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International Council for the Exploration of the Sea

CM 1980/ H:29
Pelagic Fish Committee

AN ALTERNATIVE PATTERN OF EXPLOITATION FOR THE WESTERN MACKEREL STOCK

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ABSTRACT

Mackerel exploitation patterns are described for the current Mixed fishery west of Britain, a Northern fishery limited to ICES Divisions VIa plus VIIa-c, and a Southern fishery limited to ICES Divisions VIId-k plus Sub-area VIII. Estimates of total yield and spawning stock biomass are made using yield-per-recruit and biomass-per-recruit estimates and a versatile new stock and recruitment relationship. The effect of different exploitation patterns on the total yield and biomass are described. They show that a shift in emphasis is advisable, away from the present pattern of exploitation towards fisheries along the edge of the continental shelf and west of Scotland.

INTRODUCTION

The international catch of mackerel from the area west of Britain, i.e. from the Western mackerel stock, increased from about 100,000 t in 1970 to 500,000 t in 1976. Over the same period estimates of the spawning stock biomass have remained relatively stable at 3-4 million t (Anon., 1979). This spawning stock biomass could sustain a yield of 400,000-500,000 t per annum under the present pattern of exploitation, but catches significantly greater than this, such as those taken in 1978 (ca. 550,000 t) and 1979 (ca. 650,000 t) (Anon., 1980), may result in rapid depletion of the spawning stock biomass. Over the period 1972-78 the catch-per-unit-of-effort, an index of stock abundance, in the Cornish handline fishery showed a continual decline (Dawson, 1979), and the spawning stock biomass as estimated by cohort analysis fell from about 3.9 million t to less than 3 million t over the same period (Anon., 1980). If optimal yields from this stock are to be maintained suitable action must be taken to halt and then reverse this trend.

As a first step in this process the ICES Mackerel Working Group has advocated that the fishing mortality rate should not go higher than a value F=0.15 (Anon., 1978). Despite this advice the fishing mortality rate in 1978 was 0.18 and it increased further in 1979, possibly to 0.25 (Anon., 1980).

As a second step to reduce the decline in spawning stock biomass the Working Group considered various measures which might reduce the number of immature mackerel, i.e. mackerel less than 30 cm total length (equivalent to 3 year olds), taken in the western fishery. To do this the Working Group looked at the effects of introducing a 30 cm minimum size regulation, closed areas, and seasonal controls on fishing areas. These options were discussed with the aid of Beverton and Holt yield-per-recruit and spawning biomass-per-recruit curves for certain specified fisheries. The major fault with this approach lies in the basic assumption of the Beverton and Holt model that there is knife-edge recruitment to both the fished stock and the spawning stock. It also assumes that the rate of fishing mortality, F, is constant across all age groups.

These assumptions are known to be unsound and hence undermine the validity of any conclusions which might be drawn. Advice for managing a fishery based solely on yield-per-recruit and biomass-per-recruit curves is also of limited value in that the curves give relative and not absolute values of the gains to be made under different patterns of exploitation. In this paper these shortcomings are overcome by incorporating observed exploitation patterns into the calculations and using Shepherd's (in preparation) stock and recruitment relationship to estimate total yield and total biomass under various exploitation patterns over a range of fishing mortality rates.

ASSESSMENT OF THE EXPLOITATION PATTERN

When making an assessment of the Western mackerel stock the Working Group carries out a cohort analysis and in so doing produces a matrix of estimated fishing mortality rate at age by years. These estimates for the period 1972-79 are given in Table 1.

Prior to 1979, when making a stock assessment, the Working Group assumed that recruitment to the fully exploited stock was completed at age 3, and that the fishing mortality rate was constant for all fish older than age 2. Accepting this assumption, a second matrix was drawn up where exploitation is expressed as the ratio of the fishing mortality rate at age in any year, F_t, to the fishing mortality rate on 3 year olds in the same year, i.e. F_t/F_3. The mean of these ratios for each age group were calculated to estimate the mean exploitation pattern for the period 1972-78, (Table 2). It is apparent from the distribution of the mean values of F_t/F_3 against age (Figure 1), that the assumption previously made was justified, and that exploitation was more or less constant on 3 year olds and older. Closer examination of the exploitation ratios, (Table 2) shows that throughout the 1970s there was a tendency for exploitation to increase on 2 year olds. In response to this shift in exploitation pattern, recent assessments have assumed that 2 year olds are fully recruited (Anon., 1979; 1980) and that 1 year olds are 40% recruited. To facilitate direct comparisons the assessment made here incorporates the same exploitation pattern used by the Working Group in preference to the mean for the period 1972-78 (Figure 1 and Table 3).

