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'Schaefer-type' assessments of catch/effort relationships in North Atlantic cod stocks

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Introduction

It is obviously desirable to base stock assessments upon critical analyses of the parameters influencing population size in particular stocks. For the most part these studies have in the past depended upon catch per unit effort/effort analysis, or more recently, upon 'virtual population' analysis which overcomes in some measure the inherent variability of catch per unit effort data. The use of this technique has recently led to a substantial modification of the assessment of the Iceland cod stock based upon the catch per unit effort data (ICES, 1968a), and it seems possible that analogous studies of the north-west Atlantic cod stocks will also be hampered by the difficulties of constructing an adequate series of consistent data. In this light it is relevant to seek confirmation of the analytical models by the alternative, but less rigorous, approach developed by Schaefer (1954) and extended by Gulland (1961). This method does have the advantage that its generality includes the variations in absolute yield which are generated by density dependent changes in the fundamental population parameters and which are in practice excluded from most analytical assessments to date, owing to the difficulty of defining these factors with any degree of precision. Moreover, the method facilitates rapid comparison of data from different fisheries and enables one to draw upon the effects of fishing in stocks that have been exploited intensively for a longer period than the north-west Atlantic stocks, which have been subjected to a rapid increase in fishing only in recent years.

Method

Once recruitment is complete the abundance of an exploited fish population is for the most part determined by the amount of fishing to which the constituent age groups have been exposed. However, in all exploited cod stocks it is easy to identify a number of age groups which contribute the major proportion of the abundance of the exploited stock in any year, and so, as an approximation, it can be said that the abundance in that year is determined by the fishing effort to which these age groups have been exposed. Most of the cod stocks of the north Atlantic make their major contribution as 5-, 6- and 7-year-olds, so the measured abundance would include primarily the effects of recruitment, and of fishing during the year of sampling and the preceding two years.

If the abundance is measured as the numbers of fish caught per unit effort then this index will decline exponentially with increasing fishing effort. However, data for a series of years during which effort has changed considerably are necessary to detect the effect of increasing effort upon the abundance of the stock, and at the present time only the landed weight per unit effort is available for the necessary period for most stocks. The relationship between the landed weight per unit effort and increasing effort is mathematically more complex; in fact at high levels of effort this relation would be rather lower than one based on numbers, owing to the lower mean weight of fish caught at high levels of exploitation. Conversely one can argue that this tendency would be offset by density dependent changes in the stock, or by a reduction in the rate of discarding on board the fishing vessels. Consequently it is meaningful to approximate the relationship between catch weight per unit effort and effort by the logarithmic regression that would be applied to catch numbers, plotting the logarithm of the catch per unit effort against the mean fishing effort in the year of sampling and the preceding two years.

This technique has been applied to data for the following cod fisheries;

Barents Sea	West Greenland
Bear Island	Labrador
Iceland	Newfoundland
Faroe	

set out in Table 1. There are difficulties in this area breakdown, because each area does not necessarily support one unique unit stock. The Barents Sea/Bear Island fisheries are part of the Arcto-Norwegian stock complex, so that the exclusion of the Norway coast fishery, which also exploits the same stock, will lead to an underestimate of effort. This is perhaps not important in this context, because the abundance of the stock in these two fisheries depends on the abundance of the immature cod, and at this stage of life the two stocks are independent (Garrod 1967). At Faroe two stocks - the plateau and the bank - are included in the one set of data (Jones 1966). At Iceland the stock situation is less well understood than had been thought, for it has become evident that the catch per unit effort given is not a measure of the total abundance of the stock; however, it does measure a part of it, in the same way as the Barents Sea and Bear Island data measure a part of the Arcto-Norwegian stock. To this exent the estimates of catch per unit effort are valid, but the total international effort is certainly overestimated (ICES 1968a). The distribution of the north-west Atlantic cod stocks was described by Templeman (1962); from his analysis, and subsequent national research reports (ICNAF, 1962-67), and the work of Hodder (1965) it is clear that the Labrador stock extends into Subarea 3, and even excluding this the consideration of the statistics from Subarea 3 as a single unit clearly includes data from more than one other stock.

