International Council for the Exploration of the Sea

CM 1980/H:28
Pelagic Fish Committee

MANAGEMENT OF THE NORTH SEA STOCK OF HERRING

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ABSTRACT

An assessment is made for the North Sea stock of herring, inc rporating explicitly plausible stock-recruitment relationships. The results are consistent with the recent collapse of the fishery. The implications for re-opening the fishery and future management are discussed.

INTRODUCTION

The North Sea stock of herring has collapsed because depletion of the spawning biomass since 1968 has been followed by a run of poor recruitments. In these circumstances it is essential that the management of any future fishery on this stock should take full account of the likely existence of a stock-recruitment relationship.

This is easily done by combining standard calculations of yield-per-recruit and biomass-per-recruit with a suitable relationship between recruitment and spawning stock biomass. There will in practice be substantial variability of recruitment around such an underlying relationship. However, such a procedure does permit one to select levels of fishing mortality and patterns of exploitation which, barring accidents (such as environmental changes, errors of interpretation etc.), should permit recovery of the stock to a level where substantial sustainable yields are again possible, whilst avoiding any further collapse of the stock.

BASIC DATA

We adopt the standard growth and maturity data used by previous working groups. Spawning stock biomass-per-recruit is calculated at 1 September, for consistency with the Working Group (WG) stock-recruitment data. As a consequence, fish are labelled by their age in years since birth, rather than number of winter rings. We have used WG weight-at-age data for stock weights at 1 September, and for weight in the catch in the following year. Note that full maturity of of 2-ringers, as assumed by the Working Group, is exactly equivalent (given the way the calculation is performed) to full maturity at age 3. Our assumptions are given in Table 1.

The resultant calculations for yield-per-recruit and spawning biomass-per-recruit (Note: recruitment taken at age 1) are illustrated in Figure 1 and summarised in Table 2. Curves (calculated by the sums of weights-at-age method) are given for three exploitation patterns corresponding to knife-edge selection at age 1, 2 and 3 respectively. Note that full exploitation at age 1 corresponds almost exactly to that obtained during the last few years of the fishery, assuming that the F of about 0.2 on 0-ringers was exerted almost entirely during the last few months of the year.

These curves for yield-per-recruit and biomass-per-recruit should not differ significantly from those previously calculated by the Working Group, although no such calculations have appeared in recent Working Group reports.

THE STOCK RECRUITMENT RELATIONSHIP

The relationship between stock and recruitment between 1952 and 1974 was considered by the Working Group in 1976 (Anon, 1978). Their data are reproduced in Figure 2, with recruitment reduced by 10% to allow for natural mortality up to age 1. For management purposes the essential feature of such a relationship is the decline of recruitment at low stock size, which may be expressed as the slope of a line through the origin. It would be unwise to assume that this slope is any greater than that of a line bounding the available data on the left, since there would be no data to support such an assumption. The line with slope 0.023 recruits / g is shown in Figure 2, and has been taken to represent the most optimistic assumption about recruitment at low stock size which can justifiably be made. Clearly recruitment falls systematically below this line at higher stock sizes, and this may be expressed by any of several functional forms for a stock-recruitment relationship. We use here that recently proposed by Shepherd (in preparation), namely

$$R = aB/\ 1 + (B/K)^{\beta} \qquad (1)$$

which is particularly convenient, since a variety of curves of different shapes can be generated by varying the <u>degree of compensation</u> (β). The curves are domed when $\beta > 1$, non-asymptotic when $\beta < 1$, and the Beverton-Holt form is obtained when $\beta = 1$ (see Figure 7). The other parameter, K, is referred to as the threshold biomass. When the biomass falls below this value, the curve tends to the straight line through the origin, the resilience conferred by the density-dependence of the relationship is lost, and the population is liable to collapse under exploitation. We have calculated curves for three values of β, namely

1.0, 1.2 and 1.4, using values a little greater than one because of the suggestion in the 1976 WG report that the relationship may be slightly domed. The value of a has been taken as 0.023 recruits/g, as suggested above, and the value of K then determined so as to ensure that the curves pass through a 'typical' point (recruitment = 7 E9 at a biomass of 1.2 M tonnes). The values of threshold biomass so obtained are given in Table 3.

Table 3. Stock-recruitment parameters (curves all pass through R = 7 E9, B = 1.2 M tonnes)

Curve	a (rec/g)	K (M tonnes)	β
A	0.023	0.41	1.0
B	0.023	0.49	1.2
C	0.023	0.56	1.4

The curves corresponding to these parameter values are given in Figure 2, and pass very satisfactorily through the available data. The curve labelled B, in particular, is virtually identical to that suggested in the 1976 WG report.

IMMEDIATE DEDUCTIONS

Two important deductions may be made directly, without further analysis.

(a) From biomass-per-recruit estimates

The steady-state biomass of an exploited population is given by the intersection of the stock-recruitment curve with a survival line (a straight line through the origin on Figure 2) whose slope is determined by the biomass-per-recruit for the level and pattern of exploitation. Thus if the biomass-per-recruit falls below the critical value of 1/a, which is the minimum consistent with the stock-recruitment curve (determined by its maximum slope, at the origin), the population must be expected to collapse. This critical value is 44 g/recruit in the present case, and occurs at a fishing mortality of about 0.9, when 1-year-old fish are subjected to full exploitation, according to the computation given in Table 2 and Figure 1. This is exactly in accordance with the collapse of the stock during the late 1960s, following the increase of fishing mortality on adults to 0.8 or more, with increasing exploitation of 1-group fish (reaching the full adult value after 1970). Thus we may have considerable confidence that the value selected for the parameter a is reasonable.

