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The Exploitation of the Spiny Dogfish (*Squalus acanthias L.*) in European Waters

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Introduction

It is generally agreed that the spur-dog stock is vulnerable to heavy fishing on account of the special biology of the fish. It is slow growing and requires a long time to reach sexual maturity. Moreover, it has a low reproductive potential. Once the damage has been done, long time will be necessary to build up the stock again even if no fishing took place.

The catch statistics

The European catch of spiny dogfish has shown a marked increase since the World War II which will be evident from Table 1 prepared on the basis of the catch figures published in ICES Bulletin Statistique. Unfortunately, it is not possible to arrive at the exact catch statistics of the spur-dog because the figures in the Bulletin Statistique comprise certain other species of sharks. (ICES, 1950—1962).

It will be seen that the total catch has increased from about 10.000 tons in 1945 to about 60.000 tons in 1961. Table 1 shows that the bulk of the catch is shared between four countries: England, Scotland, France and Norway. In addition to the information contained in Table 1 it may be mentioned, that in the years 1961—63 the Norwegian catch was on the average 30.384 tons.

The homogeneity of the spur-dog stock

It is reasonable to suppose that the spur-dog in the North-Atlantic is split up into two main tribes, which may be termed the North-West Atlantic stock and the North-East Atlantic stock. Extensive taggings in both areas have failed to bring to light any transoceanic migrations. On the European (excluding the Mediterranean) side the fish is caught from the Bay of Biscay to the Barents Sea (ICES statistical areas VIII and I). The commercial catches in the Barents Sea are taken mainly by USSR and in the Bay of Biscay by France. The main part of the spur-dog catches is taken in the statistical areas IVa and VIa by Great Britain and Norway.

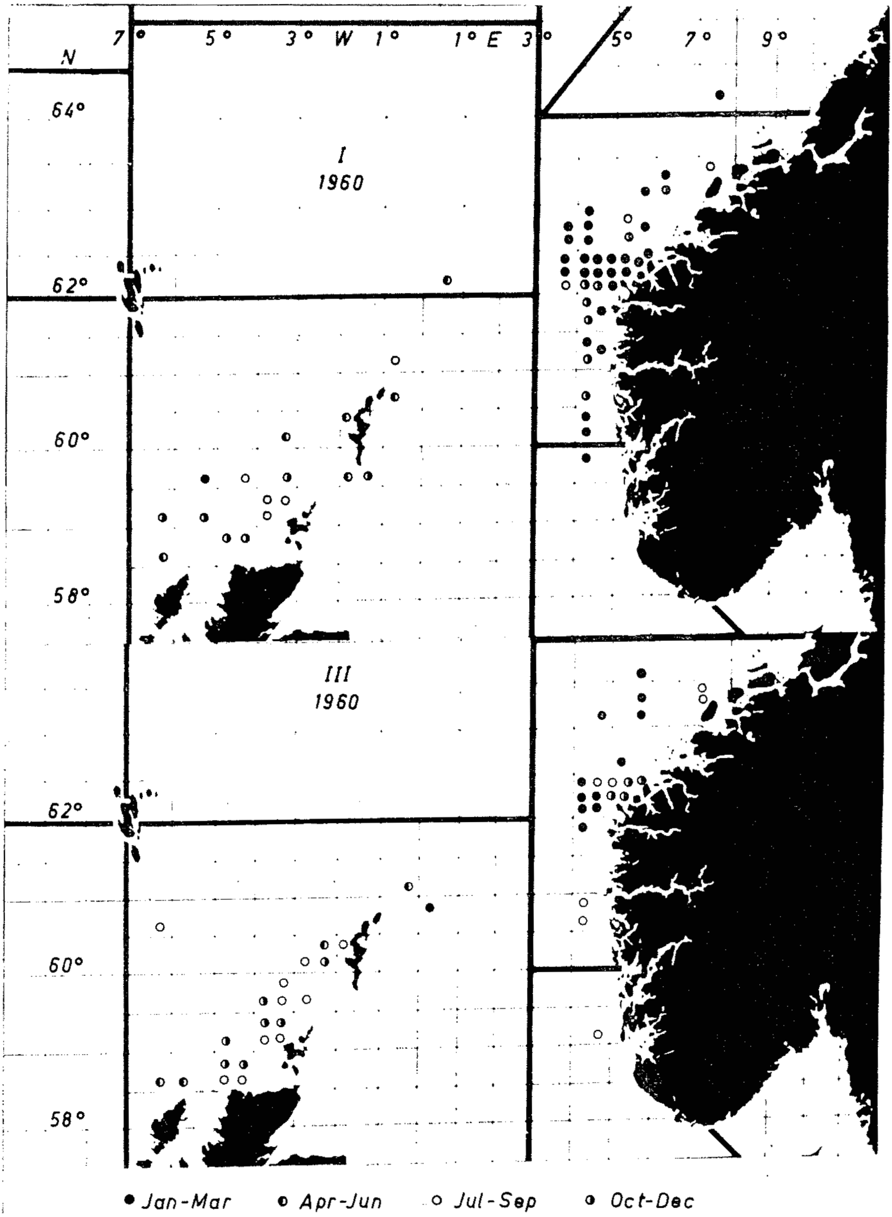

Fig. 1. The recaptures in 1960 from the first spur-dog taggings in: I Shetland waters (Nov. 1958, 1 000 fish) III Norwegian waters (Jan. 1960, 521 fish).

It is a question of some importance whether or not this stock is homogeneous. Norwegian taggings have demonstrated that there takes place a free intermixing between area IVa and VIa (Aasen, 1961, 1962,

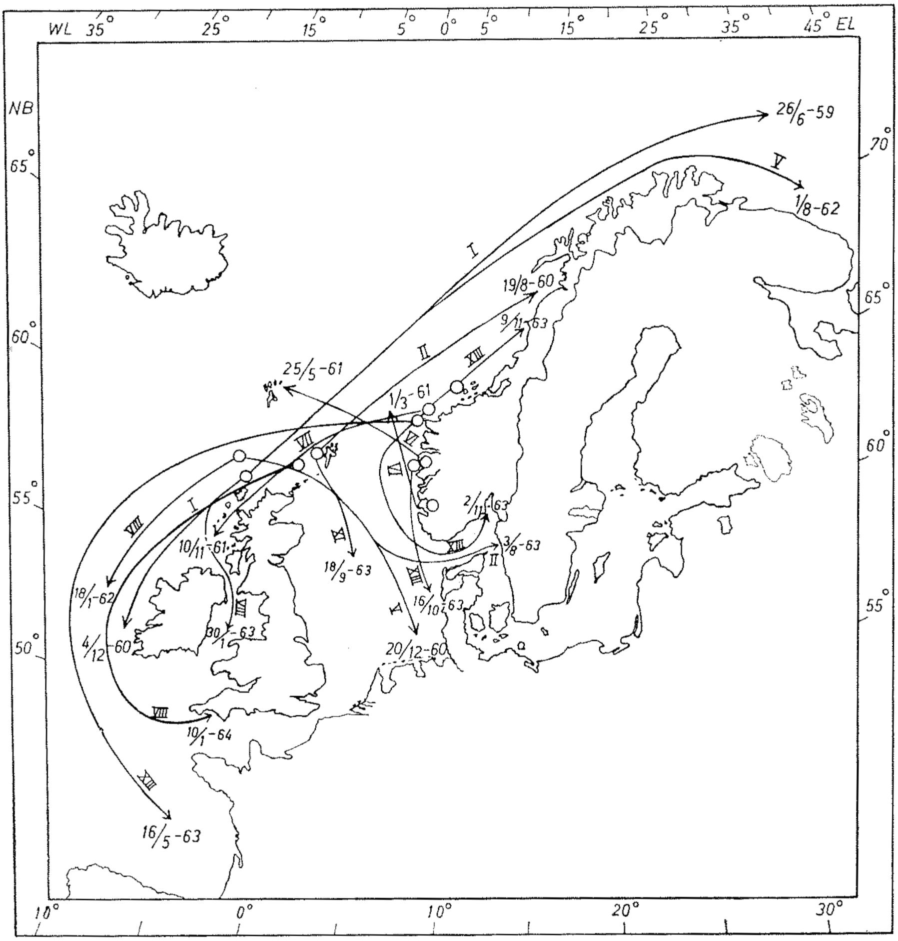

Fig. 2. Demonstration of some selected long distance migrations of spur-dog. ○ Liberation locality → 27/8—63: Time and place of recapture. Roman numeral: Experiment no. 00. (See Table 2)

1963a); but more occasionally recaptures from these same tagging areas have been recorded in the waters around Ireland and the Bay of Biscay and also in the Barents Sea. Obviously, the spiny dogfish is higly migratory, and it is possible that there is but one population with its main distribution in the areas IVa and VIa. In Fig. 1 is shown the distribution of the recaptures in 1960 from the first Norwegian taggings in Shetland waters and the first Norwegian taggings on the Norwegian coast. In Fig. 2 are illustrated some long distance migrations which may be taken as indicating the extremes of the distribution centered in the areas IVa and VIa. However, further and more extensive taggings will be necessary

Table 1. *European catch (metric tons) of spur-dog (etc.)*

Year	Europe	Nor-way	Bel-gium	Eng-land	France	Ger-many	Por-tugal	Scot-land	Den-mark
1945	9.868	2.323	315	4.090	—	—	3.092	—	1
1946	14.615	2.868	939	5.633	—	1.265	3.720	—	7
1947	20.053	6.090	1.150	7.001	—	608	3.160	—	2.017
1948	22.943	4.659	1.946	9.188	—	1.180	3.452	—	2.061
1949	26.095	6.350	1.682	11.027	—	1.621	3.085	—	1.726
1950	27.832	7.500	1.031	9.585	4.180	763	2.526	—	1.897
1951	37.827	12.577	1.007	13.392	5.170	1.245	2.526	—	1.641
1952	42.196	14.403	995	14.404	7.357	1.224	1.643	—	1.892
1953	40.087	15.217	991	11.839	7.914	861	1.879	—	1.187
1954	41.531	18.325	782	10.153	7.589	1.468	956	1.296	823
1955	44.038	18.874	960	11.084	8.200	1.138	848	1.778	816
1956	48.191	22.895	1.004	9.453	7.859	1.619	1.090	2.629	672
1957	46.642	20.574	1.188	9.677	7.352	1.386	900	3.728	694
1958	51.474	24.653	1.243	9.183	8.033	1.615	936	3.897	812
1959	48.833	21.034	1.232	8.819	9.191	1.747	1.242	3.655	728
1960	55.531	28.221	1.573	7.651	9.546	1.770	1.144	4.112	583
1961	59.442	33.762	1.538	5.982	9.389	1.449	1.156	4.574	260

to clear up this point. In the meantime, Mr. Holden's statement about a Scottish-Norwegian stock and a Channel stock may be accepted (Holden, 1964).

The mortality in the spur-dog stock

The taggings of the spur-dog may also yield information about certain aspects of the dynamics of the population. It is a common knowledge for all taggings that some tags will be lost for various reasons (e.g. shedding, tagging mortality, etc.). Taken by themselves the recapture percentages will in general give biased information about the exploitation of the stock. Table 2 shows the accumulated data from the Norwegian dogfish taggings.

The usual procedure of obtaining an estimate of the total mortality from tagging data, is to plot the natural logarithms of the recaptures against the time in liberty. The slope of the best fitting straight line gives the total instantaneous mortality coefficient. As a rule, the method involves some sort of grouping of the recaptures in fixed time intervals. If the catch is changing substantially, it will be necessary to correct the recapture figures accordingly. The data from the Norwegian dogfish taggings are treated this way, chosing one year as the time interval and correcting according to English, Scottish and Norwegian catch figures for the appropriate years. The results are entered in Table 2.

Table 2. *Norwegian taggings of spur-dog.*

Taggings					Recoveries (number)			
Exp.	*n*	Year	Month	Area	1960	1961	1962	1963
I	1 000	1958	Nov.	Shetland	59	28	15	9
II	989	1959	—	—	55	31	17	11
III	521	1960	Jan.	Norway	49	26	6	2
V	969	1960	July	Shetland		45	8	6
VII	894	1961	Jan.	Norway		75	27	12
VIII	1 000	1961	Nov.	Shetland			62	36
X	370	1962	Jan.	Norway			35	22
XI	1 022	1962	Nov.	Shetland				47
XIII	946	1963	Jan.	Norway				62
Total catch (t) U.K. and Norway					35.187	40.088	35.149	37.140

0/00 pr. 10 000 tons (r)					$\log_e r$			
Exp.	1960	1961	1962	1963	1960	1961	1962	1963
I	16.77	6.98	4.27	2.42	2.8196	1.9430	1.4516	0.8838
II	15.80	7.82	4.89	2.99	2.7600	2.0567	1.5872	1.0953
III	26.73	12.45	3.28	1.03	3.2858	2.5217	1.1878	0.0296
V		11.58	2.35	1.67		2.4493	0.8544	0.5128
VII		20.93	8.59	3.61		3.0412	2.1506	1.2837
VIII			17.64	9.69			2.8702	2.2711
X			26.91	16.01			3.2925	2.7732
XI				12.38				2.5161
XIII				17.65				2.8708

In plotting these data, it will be seen that there are variations in the slopes of the lines from the various experiments and particularly in their intercepts on the y-xais. This last feature is interpreted as being due to varying initial success of the taggings, i.e., the differences are in a way relative measures of the tagging mortalities. In the present case, experiment I is chosen as a standard and the others are corrected accordingly where the tests of significance show values outside the range of random errors. The adjusted figures are entered in Table 3, where also the calculation of the regression is shown. From this it appears that the estimate of the average total instantaneous mortality rate in the years 1960—1963 amounts to 0.7212, and this high figure is indeed a danger signal. Fig. 3 gives a graphical demonstration of the regression.

The Catch/Effort data

In view of this striking result, an attempt was made last autumn (1963) to collect data from the fishing effort in order to elucidate whether

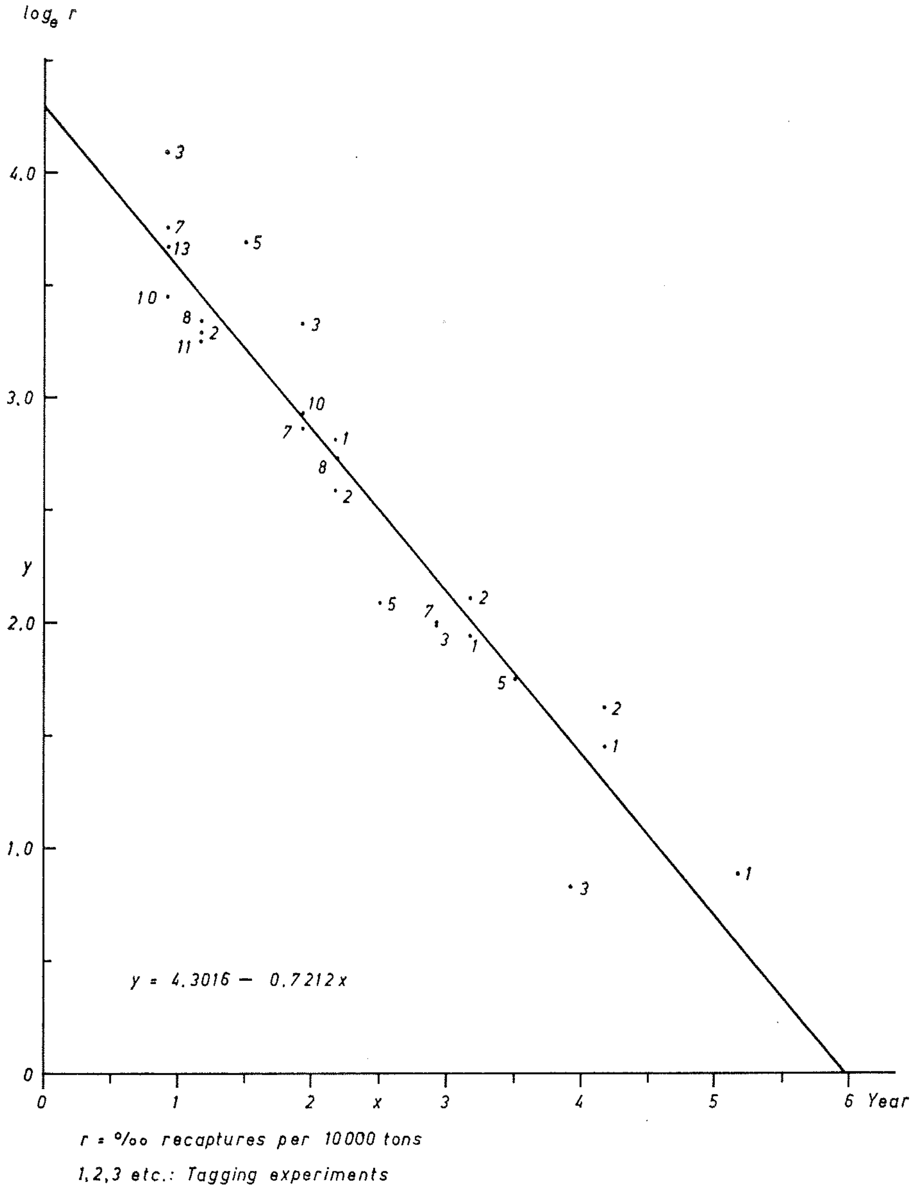

Fig. 3. The mortality in the spur-dog stock. All Norwegian taggings in the open sea combined.

or not a biological overfishing was taking place. It proved impossible to arrive at back data from the actual fishery; but a certain measure of the catch/effort was obtained from various dealers by comparing the landings

Table 3. *Norwegian spur-dog taggings (adjusted log values) x = years in liberty ; $y = \log_e r$.*

Exp.	1	2	3	5	7	8	10	11	13
x	2.17	1.17	0.92	1.50	0.92	1.17	0.92	1.17	0.92
	3.17	2.17	1.92	2.50	1.92	2.17	1.92		
	4.17	3.17	2.92	3.50	2.92				
	5.17	4.17	3.92						
y	2.8196	3.2896	4.0915	3.6886	3.7595	3.3339	3.4514	3.2522	3.6069
	1.9430	2.5863	3.3274	2.0937	2.8689	2.7348	2.9321		
	1.4516	2.1168	1.9935	1.7521	2.0020				
	0.8838	1.6249	0.8355						
Σ	x	y	x^2	y^2	xy				
	56.57	62.4394	167.4519	181.8505	122.5715				

$$n = 24,;\ \bar{x} = 2.3571\ ;\ \bar{y} = 2.6016\ ;\ y = \bar{y} + b\,(x - \bar{x})$$

$$b = \frac{S\,(xy) - n\bar{x}\bar{y}}{S\,(x^2) - n\bar{x}^2} = -0.7212\ ;\ y = 4.3016 - 0.7212\,x$$

with the amount of bait used, a method which is justified by the circumstance that the Norwegian spur-dog catches are taken almost exclusively by long lines.

Denoting the average catch per unit of effort by $\bar{U}$ (expressed as tons per 1.000 boxes (50 kg) of bait), the following series was obtained:

Year	1957	1958	1959	1960	1961	1962	1963
$\bar{U}$ ...	1104	1008	907	835	803	765	717

These figures cover about 10% of the total Norwegian landings in Målöy which is the chief port for the spur-dog fishery. The series shows a heavily declining stock, but it may, of course, be argued that a cover fraction of 1/10 is too low; for instance, a calculation of the standard error of random sampling in the series shows an average value of 38 tons. In order to follow the further development more closely, a special service was established in Målöy by the Norwegian Marine Research Institute for a more extensive and detailed collection of catch/effort data. For the last 3 months of 1963, when this service has been in operation, the average figure $\bar{U}$ was 696, and thus in fact not very different from the result obtained from other sources. It seems, therefore, justifiable to place some confidence in the obtained series of the catch per unit of effort data.

