International Council for the
Exploration of the Sea

C.M. 1964
Baltic Belt Seas Committee
att. Gadoid Fish Committee
No. 9o D/6

Possibilities of Forecasting the Distribution of Stock and Efficiency of Fishing for Baltic Cod during Pre-Spawning and Spawning Periods

by

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The literary[1] sources contain much information on the effect of the hydrological conditions of the sea on the behaviour and the distribution of cod. But this information is not sufficient to forecast the location of fishing grounds and catch per effort. The analysis of the materials obtained from the literature listed and of our own has shown that with the help of rather simple methods the quantitative expression (formulas, diagrams) of the effect of the hydrological regime of the sea can be found in relation to the behaviour and distribution of stocks, density of concentrations and efficiency of fishing for cod in the main regions of the Baltic by depth zones. The regularities found can be used in practice for the purposes of forecasting.

The following data were applied for the analysis of cod distribution and efficiency of cod fishery:- the statistics of cod fleet, M. Berner's materials on cod fishery in D.D.R., data on cod fishery in 194o-1945 (P. Meyer) and other biological evidences.

To characterize the hydrological conditions, the data of two international stations were taken as a basis (numeration is made according to the diagram of I.G.Y. for the Baltic):

No.3 (55°1o'N, 15°57'E in Bornholm Deep and
No.8 (67°22'N, 19°57'E in Gotland Deep.

The investigations have shown that the peculiarities of the effect of the regime of the sea on fish are most clearly observed on these stations as they are located on the boundaries of the Baltic cod's habitat.

The quantitative study of the effect of the regime of the sea on the behaviour of cod and on the efficiency of fishing has been carried out with application of the methods of variational statistics.

I. Distribution of Cod by Depth Zones

The echo-sounder survey and the analysis of operations of the Soviet trawling-fleet in the Eastern Baltic have shown that during the spawning period the distribution of cod depends mainly on salinity-oxygen conditions. The upper limit of a spawning zone depends on the location of isohalines 1o-11‰, the lower one is defined by isoxene 12%. These findings coincide with the data given in the above-mentioned literature.

Cod spawns in the Gotland Deep within a depth zone of 1oo-14o m in the years when deep waters are aerated. This zone diminishes and shifts up to the layer of 8o-1oo m in the years of stagnation (when no inflow of new water is observed from the Western Baltic).

Thus, cod can spawn at 1o‰ salinity too, but it strives to move into waters of a higher salinity, that is to deep water layers. But its penetration into deep water is limited by the oxygen conditions, fish does not enter water layers containing less than 12% of oxygen (Table 1). As appears from the above stated, the oxygen regime exerts the main effect on the vertical distribution of the cod in the Eastern Baltic. During the period from March to June 75-85% of the total spawning cod stock are located in the spawning zones.

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1) The investigations by Berner, Dementieva, Tokareva, Grouman, Birjukova, Pavlova, Naumova, Radakova, Otterlind, Kändler, Rutkovicz, Demel and others.

The analysis of our materials covering 1949-1963 and the data provided by Meyer has shown that this regularity in the vertical distribution of spawning cod remains unchanged every year.

Apparently the temperature conditions do not affect the vertical distribution of cod very much; the temperature influences mainly the rate of development of gonads, the terms and duration of spawning.

In the pre-spawning period a basically different situation is observed which can easily be explained from the biological point of view (Table 2); the effect of the salinity-oxygen regime is very weak, but the temperature conditions exert a rather considerable influence upon the distribution of fish. When winter is severe the pre-spawning cod migrate from the northern and the middle parts of the Gotland region towards Klaipeda-Gdansk area, where the water is warmer; during such years the catches taken by the Latvian fishermen decrease in the 1st quarter of the year, whereas the Lithuanian and Polish yields increase. These migrations may be attributed to the fact that pre-spawning cod "seeks for" water masses with a temperature regime most suitable for the development of gonads. During the spawning period cod returns to the north if the oxygen content in the Gotland Deep is favourable.

The adjustment of the reaction system of cod to the effect of the environmental factors evidently takes place when the fish reach their III and IV stages (according to the six-ball system) of maturity, i.e., usually in March.

A similar relationship of vertical distribution of spawning cod with hydrological conditions is observed in Gdańsk and Bornholm Deeps (analysis of data of Berner, Rutkowich, Demel and Pionek and other authors).