The current western mackerel fishery is a MIXED fishery comprising two major components; the autumn fishery west of Scotland (NORTHERN fishery) and the winter fishery in the Celtic Sea area (SOUTHERN fishery). (The names in uppercase type are the names used to identify these fisheries throughout this paper). The exploitation patterns for these fisheries were estimated by apportioning the exploitation pattern for the Mixed fishery by the proportion of the total catch in number from the western area taken in Divisions VIa plus VIIa,b,c for the Northern fishery, and Divisions VIId-k plus Sub-area VIII for the Southern fishery. These values are re-expressed as a proportion of the most highly exploited age group in the fishery (Table 4). They are repeated in Table 5, along with an exploitation pattern for a southern SHELF EDGE fishery. Whereas the exploitation patterns for other fisheries were derived from commercial catch data submitted to the Working Group, this last exploitation pattern is based on a relatively small amount of data, collected by English research vessels during the mackerel spawning season. The samples were collected from the edge of the continental shelf between 47° and 53°N, i.e. mainly within ICES Division VIIj. The accuracy of this exploitation pattern will no doubt improve when more data from commercial fisheries are available, e.g. the Dutch and Danish fisheries west of Ireland in the spring of 1979.

YIELD-PER-RECRUIT AND SPAWNING BIOMASS-PER-RECRUIT

Any differences in yield-per-recruit between separate fisheries in the western area will, to a certain extent, reflect different mean weights at age. The Southern fishery in the Celtic Sea area is predominantly a winter fishery, while the Northern fishery west of Scotland is at its height in the autumn months. During the winter mackerel do not feed but live off their fat reserves and hence the mean weights at age in the Southern fishery are less than in the Northern fishery, while the mean weights at age in the Mixed fishery fall between the two (Table 6). The weights at age used are weighted means of weights at age by areas and quarters (Anon., 1979) weighted by the catch (in weight) from the appropriate area in the relevant quarter in 1979 (Anon., 1980). The spawning stock weights at age are the weighted mean of the Southern and Northern areas in the second quarter only, when spawning is at its peak (Lockwood et al., 1978). In the absence of any new data to the contrary the spawning stock is assumed to be comprised of all fish 3 years old and older. The Shelf Edge data are from English research vessel samples.

These weight at age data and the exploitation patterns described above were used in calculating a family of yield-per-recruit and biomass-per-recruit curves (Figure 2). The calculations were carried out over a range of fishing mortality rate, F, values to a maximum of F = 0.5, which is approximately twice the maximum value observed to date. The value of F represents the fishing mortality rate affecting the maximally exploited age group in the exploitation pattern, other age groups being exploited proportionately less (see Table 5).

In Figure 2a the yield-per-recruit curves for three fisheries are shown, the Mixed fishery currently exploiting the Western mackerel stock, a purely Southern fishery, assuming no fishing west of Scotland, and a Northern fishery, assuming no fishing in the Celtic Sea area. While the yield-per-recruit at all values of F is consistently less in the Southern fishery than in the other two fisheries the differences are hardly sufficient to form the basis of well-founded management advice, particularly at levels of fishing mortality observed to date, i.e. F = 0.1 to 0.25 (Anon., 1980).

While there may be no clear differences in yield-per-recruit there are differences in biomass-per-recruit resulting from different exploitation patterns. The biomass-per-recruit with a purely Southern fishery is virtually the same as the biomass-per-recruit with the current Mixed fishery, but at F = 0.15, biomass-per-recruit with a Northern fishery is more than 60% greater than with the current Mixed fishery.

The apparent gains to be had from one fishery compared with another are summarised in Figure 2c where yield and biomass-per-recruit are plotted against each other and the locus of F = 0.15, the level at which the Working Group has set TACs, is drawn across the curves.

TOTAL YIELD AND SPAWNING STOCK BIOMASS

The method used for raising estimates of yield-per-recruit and biomass-per-recruit to estimates of total yield and biomass is described in detail by Shepherd (in preparation) but is summarised here.

From the generalised stock and recruitment relationship:

$$R = aBf(B/K) \quad \text{.................... (1)}$$

he develops:

$$R = aB/(1+(B/K)^{\beta}) \quad \text{.................... (2)}$$

from which:

$$K = B^*/(aB^*/R^*-1)^{1/\beta} \quad \text{.................... (3)}$$

where:

B* and R* are "typical" current levels of biomass and recruitment;
"a" is the slope of a line drawn through the origin just to the left of all available stock and recruitment data (the reciprocal of this parameter, $^1/_a$, is the critical biomass-per-recruit; if B/R falls below this level the model will predict stock collapse due to recruitment failure);
β is the degree of density-dependent compensation.

By rewriting equation (3):

$$B = K(aB/R-1)^{1/\beta} \quad \text{.................... (4)}$$

thus biomass may be calculated over a range of F from the estimates of biomass-per-recruit.

Then: $R = B/(B/R)$ .... (5)

and $Y = R(Y/R)$ .... (6)

and estimates of total yield over a range of F may also be calculated.

