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ASSESSMENTS OF THE ARCTO-NORWEGIAN COD STOCK

The yield and size of the mature stock versus fishing pattern, fishing effort, natural mortality and mesh size.

by

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INTRODUCTION

The Liaison Committee of ICES has expressed concern of the unsuitability of the present exploitation pattern of the Arcto-Norwegian cod (Anon. 1975a). The computations presented in that report show that for the present levels of fishing mortalities the optimum mean age at recruitment is considerably higher than the present age at recruitment. However, if the present fishing pattern is maintained, the present fishing mortalities are much higher than those which would give maximum yield.

The North-East Arctic Fisheries Working Group has concluded that the fishing mortalities at the time when the studies were carried out, were too high to give maximum yield with the effective mesh size in use (Anon. 1966, 1970 and 1973). Using a knife edge selection the Working Group on Arctic Fisheries (Anon. 1959) found that the total yield increases when the age at recruitment increases to 8 years, which was the highest age considered. However, the highest yield in Subarea I and Division IIb would be obtained by an age at first capture of 7 years for M = 0.20 and 6 years for M = 0.30 (Anon. 1959).

Because of the poor year classes 1965 - 1968 (see Anon. 1975b Table 12) and the high exploitation in the late 60's and in the beginning of the seventhies (see Anon. 1975b Table 7), the spawning stock is now at a very low level. Scientists working with the Arcto-Norwegian cod stock fear that because of this the probability of the production of poor year classes has increased. A reduced fishing mortality on the average year class 1969 and the very rich year class 1970 has therefore been recommended by the Liaison Committee of ICES. The first objective should be to rebuild the spawning stock to the 1970 - 1972 level (Anon. 1974a, 1975a), when one very rich and two average year classes were produced (see Anon. 1975b, Table 12). This would be achieved by 1978 if the total catch quota is maintained at 800 000 in 1976 and 1977 (Anon. 1975a).

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Garrod and Jones (1973) concluded that the stock and recruitment relationship for the Arcto-Norwegian cod is of the Ricker-type. The optimum spawning stock corresponds according to their finding to the stock size which occured in the early 1950's. Assuming a Ricker stock and recruitment relationship, M = 0.30 and the selection pattern which was prevailing in the early 1970's a constant F = 0.26 on the fully recruited age groups would generate an average maximum annual yield of 800 000 tons. A change in the selection pattern might give even greater yield (Garrod and Jones 1973). Some further studies have shown that the maximum exploitation rate which the stock can sustain is strongly dependent on the fishing mortality on the immatures (Ulltang 1973).

The present paper gives some further studies of the relation between the yield and the size of the mature stock versus fishing effort, natural mortality and fishing pattern (the relative distribution of the fishing mortalities on the different age groups). This paper also presents studies on the relationship between the mesh size in the codend of the trawl versus the long term yield and the mature stock size, while the effort is kept constant. Some studies on a method which has been used to estimate the natural mortality rate have also been undertaken.

MATERIAL AND METHODS

The analysis is based on the total number of fishes landed in each age group for each year in the period 1950 - 1974, the Soviet landings of Murman cod excluded. This is the same set of data which was used by the North-East Arctic Fisheries Working Group at its meeting in March 1975 (Anon. 1975b) to run the Virtual population analysis (VPA). This method which is described by Anon. [Gulland] (1965) gives estimates of the total F' values for the different age groups for each year in a period. The F's for the last season and for the oldest age group in all previous seasons have to be given together with a figure for the natural mortality.

The F's generated by each national fishing fleet are estimated by splitting the total F's in relation to the number of fish landed in each age group by the respective nations.

The total and the national fishing patterns used in this study are the avera for the period 1970 - 1974. The first reason for including 1974 in this period is to base the assessments on recent years. The second reason is that the period 1970 - 1974 includes years with a relative large mature stock, and years with a relative small mature stock and a great juvenile stock. When taking the averages for these 5 years, it is therefore partly corrected for changes in the fishing pattern, caused by the change in the age composition of the stock.

The following assessments are studied in relation to the fishing patterns generated by USSR, Norway, "Other nations" and the total international fleet (Fig.1, Table 1). Large differences are observed between the Norwegian fishing pattern and those of the "Other nations" and USSR. This is mainly caused by the Norwegian fishing with gill net, long line and handline on mature fishes. An extreme is the fishing pattern generated by USSR in 1973 when their fishery to a great extent concentrated on 3 year old fish. The age composition of the exploited stock this year was rather unusual because it was dominated by the very rich 1970 year class (see Anon. 1975b Table 10).

The VPA gives poor estimates of F for the oldest age groups. This is caused by a low abundance of these age groups in the samples, and because the fishing mortality on the oldest age groups, i.e. 15 years, is an assumed value in the VPA. The fishing mortalities for the age groups 13 and older have therefore been set equal to the F for age group 12.

The equations used in the constant recruitment model are:

$$C_i(N) = \frac{F_i}{F_i+M} \cdot N_i \cdot (1 - e^{-(F_i+M)}) \qquad i = 3 \ldots\ldots\ldots 15$$

$$N_{i+1} = N_i \cdot e^{-(F_i+M)} \qquad i = 3 \ldots\ldots\ldots 15$$

$$\overline{N}_{16+} = \frac{N_{16}}{F_{16+}+M}$$

$$C_{16+}(N) = F_{16+} \cdot \overline{N}_{16+}$$

$$C(W) = \sum_{i=3}^{16+} C_i(N) \cdot W_i$$

$$B(N_{j+}) = \sum_{i=j}^{15} N_i \cdot W_i + \overline{N}_{16+} \cdot \frac{F_{16+}+M}{1 - e^{-(F_{16+}+M)}} \cdot W_{16+}$$

Where

i = the age group.

F_i = instantaneous fishing mortality rate, assumed to be constant through the year.

M = instantaneous natural mortality rate, assumed to be constant for all recruited age groups.

N_i = number of fish in the age group i at the beginning of the year.

$\overline{N}_{16+}$ = the mean number of fishes in the year which is 16 years old and older.

$C_i(N)$ = the annual catch in numbers.

$C_i(W)$ = total catch in weight through the year.

W_i = mean weight at age i.

$B(N_{j+})$ = the biomass of fish j years old and older at the beginning of the year. The size of the mature stock is estimated for j = 7, 8 or 9 years.

