COOPERATIVE RESEARCH REPORT

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REPORTS OF THE *AD HOC* WORKING GROUP ON THE USE OF EFFORT DATA IN ASSESSMENTS

and of

THE WORKING GROUP ON METHODS OF FISH STOCK ASSESSMENTS

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P R E F A C E

This issue contains the Reports of two ICES Working Groups, chaired by Dr J.G. Shepherd, United Kingdom, which were established to examine important aspects of the methodology used in the assessment of fishery resources and the provision of scientific information and advice on their conservation and management.

The first Report, presented in Part I, is concerned with an evaluation of the use of fishing effort data in assessments, with special reference to the determination of fishing mortality levels; the second Report, presented in Part II, extends these considerations and also deals with other methodological problems, including the application of the separable VPA method and the evaluation of factors which may invalidate yield-per-recruit calculations and the derivation of biological reference points.

Copenhagen, March 1984

PART I: REPORT OF THE AD HOC WORKING GROUP ON THE USE OF EFFORT DATA IN ASSESSMENTS

1. PARTICIPANTS AND TERMS OF REFERENCE

1.1 Participants

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1.2 Terms of Reference

"To evaluate the use of effort data in determining fishing mortality levels, and the effect of mixed fisheries, technical interactions and quota systems on the data. The problem of determining input fishing mortality coefficients for virtual population analysis should be specially examined".

2. INTRODUCTION

The Working Group discussed its terms of reference and agreed that the principle problem was to make some progress in the use of effort data for the determination of fishing mortality and (equivalently) stock size in the most recent years, which had not so far been a very successful procedure. They recognised that there were other methods available, notably the use of egg and larval surveys, acoustic surveys, groundfish surveys and tagging experiments, and that these might be more successful in some cases. Nevertheless, in many situations none of these alternatives are available, and there is still a great need to improve methods for the use of effort data.

The Group agreed that although effort data may also be useful when allowing for technical interactions in multispecies assessments, they would concentrate their effort on the principle problem. They also recognised that although the definition and determination of fishing power was clearly of the very greatest importance for the successful use of effort data, these aspects have already been much studied (e.g. FAO Fisheries Techn.Paper No.155) and that they would not be able to add much in the time available. They therefore agreed to concentrate on the use of effort data, rather than their definition and acquisition. They recognised, however, that there is no comprehensive summary of what effort data exist and what are available (not necessarily the same thing), since data reported (for example to ICES on STATLANT 27B forms) may not be the best available. They therefore adopted a standard form on which to collect information for an "ICES Catalogue of Effort Data". The first collection of information on this form is given as Appendix A to this report.

The Working Group first discussed the need for additional information to supplement that on catch at age data, and had a fairly extended discussion on the inability of either traditional VPA or more recent variants to estimate fishing mortality in the most recent year. The results of this discussion are reported in Section 3. The success or failure of some previous attempts to use effort data to resolve the problem was discussed (see Section 4), and some general observations on the analysis and use of effort data were made (Section 5). This discussion, especially of the results reported in Section 5.3 suggested that the principle problem is that different fleets exploit different age ranges. The time series of stock abundance at age is highly stochastic, since it is dominated by fluctuations of recruitment, and a similar series appears for each age, progressively lagged in time as the fish became older. Cpue time series from different fleets are, therefore, essentially different moving averages of the recruitment time series, lagged by different amounts. The presence of even quite small lags (e.g. one year) rapidly destroys any correlation when similar but highly variable time series are compared. Thus it is very important that cpue for a particular fleet should be compared with an estimate of stock abundance which takes proper account of the level of exploitation at age. This suggested one approach to re-interpretation of cpue data, and the results of work along these lines are reported in Section 6.2. Another approach is to unscramble the moving averages by analysing cpue for individual age groups, and the results of this work are reported in Section 6.1. Further discussion indicated that disaggregated cpue data are probably best analysed using multiplicative models, and an attempt was made to apply this approach to Faroese data (Section 6.3). Finally, since it seemed that the exact nature of estimators of fishing mortality or stock abundance which one used may be very important, an attempt was made to compare the efficacy of various estimators using simulated data (for which the true answer is known).

The Working Group's conclusions and recommendations are given in Section 7, a short bibliography in Section 8, and a summary of notation in Section 9. The catalogue of effort data appears in Appendix A.

3. VPA AND EFFORT DATA

A proper assessment of a fish stock requires a reliable estimate of fishing mortality (or, equivalently, stock size) in the most recent year. If such information were available from independent evidence, a VPA would not be essential to the assessment. Since catch at age data for the most recent year may be imperfect, a VPA which enables historic information to be used as a background for the current situation is often valuable. However, as discussed below, catch at age data contain no information about natural mortality or fishing mortality in the most recent year, and thus the use of VPA cannot assist in finding a solution to the principle problems in preparing a reliable assessment. Virtual Population Analysis, VPA, is nevertheless the most used method for stock assessment and hence forecasting. In the light of the terms of reference of this Working Group it therefore seems appropriate to deal with relations between VPA and effort measurements.

VPA is used to interprete data about catch numbers at age in terms of fishing mortality and population numbers. Since more independent parameters are being estimated than there are data points, some external information is needed. Generally, assumptions are made about fishing mortality or population number for the oldest age of each year class for which a (reliable) catch number is available. Furthermore, a value for natural mortality must be assumed. These assumptions are usually made in such a way that the results show as consistent an exploitation pattern as possible.

There has been work on mathematical approaches to this estimation problem by Pope and Shepherd (working paper), Nielsen (unpubl.), and Gudmundsson.

The fishing mortalities F_{ya} are written as

$$F_{ya} = \hat{F}_y \cdot S_a$$

where $S_a = 1$ for some reference age and the selection coefficients S_a are assumed to be independent of time, and $\hat{F}_y$ is an overall measure of fishing mortality in a particular year.

Work to date shows that such separable VPA models alone do not resolve the problem of underestimation. Pope and Shepherd conclude that external information is needed about three parameters; namely for terminal values of $\hat{F}_y$ (y = latest year), S_a (a = maximal age) and the natural mortality. Others, like Gudmundsson and Nielsen, have observed that natural mortality cannot be estimated and although, formally speaking, the fishing mortalities can be uniquely estimated within their models the variance of the fishing mortalities increase with time and are considerable for the latest year.

Thus it seems to be generally acknowledged that catch at age numbers alone do not give sufficient information. However, if it can be demonstrated that proportionality of fishing mortality to fishing effort is a reliable assumption, the development of compound models which utilise this relationship internally can be envisaged. Such models would provide an alternative to that of Shepherd and Pope, who recommend running VPAs for a range of assumptions, and selecting among them on the basis of external information. Work in this field is actively in progress, but no methods are currently available for routine use.

In any case, such compound models only provide another means of utilising external information such as effort data, and emphasize the necessity for such data for the correct interpretation of catches at age.

4. PAST EXPERIENCE

4.1 Past Experience - North Sea Roundfish

At its meetings in 1979 and 1980, the North Sea Roundfish Working Group attempted to demonstrate correlations between a measure of total international fishing effort and a measure of total international F for all ages. Catch per unit effort indices relative to an arbitrary year were calculated for each fleet for which relevant data were available. Thus

$$\gamma_{yf} = ypue_{yf}/ypue_{*f}$$

An overall value of relative catch per effort for all fleets for which data were available was calculated by weighting by catch weight:

$$\Gamma_{y.} = (\Sigma_f \gamma_{yf} Y_{yf}) / (\Sigma_f Y_{yf.})$$

An index of the relative fishing effort for the total international fleet was then obtained by weighting by catch weight:

$$\hat{E}_y = \hat{Y}_y / ((\Sigma_f Y_{*f}) \Gamma_y)$$

where $\hat{E}$ = total international effort index

$\hat{Y}_y$ = total international weight landed in year y.

The total international F for all ages was calculated as a mean value weighted by stock number over what appeared to be an appropriate range of ages.

In no case was a significant correlation established between F and fishing effort.

4.2 Past Experience - NE Arctic Fisheries

In the past, data on effort or catch per unit effort have been used extensively in of the North-East Arctic cod stock. For various age groups or components of the stock regression analysis has been used to calibrate the VPA, either by a regression of catch rates against stock size from VPA or fishing effort against fishing mortality from VPA. Data from various fleets have been used and the results compared.

The data from the NE Arctic have demonstrated the dangers of using catch per unit of effort data without having additional information from for example fishing or acoustic surveys on changes in fish distribution from year to year. Extreme hydrographic conditions in 1978/79 had the effect of concentrating the stock. This could be demonstrated from the results of acoustic surveys. Without correcting for this concentration cpue data led to unrealistically low estimates of fishing mortality in 1978 and 1979, and the NE Arctic Fisheries Working Group concluded that the cpue data from 1978 and 1979 could not be used for assessment purposes.

4.3 North Sea Flatfish

For determining the level of the terminal F values in the North Sea sole assessment beam trawl cpue data of the Netherlands on yearly basis corrected for mean fishing power and fishing speed of the fleet and United Kingdom winter fishery cpue were available for the years 1962-79. The Dutch beam trawl cpue depends on a mixed fishery for sole and plaice, concentrated on sole. The United Kingdom trawl fishery provides a by-catch cpue. Both indices correlate quite well together, excluding the 1963 values ($n = 18$, $r = 0.88$).

The unweighted mean F on age groups 2-7 were plotted against two indices of international effort, one based on the Dutch and one based on the United Kingdom cpue for males and females separately. From the eye-fitted curves through the points the F_{2-7} for 1979 were derived. The F values from the plot based on the Dutch cpue and the corresponding values for the United Kingdom plot were averaged and used for the VPA. The exploitation pattern was calculated from the smoothed average F at age for 1972 to 1975 from the trial VPA.

The correlation between the Dutch and the United Kingdom cpue is remarkable, because the United Kingdom trawl fishery is a consistent fishery on species other than sole, while the Dutch beam trawl fishery is a mixed fishery mostly directed on sole, but in years (mainly the most recent years) when sole catch rates are low, increasingly direct their effort at plaice.