(b) From the stock-recruitment relationship

Secondly, the values of threshold biomass obtained lie between 0.4 and 0.6 M tonnes. When biomass is less than this value the stock is in serious danger of collapse and should not be exploited. Prudent management would not permit significant exploitation until the biomass was substantially greater than this, perhaps by a factor of two. This therefore suggests that no substantial fishery should be allowed unless and until the spawning biomass is greater than 0.8 M tonnes at least. This is exactly in agreement with previous recommendations of the Working Group, but would if anything suggest even greater caution.

TOTAL YIELD CURVES AND LONG-TERM MANAGEMENT

The immediate consequences discussed above indicate the circumstances and manner in which the stock should not be exploited. They do not however indicate immediately in what manner it may sensibly be exploited in the long term. To deduce this it is necessary to combine the yield-per-recruit and biomass-per-recruit calculations with the stock recruitment relationship to produce total yield curves. This is most easily done (Shepherd, in preparation) using the biomass-per-recruit (B/R) estimates given in Table 2. For each of these the equilibrium biomass may be calculated by rewriting equation (1) as

$$B = K\ (aB/R - 1)^{1/\beta}. \qquad (2)$$

The corresponding recruitment may be calculated as R = B/(B/R) and hence long term sustainable yield (Y) as Y = R(Y/R), using the appropriate yield-per-recruit (Y/R) value from Table 2.

The results of such calculations are given in Figures 3, 4 and 5, for each of the stock-recruitment curves A, B and C, and for first exploitation at age 1, 2 and 3, as before. In each case the collapse of biomass (and therefore sustainable yield) when $F \simeq 0.9$ with full exploitation of 1-year-old fish is clearly seen. The large biomasses estimated for low rates of exploitation should not be taken seriously, as they represent an extrapolation of current data on weight-at-age and maturity well outside their range of validity. The estimates of virgin biomass in particular are very sensitive to the choice of M (here taken as 0.1) and are not realistic.

It is clear that sustainable yields in excess of 0.6 M tonnes per year should be attainable, whichever stock-recruitment relationship is the most realistic, provided that fishing is suitably controlled. If full exploitation of 1-year-old fish were to be permitted, MSY would be reached with fishing mortality between 0.2 and 0.3 Sustainable yields which are greater by 100 000 tonnes or more may however be taken with much less risk of collapse if the age of first exploitation is deferred to 2 years. In this case the fishing mortality to take MSY is in the range 0.2 to 0.5, depending on the assumed stock-recruitment curve. There would of course be little loss of yield incurred by fishing at the lower end of this range, but a significant increase in mean age and spawning biomass. This would clearly be advantageous, especially bearing in mind that the stock obviously can collapse and may do so again. Further confirmation that fishing mortality in the range 0.2 to 0.5 (with first exploitation at age 2 or more) is a suitable regime by which to manage this stock may be drawn from the fact that it did sustain yields in excess of 0.6 M tonnes per year under these conditions for many years before 1967.

We therefore adopt a fishing mortality of 0.3 as a suitable target value for management, at the lower end of the range estimated for MSY. With full exploitation at age 2 the corresponding spawning stock biomass is estimated to be around 2.5 M tonnes or more. This estimate is already a little outside the range for which our data apply, and may be a little too high. It appears however that it would be sensible to aim for a spawning biomass of about 2 M tonnes in the long term, and this is satisfactorily in excess of the threshold biomass below which exploitation is dangerous.

We note that choosing F = 0.3 may not of course be quite optimal, but the information available suggests that it would be unlikely to precipitate a further collapse, which must be the first priority. The loss of yield incurred by failing to find the true MSY value is in any case probably less than 15%. We note finally that with full exploitation at age 2, a value of F of 0.3 corresponds very closely to a yield/biomass ratio of 0.3; we shall find this useful in what follows.

MANAGEMENT DURING RECOVERY

Formally, the optimal strategy to achieve recovery of a depleted stock is to refrain from any exploitation whatever until the stock has reached the desired target size (Clark, 1976). Such a strategy however ignores socio-economic factors of real importance and is in practice probably too extreme. Conversely, to permit immediate exploitation at the full target F once recovery seems to be underway may delay full recovery for many years. Detailed simulation of this aspect is required, but meanwhile it is sensible to explore a compromise strategy which restricts F (and therefore permits more rapid recovery) whilst biomass is small, but allows it to increase towards its target value as the biomass approaches its target value.

Specifically, we suggest that one should permit only a fraction of the full target fishing mortality ($\hat{F}$) during recovery, the fraction being the ratio of estimated spawning stock biomass (B) to the desired target biomass ($\hat{B}$); i.e. $F = \hat{F}B/\hat{B}$. Thus if biomass is 30% of the target biomass, only 30% of the target fishing mortality would be allowed. To illustrate the operation of this rule, we may work for simplicity with a target yield/biomass ratio instead of fishing mortality. We adopt a target biomass of 2 M tonnes and a yield/biomass ratio of 0.3 so that, using the rule described above, the implied fishing mortality is always less than that at which the stock is exposed to the risk of further collapse. Thus the allowable yield as a function of biomass is as shown in Figure 6. Note firstly that the biomass is that of the spawning stock at 1 September, not 1 January, and secondly that these allowable yields include catches from all fisheries, including by-catches in other fisheries.