For reasons discussed below (p. 6) these assessments have been done both for $M = 0.20$ and 0.30. Assuming $M = 0.20$ the average recruitment at 3 year of age is estimated by VPA to have been 724 million fish for the period 1950 - 1973. The same catch data but setting $M = 0.30$ gives an estimate of 1 044 million as the average recruitment for the same period. These figures are used as the constant recruitment N_3 in the analysis, and the results of the assessments are estimates of the long term averages. Comparing the assessments for $M = 0.20$ and $M = 0.30$ the difference in the estimated recruitment should be kept in mind.

The age/weight data is the same as used by Anon. (1975b) except for fish 16 years old and older.

Age group i	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Weight, W_i (kg)	0.65	1.00	1.55	2.35	3.45	4.70	6.17	7.70	9.25	10.85	12.50	13.90	15.00	16.00

In order to simplify the analysis the age/weight data is assumed to be constant through the year, and density dependent growth (Sætersdal and Cadima 1960) and density dependent recruitment have not been taken into account.

According to the mesh regulation in the North-East Arctic the mesh size for cod ends made of polyamide should be 120 mm. This is assumed to be the present effective mesh size in use. Polyamide has for cod a selection factor of 3.96 and a selection range (25 -75 %) of 90 mm (Anon. 1971a). Based on the assumption that the selection curves have the sigmoid form of the normal ogive (Pope 1966), the portion retained within each 5 cm length groups for each age group by the respective mesh sizes have been estimated. For doing this the total length compositions of the trawl landings in 1972 from Subarea I, Division IIa and IIb were split in an age/length composition. Let the subscript i denote the age group, and the subscript m the mesh size in the codend $X_{i,m}$ is the number retained by the different mesh sizes immediately after the increase from 120 mm, and $F_{i,\ o.g.}$ is the fishing mortality generated by other gears than trawl. The fishing mortality $F_{i,m}$ in the total fishery for different mesh sizes when the effort for each gear is kept constant, is estimated by

$$F_{i,m} = (F_{i,120\ mm} - F_{i,\ o.g.}) \frac{x_{i,m}}{x_{i,120\ mm}} + F_{i,o.g.}$$

$F_{i,120\ mm}$ is found by VPA and $F_{i,o.g.}$ is found by splitting $F_{i,120\ mm}$ in the portion to the numbers caught by different gears.

Linear regression between fishing effort and fishing mortality derived from VPA has previously been used to estimate the natural mortality (M). The M corresponding to that set of F's which gives a linear regression through the origo is assumed to be the best estimate of the natural mortality (Schumacher 1971, Anon. 1974e).

The input data for the VPA were the same as described on page 2. The F's for 1974 were set equal to those given for the total fishery and for $M = 0.30$ in Table 1. The fishing mortalities for 12 year olds and older in 1974 were put equal. Fishing mortality on the oldest age group in the analysis (15 years) were set equal to F_{15} for 1974 for all years in the period 1950 - 1973. These assumptions were the same for all runs of the VPA $M = 0.00$, 0.10, 0.20, 0.30, 0.50, and 1.00.

The dependent variable used in the regression analysis were the estimated mean fishing mortalities on 4, 5 and 6 years old fish for each year in the period 1950 - 1970. By using the fishing mortalities on 4 to 6 year olds and excluding the years 1971 - 1974 from the regression analysis, errors in the F values used as input data in the VPA were largely eliminated because of the converging properties of the VPA (Agger et al. 1971, Pope 1972). This was also seen by running the VPA again for each M value but using the mean F values for 1968 - 1972 given in the first set of VPA runs for the same M, as the F's for 1974. The results were only insignificantly changed.

RESULTS

Natural mortality

Fig. 2 A-B show the intercept (a_0) and the correlation coefficient (r) as functions of M, for two sets of linear regressions between fishing effort and fishing mortality rate. The origo is within a 95% confidence interval for all estimates of a_0. If the best estimate of M is given by the regression line through the origo, Fig. 2 A indicates M near 0.00, while Fig. 2 B indicates M near 1.00. Neither does the regression coefficient give any indications of M.

a_0 and r are not independent of M since both a_0 and r depend on the estimated fishing mortalities on the 4 - 6 year old fish, and these are highly depend on the corresponding M used in the VPA. This might be the main reason why this method failed to indicate the correct M in the present analysis. In addition a contributing factor might be poor effort measures. Independence between the F and the corresponding M seems to be critical if this method is to be applied.

Because of the uncertainty about the value of M and for comparison the following assessments are made both for M equal 0.20 and 0.30, which is assumed to be the limits of M.

Assessments

The total yield as a function of the yield of 3 - 7 year old fish is studied in Fig.3 for the respective fishing patterns (Fig. 1, Table 1). This figure show that the maximum yield (for M = 0.20 and 0.30) increases the more the fishing is concentrated on the older age groups. The Norwegian fishing pattern generate for both values of M the highest yield irrespective of the yield of 3 - 7 year old fish, while the lowest total yield would be obtained by the USSR fishing patterns (Fig. 3, Table 2, 3).

Table 4 and 5 show the relationship between the mesh size versus the long term yield, while the total fishing effort is kept constant at the 1970 - 1974 level. These tables show for M = 0.20 that the long term yield increases steadily from about 800 000 tons to about 1 100 000 tons when the mesh size is increased from 120 mm to 230 mm. For M = 0.30 the long term yield increases from about 820 000 tons to about 910 000 tons with mesh sizes up to about 190 mm.

The F's in Table 6 which are generated by an increase to 230 mm mesh size (M = 0.20) or to 190 mm (M = 0.30) represent a fishing pattern which is more concentrated on the older age groups than any of those given in Table 1. If the present effort is maintained, but the mesh size is increased to 160 mm (M = 0.20) or 150 mm (M = 0.30) the long term yield does increase above the maximum yield MY which can be achieved by the Norwegian fishing pattern (Table 2, 3, 4, 5).

Table 4 and 5 show that the more the fishing is concentrated on the older fish the more is the MY level dependent on the natural mortality.. This is also shown in Table 2 and 3. Following these tables, the Norwegian fishing pattern gives a MY for M = 0.20 which is 159 000 tons higher than MY for M = 0.30, while the difference is only 17 000 tons for the USSR fishing pattern in 1973.

