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The relation between fishing mortality on juveniles and total yield of Arcto-Norwegian cod.

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INTRODUCTION

In later years there has been an increasing fishing mortality on young Arcto-Norwegian cod and this has caused an increasing concern about the effect the resulting decrease in the spawning stock will have on recruitment and future yield. Garrod and Jones (GARROD and JONES, 1973) have studied the stock/recruitment relationship for this stock and estimated the optimum level of the mature stock and the corresponding annual fishing mortality and yield, assuming that the selection pattern would be the same as at present.

However, it is possible that the yield could be increased by changing the selection pattern. The aim of this study is to find how recruitment and yield varies with fishing mortality on young cod, assuming a stock/recruitment relationship.

MATERIAL AND METHODS

A Ricker stock/recruitment relationship,

$$R = a\,S\,e^{-bS}$$

was assumed. The size of the spawning stock was taken as the mean annual biomass of 8 year old and older fish.

From $R = a\,S\,e^{-bS}$, we get

$$R = \frac{\log_e S/R + \log_e a}{b \cdot S/R} \qquad (1)$$

For reasons of convenience it was assumed that S = R = S/R= 1 in the equilibrium state when there is no fishing (this implies that $b = \log_e a$ in $R = a\,S\,e^{-bS}$).

For given fishing mortalities on adults (8 year old and older) and juveniles, S/R was then calculated as the mean annual biomass per recruit of the adult stock, relative to that of the same stock when there is no exploitation. The von Bertalanffy growth equation was used. If there is no fishing mortality on juveniles, S/R for a given F on adults is given by

$$S/R = (Y'/F)_F \Big/ \lim_{F \to 0} (Y'/F)$$

where Y' is the yield per recruit using the age of maturity as the age of entry into the exploited phase. S/R may be found directly in the yield tables by Beverton and Holt (BEVERTON and HOLT, 1966).

If in addition to the fishing mortality on adults there is some fishing mortality on juveniles, the value found for S/R by the method above have to be reduced by $e^{-\sum_{i<8} F_i}$ where $\sum_{i<8} F_i$ is the sum of the yearly fishing mortalities on the juvenile age groups.

Having found S/R, R was then calculated using expression 1, and the yield is then given by

$$Y = R \cdot Y/R$$

The growth parameters were estimated using the weight at age data given in Report of the North-East Arctic Fisheries Working Group (ANON. 1973), and the following values were found:

$$K = 0.10, \quad t_o = 1.1, \qquad W = 31.34 \text{ kg.}$$

RESULTS

The results, using the stock/recruitment relationship estimated by Garrod and Jones (GARROD and JONES, 1973) are shown in Fig. 2-5, assuming that a given set of fishing mortalities has worked for so long that an equilibrium state is reached. By setting $R = S = 1$ in the equilibrium state when there is no fishing, the relation between stock and recruitment is expressed by

$$R = 12.164 \cdot S \cdot e^{-2.4984 S}$$

The curve is shown in Fig. 1. In calculating recruitment and yield, a value of $M = 0.2$ has been used, but some results are also given for $M = 0.3$. Fig. 2 shows how R varies with the fishing mortality on adults for different values of $\sum_{i<8} F_i$. If F_{adult} is higher than a critical value, no equilibrium state is reached and the stock will tend to extinction (From expression 1 we see that this happen when $S/R < \frac{1}{a}$).

The critical value is heavily dependent upon $\sum_{i<8} F_i$. In Fig. 3 the critical value is plotted against $\sum_{i<8} F_i$ for both $M = 0.2$ and $M = 0.3$.

Fig. 3 illustrates how the danger of fishing the stock to extinction level increases rapidly with increasing fishing mortality on juveniles. If $\sum_{i<8} F_i = 2.5$, the stock will tend to extinction without any fishing of adults at all. This is in agreement with Garrod and Jones (GARROD and JONES, 1973) who found that if the sum of the yearly fishing mortalities from recruitment to the mean age of the spawning stock exceeded 2.5, the stock would tend to extinction. $\sum_{i<8} F_i = 2.5$ means a yearly fishing mortality on juveniles of 0.625 if the mortality is divided equally over four years.