The estimated spawning stock biomass and estimated number of 1 year old recruits (Anon., 1980) are shown in Figure 3. Appropriate values for B* and R* are taken as 4.0×10^6 t and 4000×10^6 recruits respectively.

The critical biomass-per-recruit, as defined above, is 670 g. If this value is used in estimating total yield and biomass it assumes that the maximum observed recruitment is the maximum which the stock can produce and may project an excessively pessimistic point of stock collapse (see below and Figure 4). If the slope through the mean of all the data is used the assessment will be even more pessimistic, but the slope of the line representing the upper 10 percentile is a statistically more stable (albeit relatively arbitrary) value to use, as it assumes that the chances of recruitment (and hence "a") being greater are less than 1 in 10. The value for this line, 470 g, has been used in this assessment. No "special" density-dependent relationships are assumed, therefore the value for β is unity. The estimates of total yield and spawning stock biomass made with these parameters are shown in Figure 4a-c.

Compared with the yield-per-recruit curves the total yield curves show differences between the alternative fisheries quite clearly. A purely Southern fishery has the lowest potential yield, the Mixed fishery shows greater yields for more or less the same optimum F, but the Northern fishery has potentially the greatest yield at an optimum F more than twice that for the current Mixed fishery. The curves also suggest that at current levels of fishing mortality the stock may well collapse under the present pattern of exploitation.

The point at which the stock might collapse is also identified in Figure 4b, where biomass is plotted against fishing mortality rate. Under the present pattern of exploitation the stock might collapse if subjected to sustained fishing at about $F = 0.25$, whereas this level of fishing in the Northern fishery would not depress the stock below its highest estimated level in the period 1972-78, i.e. 4.0 million t (Anon., 1980).

In Figure 4c estimated total yield is plotted against biomass. The maximum yield from any particular fishery may be taken from the same size of stock, ca. 6 million t, but this represents different levels of fishing mortality in each fishery. The locus of $F = 0.15$ is drawn in as a reference point.

The family of yield and biomass curves for the Northern fishery are repeated in Figure 5 to enable direct comparison with the potential yield and biomass which might be obtained in a southern Shelf Edge fishery (between La Chapelle Bank and Porcupine Bank).

DISCUSSION

At present there are two major faults in the exploitation of the western mackerel stock: the international catch is exceeding the TAC by a significant margin, and too high a proportion of the catch in number are immature fish, 20-40% in recent years. While the first fault cannot be rectified by scientific advice the second fault will only improve if scientific advice for viable management action is provided.

This second fault has received detailed consideration (Anon., 1979) but for a variety of reasons the conclusions reached and advice given have been rather limited. Due to problems associated with the age structure and the density of mackerel shoals in the Celtic Sea winter fishery, a minimum landing size was considered not to be the appropriate conservation measure, in contrast to the North Sea (Hamre and Ulltang, 1972). A shift in emphasis from the Celtic Sea area to Division VIa was considered desirable but due to shortcomings in the Beverton and Holt yield-per-recruit assessment the evidence did not give adequate support to advise an area closure. While there are no new reasons to believe that a minimum size regulation would be an effective conservation measure, the data presented in this paper do clearly support the need to change the present pattern of exploitation.

The main difference between the assessment made here and others is the inclusion of Shepherd's stock and recruitment model. This in itself will no doubt be a subject for considerable debate, but it does not invalidate the conclusions which may be drawn. Inclusion of the model enables both total yield and biomass to be estimated at optimum values of F. The levels indicated are not totally divorced from reality as the maximum yield estimated for the Mixed fishery, a little over 400,000 t (Figure 4c) compares favourably with assessments made by cohort analysis (Anon., 1978) and from catch-per-effort data (Dawson, 1979). A shift from the Mixed fishery to a Shelf Edge-Northern fishery could yield an extra 150,000 t for a given stock size.

The predicted point at which the stock might collapse is heavily dependent on the stock and recruitment model, particularly on the critical biomass-per-recruit, but it should not be ignored. The level of F at which the stock collapse is indicated is not absolute, but to question its validity and to ignore the conclusions which can be drawn would be reckless. The conclusion which can be drawn with certainty is that due to the present heavy dependence on immature fish in the Celtic Sea area the stock will collapse at a lower level of F (possibly no more than that estimated for 1979) than it will if the emphasis is shifted away from the present area in the eastern Celtic Sea.

The shift need not be exclusively to the Northern fishery. Figure 5 shows that similar yields and biomass could be sustained in a southern Shelf Edge fishery. The important point is that action should be taken to alter the present pattern of exploitation in order to alleviate the dependence on immature fish and to concentrate more on those large mackerel more generally associated with the edge of the continental shelf.