The stock assessment

Using these figures in Schaeffer's model for estimation of the equilibrium catch (C_e) and the catch figures from the ICES statistical areas:

Table 4. *Spiny dog-fish ICES statistical areas : VIa, IVa, IVb, Vb, IIa, IIb, I, IIIa*

	1957	1958	1959	1960	1961	1962	1963
Catch (C)	34.380	38.797	32.487	43.940	48.570		
Catch/Effort ($\overline{U}$)...........	1 104	1 008	907	835	803	765	717
$\triangle U = \frac{\overline{U}n+1 - \overline{U}n-1}{2}$....		—98.5	—86.5	—52.0	—35.0	—44.0	
$\triangle U/\overline{U}$		−0.09772	−0.09537	−0.06228	−0.04359	−0.05752	
$C/\overline{U}$	31.141	38.489	35.818	52.623	60.486		
P ....(t).................	119.222	108.855	97.948	90.173	86.717	82.613	77.430

$$1/k_2\ (-0.09772) = a\ (M - 1\,000) - 38.489$$
$$1k_2\ (-0.09537) = a\ (M - 907) - 35.818$$
$$1/k_2\ (-0.06228) = a\ (M - 835) - 52.623$$
$$1/k_2\ (-0.04359) = a\ (M - 803) - 60.486$$
$$M = 1\,111,\ a = 0.174,\ k_2 = 0.00926$$

I, IIa, IIb, IIIa, IVa, IVb, Vb and VIa, four equations may be constructed (SHAEFFER, 1957):

$$1/k_2 \frac{\Delta U}{\overline{U}} = a\,(M - \overline{U}) - \frac{C}{\overline{U}} \text{ where}$$

k_2, M, and a are constants, C the total catch in tons, $\overline{U}$ the catch/effort, and ΔU the difference in $\overline{U}$ from one year to another (Table 4). The calculations yield as result: $k_2 = 0.00926$, $M = 1111$, and $a = 0.174$. The constant k_2 expresses that the catch per unit of effort is directly proportional to the available stock: $\overline{U} = k_2\overline{P}$. With the obtained estimate of k_2, the following stock levels are found (in tons):

Year	1957	1958	1959	1960	1961	1962	1963
$\overline{P}$	119000	109000	98000	90000	87000	83000	77000

The equilibrium catch is, according to Shaeffer, the amount which can be taken out of the stock without altering the stock level, or in other words, C_e equals the rate of natural increase. Denoting the fishing intensity ($C/\overline{U}$) by F, the following equation for C_e is obtained [$C_e = \frac{F}{a}\,(Ma - F)$]:

$$C_e = 5.747\;(193.333 - F)F$$

In form this function represents a parabola with its axis parallel to the y-axis (Fig. 4). The top of the parabola may be found by derivating the function. This gives:

$$C_e' = 1111 - 11.494\,F = 0;\; F = 96.693$$

and the maximum sustainable yield is accordingly 53.701 tons.

The accuracy of these figures is naturally dependent on the precision of the catch and effort data. As an illustration to this, an attempt is made to eliminate the "etc." in the Bulletin Statistique's catch figures by multiplying them with 0.9. (The quotient between the figures in the official Norwegian statistics and in Bulletin Statistique). The calculations yield the following results: $M = 1103.8$, $a = 0.1576$, and $k_2 = 0.00930$. With these figures a maximum equilibrium catch of 48000 tons is found, corresponding to an F of 86.980. If the Norwegian catch figures only are used, the results will be: $M = 1056$, $a = 0.1256$, and $k_2 = 0.0104$, giving C_e max $\sim$ 35.000 tons and $F \sim$ 67.000.

Discussion

The total instantaneous mortality rate found from the tagging data, can be used to indicate which set of catch figures should be used for calculations of k_2, M, and a. In 1961 the total European catch (Dogfish etc.)

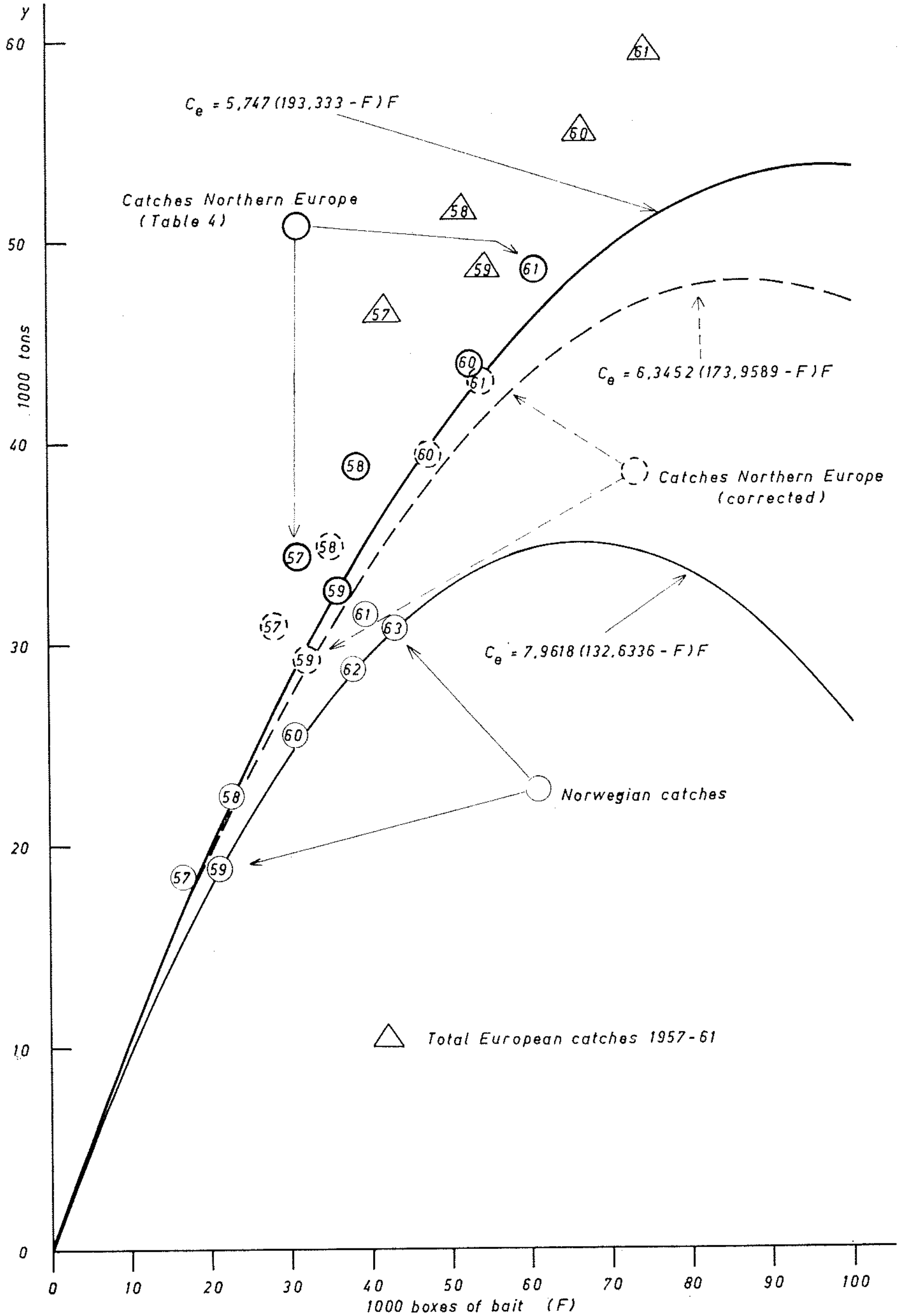

Fig. 4. Graphical demonstration of the equilibrium catch. Shaeffer's model. Norwegian catch per unit of effort data. Catch figures from Bulletin Statistique and Norwegian Official Statistics. For further explanation see text.

was 59.442 tons, in the northern area 48.570 tons (Table 4) the corrected value in the same area 43.173 tons, and the Norwegian catch 31.470 tons. This gives the following values of F in the same order: 74.025, 60.486, 53.765, and 39.210. The instantaneous fishing mortalities are accordingly: 0.62, 0.56, 0.50, and 0.41. Comparing these figures to the total instantaneous mortality coefficient found from the taggings, the following series for the natural instantaneous mortality rate is obtained: 0.10, 0.16, 0.22, and 0.31. Of these 0.16 is judged the most likely one, since the von Bertalanffy growth constant K for the spur-dog is 0.11 for females and 0.21 for males (HOLDEN and MEADOWS, 1962). Further, the natural instantaneous mortality rate for the porbeagle, with a similar longevity, is calculated to 0.18 (AASEN, 1963b). Accordingly, the uncorrected catch figures from the northern area seem to give the best fit. A reasonable estimate of the maximum sustainable yield is therefore about 50.000 tons, and as seen was this level, practically speaking, reached in 1961 for the northern area.

The present analysis seems to show that no irreparabel damage has so far (1961) been inflicted on the spur-dog stock; but the crucial question is whether the basic material is statistically sound. It must be admitted that there is a pressing need for more comprehensive and more precise statistics. It is also urgently required to extend the taggings in order to establish beyond any reasonable doubt whether or not one or more self-containing populations do in reality exist. In short, the existing data are not considered sufficient for a precise stock assessment, and further research is necessary. Also, the use of Schaeffer's original model may be questioned in this particular case. However, one important fact does emerge: The present exploitation of the stock of *Squalus acanthias* in European waters is undoubtedly very high, and there is but feeble reason for any optimism about the further development. The situation ought to be watched with utmost care.

Summary

The present paper is a short account of the state of the stock in recent years of *Squalus acanthias* in European waters.

The basic material is the catch statistics from Bulletin Statistique (ICES), the Norwegian spur-dog taggings, and certain catch/effort data from the Norwegian long line fishery for spur-dog.

The fishery has expanded rapidly since the World War II and the annual yield is now (1961) about six times higher than in 1945. The bulk of the catch is shared between four countries: England, Scotland, France, and Norway.

The main part of the yield originates from the waters around Shetland (summer) and the Norwegian west coast (winter). Extensive taggings in

these localities show a free intermixing of the fish between these areas. However, occasional recaptures from the same taggings are recorded from the Barents Sea, Lofoten, the North Sea and Skagerak, the waters around Ireland, the English Channel, and in the Bay of Biscay. It is, therefore, possible that there exists only one stock common to the Northern and Western Europe.

From a quantitative analysis of the tagging data it appears that the estimate of the average total instantaneous mortality rate in the years 1960—1963 amounts to 0.72, and this high figure is interpreted as a danger signal.

A certain measure of the catch per unit of effort was obtained from various dealers by comparing the landings with the amount of bait used. The series, comprising the years 1957—63, shows a heavily declining stock.

Using Shaeffer's model for stock assessment, the obtained series of catch/effort, and the catch statistics from Northern Europe, a maximum equilibrium catch of about 50.000 tons is found. This level was, practically speaking, reached in 1961.

The available data are not considered sufficient for a precise stock assessment; but one important fact does emerge: The present exploitation of the stock of *Squalus acanthias* in European waters is undoubtedly very high.

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A Study of the Relationship between the Water Temperature and the Concentration of Cod in West Greenlands Waters.

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The occurrence of cod in West Greenland waters is strongly influenced by variations in the hydrographical conditions (HATCHERY et al. 1954 and RODEWALD 1955). In spring winter cooled water covers the shallow parts of the banks, and the highest concentrations of cod are found on the western slopes of the banks where warm water of Atlantic origin is dominating. During June—July the deeper parts of the banks are usually covered with cold water of Arctic origin, and the cod migrate to the more shallow parts of the banks. At this time of the year the cod may also live pelagically in the upper warm water layers.

Fishing experiments have been carried out in West Greenland waters to find the most profitable temperatures for cod fishing. The highest yield (numbers/1.000 hooks) was in August—September 1952 obtained with bottom long line in the Disco area between 2 and 2.5° C. Catches above the mean were obtained in the temperature interval 2.6—3.5° C too, while fishing experiments in water masses with temperatures below 1.5° C and above 4° C, gave smaller yields (ANON 1953). Practically no fish is caught when the temperature is below 0° C, and the fishery first becomes profitable when temperature is above 1° C (HATCHERY et al. 1954).

In August 1952 the highest yield was obtained on pelagic long line at temperatures between 3.1 and 4.0° C (ANON 1953). In July—August 1953 and 1954 the fishing experiments gave the highest yield in the temperature intervals of 2.20—2.33 (RASMUSSEN 1954) and 0.8—0.9° C respectively (RASMUSSEN 1955). At the same time large amounts of food organism were concentrated in these water layers.

The estimated relationship between the cod and the water temperature in West Greenland waters is in some cases based on a small number of observations in one season only and within a small area. If observations from a larger area and more years could be considered together, some casual variations in the observations might have been less. However, in such a case the varying size of the stock will probably affect the results and must therefore be taken into consideration.

Table 1. *Fishing experiments with bottom long line off West Greenland.*

Year	I.C.N.A.F. Subdivision	Temp. C°	Catch in number pr. 1 000 hooks	$\frac{N'_{ij}}{N_{ij}} \cdot 100$	Year	I.C.N.A.F. Subdivision	Temp. C°	Catch in number pr. 1 000 hooks	$\frac{N'_{ij}}{N_{ij}}$
1949 ..	1C	1.11	231	170	1955	1C	1.2	162	108
1949 ..	1C	1.27	264	194	1955	1C	1.4	158	105
1949 ..	1B	0.83	154	136	1955	1C	1.7	158	105
1949 ..	1B	2.08	226	200	1955	1C	1.9	127	85
1949 ..	1B	2.08	265	235	1955	1C	1.9	179	119
1949 ..	1D	2.21	266	147	1955	1C	2.0	160	107
1950 ..	1C	2.40	260	125	1955	1C	1.8	172	115
1950 ..	1D	1.65	140	64	1955	1C	1.2	144	96
1950 ..	1D	3.10	260	119	1955	1C	1.8	140	93
1950 ..	1D	1.90	165	76	1955	1C	1.7	107	71
1950 ..	1D	2.85	127	58	1955	1B	3.0	144	107
1951 ..	1D	3.03	200	82	1955	1B	3.0	161	120
1951 ..	1D	2.07	105	74	1955	1B	2.8	106	79
1951 ..	1B	1.00	107	76	1956	1D	3.15	82	56
1951 ..	1B	1.38	184	130	1956	1D	3.4	75	51
1951 ..	1B	3.14	163	116	1956	1D	2.0	117	80
1951 ..	1B	1.31	104	74	1956	1D	1.7	200	136
1951 ..	1B	1.35	145	103	1956	1C	1.2	150	102
1951 ..	1B	2.88	187	133	1958	1D	3.8	200	106
1951 ..	1B	1.95	164	116	1958	1D	3.9	194	103
1951 ..	1B	1.90	184	130	1958	1D	2.5	236	125
1951 ..	1B	2.54	89	63	1958	1D	3.0	226	120
1951 ..	1B	1.12	71	50	1958	1D	2.5	174	92
1953 ..	1B	2.3	140	114	1958	1D	2.2	165	87
1954 ..	1C	0.3	116	62	1958	1B	0.6	72	61
1954 ..	1B	0.5	111	84	1958	1B	1.3	84	71
1954 ..	1B	0.5	147	111	1958	1C	0.6	103	87
1954 ..	1B	0.5	70	53	1958	1D	1.4	60	32
1954 ..	1B	0.5	159	120	1959	1D	2.5	65	53
1954 ..	1B	0.0	130	98	1959	1D	3.5	10	8
1954 ..	1B	0.6	118	89	1959	1D	0.0	15	12
1954 ..	1B	0.5	143	108	1959	1D	3.4	46	37
1955 ..	1C	1.9	126	84	1959	1D	3.7	30	24
1955 ..	1C	1.5	79	53	1959	1C	2.4	99	127
1955 ..	1D	1.8	197	105	1959	1C	2.4	91	117
1955 ..	1D	0.7	87	46					
1955 ..	1D	1.0	33	18					

Table 2. *Norwegian commercial bottom long line fishery off West Greenland. Catch in ton and number pr. 1 000 hooks during June—August (ICNAF 1955—1961).*

Subdivision	1 B		1 C		1 D	
Year	ton	*N*	ton	*N*	ton	*N*
1949	0.43	113	0.53	136	0.62	181
1950	—	—	0.77	208	0.88	218
1951	0.56	141	—	—	0.80	243
1953	0.45	123	0.59	—	0.67	—
1954	0.50	132	0.71	188	0.73	—
1955	0.47	134	0.56	150	0.67	188
1956	0.46	132	0.47	131	0.62	147
1958	0.25	118*	0.47	118	0.69	189
1959	—	—	0.31	78	0.58	123

* Estimated

A series of fishing experiments with bottom long line have been carried out off West Greenland. In the present paper the catch per unit of effort obtained in these experiments will be considered in relation to the bottom temperature.

Material

In June—August 1949—1951, 1953—1956 and 1958—1959 a series of fishing experiments with bottom long line were carried out off West-Greenland by the Norwegian Fisheries Directorate, Institute of Marine Research. In the years 1956 and 1959 the fishing experiments were executed by the research vessel "G. O. Sars" while the experiments in the other years were made by commercial long liners. The experiments were distributed in subdivisions 1B, 1C and 1D of Sub-area 1 of the ICNAF Convention Area in the same manner as the commercial fishery. All catches have been recorded in numbers (Table 1), and the water temperature is measured about 5 m above the bottom at one end of the long line. Fishing time i.e. the time between shooting and hauling is lacking for some experiments and recorded in different units for other experiments. The fishing time could therefore not ben taken into consideration.

Catch per unit of effort for the Norwegian commercial long liners operating in West Greenland waters is given as tons/1.000 hooks on a monthly basis for all subdivisions. The number of cod/1.000 hooks for the years 1954—1956 and 1956—1959 is estimated from those figures and the mean weight of the fish caught (Table 2). The mean weight is estimated by the length distribution in the Norwegian long line catches and the

Table 3. *Norwegian commercial bottom long line fishery off West Greenland, Subarea I. Ton saltet cod pr. vessel (Fiskeridirektøren 1951—1953 and 1955—1958).*

Year							
1949	1950	1951	1952	1953	1954	1955	1956
183	262	238	194	195	213	204	180

length - weight relationship given for the West Greenland cod (ANON 1962). Catch per unit of effort (tons/1.000 hooks) do not exist for the years 1949—1951, but the mean number caught/1.000 hooks in these years, have been estimated, from the mean weight of the fish caught and from the mean value of ton/1.000 hooks for the years 1953—1956 in subdivision 1B, 1C and ID raised by the relative number of ton/boat (Table 3) for the respective years in Subarea 1.

Method

The following terms are used:

N_{ij} = stock number
C_{ij} = catch in number
g_{ij} = fishing effort in 1.000 hooks
q_{ij} = catchability coefficient

These terms refer to commercial fishery, and the indexes i and j indicate year and subdivisions respectively. Corresponding terms based on data from the fishing experiments where the temperature is measured, are given as follows: N'_{ij}, C'_{ij}, g'_{ij} and q'_{ij}.

We have the following equations:

$$\frac{C'_{ij}}{g'_{ij}} = q'_{ij} N'_{ij} \quad (1)$$

$$\frac{C_{ij}}{g_{ij}} = q_{ij} N_{ij} \quad (2)$$

$$\frac{N'_{ij}}{N_{ij}} = \frac{C'_{ij}}{g'_{ij}} / \frac{C_{ij}}{g_{ij}} \cdot \frac{q_{ij}}{q'_{ij}} \quad (3)$$

The term catchability coefficient or availability is a factor relating the catch per unit of fishing effort to the stock size. After GULLAND (1955) any estimate of q will be an estimate of the cumulative interaction of the following variables:

(a) the fishing power for a vessel for a type of fish
(b) the vulnerability of that type of fish
(c) the aggregation of fishing units on the fish
(d) the concentration of fishing units on the fish

Variations in the availability, which make the catch per unit of effort unreliable as a density index, have been discussed by RICKER (1940). They include seasonal changes, steady long term changes and short-termfluctuations.

Since all data concerning the experimental long line fishery off West Greenland refers to the time June—Augst, the seasonal changes are of minor importance.

Steady long-term changes in the availability include changes in behavior of the fish, but more important is the improvement of instruments, fishing gear and fishing methods. All Norwegian fishing vessels which have taken part in the West Greenland cod fishery later than 1949 have been fitted out with echo sounders and wireless sets. Since the vessels have been similarly equipped and the fishing methods have changed but little after 1949, the steady long term changes are also of minor importance in this connection.

Short term fluctuations, influencing the catch per unit of effort are caused by variation in fishing time, weather conditions, diurnal vertical migration and by change in the feeding habit of the cod. Diurnal vertical migrations have been found for the North Sea cod (ELLIS 1956) and for the Arctic cod (KONSTANTINOV 1958). Changes in feeding habits have been recorded for cod in East Greenland waters (unpublished data from Norweigian research cruises in September 1961 and 1962). The cod fishing with hand line and artificial bait (rubber worms), was best from morning to noon (local time). After noon the catches decreased very markedly. The cod was, when these experiments took place, feeding heavily on Capelin. In another area in East Greenland the same slack period was found after noon, and the catches increased from late evening to midnight and then decreased towards the early morning. In this area the cod was feeding on Euphausids.

