INTERNATIONAL COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES

Serial No. 1352
(D.c.3)

Document No. 56

ANNUAL MEETING - JUNE 1964

Catch/effort assessment in some ICNAF Fisheries

by R. J. H. Beverton

1. Introduction

The many separate, or partially separate, fisheries of the ICNAF area, some long-established, others of recent origin, with a variety of gears and varying amounts of research data, present a peculiarly complex situation from the point of view of catch/effort assessment. No amount of theoretical manipulation can overcome the lack of reliable estimates of stock abundance or difficulties of age-determination which are still major obstacles in many of these fisheries. Nevertheless, a considerable amount of information exists which, if due allowance is made for the inevitable uncertainty attaching to it, can be used to make a rough diagnosis of the state of many of the ICNAF stocks in relation to fishing.

2. Method

Several authors (Jones, 1957: Holt, 1957, 1962; Beverton, 1963) have developed generalised forms of the yield equation by replacing age as an explicit variable by length and grouping the remaining parameters as ratios. That for equilibrium catch per recruit which is most convenient for the present purposes, although algebraically identical to the original form (Beverton & Holt, 1957), is

$$Y' = \frac{Y}{R_o W_\infty} = {}^F/_M \, (1 - c)^{M/K} \sum_{n=o}^{3} \frac{U_n \, (1 - c)^n}{1 + {}^F/_M + \frac{nK}{M}} \quad \ldots (1)$$

where

R_o = number (arbitrary) of recruits at age to

$c = {}^{L_c}/_{L_\infty}$ (where L_c = mean selection length)

and the other parameters have their usual meaning. This is the same equation used by Beverton (1954) except that E (rate of exploitation) is replaced here by the ratio of fishing to natural mortality (${}^F/_M$) from the identity

$${}^F/_M \equiv \frac{E}{1 - E} \quad \ldots (2)$$

For the present purposes $F/_M$ is preferable to E since the former is directly proportional to fishing mortality coefficient and hence, to a first approximation, to fishing effort.

Equation (1) shows that the equilibrium relation between catch per recruit and fishing mortality coefficient (in the ratio $F/_M$) is determined by two parameters only, viz: $M/_K$ and c (= $L_c/_{L_\infty}$), of which the former can be regarded as an intrinsic biological property of the stock in question, while the latter incorporates (in L_c) the selectivity of the fishing operations.

The theoretical basis of the yield equation contains a number of simplifying assumptions which are too familiar to need further stressing here. Certain of these, such as the assumption of a constant fishing mortality coefficient with age of fish are clearly unlikely to be exactly true in many of the ICNAF fisheries, especially those exploited by several different fleets and gears. This is accommodated when using equation (1) by calculating a weighted mean value of L_c and by setting appropriately wide limits to $F/_M$. It will be recalled that an analogous device is adopted in Gulland's (1961 b) method of mesh assessment, in which the exact value of E cannot be ascertained without detailed knowledge of the trend of F with age; here too, the difficulty is circumvented by assigning sufficiently broad limits to the range of E used in the calculations. Although it is theoretically possible to make explicit allowance for a trend of F with age in yield assessments it is problematic, in cases where this trend is generated by multiple gears, whether much is to be gained thereby, since such an assessment would be valid only for one particular array of fishing intensities generated by the component gears.

Other kinds of simplications are dealt with in a similar way. Thus, the growth pattern of cod in Subareas 1 and 2, with a "step" at about 75-80 cm, is manifestly not in accord with the von Bertalanffy equation or any other simple function. Its effect can, however, be allowed for by setting an appropriate range to L_∞ and hence to c.

Estimates of the ratio $M/_K$ are also bound to be uncertain, primarily through lack of knowledge of the natural mortality rate M but also, where age-determination is unreliable, of the growth parameter K. Although some distinctions can be made between certain groups of stocks, it is necessary to base conclusions on assessments using an appropriate range of $^M/_K$ for each stock.

Given that it is possible, in certain stocks, to arrive at estimates of the range within which the parameters c and $^M/_K$ are likely to lie, there remains the problem of determining the current level of fishing intensity, in terms of the magnitude of the ratio $^F/_M$. There are two possible ways of doing this. One is to calculate $^F/_M$, and its probable range, directly from estimates of F and M (or from E, using equation (2)) obtained by analysis of total mortality in relation to effort, by tagging experiments, or similar means. The other is to use information on the extent to which the abundance of the stock has been reduced by fishing up to the present time, as judged from the relation between catch per unit effort and fishing. It is shown below that this decrease can be interpreted in terms of $^F/_M$, and in what follows both methods of estimating $^F/_M$ are used, according to the kind of information available for the various stocks and fisheries.

3. Estimates of $^M/_K$, c and $^F/_M$ for certain ICNAF stocks

These are summarised in Table 1, using data from various published sources and some unpublished information kindly supplied at my request by people listed in the last column.

Table 1 is largely self-explanatory, though some supplementary notes to it are given in Appendix 1. Inevitably, the compilation of such a table involves a certain amount of personal interpretation, but as far as possible the ranges of parameter values have been made wide enough to allow for a margin of uncertainty. It is important to note that estimates of L_c and E (from which c and $^F/_M$ are calculated), are nearly all taken from the 1961 Assessment Report and therefore refer to the period 1956-8. No attempt has been made here to allow for trends since that time.

Whichever method is used for making catch/effort assessments from equation (1) and the data of Table 1, it is first necessary to decide on the range of $^M/_K$ appropriate to each stock. Inspection of column 8 shows that the ranges of $^M/_K$ can be grouped into four categories, as follows:-

(a) $^M/_K = 0.5-1.0$

Subarea 1 cod
Divs. 2 HJ cod
Subarea 5 haddock

(b) $^M/_K = 0.75-1.5$

Div. 4X haddock
Divs. 4 VW haddock
Divs. 3NO haddock

(c) $^{M}/_{K} = 0.75-2.0$

Divs. 3KL cod
Div. 3P cod
Divs. 4T and V(S) cod
Subarea 5 cod

(d) $^{M}/_{K} = 1-2.5$

Divs. 4 RST redfish
Div. 5Y redfish
Divs. 3NO cod.

To some extent this grouping undoubtedly reflects real differences; this is the case where K is large (e.g. 0.25-0.30 in Subarea 1 and 2 cod and Subarea 5 haddock), and for these stocks $^{M}/_{K}$ cannot be much greater than 1.0 without exceeding the observed range of Z. Where K is low, on the other hand, the same degree of uncertainty concerning M means that $^{M}/_{K}$ has to be allowed a correspondingly wide range. This is particularly true for redfish and some cod stocks, though it may well be that the real range of $^{M}/_{K}$ for these is not as large as this. There are, in fact, indications from other studies (Beverton and Holt, 1959; Beverton, 1963) that M and K in different stocks of the same or related species tend to vary together, thus reducing the spread of their ratio $^{M}/_{K}$. No attempt has been made here to restrict the range of $^{M}/_{K}$ on this basis, but the guess may be hazarded that as more precise estimates of M become available the range of $^{M}/_{K}$ can be made narrower than is listed above. This is particularly the case with the stocks having the lowest K values (groups (c) and (d)) and it is not without significance that in one of these (4T + V (Spr.) cod) Dickie (1963) has estimated M to be in the region of 0.1, although the author was careful to stress that confidence limits could not yet be attached to this estimate. The same may prove to be the case for redfish; indeed if the ages of up to 50 years or more not infrequently recorded for this species by several authors are true, M for redfish must be correspondingly low, in accordance with its low K value. So far, however, these stocks have not shown as sensitive a response to changes in fishing effort as would be expected if M were truly low (Gulland, 1961 c; Assessment Report), but the possibility is still open that special features of redfish distribution are masking the relation between catch per unit effort and stock abundance in this species.