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TABLE 1. The Western mackerel fishery. The distribution of fishing mortality, F, at age, calculated by cohort analysis for the period 1972-78 (Anon., 1980). Values in parentheses are either accumulated age groups or the 1979 first estimates and are omitted from the calculation of $\overline{F}$ at age

Year \ Age	0	1	2	3	4	5	6	7	8	9	≥ 10
1972	.001	.003	.006	.011	(.064)	-	-	-	-	-	-
1973	.000	.021	.015	.039	.052	(.093)	-	-	-	-	-
1974	.000	.024	.017	.045	.083	.109	(.116)	-	-	-	-
1975	.000	.020	.035	.083	.140	.195	.106	(.377)	-	-	-
1976	.007	.077	.087	.137	.200	.180	.167	.289	(.208)	-	-
1977	.005	.035	.101	.092	.092	.080	.118	.122	.133	(.102)	-
1978	.002	.093	.164	.200	.194	.192	.147	.172	.143	.168	(.182)
1979	(.01)	(.10)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)	(0.25)
$\overline{F}_{72-78}$	0.002	0.039	0.061	0.087	0.127	0.151	0.134	0.194	.038	0.168	(0.182)

TABLE 2. The Western mackerel fishery. The exploitation pattern relative to 3 year old fish, F_t/F_3, for the period 1972-78. Values in parentheses are not included in the estimated mean for the period 1972-78

Year	Age 0	1	2	3	4	5	6	7	8	9	≥ 10
1972	0.091	0.273	0.546	1.000	(5.818)	-	-	-	-	-	-
1973	0.0	0.538	0.385	1.000	1.333	(2.385)	-	-	-	-	-
1974	0.0	0.533	0.378	1.000	1.844	2.422	(2.578)	-	-	-	-
1975	0.0	0.241	0.422	1.000	1.687	2.349	1.277	(4.542)	-	-	-
1976	0.051	0.562	0.635	1.000	1.460	1.314	1.219	2.110	(1.518)	-	-
1977	0.054	0.380	1.098	1.000	1.00	0.870	1.283	1.326	1.446	(1.109)	-
1978	0.010	0.465	0.820	1.000	0.970	0.960	0.735	0.860	0.715	0.840	(0.910)
1979	(0.04)	(0.40)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
$Mean_{72-78}$	0.029	0.427	0.612	1.000	1.382	1.583	1.128	1.432	1.080	0.840	-
SD	0.036	0.131	0.267	0	0.355	0.752	0.264	0.632	0.517	-	-

$Mean_{72-78}$ ≥ 3 year olds = 1.251

sd = 0.457

TABLE 3. The Western mackerel fishery. The exploitation pattern relative to the fully recruited age groups

Age	0	1	2	3	4	5	6	7	8	9	≥ 10
Fully exploited age 3 and older											
Smoothed exploitation ration F_t/F_3 (from Figure 1)	<0.05	0.36	0.80	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Mean exploitation pattern 1972-78	<0.05	0.28	0.64	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fully exploited age 2 and older											
Mean exploitation pattern (Anon., 1980)	0.04	0.40	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 4. Calculation of the exploitation pattern for the Southern (E_S) and Northern (E_N) fisheries from the exploitation pattern in the Mixed fishery (E) and the catch in number (N)

Age	Current Western mixed fishery		Southern fishery ICES Divs VIId-k + VIII				Northern fishery ICES Divs VIa, VIIa,b,c			
	$\Sigma Nx10^{-6}$	E	$Nx10^{-6}$	Part of ΣN	Part of E	E_S	$Nx10^{-6}$	Part of ΣN	Part of E	E_N
0	79.5	0.04	79.5	1.00	0.04	0.04	0	0	0	0
1	351.1	0.40	349.6	1.00	0.40	0.40	1.5	+	+	0
2	61.6	1.00	60.7	0.98	0.98	1.00	0.9	0.01	0.02	0.02
3	602.4	1.00	582.7	0.97	0.97	0.99	19.7	0.03	0.03	0.05
4	358.9	1.00	308.1	0.86	0.86	0.88	50.8	0.14	0.14	0.25
5	202.3	1.00	133.3	0.66	0.66	0.67	69.0	0.34	0.34	0.61
6	212.9	1.00	142.2	0.67	0.67	0.68	70.7	0.33	0.33	0.59
7	77.8	1.00	41.3	0.53	0.53	0.54	36.5	0.47	0.47	0.84
8	129.0	1.00	75.1	0.58	0.58	0.59	53.9	0.42	0.42	0.75
9	68.3	1.00	30.2	0.44	0.44	0.45	38.1	0.56	0.56	1.00
≥10	204.6	1.00	109.9	0.54	0.54	0.55	94.7	0.46	0.46	0.82
			1912.6							

TABLE 5. The exploitation patterns for the four fisheries described in the assessment. The current Mixed fishery, the Northern and Southern fishery exploitations are derived from Working Group data (Anon., 1980). The Shelf Edge exploitation pattern is an interpolation between the Northern and Southern fisheries