To facilitate the comparison between stocks the catch per unit effort data for the seven areas shown in Table 1 have been reduced to a standard unit, i.e. the catch per hour of a 760 ton English distant-water side trawler. For the north-east Atlantic fisheries this is available directly from national data and has been taken from the reports of various ICES Working Groups in recent years (ICES 1967, 1968a, 1968b). For the north-west Atlantic stocks some conversion device has been necessary. For West Greenland cod the basic catch per unit effort is the mean of the index recorded by three groups of Portuguese dory vessels, Portuguese side trawlers (901-1800 t), Spanish side trawlers (901-1800 t) and German side trawlers (501-900 t), expressed relative to the index of abundance that these groups recorded in 1954. This follows a procedure adopted by the West Greenland Working Group (ICNAF 1966). Data for the Labrador stock have been derived from those given by Hodder (1965) for Portuguese trawlers in the January-June period, and for Newfoundland the basic unit is the mean of the catch per unit effort of French, Portuguese and Spanish trawlers derived in a manner analogous to that for the West Greenland stock (ICNAF 1954-1967). These various units of effort have then been converted to the English unit by appropriate conversion factors based on the comparisons of fishing between the various fleets in recent years, when the English vessels have fished these Subareas to a greater extent. In fact, provided that this conversion has remained constant its accuracy does not matter, because the subsequent treatment of the data depends on the relative changes in catch per unit effort within, rather than between, stocks.

The total international effort has been estimated in the conventional way from the total catch and the English catch per unit effort.

Results

The regression equations of these relationships between catch and effort are given in Table 2, giving the intercept as an estimate of the initial abundance of the unexploited stock, and the regression coefficient as a measure of the effect of fishing effort. The correlations are good for the north-east Atlantic stocks, showing that despite the theoretical shortcomings the relation between catch and effort is adequately described by the technique used. Variability about the regression can be ascribed to variation in year-class strength, and sampling errors. If the errors in the treatment of data are comparable between stocks, then the greater variability of the regression for the West Greenland and Labrador stocks can be attributed to proportionately greater fluctuations in year-class strength or availablity. There is ample evidence of this in more rigorous studies of those fisheries (Horsted 1967; May 1966). There is no regression for the Newfoundland fishery, owing to its stability during the period for which data are available.

The regression coefficient is a measure of the effect of the unit of effort chosen, and clearly this generates a greater effect on some stocks. But fishing mortality is more correctly related to fishing intensity: it is only related to effort where the area of a stock is constant. If a constant fishing intensity generates a constant fishing mortality, i.e. if the reaction of cod to fishing gear is constant, then the difference between the regression coefficients reflects the greater effort required to generate equivalent fishing intensity in the different stocks, which itself might be expected to be related to differences in the areas occupied by them. That this is so will be shown later (see Appendix 1 and Figure 3). The fishing effort on each stock has therefore been weighted to give a fishing intensity equal to that on the Faroe stock (that with the smallest area), using the ratios of the regression coefficients.

Similarly, although the absolute magnitudes of these stocks are different they can be generalized by measuring the proportional decline from the original unexploited stock size in relation to increasing fishing effort. The data in this form are plotted in Figure 1. The linear regression is an adequate expression of these data. It should perhaps be slightly concave downward, and this would flatten a derived yield curve, but it has no bearing on the relative positions of the various stocks on this curve, which is the object of this contribution.

This generalized yield curve and 'Schaefer plots' are given in Figure 2. The implication of this technique is that all the north Atlantic cod stocks have identical relative yield curves. This is not unacceptable when one considers the logical conclusion of the constant parameter model as developed by Beverton and Holt (1964). The values of M/K can be presumed to be nearly constant, except for Faroe cod and, for practical purposes, the ratio L_c/L_∞ is also approximately constant between stocks, since comparable mesh sizes are in use throughout the areas, and the asymptotic lengths are not very different, within the accuracy of existing data, except for the Labrador stock.

Discussion

The present level of exploitation of the various fisheries in these terms is added to Figure 2, showing the present level below the function, and, where relevant, the peak reached in earlier years above it.