4. Graphical presentation of catch/effort assessments

Using the range of estimates of c and $^{M}/_{K}$ of Table 1, sets of curves of yield per recruit as a function of $^{F}/_{M}$ can be calculated from equation (1) for each stock.* Alternatively, a generalised form of yield-isopleth diagram can be calculated with $^F/_M$ as abscissa and c as ordinate; this would enable the effect of the possible range of c and $^F/_M$ in combination to be visualised more easily, but a separate diagram would be needed for each value of $^M/_K$. If, however, diagnosis is limited to finding:-

(a) whether the present rate of fishing is likely to be greater or less than that which would generate the maximum equilibrium yield (if one exists at a finite rate of fishing); and

(b) whether the equilibrium yield generated by the present rate of fishing differs from the maximum by up to 10%, or by more,

then a simplified form of yield-isopleth diagram can be constructed which enables all the information for a particular fishery to be combined on a single diagram. Such a diagram can be used to obtain a quick appreciation of the likely level of exploitation of a stock in relation to the maximum yield; where more detailed assessments are needed and are possible from the information available, this presentation can be supplemented by the construction of individual yield curves.

An example is shown in Fig. 1, for the first group of stocks in which $^M/_K$ lies between 0.5 and 1.0. As in a yield-isopleth diagram, the ordinate is a scale of $^F/_M$ (proportional to fishing mortality coefficient) and the abscissa is a scale of c (proportional to mean selection length), but instead of showing a range of contours of yield, only the locus of the maxima of the constituent yield curves (and the loci of yields which are 95% and 90% of the maxima) are drawn. Thus, the curve forming the upper boundary of the shaded zone defines pairs of values of $^F/_M$ and c generating a maximum yield when $^M/_K = 0.5$; that forming the lower boundary defines pairs of $^F/_M$ and c generating a maximum yield when $^M/_K = 1.0$. The shaded area can therefore be regarded as the "zone of maximum yield", in as much as any pair of values of c and $^F/_M$ falling within it cannot be distinguished (because of the uncertainty of the exact value of $^M/_K$) from those generating the true maximum yield.

The full and broken lines shown above the shaded zone refer to yields which are 95% and 90% of the maxima defined by the upper boundary of the shaded area (i.e. for $^M/_K = 0.5$); they therefore refer to points on the ascending limbs of the constituent yield curves at these percentages of the maxima. Correspondingly,

* Tables of yield equation (1) are being prepared for publication; a typescript version will be available at the 1964 meeting.

the 95% and 90% lines below the shaded area refer to maxima defined by its lower boundary (i.e. $M/K = 1.0$) and therefore to points on the descending limbs of the constitutent yield curves.

If the likely range of c and F/M is known for any stock in the first group ($M/K = 0.5$ to 1.0), these can be drawn directly on this diagram as a rectangle (see Fig. 1). The location of this rectangle in relation to the shaded zone and to the 90% and 95% contour lines indicates at once the state of the fishery compared with the requirements for obtaining the maximum yield or these percentages of it on each side, with allowance made for the uncertainty of the true value of M/K. As better or more up-to-date estimates of the likely range of c or F/M become available, they can be entered directly on the same diagram.

Two other features of this and similar diagrams (Figs. 4, 5 and 6; for other ranges of M/K) need mention. One is that their use for the kind of diagnosis stated above makes no assumption about the form of the relation between fishing mortality coefficient and fishing effort, except that the two should increase or decrease together. If, however, F can be assumed to vary roughly in proportion to effort, then the abscissae of these diagrams can be taken as an approximate scale of fishing effort. This permits certain conclusions to be drawn about changes in catch per unit effort, as will appear later.

The other point is that because the curves shown in these diagrams are the loci of maxima (or percentages of those maxima) in curves of yield as a function of F/M at fixed values of c, they define only one of the two sets of maxima which can be distinguished in a full yield-isopleth diagram. They must therefore* be read in the horizontal direction only, i.e. parallel to the scale of F/M.

Assessments of this kind for stocks in each of the four groups, listed above according to their range of M/K, will now be given.

5. Assessments for stocks with $M/K = 0.5$–1.0 (Fig. 1)

(a) Subarea 5 haddock

This is a particularly useful example to begin with, since data of both E and the decrease of catch per unit effort are available. The values of c and E from columns 9 and 10 of Table 1 give the rectangle shown by full lines in Fig. 1. This covers a wide range of F/M, extending to the 90%

---

* The other set of maxima are those in the curves of yield as a function of c at fixed values of F/M. They are similar in shape to those of Fig. 1 but are displaced upwards (i.e. lie at higher values of L_c/L_∞), and are true eumetric fishing curves corresponding to curve BB^1 of Beverton and Holt (1957, Fig. 17.14). They would be used to assess catch in relation to selection length (L_c) by this method.

yield level on either side of the maximum zone. This range of F/M (1-4.5) is, however, much wider than is consistent with that which can be deduced from the relation between catch per unit effort and effort for this stock.

Fig. 2 shows this relation, taken from the U.S. Research Report for 1962. The 1960 level of catch per unit effort is about 13 units, which is about $\frac{1}{4}$ of the highest observed catch per unit effort, even with some fishing. If the theoretical catch per unit effort curves for M/K between 0.5 and 1.0, and c between 0.46 and 0.50,* are calculated from equation (1) they appear as the shaded curve in Fig. 2. No great precision can be claimed for this fit; in particular, the high points for the years 1930-2 are aberrant by any simple criterion. Nevertheless, a curvilinear relation is not only to be expected theoretically but has been demonstrated in cases where a wide range of effort and catch per unit effort data are available (e.g. for Icelandic haddock, Gulland, 1961 a). The 1960 catch per unit effort, according to Fig. 2 corresponds to a reduction to between 1/6 and 1/7 of the unexploited c/u; this is doubtless an optimistically narrow range, but it is difficult to conclude that the decrease in stock abundance due to fishing could have been outside the limits of, say, $\frac{1}{4}$ to $\frac{1}{8}$.

Fig. 3 (c) shows the relation between these estimates of stock decrease and those of F/M required to generate them. The shaded curve is the decrease of catch per unit effort (expressed as a fraction of the unexploited value) with increasing F/M, for M/K = 0.5-1.0 and c = 0.46-0.50, again calculated from equation (1). Marked on this curve are the extreme values of F/M corresponding to the possible extent of stock decrease, giving:-

Fraction of unexploited c/u	Range of F/M
$\frac{1}{4}$ - $\frac{1}{8}$	1.4-3.1
1/6-1/7	2.1-2.7

* In fitting the theoretical catch per unit effort curves to the data the following equivalence of units has been taken:-

M/K = 0.5, c = 0.46 and 0.5 } unit F/M = 3.25 units of effort; P_o = 75 units of c/u

M/K = 1.0, c = 0.46 } unit F/M = 3.5 units of effort; P_o = 75 units of c/u

M/K = 1.0, c = 0.5 } unit F/M = 3.5 units of effort; P_o = 70 units of c/u

where P_o is the unexploited catch per unit effort.