Another difference between the two fleets is that in the period 1962-79 the United Kingdom fleet kept operating in the same area, while the Dutch fleet could expand their fishing area by increasing their mobility with more powerful engined vessels in periods when sole catch rates on nearby fishing grounds were low. The above consideration can explain a non-linear trend in the relation between effort and F for the Dutch fleet, but not for the United Kingdom fleet.

Outside the Working Group, regressions were carried out between a cpue for the two fleets and a biomass from the VPA. Both correlations were significant ($r = 0.88$ for United Kingdom "winter" index for 19 df and $r = 0.89$ for the Netherlands index for 14 df). These results were given in the discussion paper to the 1980 Flatfish Working Group and to the present Working Group (Houghton, discussion paper).

The log-log regressions have slopes which are significantly greater than 1, indicating that there has been a downward trend in apparent catchability as the stock has declined. This could also be interpreted as a bias in the effort data (effort over-corrected for fishing power for example) or as a bias in the VPA (incorrect M).

For the North Sea plaice, no significant correlation exists with a combined effort using the γ method and the mean F derived from the VPA. A better result was obtained from an index of combined English motor trawl catch per effort corrected for the Lowestoft mean annual horse power. The English fleet has a directed fishery on plaice and its cpue gives a significant correlation with spawning stock biomass.

An international effort index was obtained by dividing the United Kingdom cpue by the total catch. This index correlated significantly with the mean female F from last year's VPA, though not with the male F. This effort index has been used to determine the input F level for the most recent VPA.

4.4 Experience in the NAFO Area

Catch rate and effort data are used in assessments done for NAFO in two major ways, as input for general production models and to calibrate analytical models. The raw data are operated on, generally by using some form of multiplicative model, to obtain relative annual values prior to such application.

The typical approach used to calibrate analytical models with effort or catch rate data has been regression analysis. No preference has been given to either catch rate vs biomass or effort vs fishing mortality. In fact, several attempts are generally made using various weightings, various age groups or other modifications. Most workers are satisfied with finding a descriptive relationship and are not concerned with the functional realism of the models. Although this approach can be criticized it is not entirely without merit.

The previous discussion has assumed the use of "total" values. Some recent attempts to calibrate each age of the analytical model with effort data were unsuccessful.

Frequent failure to achieve satisfactory calibration and suspicion about the quality of reported effort data have led to implementation of surveys. In general, commercial catch rate and effort data are resorted to only when attempts with survey data are unsuccessful.

4.5 Irish Sea:

4.5.1 Cod and plaice

One year old cod recruit to the fishery during the last quarter of the year and are known to congregate in discrete areas. The Irish Sea and Bristol Channel Working Group has used a correlation of United Kingdom cpue of 1 year olds in the 4th quarter with the number of 1 year olds in the stock (from VPA, year classes 1967-75) to estimate the number of 1 year olds in the latest years; the correlation was very good ($r = 0.933$ for 8 degrees of freedom). Input Fs were adjusted so that the stock of 1 year olds derived from the VPA agreed with this estimate.

A corresponding procedure for Irish Sea plaice did not give such a good correlation ($r = 0.420$ for 9 degrees of freedom), and it has been used for indicative purposes only.

4.5.2 Recent analysis of English and Welsh data for the Irish Sea

A working paper submitted by Brander describes recent work on English and Welsh data for the Irish Sea. Using a correction for fishing power and analysis of variance (i.e. linear additive model, which is probably less suitable than a multiplicative model) he demonstrates that all effects (seasonal, spatial and annual) are significant. A simple annual average cpue index (using aggregation to avoid empty cells) and weighting for the areas of the regions was constructed. This being the average of disaggregated catch/effort ratios, rather than the ratio of aggregate catch and effort, differs significantly from estimations often used previously by Assessment Working Groups. A good correlation of this index was obtained for cod ($r = 0.83$) and plaice (0.82) using yearly average biomass estimates. A poor correlation for sole ($r = 0.01$) was due to clustering of data points, and for whiting ($r = 0.40$) almost certainly because of failure to allow for discards which are very important for this species.

The results obtained by Brander are very encouraging, as they are a very substantial advance on results from previous attempts. They suggest that the use of linear (and therefore probably multiplicative) models for cpue data is likely to yield useful results, where disaggregated data are available.

4.6 Celtic Sea and Irish Sea Sole

The Celtic Sea and Irish Sea sole fishery is mainly a directed fishery carried out almost entirely during the spawning season. Therefore fishing is concentrated on high sole densities in a rather limited geographical area. The Irish Sea and Bristol Channel Working Group used effort and cpue data on several occasions and these data were very important as the data set is rather short (1970-79). Most of these data were derived from the Belgian fishery accounting for about 80% of the catches in the Celtic Sea and for about 50% in the Irish Sea. In both areas three main regressions were used:

1) The index of effort (total catch/Belgian cpue) was in good agreement with the weighted mean F values from the VPA. On this basis the input Fs were determined by the most recent trend in effort.

2) The Belgian cpue (kg/hr fishing corrected for hp) of the second quarter against total stock biomass showed a good correlation ($r = 0.79$). Also the United Kingdom otter trawl cpue data (undirected fishery) were in good agreement.

3) Due to the lack of pre-recruit estimates in these areas, the geometric mean regression of 3 year old soles from the VPA and the cpue of 3 year old soles in the Belgian beam trawl showed satisfactory correlations: $r = 0.98$ (males) and 0.97 (females) for the Celtic Sea and $r = 0.48$ (males) and $r = 0.68$ (females) for the Irish Sea.

5. GENERAL OBSERVATIONS

5.1 Disaggregation and Multiplicative Models

5.1.1 The use of disaggregated data

Within the idealistic scheme of a homogeneous exploited population, a homogeneous fishing fleet and constant fishing intensity (in time), relationships between cpue and biomass, or fishing mortality and fishing effort, are simple and equivalent. The situation becomes more critical when

- the catchability is changing from age group to age group for a given year,
- different fleets showing different fishing powers exist,
- the catchability or the fishing intensity is changing within the years,
- the fish are distributed over several areas with a low mixing rate.

Assuming that adequate disaggregated information exists, two questions appear:

a) is it possible to get a satisfactory index of overall yearly abundance?

b) is it possible to define an overall fishing effort that could be simply related to fishing mortality?

The second problem is not dealt with in this paragraph. Since most attempts to define an overall fishing effort rely upon the division of total catch by some index of abundance, the first problem has first to be solved, although some remaining difficulties would deserve a discussion. Note that since fishing power may vary with the age of the fish, it would be desirable to standardise for fishing power on an age-specific basis.

The remaining problems are related to fishing power, and heterogeneity in space and in time (within a year).

If the only problem comes from fishing power, a simple standardisation can be made by direct comparison of the cpue of the different fleets. If the only problem comes from the existence of several areas, it is also possible to obtain overall indices of abundances by weighted sums or averages of cpue in the different areas. However, one has to assume either

(i) that the vulnerability remains the same from area to area, in which case each local cpue should be weighted by the corresponding area, or

(ii) that the ratio of partial abundance in any area to total abundance remains constant in which case any weighting can give a reasonable if not optimum relative index.

An important problem remains: it is necessary to have cpue in <u>all</u> areas. If empty cells exist, and especially if they change from year to year, the only possible way is the second one, and more sophisticated data processing will be necessary.

The existence of seasonal variations will cause similar problems. If cpue exist for all seasons, any weighted average can be used, as long as the weights do not change from year to year. As soon as empty cells appear, those simple averages will become dangerous if not useless (Laurec & Le Gall, 1975). Spatial and temporal variations can of course be combined into a spatio-seasonal pattern, which includes interactions (seasonal changes of spatial distribution).

If the different problems are combined, they cannot be solved separately. For standardisation calculations, the relative cpue can be used only when the vessels have fished under the same conditions, ideally at the same place and at the same moment. This is a first major reason for using a precise mathematical model describing and combining the different influences on cpue of fishing power, spatial and seasonal effects, and annual abundance. Another reason is associated with the existence of empty cells. Simple averages over non-empty cells can lead to bias in time, so the fitting of a specific multiplicative model becomes a much preferable procedure.

5.1.2 <u>Application of multiplicative models</u>

Catch rate data are often available on a disaggregated level, at least by month, fleet and area. It would be desirable to extract the annual signal prior to any aggregation in order to avoid masking significant distributional and seasonal effects. Using a mathematical model, it is possible to separate the influence on catch rate (U) of such factors (see e.g. Robson, 1966).

Previous experience has shown that multiplicative models are more satisfactory than additive ones. This leads to the use of logarithmic transformations to give linear models. The general model can be expressed as

$$\text{Log } U = \text{Log } U_{*} + \Sigma_i G_i + \epsilon$$

the G_i being factors determined by the particular situation (spatial and seasonal etc.).

It appears that the more "useful" of these models rely upon the inclusion of categories for fleets and a limited number of time-area strata.

$$\text{Log } U^{i}_{fsy} = \text{Log } U_{*} + \text{Log } P_f + \text{Log } Q_s + \text{Log } A_y + \epsilon^{i}_{fsy}$$

U^{i}_{fsy} is the catch rate for fleet f, in time-area stratum s during year y. Several observations may be made, i being the corresponding index. P_f is the relative fishing power for fleet f, a particular fleet f_o being chosen as a reference ($P_{f_o} = 1$). Q_s is a "corrective" factor for differences in the time-area strata, a particular stratum s_o being chosen as a reference ($Q_{s_o} = 1$). A_y is an index of abundance for year y, a particular year y_o being chosen as a reference ($A_{y_o} = 1$).

An abundance index series for some standard fleet f_i and some standard time-area stratum s_j is defined by

$$U_{*} \, P_{fi} \, Q_{sj} \, A_{yk}$$

for all k.