The Barents Sea fishing reached a peak fishing intensity beyond the optimum in 1961-1963; this happened at Bear Island in 1957-1959. Since then effort has declined, especially at Bear Island. Recent analytical assessment of the Arcto-Norwegian stock as a whole showed that the maximum yield would be achieved by a 25 per cent reduction in effort (ICES 1968b). It should be recalled that this present result excludes the effort in the Norway coast fishery, and to a large extent the contribution of mature fish to the yield. So, whilst the present levels of effort may well relate to the potential yield of individual fisheries as indicated, this cannot be directly equated with the requirements of the entire stock. In fact the yield curve of Arcto-Norwegian cod under the present conditions of exploitation is flatter than that shown in Figure 2, with a maximum at a lower level of fishing intensity than this scale.

The recent assessment of the Iceland stock showed that, at the most realistic assumptions about the rate of natural mortality, the present yield is close to the maximum, though there is some doubt as to the correct measure of effort. In this examination of the data this has been overcome by the adjustment of effort to a common base, using the assumption that a common fishing intensity will generate the same proportional decline in stock abundance.

The Faroe fishery reached a peak fishing intensity in 1960-1962, from which the level of exploitation has returned to something close to the optimum, though the stock has not yet returned to its equilibrium level.

In the north-west Atlantic this treatment implies that the level of fishing at West Greenland has reached the optimum. This is in broad agreement with Gulland's conclusion (GULLAND 1967) 'that the 1965 level of effort is not substantially below the level giving the maximum sustained yield, and may well be above it'. Gulland was clearly inclined to the latter view but this was based on estimates of mortality derived ultimately from the age composition of research vessel samples. Wherever virtual population analysis has been used in conjunction with catch per unit effort analysis(e.g. for the Arcto-Norwegian and Iceland stocks) it has shown the catch per unit effort analysis to overestimate mortality. This is understandable, since the size group objective of a fishery will decrease as fishing becomes more intense. In view of this the conclusion that the level of fishing at West Greenland is close to an optimum is not unrealistic.

The position of the Labrador fishery is less certain, owing to the limitat: of the data at hand, particularly the exclusion of landings from Subareas 3K and 3L. The indication from this analysis–that the level of exploitation is probably to the left of the optimum (Figure 2)–conflicts with the conclusions drawn by May (1967). His estimate of $^F/_M$ chosen for entry into the tables of yield functions was deduced from age composition data (May 1966), and it is worth noting that it is rather higher (4.5) than Gulland's estimate (3.5) for the West Greenland stock, which one might expect to be the more heavily exploited of the two by virtue of its greater accessibility. The general logic of the position given for Labrador in Figure 2 can be seen by comparison of this fishery with that of the Barents Sea. In the latter area a fishing effort of 520 units (Table 1) is adequate to reach a point close to the optimum. The Labrador fish in Subareas 2G, 2H, 2J occupies an area equivalent to about one half that of the Barents Sea fishery, so one would expect c. 250 units of effort to reach the same level of exploitation at Labrador. The present level is c. 180 units. However, if Subareas 3K and 3L are included the area of the Labrador fishery becomes almost equivalent to that of the Barents Sea, and if the effort at Laborador is weighted up by the catches in these Subareas, then the Labrador fishery will also lie closer to the optimum level, at the alternative position (6a) shown in Figure 2.

The only justifiable conclusion from this is that the proportional decline in catch per unit effort at Labrador has been less than that observed elsewhere in securing the optimum level of fishing. Moreover, recruitment to this stock is apparently less variable than elsewhere, so that the observed maintenance of the catch rates in that area is less likely to be caused by a favourable variation in recruitment.

In the recent data for the Newfoundland stock the trend in effort is not sufficient to permit the calculation of a meaningful regression. There are signs of increase in the last two years, but on the whole the fishery has remained remarkably stable since 1950. Its present position in Figure 2 has been estimated from data given by Beverton and Hodder (1962). In their Figure 6.1 the catch per unit effort of trawl landings is given as c.35 for the period 1935-1945, and c. 22 for the period 1950-1956, and there is no evidence to show that it has changed significantly since then. The corresponding effort figures for these periods are 7 units and 16 units respectively. Thus the change from 7 to 16 units generated a 37 per cent decline in stock abundance, and on the logarithmic scale this can then be related to the abundance of the unexploited stock. The proportional decline to the present stock abundance can then be traced on Figure 1 and related to a level of effort for entry on to Figure 2. Similarly a regression coefficient can be estimated for entry in Table 2. This implies that the level of exploitation in Subarea 3 is in the region of its optimal level, or slightly beyond it if the true yield curve is flatter than that shown.