The wider of these two ranges of $F/_M$ are shown in the rectangle of Fig. 1 by the outer dotted lines; the narrower by the central shaded zone. From the former it would appear that the 1960 level of effort generated an equilibrium catch which could range from just to the left of the maximum to about 95% of it beyond. The narrower limits would set the catch just below the maximum on its descending side. These differences in equilibrium catch of a few per cent. are clearly of little significance, but it is important to note that they correspond to a two-fold range of $F/_M$ and hence, approximately, to a similar range of fishing effort and catch per unit effort.

This example also enables the correspondence between the generalised presentation and the conventional yield curve graphs to be shown. Thus the yield curves for $M/_K$ 0.5-1.0; c = 0.46-0.50, are shown in Fig. 2 by the shaded zone, all being adjusted to unit maxima. The exact maxima are shown by the arrows; as expected from the inner shaded zone of Fig. 1 they are all to the left of the 1960 effort, but the actual yields at that effort are only a few per cent. below the maxima.

(b) Subareas 1 and 2 cod

These are characterised by relatively low values of L_∞ (and hence high values of c), the range here allowing for the "stepped" character of the growth curve of these stocks and, in the case of Subarea 2, for the differences between the growth of Divs. 2H and 2J reported by May *et al.* (1964). The range of M is not known for Subarea 2 cod but May *et al.* report no difference in longevity compared with others and it seems reasonable to assign to them provisionally the same range of $M/_K$ as for Subarea 1 cod. The ranges of c and $F/_M$ are entered on Fig. 1 but are not bounded to the right because the fishing effort in both Subareas, and particularly in Subarea 2, has probably increased substantially since 1958.

The left-hand side of the rectangle for Divs. 2HJ cod is set at $F/_M = 0.7$; this is the lower limit corresponding to a decrease to $\frac{1}{2}$ of the unexploited catch per unit effort as seen from Fig. 3(a).

Since the upper limit of $F/_M$ cannot be established in either case without an analysis of recent increases in fishing effort in these two Subareas, conclusions have to be left correspondingly vague. Even so, Fig. 1 shows that even at the lower limits of c the fishing effort would need to increase several-fold above the 1958 level to reach the zone of maximum yield.

6. Assessments for stocks with $^M/_K$ = 0.75-1.5 (Fig. 4)

All the remaining haddock stocks (3NO, 4X and 4VW) fall into this group, because they all have K values appreciably lower than that of Subarea 5 haddock and there is no direct evidence to show whether M is correspondingly lower. They all have somewhat higher c values than Subarea 5 haddock, partly because they have lower L_∞'s and partly because L_c is higher (4X and 4VW). The zones of c and $^F/_M$ for these stocks are shown in Fig. 4. None extends beyond the upper limit of maximum yield. 3 NO haddock is nearest to this, however, and a knowledge of recent trends in fishing effort on this stock is clearly important here.

7. Assessments for stocks with $^M/_K$ = 0.75-2.0 (Fig. 5)

Included here are the cod stocks with values of K in the intermediate range 0.15-0.25 (3KL, 3P and Subarea 5), and also one with a low K (4T + V(S); K = 0.10) but in which the upper limit of M can reasonably be set at about 0.20. The first two 3KL and 3P) are provisionally assigned a wide range of c, since May et al. (1964) have shown two distinct growth curves to exist within each of these divisions with widely different L_∞'s.* The zones of c and $^F/_M$ for 3 KL and 3P cod shown in Fig. 5 are therefore correspondingly deep in the vertical direction. In neither case is it likely that the 1958 level of effort had appreciably exceeded that giving the maximum catch, though in both it might have reached it.

The range of $^F/_M$ for 4T + V(S) cod is based on that of Z for the years 1956-8 (0.4-0.60; Assessment Report) and the later estimates of F (0.3-0.5) obtained by Dickie (1964) from tagging experiments. An upper limit of M in the region of 0.20 is indicated from the fact that the estimate of Z in the preceding period 1951-4 was itself only 0.24 (Assessment Report). These values give the rather wide range of $^F/_M$ shown in Fig. 5 of 1-5, which span the zone of maximum yield down to the 95% yield level on either side.

Just as evidence of the relation between catch per unit effort and effort can be used to narrow the likely range of $^F/_M$ in Subarea 5 haddock, so can it also in Subarea 5 cod. Thus Fig. 8.2. of the Assessment Report suggests that the decline in abundance of this stock attributable to fishing has been even greater than that of the haddock; the 1958 level of catch per unit effort would seem to be something between 1/5 and 1/10 of the unexploited level.

---

*Some idea of the relative abundance of these growth types would enable this wide range of c to be substantially narrowed by calculating c from a weighted mean value of L_∞ in each case.

Fig. 3(b) shows that these limits correspond to a range of $^F/_M$ from 1.5 to 3.5, and this is indicated in Fig. 5 by the dotted lines. With this narrower range of $^F/_M$ it appears that the 1958 level of effort could have generated a catch ranging from about the maximum to about 95% of it on the descending side.

8. Assessments for stocks with $^M/_K$ = 1.0-2.5 (Fig. 6)

This last group comprises the stocks with the lowest K values. These include 3 NO cod and redfish of 4 RST and 5Y, all of which have K values in the region of 0.1. Again, the lack of precise estimates of M means that $^M/_K$ for these stocks has for the time being to be allowed a wide possible range up to 2.5. Fig. 6 shows the zones of c and $^F/_M$ for these stocks. Only that for 3NO cod extends to well beyond the zone of maximum yield due to the low c value for this stock, generated by a very high L_∞ (130 cm); in this case it therefore appears that the 1958 level of effort may well have exceeded by a considerable margin that corresponding to the maximum yield.

Changes in catch per unit effort due to fishing do not emerge clearly in these stocks, though in the case of 4 RST redfish it is concluded in the Assessment Report that the stock has probably been reduced to at least ½ by fishing. From Fig. 3(d) this reduction corresponds to a minimum value of $^F/_M$ = 0.5, which raises slightly the lower limit of $^F/_M$ (as shown by the dotted line in Fig. 6)but does not materially alter the diagnosis.

9. Summary

(i) A generalised form of yield equation is used in which equilibrium yield per recruit is expressed in terms of three parameters only, viz:

$^F/_M$ (incorporating the amount of fishing, as F)

$^{L_c}/_{L_\infty}$ (incorporating the selectivity of fishing, as L_c)

$^M/_K$ (the ratio of the natural mortality and growth coefficients; an intrinsic biological characteristic of the stock in question)

(ii) From a survey of the information available in the 1961 Assessment Report, supplemented by published and unpublished data from other sources, estimates of the likely range of these parameters are obtained for certain of the ICNAF cod, haddock and redfish fisheries (Table 1).

(iii) These estimates are used in the generalised yield equations to make a rough diagnosis by graphical means of the level of exploitation of those stocks during 1956-8 in relation to the requirements for obtaining the maximum equilibrium yield.