	Age	1	2	3	4	5	6	7	8	9	≥ 10
Mixed fishery		0.40	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Southern fishery		0.40	1.00	0.99	0.88	0.67	0.68	0.54	0.59	0.45	0.55
Northern fishery		0	0.02	0.05	0.25	0.61	0.59	0.84	0.75	1.00	0.82
Shelf Edge fishery		0	0.05	0.10	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 6. The Western mackerel stock. Estimated mean weights at age in the spawning stock and the four fisheries described in the assessment

	Age	1	2	3	4	5	6	7	8	9	≥ 10
Spawning stock		-	-	213	256	276	323	295	397	465	429
Mixed fishery		104	184	263	314	330	391	386	502	503	528
Southern fishery		104	154	229	285	302	370	359	495	486	528
Northern fishery		-	251	336	375	392	439	444	515	540	568
Shelf Edge fishery		-	268	335	358	409	440	529	507	484	631

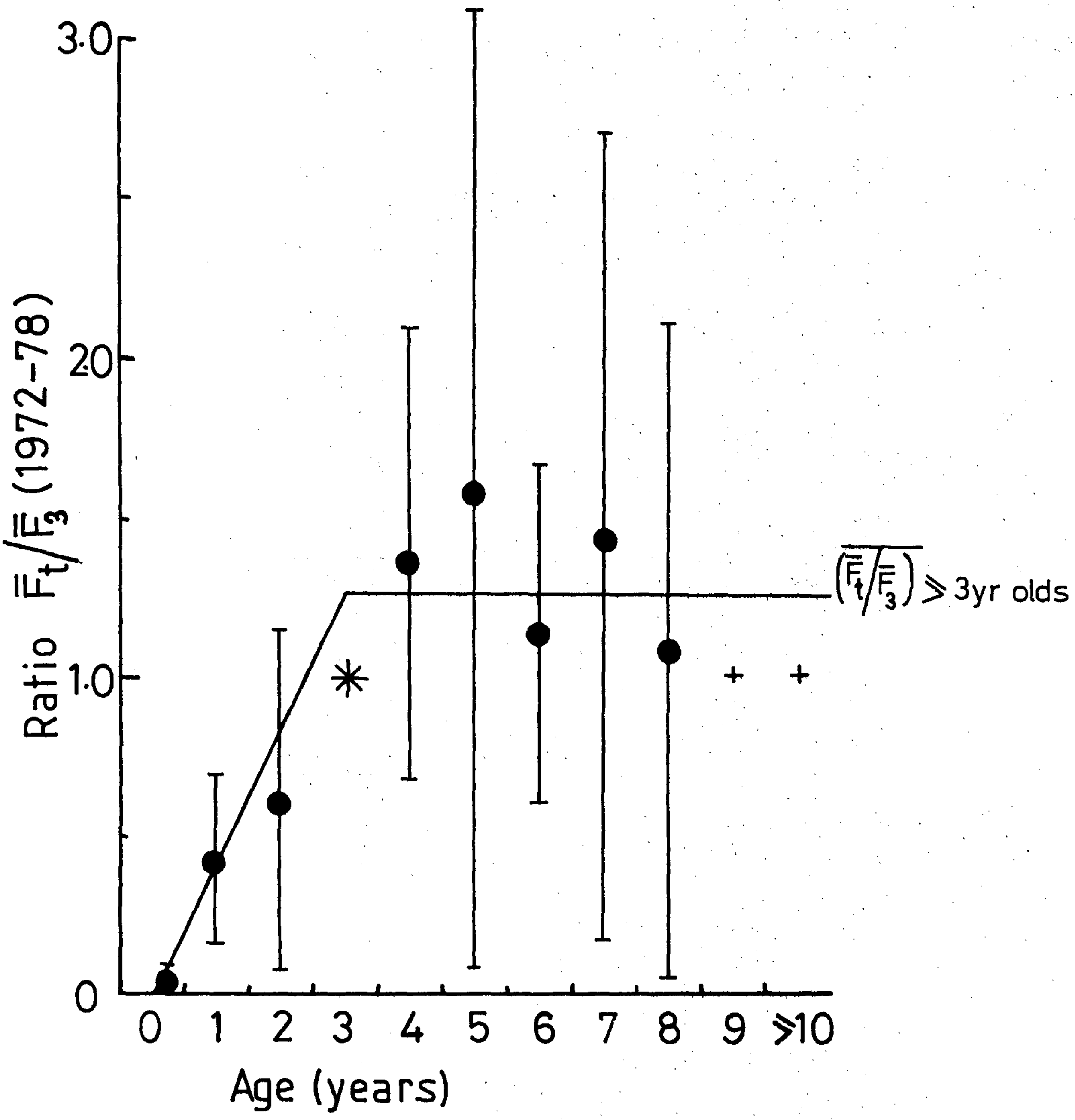

Figure 1 The Western mackerel stock exploitation pattern. The mean (± 2 sd) ratio F_t/F_3 for ages 0-8 for the period 1972-78. Single observations only for ages 9 and >9.