The size of the mature stock has also been studied for the different fishing patterns given in Table 1. A knife edge maturation has been assumed to take place at an age of 7, 8 or 9 years respectively. At the MY level the Norwegian fishing pattern gives the highest mature stock for the lowest maturation age, but the smallest spawning stock for the highest maturation age (Table 2, 3). Comparing Table 2 versus Table 3, and Table 4 versus Table 5 it appears that the size of the mature stock at the MY level is more dependent on the natural mortality than on the different fishing patterns studied in this paper. However, it is clear from Fig. 4 that the mature stock is largely dependent on the fishing pattern for a fixed total yield Increasing the mesh size in the cod end, but otherwise maintaining the average total fishing pattern in 1970 - 1974, and keeping the effort constant, allows the mature stock to increase steadily (Table 4, 5).

DISCUSSION

A natural mortality rate of 0.20 has been used in the most recent assessments for 16 out of 18 cod stocks in the North Atlantic (Table 7). According to Anon. (1974b) the natural mortality rate must be higher than 0.20 for the cod stock in the Baltic, and a range of figures from 0.20 to 0.40 has been used in the assessments. The Working Group on Arctic Fisheries concluded in their report (Anon. 1959) that the natural mortality was near to M = 0.20. A study by Anon. [Gulland] (1965) indicated that M was between 0.20 and 0.40, and Ponomarenko (1964) estimated M to be about 0.15. The North-East Arctic Fisheries Working Group adopted in 1965 M = 0.30 in their assessments (Anon. 1966) and this has since then been the working figure. Our own investigations (Fig. 2) give no indication of M. Regarding the uncertainty of M it is in our opinion no reason to use a higher natural mortality for assessment purposes on Arcto-Norwegian cod than for the great majority of the cod stocks in the North Atlantic (Table 7). However, in order to compare the consequences for the assessments when M = 0.20 is used instead of 0.30 the calculations have been made for both figures.

The mature stock size depends on the mean maturation age applied to the age composition of the stock (Table 2, 3). A maturation ogive estimated by Garrod (1967) on the basis of spawning class compositions in the period 1941 - 1953 (Rollefsen 1954) indicated a mean maturation age of 10 1/4 years. A mean maturation age of 9 years was used by Hylen and Dragesund (1973), while Garrod and Jones (1973) considered half of the 7 year old and all older fish to be mature. A knife edge maturation of 8 years has been used by the North-East Arctic Working Group (Anon. 1974c), and this seems to be in conformity with more recent Norwegian data from the spawning area (unpublished). 8 years is therefore considered as the best estimate of the mean maturation age.

NEAFC was recommended by ICES to accept a management strategy which would lead to rebuilding the spawning stock in 1978 to the 1970 - 1972 level (see page 1). From VPA the average mature stock size, B (N_{8+}), has been estimated to 600 000 tons for M = 0.20 or 680 000 tons for M = 0.30 in this period. These figures are about 60 % higher than the estimates of the long term size of the mature stock with the present total exploitation rate (Table 2, 3).

Optimalization of the fishery might be done in two ways. The first alternative is to change the fishing effort. If the total average fishing pattern for the period 1970 - 1974 is maintained and a 120 mm mesh size is used, a decrease in the fishing mortality by 64 % would be necessary to achieve the MY level for M = 0.20 (Table 4) or 25 % for M = 0.30 (Table 5). The second alternative to move the fishery towards an optimal level is to change the mean age at recruitment by regulating the mesh size in the codend. Table 4 indicates for M = 0.20 that an increase in yield of 300 000 tons can be achieved by increasing the mesh size to at least 230 mm. For M = 0.30 a mesh size of 190 mm would give a 90 000 tons higher yield than the present (Table 5). A third alternative is to regulate both the effort and the mesh size. Table 4 and 5 show that if the effort is kept constant and the mesh size is increased above 150 mm (M = 0.20) or 125 mm (M = 0.30), the long term yield will be higher than the yield which can be achieved by changing the effort while the mesh size is kept at 120 mm. The higher the mesh size is, the less is the additional gain which might be achieved by regulating the effort.

A first step towards optimalization of the fishery could be to increase the mean age at recruitment by increasing the mesh size in the trawl fishery. Curve 6 in Fig. 4 A and B shows the relation between the total yield and the size of the mature stock when the mesh size is increased from 120 mm to 230 mm while the effort is kept constant at the 1970 - 1974 level (data from Table 4, 5). It is obvious that both the long term yield and the mature stock do increase by concentrating the fishing more on the mature fish. In these assessments it is assumed that increased mesh sizes do not cause any redistribution of the fishing fleet which could change the fishing mortalities more than the mesh size increase implies.

A mesh size of 230 mm (M = 0.20), or 190 mm (M = 0.30) would give a mature stock which is more than twice of the recommended mature stock size (Table 4, 5). It might be difficult in the near future to get an international agreement on increasing the mesh size to 190 mm or above. The first aim should therefore be to increase the mesh size sufficiently to allow the long term average mature stock to be rebuilt to the minimum size of 680 000 tons (M = 0.20), or 600 000 tons (M = 0.30). This can be achieved by maintaining the level of effort in 1970 - 1974 and increasing the mesh size to 150 mm (Table 4 and 5). The long term yield would under these conditions be increased by 20 % (M = 0.20), or 8 % (M = 0.30). Keeping the 120 mm mesh size, the assessments indicate that a 20 % decrease in effort is necessary to rebuild the mature stock to the recommended minimum size. The yield would then be increased by 6 and 1 % respectively.

The strength of the year classes has varied within the range 1 - 20, and several successive poor year classes have been produced in the past (Hylen and Dragesund 1973). Similar variations would be expected in the future. It is therefore necessary to build up a higher average spawning stock than the recommend size so that the spawning stock is not reduced too far below the recommended size in years with poor recruitment.

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Table 1. The mean instantaneous fishing mortalities in 1970 to 1974 of North-East Arctic Cod for the different countries, and the fishing mortalities generated by the USSR fishing in 1973. The total F's are estimated from VPA-analysis and split for each age group between the different countries in proportion to the number caught.