Since the long line fishery is a bait fishery, the catch might be affected by the rate of feeding. Experimental work has shown that the amount of food eaten depends on the temperature. MCKENZIE (1934) found an optimal feeding temperature for cod between 13° C and 15.5° C. This means that the maximum feeding probably takes place at higher temperatures than those considered in this paper (0° C—4° C). However, earlier observations indicate an unclear relationship between lower temperatures and feeding. At 2° C some New-Foundland cod were feeding and some were not (McKenzie 1934), and in the Cape Farewell area cod was found feeding in temperatures below 2° C (Trout 1953). In the Bear Island area cod has been found feeding at a temperature as low as — 0.3° C (Lee 1952), and actively feeding cod has been found at — 0.5° C in an East Greenland fjord (unpublished observations from a cruise with R/V "G. O. Sars" in the fall 1962).

The catch per unit of effort, given as numbers per hook or some multiple of hooks, is considered by Gulland (1955), Beverton and Holt (1957) and Murphy (1960) not to be a linear estimate of abundance. Such statistics involves a number of uncertainties as the rate of hooking fish, the rate of loss of hooked fish and the loss of bait from all sources excluding hooking of the desired fish (Murphy 1960). If the rate of loss of hooked fish and bait (e.g. catching undesirable species and bait shedding) are very small, the saturation factor may at a main rate of occupied hooks of 26 percent (present material) be of minor importance (Gulland 1955). The unadjusted catches per unit effort may then be used (for the most purposes) as an index of abundance.

Most of the factors which influence the catch per unit effort (e.g. availability) are accordingly of the category short term fluctuations, and a consistent difference between q'_{ij} and q_{ij} may not exist. Equation (3) may therefore be simplified:

$$N'_{ij}/N_{ij} = \frac{C'_{ij}}{g'_{ij}} / \frac{C_{ij}}{g_{ij}} \qquad (4)$$

Results and discussion

The data from 1956 and 1959 are obtained on cruises with research vessel "G. O. Sars". As seen from Fig. 1 the catch/1.000 hooks within the temperature ranges 1.2 to 2.5° C do not differ very much from those obtained by commercial fishing vessels. The small catches in 1956 and 1959 at temperatures more than 3° C and at 0° C were taken in localities where no commercial fishing vessels were operating.

The temperature observations have been taken only at one end of the long line, and usually about 5 m above the bottom. It is thought that the temperature at the one end of the line in most cases is representative for the temperature along the whole line, anyway when the bottom is even and horizontal. In cases where the long line is set aslope, a temperature gradient may be present and a part of the variation in our material may be due to such cases.

In studying the relationship between the temperature and the catch per unit of effort for fishing experiments carried out during a number of years in a large area, fluctuation in the stock size from year to year and

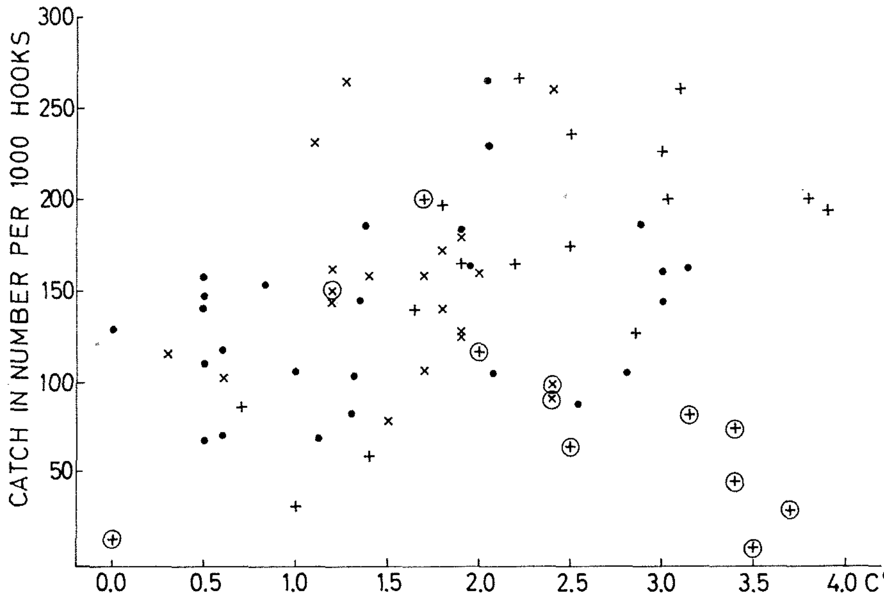

Fig. 1. Bottom long line fishery off West Greenland. Relationship between bottom temperature and catch in number/1 000 hooks. O Research vessel data. Subdivision: ● 1B, X 1C, + 1D

from subdivision to subdivision may be a complicating factor. Fluctuations in the stock size can be taken into consideration by estimating the relationship between the temperature and the ratio of the stock size in the vicinity of the gear used in each experiments and the stock size in the respective sudivisions of the ICNAF subarea 1 (4). This may involve a smaller variance in the corrected data (N'_{ij}/N_{ij}) than in the catch per unit of effort data (C'_{ij}/q'_{ij}). These estimates of the variances in the corrected data and the uncorrected data can be tested for significance by an analysis of the variances. This technique is, however, only valid when the data are approximately normally distributed, and the mean and standard deviation are independent. These conditions are not always met with in trawl fishing (Parrish 1951, Barnes and Bagenal 1951) or long line fishing (Murphy and Elliot 1954). Under such circumstances the data must be transformed prior to the applications of statistical tests. In the following the logaritmic transformations ($N + 1$) have been used. The variances relative to the squared mean in the transformed corrected data, log ($N'_{ij}/N_{ij}+1$), is the same as the variance in the transformed uncorrected data, log ($C'_{ij}/g'_{ij} + 1$), ($F = 1.004$, $P > 0.05$).

Correcting for the stock size may also involve a change in the relationship between the temperature and the term N'_{ij}/N_{ij} in proportion to the

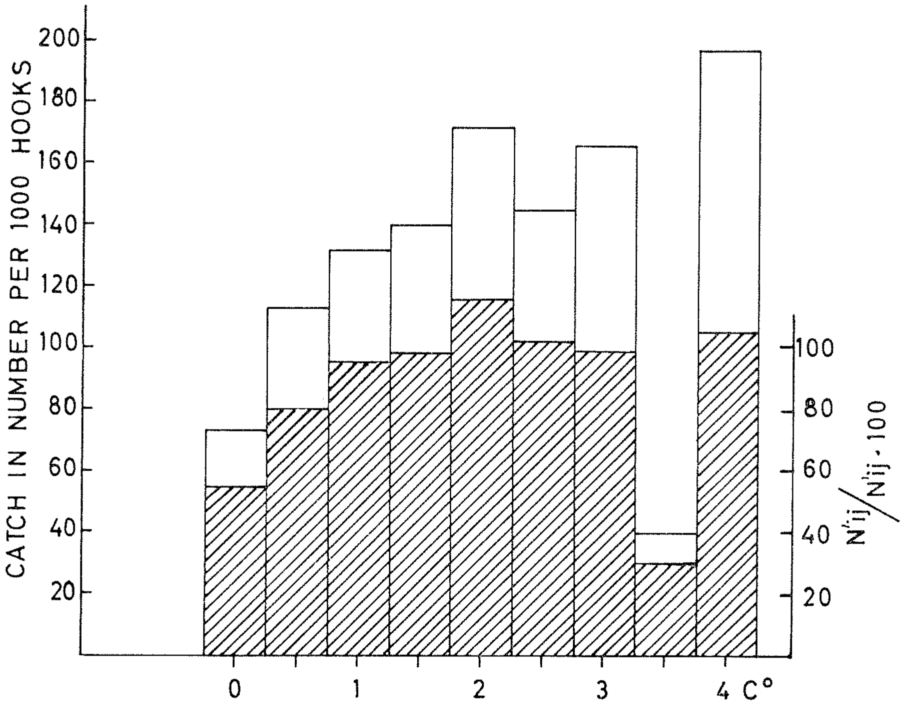

Fig. 2. Relationship between bottom temperature and mean catch in number/1 000 hooks (□) and mean *N*'ij/*N*ij (▨)

relation temperature/catch per unit of effort. Both sets of data, arranged in temperature intervals of 0.5° C (—0.25—0.24, 0.25—0.74), give nearly the same trend (Fig. 2). However, the mean values of N'_{ij}/N_{ij} at the temperature intervals 1° C—3° C are more similar than for C'_{ij}/q'_{ij}. The figures at 0.0° C and 4.0° C may not be reliable, as they are based on only two observations each. On the other hand the mean figures for temperatures below 0.75° C and above 3.24° C are less than the figures for temperatures between 0.75° C and 3.24° C. The temperature interval 0.75—3.24° C where the highest yield is obtained, is in agreement with earlier findings for the West Greenland cod (ANON 1953, RASMUSSEN 1954 and 1955 and HATCHERY et al. 1954) and for cod on the New Foundland Banks (THOMPSON 1943).

Very small changes are involved in the correction made for the fluctuation in the stock size. This may indicate that catch per unit of effort also has been influenced by other factors such as hydrographical conditions, food supply, depth, gear saturation etc. HELA and LAEVASTU (1960) mentioned that "fish search for and select a certain optimum combination of physical and biological conditions in the environment".

The different factors in the optimal conditions may however individually change from year to year and be different the same year from subdivision to subdivision. The temperature is an important factor in the environment (HELA and LAEVASTU 1960), but the temperature where the highest yield per unit of effort is obtained may be different from year to year and from area to area. When observation from a larger area and more years are handled together, the temperature range with the highest yield must therefore be expected to be an extensive one as also shown in Fig. 2.

The biological factors which influence the relation between the concentrations of the cod and the temperature may include factors as the stock density. At high stock density the gear saturation may affect the data in such a way that the temperature with the highest catch per unit of effort give a too low estimate of the concentration. It may also be that the correlation between the concentration of cod and the temperature exist only when the number of fish and the differences in the temperatures within an area reach a sufficient level (DIETRICH et al. 1959). It has, however, not been possible to estimate the effect of these factors in our material.

Summary

The relation between catch of cod/per unit effort and temperature in West Greenland waters has been studied by material from bottom long line fishing experiments and from official fishery statistics. The experiments have been carried out during June—August by Norwegian commercial fishing vessels in 1949—1950, 1953—1955 and 1958 and by Norwegian research vessels in 1956 and 1959.

When the data from subidivisions 1B, 1C and 1D of Subarea 1 of the ICNAF Convention Area from more years were considered, the stock size was taken into account. This involved only smaller differences in the cod/temperature relation, and the highest yield was obtained at the temperature interval 0.75—3.24° C.

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Coastal Cod and Skrei in the Lofoten Area

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ROLLEFSEN (1933) found along the Norwegian Coast from Bergen to Finnmark two types of cod, which could be distinguished by the shape of the otoliths, the relative breath of the zones in the otoliths and their finer structures. One of the otolith types was typical for what ROLLEFSEN (1933) called coastal cod, cod which live all the year round in the coastal area. The other type was typical for skrei (mature Arctic cod) which is in Norwegian water a short time during spring for spawning, and which are living the rest of the year in the Barents sea and in the Bear Island — West Spitsbergen area. In a later paper ROLLEFSEN (1934) showed that the coastal cod had a faster growth, mature at an younger age, had a smaller number of vertebrae, and the weight at the same length was higher for coastal cod than for skrei.

The cod otolith samples taken in January—April from purse seine, gill net, long line and hand line catches in Lofoten contain mostly the skrei type and only a small fraction is coastal cod. Most of the cod taken by Danish seine at the same time are after the fishermen's opinion not the skrei type. The body shape of this cod are more lumped, which are typical for the coastal cod (ROLLEFSEN 1954).

The results of tagging experiments in Lofoten (DANNEVIG 1953) have clearly demonstrated the migrations of skrei in the Norwegian waters, but the knowledge about the migration of coastal cod in these areas has been poor. One of the purposes of the investigations in Lofoten 1960 and 1961 were to increase our knowledge about the biology of coastal cod in these areas, and some of the results are given in the following.

Material

In March 1960 it was off Henningsvær tagged 535 hand line caught and 239 Danish seine caught cod. During April next year 644 purse seine caught cod were tagged at Höla and 300 Danish seine caught cod off Henningsvær. In all experiments were used hydrostatic tags fastened in front of the first dorsal fin. The length of all tagged fish were measured before release.

Age and length samples taken from Danish seine and long line/purse seine catches are studied together with the tagging material. The samples from the Danish seine catches are from the area off Henningsvær, while the long line and purse seine samples are from catches taken some distanse east of Henningsvær. The tagging and the sampling were each year made more or less at the same time.

Age and length

The number of coastal cod estimated on behalf of the character of the otoliths are quite different in samples from Danish seine and long line/purse seine catches. In 1960 and 1961 the Danish seine catches contained 95 and 93 percent coastal cod respectively, while the long line/purse seine catches from the same years contained about 89 and 91 percent skrei (Table 1) respectively.

The age distributions of coastal cod in long line, purse seine and Danish seine catches are different from the age distributions of skrei in the long line/purse seine catches (Fig. 1). The age groups 5, 6 and 7 are dominating among the coastal cod, while 9, 10 and 11 are the main age groups among the skrei. The age groups 8 and older occur but slightly among the coastal cod in the Danish seine samples, but they are more frequent among the coastal cod in the long line/purse seine samples.

The cod tagged from hand line and purse seine catches was on the average bigger (Fig. 2) than the cod tagged from Danish seine catches. There is a good agreement between the length distributions of skrei in the age material and the tagged hand line/purse seine caught cod on the one side and between the length distribution of the coastal cod and tagged Danish seine caught cod on the other side.

Migration

Some recaptured cod tagged in 1960 from Danish seine catches were recaptured during March—April the same year in the western part of Lofoten and in the area outside the Lofoten Islands (Fig. 3). During summer and autumn some recaptured cod were reported from Lofoten and Vesterålen, and the most northerly recovered cod from the 1960

Table 1. *The content of skrei and coastal cod in otolith samples from Lofoten.*

Gear	Date	No. in sample	Skrei per cent	Coastal cod per cent
Danish seine	28th March 1960	126	4.8	95.2
—	8th April 1961	100	7.5	92.5
Long line	4th March— 5th April 1960	955	88.9	11.1
Purse seine	13th—27th March 1961	714	90.8	9.2

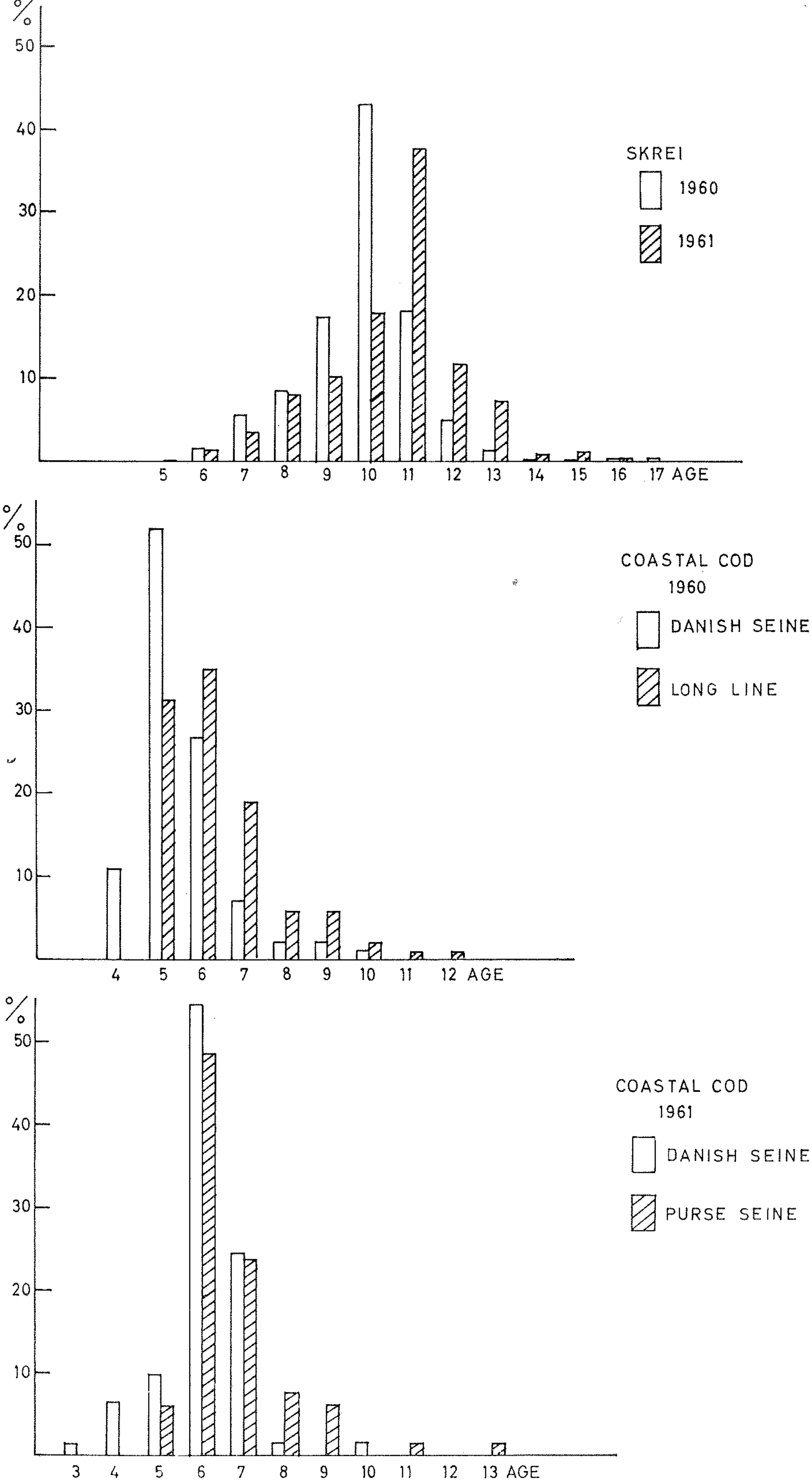

Fig. 1. Age distributions of skrei and coastal cod caught in Lofoten 1960 and 1961 by hand line and purse seine respectively, together with age distributions of coastal cod caught by Danish seine on nearly the same time and localities (See Table 1).

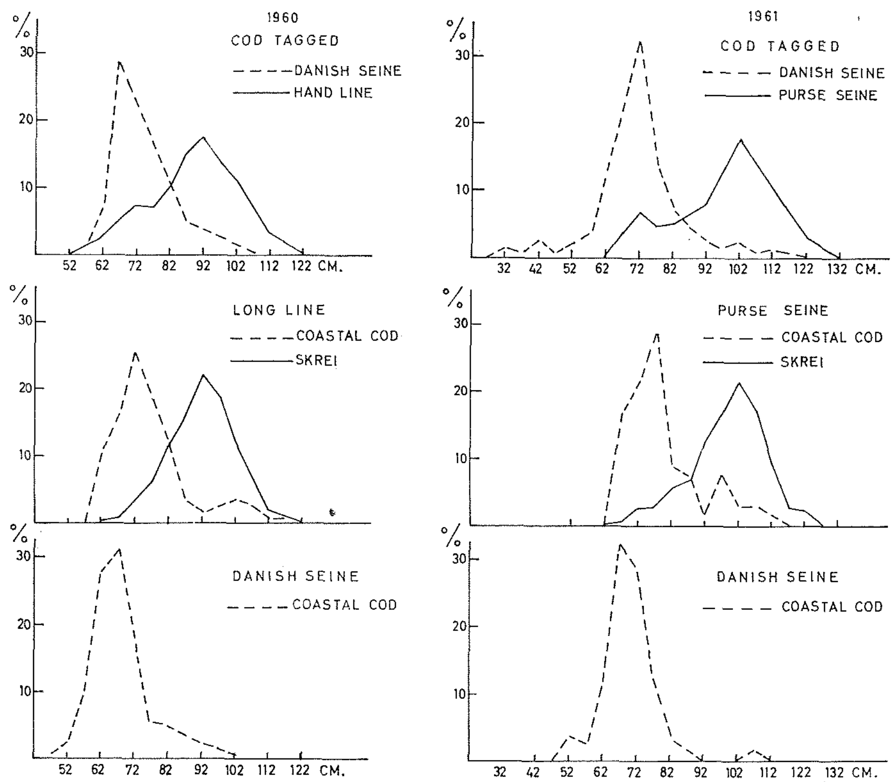

Fig. 2. Length distributions of tagged cod in 1960 and 1961 caught by Danish seine and hand line/purse seine and length distributions of coastal cod caught by Danish seine and long line/purse seine, together with length distributions of skrei caught by long line/purse seine.

experiments was reported from a locality near Tromsö. The geographical distribution of recaptured cod in 1961 from the tagging this year give the same picture. However, this year the most northerly recovered cod was recaptured in August off Bear Island.