ϵ^{i}_{fsy} is a residual following a normal distribution with mean zero, and a variance that can be considered as constant, or related to different factors (catch, effort...). The different ϵ^{i}_{fsy} have to be considered as stochastically independent if any statistical inference is to be made. Such an inference is particularly important for estimating untransformed fishing powers and abundance indices. In order to get unbiased estimates, the variance of the logarithmetic estimate has to be estimated (Gavaris, 1980).

This model does not take into account possible interactions between the P_f, Q_s and A_y (Francis, 1974). For instance, interaction between A_y and P_f could correspond to saturation problems. Between P_f and Q_s this would correspond to changes of relative fishing power from stratum to stratum.

Interaction between years and Q_s are also neglected. This means that the spatial distribution and seasonal pattern is the same from year to year. This hypothesis cannot be avoided, as well as the hypothesis of "no interaction" between year and fishing powers (Laurec, 1979). Such interactions would make it impossible to perform comparison from year to year. This is a general rule.

If the categories which are used generally include fleet, spatial and temporal dimensions, it is important then to consider the level of disaggregation necessary in these dimensions in order to apply the model successfully.

For fleets, data may be available for individual boats or only for fleet totals. Although differences may exist between boats in a fleet, it is more likely that these will be random if the fleet is homogeneous. It is advisable therefore to group the boats into relatively homogeneous fleet categories. Advantages of this procedure are that fewer parameters need to be estimated, and if the fleet is relatively homogeneous there will be more information used in estimating each parameter, resulting in smaller variances.

Spatial and temporal dimensions are by nature continuous and some approximate discrete categories must be constructed. Obviously, years must be one of the temporal dimensions since annual values are desired. Some seasonal breakdown would be advisable with the possibility of collapsing these categories to a smaller number after examination of the estimated "powers". Spatial categories should be included if it is suspected that the area can be broken down into habitats which are of variable preference to the species of interest. If not, inclusion of spatial categories could justifiably be omitted. The inclusion of spatial categories may require that spatial temporal interactions be included in the model. A large degree of such interaction could be evidence that the area cannot be decomposed into preferred habitats.

Although the minimally required level of disaggregation is the categories which will be used in the model, more detailed information may be available. For example, although fleets might be used as categories, data for individual boats may be available. In this situation, no general advice can be given as to whether the data should be used as they are or whether the totals for the fleet should be used. The decision process involves an examination of the residuals for the particular data set, since the level of aggregation used will affect the skewness of the distribution. The level of aggregation which will most likely result in a log normal distribution should be used to minimise any bias in the results. The absence of zeroes is in this respect highly desirable. If this cannot be achieved, several approaches can be used: use of delta distribution, elimination (combined with separate examination of the proportion of zeroes), addition of a constant before transformation.

Finally, it should be noticed that such calculations can obviously be performed for cpue in weights or number, over all ages or for a given age or size range.

If application of the multiplicative model to individual ages is too tedious, it may be possible to obtain satisfactory results with the following approximate method. Compute an effort series for aggregated ages, partition the effort into the fleet components for which an age distribution is available, divide the catch at age for each of these fleets by the corresponding effort (possibly correcting for exploitation pattern) and finally add the cpue arrays for the different fleets.

5.2 The Importance of Appropriate Estimators

The failure of some previous attempts to utilise effort data is quite possibly due to the use of inappropriate estimates of stock size or fishing mortality. Often quantities easily available from standard Working Group procedures have been used, such as spawning stock biomass, or mean fishing mortality weighted by stock numbers.

Clearly, the biomass of an age group which is absent from the catch cannot influence catch per unit effort. The biomass estimate to be used for correlation with cpue should therefore include age groups only in proportion to the extent that they are fully exploited by the fishery in question. One may therefore define the exploited biomass as

$$\hat{B} = \sum_a N_a W_a \frac{F_a}{F_{f*}}$$

where F_a is the partial fishing mortality in the fishery in question and F_{f*} is a reference value averaged over a suitable range of fully exploited ages (see Section 6.2.2). Clearly, if the age composition of the catch is different from that assumed (as may occur with total or spawning stock estimates) the correspondence with cpue will be degraded. This will be particularly noticeable if recruitment is highly variable, since the estimates will not only be quantitatively in error, but a lag will be introduced between the cpue and biomass time series. The presence of even a small lag (one or two years) may easily destroy the correlation between highly stochastic time series. This effect should be minimised by the use of $\hat{B}$.

A similar effect will occur if weighted mean fishing mortality is used. If the selection pattern is approximately constant, and fishing mortality is proportional to effort, the arithmetic mean fishing mortality (over any age range) should be highly correlated with effort. The weighted mean fishing mortality, however, is biased in favour of any large year classes, and the bias shifts from year to year. This also introduces a lag and quantitative error in the computation. Furthermore, it is self-evident that total international fishing mortality will not in general correlate well with effort from a small part of the total fishery; partial fishing mortality for the fishery in question must be used.

Finally, the construction of "indexes of total international effort", by dividing total international catch by cpue from a small part of the fishery, is unlikely to be successful, unless the age composition of this part of the catch is representative of the total. Otherwise, recruitment fluctuations will again introduce a lag in the time series and degrade the correlation. The success of this method for the North Sea flatfish using Dutch beam trawl and English trawl data is presumably highly dependent on their accurate reflection of the age composition of the stock.

All these considerations indicate that great care must be taken in analysing effort data to ensure that appropriate estimates of the various quantities are used. Unless this is done, success is very unlikely, since fluctuations of recruitment are always with us.

5.3 Possibilities for Analysing North Sea Roundfish Data

The North Sea cod data on cpue in the Roundfish Working Group reports, which failed to yield a usable relationship between effort and fishing mortality, were re-examined. First, the fleet cpue data were plotted as time series on a logarithmic scale along with the relative cpue (aggregated over fleets) and the VPA biomass (Figure 5.3.1). The fleets cpue show different trends although there are similarities in the sequence and coincidence of peaks and troughs. It is known that each fleet exploits a different part of the stock and that they take different age compositions. The RCPUE and total biomass trends are also similar, except that the peaks or troughs in the biomass occur 1 or 2 years later than those in RCPUE.

It seemed reasonable to infer that there was an age effect which caused the lag between RCPUE and biomass, and so the fleet cpue's were compared (by age) with the biomasses for 3 age ranges (0-2, 3-5, 6-12 years) as well as the total (0-12). These values are shown as time series in Figure 5.3.2 and were obtained from the 1980 Working Group VPA. It was striking that the cpue of each fleet appeared to be in phase with the trend in biomass of particular age ranges. The most striking were the correspondences between the Netherlands and Belgian cpue and the 0-2 year old biomasses. Correspondences can be detected between the cpue of the other fleets and other age ranges.

It became clear that a biomass measure was required (from VPA) which was appropriate (in age terms) to the RCPUE index. Pope at Lowestoft had suggested the use of "exploitable biomass", which we define as:

$$\hat{B}_{y\cdot} = \sum_{a=1}^{A} N_{ya} \cdot W_{ya} \cdot S_{ya}$$

where S_{ya} is the relative fishing mortality at age referred to some reference level within the year. We now refer to this as "total exploited biomass" to distinguish it from the "partial exploited biomass" which is appropriate to a particular fleet.

$\hat{B}_{y.}$ was calculated for North Sea cod using the arithmetic mean F over all ages in the stock as a reference value for the relative F calculation. The results are plotted as a time series in Figure 5.3.3, which also shows total biomass (0-12) and RCPUE. Regressions were calculated between ln RCPUE and ln B or ln $\hat{B}_{y.}$, and the results are shown in Figure 5.3.4. The correlation with exploited biomass is considerably higher than that with total biomass, demonstrating that the difference in age structure between the total stock and that exploited by the fleets generates a lag which is removed by the calculation of exploited biomass.

5.4 Fishing Mortality vs Effort or Cpue vs Biomass

Let $\bar{N}$ be the average stock number of some age group and $\bar{W}$ the average body weight of that age group. Then

$$\bar{N} = N_o (1-e^{-Z})/Z$$

where N_o is the number at the beginning of the year, and Z is the total mortality.

If E stands for effort and F for fishing mortality, the two models may be expressed:

$$\text{F vs E} : F \propto E \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$\text{cpue vs B} : \bar{W}\,\bar{N} \propto Y/E \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

where

$$Y = F\,\bar{N}\,\bar{W} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

is the catch in weight. These simple equations neglect the problem of aggregating dissimilar effort data (see Section 5.1) and should be regarded as idealisations. From a formal point of view the two models are identical, which is easily seen by inserting Eq (3) into Eq (2).

The real difference lies in the nature of the observations needed to perform the two regressions. The observations for the cpue vs B - regressions are expected to show a larger variation, because the variation in year class strengths is reflected in Y-observations. This may not be the case for the F vs E - regression, so in order to demonstrate a regressional relationship, the cpue vs B - regression is expected to be preferable. On the other hand, variations in effort may not be reflected in the cpue vs B - regression, so the utility, as far as regression is concerned, is dependent on the actual data in use.

Another point is that past experience shows that the F vs E - regressions should be made only on disaggregated data. That is, the Fs and Es should be partial quantities, so that each partial F (or E) accounts for a fleet consisting of fairly uniform vessels (equal gear type, fishing grounds, fishing periods, fishing performance, etc.). But for the estimation of final Fs in the VPA one needs an aggregated estimate of total-F. So far, the aggregation of partial effort estimates has turned out to be problematic, resulting in failure of demonstrating a regressional relationship between E and F. These difficulties may lie in non-proportional changes in fishing power of the various fleets.

Of course the same problems appear in the cpue vs B-regression, but the "stochastic noise" caused by variability in fishing power is less dominant due to the larger spread of observations.

Thus, neither of the two models is obviously preferable to the other, and consequently it is recommended that both should be tried, whenever possible. For schooling fish the utilisation of cpue and E-observations is highly questionable, since a tacit assumption behind the two models is that the fish spread evenly over the entire area, independent of stock size.