Fig. 4 shows how the total yield varies with F_{adult} for different values of the fishing mortality on juveniles ($F_{juvenile}$). In calculating R, nothing had to be assumed about how $\sum_{i<8} F_i$ was distributed on the different juvenile age-groups. In calculating the yield it has been assumed that the age of recruitment to the fishery is four years and $\sum_{i<8} F_i$ is equally divided on the age groups 4-7 years old, i.e. $F_{juvenile} = \sum_{i<8} F_i/4$.

The values for the fishing mortalities in recent years given in Report of the North-East Arctic Fisheries Working Group (ANON. 1973) give a mean value of $\sum_{i<8} F_i = 1.43$ for the years 1968-72, and the yield curve for this value of the fishing mortality on juveniles is given as the dotted line in Fig. 4. The maximum yield (Y_{max}) decreases rapidly with increasing fishing mortality on juveniles. If M = 0.3, the decrease in Y_{max} with incresing fishing mortality on juveniles is smaller than if M = 0.2, but still a considerable gain in yield could be expected by decreasing $F_{juvenile}$.

In Fig. 5 the maximum total yield is plotted against yearly F on juveniles for both M=0.2 and M=0.3. If F on juveniles is greater than the value indicated by the broken line, any fishing on adults can only result in a decrease in total yield.

By computer simulation, starting from the stock situation as in 1971 and exploiting the stock over a period of 25 years using the established stock/recruitment relation, Garrod and Jones (GARROD and JONES, 1973) found that an increase in mesh size from 130 mm (present mesh size) up to at least 160 mm would give a long term increase in yield for all levels of F above 0.2. This is in general agreement with the results found here: A decrease in fishing mortality on juveniles will increase Y_{max}.

In Table 1 are summarized the values of maximum total yield, corresponding fishing mortality on adults and the critical F-values for different fishing mortalities on juveniles.

DISCUSSION

In this study constant growth paramaters have been used. There are, however, strong indications that growth is density-dependent in the Arcto-Norwegian cod stock (SÆTERSDAL and CADIMA, 1960). If growth is increasing with decreasing stock size, the method used in this study gives underestimates of both the yield under high exploitation rate and the critical F-values. It would certainly be of great interest to take into account the density dependent growth. However, it seems unlikely that such an approach would lead to conclusions significantly different from those obtained here.

The fishing mortalities have for a long period exceeded the critical values estimated in the present investigation. One may therefore ask why the stock has not already completely collapsed. There are two main reasons for this:

(i) For long-living species where the age of recruitment to the adult stock is high, a relatively long period is needed before the full effect of overexploitation becomes clear under a stock/recruitment relationship.

(ii) The recruitment is not determined from the size of the spawning stock alone. Individual yearclasses show a great variation about the stock/recruitment curve, and this is not taken into account in the estimation of the critical F-values. The variation increases with decreasing stock size (GARROD and JONES, 1973). Strong year-classes may appear at very low stock levels (example: The 1963 and 1964 year-classes), and this is sufficient to delay for may years a drastic decline in stock size or a total collapse. The stock/recruitment curve cannot therefore be used to predict what will happen under low stock levels, it can only tell us when the danger for collapse or a drastic decline in recruitment and yield becomes imminent. It is in this way the estimated critical F-values should be interpreted.

CONCLUDING REMARKS

(i) The results presented here show that the Arcto-Norwegian cod stock is at present exploited at a level which will result in a further decline in stock size or possibly a total collapse if the stock/recruitment relationship used in the analysis is actually a true functional relationship in the stock. This is in agreement with the conclusions drawn by Garrod and Jones (GARROD and JONES, 1973).

(ii) The present investigation further shows that the exploitation rate the stock is able to withstand is strongly dependent on the fishing mortality on the juvenile age-groups. The maximum equilibrium yield increases with decreasing fishing mortality on the young cod. Garrod and Jones (GARROD and JONES, 1973) estimated the maximum equilibrium yield to be about 800 000 tons with the selection pattern as at present. This yield can probably be increased considerably by changing the selection pattern. The order of increase is strongly dependent on the value of M.

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Table 1. Maximum equilibrium yield (relative values), corresponding F_{adult} and the critical value of F_{adult} for different fishing mortalities on juveniles. For further explanation see text.