Conclusions

For an area such as the north-west Atlantic, where very rapid changes in fishing intensity have recently taken place, it is difficult to estimate the population parameters vital for critical stock assessment, but there is something to be gleaned from comparisons with other stocks for which more consistent data are available.

The methods used in this paper are obviously very approximate, and the paper is contributed not as a definitive statement but to stimulate a critical appraisal of catch and effort analysis before drawing far-reaching conclusions on the present levels of exploitation in the north-west Atlantic, or for that matter the north Atlantic as a whole. Although the precision of the present approach is not high the results do indicate that the level of fishing in the north-west Atlantic is probably very close to the optimum required to secure a yield close to the potential maximum, and certainly not a long way beyond this level. This points to the need to stabilize fishing effort at its present level, rather than to restrict the expansion of the existing fleet capacity.

Appendix 1.

The relationship between fishing effort, fishing intensity and the geographical area of distribution of the exploited stocks.

From basic theoretical concepts, and using the international notation

$$Y_N = \frac{FN}{Z}(1 - e^{-Z});$$

N here represents the initial abundance of the unit stock, and in the relative terms of this inter-stock comparison it is unity, i.e. $N = N^1 = N^2 \ldots\ldots$, so that

$$Y_N = F\left(\frac{1 - e^{-Z}}{Z}\right).$$

More precisely, $F = qf/A$, where A is the area of the stock, i.e. F is proportional to fishing effort per unit area, and the fishing intensity $f/A = (f/A)^1$ etc. Hence

$$Y_N = \frac{qf}{A}\left(\frac{1 - e^{-Z}}{Z}\right)$$

and

$$\frac{AY_N}{f} = q\left(\frac{1 - e^{-Z}}{Z}\right).$$

With the exclusion of the effect of area size upon catchability, the coefficient q now has the narrower sense relating to the response of fish to fishing gear, and the relative distributions of fish and fishing with time. These can also be assumed constant within the species. Hence when the proportional decline in abundance of two stocks N and N^1 is equal

$$q\left(\frac{1 - e^{-Z}}{Z}\right) = \left[q\left(\frac{1 - e^{-Z}}{Z}\right)\right]^1$$

$$\frac{AY_N}{f} = \left(\frac{AY_N}{f}\right)^1,$$

and

$$\frac{Y_N f^1}{Y_{N^1} f} = \frac{A^1}{A}.$$

Furthermore, at this equal level of depletion the yield will be an equal proportion of the initial stock, so that $Y_N = Y_{N^1}$ and $\frac{f^1}{f} = \frac{A^1}{A}$.

The fishing effort required to generate the equivalent decline in the two stocks will be proportional, and the relative catch per unit effort will be inversely proportional to their respective areas. Similarly the regression coefficient relating the change in catch per unit effort to increasing fishing effort will be inversely proportional to this area. Consequently, if the theoretical concept that fishing mortality is proportional to fishing intensity is valid, then a plot of the ratio of the regression coefficients against the ratio of geographical areas, both referred to a standard, will also be proportional.

The ratios of the regression coefficients and the geographical areas are given in Table 2, using the data for Bear Island as standard. The geographical area has here been defined as the number of nautical square miles lying between the coastline and the 200 fathom isobath circumscribing the known distribution of the stock, and limited, where necessary, by the boundaries of the Statistical Divisions from which the data have been taken. This assumes that any unaccounted area of distribution beyond the 200 fathom isobath will be proportional to the area within. Although necessarily approximate this measure is adequate to indicate the relative sizes of the areas occupied by the stocks considered here.

The relationship between these ratios is a measure of the increase in effort required to maintain an equivalent fishing intensity in each area. This is illustrated in Figure 3 showing also the bisector. There is a substantial anomaly for the Iceland fishery. It suggests that the derivation of a figure for the total international effort at Iceland from the statistics of the English fishery has led to a serious overestimate. Subsequent investigation has confirmed this; the English fishery is based mainly on immature cod, but some 50 per cent of the international catch is composed of mature fish which are barely represented in the English catch per unit effort data. The method of derivation of the international effort figure thus leads to 'double counting'.