5.5 Effect of Mixed Fisheries

5.5.1 Effect of mixed fisheries on effort data

If proportions of species caught in a mixed fishery remain constant, the derivation of catch per unit effort for all species can be achieved in the same way as for directed fisheries. By-catches may be more representative random samples than catches of species for which the fishery is directed, but problems may arise if the fishery shifts to a new target species during a period of study. If that happens in some years but not in others, the fishing power exerted by the effort may vary and cpue for the various years may become incomparable. To tackle the problem of shift in target species, the effort data could be corrected for directivity, but how a correction factor could be defined is not obvious. A reason for a shift in directivity might also be that the quota of the initial target species is fished up (see Section 5.6), so these problems are interrelated.

5.5.2 Assessment of mixed fisheries

A principle reason for thinking about mixed fishery assessments is to work out sets of single-species TACs which are not in conflict with one another. One then needs a matrix of consequent partial fishing mortalities on all ages of other species generated in the fishery by the fleets considered.

Formally this may be expressed

$$F_{yfsa} = F_{yfj*} \cdot S_{fsa}$$

where F_{yfsa} is the fishing mortality on by-catch species s age group a in year y exerted by fleet f the target species (or reference species) of which is j. F_{yfj*} is the fishing mortality of the target species for some reference age group (denoted *). S_{fsa} is the relative partial fishing mortality, i.e. the fishing mortality on the by-catch species age group a, created by a fishing mortality of 1.0 on the reference age group of the target species. The relative partial fishing mortalities can be estimated only if estimates of fishing mortalities for all species are available.

To perform a multispecies/multifleet prognosis taking mixed fisheries' effects into consideration is easily done by running the traditional forecast procedure in parallel for all species and letting the partial Fs on by-catch species be determined by the equation above. Similarly, long-term sustainable yield models (incorporating stock/recruitment relationships) utilise the same data.

A definition of a combined MSY-concept accounting for landings of all species assessed is required, if one wishes to optimise a mixed fishery. In principle, such a goal function may be written:

$$\sum_y \sum_f \sum_s \sum_a Y_{yfsa} \cdot V_{yfsa}$$

where V_{yfsa} stands for the "value" (returns) of one tonne of species s age group a landed by fleet f in year y. Giving all Vs the value of 1.0 would imply that the goal was to maximise the total biomass landed. This choice of V would not be reasonable in all cases, e.g.

it would not be sensible to assign the same value to an industrial by-catch as to a landing for human consumption. Progress is going on in the development of aggregated yield evaluation models (Shepherd, pers.comm.; Sparre, 1980), but the application of optimisation techniques is likely to be highly controversial.

To avoid inconsistent quotas, TACs might be set only for the species mainly taken as target species. Precautionary TACs for the by-catch species could then be derived from the target species TACs, by aid of the mixed fisheries model described above. However, if the aim of the management were to protect a by-catch (e.g., industrial by-catch of herring in the sprat fishery) the TAC for the target species would need to be calibrated to produce the desired catch of the more valuable by-catch.

5.6 The Effect of Quotas on Landings and Effort Data Series

The ideal set of quotas for regulation of all fish stocks within a geographical area should be such that

a) No quota is exceeded before any of the others and no quota fails to be met during the period to which it applies;

b) The fishermen consciously attempt to adhere to the quotas.

Even given the ideal set of quotas, there is the possibility that landings data series can be corrupted. For example, it may be the case with a rather restrictive quota on a particular species the fishermen may decide to land the quota as large fish whereas until the quota was implemented landings consisted of both large and small fish.

At present, however, no ideal set of quotas exist. This may result in two major effects.

1) Discarding may increase as the quota for a particular species is approached or after it has been met;

2) Fishermen consciously misreport their landings and/or the location where they were fishing.

Both of these effects can obviously corrupt a series of landings and/or effort statistics. The level of discarding can be assessed by setting up an appropriate sampling programme but correcting for conscious misreporting of landings/effort data is very difficult.

When quota management schemes are in operation, a further corruption may sometimes occur, if catches are limited to a certain quantity per day, or week, etc. In this case effort data at the level which is controlled (e.g. days) clearly become unreliable; effort data at a higher level of discrimination (e.g. hours fished) should not be seriously affected, however.

6. DEVELOPMENTS

6.1 Use of Cpue Indices Combined over Fleets

6.1.1 Estimation of combined cpue indices

As mentioned in Section 4.1, the North Sea Roundfish Working Group failed to demonstrate a correlation between fishing mortality rates from VPA and the age group aggregated index of effort. It was therefore decided to try alternative methods and the most promising one appeared to be to correlate cpue with stock numbers from VPA. As pointed out in Section 5.2, the interpretation of age group aggregated estimates is difficult, and to avoid that problem the basic calculations were made on individual age groups.

Let C_{yfa} be the number caught (landing + discard) of age group a by fleet f in year y.

E_{yf} is the effort exerted by fleet f in year y. (In the present case E was not corrected for fishing power.)

Then catch per unit becomes

$$CPUE_{yfa} = C_{yfa}/E_{yf}$$

Because the effort for the various fleets are expressed in incomparable units cpue was converted to relative values, i.e.

$$\gamma_{yfa} = CPUE_{yfa}/CPUE_{*fa}$$

where * stands for some (arbitrarily chosen) reference year.

The relative cpue for all fleets combined was derived by the sum of the γ weighted by the numbers caught, i.e.

$$\Gamma_{ya} = \frac{\sum_f \gamma_{yfa} \cdot C_{yfa}}{\sum_f C_{yfa}}$$

Finally, these figures were scaled and logarithms were taken.

$$\Gamma'_{ya} = \log_{10} (\Gamma_{ya}/\max_y \{\Gamma_{ya}\})$$

To explain why an age group aggregated cpue index is difficult to interpret we examine the mathematical expression for it:

$$\Gamma_{y..} = \sum_a \sum_f \frac{CPUE_{yfa}}{CPUE_{*fa}} \cdot \frac{C_{yfa}}{C_{y..}}$$

Obviously the values of the Γ's are dependent on the choice of the reference year (*). If the relative values of the Γ's were independent of the reference, the expression would still be useful, but as this is not the case it is impossible to give the Γ's a consistent interpretation. The difficulty arises in part because of the arbitrariness of the reference year. If aggregate measures are needed the basic data must be handled in a different way.

6.1.2 Use of combined cpue indices to estimate terminal Fs

Let $N_{y1a}, N_{y1+1,a} \dots N_{y2,a}$ be stock numbers derived from VPA. The time series, year y1 to year y2 does not include the most recent year for which VPA results are considered uncertain.

From a plot of $\log_{10}(N_{y,a})$ against Γ'_{ya} a predictive regression may be made. From the regression and effort observations, estimates of N_{ya} for the most recent years are obtained.

The Fs for the most recent years may then be calibrated so that the number caught and the N-estimates correspond to each other. If only the last year is excluded from the regression analysis, the Fs could be chosen so that a perfect agreement between C and F is achieved. If more than one recent year are excluded, some fitting procedure must be applied, e.g. one could choose the Fs which minimise

$$\sum_{\substack{y \\ \text{(for recent years)}}} \left(N_{ya}^{\text{VPA}} - N_{ya}^{\text{Predicted}}\right)^2$$

6.1.3 An example: North Sea haddock

Regressions of Γ'_{ya} on $\log(N_{ya}^{VPA})$ were made for North Sea haddock for the years 1963-78. (See Figure 6.1.1.)

Four fleets were considered: Scottish trawl, Scottish "other", English trawl, English "other". As an example input data for the calculation of relative catch per unit effort for the year 1964 is shown in Table 6.1.1.

The aggregated cpue indices (Γ_{ya}) are shown in Table 6.1.2. Table 6.1.3 gives the Γ'_{ya} values together with the $\log(N_{ya}^{VPA})$ values. Predictive and geometric functional regressions were performed and the results are shown in Table 6.1.3. Figure 6.1.1 gives a graphical presentation of the ten geometric regressions.

Input Cs do not include discards, which we decided that they should. Initially we made the calculations on landings, and due to lack of time the calculations were not redone with total catches.

6.1.4 Discussion

It is possible that the use of the age composition on both sides of the regression equation may introduce a spurious correlation. The Working Group was unable to resolve this question and the matter requires further consideration. However, the results of the regressions for North Sea haddock seem to be very promising. For ages >2 all correlation coefficients exceed 0.82. It is thus recommended that the North Sea Roundfish Working Group consider the procedure described for the three roundfish stocks. Cpue should be preferably derived from total catch and not from landings only, as was done in the present application.

6.2 Disaggregated CPUE and Biomass

6.2.1 Introduction

Section 6.1 relates to the calculation of aggregated cpue data (over fleets) and its relationship to stock abundance from VPA. This section deals with an alternative procedure of comparing the fleet cpue indices with appropriate partial exploited biomasses. These are, again, calculated from VPA but are obtained by using the catch numbers-at-age of the fleet in question. Whereas the aggregated cpue method potentially provides a single time series of cpue for comparison with a comparable series of exploited biomass from each VPA, the disaggregated method provides time series of partial exploited biomasses (PEBs) for each fleet from one VPA. This method therefore introduces the additional problem of choosing a single VPA from potentially different estimates of the terminal fishing mortalities obtained from the correlation between the fleet cpue's and PEBs. A further, and probably minor, problem in normal circumstances is the need to have the age compositions appropriate to each cpue index which one wishes to use. These were not available in each case in the North Sea Roundfish data and the Effort Working Group had to compare the cpue data with possibly inappropriate PEBs since only aggregated age compositions were available in the majority of cases for the North Sea cod, which was the example chosen. It should be noted that it is not necessary to include discards in the yields as long as the landed age composition is available for the appropriate fleet.