Age group	Instantaneous fishing mortalities (F)									
	M = 0.20					M = 0.30				
	1970 - 1974				1973	1970 - 1974				1973
	USSR	Norway	Other countries	Total	USSR	USSR	Norway	Other countries	Total	USSR
3	.07	+	.03	.10	.15	.06	.01	.01	.08	.11
4	.11	.04	.06	.21	.12	.08	.03	.06	.17	.09
5	.18	.12	.09	.39	.22	.15	.10	.07	.32	.18
6	.18	.19	.12	.49	.30	.16	.16	.10	.42	.26
7	.21	.27	.11	.59	.28	.18	.24	.10	.52	.24
8	.22	.53	.10	.85	.05	.20	.47	.09	.76	.05
9	.24	.68	.09	1.01	.03	.22	.60	.08	.90	.03
10	.23	.61	.11	.95	.06	.20	.53	.11	.84	.05
11	.14	.56	.10	.80	.11	.12	.49	.08	.69	.09
12	.12	.38	.09	.59	.17	.10	.33	.08	.51	.15

Table 2. Comparing the catches and different measures of mature stock by different fishing patterns at the respective effort levels which give maximum yield in tons. The mature stock is measured by N_{8+}, number of fish 8 years and older; $B(N_{j+})$, biomass of fish j years and older. N_{8+} and $B(N_{j+})$ refer to the beginning of the season.

M = 0.20									
$N_3 = 724 \times 10^6$									
Fishing pattern	Present situation		At mazimum yield level						
	$\sum_{i=3}^{7} F_i$	$\sum_{i=8}^{12} F_i$	$\sum_{i=3}^{7} F_i$	$\sum_{i=8}^{12} F_i$	catch in (10^3 tons)	N_{8+} (Mill.)	$B(N_{7+})$ (10^3 tons)	$B(N_{8+})$ (10^3 tons)	$B(N_{9+})$ (10^3 tons)
1970 - 1974									
USSR	.75	.95	.90	1.14	837	310	2900	2300	1800
Norway	.62	2.76	.45	2.00	1039	370	3300	2400	1600
Other countries	.41	.49	.87	1.04	854	330	3100	2500	2000
Total	1.78	4.20	.64	1.51	943	350	3200	2500	1800
USSR 1973	1.07	.42	1.19	.47	752	320	3100	2600	2300

Table 3. Text, see Table 2.

$M = 0.30$			$N_3 = 1044 \times 10^6$						
Fishing pattern	Present situation		At maximum yield level						
	$\sum_{i=3}^{7} F_i$	$\sum_{i=8}^{12} F_i$	$\sum_{i=3}^{7} F_i$	$\sum_{i=8}^{12} F_i$	catch in (10^3 tons)	N_{8+} (mill.)	$B(N_{7+})$ (10^3 tons)	$B(N_{8+})$ (10^3 tons)	$B(N_{9+})$ (10^3 tons)
1970 - 1974									
USSR	.63	.84	1.48	1.97	782	100	990	620	370
Norway	.54	2.42	.89	4.00	880	140	1420	760	310
Other countries	.34	.44	1.56	2.02	793	100	960	600	370
Total	1.51	3.70	1.13	2.77	830	130	1250	730	380
USSR 1973	.88	.37	2.19	.92	735	70	720	500	380

Table 4. For M = 0.20. The yield and the mature stock size for different mesh sizes when the effort is kept at the 1970 - 1974 level. The maximum yield, the mature stock at the MY-level and the necessary change in the effort needed to achieve the MY-level.

Mesh size (mm)	Yield with present effort (10^3 tons)	Maximum yield (10^3 tons)	Mature Stock with present effort (10^3 tons)	Mature Stock at maximum yield (10^3 tons)	% Change in effort needed to achieve maximum yield
120	799	943	370	2500	- 64
130	857	973	461	2500	- 62
140	915	1004	569	2400	- 59
150	957	1030	674	2400	- 57
160	988	1048	783	2400	- 54
170	1020	1067	905	2400	- 51
180	1040	1080	1024	2300	- 47
190	1056	1090	1144	2300	- 43
200	1065	1095	1255	2300	- 41
230	1094	1112	1557	2300	- 33

Table 5. For M = 0.30. The yield and the mature stock size for different mesh sizes when the effort is kept at the 1970 - 1974 level. The maximum yield, the mature stock at the MY-level and the necessary change in the effort needed to achieve the MY-level.

Mesh size (mm)	Yield with present effort (10^3 tons)	Maximum yield (10^3 tons)	Mature Stock with present effort (10^3 tons)	Mature Stock at maximum yield (10^3 tons)	% Change in effort needed to achieve maximum yield
120	822	830	423	730	- 25
130	849	852	506	680	- 15
140	870	870	594	650	- 5
150	887	888	697	630	+ 5
160	899	901	794	600	+ 20
170	905	910	899	590	+ 35
180	909	917	998	580	+ 50
190	910	921	1092	580	+ 65
200	908	922	1192	610	+ 75
230	904	928	1422	630	+110

Table 6. The fishing mortalities for two mesh sizes when the effort is at the 1970 - 1974 level.

	M = 0.20	M = 0.30
Mesh size	230 mm	190 mm
Age group	Fishing mortalities	Fishing mortalities
3	0.00	0.00
4	0.00	0.01
5	0.04	0.04
6	0.13	0.15
7	0.29	0.38
8	0.67	0.72
9	0.86	0.89
10	0.88	0.84
11	0.79	0.69
12	0.59	0.51

Table 7. Instantaneous natural mortality rates used in recent assessments of the cod stocks in the North Atlantic.