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Table 1. Basic catch statistics of North Atlantic cod stocks
Catch - thousands of tons round fresh
Effort - equivalent U.K. hours fishing by 760 ton side trawler
Catch per unit effort - tons per hour U.K. 760 ton side trawler

	BARENTS SEA			BEAR ISLAND			ICELAND			FAROE		
	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.
1946	200	88	2.32	210	31	6.95	279	161	1.76	30	39	0.80
1947	341	136	2.55	165	51	3.32	306	230	1.35	31	53	0.59
1948	407	207	1.98	131	52	2.58	322	281	1.16	21	52	0.41
1949	485	227	2.15	127	45	2.88	362	344	1.06	28	53	0.54
1950	356	322	1.12	164	84	1.98	362	404	0.90	36	73	0.50
1951	408	418	0.99	140	97	1.45	347	399	0.87	35	86	0.42
1952	524	549	0.97	106	72	1.48	401	477	0.85	34	86	0.39
1953	443	527	0.85	104	76	1.40	523	515	1.03	27	70	0.40
1954	598	564	1.07	99	72	1.38	545	587	0.94	36	74	0.49
1955	831	731	1.15	153	86	1.79	537	561	0.97	39	78	0.50
1956	787	838	0.95	324	178	1.83	482	513	0.95	28	76	0.36
1957	400	612	0.66	257	251	1.03	457	613	0.75	31	81	0.40
1958	388	621	0.63	229	251	0.92	520	706	0.74	28	101	0.28
1959	323	472	0.69	243	267	0.92	460	745	0.62	26	105	0.25
1960	380	702	0.55	102	129	0.80	474	899	0.53	39	160	0.25
1961	408	714	0.58	222	229	0.98	383	895	0.43	27	170	0.16
1962	540	789	0.69	223	223	1.01	388	844	0.46	24	129	0.19
1963	540	855	0.64	116	157	0.74	412	875	0.49	24	113	0.21
1964	203	539	0.43	126	109	0.69	435	109	0.42	25	96	0.27
1965	241	415	0.49	107	100	0.81	394	922	0.43	27	102	0.27
1966	289	519	0.56	55	93	0.59	357	787	0.46	23	82	0.28

Table 1. (continued)

	WEST GREENLAND			LABRADOR			NEWFOUNDLAND		
	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.
1954	297	125	2.38	22	7	3.07	472	384	1.23
1955	268	123	2.18	26	10	2.69	429	394	1.09
1956	322	131	2.45	34	10	3.36	390	342	1.14
1957	269	155	1.73	32	12	2.78	449	420	1.07
1958	320	200	1.60	40	21	1.92	294	330	0.89
1959	233	204	1.14	60	29	2.08	425	373	1.14
1960	236	231	1.02	150	58	2.60	470	465	1.01
1961	348	247	1.41	265	109	2.44	461	387	1.19
1962	451	228	1.98	255	106	2.40	389	357	1.09
1963	396	285	1.39	216	85	2.53	466	324	1.44
1964	350	248	1.41	213	102	2.09	581	421	1.38
1965	358	298	1.20	332	193	1.72	496	517	0.96
1966	366	248	1.47	338	181	1.87	499	466	1.07

Table 2. Regression equations of $\log_e$ catch, in tons per hour, against international fishing effort, in standard U.K. trawler units, for North Atlantic cod stocks

Fishing area	Regression intercept	Regression slope coefficient	S.E. of R	Correlation coefficient	Ratio of R (Bear Island) / R (stock)	Area of stock (thousands of sq. naut. miles)	Ratio of stock area / Bear Island area
Barents Sea	+0.734	-0.00173	0.00035	-0.766	2.693	210	4.04
Bear Island	+0.803	-0.00466	0.00113	-0.705	1.000	52	1.00
Iceland	+0.508	-0.00152	0.00027	-0.805	3.065	51	1.00
Faroe	-0.125	-0.01081	0.00115	-0.916	0.431	6	0.12
W. Greenland	+0.893	-0.00235	0.00139	-0.492	1.982	81	1.56
Labrador	+0.975	-0.00213	0.00105	-0.561	2.187	149	2.63
Newfoundland	-	(-0.00209)	-	-	2.230	111	2.13