II. Distribution of Cod Stock by Areas in the Baltic and Efficiency of Fishing

Studies of the regularities in distribution and migrations of cod have been carried out in Gotland and Bornholm - Stolpen regions.

The effect of regime of the sea on migration of cod from the Eastern to the Western Baltic (and back to the Eastern Baltic) have been ascertained by Swedish, Polish and Soviet experiments on cod tagging. It is also known that the efficiency of fishing (total catch, catch per unit of effort) depends not only on the size of the stock but also on the density of the fish concentrations. Thus, T. Dementjeva explains correctly that low catches of cod in 1953 were caused by dispersion of the cod stock over a large area of spawning grounds.

For the quantitative study of the effect of the regime of the sea on the cod distribution and the efficiency of fishing, the following data were taken as the most accessible parameters of regime and extent of spawning grounds:

a) in the Gotland region at Station 8 (57°22'N and 19°57'E) depth (h) of a layer of water feasibly suitable for spawning (for example, the distance between the depth of isohaline 11‰ and isoxen 12%) in different variants, and a mean water temperature in the layers 4o-8o, 8o-1oo, 1oo-15o m;

b) in the Bornholm region at Station 3 (55°1o'N and 15°57'E) mean values of salinity, oxygen content and spring temperature in layers 6o-8o m, 6o m - bottom, 8o m - bottom.

Other hydrological data have been also analysed.

The comparison of catches taken by Soviet trawlers in 195o-1963 with the regime of the Eastern Baltic as well as the progress of fishing with the conditions in the Bornholm area have shown rather conspicuous regularities:-[1)]

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1)
Basic indices for Gotland and Bornholm are given in Figure 1 and Tables 3 and 4; it does not represent difficulty to turn these tables into diagrams (in order to make them more instructive). In the Eastern Baltic catches per effort give the same picture as total catches, because the fishing intensity was constant during the period in question.

1) There are noticeable interrelations between the fishing efficiency and the extent of the cod spawning grounds; the degree of relationship between catch and depth of the spawning zone in the Eastern Baltic is characterized by a correlative relation (η, Table 3) of the order of o.85-o.91, when P = o.95-o.99; for the Bornholm area the coefficients of correlation of catch per effort with the regime (r, Table 4) are also high and reliable.

Thus the hypothesis implying the effect of the salinity-oxygen regime (function of regime - the extent of spawning grounds) on migration and distribution of pre-spawning and spawning cod is well confirmed by the data covering the Eastern Baltic and by the data on the Bornholm area as well.

The results do not contradict each other and take a shape of a comprising system of regularities in the distribution of Baltic cod.

2) The relationship between the distribution of fish and thermal regime of the sea is much weaker and, probably, of a formal character, since in the Eastern Baltic not so strong relationship (Table 3, η = o.67) only with temperature of a water layer of 8o-1oo m, has been found, which is usually located above the spawning zone; but with temperature of the spawning zone itself (1oo-125, 1oo-15o m) no relation has been revealed.

It may be supposed that the temperature of the layer 8o-1oo m affects the migration of fish before the spawning takes place and this fact defines the magnitude of a stock and the efficiency of fishing for the spawning fish in the basic regions of the Baltic. But some objections arise to this hypothesis:-

a) In this case the indices of the relationship between temperature and catch must have been higher than those of the relationship between catch and oxygen regime; but in fact we face quite an opposite situation.

b) One can assume that if the temperature of the layer 8o-1oo m goes down below +4,6°C, cod migrates from the Eastern to the Western Baltic; actually, in 1957-196o this temperature was low (+4.1 - +4.5°C) and the cod migrated to the west (catches decreased in the east and increased in the west; the same changes were determined by tagging experiments); but in the Bornholm area the water temperature in the layers 6o-8o m and 8o m-down to the bottom was still lower ranging from +2.6°C to +3.8°C. A contradiction emerges.

c) With the temperature going up from +4.6°C to +5.5°C the fishing efficiency drops sharply in the Eastern Baltic. The question is, where do fish go once the catches in the Bornholm area also go down? The salinity-oxygen hypothesis explains this fact very well.