Area stock	M	References
ICES		
I, IIa, IIb	0.30	Anon 1975b
Va	0.20	Anon 1971b, Schopka and Jónsson 1973
XIV	0.20	Anon 1971b
Vb (Plateau)	0.20	Anon 1975c
IVa	0.20	Anon 1974d
IVb, c	0.20	Anon 1974d
VIa	0.20	Anon 1975d
IIId	0.20 - 0.40	Anon 1974b
ICNAF		
1A - 1F	0.20	Horsted 1975
2GH	0.20	Wells 1973a
2J - 3K - L	0.20	Pinhorn and Wells 1972
3M	0.20	Wells 1973b
3NO	0.20	Pinhorn and Wells 1973
3Ps	0.20	Pinhorn 1972
4T - 4Vn	0.20	Halliday 1974a
4Vs - W	0.20	Halliday 1972
4X	0.20	Halliday 1974b
5Y	0.20	Penttila and Gifford 1975
5Z	0.20	Penttila and Gifford 1975

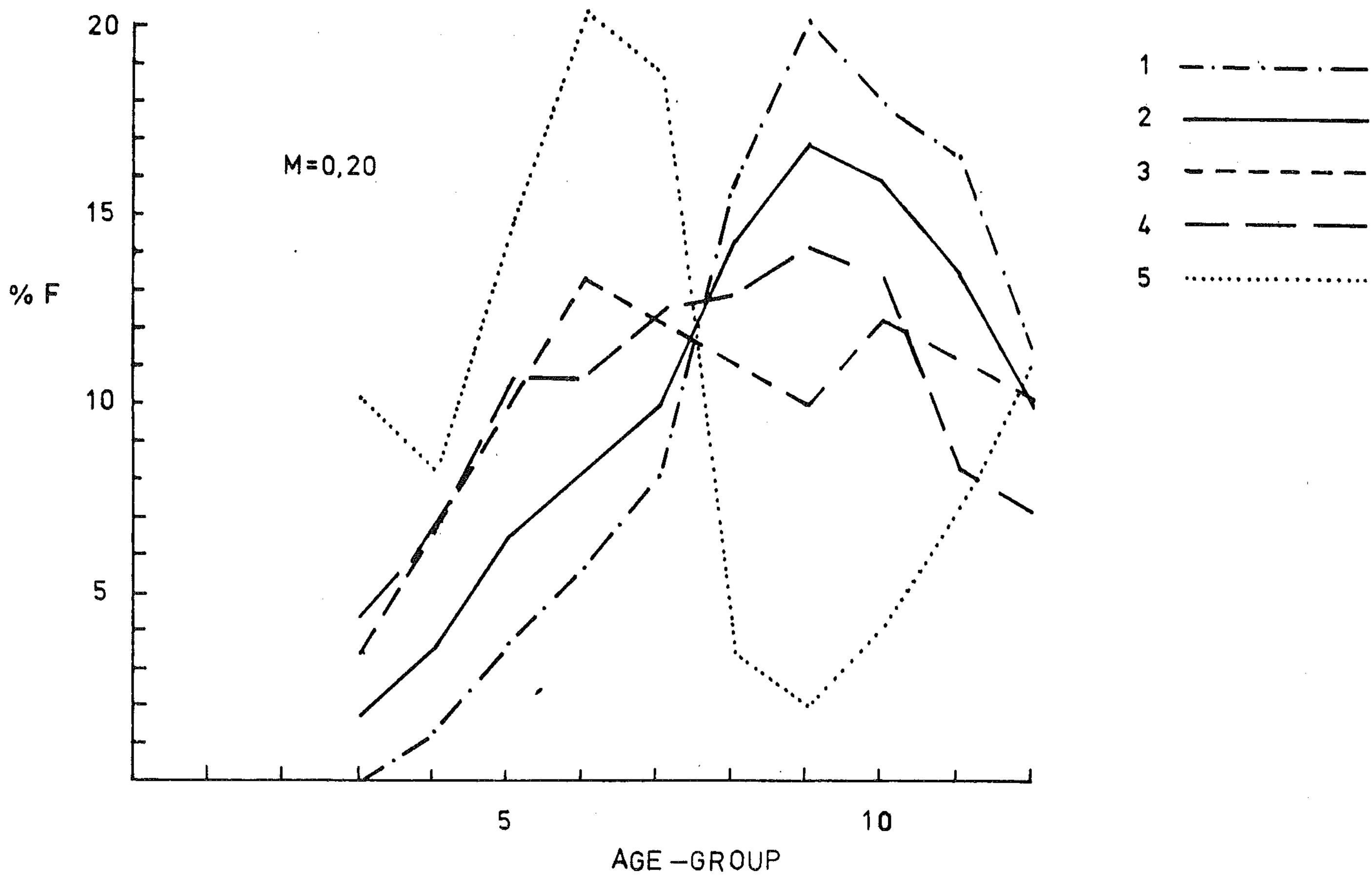

Fig. 1. Fishing patterns on the Arcto-Norwegian Cod stock as determined by the relative distribution of fishing mortalities, F_i, on the age groups 3 to 12 years. The patterns shown are the average for 1970 to 1974 as generated by the fishery by Norway, USSR, "Other countries" and the total fishery. The fishing pattern by USSR in 1973 is also included. The total fishing pattern is estimated from VPA for M = 0.20.

1) The Norwegian fishing pattern.
2) The total fishing pattern.
3) "Other countries" (excluding Norway and USSR) fishing pattern.
4) The USSR fishing pattern.
1) to 4) are the mean fishing pattern for the period 1970 - 1974.
5) The USSR fishing pattern in 1973.