(iv) From this analysis the following conclusions emerge:-

(a) In only three stocks was the fishing effort during this period clearly below that giving the maximum yield. These are:-

<u>cod</u> of Subareas 1 and 2 (Fig. 2)

<u>haddock</u> of divisions 4VW (Fig. 5)

(b) A number of stocks were fished at an intensity equal to or below, but not appreciably above, that giving the maximum yield. These are:-

<u>Cod</u> of divisions 3KL and 3P (Fig. 6)

<u>haddock</u> of divisions 3NO and 4X (Fig. 5)

<u>redfish</u> of divisions 4 RST and 5Y (Fig. 7)

(c) In the remaining stocks dealt with here the possible rate of fishing during the period 1956-8 spanned that giving the maximum yield and extended well beyond it. These are:-

<u>cod</u> of divisions 3NO (Fig. 7) and 4T + V(S), and Subarea 5 (Fig. 6)

<u>haddock</u> of Subarea 5. (Fig. 2)

In none of these can it therefore be established on the evidence considered here that the fishing effort had clearly exceeded that giving the maximum yield, but in all except cod of divisions 4T + V(S) it is more likely than not to have done so, particularly in 3NO cod.

TABLE 1

Species	Subarea	Division	1 L_c cm	2 L_∞ cm	3 K	4 Z	5 E	6 M	7 Decrease in c/u to	8 M/K	9 L_c/L_∞	10 F/M from $E/_{1-E}$	11 F/M from decrease in c/u	Source of data for estimates of L_∞ and K
COD	1		55-60	85-90	0.25-0.30	0.35	0.4-0.6	0.14-0.21		0.5-1.0	0.61-0.71	0.7-1.5		Hansen (Ann. Biol., 1959-61)
	2	2HJ	48	65-75	0.24-0.31				<½	(0.5-1.0)	0.64-0.74		>0.7	May, *et al.* (1964)
	3	3KL	50	77-102	0.16-0.26	0.6	0.42-0.75	0.15-0.35		0.75-2.0	0.49-0.65	0.7-3.0		May, *et al.* (1964)
		3M	43	100	0.15						0.43			May, *et al.* (1964)
		3NO	40	130	0.12	0.7	0.50-0.79	0.15-0.35		1-2.5	0.31	1.0-3.8		May, *et al.* (1964)
		3P	46	78-101	0.17-0.25	0.6	0.42-0.75	0.15-0.35		0.75-2.0	0.46-0.59	0.7-3.0		May, *et al.* (1964)
	4	4X	45	(105)		0.45	0.67-0.89	0.05-0.15			(0.43)	2.0-3.0		
		4T + V(spr.)	50	(110-) (120)	0.10	0.4-0.6	0.50-0.83	0.1-0.2		1-2.0	(0.42-0.46)	1.0-5.0		Kohler (1964)
		4W +V(ex.spr.)	50	(110)		0.4-0.6	0.50-0.67	0.20			(0.46)	1.0-2.0		
	5		45	105-120	0.16	0.55	0.45-0.82	0.1-0.3	1/5-1/10	0.75-2.0	0.38-0.43	0.8-4.5	1.6-3.5	Schroeder (1930)
HADDOCK	3	3NO	33	56	0.22	0.75	0.53-0.80	0.15-0.35		0.75-1.5	0.59	1.1-4.0		Hodder (pers. comm.)
	4	4X	41	60-65	0.17-0.22	0.45	0.33-0.78	0.1-0.3		0.75-1.5	0.63-0.68	0.5-3.5		U.S. Res. Rept. 1962 (ICNAF)
		4VW	43	68-70	0.17-0.22	0.4-0.6	0.50-0.67	0.2		0.75-1.5	0.61-0.63	1.0-2.0		Hart (pers. comm.)
	5		36	73	0.28	0.6	0.50-0.83	0.1-0.3	1/4-1/8 (1/6-1/7)	0.5-1.0	0.49	1.0-4.5	1.4-3.1 (2.2-2.7)	Hennemuth (pers. comm.)
REDFISH	1		36	(65)							(0.55)			
	2	2J	32	50-55	≈0.1						0.58-0.64			USSR; ICNAF Sampling Yearbook, 1961.
	3	3K	30	(47)							(0.64)			
		3M	27	45	0.12						0.60			USSR; ICNAF Sampling Yearbook 1961
		3NOP	22	38	0.11-0.12					1-2.5	0.58			Sandeman (Hodder; pers. comm.)
	4	RST	28	(45)	≈0.1	0.4	0.25-0.75	0.1-0.3	½		(0.62)	0.3-3.0	0.5	Sandeman (Hodder; pers. comm.)
		VWX	23	(42)	≈0.1	0.4	0.50-0.83	0.1-0.3			(0.55)	1.0-4.5		
	5	Y	20	38-42	0.09-0.14	0.6	0.50-0.83	0.1-0.3		1-2.5	0.48-0.52	1.0-4.5		Kelly & Wolf (1959)

Appendix.

Supplementary notes to Table 1.

Col. 1. (L_c). Since the method does not take account of a variation of F with age (as probably occurs, for example, in multiple-gear fisheries), the value of L_c is an average of the mean selection lengths for the constituent gears and/or fleets, weighted by their respective catches. The data are taken from the length compositions of the commercial catches given in the 1961 Assessment Report and therefore refer for the most part to the period 1956-58.

Cols. 2 and 3 (L_∞ and K)

These are taken from published growth data, or from published estimates kindly provided by personal communication. Sources are given in the last column. Values of L_∞ in parenthesis are based, in the absence of growth data, on the maximum length of fish in length compositions of commercial catches.

Cols. 4, 5 and 6 (Z, E and M)

These are taken from the Assessment Report except in the case of M for 4T + V(S) cod, which is from Dickie (1964). The values of Z and E therefore refer to the period 1956-8.

Col. 7 Estimates of the decrease in catch per unit effort from the unexploited level, due to fishing, are based on data from the Assessment Report, except in the case of Subarea 5 haddock which is taken from the 1962 U.S. Research Report. As is described in the text, the extent of the decrease in catch per unit effort can be interpreted in terms of F/M, giving the estimates of this ratio tabulated in col. 11.

Cols. 8 and 9 (M/K and L_c/L_∞)

These are calculated from the estimates of the component parameters given in cols. 1, 2, 3 and 6.

Cols. 10 and 11 (F/M)

Two sets of values of F/M are given. One (col. 10) is calculated from the values of E in col. 5 from the identity

$$F/M \equiv \frac{E}{1 - E}$$

The other (col. 11) is estimated from the decrease in catch per unit effort of col. 7 as described in the text.

Bibliography

Beverton, R. J. H. 1963 — Maturation, growth and mortality of clupeid and Engraulid stocks in relation to fishing. Rapp. Cons. Explor. Mer, Vol. 154, pp. 44-67

Beverton, R. J. H. and Holt, S. J. 1957 — On the dynamics of exploited fish populations. Fish. Invest., Lond., Ser. 2, vol. 19.

Beverton, R. J. H. and Holt, S. J. 1959. — A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. Ciba Fdn Colloq. Ageing, vol. 5, pp. 142-180. (Eds. G. E. W. Wolstenholme and M. O'Connor).

Dickie, L. M. 1963. — Estimation of mortality rates of Gulf of St. Lawrence cod from results of a tagging experiment. ICNAF Spec. Publ. No. 3, pp. 71-80.

Gulland, J. A. 1961 a. — A note on the population dynamics of redfish, with special reference to the problem of age determination. ICNAF Spec. Publ. No. 3, pp. 254-257.