Thus, our analysis makes up the following picture of regularities in distribution and migration of Baltic cod during the first half of a year:

1) In the years when the conditions are favourable for spawning (years of aeration of deep waters) the cod only perform short migrations in the Eastern Baltic - from the wintering places to the spawning grounds located in deep waters. If the stocks of cod are bigger in the western regions of the sea as compared with the eastern areas, the fish migrate to the Eastern Baltic (the expansion of population areas). In such years the catches per unit of effort are small (1953) in the whole Baltic area.

2) When the conditions become worse[1]) the extent of spawning grounds diminishes in the Eastern Baltic, but the main bulk of the cod does not migrate from here yet. Consequently, together with this reduction the density of concentration and catch per effort rise to a certain maximum.

In the period of 1949-1959 in Gotland Deep the maximum of function (of catch) was observed when the value of argument (X - the extent of spawning ground) taken at Station 6, is characterized by the layer of water between isohaline 11‰ and isoxene 15% h = 35-4o m.

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1) The reduction of water inflow from Kattegat, or the accumulation of old water of great density in Gotland Deep which prevents the inflow of new aerated water from Bornholm Deep (as it apparently occurred in spring 1954).

3) There are all reasons to believe that the point of maximum (index of the argument at which the function has its maximum value) depends upon the magnitude of a stock of spawning cod:- with a larger fish stock the function (catch) reaches its maximum value in case of bigger index X (the extent of spawning grounds in Gotland Deep), rather than in case of a small stock. Thus in the periods of 194o-1945, 195o-1959 and 196o-1964 the functions reached their extremes with the values of X = 1.6-2, 1-1.2, o.3-o.5 of the conventional units, respectively[1]). Hence, the conclusion may be drawn that the cod do not leave a given spawning ground if the mean density of its concentration is below a certain limit; that the "critical" density represents a rather constant and specific value for a given species, the exceeding of which gives rise to the migration of cod from the given area; there are other proofs of the availability of this "critical" density.

4) When a further stagnation of the waters is going on, the spawning grounds loose their significance and the cod moves to the Bornholm - Stolpen area in order to spawn; this happened in 1958-1959 and 196o, when at the Station 6 h (S 11‰ - o_2 15%) = -9-(-15) m; the catches decrease in the Eastern Baltic and rise in the Western (r^2 = o.71-o.95 when P >o.95). One of the quantitative evidences of cod with-drawal from the Eastern Baltic spawning grounds is the break of the relationship "catch-regime" in the Bornholm area; in 1958-1959 the catch per effort amounted to 15o% of the theoretical value calculated according to the formula of relationship "catch - oxygen" for this area; if conditions improve next year in the Eastern Baltic, the fish will return (196o).

5) The general picture of the regularities in the distribution of stock and dynamics of catch of cod remained almost unchanged during the period 194o-1963 (deviations were very small and explicable); that is why it can be expressed in the terms of quantity (formulas, diagrams, calculation, methods, basic indices, etc.) with a precision and reliability acceptable for practical work.

Let us examine two cases:-

a) Estimation of Cod Stock in the Eastern Baltic

This can be done in two separate ways. The first is: to compare the actual catch per effort in the year of stagnation (Figure 1,a) with the theoretically expected, provided that cod does not migrate to the east, and hence the catch would be equivalent to the extent of spawning grounds (Figure 1,b); years are taken for comparison from the long-term periods of equal stocks. As follows from Figure 1 in the Gotland region in the spring 1958-1959 and 1963 4o and 45% of the stock of 1952-1956 and 196o-1962, respectively, remained.

The second method: to analyse the ratio of maturity of cod in the years when stagnation and aeration occurred in the Gotland region. In the years when stagnation takes place the ratio of spawning fish is much lower than in the years when aeration occurs. The biological data and the analysis of fishing operations show that such phenomenon occurs just because of the withdrawal of spawning cod, but not due to the delay in fish maturing in the years of stagnation. So the estimation of fish withdrawal can be made assuming that the quantity of immature fish in both periods remains a constant value[2]). Here is the result of the calculation:- in 1958-1959 and 196o, 31 and 47% of the stock of cod of the 1952-1956 and 196o-1962 year-classes, respectively, remained in the Eastern Baltic. The results obtained by both methods proved to be practically identical.