The horizontal line is drawn through the mean of all F_t/F_3 values for fish 3 years and older (Table 2). The slope is drawn from zero exploitation at spawning to fully exploited at age 3.

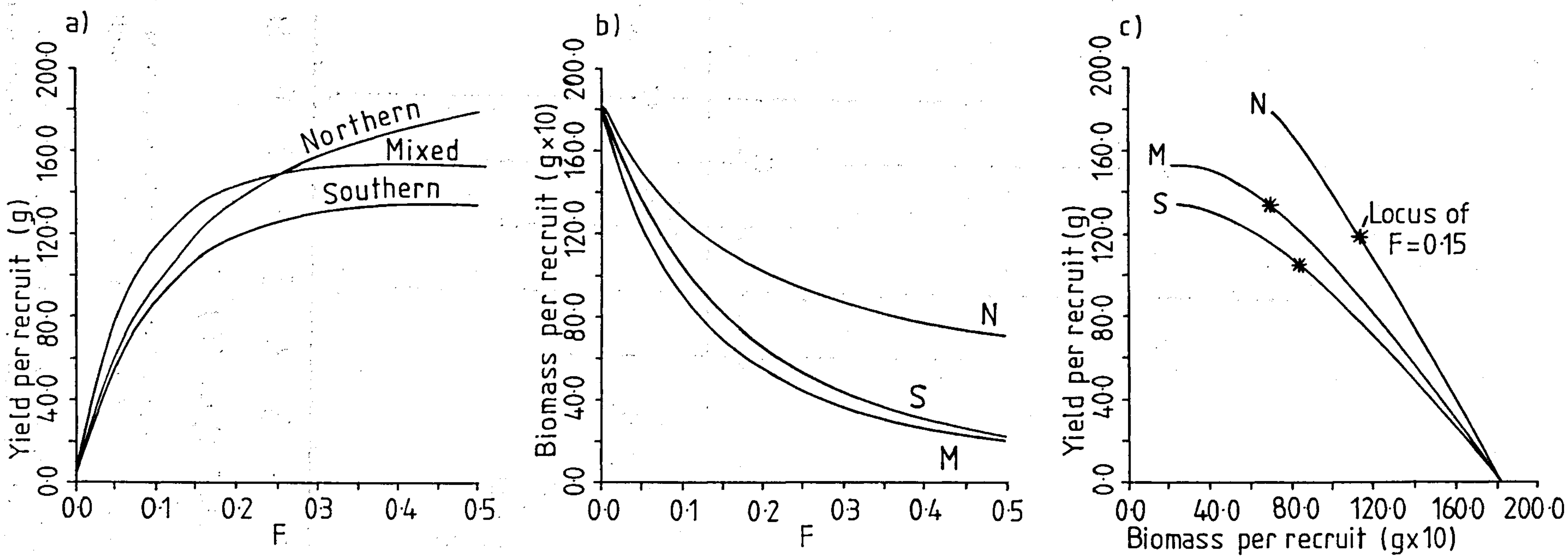

Figure 2 Yield-per-recruit and spawning biomass-per-recruit for the current Mixed fishery (M) west of Britain, a Northern fishery (N) limited to Division VIa plus VIIa-c and a Southern fishery (S) limited to Division VIId-k plus Sub-area VIII.