Gulland, J. A. 1961 b. — The estimation of the effect on catches of changes in gear selectivity. J. Cons. int. Explor. Mer, vol. 26, pp. 204-214.

Gulland, J. A. 1961 c. — Fishing and the stocks of fish at Iceland. Fish. Invest., Lond., Ser. 2, vol. 23, No. 4.

Hansen, P. M. 1961-1963. — Cod investigations in the coastal waters and on the offshore banks of West Greenland in 1959-1961. Annls. biol., Copenh., vols. 16, 17, 18.

Holt , S. J. 1957. — General tables for characteristics of steady-state yields. Joint sci. Meeting of ICNAF/ICES/FAO, Lisbon, 27 May-3 June 1957. P. 11, 66 pp. mimeo.

Holt, S. J. 1962 — The application of comparative population studies to fishery biology - an exploration. In: E. D. Le Cren and M. W. Holdgate (Eds.). The exploitation of natural animal populations, pp. 51-71. Blackwell Scientific Publications, Oxford.

Jones, R. 1957. — A much shortened version of the fish yield equation. Joint sci. Meeting of ICNAF/ICES/FAO, Lisbon, 27 May-3 June 1957. P. 21, 6 pp., mimeo.

Kelly, G. F. and Wolf, R. S. 1959. — Age and growth of the redfish (*Sebastes marinus*) in the Gulf of Maine. Fish. Bull., U.S., vol. 60, pp. 1-31.

Kohler, A. C. 1964. — Variations in the growth of Atlantic cod (*Gadus morhua* L.). J. Fish. Res. Bd Can., vol. 21, pp. 57-100.

May, A. W. et al. 1964. — Cod growth and temperature in the Newfoundland area. ICNAF Environmental Symposium, Rome, 1964. (mimeo).

Schroeder, W. C. 1930. — Migrations and other phases in the life-history of the cod off southern New England. Fish. Bull., U.S., vol. 46, pp. 1-136.

Figure Legends

Fig. 1. Catch/effort nomogram for stocks with $^M/_K$ = 0.5-1.0. The shaded zone defines the range of values of $^F/_M$ (ratio of fishing to natural mortality; approximately proportional to fishing effort) and c (= $^{L_c}/_{L_\infty}$; proportional to mean selection length L_c) which may generate a maximum in the catch/effort curve, allowing for the uncertainty of the true value of $^M/_K$ within the range of 0.5-1.0. The actual range of values of c and $^F/_M$ (Table 1) for cod of Subareas 1 and 2, and Subarea 5 haddock, are shown on the diagram.

Fig. 2. Plot of catch per unit effort against fishing effort for Subarea 5 haddock (from 1962 U.S. Res. Rept.). Shown also are the theoretical catch per unit effort/effort curves (left hand scale) and the corresponding yield/effort curves (right hand scale) for $^M/_K$ = 0.5-1.0 and c = 0.46-0.50.

Fig. 3 Graphs showing the theoretical decrease in catch per unit effort (as a fraction of the value in the unexploited stock) as a function of $^F/_M$ (approximately proportional to fishing effort) for certain stocks. Marked on these graphs are the observed limits of decrease of catch per unit effort and the values of $^F/_M$ to which they correspond.

Fig. 4 Catch/effort nomogram for stocks with $^M/_K$ = 0.75-1.5.

Fig. 5 Catch/effort nomogram for stocks with $^M/_K$ = 0.75-2.0

Fig. 6 Catch/effort nomogram for stocks with $^M/_K$ = 1.0-2.5

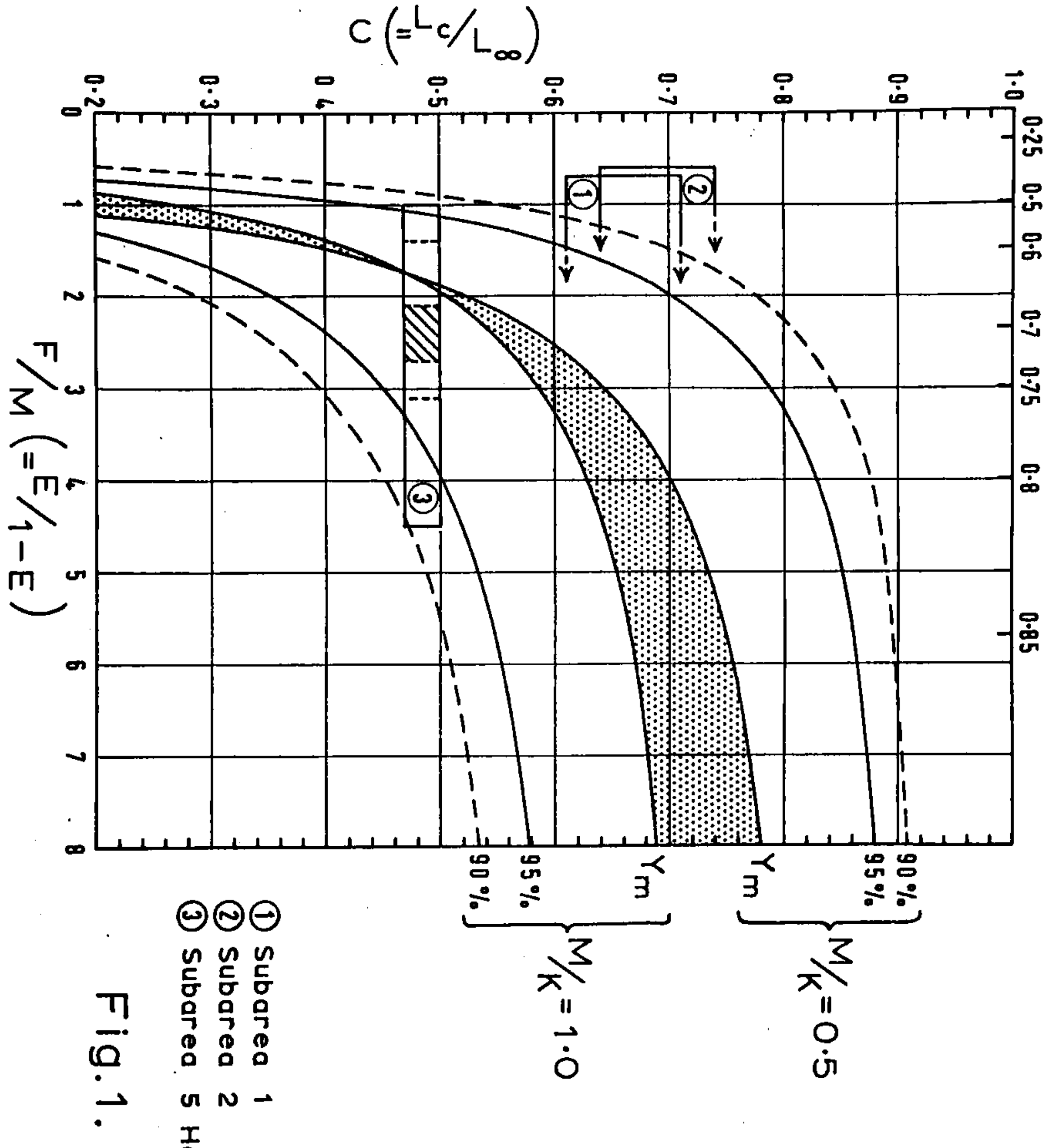

C (=Lc/L∞)
E
F/M (=E/1-E)
Ym
Ym
90 %
95 %
90 %
95 %
M/K = 0·5
M/K = 1·0
① Subarea 1 Cod
② Subarea 2 Cod
③ Subarea 5 Haddock

Fig. 1.