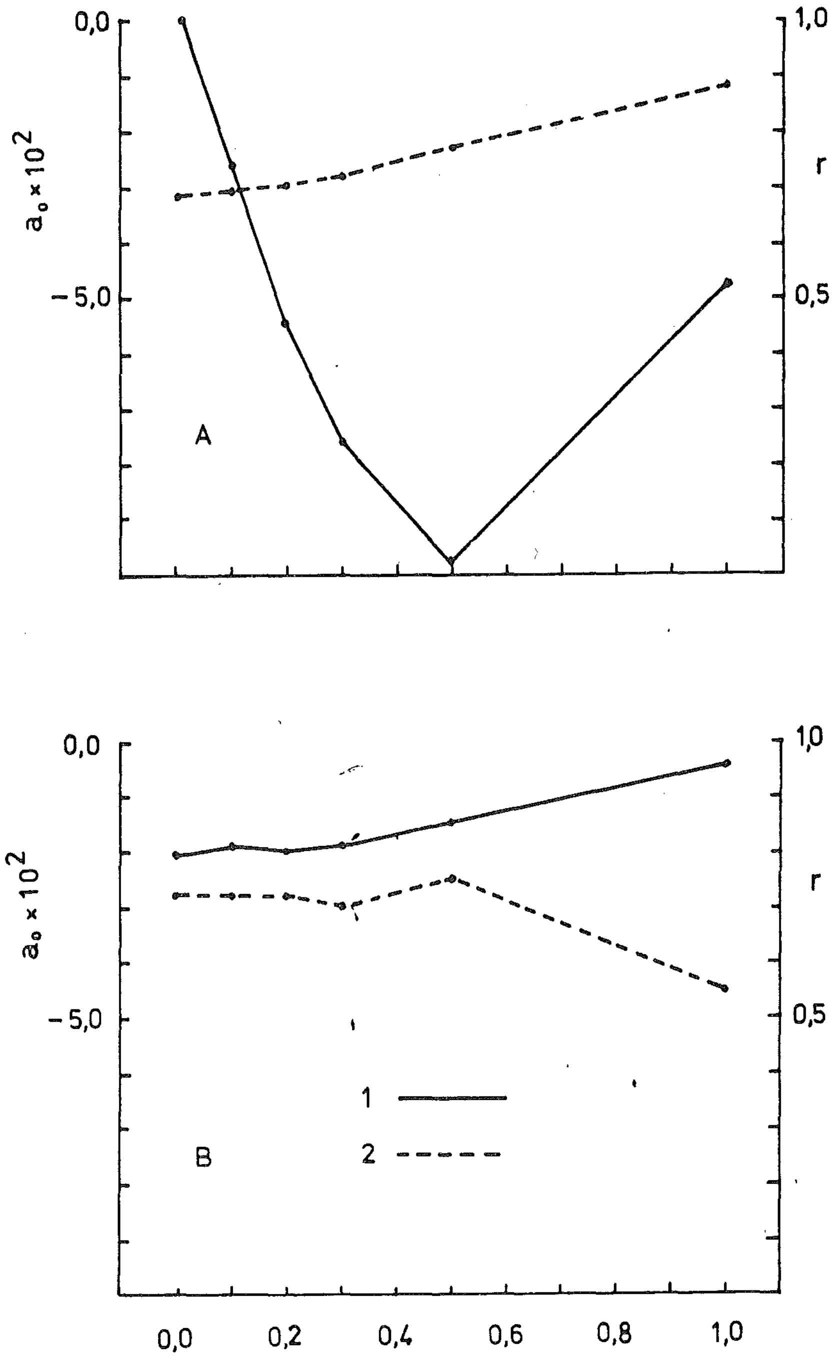

Fig. 2 A-B. The intercept (a) and the correlation coefficient (r) as a function of the natural mortality rate (M). a_0 and r are given by linear regression between the effort in OK units (ton hours) in Subarea I, and Division IIb and IIa, versus the average fishing mortality on 4 to 6 year old fish, in the years 1950 to 1970. The fishing mortalities are estimated from VPA.

A. From linear regression between the total effort and the total fishing mortality.

B. From linear regression between the effort exercised by the British fishing fleet and the fishing mortality generated by the British fleet.

1) a_0 2) r

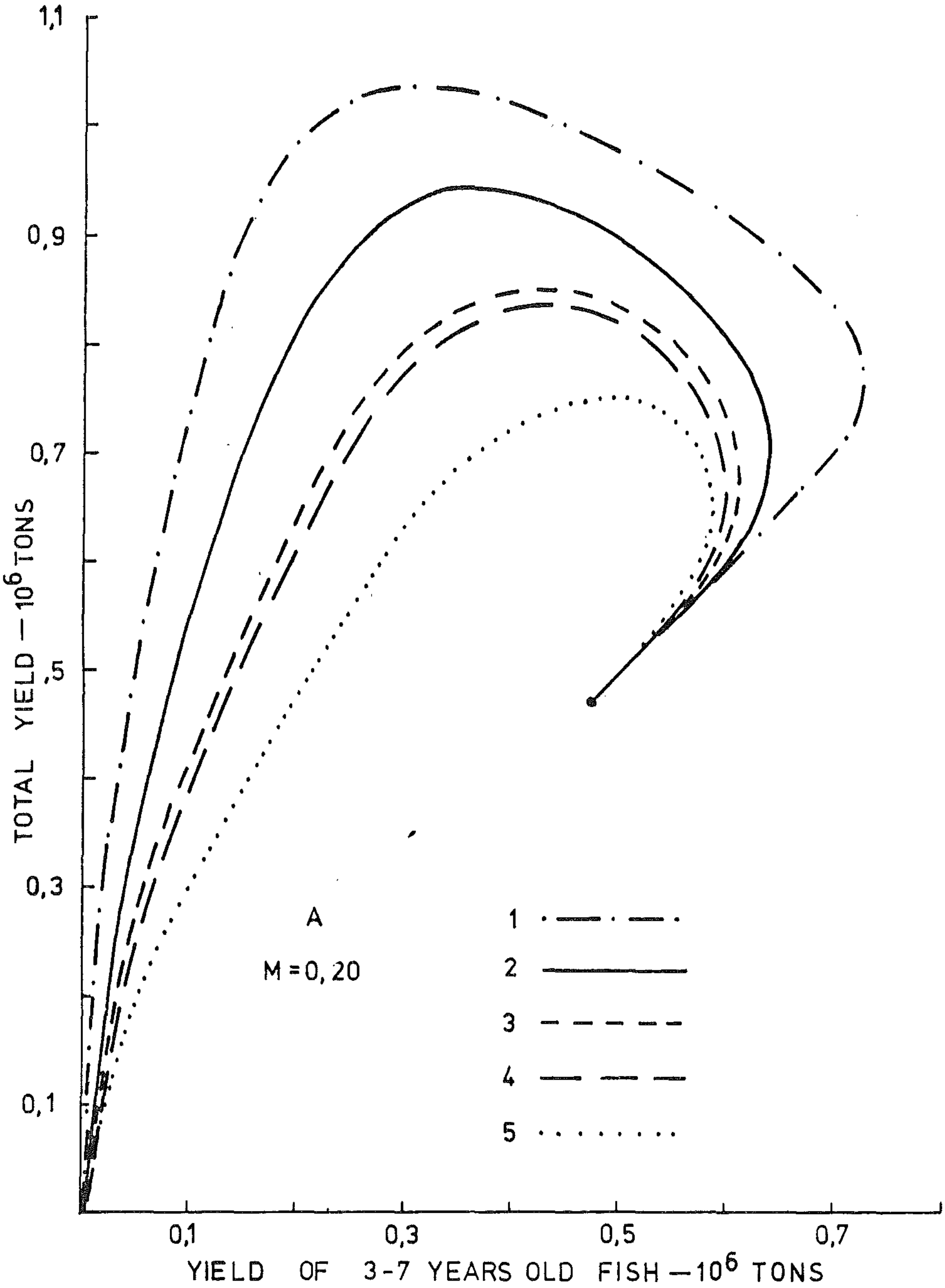

Fig. 3 A. The total yield of the Arcto-Norwegian cod stock as function of the yield of the 3 - 7 year old fish by different fishing pattern. Legend as Fig. 1.