The application of this reduced yield rule whilst the stock is depleted should enable the stock to recover reasonably quickly to a state where a substantial and sustainable catch may be taken, and permit moderate catches to be taken as soon as possible without unduly delaying the recovery. It is incidentally similar to the 'new management policy' used by the International Whaling Commission, but much less severe in operation.

It is clear from Figure 6 that even if one were to relax the prohibition on fishing at biomass levels less than 800 000 tonnes, all the allowable catch is taken up by by-catches in other fisheries until the biomass exceeds 400 000 tonnes. On the other hand, it would be possible to re-open the fishery at a worthwhile level - say 75 000 tonnes in the directed fishery - once the biomass has recovered to 800 000 tonnes. These results may be summarised as follows:

Spawning stock biomass (at 1 September)	Allowable catch in directed fishery
400 000 t	(zero)*
600 000 t	(25 000)* t
800 000 t	75 000 t
1 000 000 t	125 000 t

* Note: catches in parentheses are disallowed because the biomass is in the danger region.

CONCLUSIONS

Our analysis indicates that the North Sea herring is a remarkably potent and resilient stock, which collapsed only under the most extreme over-exploitation. Between 1967 and 1975 the yield/biomass ratio hovered in the region of 1.0 to 2.0, whereas the present analysis indicates that it should not exceed 0.5, and should preferably be nearer 0.3. Nevertheless it is likely that the fishery would have survived had there been less than full exploitation of 1-year-old fish.

There seem to be reasonable grounds to expect that a full recovery of this stock may therefore be possible, provided it is correctly managed. The main features of the necessary management are:

(a) continuation of the present ban on fishing until the spawning biomass exceeds 800 000 tonnes, since below this level the probability of further collapse is too great;

(b) in the long term, exploitation with a fishing mortality or yield/biomass ratio in the range 0.2 to 0.5, excluding 0 and 1-ringed fish. This should allow sustainable yields in excess of 600 000 tonnes to be taken eventually, once the spawning biomass has reached several million tonnes. Exploitation at F = 0.3, at the lower end of the range suggested, would allow a larger spawning biomass, with a greater range of ages in the stock, and would therefore be preferable;

(c) during the recovery period (i.e. while the spawning biomass is less than the 'target' value of 2 million tonnes) the allowable yield/biomass ratio should be reduced by the ratio of actual biomass to target biomass. This will permit faster, surer recovery, without prohibiting catches entirely, and will allow a progressive build-up to the full-scale fishery as and when the recovery takes place.

REFERENCES

Anon., 1978. Report of the Herring Assessment Working Group for the area south of 62°N, 1976.
Coop. Res. Rep., Cons. int. Explor. Mer, (78) 69 pp.

Clark, C. W., 1976.
"Mathematical Bioeconomics: The Optimal Management of Renewable Resources," Wiley-Interscience, New York and London, 352 pp

Shepherd, J. G., in preparation.
A versatile new stock-recruitment relationship for fisheries, and the construction of sustainable yield curves.

Table 1. Basic data

Age	Weight	%Mature
1	50	0
2	126	0
3	176	100
4	211	100
5	243	100
6	251	100
7	267	100
≥8	271	100

Notes: (1) M* taken as 0.1 throughout.

(2) Recruitment estimated at 1-year-old throughout (i.e, 0-group fish at 1 September).

(3) Working Group weight-at-age data used for stock at 1 September, and catch in subsequent year.

Table 2. Yield-per-recruit and Biomass-per-recruit

First exploitation at:-

Age=1			Age=2			Age=3		
F	YPR	BPR	F	YPR	BPR	F	YPR	BPR
.00	.0	2176.2	.00	.0	2176.2	.00	.0	2176.2
.02	35.8	1738.3	.02	35.6	1773.5	.02	34.1	1809.3
.04	59.3	1428.9	.04	59.8	1487.2	.04	57.8	1547.9
.06	75.2	1199.5	.06	76.9	1273.7	.06	75.0	1352.5
.08	86.3	1023.4	.08	89.5	1108.6	.08	87.9	1201.0
.10	94.0	884.4	.10	98.9	977.4	.10	97.9	1080.2
.12	99.5	772.3	.12	106.1	870.7	.12	105.8	981.7
.14	103.2	680.2	.14	111.6	782.4	.14	112.0	900.0
.16	105.8	603.5	.16	115.9	708.3	.16	117.1	831.2
.18	107.4	538.9	.18	119.2	645.1	.18	121.3	772.4
.20	108.4	483.7	.20	121.8	590.9	.20	124.7	721.7
.22	108.8	436.3	.22	123.8	543.7	.22	127.6	677.5
.24	108.8	395.2	.24	125.4	502.4	.24	129.9	638.7
.26	108.6	359.3	.26	126.6	466.0	.26	132.0	604.4
.28	108.1	327.8	.28	127.6	433.7	.28	133.7	573.8
.30	107.4	299.9	.30	128.3	404.8	.30	135.1	546.4
.32	106.6	275.1	.32	128.8	378.9	.32	136.3	521.7
.34	105.7	253.0	.34	129.1	355.5	.34	137.4	499.4
.36	104.7	233.2	.36	129.4	334.3	.36	138.3	479.2
.38	103.6	215.5	.38	129.5	315.1	.38	139.0	460.7
.40	102.6	199.4	.40	129.5	297.5	.40	139.7	443.8
.42	101.5	184.9	.42	129.5	281.4	.42	140.3	428.3
.44	100.3	171.7	.44	129.4	266.6	.44	140.7	413.9
.46	99.2	159.7	.46	129.3	253.0	.46	141.1	400.7
.48	98.1	148.7	.48	129.1	240.4	.48	141.5	388.5
.50	97.0	138.7	.50	128.9	228.7	.50	141.8	377.1
.52	95.8	129.6	.52	128.6	217.9	.52	142.0	366.5
.54	94.8	121.1	.54	128.4	207.8	.54	142.3	356.7
.56	93.7	113.4	.56	128.1	198.5	.56	142.4	347.4
.58	92.6	106.2	.58	127.8	189.7	.58	142.6	338.8
.60	91.6	99.6	.60	127.5	181.5	.60	142.7	330.7
.62	90.5	93.5	.62	127.2	173.8	.62	142.8	323.1