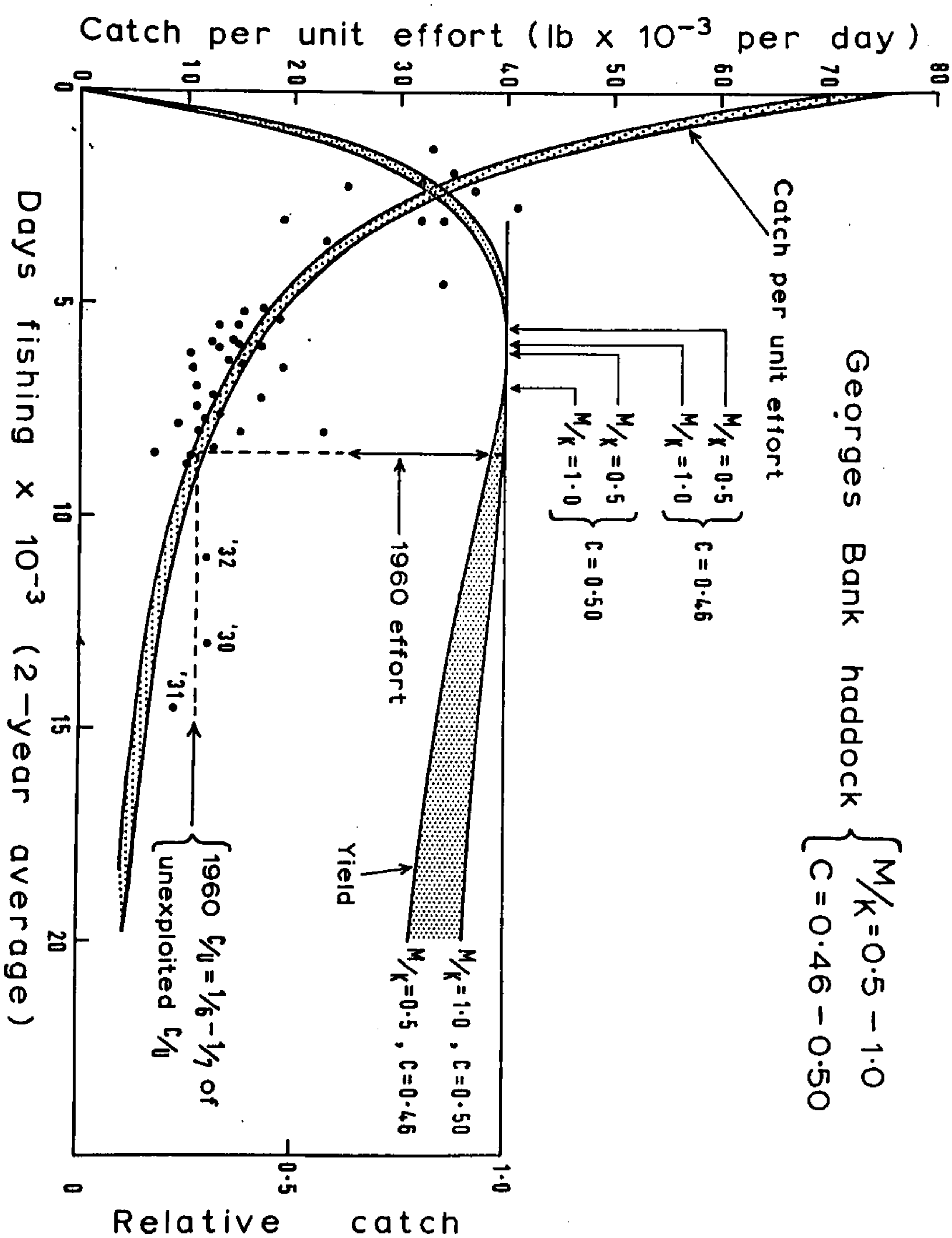

Georges Bank haddock {M/K = 0·5 – 1·0, C = 0·46 – 0·50
Catch per unit effort (lb x 10⁻³ per day)
Catch per unit effort
M/K = 0·5, M/K = 1·0 } C = 0·46
M/K = 0·5, M/K = 1·0 } C = 0·50
1960 effort
Yield
M/K = 1·0 , C = 0·50
M/K = 0·5 , C = 0·46
'32
'30
'31
1960 C/U = 1/6 – 1/7 of unexploited C/U
Days fishing x 10⁻³ (2-year average)
Relative catch

Fig. 2.