(i) M = 0.2

$F_{juvenile}$	0	0.1	0.2	0.3	0.4	0.5
Y_{max}	1.0	0.864	0.737	0.626	0.530	0.440
F_{max} (adult)	0.43	0.28	0.18	0.09	0.03	0
$F_{critical}$ (adult)	0.99	0.70	0.47	0.30	0.17	0.08

(ii) M = 0.3

$F_{juvenile}$	0	0.1	0.2	0.3	0.4	0.5
Y_{max}	1.0	0.950	0.876	0.814	0.752	0.636
F_{max} (adult)	0.75	0.45	0.27	0.14	0.03	0
$F_{critical}$ (adult)	1.84	1.22	0.79	0.48	0.27	0.12

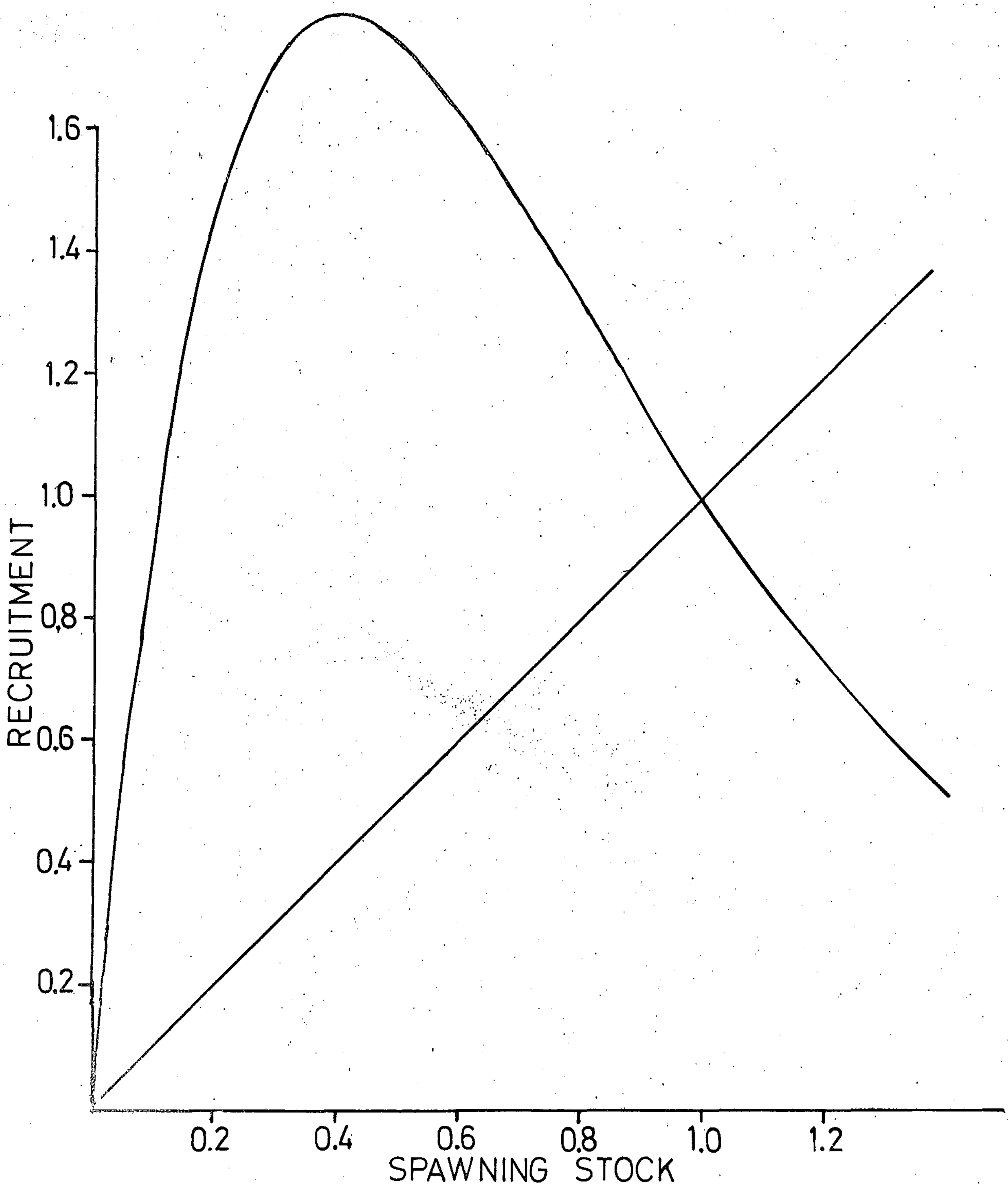

Fig. 1. Stock/recruitment curve for Arcto-Norwegian cod.