The cod tagged in 1960 from hand line catches was during March—April recaptured from the western part of Lofoten and from the area Röst—Nordkapp. The geographical distribution of recaptured cod in 1961 of cod tagged from purse seine catches in 1961 is similar (Fig. 4), but in addition some recaptures were recorded from the districts north and east of Nordkapp.

Cod tagged from Danish seine catches was recaptured in Lofoten in most of the months after tagging in the tagging year. However, the main part was recovered during March—June (Table 2), while the recaptures in the following years were consentrated in February—April.

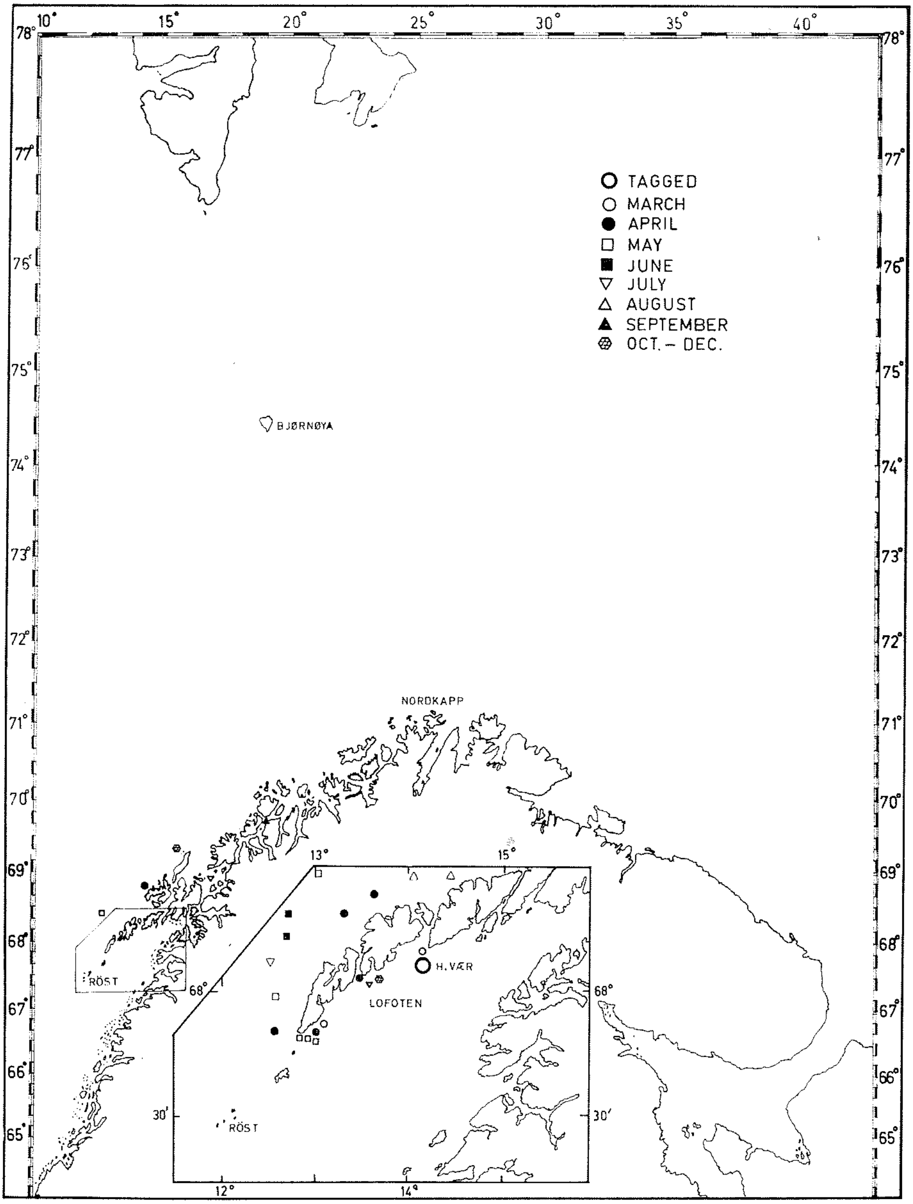

Fig. 3. Danish seine tagging experiments in Lofoten 1960. Recaptures in the tagging year.

Recoveries from the district Röst—Nordkapp were recorded in almost all months after tagging in the tagging year and in most of the months in following years.

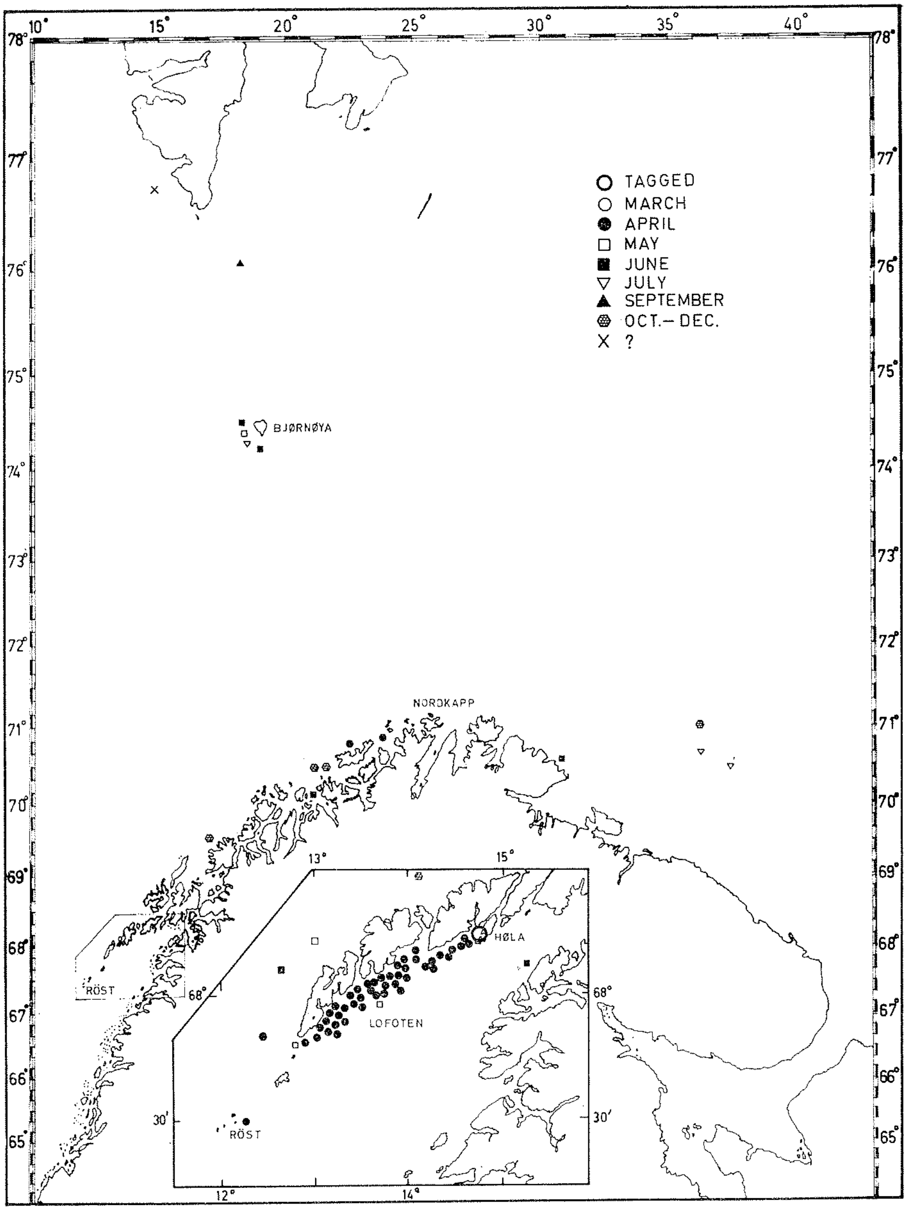

Fig. 4. Purse seine tagging experiments in Lofoten 1961. Recaptures in the tagging year.

The monthly distribution of the recaptured cod tagged from hand line/purse seine catches is different. The recoveries taken in Lofoten both in the tagging year and in the following years are concentrated in March—

Table 2. *Danish seine caught cod tagged in Lofoten 1960 and 1961. Number of fish recaptured in different areas.*

Recapture locality	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	?	Total
Lofoten														
Tagging year			13	20	30	23	4	4	1		3	1	30	129
Following years	4	8	40	18	4	4				1		1	6	86
Norwegian coast *Røst—Nordkapp*														
Tagging year				3	3	3	2	3	2	3	2		1	22
Following years	3	2		1	4	1		1		1	1		1	15
North and east *of Nordkapp*	1							1						2
Norwegian coast *south of Lofoten* ...		1	1		1	1								4
?													1	1

Table 3. *Hand line/purse seine caught cod tagged in Lofoten 1960 and 1961. Number of fish recaptured in different areas.*

Recapture locality	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	?	Total
Lofoten														
Tagging year			50	60	6	1							6	123
Following years	3	43	166	46	1	1							9	269
Norwegian coast *Røst—Nordkapp*														
Tagging year				2	3	1				4	1		2	13
Following years	10	23	11	5	3								4	56
North and east *of Nordkapp*	4	1	1	1	3	10	6		1	1	2	2	3	35
Norwegian coast *south of Lofoten* ...		1												1
?	1		2	1		2	2						7	15

Table 4. *Recaptured cod tagged from Danish seine catches.*

Recapture area	Otolith present		Lack of otolith	Total
	Skrei	Coastal cod		
Lofoten	11	45	159	215
Røst—70° N		17	17	34
70° N—Nordkapp			3	3
North and east of Nordkapp			2*	2
South of the Vestfjord	1	1	2	4
?			1	1
Total	12	63	184	259

* One recaptured by foreign fishermen.

April and February—April respectively (Table 3), and very few are recaptured later than April. Most of the recaptures from the districts Röst—Nordkapp are made during April—May in the tagging year, and mostly during January—April in the following years. In the area north and east of Nordkapp the recaptured cod were taken during the whole year, with some concentration in the summer months.

Tagged Danish seine caught cod recaptured in the area Röst—70° N (Table 4) are in all cases, where the otoliths of the recaptured fish are present, determined as coastal cod. The cod recaptured in the same area but tagged from hand line/purse seine catches, are only one fifth determined as coastal cod (Table 5). In the area 70° N—Nordkapp are alltogether reported 15 recoveries (Table 4 and 5), but there are only otoliths from 9 of them, all tagged from hand line/purse seine catches.

Table 5. *Recaptured cod tagged from hand line/purse seine catches.*

Recapture area	Otolith present		Lack of otolith	Total
	Skrei	Coastal cod		
Lofoten	161	25	206	392
Røst—70° N	27	7*	23	57
70° N—Nordkapp	6	3**	3	12
North and east of Nordkapp	22	2***	11	35
South of the Vestfjord			1	1
?	1		14	15
Total	217	37	258	512

* One recaptured by a foreign fisherman.
** One recaptured by a foreign fisherman.
*** Two recaptured by foreign fishermen.

Table 6. *Total number recaptured in different length groups.*

Tagging		Length group cm	Number tagged	Recaptured before 1st May in tagging year		Maximum back in the sea at 1st May in tagging year.	Recaptured in the rest of the tagging year and the next year.	
gear	year			Number	Percent		Number	Percent
Danish seine	1960	<85	211	37	17.5	174	70	40.2
Danish seine	1961	<85	273	20	17.3	253	91	36.0
Hand line	1960	<85	171	16	9.4	155	26	16.8
Purse seine	1961	<85	135	10	7.4	125	52	41.6
Danish seine	1960	>84	28	3	10.7	25	8	32.0
Danish seine	1961	>84	27	—	—	27	11	40.7
Hand line	1960	>84	364	54	14.8	310	70	22.6
Purse seine	1961	>84	508	36	7.1	472	160	33.9
Danish seine	1960	Total	239	40	16.7	199	78	39.2
Danish seine	1961	«	300	20	6.7	280	102	36.4
Hand line	1960	«	535	70	13.1	465	96	20.6
Purse seine	1961	«	644	46	7.1	598	213	35.6

Three of these were determined as coastal cod and six as skrei. Of cod recaptured north and east of Nordkapp, two were determined as coastal cod (Table 5). They were both tagged in 1960 from hand line catches. One of these was in July 1960 recaptured on the Skolpen Bank. The fish was at that time 6 years old, and had been spawning for the first time that year. The other one was recaptured in March 1961 at the Finnmark coast at an age of 11 years and had this year been spawning for the second time. However, in the last case the determination of the type was a little uncertain. Of the recaptures taken south of Lofoten (Table 4 and 5) where otoliths are present one is determined as coastal cod and two as skrei.

Exploitation

The tagging experiments have been carried out during the last part of the main fishing season in Lofoten. Tagged fish will not at once be distributed in a representative manner within the population occurring in Lofoten (DANNEVIG 1953) and the fishing vessels are not randomly distributed. The percent recovery in the first months after tagging does not therefore give adequate information with respect to the exploitation of the stock. The recaptures made in Lofoten within the 30th April in the tagging year are therefore necessary to leave out of consideration. The number of tagged fish unaccounted for at the end of April is taken as basis when calculating the percent recovery in the following periods.

It was during March and April 1960 reported recaptured 17 and 13 percent of the cod tagged in 1960 from hand line and Danish seine catches respectively (Table 6), while the corresponding figures of the 1961 experiments are 7 percent in both cases. The recapture rate of the Danish

Table 7. *Total number recaptured.*

Tagging		Recaptured			Total
gear	year	Lofoten before 1st May in tagging year	Lofoten later	Other localities	
Danish seine	1960	40	60	26	126
Danish seine	1961	20	95	18	133
Total		60	155	44	259
Hand line	1960	70	89	41	200
Purse seine	1961	46	187	78	311
Total		116	276	119	511

Table 8. *Recaptures taken outside Lofoten.*

Tagging gear	Tagging year	Recaptures taken by foreign countries: trawl	Norway: trawl	Norway: Danish seine	Norway: other gear	Norway: ?
Danish seine	1960			13	11	2
Danish seine	1961	1		5	10	2
Total		1		18	21	4
Hand line	1960	17	2	1	18	3
Purse seine	1961	25	11	1	39	2
Total		42	13	2	57	5

seine experiments in 1960 and 1961 based on the total number recaptures taken during May in the tagging year and December the following year are 39 and 36 percent respectively, while the estimated rate of the hand line/purse seine experiments in 1960 and 1961 are 21 and 36 percent respectively.

The relative number of recaptures taken outside Lofoten after 30th April in the tagging year is 22 percent for the Danish seine experiments and 30 percent for the hand line/purse seine experiments (Table 7). Only one of the tagged Danish seine caught cod is recovered by a foreign fisherman, while 11 percent of the tagged cod from the hand line/purse seine experiments are recaptured by fishermen from foreign countries (Table 8). In the area fished by all nations the foreign fishermen have returned about 35 percent of the recaptured cod from the hand line/purse seine experiments. In total 46 percent of the recaptured cod were taken in this area by trawl and two tagged cod were found in Danish seine catches (Table 7 and 8). From the same localities 41 percent of the recaptured cod from the Danish seine experiments were taken by this gear and only one tagged cod was taken by trawl.

During the tagging year about 5/6 of the total number recaptured in Lofoten of cod tagged from Danish seine catches were taken by Danish seine, while in later years about 3/5 of the recaptures were taken by gill net, long line, hand line and purse seine. On the other hand only 3 percent of the recaptured tagged hand line/purse seine caught cod were taken by Danish seine.

Discussion

The length distribution of the cod tagged from hand line/purse seine catches have nearly the same trend as the length distribution of skrei in the age material (Fig. 2), while the length distribution of the tagged Danish seine caught cod have the same trend as coastal cod in the age material. It is therefore probable that the skrei type was the main part of the cod tagged from hand line/purse seine catches, and that the coastal cod was the main part of the cod tagged from the Danish seine catches.

The results of the recent skrei taggings confirm earlier investigations (DANNEVIG 1953). During March—April the skrei are migrating out of Lofoten and northwards along the Norwegian coast. Some cod move towards Bear Island and West Spitsbergen and some reach the South-East Barents Sea (Fig. 3), where they arrive in early summer. The cod are during autumn living in the Northern area (Table 3), and in the last months of the year they start migrating towards the Norwegian coast. In January the first cod arrive at Lofoten again.

The taxation of the 1960 tagged hand line caught cod after ended Lofoten fishery in 1960 and to the end of the next year have been 21 percent, which is of the same order as the figures calculated for the experiments in 1947—1951 (DANNEVIG 1953) and 1954—1959 (HYLEN et. al. 1961), except the 1958 experiment. The estimated rate for the experiments in 1958 and 1961 were 34 and 36 percent respectively. This high taxation was caused by the high availability and good weather conditions during the fishing season 1959 and 1962.

Some coastal cod from purse seine and hand line catches may have in earlier years been tagged, but the migrations have not been recognized. The tagging experiments of Danish seine caught cod in 1960 and 1961 have demonstrated a migration in the spring months out of Lofoten and northwards (Fig. 2). Most of the coastal cod seems to stop in the area Röst—70° N (Table 4 and 5), and very few are reaching the Barents Sea and the Bear Island — West Spitsbergen area.

Some coastal cod are staying in Lofoten during summer months in the tagging year (Table 2). Tagged hand line/purse seine caught cod recaptured during summer and early autumn (Table 2) may therefore be coastal cod. Seven recaptures are actually in this connection, but there are only otoliths from two of them, which both were determined as coastal cod.

Most of the fishing effort in Lofoten by gill net, long line, hand line and Danish seine is concentrated in January—April, but seining are to some extent going on through the whole year. A delayed westward migration of coastal cod (in proportion to skrei) in Lofoten during the tagging year or an overstaying in Lofoten (Fig. 3 and Table 2) may have caused that a much higher number of tagged Danish seine caught cod are recaptured by Danish seine than tagged hand line/purse seine caught cod (Table 9). The increased relative number of Danish seine caught cod

Table 9. *Number of tagged cod recaptured in Lofoten.*

Tagging gear	Tagging year	Recapture gear	Tagging year 01–04	Tagging year 05–08	Tagging year 09–12	1st year aft. tag. 01–04	1st year aft. tag. 05–08	1st year aft. tag. 09–12	2nd year aft. tag. 01–04	2nd year aft. tag. 05–08	2nd year aft. tag. 09–12	3rd year aft. tag. 01–04	3rd year aft. tag. 05–08	3rd year aft. tag. 09–12	?	Total
			Recapture month													
Danish seine	1960	Danish seine	33	30		7		1	3		1					75
« «	1961	« «	18	26	2	12	5		1							64
« «	1960	Other gears	7	1	1	11	2		1							23
« «	1961	« «	2	5	1	31			6							45
« «	1960	?				2										2
« «	1961	?		2	1	1	1		1							6
Hand line	1960	Danish seine	2	3		1	1		1							8
Purse seine	1961	« «	4	1		2										7
Hand line	1960	Other gears	67			58			21							146
Purse seine	1961	« «	42	1		137	2		131							313
Hand line	1960	?	1			2			1			1			1	6
Purse seine	1961	?	1	2		6			5						1	15

recaptured in later fishing seasons in Lofoten by long line, gill net and hand line, may be a consequence of the great effort expanded in January—April by these gears in proportion to that by the Danish seine. It may also indicate a change in the behavior of the coastal cod.

Since long line are selective for fish up to about 65 cm (SÆTERSDAL 1957) and for fish more than 95 cm (HYLEN 1962) the age and length data from long line samples are biased. Age and length samples from purse seine catches are however, more representative for the population fished by long line, gill net, hand line and purse seine. In 1961 the coastal cod more than 75 cm are more abundant in the population fished by purse seine, than the population fished by Danish seine (Fig. 2). The difference may be even greater, because the Danish seine are selective for smaller fish. It is therefore possible, that the coastal cod with increasing length, join the skrei shoals and follow the skrei out of Lofoten. A tendency of a higher proportional recapture of bigger fish from the area outside Lofoten than inside (Table 10) support this. Change in behavior of coastal cod may happen when the fish are maturing, as also mentioned by HYLEN (1964) for the coastal cod living in the Smöla—Fröya district. The consequences should then be a higher proportion of mature coastal cod in the purse seine catches than in the Danish seine catches. Unfortunately the maturity stage of the gonads in our samples are missing. The proportion of cod otoliths with spawning zones in our samples might be a help too, but since it is very difficult to distinguish between the first time spawners and the immatures at this time of the year, no conclusion is drawn.

