ERRATA / DOC. G:29

The ancient Greek gods have been angry and inserted Greek letters in the text, apparently at random. The sentences that have been affected should read as follows:

Page 8, 7th paragraph, 1st sentence
It is obvious that changes in growth can result in a biased Fmed estimate if the wrong data set is used for the SSB/recruit calculation.

Page 9, 5th paragraph, 3rd and 4th sentence
An examination of the plot in Figure 4.5 shows that the points above the Fmed line on the average are farther away from the line than those below the line. Hence, if average recruit/SSB had been used instead of the middle value to estimate Fmed, the estimate for cod would have been higher.

Page 10, 2nd paragraph, 2nd sentence
For cod, however, it indicates that fishing mortality of about 0.3 may be a sound level if the goal is to rebuild the stock at a fairly quick rate.

Page 10, 3rd paragraph, 1st sentence
The Fhigh estimate for cod is fairly robust and its credibility as an indicator of a dangerously high level of fishing mortality has been strengthened.

Page 10, 5th paragraph, 4th and 5th sentence
When the spawning stock has been rebuilt to a satisfactory level, an appropriate level of fishing mortality may be recommended. This should be either Fmed or a "conditional" Fmed.

BIOLOGICAL REFERENCE POINTS FOR NORTH-EAST ARCTIC COD AND HADDOCK

by

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ABSTRACT

It has been suggested by ACFM that Fmed might be preferable to Fmax as a biological reference point for the North-East Arctic cod. However, the Fmed level of more than twice Fmax appeared high, and it was known to have been based on biased historic SSB estimates. Also, the robustness of Fmed and its related points Flow and Fhigh to changes in the parameters used for their estimation has not been thoroughly investigated. The effect of the various parameters on the biological reference points for North-East Arctic cod and haddock is tested.

FO.1 and Fmax are strongly dependent on the parameters used to estimate them, especially the natural mortality. Fmed is generally much more robust and the estimates of Flow and Fhigh are also relatively stable. Fmed for cod is estimated to be considerably lower than the previous estimate. The crucial factor in the estimation is to decide whether the maturity is density dependent or not.

It is suggested that the Fmed-family of reference points provide a better founded basis for management of these stocks than FO.1 and Fmax. Flow may represent a suitable level for rebuilding the stocks, although for haddock it is too low to be achieved in practice. Once the stocks are at a satisfactory level, Fmed may be applied, possibly adjusted to correspond to a target spawning stock biomass.

1. INTRODUCTION

A biological reference points is a level of fishing mortality defined on the basis of biological parameters and with properties which may be useful in stock management considerations. Fishing mortality corresponding to one of these points has frequently been recommended as a target by ACFM, but the tendency has been to treat the points more as markers in the recommendations. A brief review of their properties and how they are estimated is given in Section 2.

Fmax, introduced by Beverton and Holt (1957), has been the most used biological reference point in recommendations for fish stock management within the ICES system. Fmax is the level of exploitation which will give the highest long-term yield.

An alternative has been FO.1, used by ACFM where appropriate since 1978. FO.1 is based on considerations of marginal yield and corresponds to the level of exploitation where the increase in catch per unit effort by introducing an additional unit of effort will be only 1/10 of the catch per unit effort in a very lightly exploited fishery (Gulland and Boerema 1973). FO.1 will always be lower than Fmax.

The biological reference points Flow, Fmed and Fhigh were introduced by the Working Group on Methods of Fish Stock Assessment (Anon. 1984). Of these, Fmed appears to be the most useful in management considerations. The points are based on historic recruitment/spawning stock biomass ratios and are in contrast to FO.1 and Fmax not concerned with the yield.

Traditionally, Fmax has been recommended as the target for the management of the North-East Arctic cod, i.e., the recommendation has been to reduce fishing mortality to or towards Fmax.

For the North-East Arctic haddock, the estimated level of Fmax has been variable and in some years it has not been defined on the yield-per-recruit curve. FO.1 has been more stable and has therefore been considered a more useful reference point, but not necessarily a target.

In the ACFM recommendation from November 1988 (Anon. 1989a) for the North-East Arctic cod in 1989, Fmax is not mentioned. Instead, Fmed, which was estimated to be more than twice the Fmax-level, is indicated as an option for the TAC.

There may be good reasons to question the scientific justification for using Fmax as a target level in management recommendations, or even as a reference point, but this has been the practice for many stocks and Fmax has become a familiar term for managers. Fmed, on the other hand, is a relatively new property and its use in the ACFM recommendations so far appears to be a bit arbitrary. Although the significance of Fmed is explained in the ACFM report (Anon. 1989a) and comments are given in connection with the recommendations, a sudden shift from Fmax to Fmed as the preferred biological reference point must be confusing to the managers, especially since Fmed for many stocks has been estimated to be well above Fmax. Thus, in the case of the North-East Arctic cod, Fmax has always been in the range 0.25-0.35 and is currently estimated to be 0.28 (Anon. 1989b). ACFM, however, suggested that Fmed which was estimated to be 0.69, might be a more appropriate biological reference point. The reason given for disregarding Fmax, the fact that the estimate is sensible to growth changes, is hardly convincing.

The current paper was prepared partly because it was generally felt among the Norwegian scientists familiar with the stock, that the level of Fmed

estimated for the North-East Arctic cod was higher than the stock could sustain in the long-term. The stock biomass had been declining for a long period at levels of fishing mortalities below Fmed. Although a decline would be expected, both because a large stock had accumulated during the war and because of the increasing trend in fishing mortality in the whole post-war period, the feeling was that reduction to the Fmed level would not be sufficient to stop the decline. It was also known that the estimate of Fmed was based on biased estimates of the historic spawning stock biomass and there was concern that Fmed for that reason might have been overestimated.

The other reason for preparing the paper was that the robustness of the estimates of Flow, Fmed and Fhigh in general has not been tested. The level of Fmax is known to be dependent on the parameters used for its estimation, and this must to some extent also be the case for Flow, Fmed and Fhigh.

The North-East Arctic haddock was included in the exercises because a long time series of stock data exists and because the additional results might give a better basis for drawing conclusions about the robustness of the estimates of Flow, Fmed and Fhigh.

2. BIOLOGICAL REFERENCE POINTS

Fmax is defined as the fishing mortality corresponding to the top of the yield-per-recruit curve (Beverton and Holt 1957). The calculatons require an exploitation pattern, weight-at-age in the catches, and natural mortality at age. The latter is for most stocks assumed to be constant over all age groups. Fmax is strongly dependent on the choice of natural mortality (Beverton and Holt 1957, Anon. 1985), for which there is usually no firm basis. Changes in growth rate and exploitation pattern may also affect the Fmax estimate, in some cases seriously. Density dependence, which usually is not taken into account in yield-per-recruit calculations, can have a large effect on Fmax.

F0.1 is defined as the fishing mortality corresponding to the point on the yield-per-recruit curve where the slope is 1/10 of that at the origin. It is based on the same parameters as Fmax, and responds to changes in those in a similar way, but is generally more robust. It is always smaller than Fmax and will produce a smaller yield. Its advantages over Fmax is that fishing at the F0.1 level will give a bigger and more stable stock, higher and more stable catch rates, and bigger fish in the catches.

Being based only on yield considerations, neither Fmax nor F0.1 represent particular levels of stock size. However, long-term biomass estimates at F0.1 and Fmax are often at high historic levels.

Flow, Fmed and Fhigh are a family of biological reference points based on the recruitment versus spawning stock biomass (SSB) scatter diagram (Anon. 1984, 1985). The procedure is to draw lines through the origin which leave 90% (Flow), 50% (Fmed) and 10% (Fhigh) of the points above the line. The slopes correspond to values of recruits per unit SSB and the reciprocals are SSB/recruit. The corresponding fishing mortalities can then be read from the SSB/recruit graphs.

Fmed corresponds to the level of fishing mortality where recruitment in half of the years has been more than sufficient to balance the mortality. With fishing at the Fmed level it is therefore a good chance that the stock will be sustained.

Flow represents a level of fishing mortality where recruitment has been sufficient to balance the mortality about 9 years out of 10. The likelihood

of a decline in the stock at this level of exploitation is therefore very low and an increase is far more likely.

Fhigh, on the other hand, represents a level of fishing mortality where recruitment has not been sufficient to balance the mortality about 9 years out of 10. The likelihood of a decline in the stock at this level of exploitation is therefore very high.

The parameters used for estimating Fmax are also included in the calculation of SSB/recruit and accordingly in the estimates of Flow, Fmed and Fhigh. The exception is the weight-at-age in the catch which is replaced by weight-at-age in the stock. In addition, a maturity ogive is required. The other part of the Fmed estimation, the scatter plot of Recruitment versus SSB, is usually based on a VPA, i.e. catch-at-age data, and requires a maturity ogive and stock weight-at-age for each year. In addition, both the length of the time series used and the history of the stock during that period are factors that may be important in the estimation.

In addition to the biological reference points mentioned, there are others, e.g. Fmsy of surplus production models. However, the points discussed are those currently referred to in ACFM recommendations.

3. MATERIAL AND METHODS

The data allow a VPA for the North-East Arctic cod and haddock to be carried out back to 1946 and 1950, respectively. The assessment for cod had to be changed slightly from the one made by the Arctic Fisheries Working Group (Anon. 1989b) in order to make the assessments with different natural mortalities exactly comparable. In addition, the basis for estimating F on the oldest age in the VPA was increased from three to four years for both species. The resulting differences from the Working Group assessment were small. F_{5-10} (1987) for cod changed from 0.958 to 0.975, while F_{4-7} (1987) for haddock remained at 0.722.

The recruitment versus SSB scatter plot used for estimating Flow, Fmed and Fhigh has been restricted to the period 1950-1982 for both cod and haddock.

For both stocks natural mortality (M) of 0.2 has been assumed for all age groups in the Working Group assessment, i.e., for fish of age three and older. There is little evidence to support that exact figure, but most assessment biologists would probably agree that 0.1 - 0.3 is a likely range. To test the effect of the natural mortality, the VPA was re-run with M-values in the range 0 - 0.4, following exactly the procedure described by the Working Group, with the mentioned amendments.

The yield- and SSB-per-recruit calculations in this exercise are based on the 1987 exploitation pattern. However, the exploitation pattern has changed over the years, and especially in the 1970's there were high fishing mortalities on the youngest age groups of both cod and haddock. Average exploitation patterns from 5-year periods are therefore used in yield- and SSB-per-recruit calculations to test the effect on the reference points.

For both cod and haddock there are fixed sets of catch and stock weights in the data files up to 1982, and the stock weights are equal to the catch weights. These weights have been used as basis for all the calculations, whereas the Working Group used more recent and considerably lower weights in the yield- and SSB-per-recruit calculations.

An investigation by Jørgensen (1989b) has demonstrated that the growth of the North-East Arctic cod has increased steadily in the period after 1946

until it suddenly was severely reduced in 1986. The same trend is reflected in the nominal landings/SOP (sum of products of weight and number) ratio which was about 0.65 in 1946-1949 and then increased gradually to reach 1 in the 1970's. The increase in the nominal landings/SOP ratio coincide with a declining trend in the stock and may reflect a density dependent growth. Using the linear regression of the nominal landings/SOP ratio on stock biomass as an expression of density dependence, the effect of density dependent growth on the biological reference points was tested.