Table 2 continued

Age = 1			Age = 2			Age = 3		
F	YPR	BPR	F	YPR	BPR	F	YPR	BPR
.64	89.5	87.8	.64	126.9	166.6	.64	142.9	315.9
.66	88.5	82.6	.66	126.6	159.8	.66	142.9	309.2
.68	87.6	77.7	.68	126.3	153.4	.68	143.0	302.8
.70	86.6	73.2	.70	126.0	147.4	.70	143.0	296.8
.72	85.7	69.0	.72	125.6	141.7	.72	143.0	291.1
.74	84.8	65.0	.74	125.3	136.3	.74	143.1	285.7
.76	84.0	61.4	.76	125.0	131.2	.76	143.1	280.6
.78	83.1	57.9	.78	124.7	126.4	.78	143.0	275.8
.80	82.3	54.7	.80	124.4	121.8	.80	143.0	271.2
.82	81.5	51.7	.82	124.1	117.5	.82	143.0	266.8
.84	80.7	48.9	.84	123.8	113.4	.84	143.0	262.6
.86	79.9	46.3	.86	123.5	109.4	.86	143.0	258.6
.88	79.2	43.8	.88	123.2	105.7	.88	142.9	254.8
.90	78.4	41.5	.90	123.0	102.1	.90	142.9	251.2
.92	77.7	39.3	.92	122.7	98.7	.92	142.9	247.7
.94	77.0	37.3	.94	122.4	95.5	.94	142.8	244.4
.96	76.4	35.4	.96	122.1	92.4	.96	142.8	241.2
.98	75.7	33.5	.98	121.9	89.4	.98	142.7	238.2
1.00	75.1	31.8	1.00	121.6	86.6	1.00	142.7	235.3

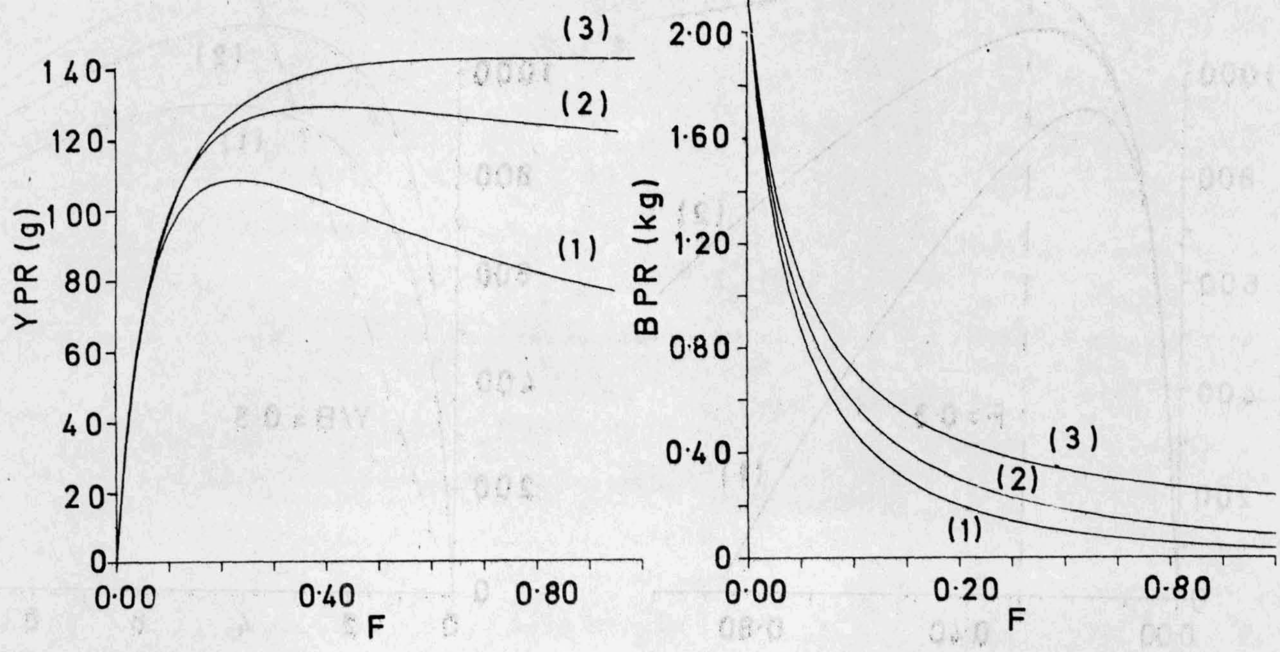

Figure 1 Yield-per-recruit and spawning biomass-per-recruit.