Figures in parentheses are estimated values only

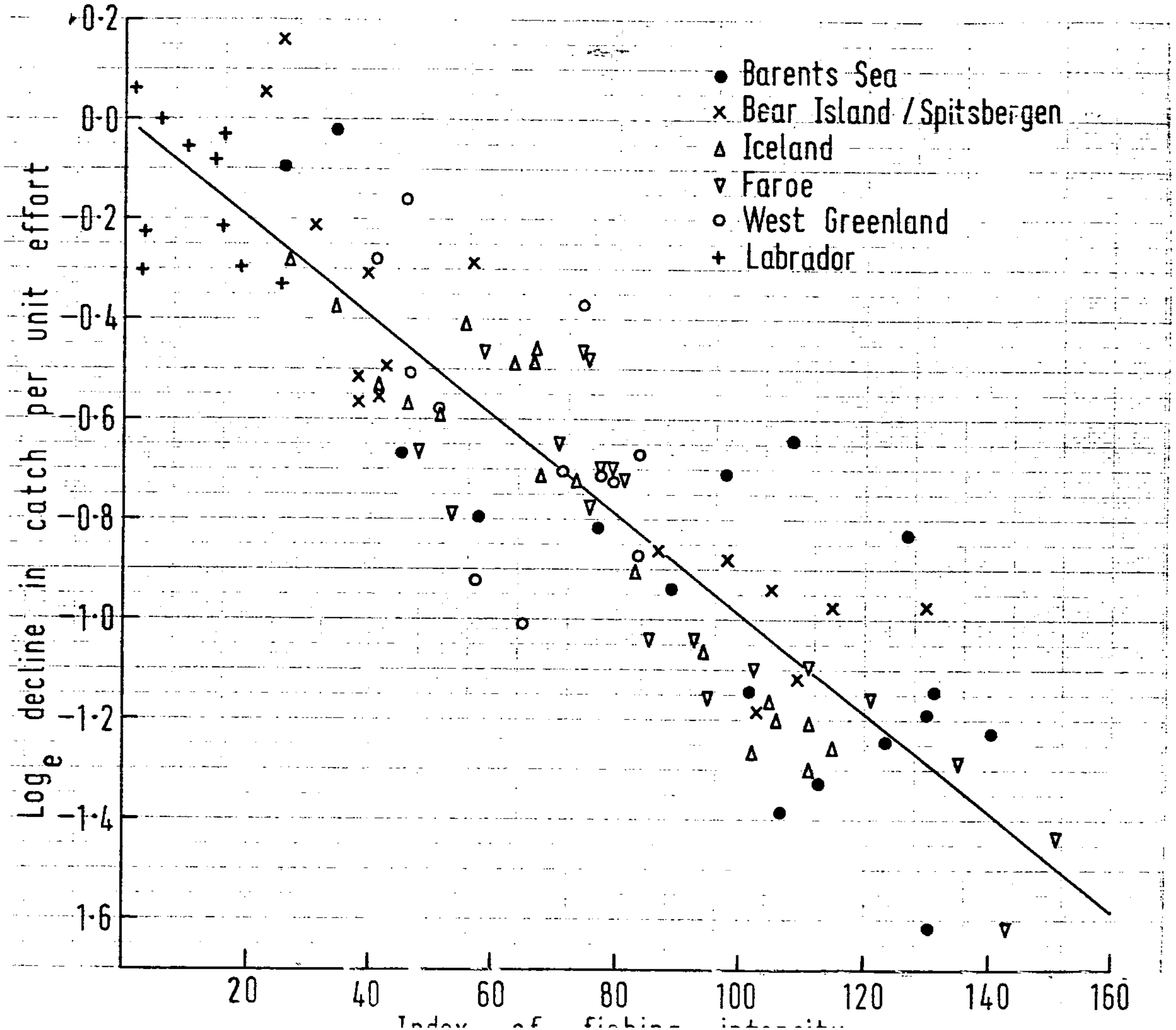

Fig. 1. The regression of catch per unit effort against international fishing effort, generalized for some North Atlantic cod stocks.