For cod, knife-edge maturity at age 8 (in the data files 1946-1981) has been used in all the calculations unless otherwise stated. However, there is strong evidence that age at first maturity has been reduced during the post-war period (Anon. 1983). Jørgensen (1989a) has calculated maturity ogives based on spawning zones in otoliths. The resulting SSB estimates probably reflect the historic trend better, except for a brief period with peculiarly low values in the late 1960's. The effect on the estimates of Flow, Fmed and Fhigh of changing from knife-edge maturity at age 8 to the Jørgensen maturity ogives was tested.

For haddock, the maturity ogive calculated by Sætersdal (1954) is used for the whole period, as by the Working Group.

The spawning stock biomass estimates for cod and haddock may be biased. The effect of changing the age at first maturity was therefore tested.

The number of points (recruit/SSB ratios) available for estimating Flow, Fmed and Fhigh may be important and this was tested by reducing the number of years step-wise by two, starting with both 1950 and 1982.

The latter experiment also relates to the possibility that the stock/recruitment relationship may change with time or with biomass. To test the latter possibility, the SSB/recruit ratios were ranked according to the size of the spawning stock. Estimates of Flow, Fmed and Fhigh were made from plots with 11 points, starting with the highest SSB's and shifting by two at the time.

All the estimates of Fmed are based on an odd number of points in the recruitment/SSB plot and the Fmed-line is the one passing through the middle point. To avoid subjectivity, the Flow and Fhigh lines are defined as those passing through the last point needed to make up more than 10% below and above the line, respectively.

4. RESULTS - NORTH-EAST ARCTIC COD

4.1. History of Stock and Exploitation.

Figure 4.1 shows the development of the stock biomass and the fishing mortality from 1946 to 1987. There are large fluctuations in the stock size which are caused mainly by variations in the recruitment, but the trend has nevertheless been clearly declining. The fishing mortality has increased steadily and was nearly three times higher in 1987 than in 1950.

4.2. Natural Mortality.

Estimates of F0.1, Fmax, Flow, Fmed, and Fhigh for different assumptions of natural mortality are given in Table 4.1. F0.1 and Fmax, which are not defined for M=0, are clearly very dependent on the natural mortality. Increasing M from 0.1 to 0.3 increases F0.1 by a factor of 2.5 and Fmax by a factor of 3.4. Flow, Fmed and Fhigh are less influenced, but are reduced by a factor of 0.57, 0.63 and 0.76, respectively.

However, the overall F-level in the VPA is also influenced by M, and for stock management the ratios between current fishing mortality and the biological reference points are of more interest than the actual values. These ratios, given in the lower part of the table, show that also in this respect are Flow, Fmed and Fhigh clearly less affected by M than F0.1 and Fmax. Thus, considering the range of M from 0.1 to 0.3, reduction of the current fishing mortality to Fmax could mean anything from 85% to 35% reduction, while the reduction needed to reach Fmed would be in the range 48-58%. The ratio Fhigh/F87 is remarkably stable and close to 0.8 for all choices of M.

4.3. Exploitation Pattern.

Table 4.2. shows mean exploitation patterns for five-year periods since 1946 and Table 4.3 shows how the biological reference points change when these exploitation patterns are used in the yield- and SSB-per-recruit calculations.

F0.1 and Fmax were quite stable for exploitation patterns from the period 1946 to 1980. However, the change in the exploitation pattern after 1980 with relatively lower mortalities on the younger fish, made F0.1 and Fmax increase considerably. Flow and Fmed, on the other hand, were within 10% from the 1987 estimates through the whole period. Fhigh was more sensitive to the changes in the exploitation pattern and the values were generally higher than the 1987 estimate.

4.4. Growth.

The growth of young individuals of North-East Arctic cod has been extremely slow in the most recent years. However, using the low 1988 weights-at-age (Anon. 1989b) instead of the fixed 1946-1982 values had little effect on the estimates of the biological reference points. Only Fmax was shifted by more than 0.01, from 0.30 to 0.26. The differences in weight are small for the age groups in the spawning stock.

The change of the nominal catch/SOP ratio with time is shown in Figure 4.2. There has been an increasing trend in the period 1946-1982, at an average rate of about 1% per year. Since the apparent increase in growth coincides with a declining trend in biomass, density dependent growth is indicated, but regression of nominal catch/SOP ratio on biomass gives a rather poor correlation (r^2=0.20 for 1950-82). It is nevertheless assumed that the regression line reflects a density dependent growth in the long term which is obscured by the relatively large short-term fluctuations in the biomass.

Figure 4.3 shows how the yield- and SSB-per-recruit curves are changed if this density-dependent growth relationship is used (assuming mean recruitment 1950-1982 of 605 millions at age). The unusual shape of the density dependent SSB/recruit curve for very low fishing mortalities indicates that the linear relationship between biomass and growth does not hold for very high biomass levels. Fmax is increased from 0.30 to 0.47. A computer program for finding F0.1 is not available, but the yield-per-recruit curve indicates that it is increased from 0.17 to about 0.30. Flow (0.31), Fmed (0.46) and Fhigh (0.77) are virtually unchanged.

4.5. Maturity Ogive.

The maturity ogives estimated by Jørgensen (1989a) are given in Table 4.4. Except for 1981 and 1982, these always give lower estimates of spawning stock biomass than knife-edge maturity at age 8, on the average less than

half (Figure 4.4). The trend is in both cases declining, but the patterns deviate.

In the recruitment/SSB plot, the 8+ SSB values were substituted with those based on the Jørgensen maturity ogives. Both plots are shown in Figure 4.5. The SSB-per-Recruit calculations had to be changed correspondingly. Means of Jørgensen maturity ogives from different earlier periods were used. The estimates of Flow, Fmed and Fhigh are stable for maturity ogives from the period before 1970, but increase when the ogives from more recent years is used. Thus, with the 1982 ogive, Fmed=0.74, while the estimates of Fmed for pre-1970 maturity ogives are in the range 0.46-0.48, which is very close to the estimate of 0.46 based on 8+ SSB. However, Flow is approximately 0.1 higher and Fhigh 0.1 lower than the 8+ estimates. Figure 4.6 shows SSB/recruit for knife-edge maturity at age 8 and for average of Jørgensen maturity ogives 1951-60.

The effect on Flow, Fmed and Fhigh of assuming knife-edge maturity at different ages is shown in Table 4.5. Fmed is least influenced and is fairly stable over the ages 5-9. Fhigh is quite stable for ages 6-12, but increases rapidly at younger ages. Flow is increasing with age and is clearly most affected.

4.6. Time Series.

The effect on Flow, Fmed and Fhigh by reducing the time series in the recruitment/SSB plot was examined by a step-wise reduction of the number of years by two. The results are given in Table 4.6. The left-hand column shows the development in Flow, Fmed and Fhigh if the estimation had started already with the period 1950-1952, i.e. with only three years in the plot, and then increasing the number of years by two up to 1950-1982, i.e. 33 years. The right-hand column starts with the recent period 1980-1982 and is extended backwards in time. Both series shows that the estimates are always within 10% of the 1950-82 values if more than 20 years are included in the plot, and in five out of six cases if 11 to 19 points are included.

4.7. Stock/Recruitment Relationship.

The SSB/Recruit ratios were ranked according to the size of the spawning stock biomass. Fmed was then calculated for groups of 11 years, shifting in steps of two years. This was done for both 8+ SSB's and the ones based on the Jørgensen (1989a) ogives (mean for 1951-60 was used to find SSB/recruit). Fmed is plotted against the mean SSB of the years used for each estimate. The results are shown in Figure 4.7 together with lines fitted by linear regression. There is a similar slight decrease in Fmed with increasing SSB in both cases. Between the highest and lowest levels of SSB, the lines indicate ranges of Fmed of 0.43-0.50 (8+ SSB) and 0.44-0.51 (Jørgensen ogives).

5. RESULTS - NORTH-EAST ARCTIC HADDOCK.

5.1. History of Stock and Exploitation.

Figure 5.1 shows the development of stock biomass, spawning stock biomass, and fishing mortality from 1950 to 1987. Although there is a declining trend in the biomass, it is much less pronounced than for cod and there are large fluctuations which are caused mainly by the two extremely strong year classes 1950 and 1969. The fishing mortality is very variable, but shows no clear trend.

The fishing mortality has on the average been 0.57, more than 60% higher

than the Fmed estimate of 0.35 (Anon. 1989b).

Figure 5.2 shows the plot of recruitment versus SSB and Figure 5.3 shows the yield- and SSB-per-recruit curves.

5.2. Natural Mortality.

The effect on the biological reference points by varying the natural mortality is shown in Table 5.1. F0.1 and Fmax are even more influenced than for cod and Fmax cannot be found for M=0.4. Increasing M from 0.1 to 0.3, increases F0.1 and Fmax by a factor of 3.1 and 5.1, respectively. Within the same range of M, reducing fishing mortality to F0.1 could mean anything from 59% to 90% reduction, and correspondingly fishing at Fmax could require 81% reduction or 23% increase.

Flow, Fmed and Fhigh roughly follow the same pattern as for cod, but Flow is at a very low level and at M=0.3 and M=0.4 it cannot be found. The reason is that the SSB/recruit corresponding to the estimated slope is higher than the long-term value estimated for an unexploited stock.

Compared to the current F, Fmed varies more than for cod, but still considerably less than F0.1 and Fmax. Thus, for M of 0.1 - 0.3 the reduction needed to reach Fmed is 42-65%. The ratio Fhigh/F(1987) varies very little with M.

5.3. Exploitation Pattern.

Mean exploitation patterns for different periods are shown in Table 5.2. As for cod, fishing mortality on the youngest age groups was relatively high in the 1970's. The effect of these exploitation patterns on the biological reference points is shown in Table 5.3. The estimates for F0.1, Fmax, Flow and Fhigh may deviate as much as 15-20% from the mean, whereas Fmed always is within 8% of the mean.

5.4. Growth.

The change of weights-at-age from the low values (on the youngest age groups) used by the Arctic Fisheries Working Group (Anon. 1989b) to those in the 1950-1982 data base, increased F0.1 from 0.13 to 0.16 and Fmax from 0.23 to 0.39, but had little effect on Flow, Fmed and Fhigh.

The nominal landings/SOP ratio shows a similar increasing trend with time as for cod, indicating an increase in the growth rate, However, no relationship between biomass and SOP discrepancy was found.

5.5. Maturity Ogive.

There is no evidence of changes in maturity for haddock, but the similarity with the SOP development for cod indicates that there may be similarities also in maturity. However, even if no change has taken place, it is possible that the maturity ogive from Sætersdal (1954), corresponding roughly to 50% maturity at age 6, gives biased estimates. The estimates of Flow, Fmed and Fhigh for different assumptions of age of knife-edge maturity are given in Table 5.4. The effect is relatively large, with Flow and Fmed generally increasing with the age, whereas Fhigh is decreasing.

5.6. Time Series.

As for cod the time series used in the recruitment/SSB plot was reduced both from 1950 and from 1982 and the results are given in Table 5.5. If the

estimation had started in the 1950's, the left-hand part of the table, the estimates of Flow, Fmed and Fhigh would have been decreasing, but the main change for Flow and Fmed would not have occurred before the late 1970's.