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1)
That is why the relationship between "catch and regime" apart from the study of distribution of fish permits to define: a) the amount of stock of cod in the Baltic at different periods of years, b) the amount of stock and abundance of constituting year-classes in a given year.

2)
An example of how to make estimation: immature cod-stages I-II, mature cod-stages III-VI according to the six-ball scale; the amount of immature cod is equal (constant) in both periods (of stagnation and aeration)

stagnation - 1963: I-II = 36%, III-VI = 64%
aeration 196o-62 : I-II = 17%, III-VI = 83%;

then 36 = 17 conventional units of immature cod, if the total amount of cod stock = loo in the year of aeration; therefore, the amount of mature cod in 1963 can be found in form of indices (but not in percentage) from the proportion $X = \frac{64.17}{36} = 3o$; hence the stock in 1963 = 17+3o = 47 conventional units.

b) Estimation of Distribution of Total Stock of Cod in the Years of Aeration and Stagnation by Regions in the Baltic

The opposite trend in changes of catches per effort in the eastern and western regions of the sea is attributed to the migrations of cod, the catch per effort being equivalent to the amount of the stock in each region. The correlation between the catches per effort in the eastern and western areas is characterized by r = -(o.72-o.98) which ensures the precision of the results of estimation if P = o.52-o.89; this is quite sufficient for the preliminary calculation. Then the differences in the scales of changes of the catches per effort (a relative increment of stock - y') in both regions will be inversely proportional to the ratio of the amount of stock of fish in the east and in the west, provided that conditions change in the Eastern Baltic (the transition from aeration to stagnation).

The method of estimation is shown in Table 5. The results of estimation are as follows:- the stocks of cod are approximately equal in the Eastern and Western Baltic in the years of aeration, and about 8o% of the total stock of cod of these two regions are concentrated in the western region in the years of stagnation.

III. The Possibility of Forecasting the Stock and Catch of Cod in the Eastern Baltic

The forecasting is based on the fact that there are close statistical relations between:-

a) catches and hydrological conditions in the Eastern Baltic (the indices of relationship are given above).

b) conditions of the Gotland and the Bornholm regions.

Quite sound interrelation exists also between the salinity of the water layer 6o m - bottom in the Bornholm region in autumn - winter time and the indicec "h" in the Gotland Deep next spring. For the period 1949-1964 the coefficient of correlation (when different variations are recorded between the isohaline lo and 11‰ and isoxenes 12, 15 and 18%) r = +(o.86-o.89) when P = o.99.

The relationship between salinity in autumn-winter time and the efficiency of the fishing operations (total catch, catch per effort) of Soviet trawling fleet in the Gotland region next spring is characterized by rather high indices. For instance, the correlative relationship r(S‰ - ξ of catch) = o.87 (Table 3).

Thus, formulas can be made to a further forecast of the efficiency of fishing for pre-spawning and spawning cod in the Eastern and Western Baltic with application of a regressive analysis.

For example, the formula for forecasting the Latvian catch in the Gotland Deep during the first half-year is as follows:-

$$Y = -17x^2 + 487.97x - 34c8.7 = -17(x-14.35)^2 + 91.97,$$

where Y - is a total catch in metric centners, and x - is mean salinity of the water layer from 6o m to the sea-bed in the Bornholm Deep in autumn-winter.

The probability of correct forecasting P = o.7-o.8, and the precision of the result a = ± 11% are quite satisfactory for the beginning of the study. The actual catch made up 111% in 1962, and 88% in 1963 in comparison with the forecasted.

The precision of forecasting will be improved if the calculation include corrections as to the level of stock, abundance of year-classes composing the commercial stock in the year under forecasting, the relationship "length weight" and the coefficient of catchability of fishing gear.

The study has shown that it is possible in principle to make a quantitative analysis of the effect of the hydrological regime of the sea on the dynamics of stocks and distribution of cod and on this basis to prepare a prospective forecast of the magnitude of fishing and catches per effort calculated by depth zones and main regions of the Baltic.