6.2.2. Definition of PEB

A VPA is required with the input total age compositions and stock weights-at-age as well as the age compositions for the fleets for which one has cpue data. The required parameters are defined in Section 9. They are as follows:

$$T_{yfa};\quad C_{y\cdot a};\quad W_{y.a};\quad L_y;\quad N_{ya};\quad F_{ya}$$

We define the partial fishing mortality at age as:

$$F_{yfa} = F_{ya} \cdot T_{yfa}/C_{y\cdot a}$$

and the relative partial fishing mortality at age as:

$$S_{yfa} = F_{yfa} / \bar{F}_{yf*}$$

where $\bar{F}_{yf*}$ is a reference fishing mortality which may be selected in various ways (the implications of these choices have not yet been fully explored). It may be chosen as the fishing mortality on the age for which it is maximum, as that on an age which is highly represented in the catch, or as an average over some range of fully exploited ages. The last choice is used here, so

$$\bar{F}_{yf*} = \sum_{a=a_1}^{a_2} F_{yfa} / (a_2 - a_1 + 1)$$

For North Sea cod we have used $a_1 = 2$, $a_2 = 8$.

The partial exploited biomasses (PEBs) are then

$$B_{yf} = \sum_a N_{ya} \cdot W_{y\cdot a} \cdot S_{yfa}$$

Each value of potential exploited biomass is of the same order of magnitude as the total exploited biomass in the same year and the deviation from it is a reflection of the part of the total biomass which is exploited by the fleet in question.

6.2.3 Theoretical relationship between PEB and CPUE for one fleet

If fishing effort E_{yf} is known for fleet f in year y, the cpue will be $Y_{yf}/E_{yf} = U_{yf}$. From the partial fishing effort and the partial fishing mortality at age (F_{yfa}) one can deduce the partial catchability:

$$q_{yfa} = F_{yfa} / E_{yf}$$

It can be shown that:

$$U_{yf}/B_{yf.} = \frac{1}{A_2 - A_1 + 1} \sum_{a=A_1}^{A_2} q_{yfa} = \bar{q}_{yf}$$

$\bar{q}_{yf}$ is an average catchability for year y and fleet f. If it does not change from year to year the ratio between $U_{yf.}$ and B_{yf} is constant.

If it changes, the situation becomes more difficult. However, if it changes with partial exploited biomass within a simple relationship such as

$$\bar{q} = \alpha \; B_{yf.}^{\;\beta}$$

where α and β are constants, the situation can be dealt with. One may write:

$$U_{yf} = B_{yf.} \cdot \bar{q}_{yf}$$

$$= B_{yf.} (\alpha \; B_{yf.}^{\;\beta})$$

$$\therefore \quad U_{yf} = \alpha \; B_{yf.}^{\;(\beta+1)}$$

If, however, there is any change of $\bar{q}_{yf}$ with time, this would create a different problem which may be resolved, perhaps, by modelling the trend in q against environmental variables. These conclusions also apply to the other models of relating cpue to total stock number or total biomass; however, the present model (fleets separate, ages combined) includes the additional assumption that the shape of the relative q_a with age does not vary with time. This is probably a reasonable assumption since the shape will be determined by fish behaviour rather than that of the fleet.

6.2.4 Application to North Sea cod

A new VPA was prepared based on the new Roundfish Working Group data base; the input terminal F values were derived from the 1980 Working Group Report VPA. This should not create a problem in the subsequent analysis, because the eventual aim was to correlate cpue with PEB from the historic data which will be only moderately influenced by the input F values. The VPA input data were available for the years 1963-78. An M of 0.2 was assumed. Stock weights at age were not available and so a set was calculated from the catch weights at age for discards and human consumption landings in the VPA data files. A weighted mean (by catch number in each fishery) was calculated. Empty cells were filled by using the average weight at age for that age group over the time series.

The following age composition data were available in the new data base:

Scotland - Trawl Scotland - Other gears England - All gears	1963-78
Belgium - All gears Netherlands - All gears	1968-78

Also available were age compositions for France - trawl, Denmark - all gears for a number of years but only a small amount of cpue data were available for these fleets.

Cpue data were available as follows (from Anon., 1979b and Anon., 1980d):

Scotland - Trawl Scotland - Seine Scotland - Light trawl	Total catch/total effort; no fishing power correction
England - Trawl England - Seine England - Pair trawl	Total catch/total effort; effort in ton-hrs (i.e. over-corrected)
Belgium - Otter trawl Belgium - Danish seine	
Netherlands - Otter trawl Netherlands - Beam trawl Netherlands - Pair trawl	Total catch/total effort; no fishing power correction

These data have been plotted in Figure 5.3.1.

As discussed earlier, it was thought unreasonable to aggregate these data and therefore the comparison of PEB with cpue was made between the national PEBs and each of that nation's cpue indices.

The calculations were carried out on a TI-59 programmable calculator (with printer) and the whole calculation for cod took about 9 hours. It is, therefore, recommended, that a suitable computer program be made available on the ICES machine if it is intended that these calculations shall be carried out in the Assessment Working Groups.

The program also produced the reference partial fishing mortality in each year for each fleet ($\bar{F}_{yf*}$) and the relative partial fishing mortalities for each age and year = (S_{yfa}). It was therefore possible to compare partial F and national effort as well as cpue and PEB.

6.2.5 Results for North Sea cod

The time series of PEBs is shown in Table 6.2.1 and the PEBs have been plotted as time series in Figure 6.2.1 for comparison with Figure 5.3.1, which shows the cpue data. The trends may be compared with those in Figure 5.3.2 in which the age groups are identified; it appears that each fleet is concentrating on younger fish.

Regressions were performed on the logarithms of cpue and PEB of appropriate data sets. The log transformation allows one to test the constancy of q, at least in relation to the biomass level since

$$\ln (Y_{yf} / E_{yf}) = \ln \alpha + (\beta + 1) \ln B_{yf}.$$

which incorporates the empirical function $Y/E = \alpha B^{\beta}$, so that when $\beta = 0$ the catchability is constant with biomass and is equal to α.

The regression data have been plotted in Figures 6.2.2 - 6.2.5, and the results of the analysis have been summarised in Table 6.2.2. The results are encouraging, bearing in mind the inappropriateness of the data sets available. Four of the eleven regressions were significant with $P < 0.05$, which is considerably more than one would expect by chance. Appropriate age composition data are available in the national laboratories, and one would expect that better correlations would be obtained for at least some fleets if these data were used, especially if the time series of cpue data were extended as well. The negative correlation for English pair trawl for which 10 data points were available perhaps suggests that the data are not accurate. The lack of correlation with the Scottish seine data needs further investigation.

6.3 Analysis of Faroese Data

6.3.1 Faroese longline data used to calibrate a VPA of cod in ICES Sub-division Vb_1

A VPA was run using the same input fishing mortality rates for 1980 as used for 1979 in last year's assessment.

The partial fishing mortality rates for the Faroese longline fleet were then calculated from the equation

$$F_{LL} = \frac{C_{LL}}{C_{TOT}} F_{TOT}$$

for each age. F_{TOT} is the F estimated from VPA.

Ages 6-8 are considered subject to full exploitation so the mean of these three ages was calculated as a measure of fishing mortality. Partial Fs for longline and total F calculated for the same ages are shown in Table 6.3.1 together with effort estimates as million of hooks operated.

In Figure 6.3.1 the logarithms of partial F values from the VPA are shown plotted against the logarithms of the associated values of fishing effort. There is a definite correlation but the estimate of partial F in 1980 lies well above any line drawn through the points.

A new VPA was run then to bring the 1980 point more in line. This new VPA affects the 1978, 1979 and 1980 point. It moves the 1979 and 1978 away from the line and brings the 1980 point almost to the line.

Without going into any discussion of the special features of longline at the Faroes, this seems to indicate a possibility of calibrating a VPA if data are available for one of the major fleets.

This can of course be tried for several fleets and compared.

6.3.2 Application of multiplicative models to Faroese data

The specific model

$$\log U^{i}_{fsy} = \log U_{*} + \log P_f + \log Q_s + \log A_y + \epsilon$$

was applied to the Faroese data for cod.

Ten fleets corresponding to the P_f's were included and only time (months) was used for the time-area strata (Q_s). Data were available for 1975-80. Three attempts were made with the model to examine the effect on the results:

a) with individual haul data excluding zeroes

b) with individual haul data + 1

c) with monthly totals excluding zeroes.

The results showed that for this stock the monthly totals fit the model better. It is likely that the individual haul data are even more skewed than the log normal distribution can accommodate. Nevertheless, the relative abundance, seasonal pattern and fishing powers maintained approximately the same relationships in all attempts indicating that for obtaining an index, the method is relatively robust.

The seasonal pattern (Figure 6.3.2) is in accord with general knowledge of the biology of this species, i.e. the catch rates are highest during March which is the spawning period. The annual relative abundance also appears to confirm the external information which has indicated a general decline since 1975 with a slight increase in 1980 (Figure 6.3.3). The correlation between the longline series (Figure 6.3.4) and the abundance index is very good (Figure 6.3.5) considering that the longline fleet may be exploiting a different component of the stock (the longline data were not used in the multiplicative model so that these measures are independent). The correlation between the estimate of exploited biomass from the VPA runs was also good (Figure 6.3.6).

It should be pointed out that even the best trial of the multiplicative model accounted for only about 35% of the variation in the data; however, weighting the observations would result in considerable improvement but time limits prevented such a trial.

In addition, it may be possible to segregate the stock area into several units of different preference for cod. As a first attempt time-area interaction may be excluded.

6.4 Analysis of Simulated Data

6.4.1 Introduction

Various indices of fishing mortality and catch per unit effort were correlated with effort and biomass using simulated data. The object of these correlations was to indicate which measures perform best with perfect, noisy and biased data. An index of effort combining YPUEs into an aggregated value, recently introduced to the North Sea Roundfish Working Group, and an index of biomass discussed by the Working Group, the exploited biomass, were included with the more traditional approaches. Results show that both of these methods usually perform better than the traditional indices.