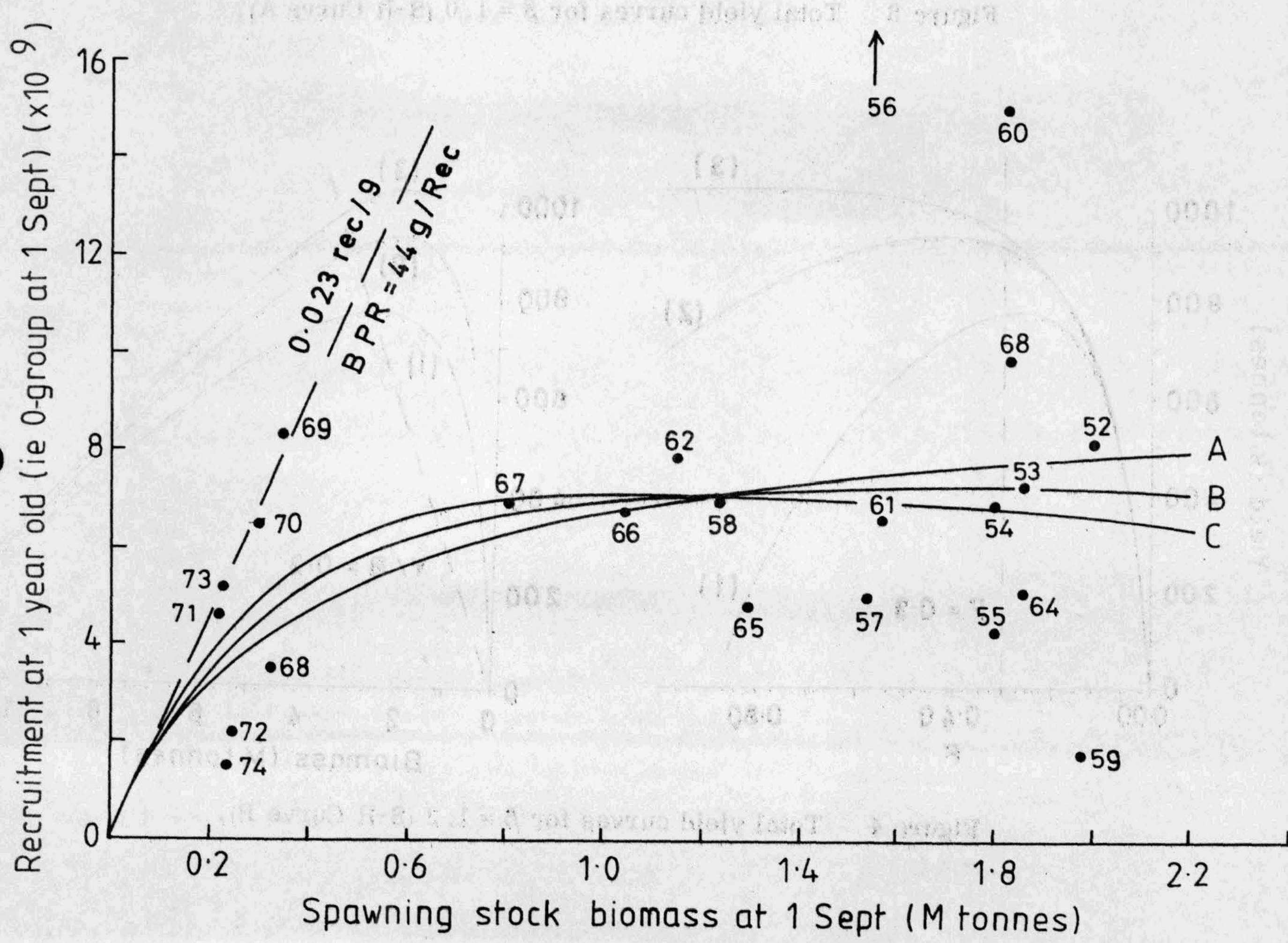

Figure 2 Stock-recruitment relationships.