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Table 1. The Distribution of Cod during the Spawning Period, and the Hydrological Conditions in the Eastern Baltic in the Years of Aeration (196o-1962) and Stagnation (1958-1959 and 1963)

Depth zones (in metres)	Aeration			Stagnation			t° of water	
	Catch %[1]	S‰	o_2%	Catch %[1]	S‰	o_2%	aeration	stagn.
55-65	3	8.o	66	15	7.7	66	+3.39°C	+3.41°C
65-75	1	8.9	5o	17	8.o	5o	+3.39°C	+3.41°C
75-85	1	1o.o	29	3o	9.o	28)		
85-95	3	1o.8	23	11	1o.2	2o)	+4.91°C	+4.67°C
95-1o5	1o	11.2	2o	24	1o.7	14)		
1o5-115	7	11.7	2o	2	11.1	11)		
115-125	2o	11.9	19	1	11.7	1o)		
125-135	54	12.3	17	o	11.8	7)	+5.52°C	+5.o3°C
135-145	1	12.6	12	o	12.o	3)		

1) Immature fish are found in zone 55-9o m.

Table 2. The Relationship between the Amount of Catch of Cod in the Gotland area (Latvian Fishery) and the Hydrological Conditions

	Pre-spawning period	Spawning period
Stages of maturity I-II	76%	3o%
III-VI	24%	7o%
Temperature conditions	r = +o.83	r = -o.11
Oxygen conditions	r = -o.2o	η = o.91

Coefficient of correlation (r) and correlation relationship (η) are true, P > o.95 after t - criterion (Student)

Table 3. Dependence of the amount of catch on the hydrological conditions; spawning period; catch in thousands of metric tons (Eastern Baltic).

Years	1959	1958	1963	1957	196o	1962	1961	1956	195o	1951	1952	1955	1953	The extent of relationship with the catch
h $S = 1o‰$ $O_2 = 12\%$	12	22	25	49	55	65	7o	8o	122	13o	135	145	16o	η *) = o.91
h $S = 11‰$ $O_2 = 12\%$	-13	-3	2	32	32	49	47	55	1o1	1oo	125	133	14o	η *) = o.85
h $S = 11‰$ $O_2 = 15\%$	-1o	-16	-9	22	22	29	39	37	76	8o	112	133	14o	η *) = o.85
t° 8o-1oo	4.o9	4.28	4.73	4.53	4.46	5.2o	5.o6	4.67	-	4.94	4.9o	4.94	5.5o	η = o.67
$\lesssim$ of catch	13	14	7	18	14	1o	8	2o	16	13	13	11	5	
S‰, 6o Lottom Bornholm	13.5	14.4	14.2	15.1	14.6	15.9	16.2	15.7	16.8	16.1	17.4	16.8	18.4	η *) = o.87

The salinity in the Bornholm Deep: mean value in the autumn of the previous year and in winter (February) of the given year.

Curves show two levels of stock: a) the period of 195o-59, and b) the period of 196o-63.

*) the correlative relationship (η) for 195o-59.

Table 4. The Relationship between the Catch per Effort (accord. to M. Berner) and the Conditions in the Bornholm Region

(average annual indices; ‰ and t°-6o m - bottom; o_2-85-9o m)

Years	1958	1959	1957	1956	196o	1961	1955	1954	1953	1952
‰	13.4	14.1	14.7	15.2	15.2	15.6	16.5	16.8	17.6	19.1
t°C	3.6	5.o	3.9	3.7	5.3	6.2	5.8	5.o	5.5	5.9
o_2%	4	24	16	6	43	29	6	5	5	47
catch,kg	69o	76o	79o	72o	44o	53o	52o	52o	41o	43o
Situation in the Eastern Baltic										
Stagnation; the withdrawal of fish			transitional period				aeration; fish does not migrate to the west			
Characteristic of the relationship			catch-‰				catch - t°		catch - o_2	
(P>o.95)			r = -o.76				r = -o.74		r_t = o.64	

Table 5. Technique (principle of the estimation of the distribution of stock of cod in the Baltic in the years of aeration and stagnation

			West	East
catch/effort (stock) = Y		a e r a t i o n stagnation	n N	M m
increment of stock = Y^1 =		$\frac{\triangle Y}{Y}$	$N^1 = \frac{N - n}{n}$	$M^1 = \frac{M - m}{M}$
$\frac{n}{M} = \frac{M^1}{N^1}$; $n = \frac{M \cdot M^1}{N^1}$	indices	$= \frac{100\ M^1}{N^1}$ (per cent)		
The distribution of stock	aeration	$\frac{MM^1}{N^1}$		M
indices	stagnation	$\frac{MM^1}{N^1} + MM^1$		$M - MM^1$

