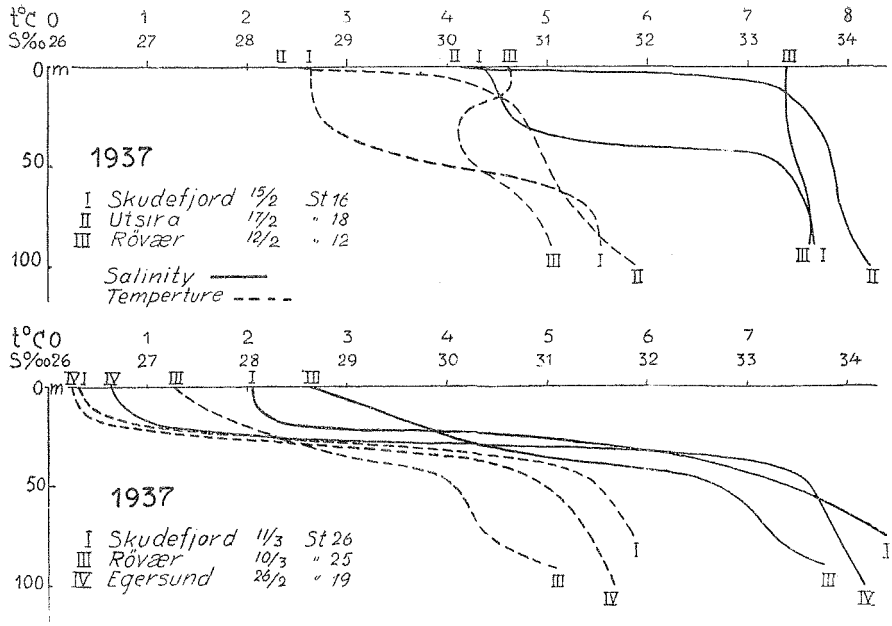

Fig. 24. Observations in February and March show a radical change in the oceanographical situation in the S. Spring Herring district. See fig. 25.

spawning areas in the beginning of March. As already reported great herring masses were present in these areas since the beginning or middle of February. Apparently this herring was not quite ripe when arriving and the spawning only began on Feb. 20th at Utsira and on Feb. 24th at Røvær and lasted until the first days of March when the herring masses suddenly disappeared. No large quantities of roe were found on these grounds and the eggs were deposited in rather deep water, in about 50 m to 130 and even 140 m. Apparently the herring disappeared before the main spawning due to the changes in the hydrographical conditions. As we have seen the herring moved northwards without visiting the more northern spawning grounds on Sletta and off Bømmelen where spawning usually takes place in the beginning of March.

There is apparently a close relation between the movement of the cold water front and the disappearence of the herring from the spawning grounds. This is however scarcely a direct effect of the presence of Baltic water which only reached to a depth of 30—40 m, the real cause is probably that the Bank water has been driven away from the coast by the wind and has been partly replaced by Baltic water, partly by salt deep-water. According to EGGVIN coastal water was found over great areas W of Feie in March where Atlantic water was found near to the coast at the end of January.

In the following I will give a short discussion of the hydrographical conditions in the years 1931—36 based on the figures 25 and 26 which show salinity and temperature observed near Røvær, Utsira, the south end of Karmøy (Skudefjord) and Egersund during the spawning season.

In *1931* a surface layer with salinities below 32 $^0/_{00}$ was found south of Karmøy down to a depth of 30 m. Bank water of 33—34 $^0/_{00}$ occurred in rather great depths from 60 to 100 m. At Røvær the Bank water was found from 50 to about 125 m. At Utsira, however, the Bank water was met with already at a depth of 10 m and here, accordingly, the warmest water was found. As we know the main spawning took place at Utsira and the northern banks while the spawning on the inner Banks at Karmøy was very unimportant. In the beginning of April the Bank water had entirely disappeared as shown by the observations in the Boknfjord.

In *1932*, however, the hydrographical situation was more favourable. The shallower parts of the spawning banks were covered by Bank water also at Karmøy where water of 33—34 $^0/_{00}$ occurred from 20 to 60 m and the surface layer of less saline water was rather thin. At Utsira the surface layer was, however, somewhat thicker and water of $33^0/_{00}$ was found at a depth of about 35 m. A temperature of 5° C was reached at a depth of only 5—10 m at all stations. At Egersund also rather saline water was found from the surface downwards and no signs of cold Baltic water was observed. In this year the fishery was indeed very rich, the herring migrating close in to the shore. The main spawning took place in the Karmøy areas, while the spawning at Utsira, lying farther from the coast, was very poor.