$R = 12.164\ S\ e^{-2.4984\ S}$ (GARROD and JONES, 1973).

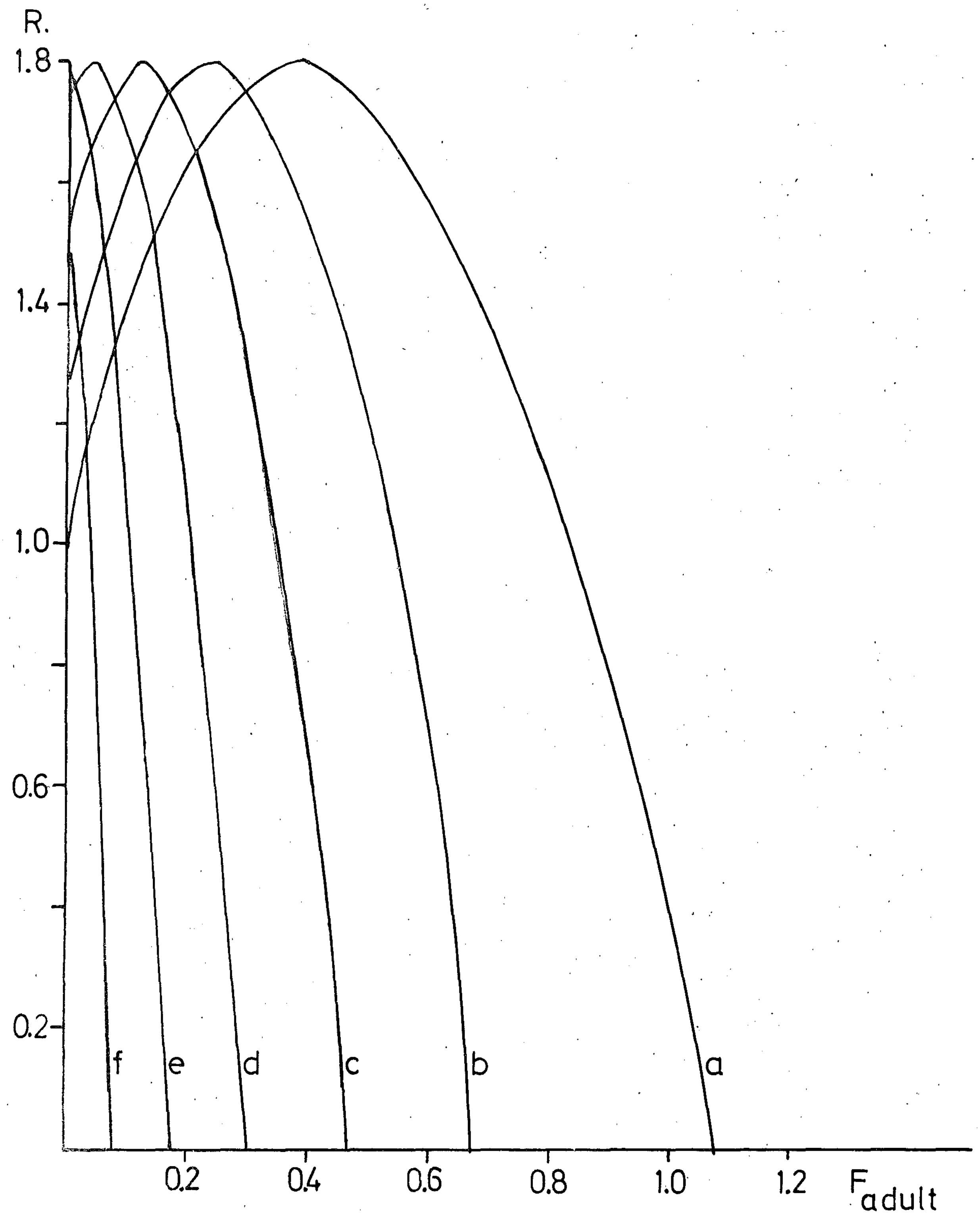

Fig. 2. Recruitment against fishing mortality on adults (F_{adult}) for different values of the sum of the fishing mortalities on the juvenile age-groups ($\sum_{i<8} F_i$), M= 0. 2. a) $\sum_{i<8} F_i = 0$, b) $\sum_{i<8} F_i = 0.4$, c) $\sum_{i<8} F_i = 0.8$, d) $\sum_{i<8} F_i = 1.2$, e) $\sum_{i<8} F_i = 1.6$, f) $\sum_{i<8} F_i = 2.0$.