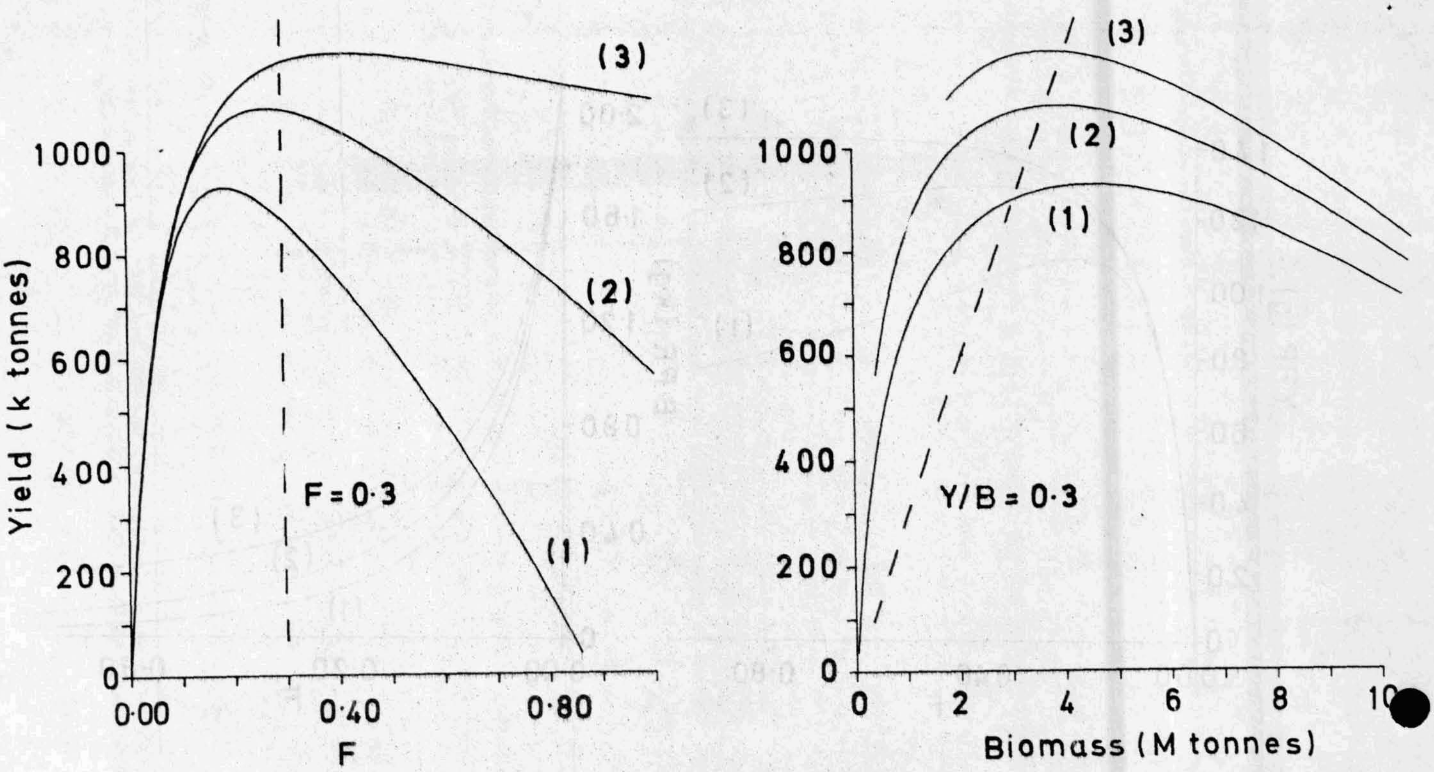

Figure 3 Total yield curves for $\beta = 1.0$ (S-R Curve A).

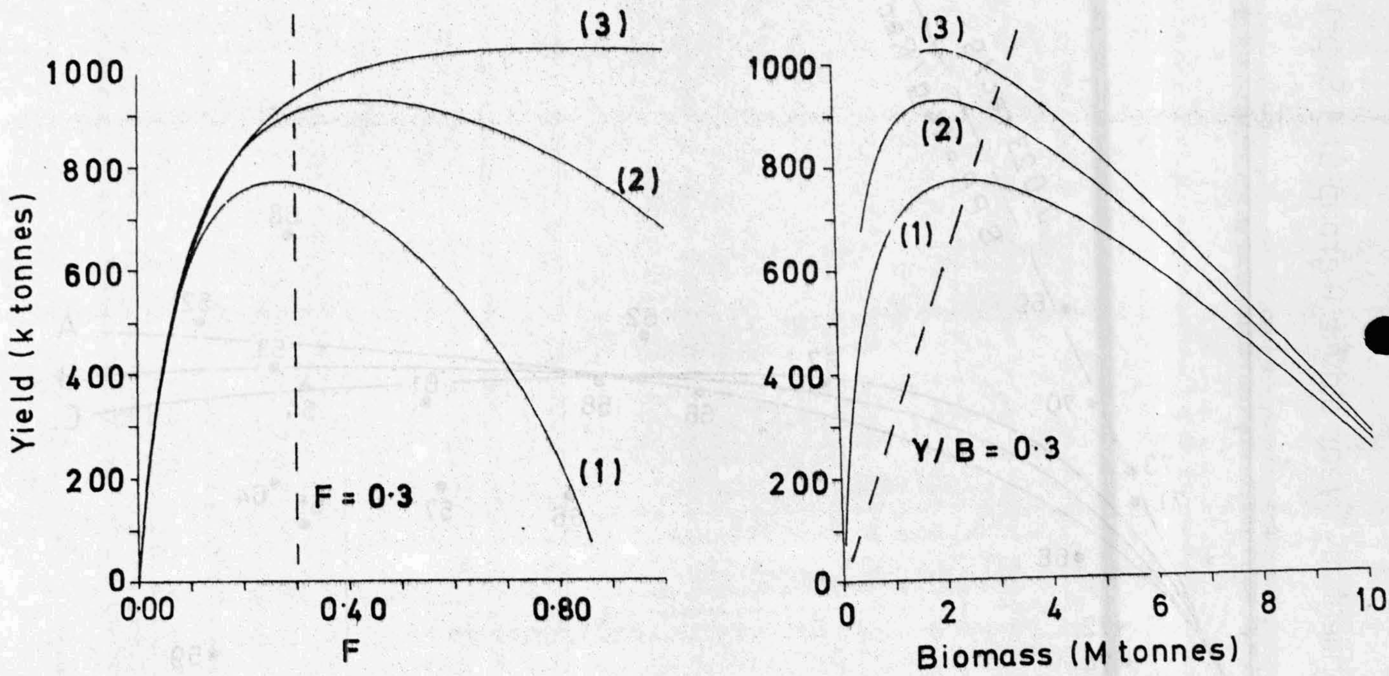

Figure 4 Total yield curves for $\beta = 1.2$ (S-R Curve B).