In *1933*, when the fishery as well the spawning on all the banks was rather poor, one found in February a strong stratification of the water masses with a layer of less saline water (32—33 $^0/_{00}$) close above the North Sea water which was met with only about 50 m below the surface. The Bank water (33—34 $^0/_{00}$) which seems to be the most favourable for the spawning, was reduced to a layer only 5—15 m thick. We have no observations from the Egersund area but the Fishery Inspector reports, that a strong westerly current in connection with SE wind was unfavourable for the fishery, and the herring visited only the outer slope of the banks.

In *1934* the fishery was a failure, mainly because of the stormy weather but the fishermen also ascribed the failure to no great herring masses being present. The total quantity of roe deposited was rather great but the spawning was chiefly concentrated to the area VII where the fishermen did not come in contact with the herring masses because of gales. On the northern grounds no spawning took place and also in the

Egersund district the spawning was very poor. As shown in fig. 26 the layer of Bank water (33—34 $^0/_{00}$ was rather thin in the Skudefjord and at Utsira North Sea water being met with at a depth of 40—50 m. At Røvær North Sea water covered the greater area of the Bank and was found only 30 m below the surface. Probably also the northern grounds have been covered by this salt water which was, apparently, unfavourable for the spawning.

In *1935* the spring herring fishery was very good, and a rich spawning took place at Utsira and Karmøy as well as in the Egersund district. In the northern areas from Røvær and northwards, however, no, or a very unimportant, spawning took place, in the same manner as in the previous year. As regards the hydrographical situation one finds that the spawning banks commonly were covered by Bank water, favourable for the spawning, from the surface down to a depth of about 50 m. The surface temperature was also very high. At Røvær the banks were, however, covered by North Sea water to a still greater degree than in the previous year and this water reached here up to the surface. Apparently the Bank water had entirely disappeared from the northernmost grounds and had been replaced by salt deep-water and, as mentioned no spawning took place here.

The situation in *1936* was remarkable as no spawning and also no fishery took place on the usual grounds at the south end of Karmøy and at Bokn in the inner part of the Skudefjord. A rich spawning occurred, however, at Egersund and to a lesser degree off the west coast of Karmøy and at Utsira. At Røvær and on Sletta the spawning was very poor. At Utsira and Egersund the hydrographic situation was rather favourable with Bank water at a depth of 20—30 m. A rather salt surface layer was present and no Baltic water had reached the southern part of the coast. At Skudefjord, however, a rather extensive poorly saline surface layer was found with only 30.2 $^0/_{00}$ at the surface. Apparently cold and poorly saline water, carried out from the inner fjord, had an unfavourable local effect on the spawning in this area. In the Røvær area the salinity at the surface was comparatively high, but Bank water, favourable for the spawning, occurred only as a deep layer (at 70—100 m) and temperatures above 5° C were only met with at depths greater than 90 m. As already stated the spawning on the northern grounds was a failure.

Summarizing these experiences, it has been established that great fluctuations in the spawning immigration to the coastal banks take place. These fluctuations are closely related to variations in the hydrographical conditions. The main spawning seems to take place in water