Extending the series backwards from 1982, 31 years are needed before Flow is found and Fhigh is virtually unchanged over the period, though some odd estimates occur. For the most recent period even Fmed cannot be found and more than 20 years is needed before it approximates the level of the 1950-82 estimate.

5.7. Stock/Recruitment Relationship.

Fmed estimates resulting from ranking SSB/recruit ratios according to the size of the spawning stock biomass, are plotted in Figure 5.4 versus the mean SSB of the years used for each estimate. In contrast to cod, there is a slight increase in Fmed with increasing SSB. The regression line indicates n increase from 0.32 to 0.40 over the range of SSB.

6. DISCUSSION.

The results demonstrate that FO.1 and Fmax are strongly influenced by the choice of natural mortality, as shown by Beverton and Holt (1957) and Anon. (1985). Furthermore, the estimate of current fishing mortality also changes with the natural mortality, but in the opposite direction. Thus, the ratios FO.1/current F and Fmax/current F are even more dependent on the natural mortality. These ratios are of most interest to the stock managers, since they indicate how large reduction in effort is needed to reduce fishing mortality to the F.01 or Fmax level. The ratios are also important for the TAC's corresponding to FO.1 and Fmax.

The estimates of FO.1 and Fmax may be severely underestimated if there is a density dependent growth which is not taken into account. Compared to the influence of natural mortality and density dependence, the effect of the exploitation pattern and the weight-at-age data is small. In fact, the variations caused by these parameters do not necessarily represent errors in the estimates, but there is a problem in choosing the appropriate values for the estimation if changes in fishing mortality can be expected to change the exploitation pattern or the growth. Otherwise, the variations only reflect that FO.1 and Fmax are not constant values.

The estimate of Fmed for cod by the Arctic Fisheries Working Group was 0.69 (Anon. 1989b), whereas the level estimated in the current paper in most cases is between 0.4 and 0.5. This difference is caused mainly by the maturity ogive. The ogive used by the Working Group has maturity at a considerably younger age than knife-edge maturity at age 8 or the ogives of Jørgensen (1989a). This shows that the estimate of Fmed may be strongly biased if the ogive used in the SSB-per-Recruit calculation is very different from the ogives during the period used for the recruitment/SSB plot.

Iτ is obvious that changes ιν growth can result in a biased Fmed estimate ιφ τηε ωρονγ δατα σετ ισ υσεδ φορ τηε ΣΣΒ/ρεξρυιτ ξαλξυλατιον. For all other possible sources of errors assumed, the Fmed estimate for cod is remarkably stable, usually within 10% from the basis estimate of 0.46. The basis estimate is the one based on the parameters that are kept as constants varying other parameters, i.e., the value corresponding to M=0.2 in Tables 4.1 and 5.1.

For haddock the Fmed estimate is more sensitive to change in the parameters, especially age at maturity and the time series in the recruitment/SSB plot.

Nevertheless, there is a basis estimate of 0.35 and a strong indication of a level of 0.3-0.4.

For cod the estimate of Flow is fairly robust and a level slightly in excess of 0.3 is indicated, with a basis estimate of 0.32. Flow for haddock is estimated to be very small (basis=0.02). The assumptions about natural mortality and maturity are most important for the Flow estimate.

One interesting aspect of Fhigh is that the ratio Fhigh/current F is virtually unaffected by the choice of natural mortality. For cod it appears to be most affected by the exploitation pattern which gives somewhat higher estimates in the past. With the current exploitation pattern, the estimate is fairly stable at 0.75-0.80 (basis=0.78) for what appears to be reasonable assumptions about the other parameters.

For haddock, Fhigh is more sensitive to the exploitation pattern than for cod and it is also quite sensitive to the maturity ogive. Altogether, the results indicate a range for Fhigh of about 0.8-1.3, while the basis estimate is 1.11.

The estimate of Fmed does not take into account how the points in the recruitment/SSB plot are distributed about the line. If the distribution is skewed, the estimate may be biased. Av examination of the plot in Figure 4.5 shows that the points above the Fmed line on the average are farther away from the line than those below the line. Hence, if average $\varrho\in\text{Souit}/\Sigma\Sigma B$ had been used instead of the middle value to estimate Fmed, the estimate for cod would have been higher. However, when the distribution is skewed, the middle value will be more robust than the average. Furthermore, using the middle value means not relying on the chance occurrence of a strong year class to sustain the stock, which is especially important when the stock is at a low level.

In the recruitment/SSB plot for haddock (Figure 5.2), the points are clearly less evenly distributed around the Fmed line than for cod, mainly because of the extremely abundant year classes 1950 and 1969. These may also explain why the haddock stock has been sustained for a long time at fishing mortalities above Fmed. Apart from these two year classes, however, the distribution is similar to that of the cod. The haddock's potential for producing extremely strong year classes gives hope of a quicker recovery, but with an interval of nearly 20 years between the two, management cannot be based on the assumption that another will come in the near future.

Figure 4.7 indicates that the recruitment/SSB relationship for cod is to some extent dependent on the size of the spawning stock. This suggests that fishing mortality below Fmed is needed to sustain the stock at higher levels. For haddock the trend is opposite (Figure 5.4) which suggests that fishing mortality below Fmed is needed to sustain the stock at its current level. A possibility is to introduce the concept "conditional Fmed" which corresponds to a certain target level of spawning stock biomass. However, the differences for the cod and the haddock are small and possibly not statistically significant, and the "conditional Fmed" may be more relevant for other stocks.

The results for both cod and haddock strongly indicate that Fmed is the biological reference point which is most reliably estimated. The crucial point, at least for the cod, seems to be whether the maturity is density dependent oo vot. There is substantial evidence of reduced age at maturity for cod during the post-war period (Anon. 1983, Jørgensen 1989a) and the alternative explanation is that this is a response to long-term changes in the environment. An environmental effect cannot be ruled out. However, if

this is accepted as the sole cause, and fishing therefore is allowed to continue at a high level, e.g. at the previous Fmed estimate of 0.69, it could mean disaster to the stock.

Flow seems too low to be of practical use in the management for haddock, although it suggests that stopping the fishery for a period would be safest. For cod, however, it indicates that fishing mortality of about 0.3 may be a σουνδ level ιφ τηε γοαλ ισ το rebuild the stock at a fairly quick rate.

The Fhigh estimate for cod is fairly robust and its ξοεδιβιλιτΨ as an indicator of a dangerously high level of fishing mortality has been strengthened. The more variable Fhigh estimates for haddock makes it less useful as a reference point for that stock.

Which, if any, biological reference points should be used in the recommendation for cod and haddock? There are good arguments to favour the Fmed-group over FO.1 and Fmax as far as the reliability of the estimates are concerned and also because the former are based on historic evidence. This does not necessarily mean that FO.1 and Fmax are unsuitable as recommended levels in the present stock situation, but it is difficult to defend their use based on the yield considerations alone.

For both cod and haddock, the first objective must be to rebuild the stocks. Since Fmed will tend to sustain the stocks at their current level, fishing mortality below Fmed is needed. For cod, Flow may represent a suitable, and relatively safe level in the short-term. When the spawning stock has been rebuilt to a σατισφαξτοοΨ level, an appropriate level of fishing mortality may be recommended. This σηould be ειτηεο Φμεδ or a "conditional Fmed".

For haddock a similar approach may be used, but FO.1 may be an alternative to Flow in the short-term, especially since substantial by-catches in the cod fishery are difficult to avouid. Although the estimate of FO.1 is unreliable in relative terms, it will always be at a fairly low level which normally should not endanger the stock.

7. REFERENCES

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Table 4.1. NORTH-EAST ARCTIC COD.
        Effect of Natural Mortality on Biological Reference Points.

M	F87	FO.1	Fmax	Flow	Fmed	Fhigh
0.0	1.22	--	--	0.51	0.67	0.99
0.1	1.10	0.10	0.16	0.42	0.57	0.88
0.2	0.98	0.17	0.30	0.32	0.46	0.78
0.3	0.85	0.25	0.55	0.24	0.36	0.67
0.4	0.73	0.35	2.65	0.15	0.26	0.57

M	FO.1/F87	Fmax/F87	Flow/F87	Fmed/F87	Fhigh/F87
0.0	--	--	0.42	0.55	0.81
0.1	0.09	0.15	0.38	0.52	0.80
0.2	0.18	0.31	0.33	0.47	0.80
0.3	0.30	0.65	0.28	0.42	0.79
0.4	0.48	3.64	0.20	0.36	0.78

Table 4.2. NORTH-EAST ARCTIC COD.
Exploitation Patterns ($F_{5-10}=1$).

Age	Period								
	46-50	51-55	56-60	61-65	66-70	71-75	76-80	81-85	87
3	0.01	0.05	0.09	0.06	0.05	0.18	0.14	0.05	0.04
4	0.07	0.31	0.37	0.30	0.26	0.39	0.38	0.20	0.14
5	0.32	0.63	0.70	0.74	0.53	0.64	0.68	0.39	0.61
6	0.73	0.89	1.00	0.92	0.69	0.73	0.85	0.69	1.07
7	1.28	0.98	0.98	0.87	0.86	0.79	0.92	1.14	1.33
8	0.98	0.90	1.02	0.97	1.13	1.10	1.09	1.34	1.23
9	1.37	1.13	0.98	1.19	1.42	1.35	1.35	1.41	0.97
10	1.32	1.47	1.32	1.31	1.37	1.39	1.11	1.04	0.79
11	2.26	1.78	1.58	1.39	1.22	1.54	1.39	0.87	0.59
12	1.93	1.81	1.74	1.22	1.07	1.13	1.30	0.89	0.70
13	1.79	1.62	1.64	1.41	1.39	1.73	1.67	0.98	0.57
14	1.83	1.67	1.57	1.34	1.26	1.45	1.37	0.95	0.66

Table 4.3. NORTH-EAST ARCTIC COD.
Effect of Exploitation Pattern on Biological Reference Points.

	Period								
	46-50	51-55	56-60	61-65	66-70	71-75	76-80	81-85	87
F0.1	0.10	0.10	0.11	0.12	0.13	0.11	0.11	0.15	0.17
Fmax	0.22	0.20	0.20	0.22	0.24	0.20	0.21	0.28	0.30
Flow	0.33	0.31	0.30	0.31	0.34	0.31	0.30	0.34	0.32
Fmed	0.50	0.46	0.44	0.47	0.51	0.44	0.45	0.50	0.46
Fhigh	0.97	0.86	0.79	0.84	0.95	0.86	0.81	0.90	0.78

Table 4.4. NORTH-EAST ARCTIC COD.
Maturity ogives (Jørgensen 1989a).