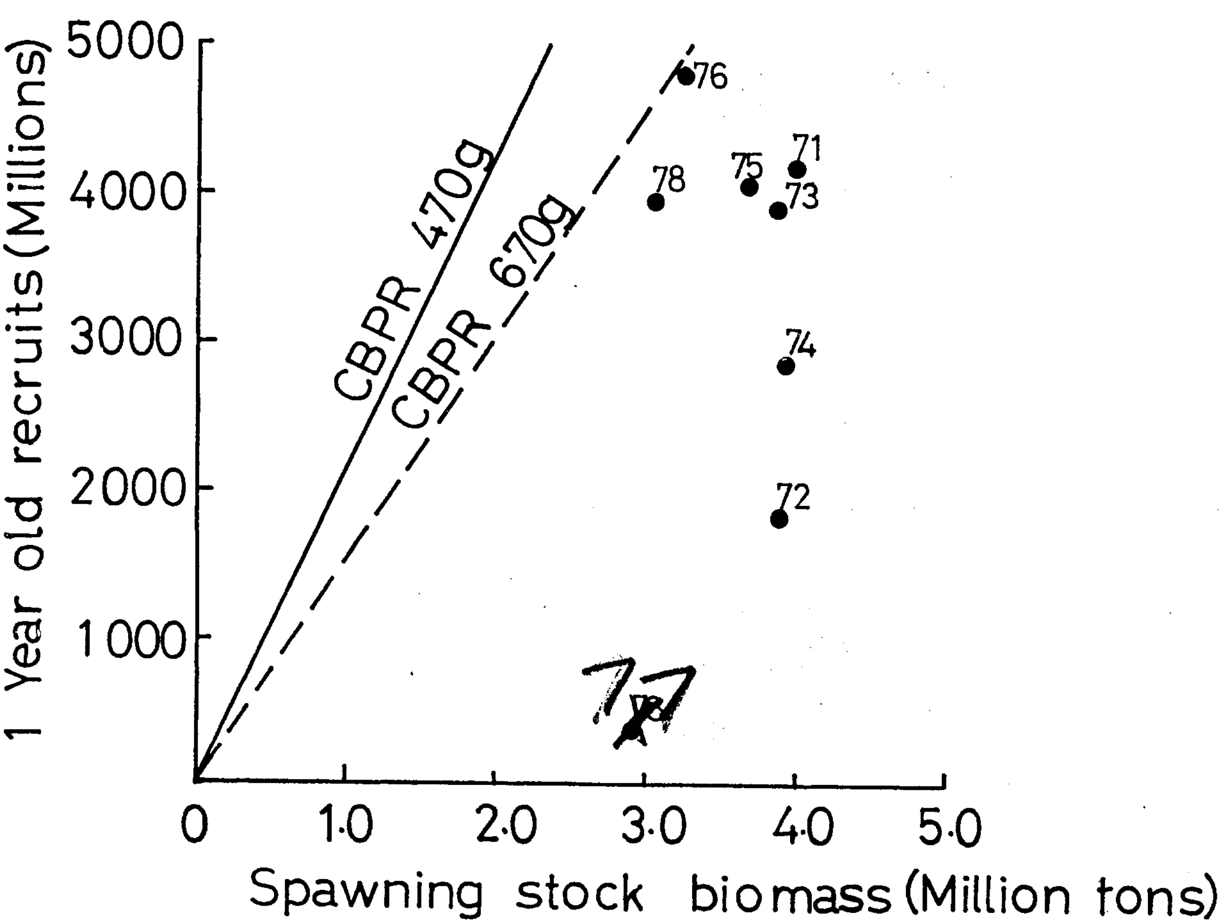

Figure 3 The Western mackerel stock spawning biomass and 1 year old recruits. The critical biomass-per-recruit (CBPR) for the observed data is estimated by the broken line, but the (solid) line drawn at the upper 10 percentile level is used in the assessment.

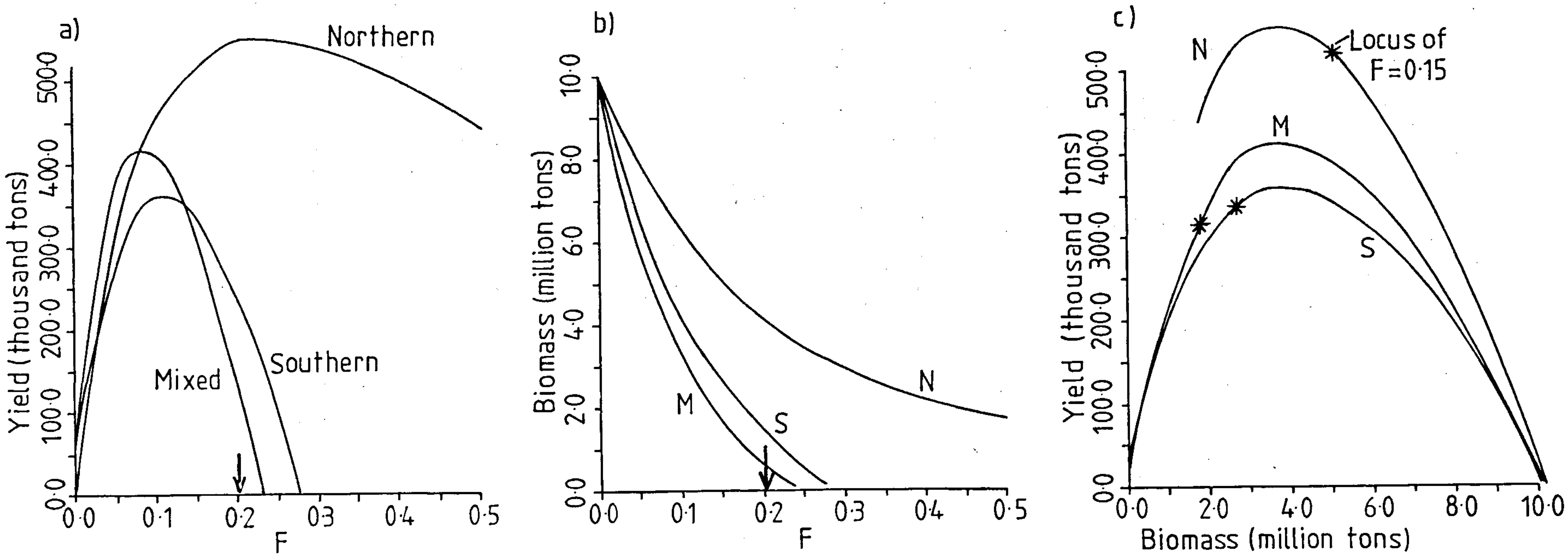

Figure 4 Total yield and spawning biomass for the current Mixed fishery (M) west of Britain, a Northern fishery (N) and a Southern fishery (S). The calculations were made assuming a critical biomass-per-recruit (CBPR) of 470 g. The arrow indicates the point of collapse in the Mixed fishery when CBPR is 670 g.