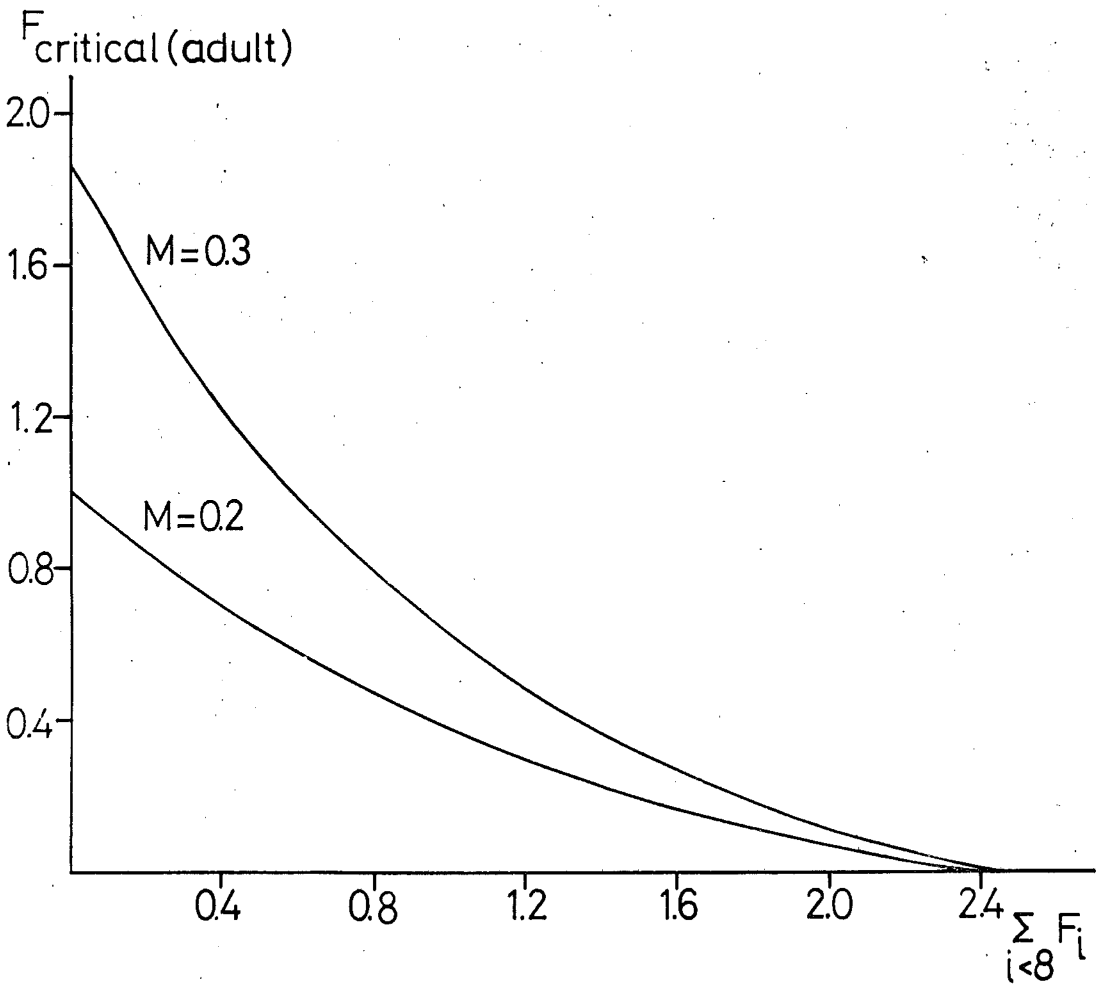

Fig. 3. Critical value of the fishing mortality on adults ($F_{critical\ (adult)}$) against the sum of the fishing mortalities on the juvenile age-groups ($\sum_{i<8} F_i$) for M= 0.2 and M= 0.3. For further explanation see text.