Year	Age												
	3	4	5	6	7	8	9	10	11	12	13	14	15+
1950	-	-	-	-	5	19	36	61	86	98	100	100	100
1951	-	-	-	-	6	21	43	61	82	92	100	100	100
1952	-	-	-	-	4	22	48	73	88	98	100	100	100
1953	-	-	-	-	2	15	47	74	92	99	100	100	100
1954	-	-	-	-	4	14	43	78	93	98	99	100	100
1955	-	-	-	-	3	11	33	64	92	97	100	100	100
1956	-	-	-	-	-	12	25	57	81	98	100	100	100
1957	-	-	-	-	1	4	30	47	79	95	100	100	100
1958	-	-	-	-	1	5	13	52	74	95	100	100	100
1959	-	-	-	-	1	8	23	41	88	91	100	100	100
1960	-	-	-	-	1	10	35	62	81	98	100	100	100
1961	-	-	-	-	1	10	47	83	93	98	100	100	100
1962	-	-	-	-	3	13	39	80	95	95	100	100	100
1963	-	-	-	-	3	17	45	67	96	98	96	100	100
1964	-	-	-	-	2	19	53	85	90	99	100	100	100
1965	-	-	-	-	-	14	53	76	99	98	100	100	100
1966	-	-	-	-	-	2	42	81	83	99	100	100	100
1967	-	-	-	-	-	2	10	82	100	100	100	100	100
1968	-	-	-	-	-	3	20	70	100	100	100	100	100
1969	-	-	-	-	1	12	40	72	87	100	100	100	100
1970	-	-	-	-	4	13	63	90	99	94	100	100	100
1971	-	-	-	-	4	33	68	91	100	100	100	100	100
1972	-	-	-	1	12	37	78	92	94	100	100	100	100
1973	-	-	-	-	11	48	76	97	98	95	100	100	100
1974	-	-	-	-	7	40	82	94	100	100	100	100	100
1975	-	-	-	1	10	30	76	99	98	100	100	100	100
1976	-	-	-	1	8	30	66	100	100	100	100	100	100
1977	-	-	-	1	10	31	58	83	100	100	100	100	100
1978	-	-	-	3	20	55	84	98	97	100	100	100	100
1979	-	-	-	2	14	53	86	99	100	100	100	100	100
1980	-	-	-	2	20	50	84	96	100	100	100	100	100
1981	-	-	-	8	23	65	93	98	97	100	100	100	100
1982	-	-	-	15	46	74	98	100	100	100	100	100	100

Table 4.5. NORTH-EAST ARCTIC COD.
Effect of Age at first Maturity on Flow, Fmed and Fhigh.

Age at maturity	Flow	Fmed	Fhigh
4	0.12	0.38	1.87
5	0.18	0.42	1.19
6	0.22	0.46	0.87
7	0.29	0.46	0.75
8	0.33	0.46	0.78
9	0.41	0.49	0.75
10	0.42	0.55	0.77
11	0.44	0.60	0.78
12	0.49	0.69	0.85

Table 4.6. NORTH-EAST ARCTIC COD.
Effect of Time Series on Flow, Fmed and Fhigh.

Number of years	Period	Flow	Fmed	Fhigh	Period	Flow	Fmed	Fhigh
3	1950-52	0.22	0.34	0.50	1980-82	0.49	0.69	0.78
5	1950-54	0.22	0.35	0.50	1978-82	0.31	0.49	0.78
7	1950-56	0.22	0.38	0.50	1976-82	0.31	0.46	0.78
9	1950-58	0.22	0.41	0.50	1974-82	0.31	0.49	0.78
11	1950-60	0.34	0.44	0.48	1972-82	0.34	0.49	0.73
13	1950-62	0.34	0.44	0.50	1970-82	0.34	0.49	0.78
15	1950-64	0.34	0.46	0.81	1968-82	0.34	0.49	0.78
17	1950-66	0.28	0.44	0.81	1966-82	0.31	0.47	0.78
19	1950-68	0.28	0.44	0.81	1964-82	0.31	0.47	0.79
21	1950-70	0.33	0.46	0.79	1962-82	0.33	0.49	0.79
23	1950-72	0.33	0.46	0.79	1960-82	0.33	0.47	0.79
25	1950-74	0.33	0.46	0.79	1958-82	0.33	0.47	0.79
27	1950-76	0.33	0.46	0.79	1956-82	0.33	0.47	0.79
29	1950-78	0.31	0.46	0.79	1954-82	0.33	0.47	0.79
31	1950-80	0.33	0.46	0.73	1952-82	0.33	0.46	0.78
33	1950-82	0.33	0.46	0.78	1950-82	0.33	0.46	0.78

Table 5.1. NORTH-EAST ARCTIC HADDOCK.
Effect of Natural Mortality on Biological Reference Points.

M	F87	FO.1	Fmax	Flow	Fmed	Fhigh
0.0	0.92	--	--	0.21	0.56	1.34
0.1	0.82	0.08	0.16	0.12	0.47	1.24
0.2	0.72	0.16	0.39	0.02	0.35	1.11
0.3	0.64	0.26	0.79	--	0.22	0.95
0.4	0.58	0.38	--	--	0.14	0.78

M	FO.1/F87	Fmax/F87	Flow/F87	Fmed/F87	Fhigh/F87
0.0	--	--	0.23	0.61	1.45
0.1	0.10	0.19	0.14	0.58	1.51
0.2	0.22	0.54	0.03	0.48	1.54
0.3	0.41	1.23	--	0.35	1.49
0.4	0.67	--	--	0.24	1.36

Table 5.2. NORTH-EAST ARCTIC HADDOCK.
Exploitation Patterns $(F_{4-7}=1)$.

Age	Period							
	51-55	56-60	61-65	66-70	71-75	76-80	81-85	87
3	0.15	0.20	0.18	0.21	0.44	0.47	0.26	0.08
4	0.54	0.49	0.66	0.63	0.85	0.97	0.69	0.47
5	0.91	0.88	1.08	0.98	1.23	1.17	0.95	1.01
6	1.11	1.22	1.21	1.18	1.05	0.98	1.21	1.53
7	1.44	1.41	1.05	1.22	0.87	0.88	1.15	0.99
8	1.50	1.31	0.94	1.09	0.78	0.83	1.18	0.87
9	1.52	1.33	1.09	0.83	0.71	0.77	1.03	1.04
10	1.03	1.35	0.58	0.83	0.78	0.82	1.12	1.06
11	1.31	1.55	0.88	0.96	0.77	1.40	1.35	0.84
12	1.04	1.55	1.60	1.11	1.02	1.12	2.46	1.51
13	1.23	1.44	1.04	0.93	0.82	1.03	1.49	1.11

Table 5.3. NORTH-EAST ARCTIC HADDOCK.
Effect of Exploitation Pattern on Biological Reference Points.

	Period							
	51-55	56-60	61-65	66-70	71-75	76-80	81-85	87
FO.1	0.14	0.13	0.16	0.17	0.17	0.15	0.12	0.16
Fmax	0.34	0.32	0.35	0.36	0.33	0.30	0.29	0.39
Flow	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02
Fmed	0.32	0.32	0.34	0.34	0.32	0.31	0.31	0.35
Fhigh	1.09	1.08	0.95	0.97	0.79	0.77	0.92	1.11

Table 5.4. NORTH-EAST ARCTIC HADDOCK.
         Effect of Age at first Maturity on Flow, Fmed and Fhigh.

Age at maturity	Flow	Fmed	Fhigh
3	--	0.24	2.99
4	--	0.34	2.03
5	--	0.31	1.46
6	0.04	0.34	1.05
7	0.07	0.41	0.75
8	0.07	0.50	0.74
9	0.13	0.52	0.74
10	0.17	0.50	0.70

Table 5.5. NORTH-EAST ARCTIC HADDOCK.
         Effect of Time Series on Flow, Fmed and Fhigh.