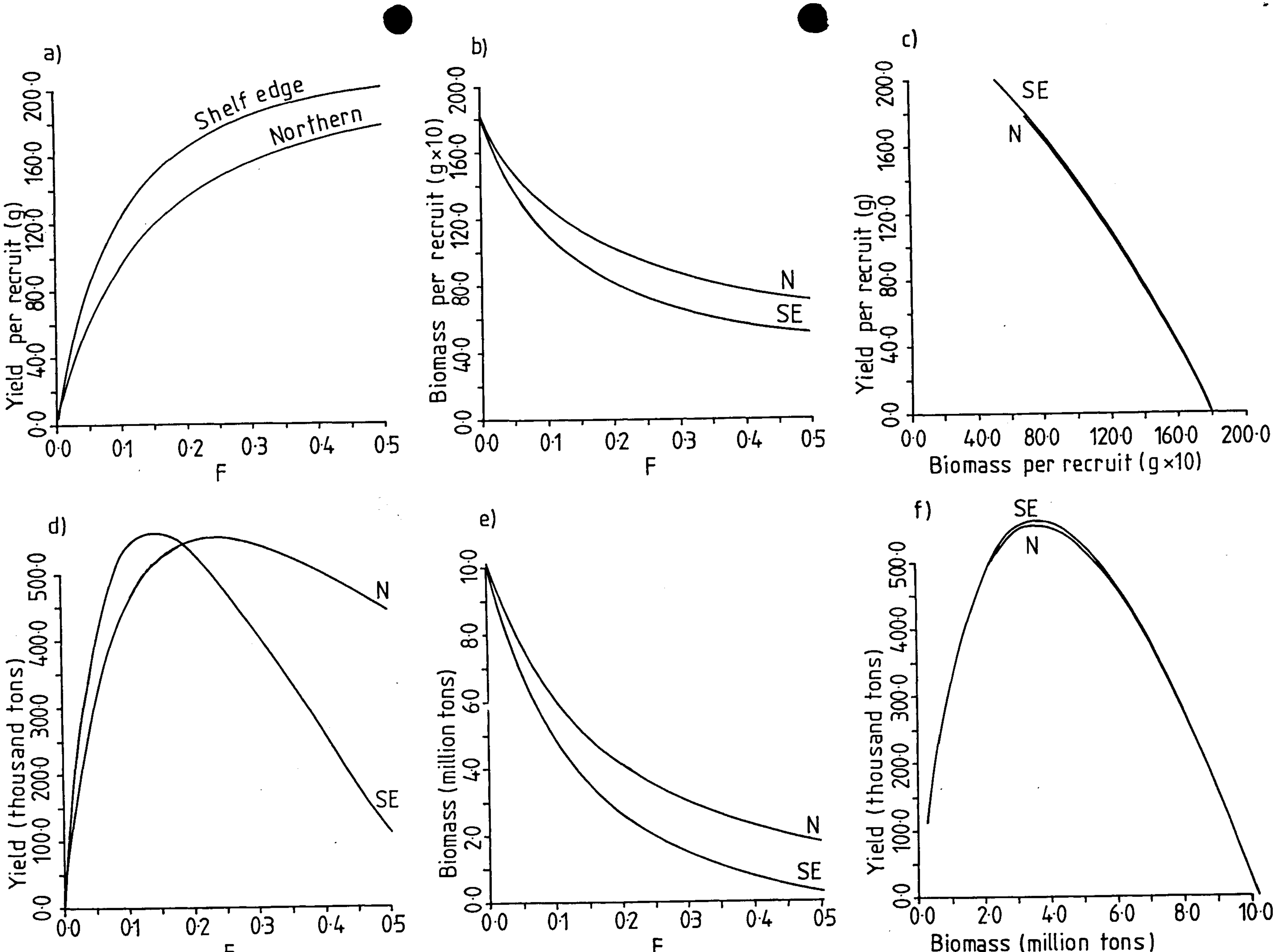

Figure 5 The yield-per-recruit, biomass-per-recruit and total biomass for a Northern fishery (N) and a southern Shelf Edge fishery (SE) between La Chapelle Bank and Porcupine Bank.