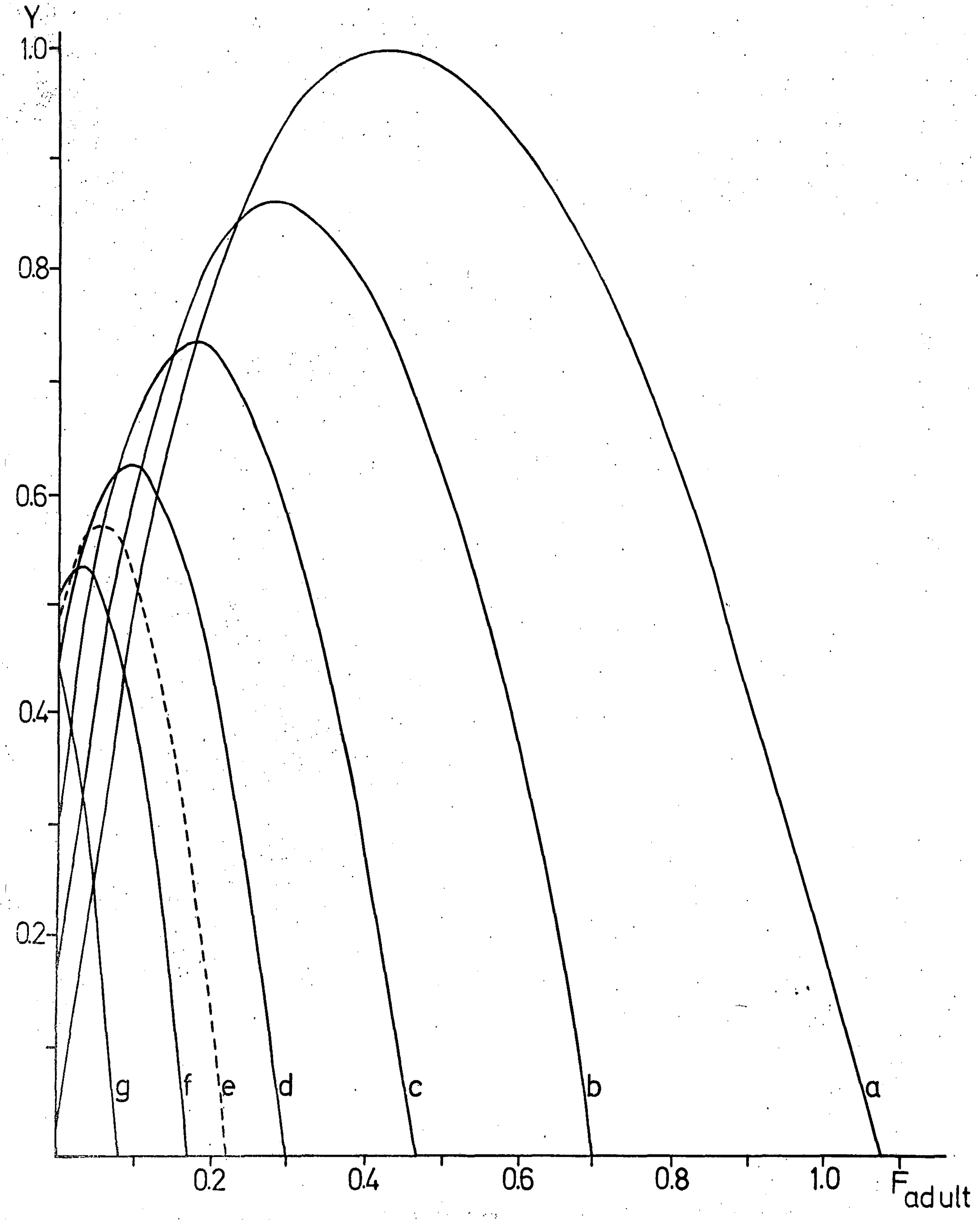

Fig. 4. Equilibrium yield (Y) against fishing mortality on adults (F_{adult}) for different values of the yearly fishing mortality on juveniles (4-7 years old), M= 0.2. a) $F_{juvenile}$= 0, b) $F_{juvenile}$=0.1, c) $F_{juvenile}$= 0.2, d) $F_{juvenile}$= 0.3, e) $F_{juvenile}$= 0.36 (approximation to present situation), f) $F_{juvenile}$= 0.4, g) $F_{juvenile}$= 0.5.

