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 1D 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:

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

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

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

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:

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

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

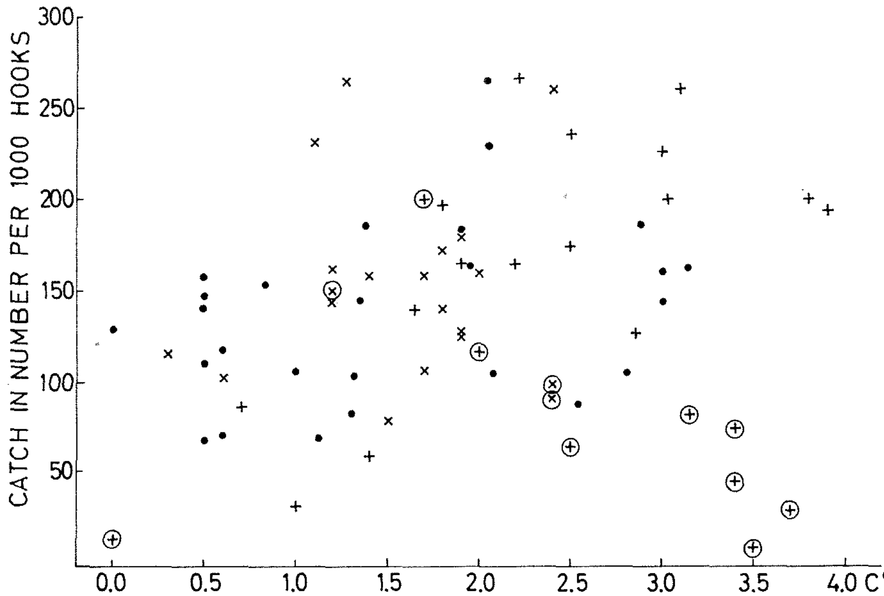

Fig. 1. Bottom long line fishery off West Greenland. Relationship between bottom temperature and catch in number/1 000 hooks. O Research vessel data. Subdivision: ● 1B, X 1C, + 1D

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

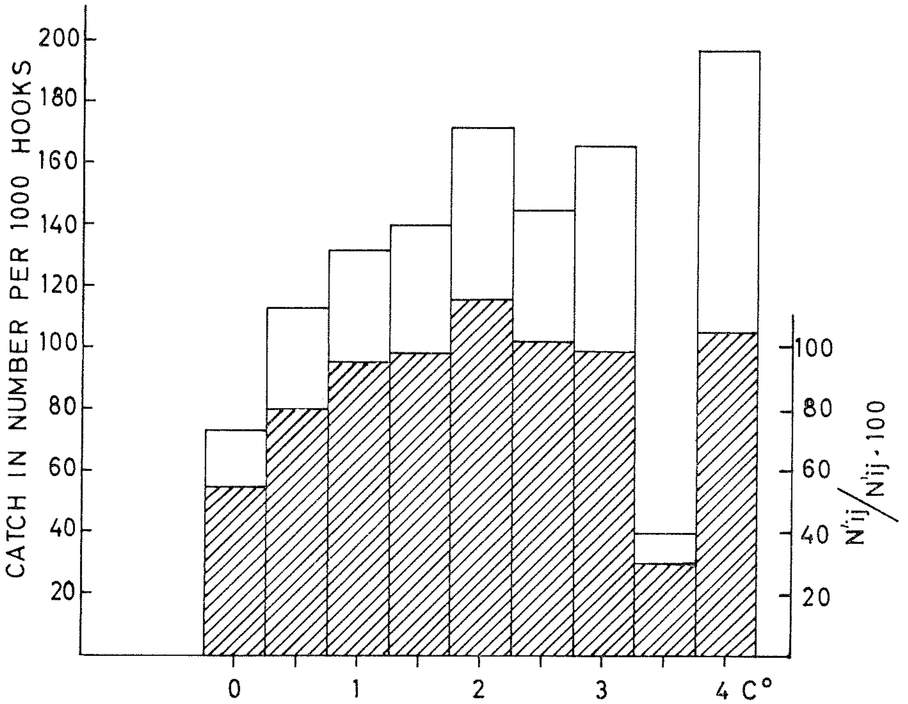

Fig. 2. Relationship between bottom temperature and mean catch in number/1 000 hooks (□) and mean *N*'ij/*N*ij (▨)

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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