Most of the tagged cod less than 85 cm are coastal cod (Fig. 2). An attemp to compare the recapture rate of coastal cod tagged from Danish seine and hand line/purse seine catches is made by estimating the recapture rate for the time between 1st May in the tagging year and the following year (Table 6). The estimated rate is about the same for the two groups of cod tagged in 1961 (Table 6), but the estimated recapture rate for the group of tagged hand line caught cod in 1960 is less than the half of the rate estimated for the group tagged in 1960 from Danish seine catches. A part of this difference may be due to a higher tagging mortality.

The great number of tagged Danish seine caught cod recaptured by Danish seine, hand line, long line and gill net outside Lofoten in proportion to the small number recaptured by trawl (Table 8), indicate a higher availability of coastal cod for other gears than trawl. Since foreign fishermen are using only trawl in these areas, the coastal cod tagged in Lofoten during winter months, is later mainly fished by Norwegian fishermen (Table 7).

Table 10. *Total number tagged from Danish seine catches and the number recaptured in Lofoten and outside Lofoten.*

Localities ↓ / Length →	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–99	100–104	105–109	110–114	115–119	Total
Tagged	2		6		4	12	50	135	151	79	45	22	12	9	8	1	1	2	539
Recaptured Lof. in tagging year	1		1		2	5	15	35	35	18	10	2	2	1	1		1		129
Recaptured outside Lofoten in tagging year							3	3	8	5	2	1	1						23
Recaptured Lofoten in later years							7	18	30	9	9	5	3	1	4				86
Recaptured outside Lofoten in later years								7	3	3	3	2		1	1				20
Total recaptured	1		1		2	5	25	63	76	35	24	10	6	3	6		1		258

Summary

1) Otolith samples and length measurement of cod taken in Lofoten during March—April 1960 and 1961 by long line/purse seine and Danish seine are studied together with the recaptures of cod tagged in the same years from catches taken by hand line/purse seine and Danish seine.

2) The cod in the otolith samples was splitted into skrei and coastal cod by the structure of the zones in the otoliths. The relative number of coastal cod in the Danish seine catches was 73—92 percent, while the content of coastal cod in the long line/purse seine catches was estimated to 9—11 percent. The dominating age groups among skrei and coastal cod were 9—11 and 5—7 respectively, and the older age groups among the coastal cod were more abundant in the population fished by long line/purse seine than the population fished by Danish seine.

3) Both coastal cod and skrei were during spring and summer migrating out of Lofoten. A very small part of the coastal cod seems to migrate further north than 70° N, while the skrei spread into the northern waters from Bear Island and West Spitsbergen to the South-East Barents Sea. On the migration from Lofoten in the tagging year the coastal cod and the skrei seem to some extent to be separated, but as the coastal cod grow older they join the skrei shoals.

4) Considerable inroads have been made by the fishermen on both the coastal cod and the skrei present in Lofoten during March—April 1960 and 1961. While several nations have been fishing the skrei, the coastal cod has mainly been fished by Norwegian fishermen.

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Norwegian Tagging of Harp Seals and Hooded Seals in north atlantic waters

Ey

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Introduction

The harp seal, *Pagophilus groenlandicus* (Erxleben), and the hooded seal, *Cystophora cristata* (Erxleben), both breed at Newfoundland and in the Jan Mayen area, the former species also in the White Sea. Whereas the harp seals of the three areas are regarded as three separate and self-sustaining herds or populations, even as separate races (SIVERTSEN 1941), the hooded seal is believed to consist of only one population (RASMUSSEN 1960), as hooded seals from both the Jan Mayen and the Newfoundland breeding areas probably mix during the summer moult in the Denmark Strait. But the question of populations has never been finally solved for these species.

As part of a program that includes craniometry, and recently also blood-typing and study of haemoglobins and serum-proteins by electrophoresis, both harps and hoods have been and are being tagged in North Atlantic waters by the Institute of Marine Research. The purpose of the tagging is primarily to gain further knowledge of the migrations and distribution of both species, and thus get clues for solving the question of populations. A second aim is to verify the annual formation of the dentine layers in the teeth, used as basis for age determinations (RASMUSSEN 1957a and 1960).

Taggings and recoveries in separate years have been published in printed reports of field work for the years 1951—1954 (HALMÖ 1952 and 1955; RASMUSSEN 1952, 1954, and 1957b; ÖYNES and RASMUSSEN 1955), and some of the results have also been mentioned in previous papers by RASMUSSEN (1957a and 1960). The present paper is an attempt to summarize all taggings performed in the years 1951—1963, and to report all recoveries up to 15th October 1963.

Methods

A modification of the tail tag described by SIVERTSEN (1941), made of plastic material was adopted for this program. In the years 1951—1959, 30 mm wide discs made of yellow polystyrene, were used. Two holes were drilled in the discs, 20 mm apart, and on each disc a black triangle, the

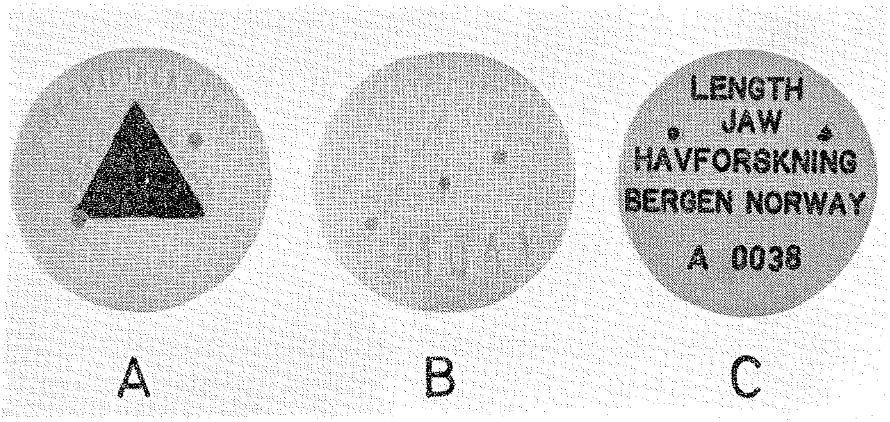

Fig. 1. Plastic tail tags: A) disc made of polystyrene, used 1951—1959. B) disc made of polyethylene, used 1960—1962. C) disc made of PVC (polyvinylchloride), used 1963.

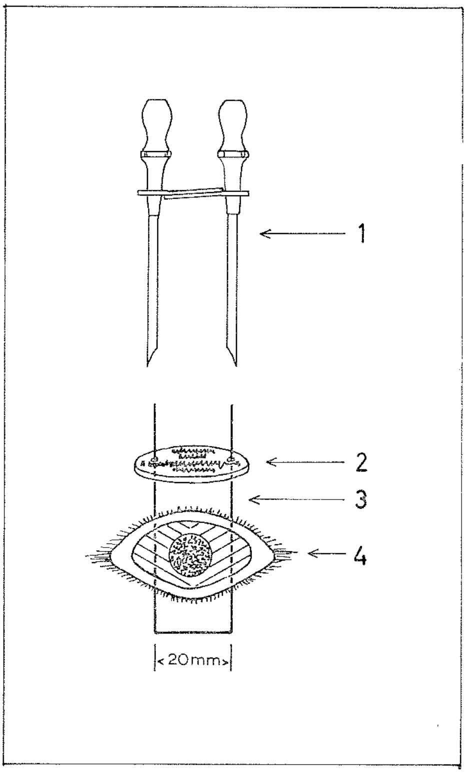

Fig. 2. Schematic illustration of the tagging procedure. 1) Two hollow needles soldered together. 2) Plastic tag. 3) Silver wire loop. 4) Section through root of the seal's tail.

name and adress of the Institute, and a serial number were printed (Fig. 1A). The material of these discs is brittle, and the tags are liable to break when applied, so in 1960—1962 they were replaced with discs made of polyethylene, without the black triangles (Fig. 1B). As a further improvement, tags made of PVC (polyvinylchloride) were used in the 1963-season (Fig. 1C).

Two hollow needles, soldered together, are used to apply the tag (see Fig. 2). With these needles the root of the seal's tail is perforated from the dorsal side, on each side of the vertebra. A loop of silver wire, 1.4 mm thick, is then inserted into the needles from under the tail, and the needles are pulled out. The ends of the wire are threaded through the holes in the tag, and twisted together above the tag with or without pliers. When twisting, the tip of one finger is held in the loop under the tail to make room for future growth.

A few measures to avoid sepsis were introduced in the 1963-season: The needles and the wire loops are kept in a jar with 70% alcohol, and the loops are smeared with an antibiotic ointment before use.

After tagging, a cross is painted on the back and belly of the animal, with fast-drying cellulose-paint that is rubbed into the fur. The purpose of the paint is to let the sealers know, even at a distance, that the animal

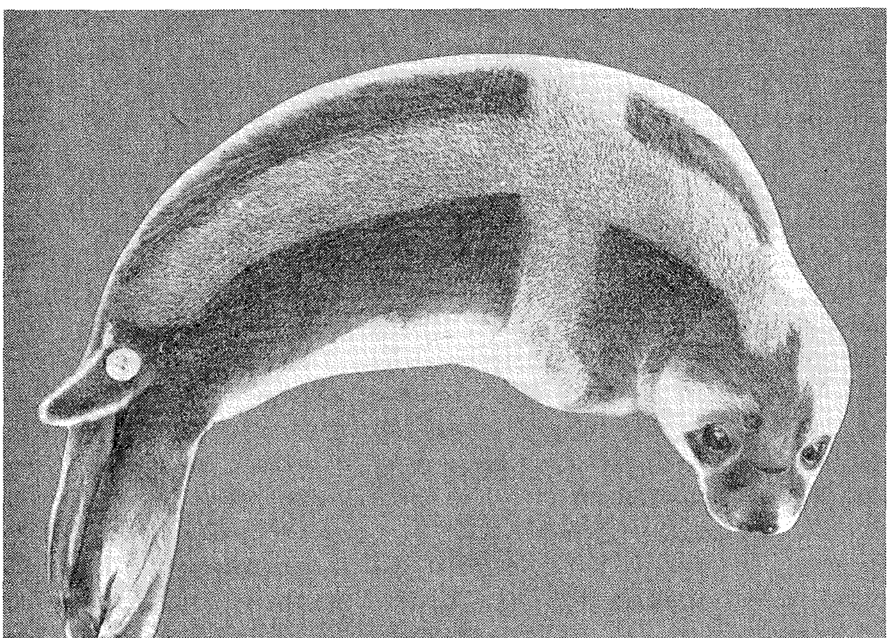

Fig. 3. Tagged and painted hooded seal pup.

is tagged and should be left alive. Red paint was used the first years, but the paint was in some cases mistaken for blood, and some of the tagged seals were shot, so from 1959 on, yellow paint was used for the bluebacks or hooded seal pups, while green paint was used for the whitecoated harp seal pups. A tagged and painted hooded seal pup is shown in Fig. 3.

A reward, 25.— N. kroner, is paid for the report or return of each tag from animals that are killed one year or more after the tagging. For the lower jaw of tagged animals, an extra reward of 10.— N. kroner is paid. No reward is paid for the recapture of seals that are tagged within the same season.

Taggings in the years 1951—1963

The number of seals tagged in the separate years and in the different areas, are set out in Table 1. It will appear that a total of 711 seals have been tagged in the 13 seasons which have passed since the taggings were started. Of these 523 were harp seals and 188 were hooded seals.

Canadian biologists conduct seal research at Newfoundland. With limited resources, the Norwegian taggings and other seal-studies therefore have been concentrated to the Jan Mayen area since 1953. The studies were extended to include also harp seals in the Barents Sea in 1963, when a total of 31 harp seals were tagged in that area by Per Öynes, observer from the Institute of Marine research. As an experiment he tagged one mature male and 18 immature seals. This was achieved without any severe difficulty: Once the seals were chased down and were resting on the ice, they could be kept quiet with a moderate pressure on the neck.

Excepting this experiment, only pups have been tagged every year in all areas. In the first year an effort was made to tag only weaned pups, but as it appeared that tagged and painted pups were readily accepted by their mothers (Rasmussen 1952), in subsequent years all available pups were tagged. Lactating pups of both species are easy to hold during the tagging process, but the hooded seal mothers may disturb and even prevent the tagging, while defending their young against any intruder. This never happens with harp seal mothers who desert their pups for the slightest reason. Weaned pups are easily exited, and it is preferable to have a helper hold the seal while it is being tagged, but even the most quick-tempered blueback may be tagged singlehanded.

All taggings have been performed by observers on commercial sealing vessels, and from 1953 on, also by observers and crew-members on the relief vessel operating in the Jan Mayen area during the sealing season every year.

All animals tagged from the sealing vessels are regarded as part of the ships' catches, and must be paid according to top skin value. The relief

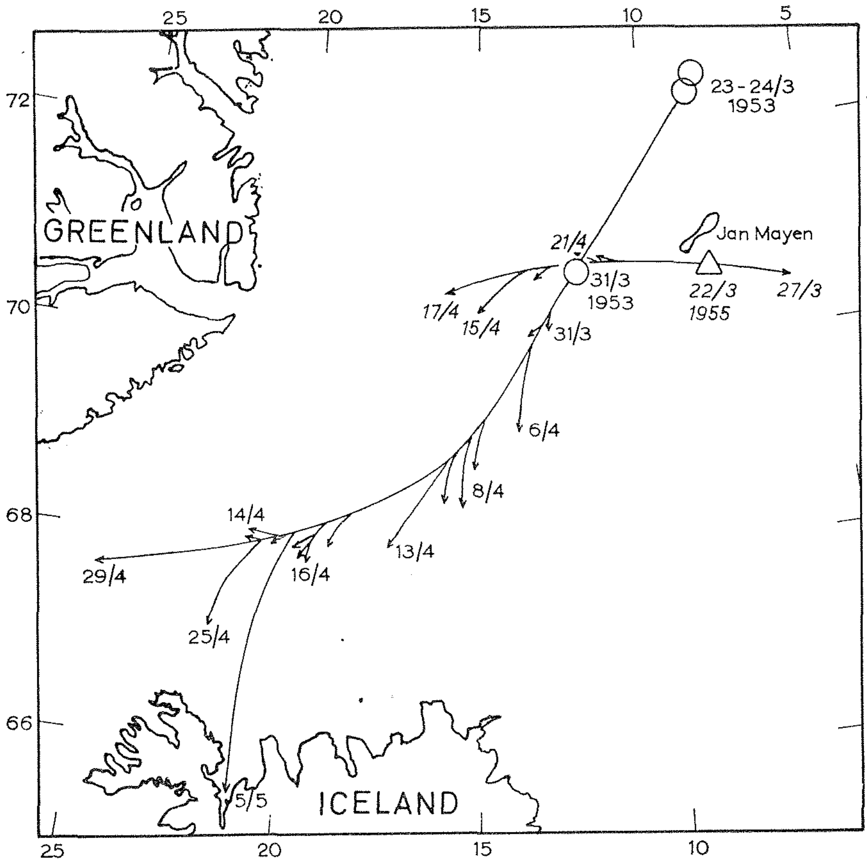

Fig. 4. The dispersion of weaned harp seal pups in the Jan Mayen area in 1953 and 1955. Tagging localities are plotted as rings (1953) and triangle (1955). Arrows indicate recaptures within the first six weeks after tagging.

vessel on the other hand, must be available for medical or technical assistance to the sealers at any moment. These economic and practical factors limit the number of seals that can be tagged in any one season.

Recoveries during the tagging-season

The paint-marks on the tagged pups last for 8—14 days only, and give them protection from the sealers while it is most needed, i.e. before they take to the water. The tagging program is made known to the sealers by radio-telephone every year, and being keenly interested in the experiments, the men will leave the painted pups alive. Nevertheless, some tagged pups are killed by unavoidable accident before the season is over. In Table 1 these are set out as "recoveries, same year". In fact they are

Table 1. *Summary of Norwegian tagging of seal pups and recoveries up to 15th October 1963.*

Year of tagging	Harp seals			Hooded seals		
	Number tagged	Recoveries		Number tagged	Recoveries	
		Same year	Later		Same year	Later
A) *Newfoundland*						
1951	29	6	1	1		1
1952	68	6	1	0		
SUM A) ..	97	12	2	1		1
B) *Jan Mayen Area*						
1951	50	0	0	18	0	0
1952	33	0	1	13	1	0
1953	159	17	4	8	0	1
1954	17	2	0	0		
1955	99	9	1	4	0	0
1956	0			16	3	0
1957	2	0	0	0		
1958	18	1	1	9	0	0
1959	1	1		21	2	1
1960	2	1	0	18	1	1
1961	9	0	1	26	1	0
1962	0			11	1	0
1963	5	0		43	2	
SUM B) ...	395	31	8	187	11	3
C) *Barents Sea*						
1963	31*	0		0		
Total	523	43	10	188	11	4

* 12 pups, 18 subadults, 1 adult.

all recaptured within six weeks after the tagging. The mean number of such immediate recoveries for all years as calculated from Table 1, constitute about 7.6 per cent of all seals marked.

All early recoveries of harp seal pups are listed in Table 2, and early recoveries of hooded seal pups are listed in Table 3. One tag, S 434, which was returned three years after the tagging without any information on the recovery, is included in Table 2. It is assumed that this animal was recaptured in the tagging season.

In the Jan Mayen area the greatest number of pups were tagged in 1953 (167) and in 1955 (103). All early recoveries in 1953, and 6 recoveries in 1955, yield some information on the dispersion of harp seal pups after weaning, as shown in Fig. 4. The movements of weaned pups are composed of an active wandering from the breeding lairs toward

Table 2. *Recoveries of tagged Harp seal pups within the first 6 weeks.*

Tag No.	Tagged		Recovered	
	Date	Position	Date	Position
Newfoundland				
S 210	09.03.51	52°15′ N, 54°50′ W	27.03.51	Horse Isl., Nfl.
S 215	10.03.51	52°00′ N, 55°05′ W	s. d.	s. pos.
S 225	11.03.51	51°57′ N, 55°14′ W		
S 226	—	— —		
S 227	—	— —	Same week	Same area
S 228	—	— —	Same week	Same area
S 232	15.03.52	52°18′ N, 55°31′ W	31.03.52	Horse Isl., Nfl.
S 235	16.03.52	52°18′ N, 55°30′ W	06.04.52	50°07′ N, 55°27′ W
S 253	19.03.52	51°45′ N, 56°05′ W	09.04.52	50°25′ N, 55°10′ W
S 270	24.03.52	51°04′ N, 55°13′ W	s. d.	s. pos.
S 272	—	— —	07.04.52	50°07′ N, 55°26′ W
S 276	—	— —	01.04.52	Horse Isl., Nfl.
Jan Mayen area				
S 127	23.03.53	72°30′ N, 08°15′ W	13.04.53	68°24′ N, 16°00′ W
S 145	—	— —	29.04.53	67°40′ N, 25°00′ W
S 150	—	— —	14.04.53	68°02′ N, 21°10′ W
S 160	24.03.53	72°20′ N, 08°30′ W	16.04.53	67°54′ N, 19°45′ W
S 173	—	— —	31.03.53	70°04′ N, 13°30′ W
S 176	—	— —	25.04.53	67°10′ N, 22°00′ W
S 180	—	— —	08.04.53	68°46′ N, 15°10′ W
S 188	—	— —	13.04.53	68°00′ N, 17°30′ W
S 190	—	— —	31.03.53	70°04′ N, 13°30′ W
S 310	—	— —	17.04.53	68°00′ N, 20°30′ W
S 314	—	— —	05.05.53	Hunafloi, Iceland (65°22′N, 21°10′W)
S 316	—	— —	14.04.53	67°58′ N, 20°00′ W
S 323	—	— —	06.04.53	69°10′ N, 14°00′ W
S 342	31.03.53	70°40′ N, 12°10′ W	16.04.53	67°54′ N, 19°45′ W
S 344	24.03.53	72°20′ N, 08°30′ W	08.04.53	68°22′ N, 15°30′ W
S 353	—	— —	14.04.53	68°02′ N, 21°10′ W
S 388	31.03.53	70°40′ N, 12°10′ W	14.04.53	68°00′ N, 19°00′ W
S 392	14.04.54	72°27′ N, 00°15′ E	24.04.54	72°07′ N, 00°00′ W
S 404	—	— —	—	72°00′ N, 00°00′ W
S 377	22.03.55	70°40′ N, 08°14′ W	20.04.55	70°40′ N, 13°15′ W
S 421	—	— —	27.03.55	70°28′ N, 05°58′ W
S 431	—	— —	21.04.55	70°48′ N, 12°00′ W
S 434	—	— —	?	?
S 438	—	— —	17.04.55	70°30′ N, 16°00′ W
S 441	—	— —	15.04.55	70°18′ N, 15°00′ W
S 462	—	— —	21.04.55	70°48′ N, 11°30′ W
S 489	12.04.55	71°42′ N, 11°48′ W	25.04.55	73°20′ N, 02°30′ W
S 500	—	— —	21.04.55	70°40′ N, 12°30′ W
S 566	15.04.58	71°30′ N, 13°20′ W	s. d.	s. pos.
S 701	21.03.59	72°30′ N, 08°00′ W	25.03.59	72°40′ N, 06°10′ W
S 1001	30.03.60	71°00′ N, 16°30′ W	21.04.60	s.area

Table 3. *Recoveries within the first 6 weeks, of Hooded seal pups tagged in the Jan Mayen area.*

Tag. No.	Tagged		Recovered	
	Date	Position	Date	Position
S 73	28.03.52	71°46′ N, 13°00′ W	31.03.52	71°10′ N, 11°00′ W
S 502	24.03.56	72°32′ N, 10°50′ W	02.04.56	72°09′ N, 11°00′ W
S 516	—	— —	29.03.56	72°24′ N, 11°20′ W
S 519	25.03.56	72°45′ N, 10°00′ W	31.03.56	72°20′ N, 10°10′ W
S 576	04.04.59	71°28′ N, 14°15′ W	s. d.	s. pos.
S 702	08.04.59	70°10′ N, 14°50′ W	...04.59	69°50′ N, 13°00′ W
S 1006	15.04.60	67°30′ N, 24°00′ W	18.04.60	67°30′ N, 27°00′ W
S 1023	08.04.61	69°09′ N, 15°45′ W	09.04.61	s. pos.
S 1031	18.03.62	71°38′ N, 17°30′ W	s. season	?
A 0001	26.03.63	72°23′ N, 06°44′ W	29.04.63	72°35′ N, 09°30′ W
A 0102	06.04.63	71°44′ N, 09°05′ W	08.04.63	71°22′ N, 09°10′ W

the edge of the pack-ice, and a passive drift with the pack, following the prevailing winds and currents.