6.4.2 Methods

The modelled fishery comprised two fleets with catches from 7 ages compiled for 20 years

$$C_{yfa} \qquad y = 1,20 \quad f = 1,2 \quad a = 1,7$$

Each fleet had its own catchability coefficient, "q", selectivity and effort patterns. A reasonable starting population was taken from a cod cohort analysis (Rivard, 1980).

$$F_{y \cdot a} = q_1 E_{y1} S_{1a} + q_2 E_{y2} S_{2a}$$

$$N_{y+1 \cdot a+1} = N_{y \cdot a} \; e^{-(F_{y \cdot a} + M)}$$

$$C_{y \cdot a} = \frac{F_{y \cdot a}}{F_{y \cdot a} + M} N_{y \cdot a} \left(1 - e^{-(F_{y \cdot a} + M)}\right)$$

The catch was then partitioned according to the ratios of the fishing mortalities generated by each fleet:

$$C_{yfa} = \frac{F_{yfa}}{F_{y \cdot a}} C_{y \cdot a}$$

Recruitments were randomly generated from a flat distribution to vary over one order of magnitude, from 1 000 to 10 000 fish. The simulation parameters are given in the Appendix to Table 6.4.1.

Statistics from the modelled fishing mortalities and biomasses were compared via correlation analysis with indices from the catch and effort data from each fleet. The indices of fishing mortalities were:

$\bar{F}_y$	average F_y over all ages
$\bar{F}_{wc}$	average F_y weighted by catches
$\bar{F}_{wn}$	average F_y weighted by numbers
$\bar{F}_p$	annual F estimated by Paloheimo's method

$$F_p = \ln \frac{N_{y+1 \cdot a+1}}{N_{y \cdot a}} - M$$

Three biomass indices were developed from the numbers at age after multiplication by weights at age (constant over the 20 years). These biomasses, calculated for mid-year, were:

B_{tot}	total biomass
B_{ss}	spawning biomass
B_{exp}	exploited biomass (using F_{max} as the reference)

Three simulations were made; the first with perfect data, the second with 20% variation added to both catch and effort data and in the third the catchabilities were function of time. The catchability of the first fleet increased at 2.5% per year while the catchability of the second fleet dropped discontinuously from 0.0003 to 0.0001 between year 10 and 11.

6.4.3 Results and discussion

The population parameters (catch numbers, population numbers, fishing mortalities at age and biomasses) are given in Table 6.4.1, while Table 6.4.2 shows the results of the three simulations. The r^2 for the various correlations for the "perfect" data are given in column 1. Correlations of unity are seen for:

- average F versus effort as defined from aggregated effort
- average F versus effort as defined by the total catch divided by $YPUE_{y1}$.
- $YPUE_{y}$ ·. versus exploited biomass
- $YPUE_{y1}$ · versus exploited biomass

The good fit with the data from fleet 1 is not surprising since it is the major sector in the fishery.

Weighting Fs by numbers or catch greatly decreases the correlation. The same is true of the Fs derived from successive numbers in the population (Paloheimo's method). Paloheimo's F correlated very well with $\bar{F}_{wn}(r^2 = .98)$.

The addition of noise to the catch and effort data seriously decreased the correlations, as expected. As only one run was made with random variation, the resultant r^2 may not equal the expected values. As expected, however, the better methods for the pure data were also generally better here.

The last three columns are the results from the simulations with time dependent q's. Again the correlations decreased significantly. The YPUE versus biomass were more resistant to degradation than the F vs E relationships. It has been suggested that this is due to the larger dynamic range of the biomass (≈ 3) than that of the fishing mortalities (≈ 2).

It is realised that simulations could be made more sophisticated (stochastic averaging, perform VPA on noisy catches, etc.), but it is felt that this study gives clear indications of the dangers of using some of the currently accepted methods.

6.4.4 More simulations

Three more runs were carried out to answer the questions:

1) what will be the effect of increasing the dynamic range of the fishing mortality, and
2) what will be the effect of selectivities changing with time.

A first run was made to give a basis for comparison with the more dynamic effort with constant catchability and selectivities over time (the first column of Table 6.4.3). The second column has varying catchability and the effects of this biasing are reflected by the results in the second column. The dynamic ranges were approximately three for both the average F and the total biomass. As was seen in the earlier runs, the regressions of cpue vs B performed better than did the F vs Es. However, increasing the dynamic range of the effort improved the robustness of the F vs E correlation.

In the third run the q's were held constant but the selectivities changed over time. The selectivities of the first run increased for the lower age classes to twice their initial values over the twenty-year period. Generally, the YPUE vs biomass correlations were resistant to this biasing, especially those using B_{exp}. A few regressions increased compared to the "pure" run, this may be an artefact of the particular values used.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Catch at age data (and thus virtual population analysis) contain no information about fishing mortality in the most recent year. A reliable stock assessment can only be carried out if there is independent information which may be used to deduce current fishing mortality (or, equivalently, stock size). An updated VPA, on the other hand, is not absolutely necessary, though one may be desirable.

7.2 Independent information from various sources may be useful. Examples are egg or larval surveys, acoustic surveys, groundfish surveys, and tagging experiments. Commercial effort data are valuable but are not obviously preferable to these other types of information. It would be unwise to rely on an analysis of effort data unless this is known to be of good quality. If effort data are known to be unreliable, another type of independent information should be sought.

7.3 The Working Group has found that effort data can be used to estimate fishing mortality and population size in several fish stocks. If the analysis fails for non-schooling species this is more likely to be caused by the use of inappropriate estimates than by a failure of the basic method. The successful analysis of effort data demands a detailed and thorough understanding of the basic data, and great care in the selection of appropriate procedures.

7.4 The Working Group advises that the responsibility for the collection and use of effort data must therefore remain the responsibility of the normal Assessment Working Groups, who alone possess the specialist knowledge of the stocks required.

7.5 It is unlikely to be feasible to analyse very detailed (disaggregated) effort data in the Assessment Working Group environment in the immediate future. Such data would more appropriately be analysed in Working Group members' own institutes, where computer programs and file structures can be harmonised. The Working Group recommends that the ACFM Study Group on Standard Computer Programs for Assessment Working Groups should be requested to consider, in consultation with ICES staff, what computer processing facilities for disaggregated data could be provided at ICES in the longer term, and what file structures would be desirable (STATLANT 27B format may be appropriate).

7.6 Moderately aggregated data may appropriately be analysed in the Assessment Working Group environment. Members of Assessment Working Groups should make strenuous efforts to ensure that age compositions are available at the same level of aggregation as any catch and effort data brought to Working Group meetings, since it is very difficult to utilise the effort data unless this information is available, and the labour of utilising the data is much increased unless this preparatory work is done.

7.7 From their examination of certain examples where the application of effort data has been unsuccessful in the past, the Working Group found that this was primarily caused by the use of inappropriate methods. Great care is required to select appropriate measures of fishing mortality for comparison with effort, and of biomass for comparison with yield per unit effort. Simple comparison of aggregated cpue with spawning stock or total biomass is unlikely to succeed. Disaggregation by age clarifies the comparisons considerably, and greatly increases the range of cpue data especially, and should be used whenever possible. Estimations which combine several age groups (e.g. simple catch weight!) confound the normally strong signal from variable recruitment and require especial care.

7.8 The Working Group considers that with careful attention to detail and to the use of appropriate estimators of quantities such as fishing mortality and stock abundance, the use of effort data can be made much more successful than in the past. In general, the use of weighted average fishing mortality, and total or spawning stock biomasses should be avoided.

7.9 The comparison of fishing mortality with effort, and of yield per unit effort with biomass are not entirely equivalent. The former exhibits a signal primarily due to changes of effort, whilst the latter responds primarily to fluctuations of recruitment. Which is most useful depends on the case in question, and the Working Group recommends that both should be used in parallel.

7.10 The Working Group experimented with several methods of analysis of effort data which appeared to be promising, namely:

a) the use of compound indices of catch per unit effort constructed from data from several fleets, for separate ages, for comparison with estimates of population at age;

b) the comparison of disaggregated yield per unit effort indices with partial exploited biomass estimates, and partial fishing mortality with disaggregated cpue;

c) the application of multiplicative models to highly disaggregated yield per unit effort data, in order to extract a best estimate of the annual signal, taking account of other factors;

d) the examination of the efficacy of various methods of analysis on simulated data, both with and without the presence of noise.

7.11 With the imperfect data available, method (a) was found to be most successful. The simulation studies (d) suggested that a cpue index aggregated over ages should also correlate well with aggregate exploited biomass, as also observed for North Sea cod (Section 5.3). Method (b) performed less well, though it was still superior to many previous attempts to utilise effort data. The Working Group felt that the poorer performance was probably due to the incomplete data available (proper age compositions were not available for all fleets), and that good results would be obtained with better data.

Method (c) successfully identified a strong annual signal, but it is not clear with which estimate of stock abundance it should be compared although it correlates well with exploited biomass. Use of the method on more aggregated data for which age compositions are available would be worth investigating.

Simulation studies (d) indicated that comparison of compound cpue indices with exploitable biomass was a good and robust procedure, as was comparison of arithmetic mean fishing mortality with effort. Use of spawning stock or total biomass, construction of "effort" measures using cpue from a small component of the catch, and use of weighted mean fishing mortality (using catch or - especially - population numbers)were unsatisfactory, and would probably fail to detect a relationship even when it was present.

7.12 Age composition data are necessary for the correct interpretation of effort data. The inadequacies of VPA as an assessment tool do not therefore justify any relaxation of efforts to improve the collection of samples for age composition analysis.

7.13 The Working Group found that exploited biomass seems in practice to be an appropriate estimator of stock size, but it may no longer be a valid estimator when selection at age changes. Some theoretical justification was presented ((Section 6.2.3) that this is indeed so for partial exploited biomass. Further investigation of the basis of this quantity, especially the selection of reference fishing mortality and its use is desirable.