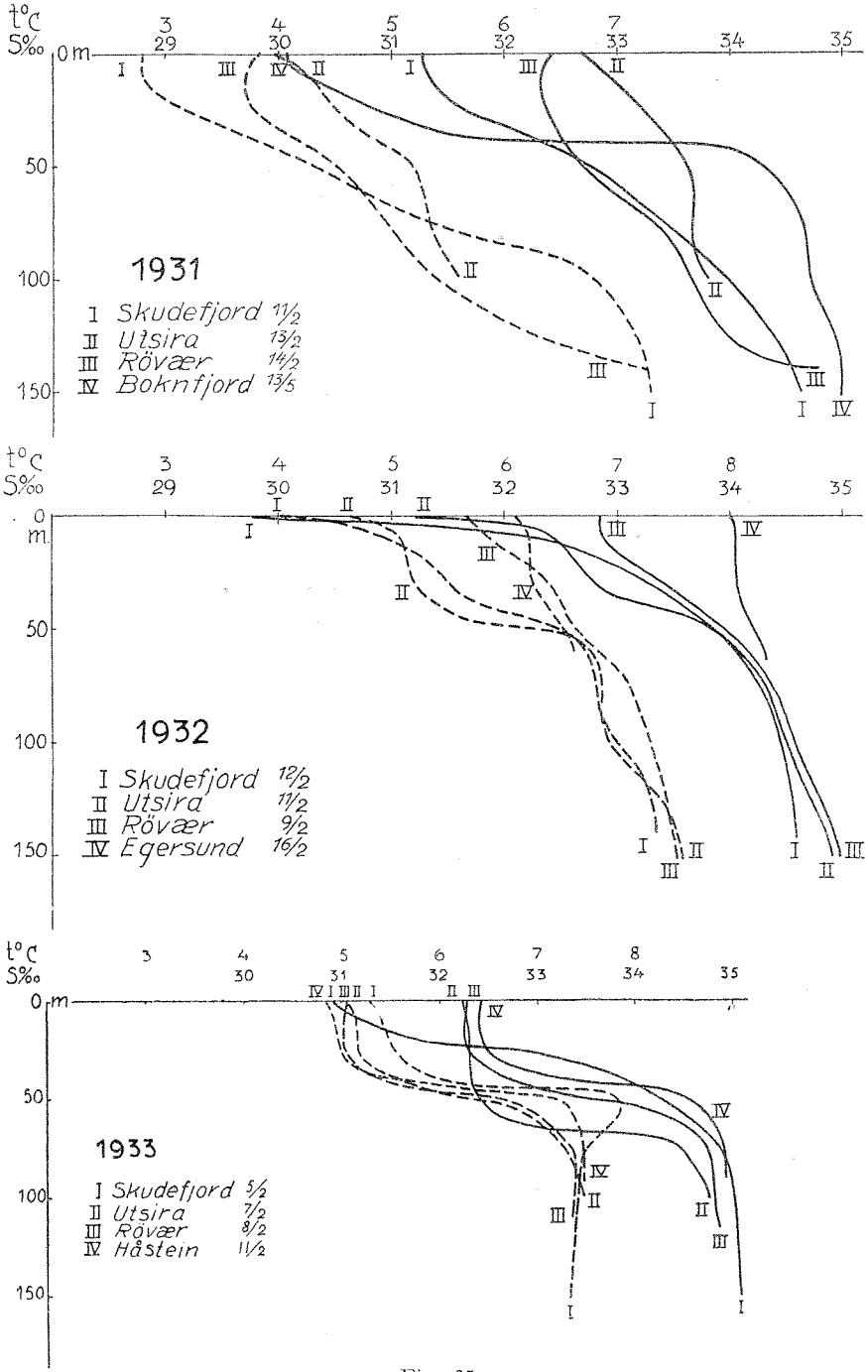

Fig. 25.