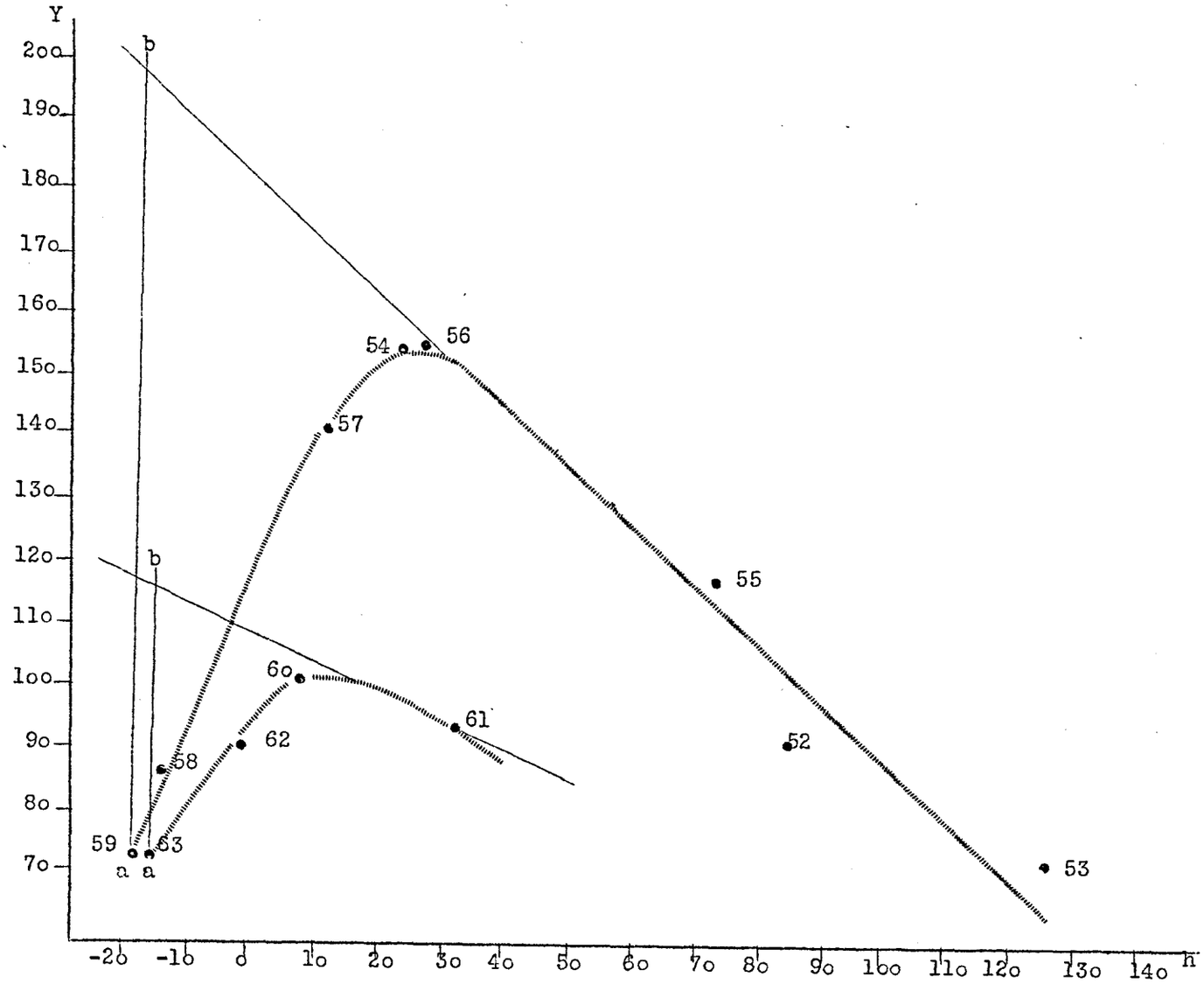

Figure 1. The relationship between the amount of catch /y(t)/ per trawler in the Gotland Deep in the first half of a year and h/S 11‰ - o_2 18% (metres).

a - actual catch

b - theoretical catch when no migration is noted