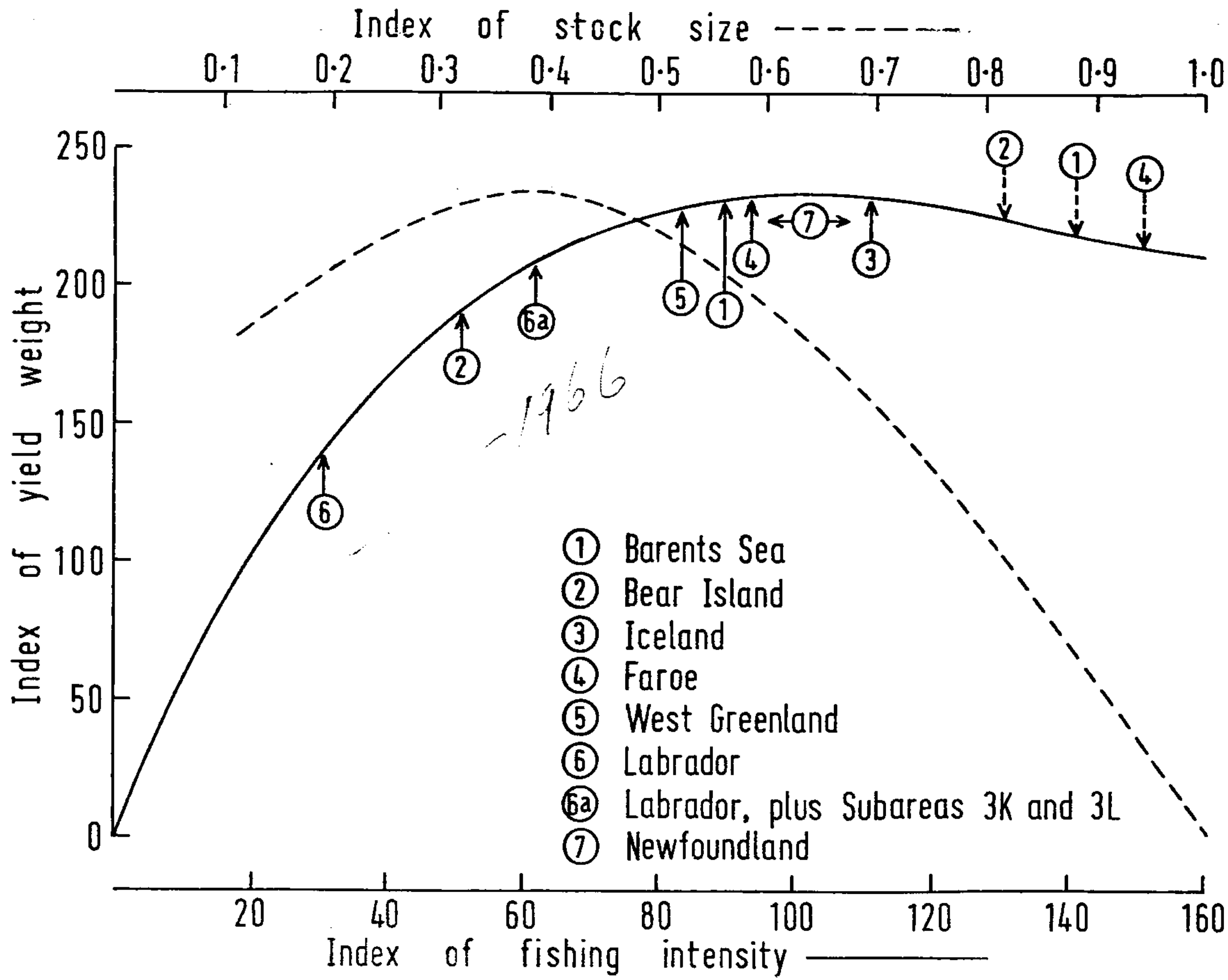

Fig. 2. The generalized yield curve for some North Atlantic cod stocks, and 'Schaefer plots' derived from the catch per unit effort/effort relation.