Number of years	Period	Flow	Fmed	Fhigh	Period	Flow	Fmed	Fhigh
3	1950-52	0.29	0.45	1.28	1980-82	--	--	1.11
5	1950-54	0.19	0.45	1.28	1978-82	--	--	1.11
7	1950-56	0.13	0.45	1.28	1976-82	--	0.04	1.11
9	1950-58	0.13	0.44	1.28	1974-82	--	0.05	1.11
11	1950-60	0.19	0.45	0.83	1972-82	--	0.21	0.39
13	1950-62	0.19	0.45	0.87	1970-82	--	0.22	0.67
15	1950-64	0.19	0.46	1.14	1968-82	--	0.27	1.11
17	1950-66	0.10	0.45	1.14	1966-82	--	0.27	1.11
19	1950-68	0.10	0.45	1.14	1964-82	--	0.27	1.14
21	1950-70	0.13	0.46	1.14	1962-82	--	0.29	1.11
23	1950-72	0.13	0.45	1.14	1960-82	--	0.31	1.11
25	1950-74	0.13	0.44	1.14	1958-82	--	0.31	1.11
27	1950-76	0.13	0.39	1.14	1956-82	--	0.35	1.11
29	1950-78	0.04	0.39	1.14	1954-82	--	0.31	1.11
31	1950-80	0.04	0.35	0.88	1952-82	0.02	0.31	0.88
33	1950-82	0.02	0.35	1.11	1950-82	0.02	0.35	1.11
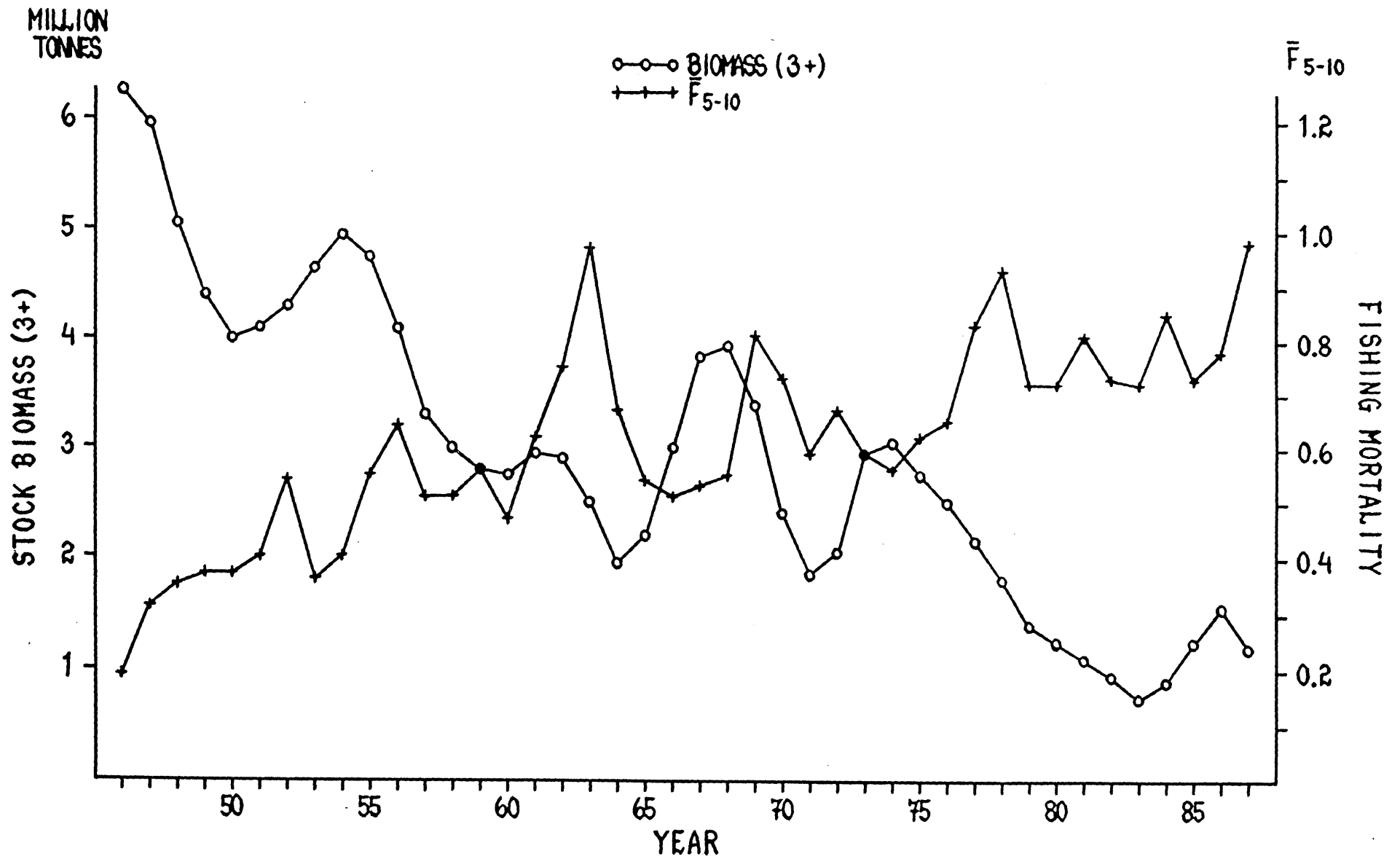
Figure 4.1. NORTH-EAST ARCTIC COD.
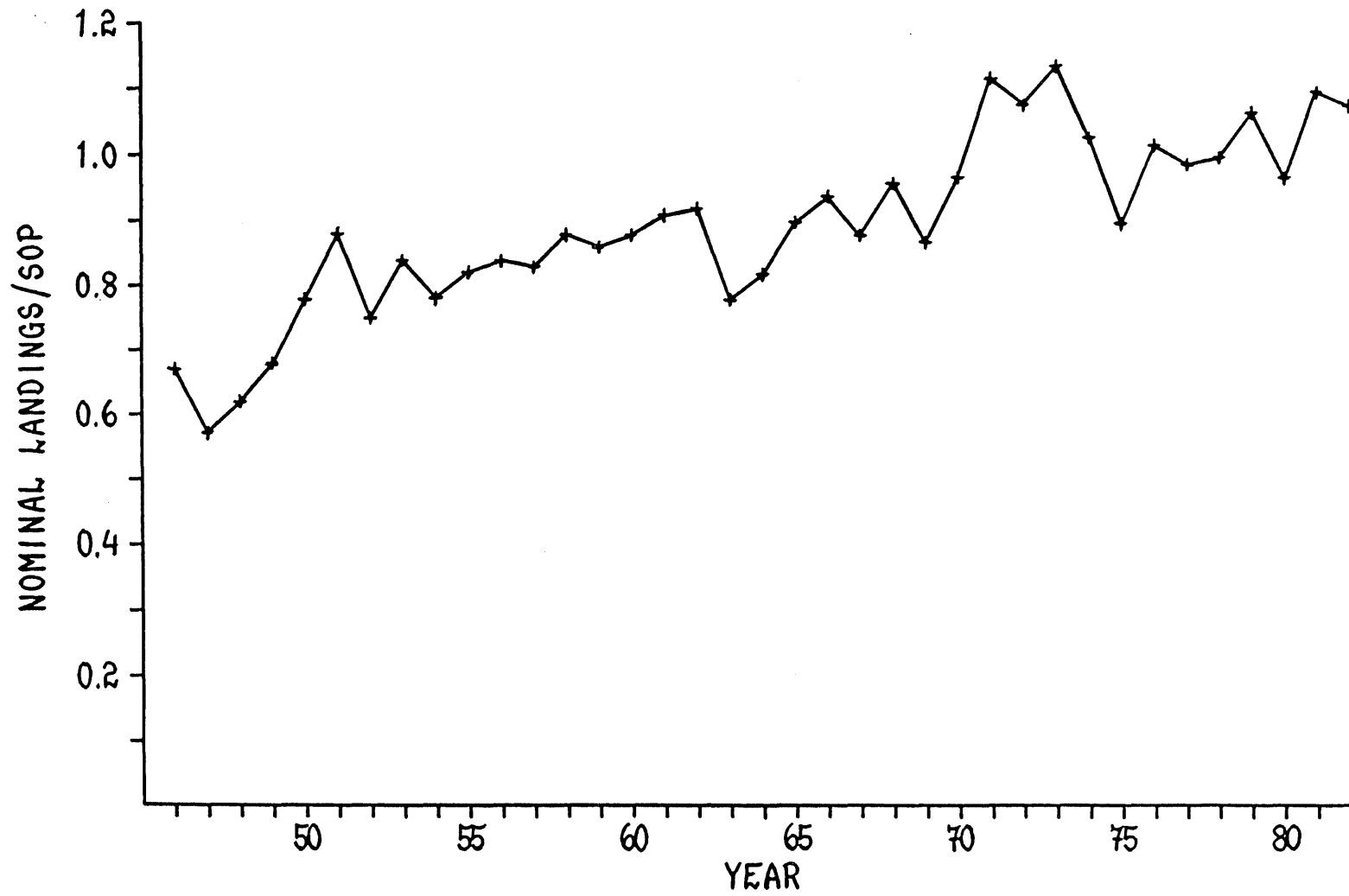Stock Biomass and Fishing Mortality 1946-1987.

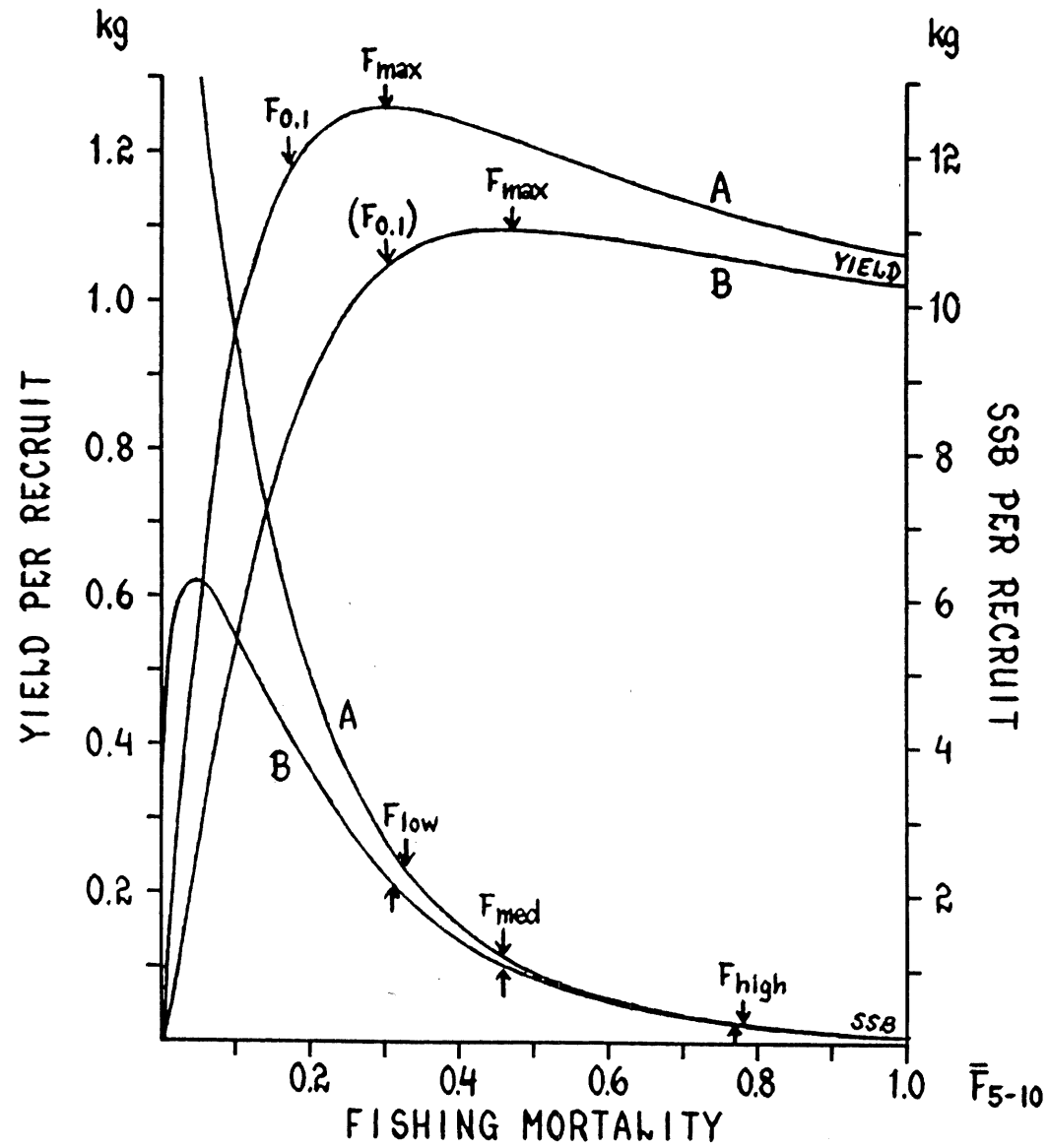Figure 4.2. NORTH-EAST ARCTIC COD.
Nominal landings/SOP ratio 1946-1982.