In 1953 the pups drifted south-westwards at an average speed of 16—17 nautical miles per day. The longest drift observed was 500 miles in about one month (RASMUSSEN 1957a). In 1955 the pups were tagged in a projecting tongue of pack-ice to the south-east of Jan Mayen, and one recovery was made east of the tagging locality within a few days. Easterly winds prevailed during the first two weeks of April, however, and later recoveries were made westwards from the tagging locality.

Recoveries one year or more after the tagging

A total of 14 recoveries made one year or more after tagging, are recorded in Table 1. The particulars of these are listed in Table 4, while the tagging- and recovery-localities are plotted in Fig. 5.

Most of the tagged animals are recaptured in the same area where they were tagged. The recapture of S 336, a female hooded seal with a pup, is mentioned in a discussion of sexual maturity in this species by RASMUSSEN (1960). This is one of three recaptures of hoods in the Jan Mayen area that show no marked trend of migration. The one male hooded seal, S 230, that was tagged at Newfoundland in 1951 and recaptured near Cape Farewell, Greenland, five years later, indicates a connection between the hooded seals that breed at Newfoundland and the moulting hooded seals in the Denmark Strait (RASMUSSEN 1957a and 1960). The animal was killed in February, when mature hooded selas are migrating towards Newfoundland or Jan Mayen to breed, and therefore probably was a late straggler.

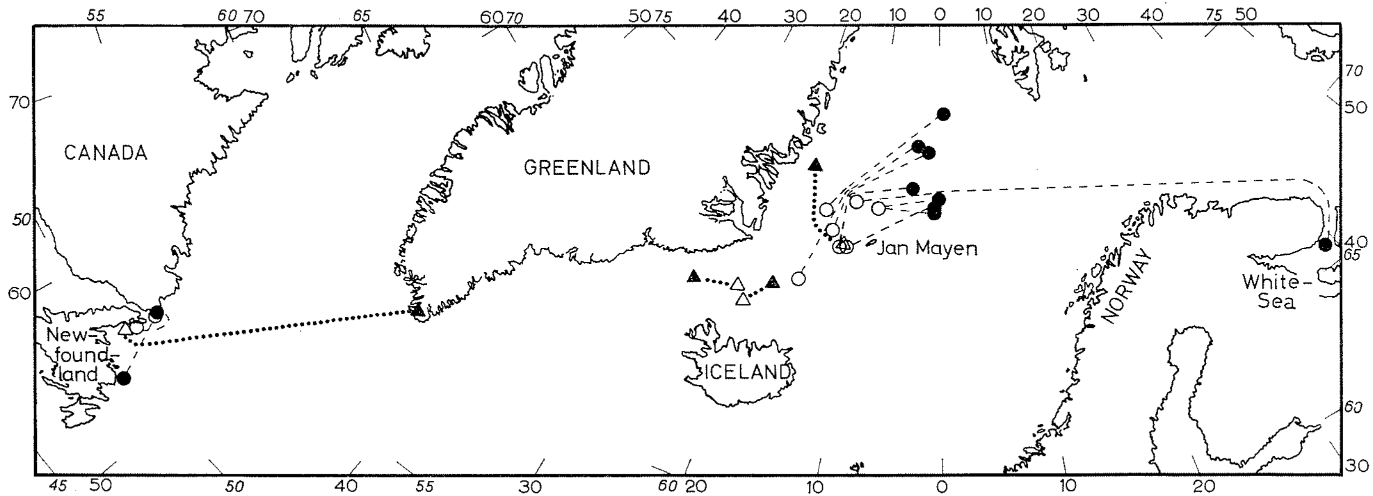

Fig. 5. Tagged harp seals (rings) and hooded seals (triangles) recaptured one year or more after the tagging. Open symbols indicate tagging localities, and filled-in symbols indicate recaptures.

Table 4. *Seal-tags recovered one year or more after tagging.*

Tag No.	Tagged		Recovered	
	Date	Position	Date	Position
Harp seals				
S 217	10.03.51	52°00′ N, 55°05′ W	09.04.52	49°35′ N, 53°15′ W
S 277	24.03.52	51°04′ N, 55°13′ W	18.04.55	52°10′ N, 55°05′ W
S 98	29.03.52	72°40′ N, 11°00′ W	25.04.53	White Sea
S 124	23.03.53	72°30′ N, 08°15′ W	12.05.54	73°00′ N, 00°15′ W
S 130	23.03.53	72°30′ N, 08°15′ W	03.05.54	72°27′ N, 01°00′ W
S 335	31.03.53	70°40′ N, 12°10′ W	02.05.63	73°20′ N, 04°00′ W
S 374	31.03.53	70°40′ N, 12°10′ W	05.05.54	72°35′ N, 01°00′ E
S 471	18.04.55	71°17′ N, 13°05′ W	03.05.61	74°50′ N, 02°00′ W
S 554	11.04.58	72°00′ N, 14°30′ W	03.05.62	76°25′ N, 00°45′ E
S 1021	08.04.61	69°09′ N, 15°45′ W	21.04.62	75°00′ N, 03°30′ W
Hooded seals				
S 230	31.03.51	50°42′ N, 55°23′ W	11.03.56	Augpilagtok, Gr.ld. (60°07′N, 44°15′W)
S 336	31.03.53	70°40′ N, 12°10′ W	29.03.58	73°30′ N, 17°20′ W
S 707	29.04.59	67°35′ N, 20°30′ W	28.04.60	68°33′ N, 18°25′ W
S 1104	07.04.60	68°04′ N, 21°45′ W	30.04.61	67°40′ N, 26°00′ W

Up to now only one recovery has verified the ageing-method for hooded selas: S 707 was recaptured one year after tagging. The lower jaw was delivered with the tag, and in the dentine of the canine teeth, a pattern of rings was found inside the neo-natal line, corresponding to a full first-year zone.

All late recaptures of harp seals within the Jan Mayen area have been made to the north-east or east of the tagging localities. This trend may be explained by the fact that very few adult harp seals are caught in the breeding lairs in this area. The males do not stay on the ice during the lactation period, and the females will readily desert their pups when disturbed, if ice-conditions so permit. Practically all of the immatures and adult harp seals taken in this area, are killed in the moulting patches usually situated to the north-east of where the breeding lairs are found earlier in the season.

One important recovery of a harp seal tag reported in December 1962, has been made by Russian biologists: S 98 was tagged in the Jan Mayen area in 1952, and recaptured in the White Sea one year later. This is the only indication known to us of any interchange between the White Sea and the Jan Mayen populations of harp seals.

One recovery has so far verified the ageing-method for harp seals: One canine tooth from S 554, recaptured four years after tagging, show four fully developed year-zones.

Discussion

With regard to migrations and the question of mixing of animals from different breeding grounds, the tagging experiments have so far yielded only suggestive results. There is no indication of any mixing of harp seals from Jan Mayen and Newfoundland, and further taggings might verify the assumed separation of these two populations. The recaptures of 7 tagged harp seals within the tagging area in the Greenland Sea in the present program, and 3 recaptures within the Barents Sea of harp seals tagged earlier in the White Sea (SIVERTSEN 1941), all seemed to rule out the possibility of mixing between the Jan Mayen and the White Sea populations. It is, however, probable that animals from both areas in May–June may meet in the drift ice off South Cape of Spitsbergen. The recovery of S 98 in the White Sea indicates that such mixing may occur, at least among immature animals. Only further tagging experiments, supported by other studies, can give an idea of the extent of mixing of these populations.

The recoveries of hooded seals are even less conclusive. Migrations from the Newfoundland breeding ground to the West Greenland coast and past Cape Farewell to and from the summer moult in the Denmark Strait, are known (RASMUSSEN 1960). Only future recoveries and continued taggings can give further clues to the possible exchange of hoods between the breeding grounds at Newfoundland and Jan Mayen.

The tagging of harp and hooded seals will therefore be continued at every opportunity. Also other types of tags and new tagging methods are being considered as supplements to the current method.

Only a total of 68 seals have been recaptured of 711 animals tagged. The paint-marks on the tagged pups, the reward system, and the good-will of interested sealers, tend to keep the number of immediate recoveries within the tagging-season low. The taggings are not intended as studies of pup-production or taxation. The very low number of late recoveries is discouraging, however: From 580 seals tagged in the years 1951–1962 and not reported captured again during the tagging-seasons, only 14 tags have been recovered one or more years after the taggings. Of many possible causes for this, one may be that the tags break or wear down, as suggested by two recovered polystyrene tags (Fig. 6). It is hoped that the new PVC tags will minimize this factor.

The fact that the tags are fastened to the dorsal side of the tail, may be significant, as killed animals always are skinned from the ventral side,

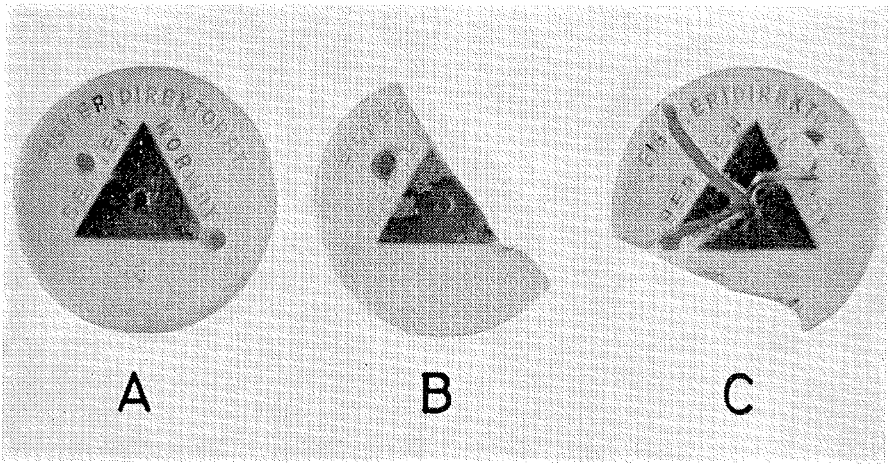

Fig. 6. Recovered polystyrene tags. A) Tag No. S 336, recovered after 5 years. B) Tag No. S 554, recovered after 4 years. C) Tag No. S 335, recovered after 10 years.

and tags therefore may be overlooked. A measure as simple as putting a blind tag under the tail might remedy this deficiency of the tagging method.

Sepsis caused by the tag has only been reported once (S 124). The paint-marks on the tagged harp seal pups cause no harm, as the white coat with the paint is shed after a short interval. As regards the paint-marks on the hooded seal pups, this may reduce the insulating power of the fur. However, paint-marks on hood pups kept both on board a sealing vessel for two weeks as well as in the Bergen Aquarium wore off rather quickly and did not seem to do any harm. Mortality caused directly or indirectly by the tagging is assumed to be low, but no estimate of this factor can be made.

It may be repeated in this connection that the enthusiasm of Norwegian sealers is great, and it is believed that a very high proportion of recovered tags are reported. In recent years also foreign sealers have reported recaptures.

Summary

The tail tag and the tagging method are described. A total of 711 harp and hooded seals have been tagged in the years 1951—1963.

Excepting experimental tagging of one adult and 18 immature harp seals in the Barents Sea in 1963, all seals have been tagged as pups, at Newfoundland in 1951—1952, in the Jan Mayen area in 1951—1963, and in the Barents Sea in 1963.

Of the tagged seals, 54 have been recaptured within the first six weeks after tagging. Early recoveries in 1953 and 1955 illustrate the dispersion of weaned harp seal pups in the Jan Mayen area.

Recoveries after one or more years amount to 14, and most of these are from the tagging areas. One recovery indicates a connection between hooded seals breeding at Newfoundland and the moulting hoods in the Denmark Strait. One other recovery suggests some contact between the Jan Mayen and the White Sea harp seal populations.

Recaptures of one harp and one hooded seal have provisionally verified the ageing method based on dentine growth zones for these species.

Finally, some factors that may influence the number of recoveries are discussed, and means of improving the tagging method are suggested.

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For bringing the observers to the ice, and for assistance with the taggings, we owe a debt of gratitude to owners, skippers, and crews of the following sealing vessels: "Brandal", "Eskimo", "Fortuna", "Kvitungen" "Norbjörn", "Polarfart", and "Polaris". Our thanks are also due to Björn Berland, Alfred Fröland, Kaare Halmö, Gunnar Nævdal, and Per Öynes who have been responsible for the taggings in different years.

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The Decline of the Skrei Fisheries

(A review of the landing statistics 1866—1957 and an evalutation of the effects of the postwar increase in the total exploitation of the Arctic cod.)

By

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Introduction

This work which we now publish under the title "The decline of the Skrei Fisheries" is a summary of the results of an analysis made already in 1957. In nearly identical form, but under the title "The State of the Arctic Cod" it was submittet as a technical document to the sixth meeting of the Permanent Commission of the International Fisheries Convention held in London in October 1957. Its consideration by that meeting initiated the formation of "The Working Group on Arctic Fisheries" — an international team of fisheries biologists whose work has now brought our knowledge far beyond the stage of our analysis from 1957. The first steps towards a more rational utilization of the resources of the Arctic cod have already been taken, and efforts are being continued to improve further on the international regulation of the exploitation.

The following account is thus seemingly outdated and does not contain any new scientific evidence. When in spite of this it has been decided to put it on record in this series, it is because we believe it may be a document of some historical interest. It is the story of an old and famous fishery being drastically reduced by the increased competition for the riches of the sea in our days.

The yield of the skrei fisheries since 1866

In Norway a systematic exploitation of the migrating skrei can be dated back at least one thousand years. Official statistics are available from about 1860. They record the yield for each season and the number of men and vessels taking part in the fishery. Fig. 1 and Table 1 shows the total annual catch of skrei in numbers and the distribution by districts since 1866. The "southern district" comprises Vestlandet, Möre and Romsdal and Tröndelag. Nordland county including Lofoten is shown separately because it is the most important spawning district, and Troms

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Table 1. *Annual catch of skrei. Numbers in 1.000 fish.*

Year	Southern district	Nordland	Northern district	Total
1866	5.798	22.793	355	28.946
67	5.698	28.358	148	34.204
68	5.747	26.349	155	32.251
69	6.502	23.115	914	30.531
1870	7.386	25.291	2.061	34.738
71	4.369	22.166	412	26.947
72	9.269	25.147	741	35.157
73	7.960	23.324	1.850	33.134
74	7.558	21.936	350	29.844
1875	9.546	27.664	853	38.063
76	6.099	28.222	552	34.873
77	11.177	36.788	1.198	49.163
78	8.041	30.220	511	38.772
79	8.850	34.059	951	43.860
1880	12.199	32.099	349	44.647
81	5.835	35.847	623	42.305
82	8.529	34.078	503	43.110
83	6.205	22.744	997	29.946
84	9.040	24.171	1.242	34.453
1885	4.946	34.888	1.434	41.268
86	13.382	38.447	1.488	53.317
87	6.308	32.640	1.571	40.519
88	11.567	34.633	1.792	47.992
89	11.234	23.287	2.057	36.578
1890	11.558	36.387	1.705	49.650
91	9.562	25.337	1.209	36.108
92	13.689	25.635	3.448	42.772
93	13.576	37.004	4.169	54.749
94	13.882	37.245	3.226	54.353
1895	9.186	47.293	2.373	58.852
96	8.174	24.671	2.035	34.880
97	13.314	31.720	3.865	48.899
98	12.652	17.391	2.303	32.346
99	7.499	18.083	2.424	28.006
1900	9.425	11.615	3.027	24.067
01	8.879	16.554	5.545	30.978
02	10.485	19.256	5.052	34.793
03	12.379	21.942	4.263	38.584
04	12.053	21.037	5.178	38.268
1905	10.172	19.540	709	30.421
06	7.326	24.333	2.681	34.340
07	10.567	21.955	872	33.394
08	12.367	18.259	2.620	33.246
09	11.947	21.540	3.384	36.871
10	8.582	18.849	4.327	31.758

Table 1. (Cont.).

Year	Southern district	Nordland	Northern district	Total
1911	13.641	16.948	4.210	34.799
12	25.128	28.614	8.545	62.287
13	19 136	17.454	3.645	40.235
14	30.811	22.803	2.384	55.998
1915	24.065	25.418	1.921	51.404
16	23.374	18.209	1.943	43.526
17	11.005	10.326	896	22.227
18	7.502	6.908	863	15.273
19	8.743	7.752	1.516	18.011
1920	14.326	13.417	3.041	30.784
1921	10.160	20.503	1.569	32.232
22	10.835	16.000	2.758	29.593
23	11.233	20.286	1.659	33.178
24	13.592	19.257	2.116	34.965
1925	6.599	25.047	2.531	34.177
26	15.966	32.736	2.794	51.496
27	9.498	40.719	2.564	52.781
28	9.565	39.829	4.209	53.603
29	7.507	50.937	6.989	65.433
1930	8.467	42.123	4.363	54.953
31	6.881	22.086	3.291	32.258
32	4.906	29.548	2.522	36.976
33	2.148	22.844	2.823	27.815
34	1.440	22.648	3.755	27.843
1935	1.288	15.275	3.227	19.790
36	953	15.376	6.007	22.336
37	1.676	25.735	8.623	36.034
38	905	26.932	6.705	34.542
39	1.107	34.886	13.318	49.311
1940	1.049	27.977	10.858	39.884
41	1.101	27.364	6.149	34.614
42	996	25.148	3.369	29.513
43	1.404	18.983	2.735	23.122
44	2.103	27.401	2.033	31.537
1945	2.734	22.583	1.032	26.349
46	1.886	40.461	3.795	46.142
47	1.161	45.195	7.801	54.157
48	1.233	21.308	5.317	27.858
49	855	17.999	2.926	21.780
1950	927	20.274	4.801	26.002
51	1.204	28.841	4.252	34.297
52	639	21.036	4.398	26.073
53	755	12.601	2.500	15.856
54	559	11.067	2.664	14.290
1955	846	12.699	5.586	19.131
56	1.534	19.840	6.042	27.416
57	1.921	8.617	3.807	14.345

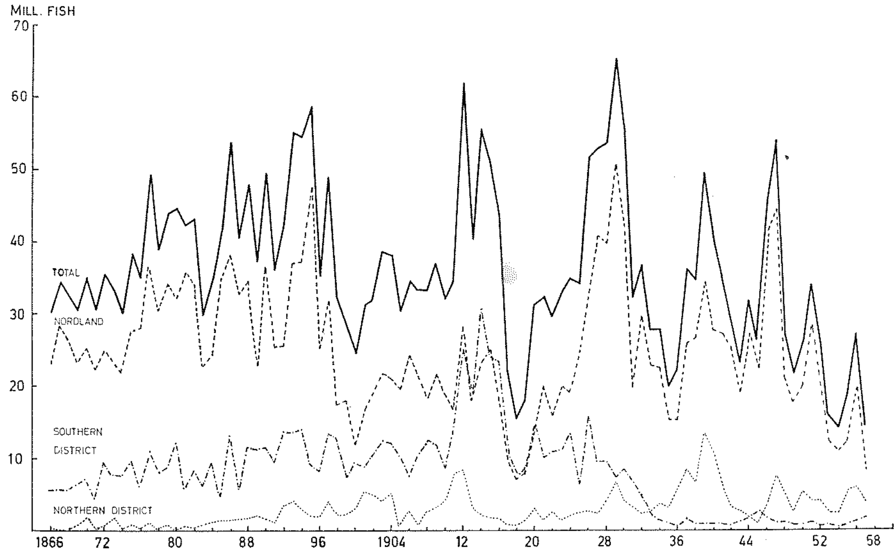

Fig. 1. Annual catch of skrei since 1866.

and Finnmark counties are given as the "northern district". (Owing to lack of data, Finnmark has not been included in the statistics until 1908). Fig. 2 presents the same data, but here the short-time fluctuations have been smoothed out by a moving five-year mean. The figure for 1868 is thus the mean of the years 1866—1870, that for 1869, the mean of 1867—1871, etc. From figures 1 and 2 it is evident that both the total yield and the yields of the various districts have fluctuated greatly during the last ninety years.