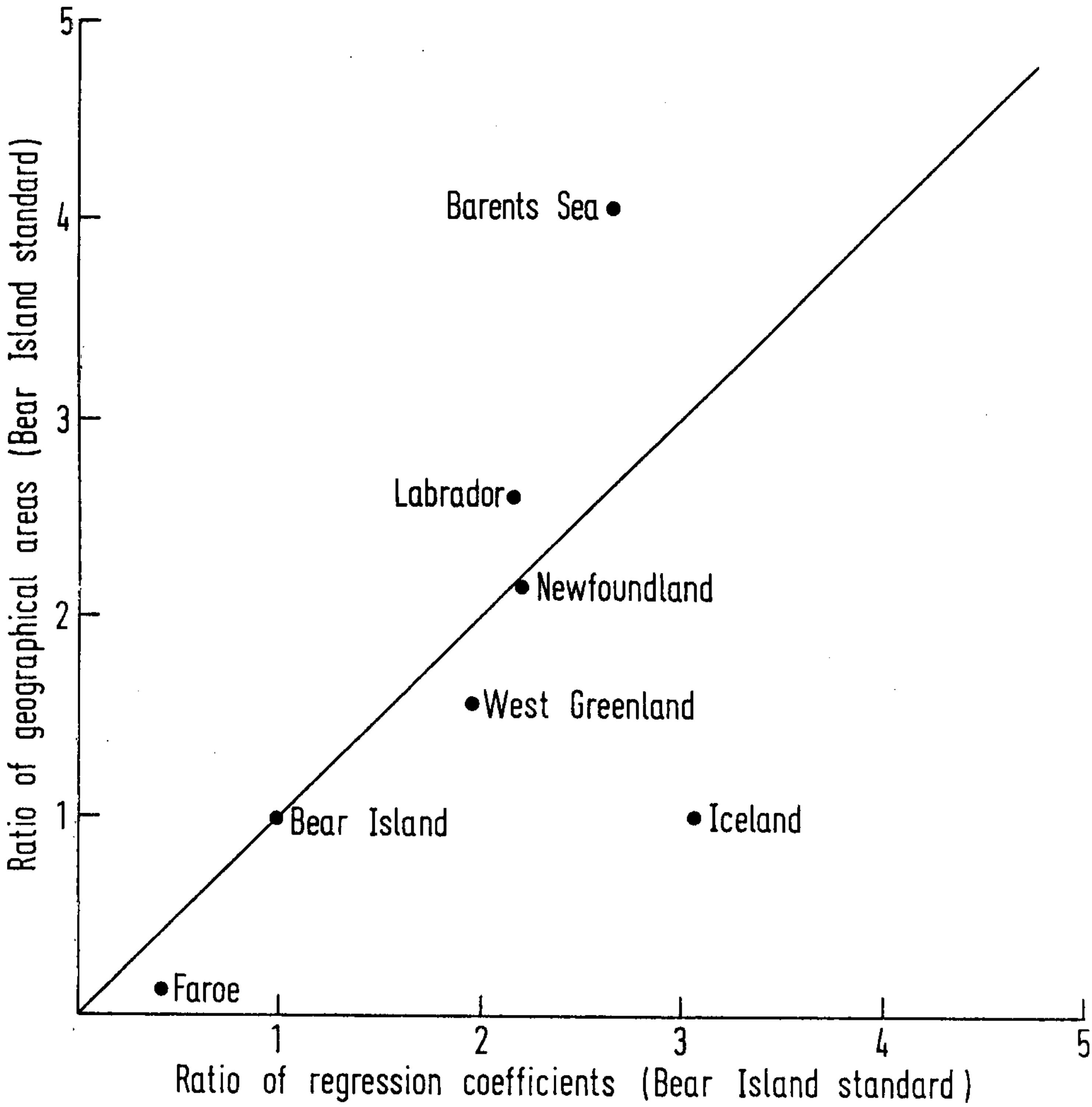

Fig. 3. The relation between fishing effort and fishing area in the North Atlantic. The ratio of regression coefficients represents the ratio of fishing effort required to generate a given proportional decline in stock abundance.