Figure 4.3. NORTH-EAST ARCTIC COD.
Yield and Spawning Stock Biomass per Recruit (age 3).
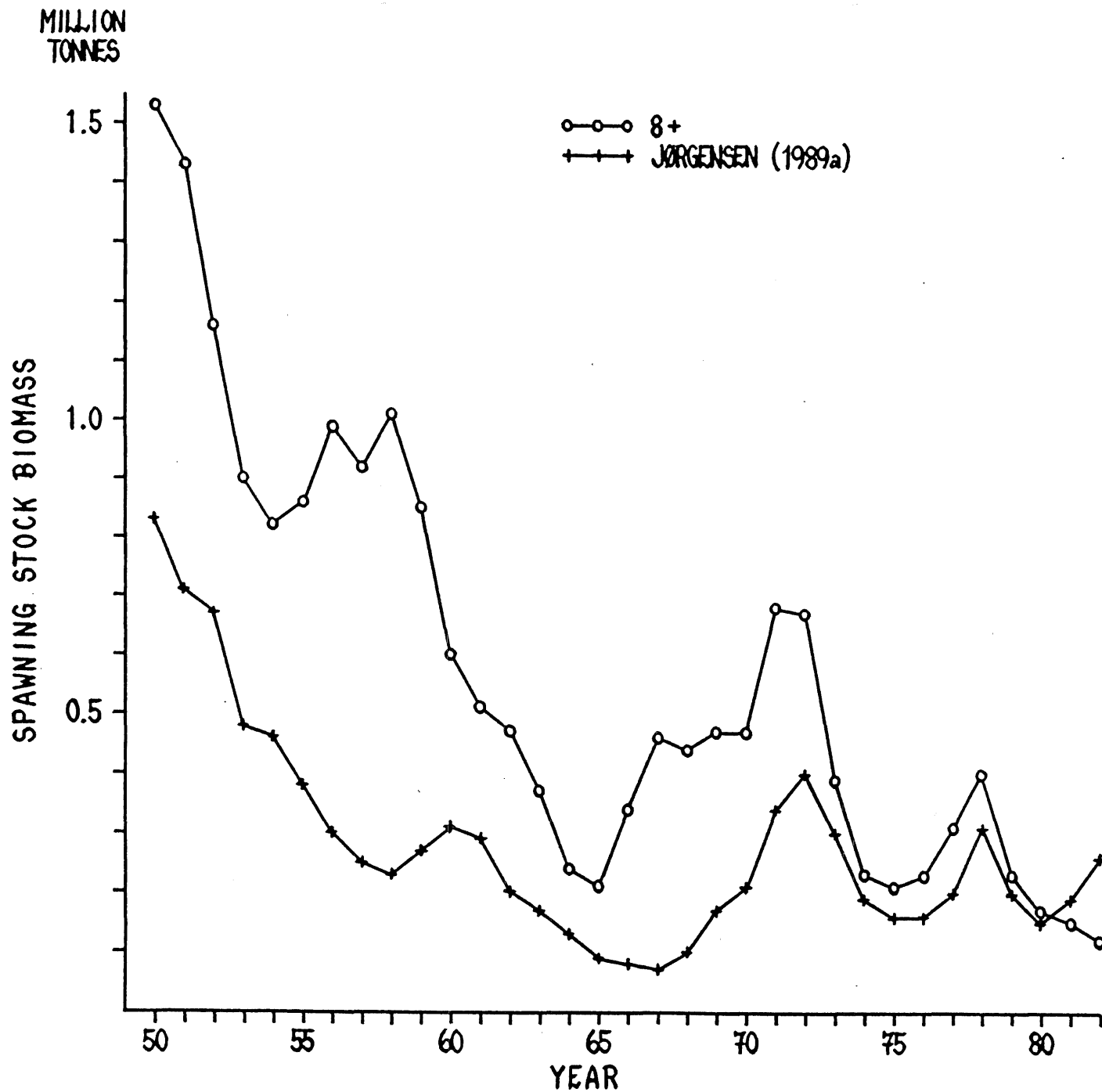A) Stable growth, B) Density dependent growth.

Figure 4.4. NORTH-EAST ARCTIC COD.
Spawning Stock Biomass 1950-1982, based on knife-edge maturity
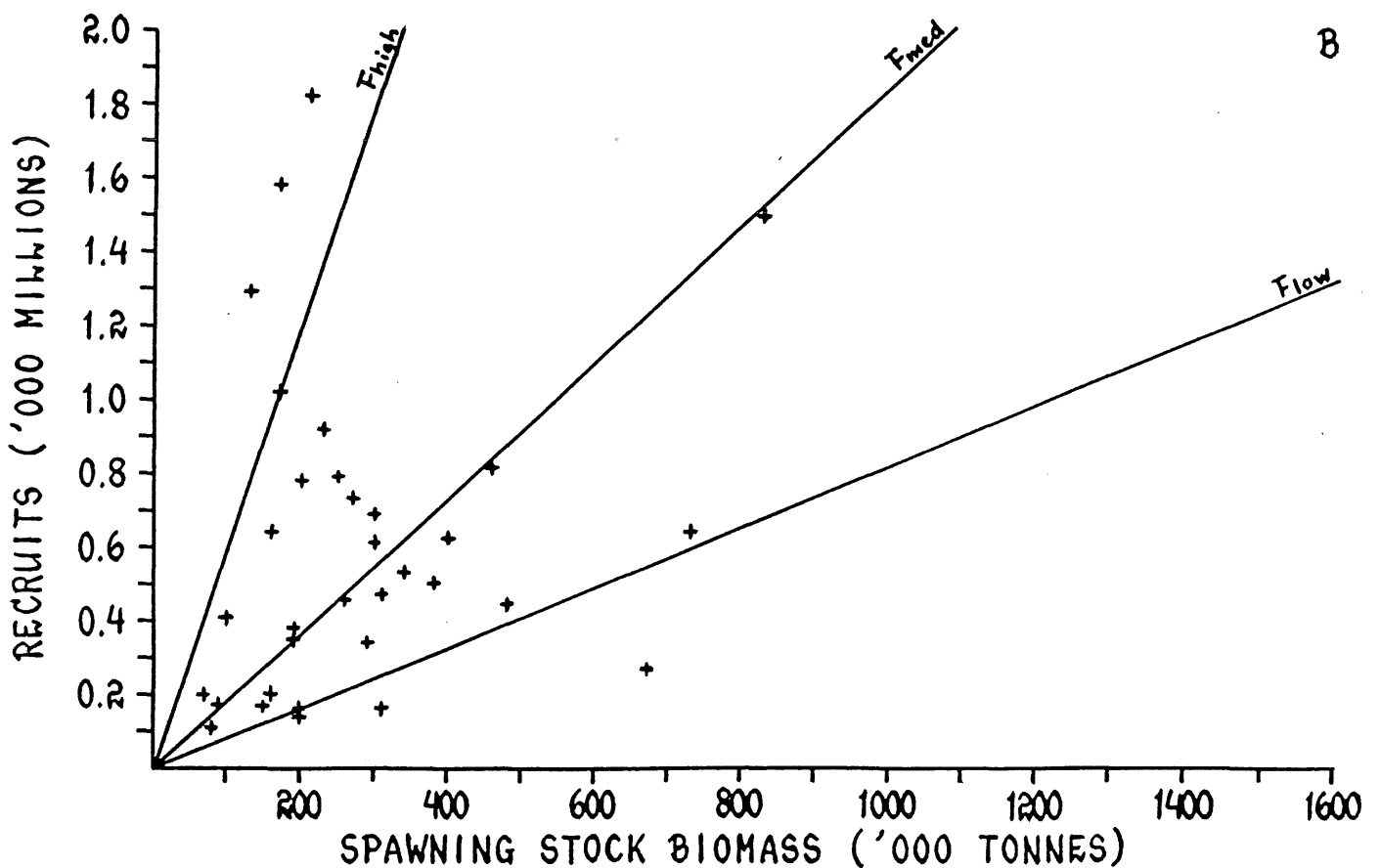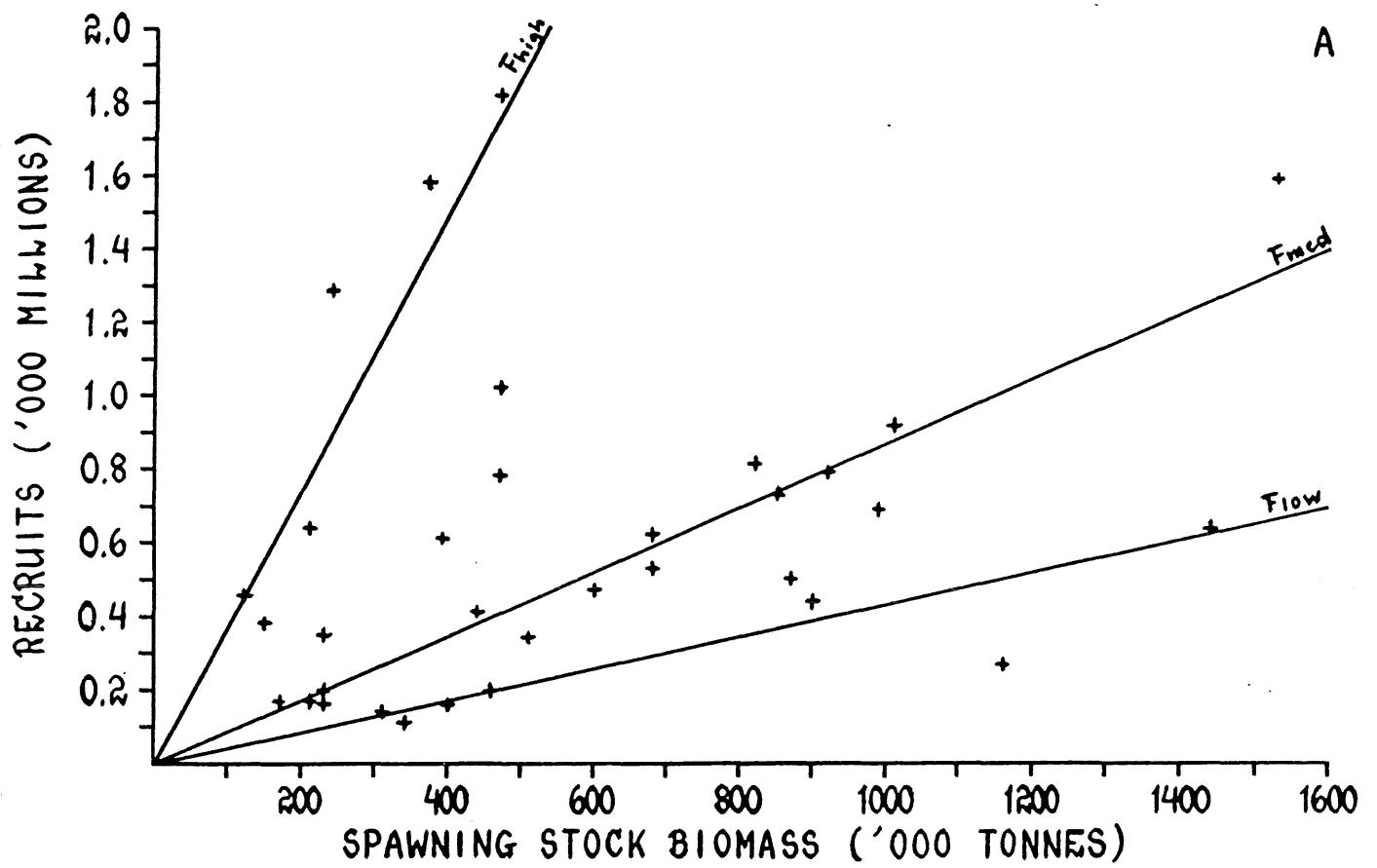at age 8 and the maturity ogives from Jørgensen (1989a).