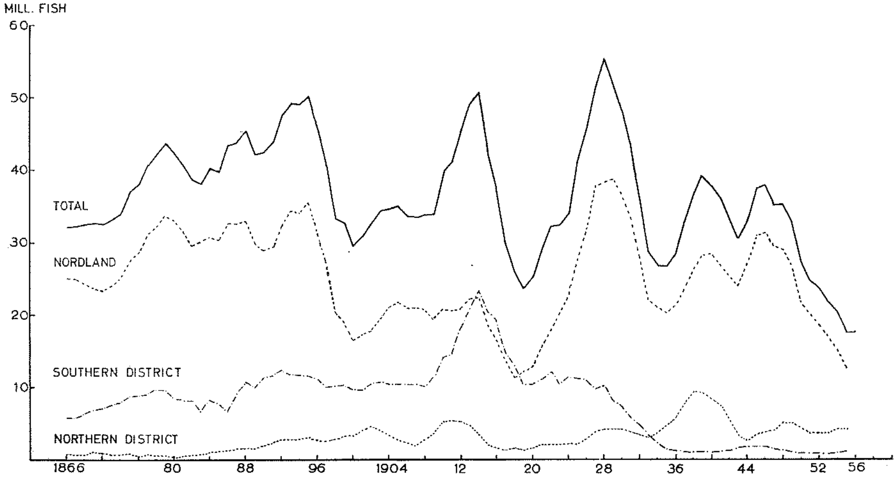

Fig. 2. Catch of skrei since 1866. Moving five-year mean.

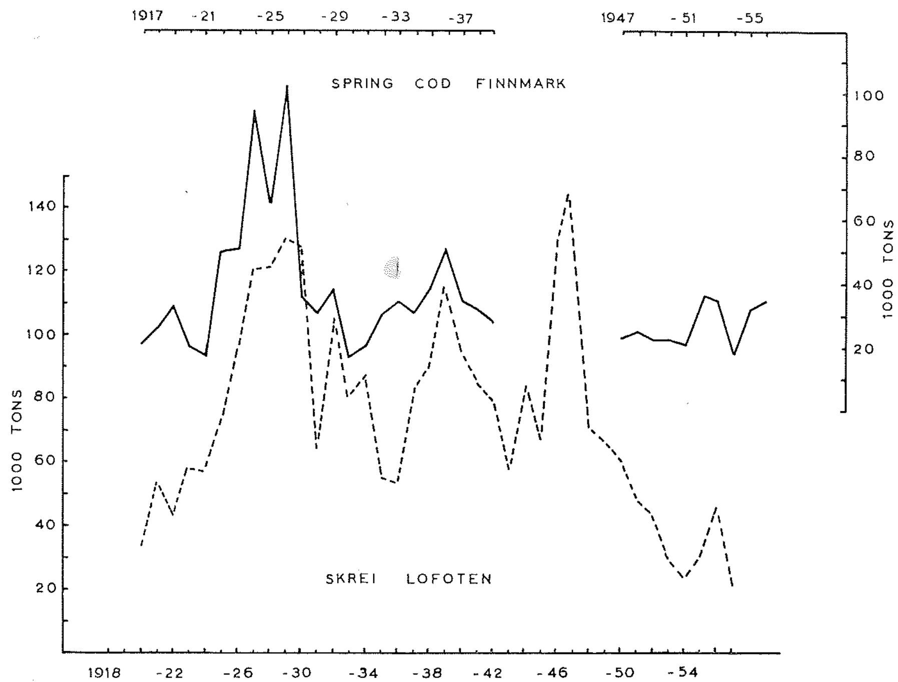

Fig. 3. Annual yield of spring cod in Finnmark and of skrei in Lofoten. Part of catch taken by trawl in Finnmark 1952—56 and by purse seine in Lofoten 1950—57 not included. Three years' displacement of time scales.

Causes of the fluctuations in yield

The size of the yield in the various years is determined by several factors of which the following three are probably the most important; the abundance of fish present on the fishing grounds, the availability of the fish to the various gears, and the magnitude of the fishing effort.

It is highly probable that, in some cases, variations in availability have had an important influence on the yield of the skrei fisheries. Thus in the Lofotens the skrei is in some years found farther from the shore and in deeper waters than usual. Especially in earlier times when the vessels were small and driven by oars and sails only, this factor must have been important. Today it is mainly the fishery with hand lines and purse seines which is influenced by variations in the vertical distribution of the fish shoals.

As shown in Fig. 2 there has also been some shifting of the yield by districts in the last ninety years. In the southern district the skrei fishery has been insignificant since about 1930. This is not due to lack of interest in the fishery in this area, but probably to a displacement of the spawning district northwards. We believe, however, that at present such geographical variations in the migrations of the skrei can have but little influence on the yield. In the skrei season, fishing takes place all along the coast. Major concentrations of skrei cannot escape notice, and with our modern mobile fishing fleet they would soon be effectively exploited.

The abundance of the skrei is undoubtedly the factor which, besides the fishing effort, has the greatest influence on the yield. Its dominating influence comes out in a simple way in Fig. 3. This diagram is a comparison of the catch of the spring cod fishery in Finnmark and the skrei fishery in Lofoten for some years. The spring cod fishery is mainly based on young immature Barents Sea cod. A difference of three years has been applied in the time scale of the two curves because this is the average age difference between the spring cod and the skrei.

There is a fair agreement between the fluctuations of the curves; the tendency of the variation in the Finnmark fishery is later repeated in the Lofoten one. And there is only one feature that can be said to be common to the Finnmark fishery in one year and the Lofoten fishery three years later, namely that they are based on mainly the same year classes of the arctic cod. Thus, the fluctuations in yield must in a great measure have been caused by variations in the abundance of the stock of skrei. Probably these variations are largely so-called natural fluctuations of the population. It is a well-known phenomenon in fishery science that the abundance of the various broods may vary greatly.

Unfortunately detailed information on the abundance of the stock of skrei in various periods is difficult to obtain. If we suppose that variations in availability have had only a comparatively insignificant influence on the yield of the skrei fishery, a relative measure of the abundance could be obtained by dividing the yield by the total fishing effort. But our knowledge of the effort in the skrei fishery is incomplete. Mostly it consists of only a seasonal census of the number of men and vessels taking part in the fishery. The relation between the number of men or vessels and the actual fishing effort is complicated and has changed considerably over the years. It is influenced by a number of factors, such as the size of the vessels, their seaworthiness and engine power, further, by the type and the number of units of gear used, by the operation of the gears, by the ability of the fishermen to set their gear in the best concentrations of fish, by the quality of the bait, and by several other factors, all of which we know have changed markedly during the period we consider. For these reasons the catch per fishermen or per vessel will not give us comparable values of abundance over longer periods.

Fig. 4 shows the variations in the number of men taking part in the skrei fisheries since 1876. There is a conciderable drop in the total number

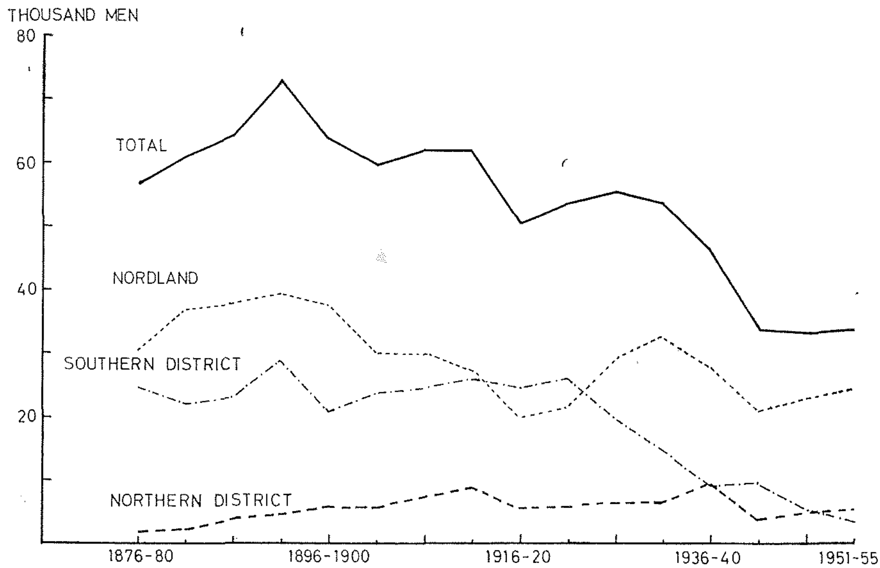

Fig. 4. Number of men engaged in the Norwegian skrei fisheries. Seasonal averages of five-year periods based on the official censuses.

of men from the nineteen-thirties till the postwar years. This drop is the sharpest in the southern district where, as already mentioned, the concentrations of skrei have been thin since 1930. As for North Norway (i.e. Nordland, Troms and Finnmark), which in the last 25 years has been the most important skrei district, the average seasonal number of fishermen for the period 1951—55 is 20 per cent lower than for the 1936—40 period. During this same period, however, a significant increase has occurred in the efficiency of the fleet through improvement in machinery, increased mechanization and the introduction of new instruments such as echo sounders and radio telephones. Changes have also occurred in the types of gear used. Thus in the course of the last few years, gill nets made of artificial fibers (nylon and perlon) have almost completely replaced the earlier conventional nets which were made of cotton and hemp. Comparative experiments have shown that the fishing power of these new types of net is from three to four times greater than the cotton or hemp nets (Sætersdal 1957). In the long line fishery also, materials made of artificial fibres have to a large extent replaced the old types. Here too a change in the fishing power has been observed, not indeed as marked as that due to the gillnets, but still significant (Oppedal 1956). Even the characteristics of the hand line, the simplest of the gears, have probably changed as a result of the change-

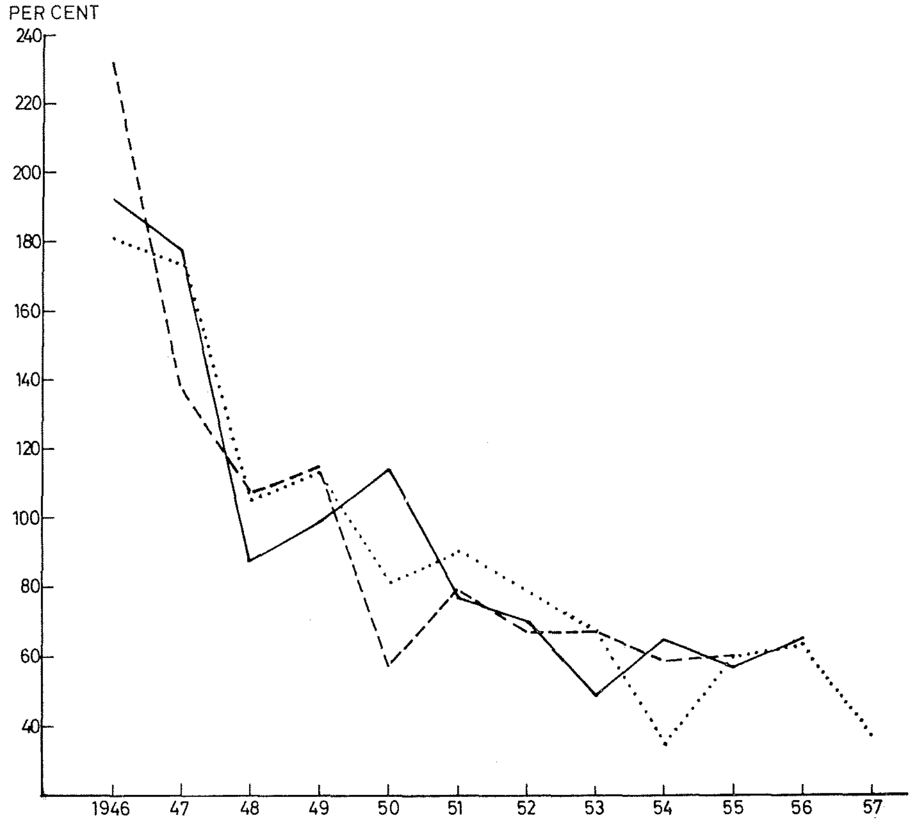

Fig. 5. Comparison of data showing mean annual catch of cod per unit of fishing effort expressed as a percentage of mean values for the period 1946—1955. English data from offical statistics. Soviet data from Maslov (1956).

over to nylon filament and the Swedish tin-bait. Finally, since 1950 a new and efficient gear, the cod purse seine, has been used in the Lofoten fishery.*

This increased efficiency of the fishing fleet and of the gears has probably more than compensated for the reduced participation in the skrei fisheries in North Norway over the last twenty years.

The abundance of the population of skrei in recent years

As shown in figures 1 and 2 the yield of the skrei fisheries has been unusually low in recent years. The averages of the last three five-year periods, 1951—55, 1952—56, 1953—57, have all been lower than in any similar period since 1866. In view of what has already been said of the

* The purse seine has not since 1958 been used in the commercial Lofoten fishery.

fishing effort, there is every reason to think that the abundance of skrei has been abnormally low of late years, probably lower than at any time since 1866.

For the comparatively short period since 1946 there are some data available on the catch per unit of fishing effort which may give a reasonably correct picture of the changes in the abundance of skrei in these years. In Fig. 5 three different sets of observations are compared, namely catch per hours of trawling by British trawlers on the Norweigian coast during the skrei season; catch of "large" cod per hours of trawling by Soviet trawlers in the Barents Sea, and catch per vessel per week of the gill net fishery in Lofoten. The three curves agree fairly well. As they are of very different origin this agreement confirms that the observations are closely related to the abundance of the skrei.

Fig. 5 shows that the catch per unit of effort was high in 1946 and in 1947. The 1937 year class which entered the stock of skrei in these years was very rich (ROLLEFSEN 1951). The partial protection of the arctic cod during the war must also have contributed to the high abundance of the immidiate postwar years. Since 1947 there has apparently been an almost continous reduction of the abundance. It should be noted that the values of the Lofoten gill net fisheries are probably too high for the last few years because the increased efficiency of the nylon nets has not been accounted for.

We are thus of the opinion that the stock of skrei has been unusually poor in recent years — so poor, in fact, that there is serious reason to ask whether this can have been caused by natural fluctuations alone.

The relation between the abundance of the young cod and the skrei

In Fig. 6 we have made an attempt to compare the relative abundance of the two different stages of the arctic cod, namely the young immature fish and the skrei. The curves represent the seasonal catch divided by our measures of fishing effort. Since long lines and hand lines are the dominating gears in the Finnmark fishery, we have for this comparison used the catch per vessel per week by these same gears also in Lofoten.

As the purpose of these data is to compare contemporaneous intervals, the change in the efficiency of the vessels and gears should not invalidate this comparison, for the technical development has been largely the same in the two fisheries.

Fig 6 shows that our measures of the relative abundance of young cod and skrei fluctuate in very much the same way. But in later years the skrei curve drops off relatively to the one representing the young cod; *the skrei population has apparently been less abundant as compared with the population of young cod than it was before the war.* This is the type of effect we

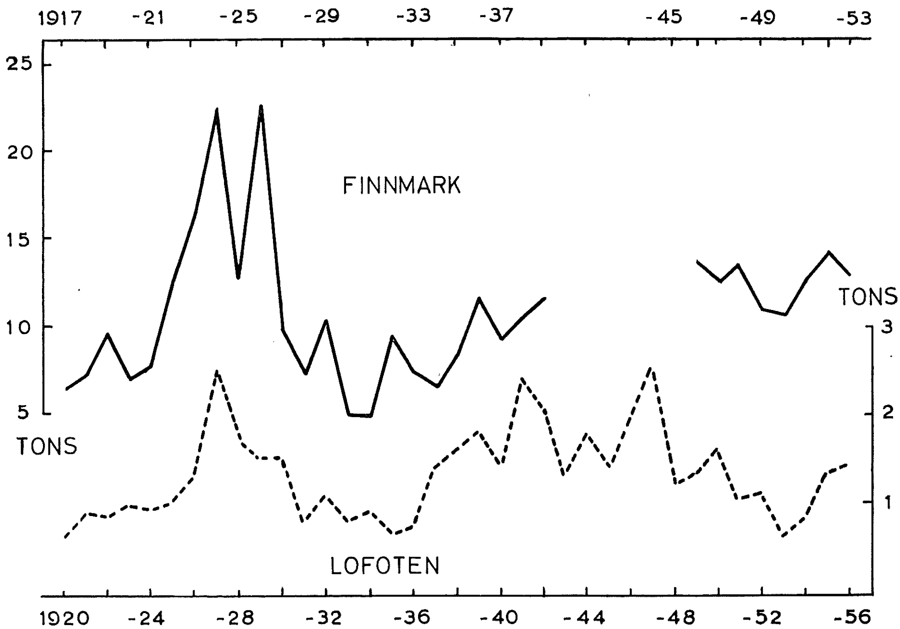

Fig. 6. The abundance of young cod and of skrei. Annual mean catch of spring cod per vessel in Finnmark compared with mean catch of skrei per vessel per week on long lines and hand lines in Lofoten. Note the three years' displacement in the time scales.

must expect to find if the reduction of the stock of skrei is not largely a result of natural fluctuations, but has been caused by an increase in the total exploitation of the arctic cod. The number of old and large fish is reduced relatively to that of the younger and smaller fish.

Detailed information of the abundance of the various broods is regularly obtained by age analysis of the catches of young cod from the Barents Sea. Thus Norwegian (Sætersdal 1957), German (Lundbeck 1954) and Russian (Maslov 1955) investigations agreed in showing that the younger age groups of the year class 1948 was relatively abundant in the Barents Sea. In accordance with this, an increase was expected in the abundance of the skrei from the 1956 to the 1957 season after this year class had matured, but no such increase occurred.

The present situation is that we expect a relative increase in the abundance of skrei in the seasons 1958 and 1959, when the rich year class of 1950 (Maslov 1956) enters the mature stock.

Changes in the mean age of the skrei

It has already been mentioned that the age and size composition of the total population may be influenced by the exploitation. As the fishing

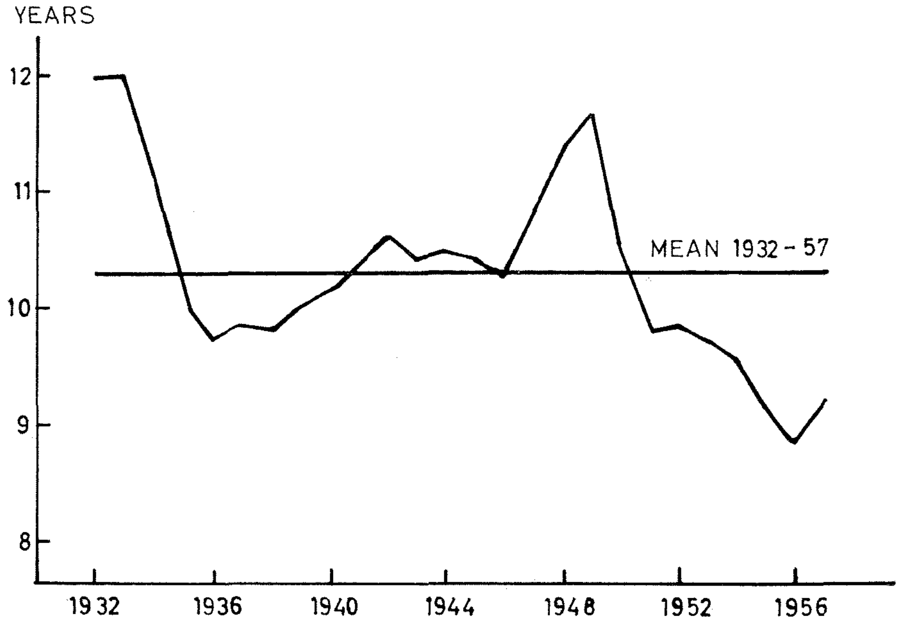

Fig. 7. Annual mean age of the skrei caught on long lines in Lofoten since 1932 and the total mean of the period 1932—1957.

intensity increases, fewer fish will reach the higher age groups and the mean age will be reduced. We are not able to present a comprehensive picture of the changes in the age of the total population of the arctic cod, but we have a series of observations of the age of the Lofoten skrei for each year since 1932.