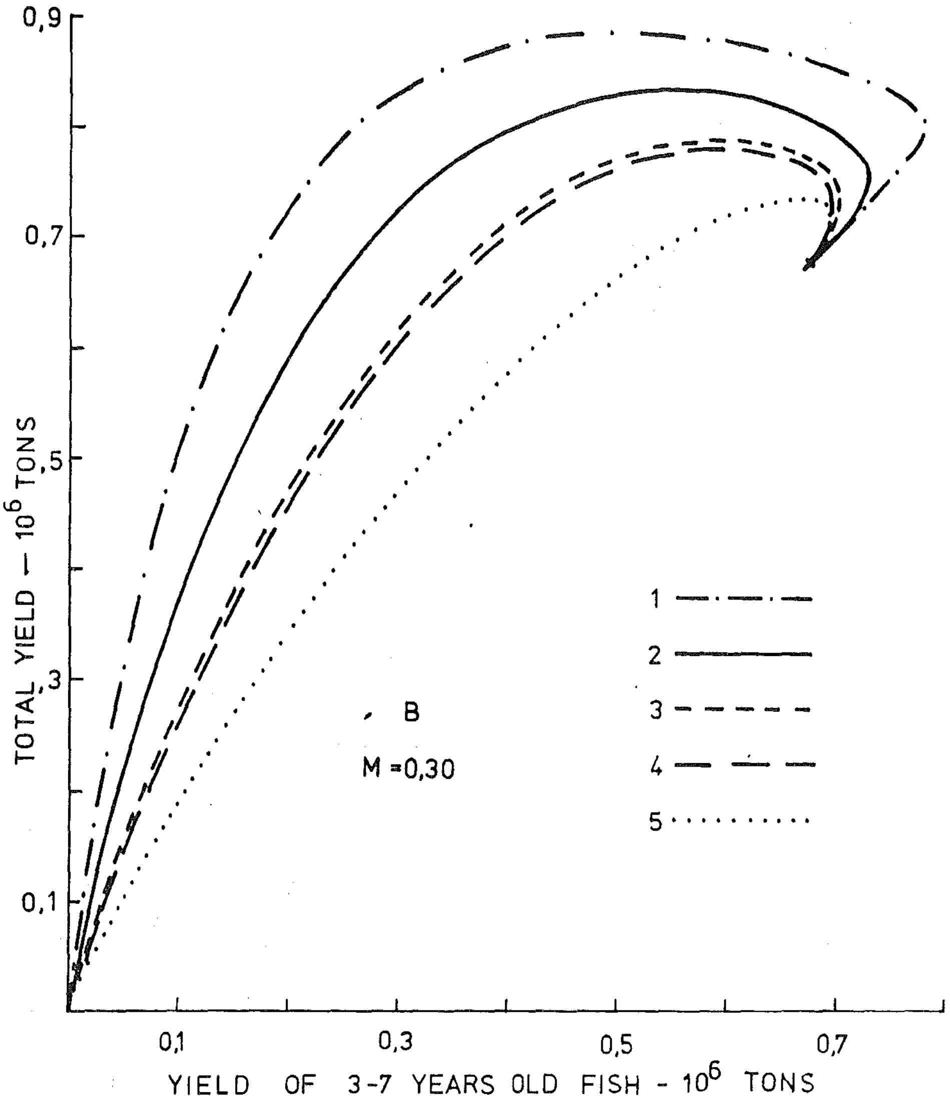

Fig. 3 B. The total yield of the Arcto-Norwegian cod stock as function of the yield of the 3 - 7 year old fish by different fishing pattern. Legend as Fig. 1.