Figure 4.5. NORTH-EAST ARCTIC COD.
Recruitment (age 3) versus Spawning Stock Biomass.
A) Knife-edge maturity at age 8.
B) Maturity ogives from Jørgensen (1989a).
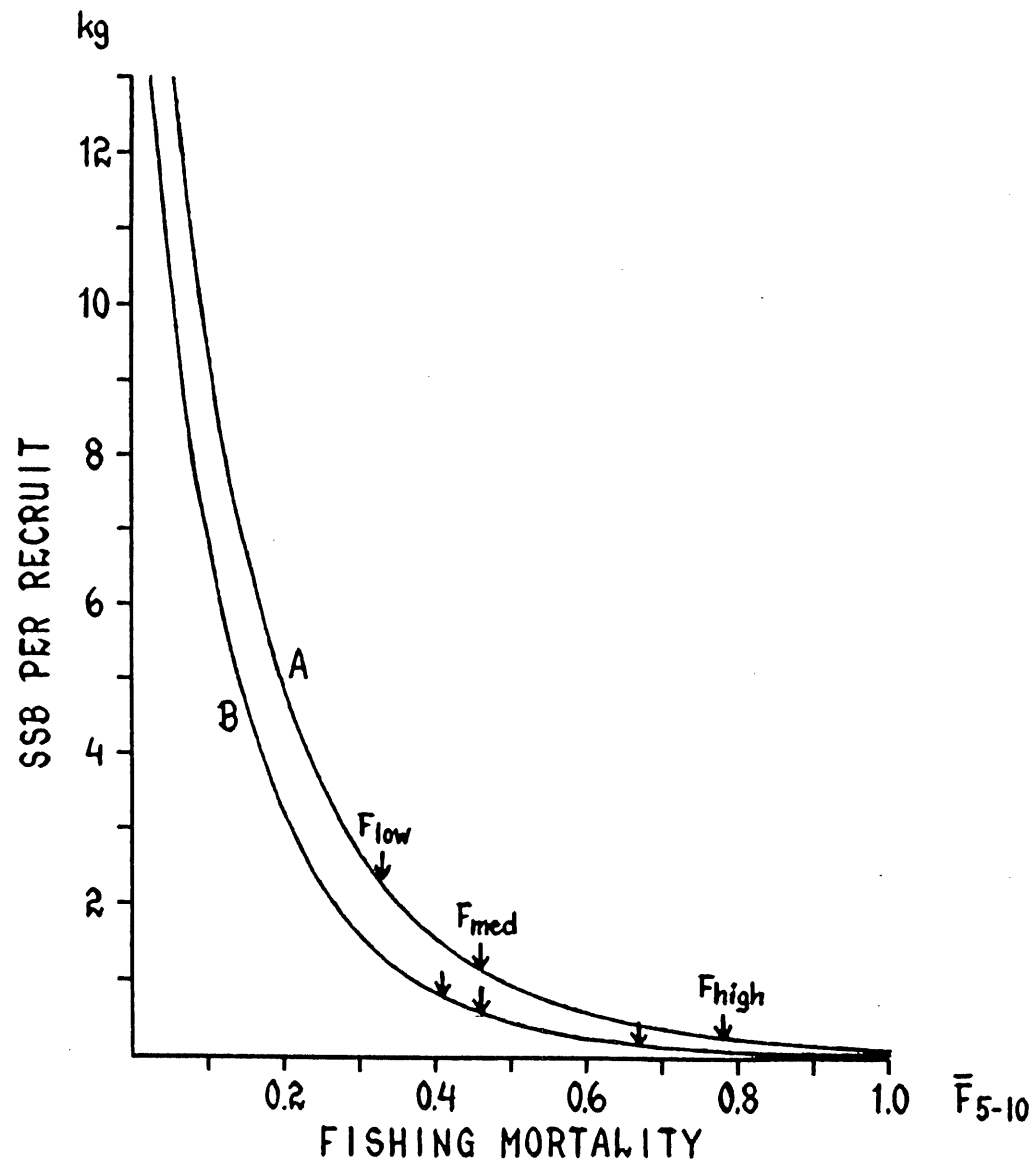
Figure 4.6. NORTH-EAST ARCTIC COD.
        Spawning Stock Biomass per Recruit (age 3).
        A) Knife-edge maturity at age 8.
        B) Mean maturity ogive for 1951-1960 from Jørgensen (1989a).
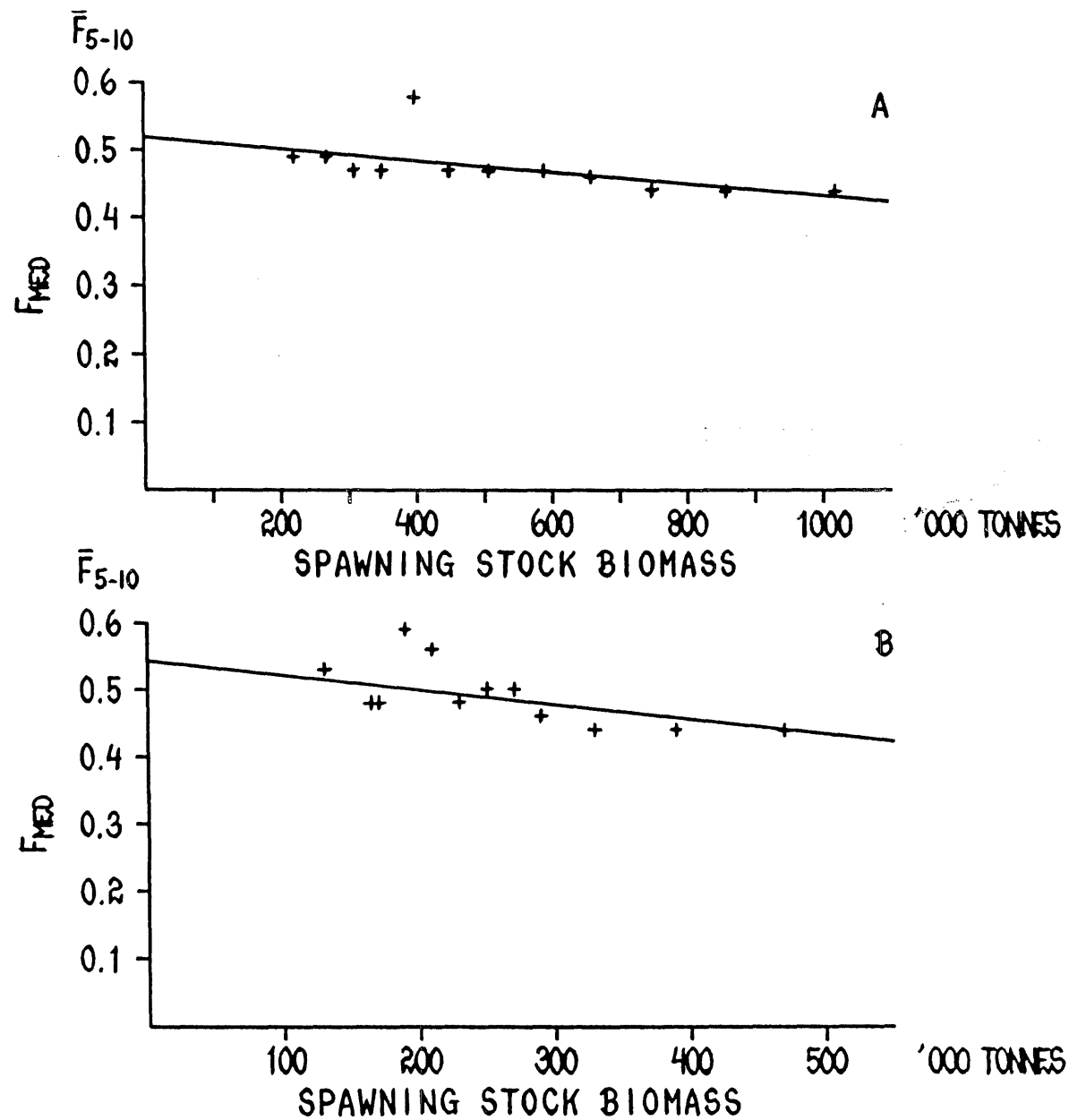
Figure 4.7. NORTH-EAST ARCTIC COD.
Fmed-estimate versus mean Spawning Stock Biomass.
A) Knife-edge maturity at age 8.
B) Maturity ogives from Jørgensen (1989a).
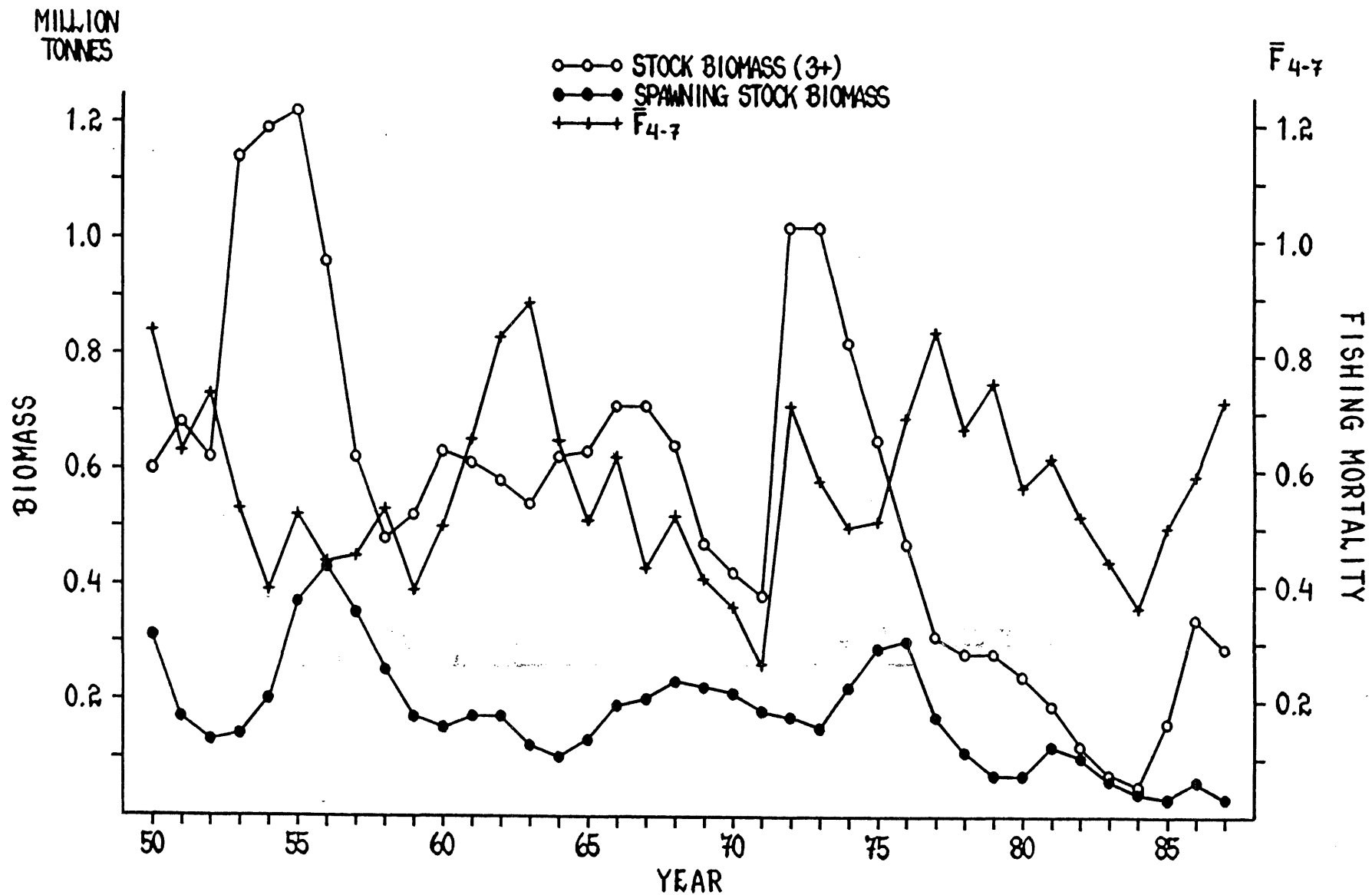
Figure 5.1. NORTH-EAST ARCTIC HADDOCK.
Stock Biomass, Spawning Stock Biomass and Fishing Mortality 1950-1987.
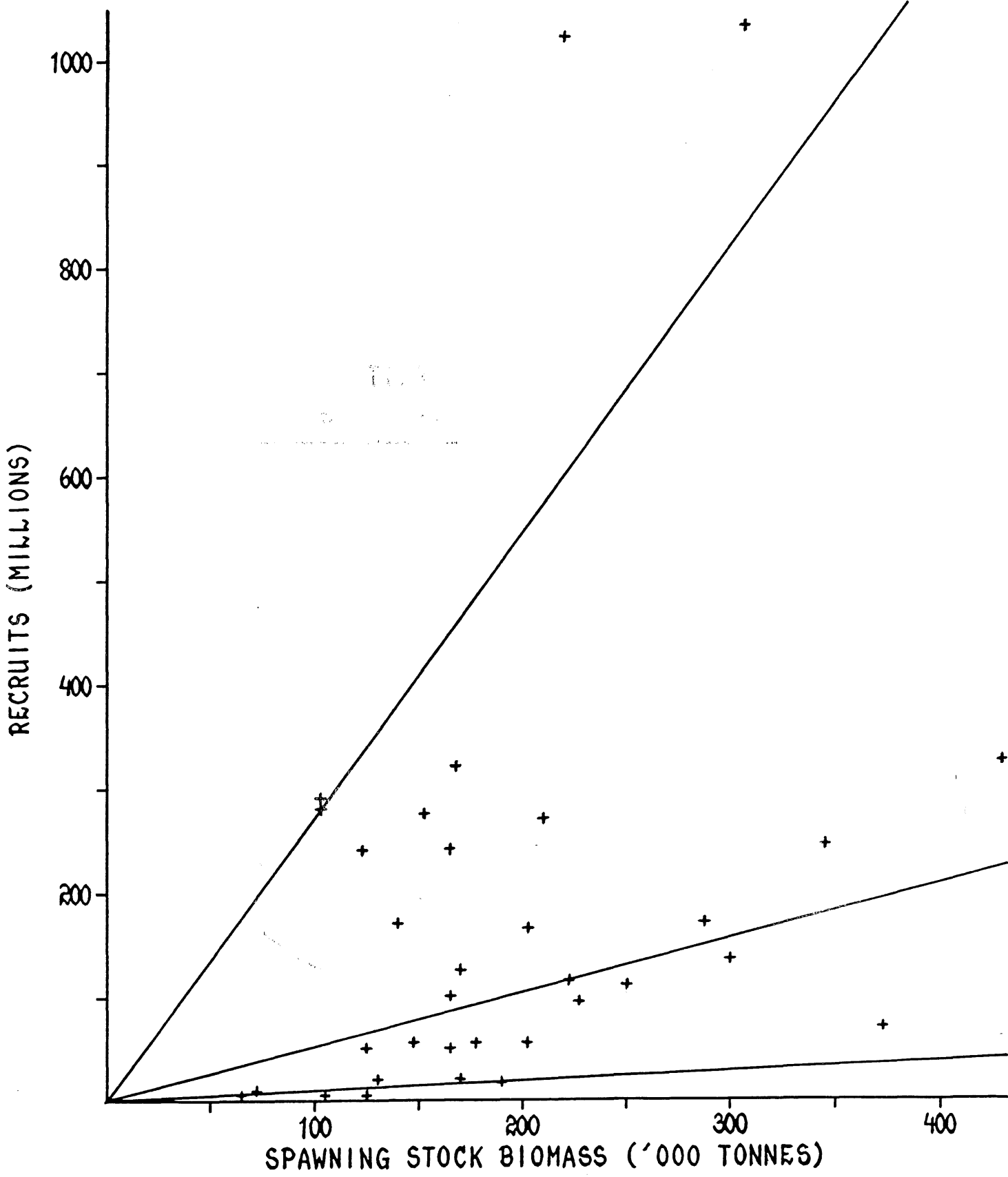
Figure 5.2. NORTH-EAST ARCTIC HADDOCK.
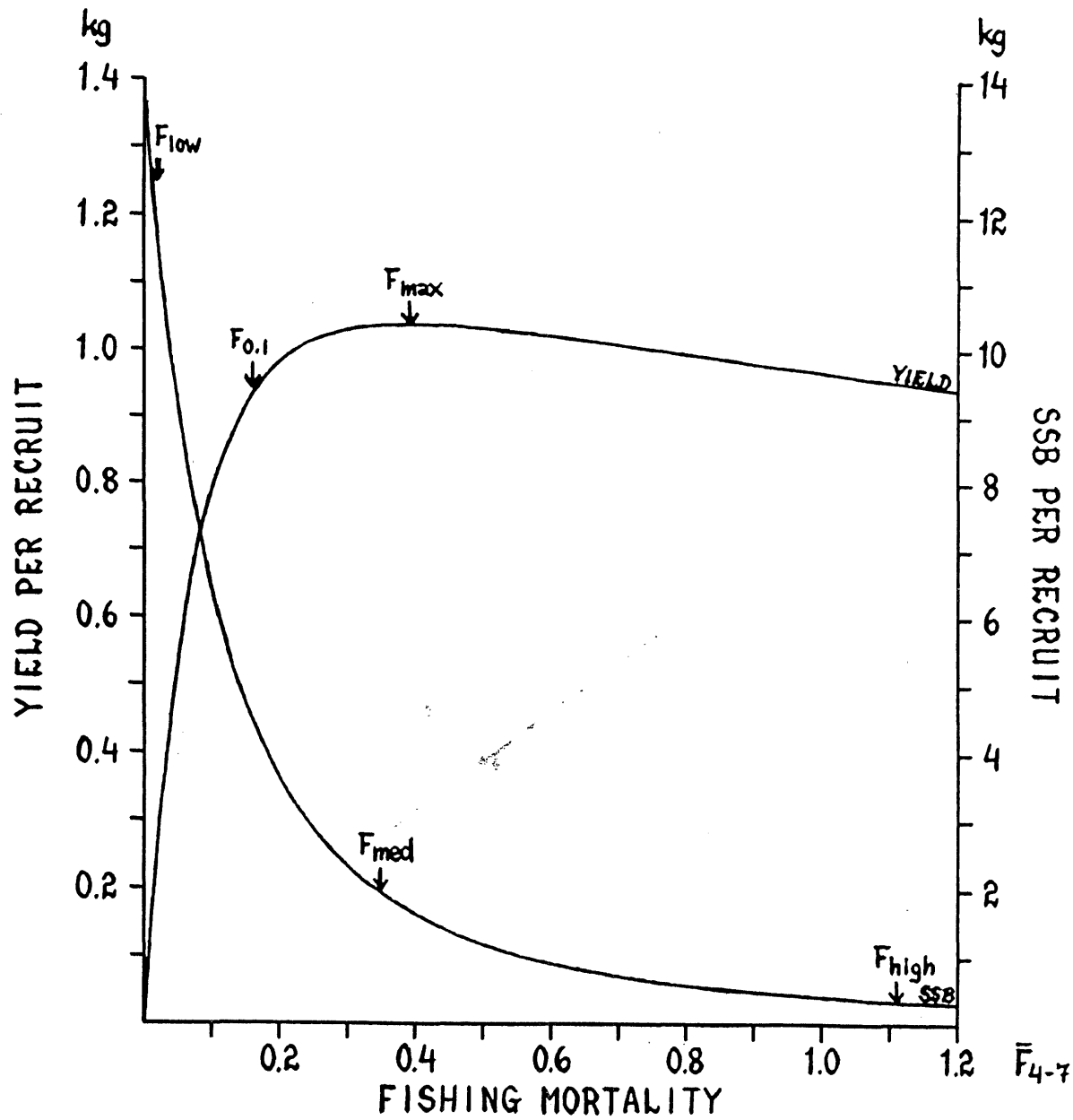   Recruitment (age 3) versus Spawning Stock Biomass.