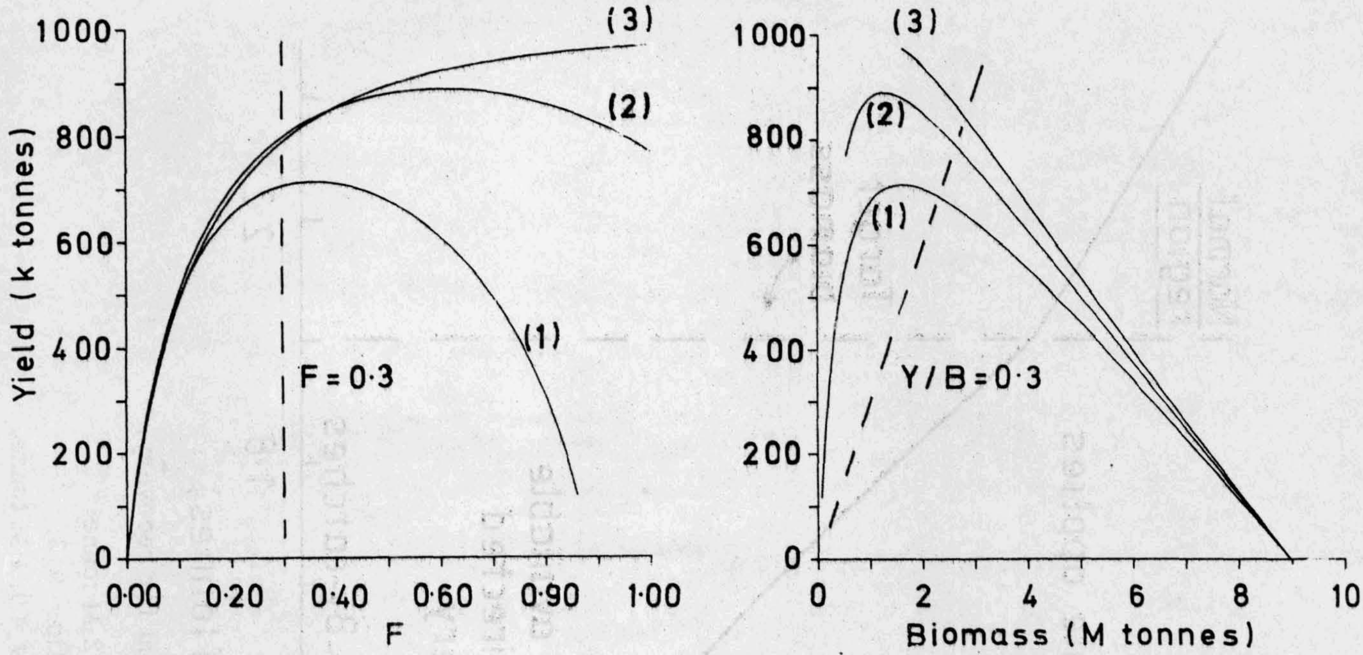

Figure 5 Total yield curves for $\beta = 1.4$ (S-R Curve C).