Fig. 7 shows the variations in the mean age compared with the total mean for the period 1932—57. There has been a considerable and almost continuous reduction since 1949. Undoubtedly the course of this curve is in part determined by the natural fluctuations in the abundance of the broods, but this factor alone should cause only relatively short fluctuations above and below a mean value. There is also the possibility that a physiological change in the maturity age has occurred, but the fact that this striking reduction of the mean age has taken place simultaneously with a serious reduction in the abundance of the stock of skrei (but not of the young fish) is to us an indication that the change in age is an effect of an increased exploitation.

The total annual catch of the arctic cod

Up to about 1920 Norway was almost alone in the cod fisheries in northern waters; but at that time British and German trawlers started fishing in the Barents Sea. About 1930 a trawl fishery also developed on

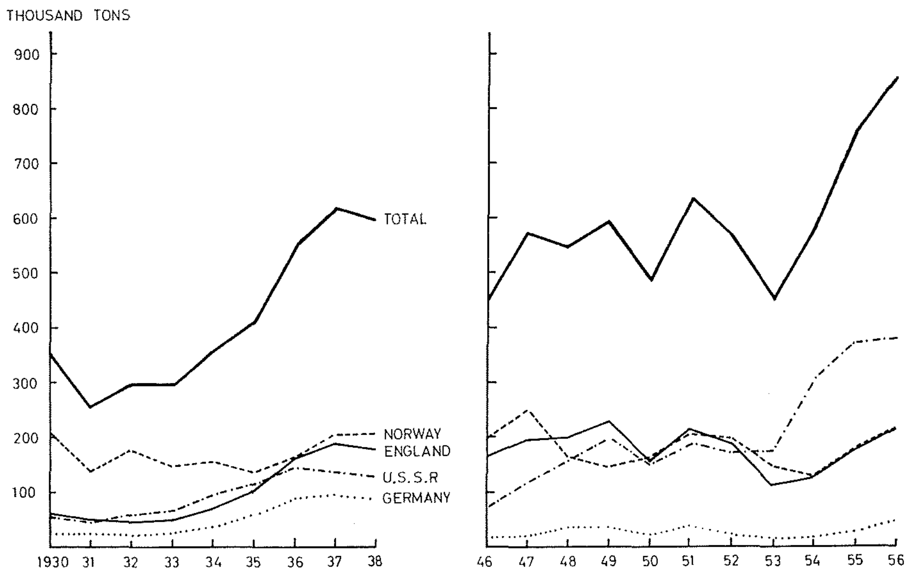

Fig. 8. Total catch of arctic cod and by nations (Gutted Weight). See text for comments on data given for U.S.S.R.

the Bear Island Grounds and along the coastal banks off Lofoten and Troms. During the last war there was a decline in the fishing, as it was confined mainly to a Norwegian exploitation of the stock of skrei. Since the war there has been a considerable and probably almost continuous increase of the total fishing effort in northern waters.

Unfortunately we have not had complete information of the catch of the arctic cod by all the nations which take part in this fishery. In spite of this we venture to present a diagram of the total catch (Fig. 8); but we wish to stress that the figures relating to the Soviet-Russian catch and to its proportion of the total are given with reservations. For most of the years before 1952 our data of the Russian catch are estimates based on scarce information of the size of the fleet and its efficiency. For the years 1952 to 1956, however, there are more exact data. Records of the total Russian catch of Gadidae taken by trawlers in the Barents Sea are available (Anon 1957). Now, from Maslov (1955) it seems probable that the cod forms some 80 per cent of these catches. As the figures refer to round weight a conversion factor of 1.33 has been used to get the gutted weight shown in Fig. 8. There has been a great increase in the total yield of the arctic cod fisheries since the middle of the nineteen-thirties, probably to twice or three times as much. This higher yield has been obtained by an increase in the fishing effort of trawlers, mainly in the Barents Sea and Bear Island areas.

Table 2. *Selective proporties of lines and trawls.*

	Characteristics of fish when fully vulnerable to gear. (Mean values).		
	Age	Length	Weight
Lines (Hook No. 7)	5 years	55 cm	1.5 kilos
Trawl (Mesh size 11 cm)	3 years	40 cm	0.6 kilos

The change in the character of the exploitation

The increased yield in terms of weight does not, however, reveal the real change in the exploitation which has taken place in the last two decades. The change in the character of the fishery may be of equal importance. While previously long lines, hand lines and gill nets were the most frequent gears, by far the largest part of the catch is now taken by trawl. There has also been a shifting of the most important fishing areas from the Norwegian coastal banks, populated mainly by old and large fish, to the more distant fishing grounds of the Barents Sea which form the feeding grounds of the young cod.

The effect of these changes has been to reduce the mean age of exploitation. We are not in the position to show the actual magnitude of this reduction; but Table 2, which compares the selectivety of long lines and of trawls (of a mesh size of 11 cm), shows that the age at first capture is about two years lower for the trawl. We know that part of the trawler fleet in these waters use a mesh size of 11 cm, but the mean effective mesh size of the whole fleet is probably lower than that.*

The change in the character of the exploitation is essential because *the number* of fish caught is very important from the point of view of conservation. As a result of the smaller mean weight of the trawl-caught fish, the yield of arctic cod in terms of numbers must have increased considerably more than that in terms of weight shown by statistics.

The decrease of the yield of the Norwegian skrei fishery is nearly concurrent with this increase in total yield. When we consider the evidence which we presented in the first chapter of this report we think it is reasonable to relate these two phenomena to each other.

Summary

The shoals of skrei (i.e. large mature cod) which migrate to the spawning grounds on the Norwegian coast have always formed an important part of the natural resources of the cod fisheries of Norway. The official statistics of the yield of the skrei fishery which are available since

* Note that this refers to the situation in 1957.

1866 show that, during the last 90 years, considerable fluctuations have occurred. These have mainly been due to variations in the fishing effort and to the differing abundance and availability of the fish. The general opinion is that the fluctuations up to recent years have probably been chiefly caused by the natural variation in the abundance. The average yield of the skrei fishery over the last seven years is, however, unusually low. This is not a result of a decrease in the fishing effort, but it is probably caused by a reduction in the abundance of the skrei in later years. A main part of this reduction is not of the same nature as the natural fluctuations because a similar reduction has apparently not taken place in the young immature part of the arctic cod population.

A striking decrease in the mean age of the skrei has occurred at the same time as the abundance has dropped. Although detailed statistics of the total international catch of arctic cod is not avilable, there is no doubt that there has been a great increase of late years. The change-over to trawl as the main fishing gear has brought about a considerable decrease in the mean age of exploitation. If we therefore consider the total yield in terms of numbers, the increase of the exploitation is far greater than that shown by the statistics of the catch in terms of weight. It is concluded that the decrease of the yield of the skrei fisheries in recent years must be related to the increased total exploitation.

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Inland transport of live cod

by

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Commercial inland transport of live cod was carried out during the period from World War I to World War II between Trondheim and Oslo using railway wagons which were specially equipped for live fish transport. The water was circulated in a closed system in which it was aerated and all undissolved particles were removed by a filtration unit. After World War II the inland transport of live cod was re-established and the "Danish System" was introduced. This used tanks in which there was no circulation, the water being aerated with oxygen. This system has been used in Norway in both railway wagons and road trucks, but like the others this system imposes a time limitation on the transportation. This has been a problem with all the systems used for transportation over distances as far as from Trondheim to Oslo (560 km) or further.

In closed aquaria systems such as those used in the transport of marine fish a number of factors are of importance for the survival of the fish, but the major lethal factors are lack of oxygen, abnormal temperatures, and pH changes. This was discussed by HJORT-HANSEN (1951) in connection with the pre World War II transport of live fish. In the "Danish System" the lethal factor which imposes the time limitation on the duration of transport is the large pH change which occurs in the tanks (SUNDNES 1957). The same pH effect was also found by MCFARLAND and NORRIS (1958). The rate of pH change depends on the degree of crowding of the fish in the water. For commercial use a load of 1 kg of fish per liter of water is necessary. With such a load the self buffering capacity of the seawater is only sufficient to give a maximum transport time of 14 hours (SUNDNES, loc.sit.). This time is the minimum necessary for a journey of 500—600 km on Norwegian roads and leaves no time for delays which may occur during the transport. The obvious approach to this problem is to buffer the seawater to maintain the pH within a suitable range. Work along these lines was first reported by MCFARLAND and NORRIS (loc.sit.) who recommended the use of "tris", 2-amino-2-hydroxymethyl —1.3-propandiol. This buffer is too expensive for commercial use, so we tried to find a suitable cheap substitute.

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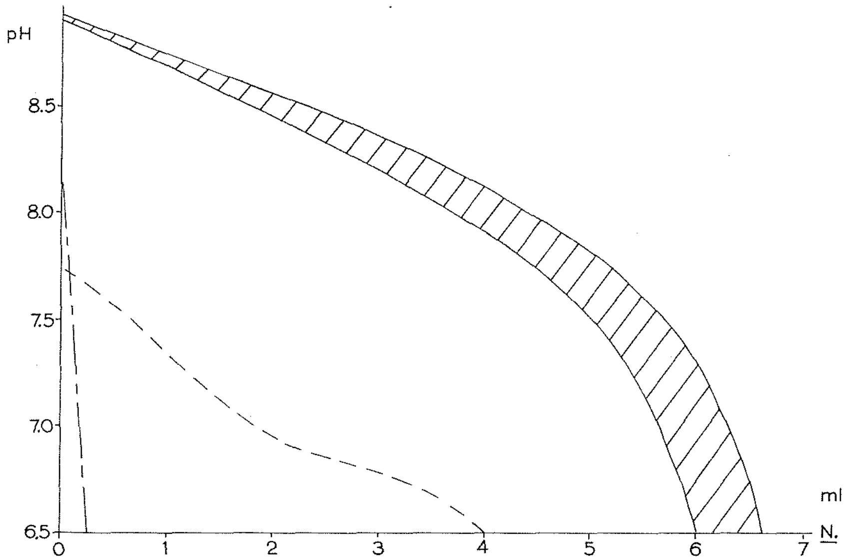

Fig. 1. pH versus ml N hydrochloric acid added to 1 g of buffer dissolved in 100 ml of seawater. — ——— — ——— Buffer curve of seawater. — — — Buffer curves of borax, "tris", glycylglycine and taurine lie within this envelope. //////// Buffer curve of sodium bicarbonate.

Material and methods

We sought a suitable buffer among the naturally occurring salts in the sea. Here the major buffers are the carbonate-bicarbonate and the borate systems.

The carbonate-bicarbonate system is the one augmented by the respiratory products of the fish and has its main buffering action in the pH range intolerable to the fish (Fig. 1). The pH of seawater appears to be maintained at its normal high level of 7.9—8.3 mainly by the borate system which buffers strongly between pH 7.5 and 8.5, the minor fluctuations which occur in seawater being caused by alteration in the balance between the borate and carbonate systems. A major change in this balance such is caused by gross overcrowding and hence enormous increases in the carbon dioxide content leads to marked changes in pH, which may become lethal. Addition of borate should partly restore the balance and retard the pH changes. Of a large number of buffer systems investigated three organic buffers, "tris", taurine, and glycyl glycine, gave very similar buffer curves to borax. From the commercial point of view borax is far cheaper.

The live cod used in the experiments were of ordinary commercial quality with regard to physiological condition. For public health reasons tests were made on the borate content of the treated fish.

The initial transport experiments were made in small aquaria, but later full scale commercial tanks were used. In the full scale experiments the tanks were loaded with 600 kg live cod in 600 liters of seawater and parallel experiments were run with and without borate buffer added. The water was aerated by the "Danish System" using pure oxygen. One gram of buffer mixture containing 2 parts of sodium borate and one part of boric acid was added per liter of seawater in the tank.

Borate analyses

There are restrictions upon chemical additives to fish for human consumption and these also affect fish which have been swimming in seawater with borate added.

Some experiments were therefore performed to get information on the borate content in the fish in seawater containing borate buffer (GAST and THOMPSON 1958).

In these tests seawater of a much higher borate content was used than in the transport experiments and the time that the fish were kept in the solution was increased. In the transport experiments 1 gram of the buffer was added per liter of seawater and the time that the fish lived in this solution was 1 day (24 hours). In the borate tests we added 4 grams of the buffer per liter of seawater and kept the fish there from 4—6 days. The borate contents of the fish in the tests are shown in Table 1.

Table 1. *Borate content in fish.*

Fish from untreated seawater	Fish from treated seawater	Unwashed fish from treated seawater including adhering salt
0.0013—0.0016 %	0.0015 %	Max 0.009 %

Aquaria test of the borate buffer

Small scale transport experiments were performed in aquaria which were aerated with pure oxygen as in the commercial transport system. Two parallel experiments were run, one with untreated seawater and one with seawater treated with a sodium borate/boric acid buffer. 1 gram of the buffer to 1 liter of water gave a good buffering effect and had no toxic effect on the fish. The "loading density" was 0.7 kg fish/liter of water. This loading is not dense enough for commercial use. The temperature during the experiments was 12—13° C.

Here again we found the typical pH changes (Fig. 2) but in the borate treated water the buffering effect increased the time of the pH

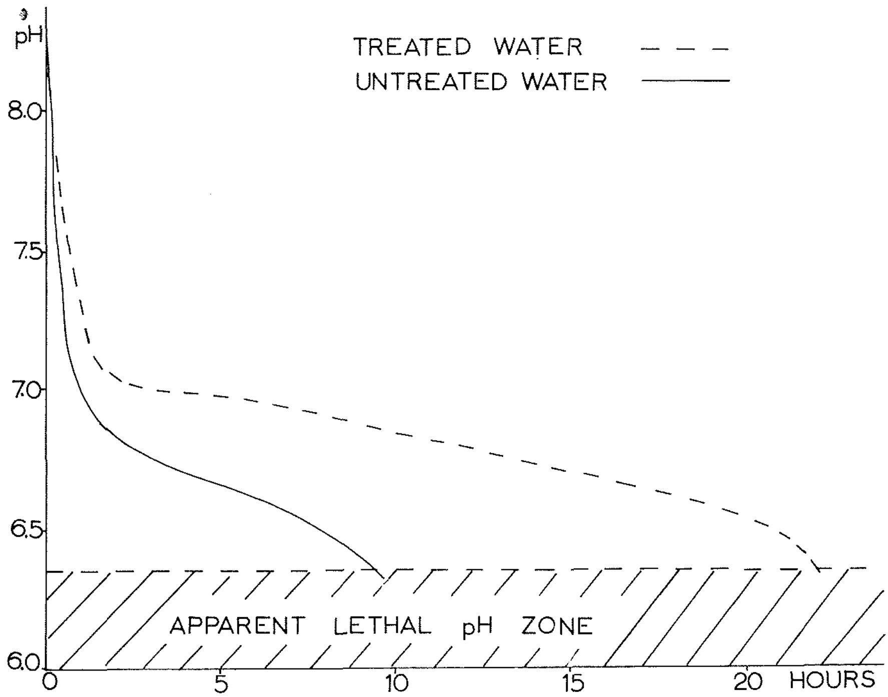

Fig. 2. pH versus time in a tank loaded with 35 kg cod/ 47.5 liter of untreated seawater and a tank loaded with 35 kg cod/ 47.5 liter of borate buffer treated seawater.

change. As can be seen from the figure the "transport time" was doubled. This indicated that full scale experiments would give results in the same direction.

Transport experiments in full scale tanks

These experiments were performed in extremely cold winter conditions, the water temperature was 2—3° C. Two parallel experiments were run, one with seawater only and one with borate buffered seawater. The tanks contained 600 kg of fish in 600 liters of seawater.

In Fig. 3 the pH curves versus time are shown. In the untreated water we see that as in the former experiments (Sundnes 1957) the maximum transport time was 13—14 hours. By using the borate buffer we see from the curve that another 6 hours can be added to the transport time. This would mean safer transport on a 600 km journey or alternatively other new markets at a distance of 800 km could be reached.

In these heavily loaded tanks we do not get such a good relation-ship between the treated and untreated water as in the aquaria experiments.

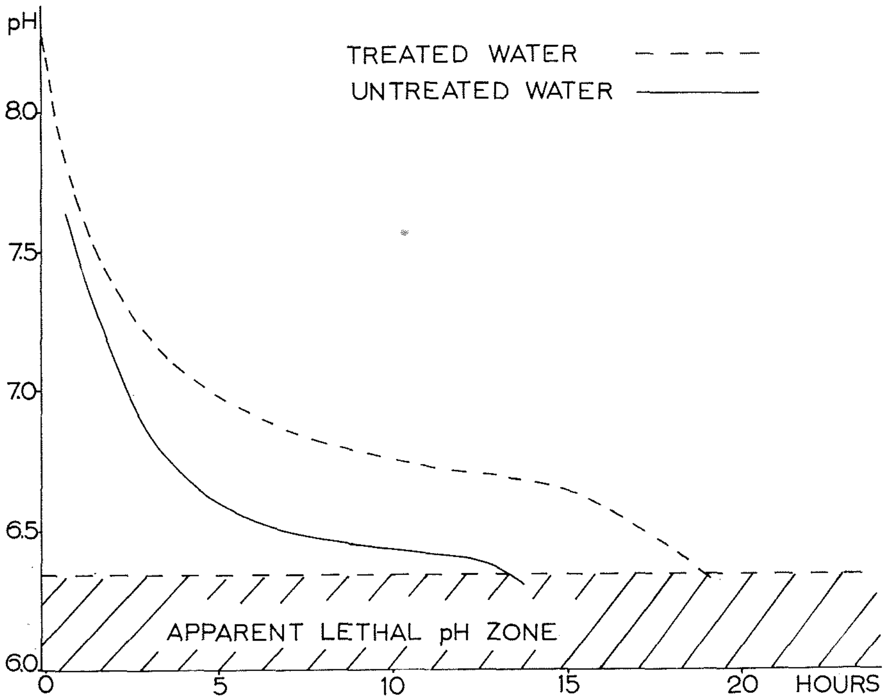

Fig. 3. pH versus time in a tank loaded with 600 kg cod/ 600 liter of untreated seawater and a tank with 600 kg cod/600 liter of borate buffer treated seawater.

This is due to the more dense loading which is absolutely important in commercial use and which diminished the buffer effect as a whole compared with the smaller concentrations in the aquaria experiments. In cases where it was possible to make further buffer additions during the journey however, the transport times could be even further extended.

Comments

Biological experiments with technological application do not always give basic biological and physiological data, but these experiments are based on basic data from which the technological experiments were derived. The aim is to give a technological answer to the biological demand from the fishg. The technical systems do not always give optimum environmental conditions, but because of the excellent regulation mechanism in the fish these can survive if the conditions are not too extreme.

In seawater with 80—90% oxygen saturation a decreasing pH gives a slight decreasing energy metabolism in the fish. When the pH falls below 7.3—7.2 there is a steeper fall in the metabolic rate. In the present transport system this stress on the fish is diminished by aerating the water with pure oxygen. The environment is therefore always supersaturated with respect to oxygen and the metabolism is not affected at higher pH in the same way as in normally oxygenated seawater.

Commercial

Inland transport of live cod is a far cheaper method than wellboat transport. On the other hand the physiological stress on the fish is much higher and it can by no means be compared with wellboat transport in this field. The primary limitation on land transport was the time taken for the pH to change, but this drawback has now been partly overcome by using a borate buffer with a cost of less than 10 Kr. (or £ 0-10-0) per metric ton of live cod.

Acknowledgement

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