Figure 5.3. NORTH-EAST ARCTIC HADDOCK.
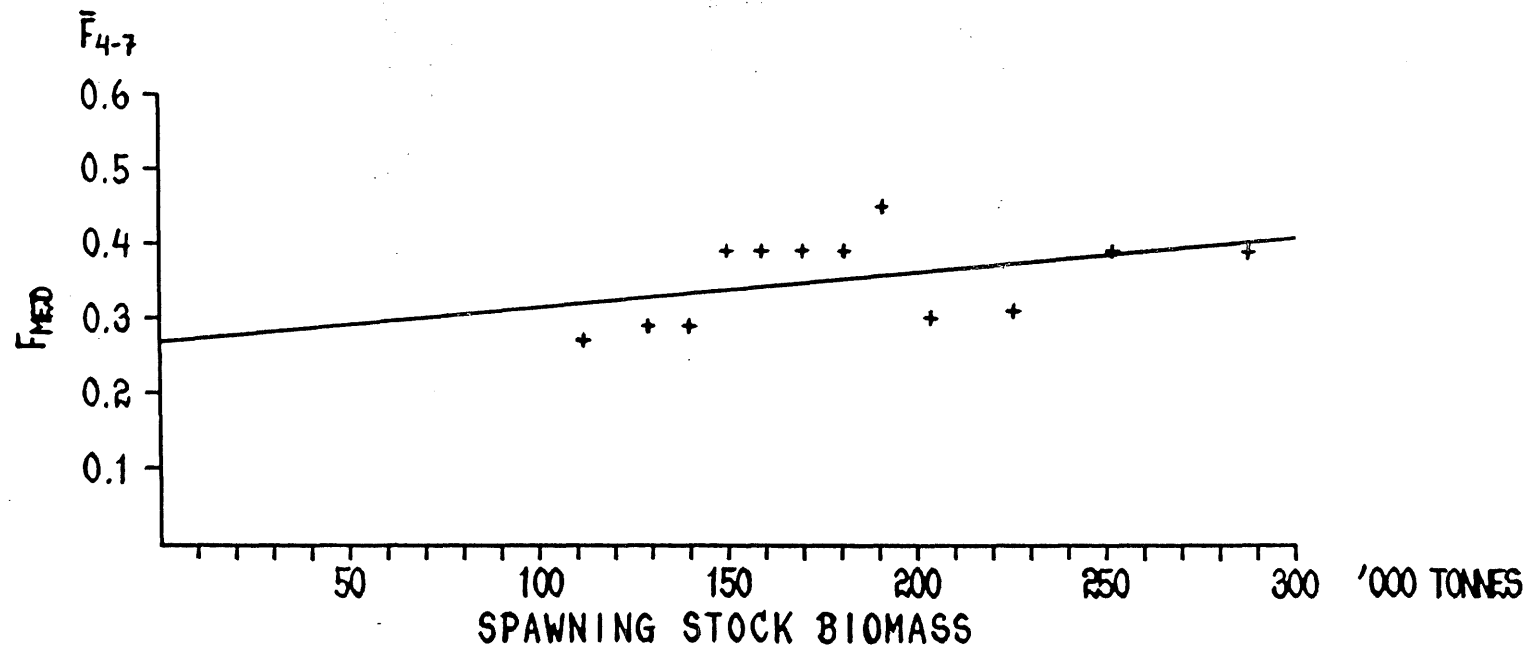Yield and Spawning Stock Biomass per Recruit (age 3).

Figure 5.4. NORTH-EAST ARCTIC HADDOCK.
Fmed-estimate versus mean Spawning Stock Biomass.