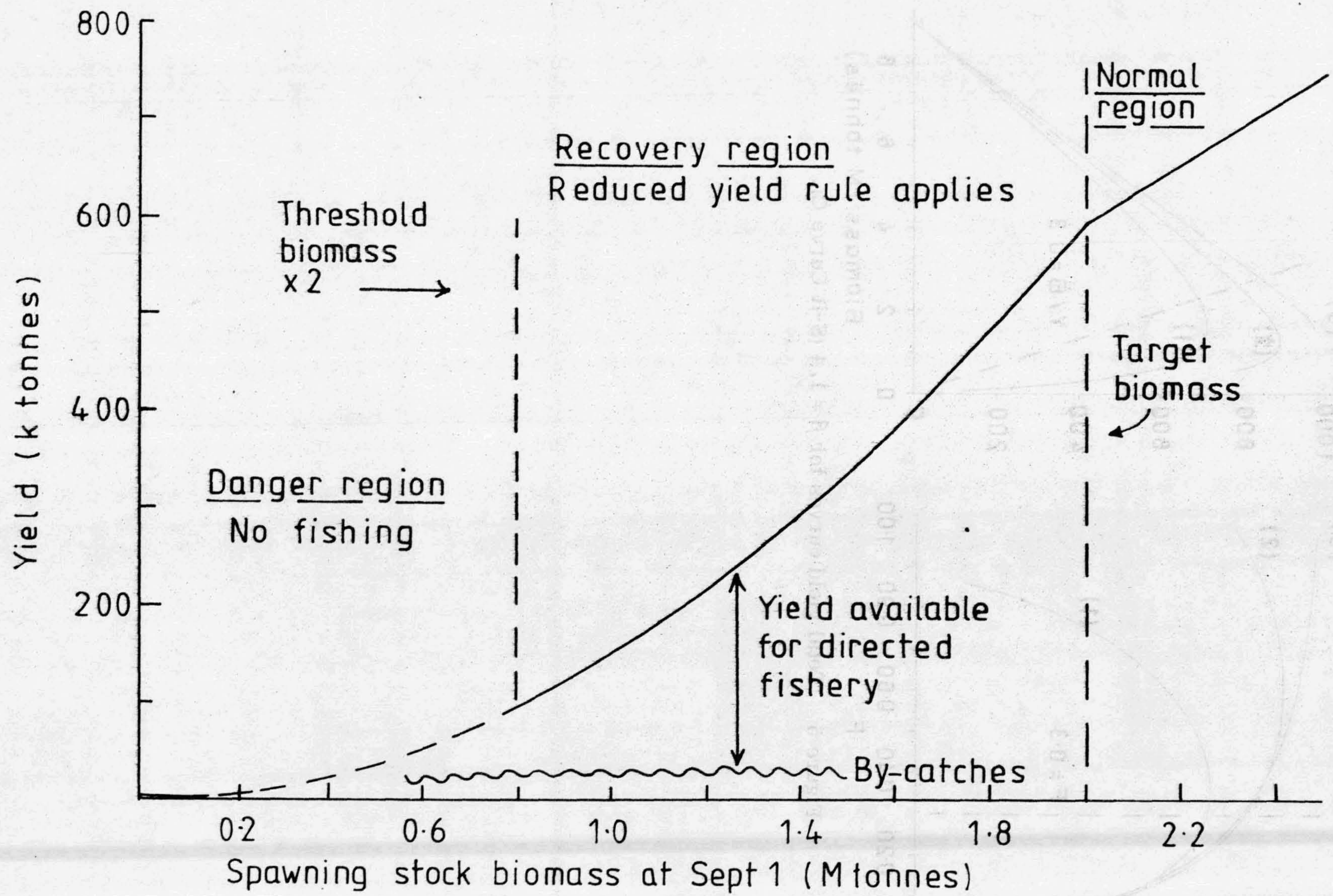

Figure 6 Allowable yield during management for recovery.

Based on:
1. Target Biomass = 2 M tonne
2. Yield/Biomass Ratio = 0.3
3. Threshold Biomass = 0.4 M tonne.

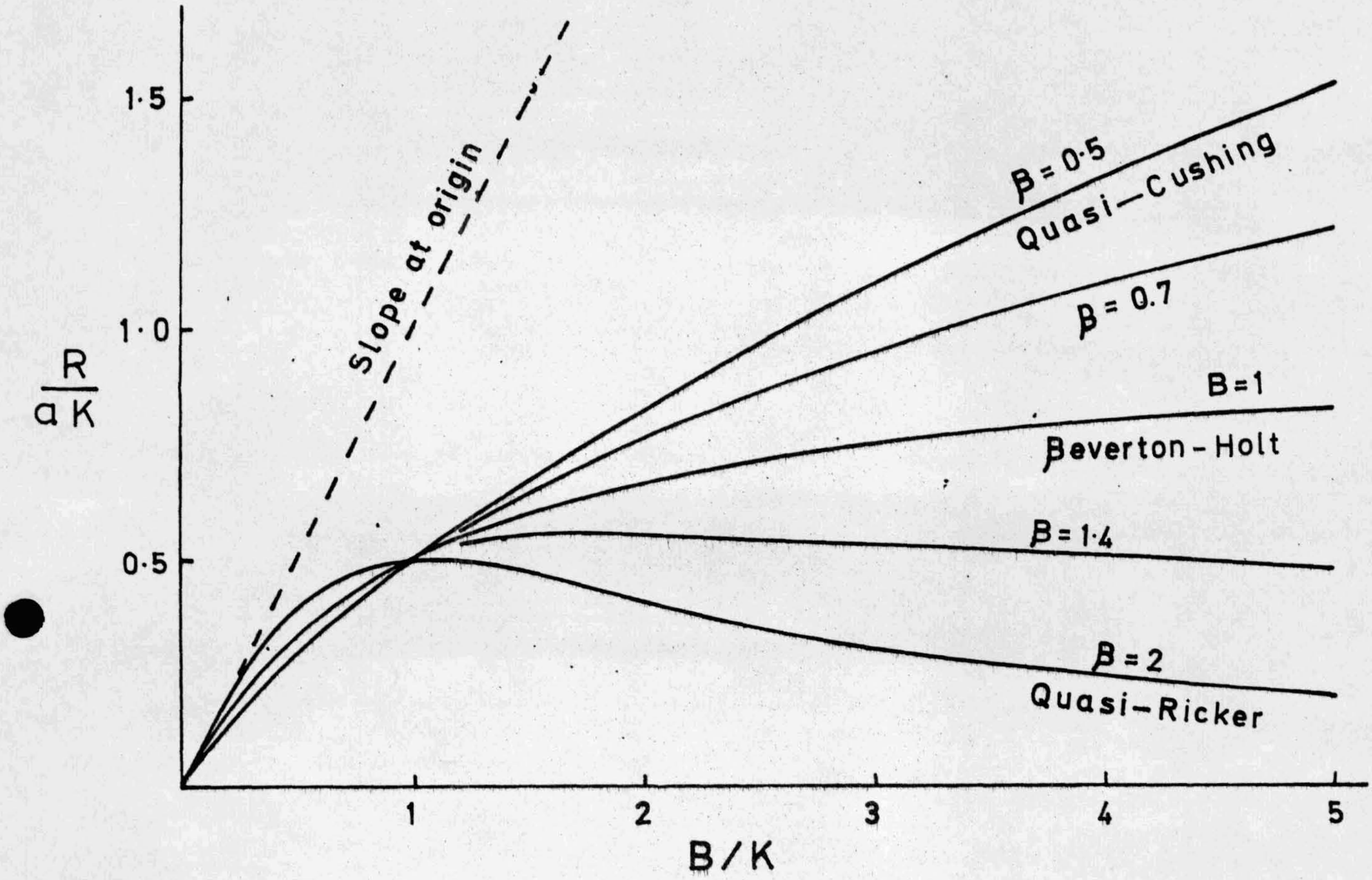

Figure 7 Form of stock-recruitment relationship.