Main oceanographical features of each fishing season 1931—36 in the

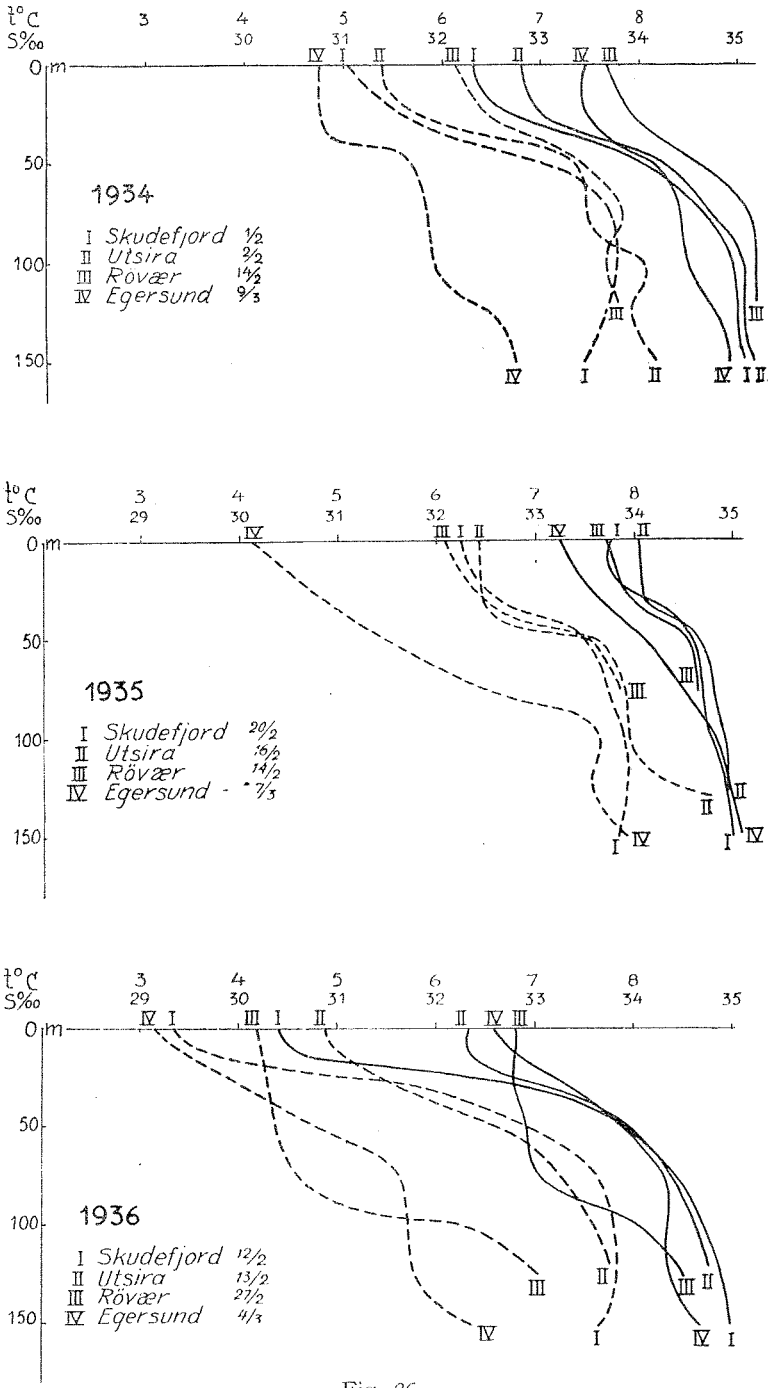

Fig. 26.

S. Spring Herring district. Broken lines: temperature, full-drawn: salinity.

characterized by a salinity of 33—34 ‰ and a temperature of 5—6° C. As the spawning is mainly limited to the banks within the 100 m-line due to the bottom conditions, it is of importance for a favourable spawning that the grounds be largely covered with Bank water. When the banks are covered by less saline surface water, or when the salt deep-water rises towards the surface, the herring do not enter the banks in order to spawn. One must therefore be careful in predicting the fishery on the basis only of the estimated relative strength of the herring stock. Unperiodical changes in the meteorological conditions may cause great shifts of the watermasses, suddenly altering the conditions for the spawning immigration to the coastal grounds. As EGGVIN (1940) has mentioned it will be of great interest to maintain some permanent hydrographic stations in the spring-herring district in order to follow the development of the hydrographical situation during the spawning season. It is also to be hoped that the observations in the northern North Sea, which have been continued in the later years, will in future throw some light upon the more periodical oceanographical changes and their influence on the herring fishery.

LITTERATURE.

BOECK, A. 1871: Om silden og sildefiskeriene, navnlig om det norske vaarsildfiske. Christiania.

BUCH, S. A. 1883: Indberetning til departementet for det indre. Christiania.

EGGVIN, J. *1937:* New oceanographic investigations in the northern North Sea. Rapp. et Proces- Verb. 105.

— *1940:* The movements of a cold water front. Fiskeridirektoratets Skrifter Vol. VI, Nr. 5.

HART, J. L. and TESTER, A. L. *1934:* Quantitative studies on herring spawning. Trans. American Fisheries Soc. Vol. 64.

HJORT, J. *1895:* Hydrografisk-biologiske studier over norske fiskerier. Kristiania.

— *1914:* Vekslinger i de store fiskerier. Kristiania.

JENSEN, O. S. *1881:* Indberetn. til Departementet for det Indre, Christiania.

LEA, E. *1928:* Sildeundersøkelser. Årsb. vedk. Norges Fiskerier.

— *1929:* The oceanic stage in the life history of the norwegian herring. Journ. Conseil, Vol. IV, Nr. 1.

— *1930:* Mortality in the tribe of norwegian herring. Rapp. et Proces- Verb. Vol. 65.

PETTERSSON, O. and EKMAN, G. *1891:* Grunddragen af Skageracks och Kattegats hydrografi. K. Sv. Ak. Handl., Bd. 24.

— *1891:* Om det hydrografiska tillståndet i Bohusläns skärgård vid tiden för vintersillfiskets upphörande. Öfvers. K. Vet. Ak. Förhandl., nr. 7.

RASMUSSEN, TH. *1939:* Fluktuasjoner i vintersildens utvikling og gytning. Fiskeridirektoratets Skrifter, Vol. VI, Nr. 1.

— *1940:* To raser innenfor den norske vintersild, Fiskeridirektoratets Skrifter Vol. VI, Nr. 4.

ROLLEFSEN, G. *1934:* The cod otholith as a guide to race, sexual development and mortality. Rapp. et Proces- Verb. 88.

RUNNSTRÖM, S. *1937:* Sildeundersøkelserne 1937, Årsberetn. Norges Fiskerier.

— *1941:* Racial analysis of the herring in norwegian waters, Fiskeridirektoratets Skrifter, vol. VI, nr. 7.

SOLEIM, P. *1940:* Sildelarvene på vårsildfeltet, Fiskeridirektoratets Skrifter, vol. VI, Nr. 4.

— *1940:* Storsildas og vårsildas gytefelter, Ibidem.

SUND, O. *1940:* Sildeundersøkelser i 1939, Ibidem.