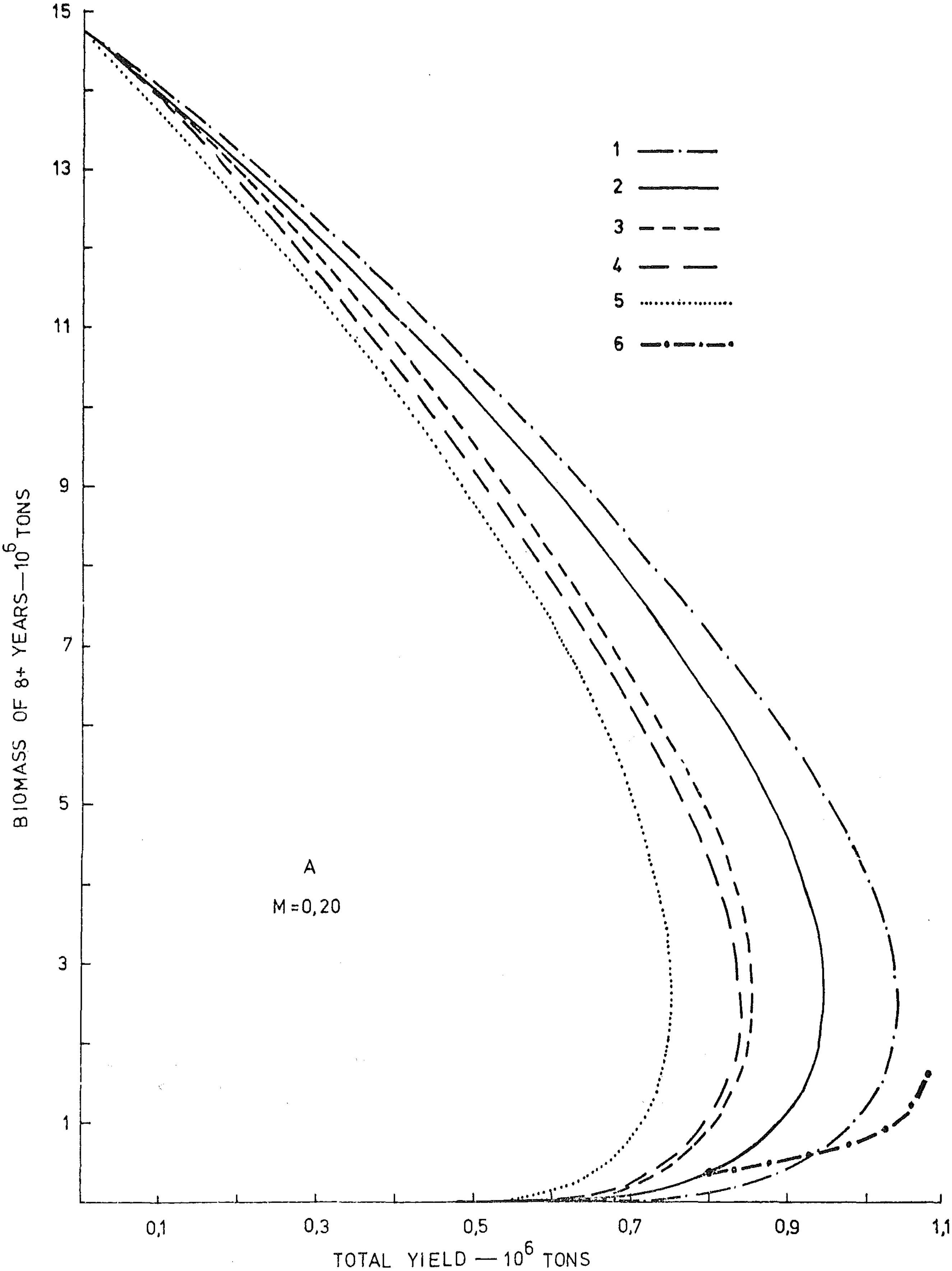

Fig. 4 A. The curves 1 to 5 show the size of the mature stock, measured by the biomass of fish 8 year old and older, as function of the total yield by different fishing patterns. Legend as in Fig.1. Curve 6 shows the relation between the total yield and the size of the mature stock when the mesh sizes in the total trawl fishery is increased from 120 mm to 230 mm, while the effort is kept constant at the 1970 - 1974 level.

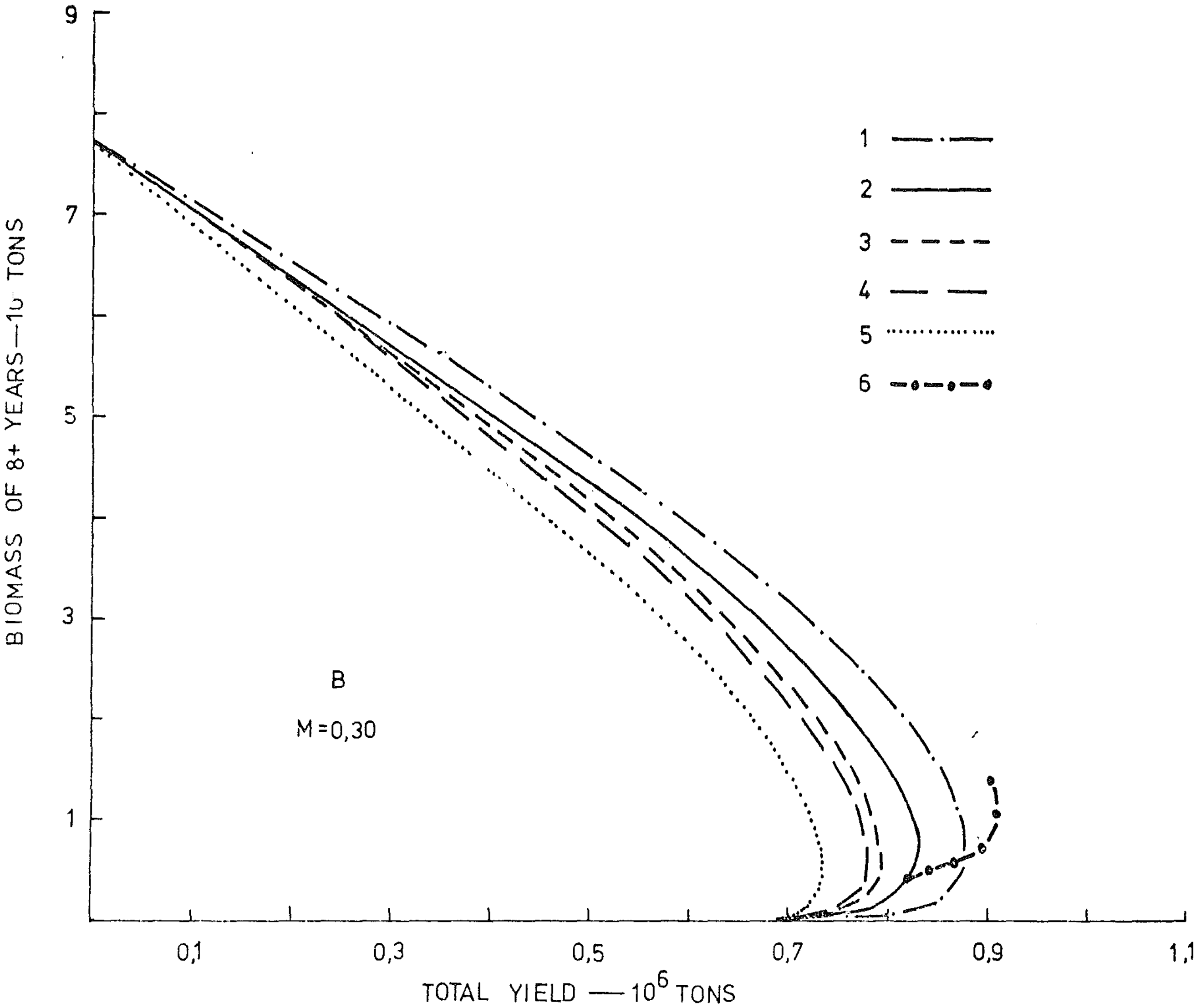

Fig. 4 B. The curves 1 to 5 show the size of the mature stock, measured by the biomass of fish 8 year old and older, as function of the total yield by different fishing patterns. Legend as in Fig.1. Curve 6 shows the relation between the total yield and the size of the mature stock when the mesh sizes in the total trawl fishery is increased from 120 mm to 230 mm, while the effort is kept constant at the 1970 - 1974 level.