7.14 It is in some cases desirable that catch per unit effort data and fishing mortalities should be based on catch data including discards (see Sections 6.1.3 and 6.2.1). There are practical difficulties in achieving this, since discard data are usually collected on a different basis to landings data. Methods for including discard data, or allowing for their omission, need to be further investigated.

7.15 The difficulties of analysing large amounts of data in a Working Group are very great. For real progress to be made on these methods, it is essential that a method be found for circulating, collating, and analysing the data before the Working Group meets.

7.16 The Working Group stresses that the investigations carried out are only examples of the sorts of calculations which can be performed. They are in part based on inadequate data and the detailed results should not be used for assessment purposes. The Group recommends that members of Assessment Working Groups should undertake further investigation of the methods used.

8. BIBLIOGRAPHY

8.1 Discussion Papers Prepared for the Meeting

Houghton, R.G. - United Kingdom catch per effort data as an index of the stock biomass of North Sea sole.

__________ - A mixed fishing assessment of the otter and beam trawler fisheries for flatfish in the North Sea.

Brander, K. - A new analysis of English and Welsh effort and catch per unit effort data for the Irish Sea.

Pope, J.G. and J.G. Shepherd - A method for the automatic construction of internally consistent VPA.

8.2 Published Papers

Gavaris, S. (1980) - Use of multiplicative model to estimate catch rate and effort from commercial data. Can. J. Fish. Aquat. Sci. 37: 2272-2275.

Rivard, D. (1980) - 8. Estimating survivors in the current year (SURVIVOR) in: "APL Programs for stock assessment". Can. Tech. Rep. Fish. Aquat. Sci., 953.

Anon. (1979a) - Report of the Irish Sea and Bristol Channel Working Group, 1979. ICES, Doc.C.M.1979/G:23.

__________ (1979b) - Report of the North Sea Roundfish Working Group, 1979. ICES, Doc.C.M.1979/G:7.

__________ (1980a) - Report of the Irish Sea and Bristol Channel Working Group, 1980. ICES, Doc.C.M.1980/G:9.

__________ (1980b) - Report of the Arctic Fisheries Working Group, 1980. ICES, Doc.C.M.1980/G:12.

__________ (1980c) - Report of the North Sea Flatfish Working Group, 1980. ICES, Doc.C.M.1980/G:7.

__________ (1980d) - Report of the North Sea Roundfish Working Group, 1980. ICES, Doc.C.M.1980/G:8.

Paloheimo, J.E. (1961) - Studies on estimation of mortalities. I. Comparison of a method described by Beverton and Holt and a new linear formula. J. Fish. Res. Bd. Can. 18:645-662 (summarised in Ricker 1975).

Laurec, A. and A. Fonteneau (1979) - Estimation de l'abondance d'une Classe d'age: utilisation des cpue de plusieurs engins, en différentes zones et saisons. Recueil de documents scientifiques, CICTA 1979. SCRS/78/86.

Ricker, W.E. (1975) - Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd. Can., 191.

Francis, R.C. (1974) - Effects of fishing modes on estimates of fishing power, relative abundance and surplus production in the Eastern Pacific yellowfin fishery. Seminaire sur la dynamique des populations des Thonidés - Nantes. Recueil des documents scientifiques CICTA, pp. 190-193.

Laurec, A. et J.Y. Le Gall (1975) - De-seasonalising of the abundance index of a species. Application to the albacore (Thunnus alalunga) monthly catch per unit of effort (cpue) by the Atlantic Japanese longline fishery. Bull. Far Seas Res. Lab., 12:145-169.

McCall (cited in Section 6.2.3) - Reference not available.

Parrish, B.B. (ed.) (1975) - Monitoring of fish stock abundance: The use of catch and effort data. FAO Fisheries Technical Paper 155 (FIRST/155).

Robson, D.S. (1966) - Estimation of the relative fishing power of individual ships. ICNAF Res. Bull. 3:5-14.

Sparre, P. (1980) - A goal function of fisheries (Legion analysis). ICES, Doc.C.M.1980/G:40.

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9. NOTATION

Symbols

q	catchability coefficient (in $F = qE$)
Y	yield in weight (including discards)
L	landings in weight (excluding discards)
W	weight of an individual fish
B	biomass
P	relative fishing power of a fishing boat or fleet
E	fishing effort
U	yield or landings per unit of effort (see abbreviations)
C	catch in numbers of fish (including discards)
T	landed catch in numbers of fish
N	stock in numbers of fish
A	abundance effect in the linear model
Q	"corrective" factor for differences in time-area strata in the linear model
G	factors in the linear model
V	value of a quantity of fish
F	instantaneous fishing mortality
Z	instantaneous total mortality
M	instantaneous natural mortality
S	selection coefficient defined as the relative fishing mortality (over age)
γ	relative catch rate (over years) for one fleet
Γ	relative catch rate over years for several fleets combined

(Note: " ^ " over a symbol has been used in various ways and its use is defined in the relevant section.)

Suffices (others occur and are defined locally)

y	years
f	fleets
a	ages
s	species or time-area strata in the linear model
*	denotes a reference year, fleet, age or species
•	denotes a summation over a suffix

Abbreviations

VPA	Virtual Population Analysis
CPUE	catch per unit effort either with catch equal to yield or landings or numbers of fish as defined in the text
YPUE	yield per unit effort (including discards)
LPUE	landings per unit effort (excluding discards)
PEB	partial exploited biomass
RCPUE	relative CPUE over years averaged across fleets weighted in various ways
TAC	total allowable catch
NAFO	Northwest Atlantic Fisheries Organisation
WG	Working Group

Table 6.1.1. Example of input data and calculation of relative CPUE for year 1964. Data are number at age of North Sea haddock landed in 1964 by Scottish trawlers. The reference year is 1978.

Age	$C_{1964,1,a}$	$CPUE_{1964,1,a}$	Relative $CPUE_{1964,1,a}$	Reference: $CPUE_{1978,1,a}$
1	0	0	0	4.548
2	44 147	228.741	7.195	31.793
3	8 810	45.648	3.532	12.926
4	784	4.062	0.036	114.007
5	630	3.264	0.254	12.837
6	566	2.933	2.459	1.193
7	22	0.114	0.046	2.459
8	22	0.114	0.252	0.452
9	44	0.228	1.924	0.119
10	1	0.005	0.349	0.015
Effort	193			

Table 6.1.2. Values of Γ_{ya} for North Sea haddock.

Age	1963	1964	1965	1966	1967	1968	1969	1970
1	1.611	0.002	0.144	1.329	3.606	0.692	0.003	0.054
2	1.545	3.141	0.025	0.059	0.469	2.471	3.380	0.306
3	0.502	2.738	8.281	0.194	0.115	0.553	2.899	17.757
4	0.072	0.078	0.153	1.475	0.018	0.015	0.020	0.165
5	0.448	0.321	0.417	0.427	11.488	0.307	0.087	0.060
6	0.292	1.594	1.973	0.693	1.235	30.533	1.256	0.311
7	0.262	0.217	0.287	0.355	0.035	0.065	3.299	0.051
8	1.179	0.386	0.215	0.200	0.286	0.082	0.226	5.663
9	0.491	1.487	0.876	0.595	0.287	0.063	0.058	0.138
10	2.757	2.882	3.670	3.110	2.091	0.229	0.470	0.571
Age	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**
1	1.639	0.625	0.321	1.355	1.131	0.131	0.629	1.000
2	0.456	3.100	2.359	0.635	2.488	3.204	0.639	1.000
3	0.593	1.096	6.012	6.335	1.032	5.306	11.961	1.000
4	1.669	0.137	0.034	0.290	0.570	0.073	0.438	1.000
5	0.673	11.426	0.305	0.134	1.186	2.795	0.578	1.000
6	0.208	2.103	21.613	0.780	0.409	3.789	5.801	1.000
7	0.043	0.063	0.430	3.864	0.166	0.081	0.774	1.000
8	0.252	0.065	0.279	0.454	5.131	0.154	0.373	1.000
9	8.285	0.309	0.170	0.209	2.630	5.690	0.318	1.000
10	9.929	26.758	8.512	2.210	3.043	4.379	19.369	1.000

Table 6.1.3. Values of log (N_{ya}^{VPA}) and Γ'_{ya} for age groups 1-10 for North Sea haddock. Results of predictive regression (y = a+bx) and geometric regression (y = u+vx), y = log N, x = Γ'