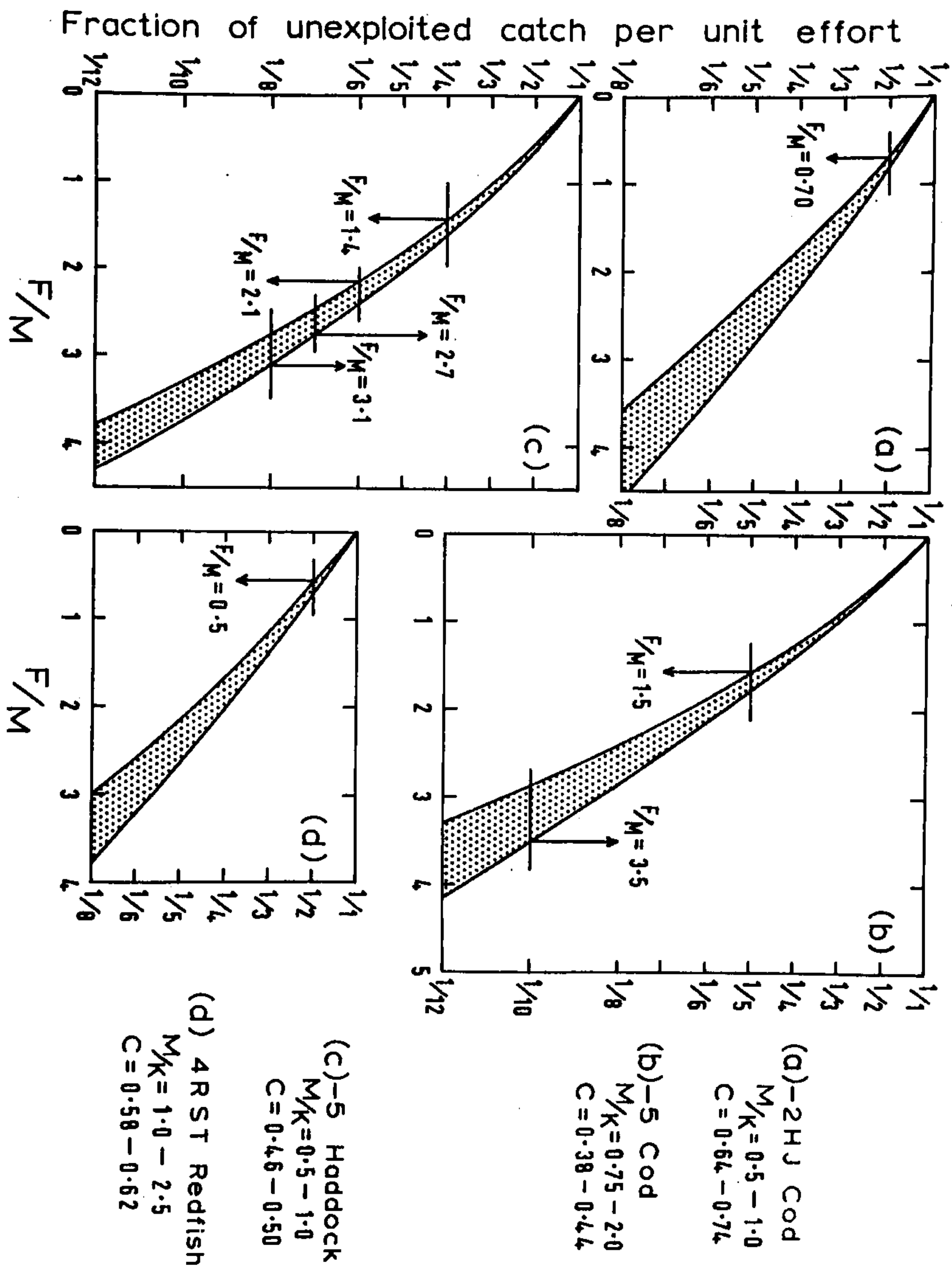
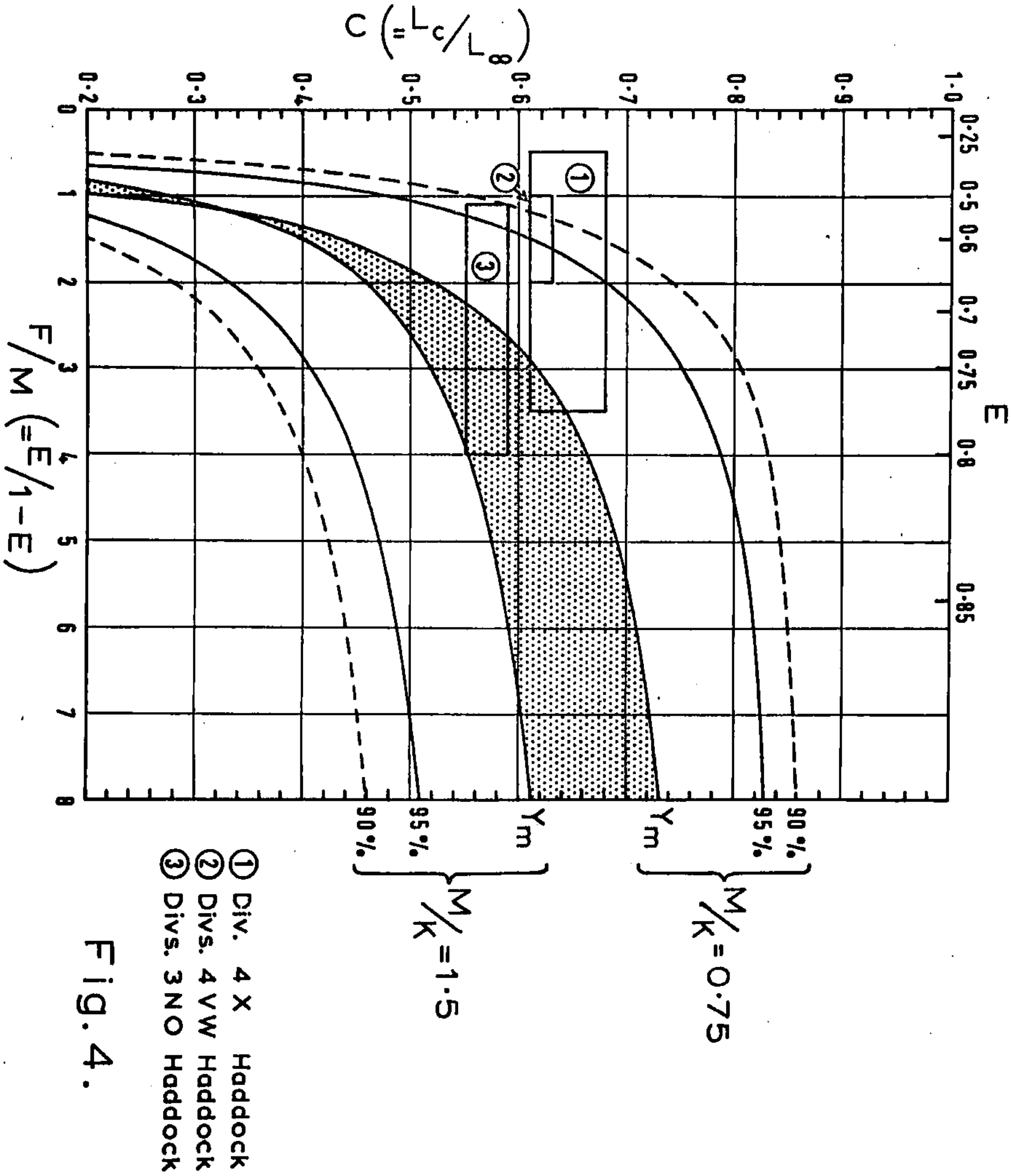

Fraction of unexploited catch per unit effort
F/M
(a)
(b)
(c)
(d)
F/M = 0·70
F/M = 1·5
F/M = 3·5
F/M = 1·4
F/M = 2·1
F/M = 2·7
F/M = 3·1
F/M = 0·5
(a)–2HJ Cod
M/K = 0·5 – 1·0
C = 0·64 – 0·74
(b)–5 Cod
M/K = 0·75 – 2·0
C = 0·38 – 0·44
(c)–5 Haddock
M/K = 0·5 – 1·0
C = 0·46 – 0·50
(d) 4RST Redfish
M/K = 1·0 – 2·5
C = 0·58 – 0·62

Fig. 3.



C (=Lc/L∞)
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
E
0·25
0·5
0·6
0·7
0·75
0·8
0·85
F/M (=E/1−E)
0
1
2
3
4
5
6
7
8
①
②
③
90 %
95 %
Ym
M/K = 0·75
M/K = 1·5
① Div. 4 X Haddock
② Divs. 4 VW Haddock
③ Divs. 3 NO Haddock

Fig. 4.