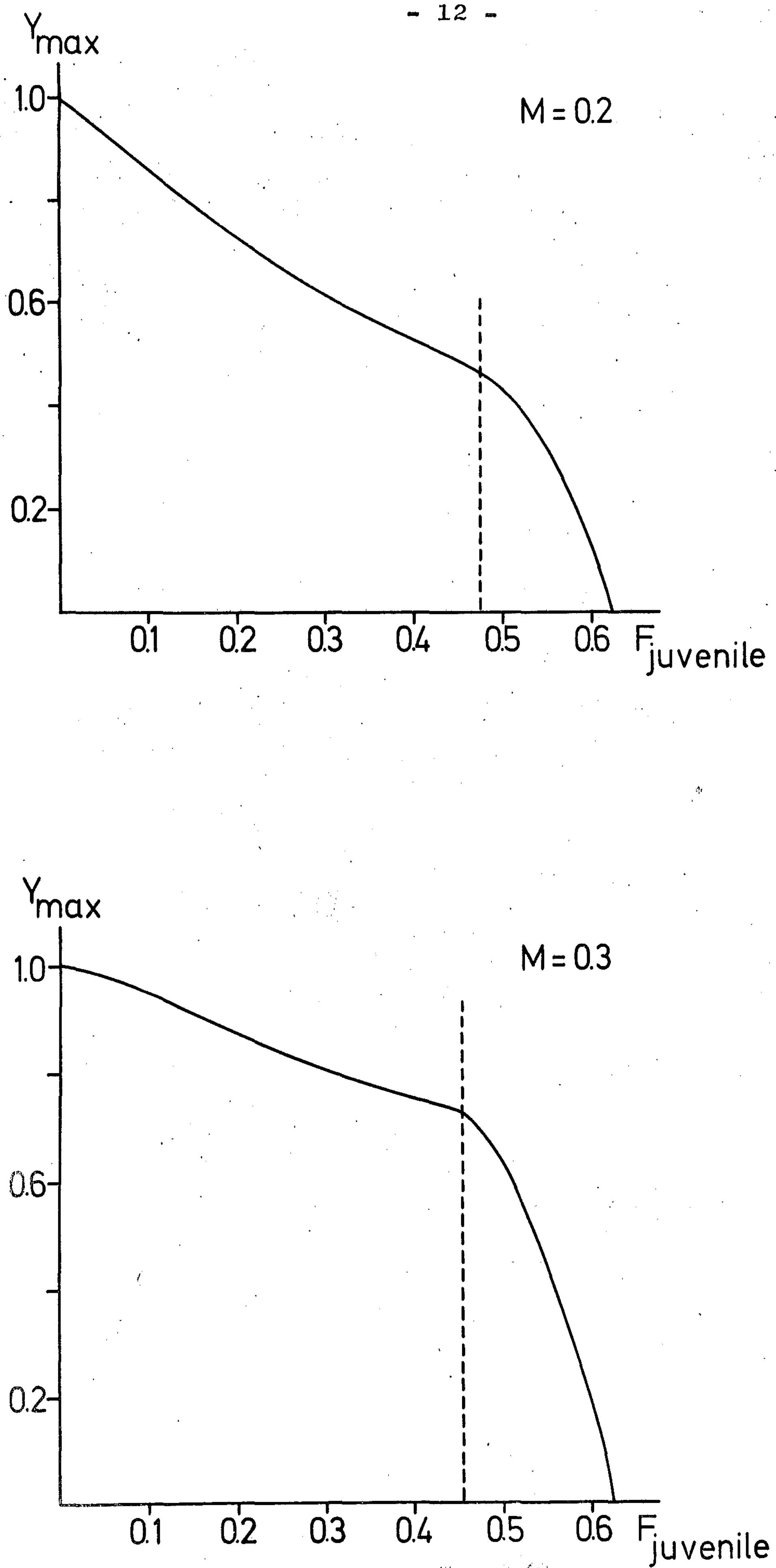

Fig. 5. Maximum equilibrium yield (Y_{max}) against yearly fishing mortality on juveniles (4-7 years old) for M = 0.2 and M = 0.3.