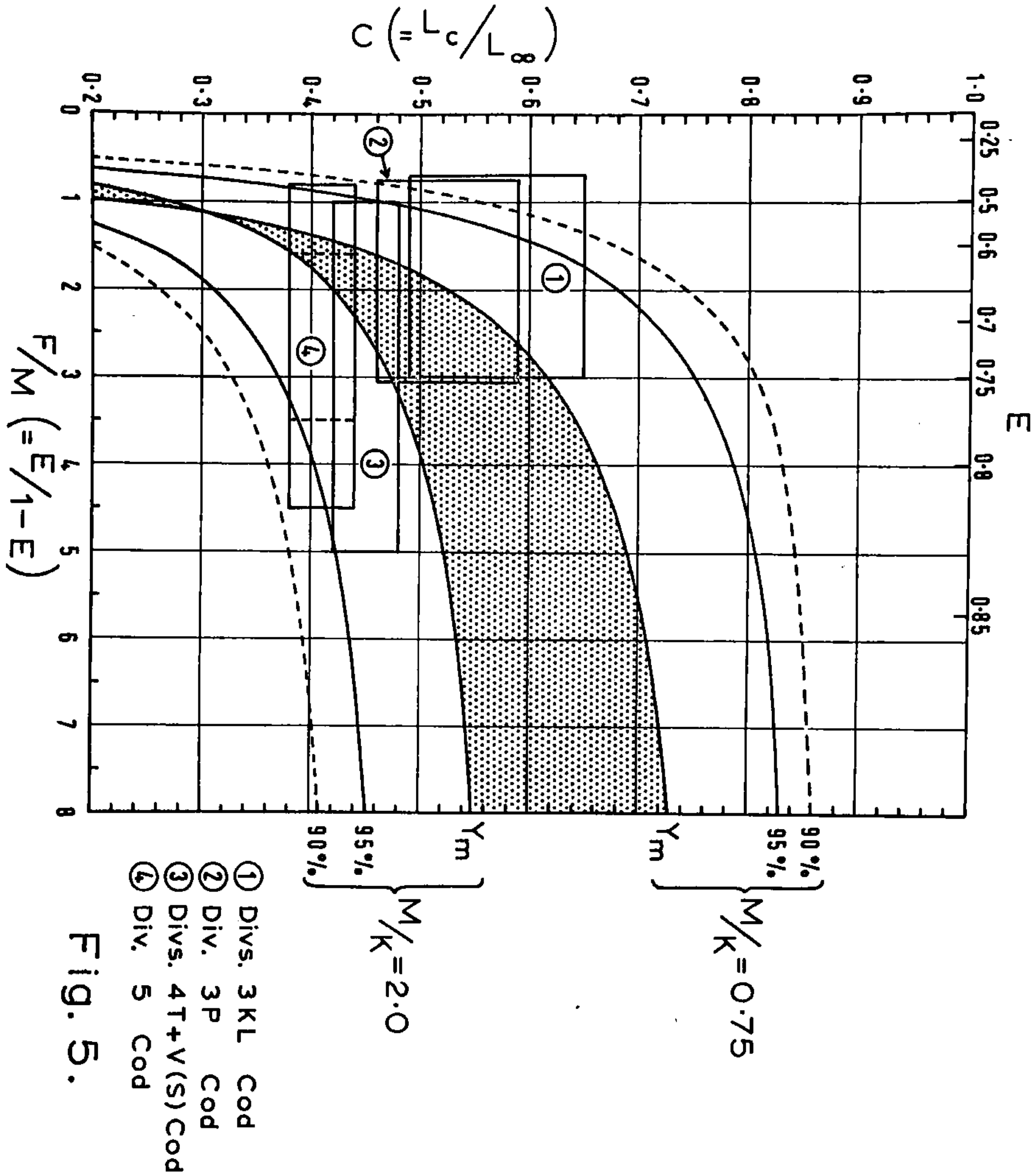

C (= Lc/L∞)
E
F/M (= E/1−E)
M/K = 0·75
M/K = 2·0
Ym
95 %
90 %
① Divs. 3KL Cod
② Div. 3P Cod
③ Divs. 4T+V(S) Cod
④ Div. 5 Cod

Fig. 5.

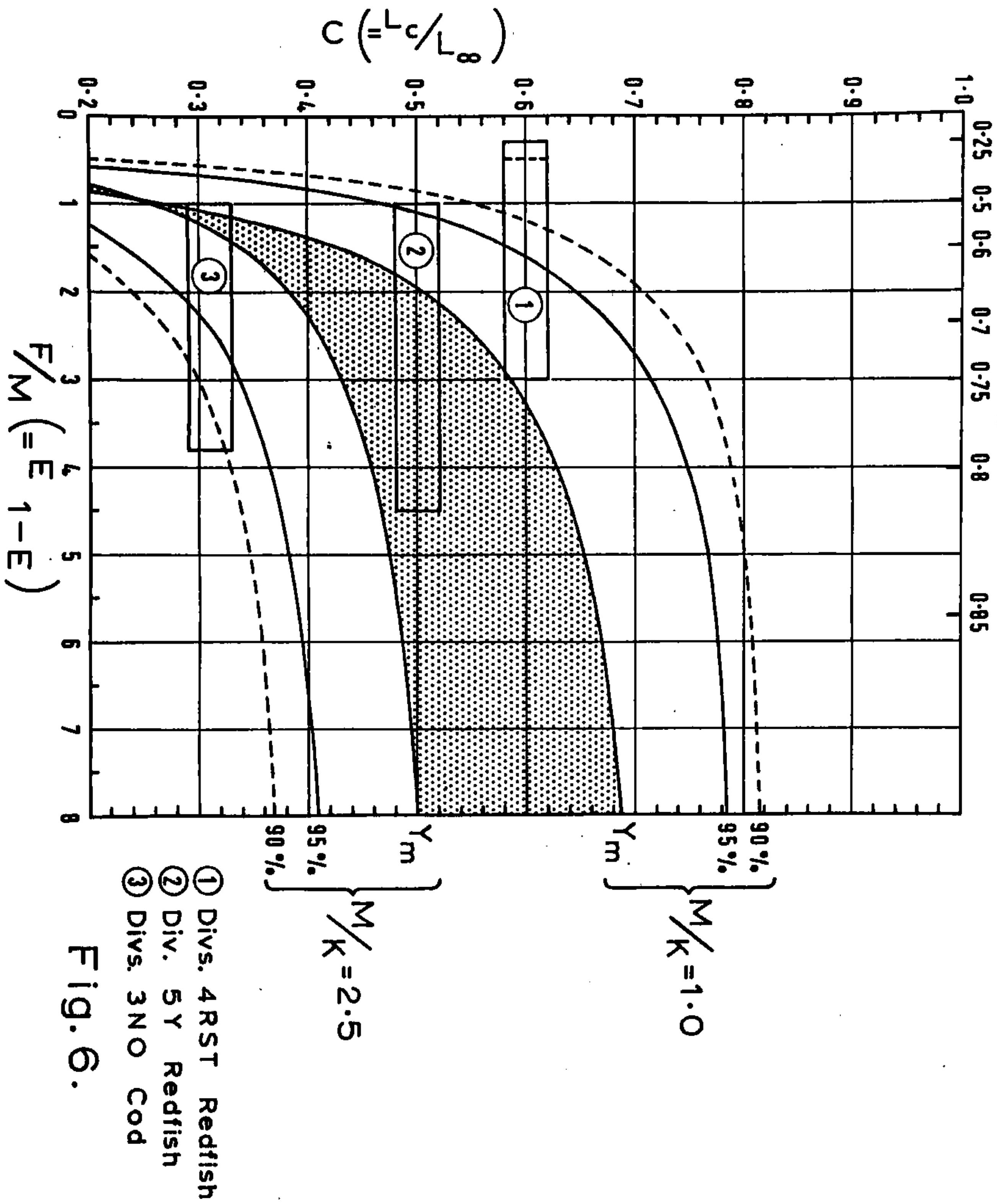

C (= Lc/L∞)
E
F/M (= E/1−E)
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
0·25
0·5
0·6
0·7
0·75
0·8
0·85
0
1
2
3
4
5
6
7
8
Ym
95 %
90 %
M/K = 1·0
M/K = 2·5
① Divs. 4RST Redfish
② Div. 5Y Redfish
③ Divs. 3NO Cod

Fig. 6.