Year / Age Group	I		II		III		IV		V		VI		VII		VIII		IX		X	
	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'	Log N	Γ'
1963	9.739	-0.350	8.724	-0.340	7.674	-1.548	7.423	-1.365	7.023	-1.409	6.158	-2.019	6.098	-1.169	6.018	-0.681	5.111	-1.227	4.591	-0.987
1964	7.774	-3.162	9.597	-0.032	8.353	-0.812	7.262	-1.332	6.993	-1.554	6.554	-1.282	5.865	-1.250	5.651	-1.167	5.549	-0.746	4.732	-0.968
1965	8.513	-1.398	7.591	-2.130	9.258	-0.331	7.778	-1.037	6.841	-1.440	6.522	-1.190	5.912	-1.130	5.534	-1.420	5.201	-0.976	4.940	-0.863
1966	8.904	-0.434	7.551	-1.757	7.341	-1.961	8.907	-0.054	7.204	-1.430	6.198	-1.644	5.993	-1.036	5.428	-1.451	5.265	-1.144	4.699	-0.935
1967	9.338	0	7.982	-0.857	7.182	-2.188	7.115	-1.963	8.478	0	6.634	-1.393	5.566	-2.048	5.436	-1.296	4.869	-1.461	4.851	-1.107
1968	10.097	-0.717	8.912	-0.136	7.525	-1.507	6.906	-2.054	6.873	-1.573	7.953	0	6.136	-1.776	5.045	-1.841	4.531	-2.117	4.041	-2.058
1969	8.656	-3.063	9.845	0	8.596	-0.787	7.058	-1.931	6.683	-2.119	6.588	-1.386	7.516	-0.069	5.918	-1.400	4.732	-2.155	4.176	-1.755
1970	8.523	-1.822	8.553	-1.043	9.452	0	7.922	-1.005	6.449	-2.280	6.257	-1.991	5.977	-1.884	6.993	0	5.698	-1.778	4.380	-1.671
1971	9.345	-0.342	8.074	-0.870	7.955	-1.476	8.860	0	7.283	-1.232	6.100	-2.168	5.631	-1.949	5.737	-1.351	6.443	0	5.537	-0.431
1972	9.360	-0.761	8.957	-0.038	7.750	-1.210	7.499	-1.084	8.386	-0.002	6.819	-1.162	5.794	-1.785	5.253	-1.939	5.500	-1.428	5.939	0
1973	8.713	-1.051	9.056	-0.156	8.539	-0.470	7.077	-1.696	6.892	-1.576	7.795	-0.150	6.358	-0.954	5.534	-1.307	5.068	-1.687	5.369	-0.497
1974	9.567	-0.425	8.391	-0.726	8.763	-0.448	7.954	-0.760	6.637	-1.933	6.397	-1.593	7.222	0	5.884	-1.096	5.270	-1.597	4.839	-1.083
1975	9.582	-0.503	9.059	-0.133	8.037	-1.236	8.316	-0.466	7.443	-0.986	6.283	-1.873	5.940	-1.366	6.631	-0.043	5.617	-0.498	5.121	-0.944
1976	8.564	-1.440	9.253	-0.023	8.480	-0.525	7.283	-1.358	7.671	-0.614	6.900	-0.906	5.858	-1.679	5.262	-1.566	6.069	-0.163	5.053	-0.786
1977	8.809	-0.758	8.245	-0.723	8.825	-0.172	7.792	-0.581	6.854	-1.298	7.055	-0.721	6.354	-0.698	5.626	-1.182	4.954	-1.416	5.548	-0.140
1978	8.996	-0.557	8.479	-0.529	7.687	-1.249	8.300	-0.222	7.196	-1.060	6.368	-1.485	6.596	-0.587	5.922	-0.753	5.386	-0.918	4.716	-1.427
r	0.746		0.890		0.954		0.958		0.967		0.968		0.897		0.942		0.820		0.954	
a	9.521		9.190		9.201		8.665		8.285		7.774		7.092		6.725		6.093		5.759	
b	0.469		0.925		0.992		0.898		0.861		0.848		0.756		0.852		0.633		0.869	
$\bar{x}$	-1.049		-0.593		-0.995		-1.057		-1.282		-1.312		-1.211		-1.153		-1.207		-0.979	
$\bar{y}$	9.030		8.642		8.214		7.716		7.182		6.661		6.176		5.742		5.329		4.908	
u	9.689		9.258		9.249		8.707		8.323		7.810		7.197		6.785		6.261		5.800	
v	0.629		1.039		1.040		0.937		0.890		0.876		0.843		0.904		0.772		0.911	

Table 6.2.1. North Sea cod. Partial exploited biomasses (PEBs).

Year/Fleet	Scotland Trawl	Scotland Other Gears	England All Gears	Belgium All Gears	Netherlands All Gears
1963	416.4	423.6	235.6	-	-
1964	473.6	466.9	244.7	-	-
1965	504.2	499.9	406.1	-	-
1966	661.5	602.6	570.1	-	-
1967	584.8	664.4	577.3	-	-
1968	667.0	745.1	666.9	566.5	915.9
1969	286.1	507.8	512.4	415.6	494.9
1970	488.1	529.0	482.0	633.6	650.4
1971	543.2	715.2	577.3	1 102.0	1 099.1
1972	576.4	856.0	539.9	1 239.0	1 096.0
1973	432.9	488.3	332.3	420.6	535.8
1974	341.5	468.1	362.2	457.9	515.3
1975	304.7	496.9	389.2	421.2	579.6
1976	393.1	587.1	463.0	647.8	641.1
1977	399.7	640.0	529.4	169.0	992.8
1978	313.9	516.6	391.5	856.3	1 332.6

Table 6.2.2. Results of regression analysis on log PEB and log CPUE for various fleets and North Sea cod. The equation is $\ln (Y_{yf}/E_{yf}) = \ln x + (\beta + 1) \ln B_{yf}$.

PEB Fleet	CPUE Fleet	Period	n	r	β+1	Significance Level
SCO TRA	SCO MT	1970-75	6	0.378	0.597	ns
SCO TRA	SCO LT	1970-75	6	0.439	0.667	ns
SCO OTH	SCO S	1963-75	13	0.456	1.628	ns
ENG ALL	ENG MT	1963-75	13	0.780	1.493	**
ENG ALL	ENG S	1963-75	13	0.878	0.980	**
ENG ALL	ENG PT	1966-75	10	-0.620	-5.183	ns
BEL ALL	BEL OT	1971-75	5	0.910	0.972	**
BEL ALL	BEL DS	1973-75	3	-0.118	-3.666	ns
NET ALL	NET OT	1968-75	8	0.745	1.413	*
NET ALL	NET BT	1968-75	8	0.650	1.063	ns
NET ALL	NET PT	1968-75	8	0.596	0.922	ns

Table 6.3.1. Basic data for Figure 6.3.1. Faroese longline boats 1973-80. Cod in Sub-division Vb_1.

Year	Effort Mill. Hooks	Total F from VPA		Partial F Longline	
		1 Run	2 Run	1 Run	2 Run
1973	27	0.386	-	0.067	-
1974	25	0.392	-	0.065	-
1975	30	0.373	-	0.055	-
1976	49	0.539	-	0.153	-
1977	62	0.985	0.978	0.329	0.326
1978	52	0.553	0.452	0.145	0.137
1979	45	0.558	0.447	0.115	0.101
1980	41	0.490	0.375	0.145	0.109

Table 6.4.1.

Catch

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	11	8	4	4	1	5	4	2	1	6	5	3	2	6	1	1	1	2	4	4
2	773	1 421	1 088	520	495	117	667	521	293	182	847	702	390	341	827	197	210	111	235	619
3	596	883	1 642	1 273	615	592	142	811	644	366	230	1 075	977	591	501	1 189	278	290	151	314
4	482	575	878	1 680	1 340	666	660	162	959	782	456	294	1 514	1 476	849	694	1 588	357	361	181
5	205	128	160	256	515	431	224	231	60	371	316	193	139	775	706	384	296	642	137	131
6	87	53	35	46	77	162	142	77	84	23	148	132	90	70	361	311	160	117	241	49
7	37	23	15	10	14	24	53	49	28	32	9	62	62	46	33	159	130	63	44	86
1+	2 192	3 092	3 822	3 788	3 056	1 998	1 893	1 853	2 070	1 763	2 012	2 461	3 175	3 304	3 278	2 935	2 662	1 583	1 173	1 383

Numbers

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	10 000	8 000	4 000	4 000	1 000	6 000	5 000	3 000	2 000	10 000	9 000	5 000	4 000	9 000	2 000	2 000	1 000	2 000	5 000	4 000
2	4 270	8 177	6 542	3 271	3 271	818	4 903	4 090	2 454	1 636	8 182	7 364	4 091	3 273	7 363	1 636	1 636	818	1 636	4 090
3	1 820	2 800	5 416	4 377	2 210	2 233	564	3 417	2 879	1 745	1 175	5 935	5 396	2 998	2 372	5 283	1 162	1 151	570	1 128
4	780	956	1 500	2 961	2 441	1 258	1 296	334	2 068	1 778	1 099	755	3 892	3 538	1 923	1 491	3 256	702	681	331
5	330	211	272	448	930	806	437	473	129	838	757	492	355	1 831	1 577	815	602	1 249	256	237
6	140	88	59	80	139	303	276	157	181	52	354	337	230	166	806	661	325	228	450	88
7	60	37	25	17	25	45	104	100	60	73	22	158	157	108	73	338	263	123	82	155
1+	17 400	20 270	17 814	15 155	10 017	11 463	12 585	11 571	9 772	16 122	20 589	20 041	18 122	20 914	16 115	12 225	8 244	6 271	8 676	10 027

Biomass

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	16 848	13 479	6 740	6 740	1 685	10 110	8 425	5 055	3 370	16 852	15 167	8 427	6 741	15 167	3 370	3 370	1 685	3 370	8 425	6 740
2	19 263	37 064	29 791	14 966	15 037	3 777	22 770	19 075	11 500	7 703	38 701	34 998	19 444	15 475	34 650	7 663	7 627	3 795	7 555	18 798
3	11 808	18 330	35 777	29 172	14 867	15 154	3 862	23 642	20 105	12 298	8 358	42 608	38 735	21 302	16 700	36 856	8 034	7 881	3 866	7 585
4	4 786	5 982	9 579	19 289	16 229	8 536	8 981	2 367	14 977	13 153	8 310	5 835	30 065	26 696	14 200	10 780	23 043	4 866	4 625	2 198
5	2 254	1 469	1 930	3 250	6 881	6 087	3 366	3 740	1 039	6 910	6 381	4 239	3 062	15 369	12 955	6 557	4 736	9 632	1 935	1 750
6	1 057	679	465	643	1 138	2 534	2 357	1 376	1 617	472	3 304	3 208	2 192	1 542	7 325	5 875	2 829	1 944	3 762	719
7	483	307	207	149	217	404	946	929	574	709	218	1 601	1 599	1 065	709	3 203	2 444	1 120	732	1 348
1+	73 642	99 591	112 290	103 470	79 943	63 863	66 296	71 345	70 301	74 628	98 868	123 477	130 140	126 480	117 892	99 579	72 589	46 346	41 325	49 963

Fishing Mortality

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2	0.222	0.212	0.202	0.192	0.182	0.172	0.162	0.151	0.141	0.131	0.121	0.111	0.111	0.122	0.132	0.142	0.152	0.162	0.172	0.182
3	0.444	0.424	0.404	0.384	0.364	0.344	0.324	0.302	0.282	0.262	0.242	0.222	0.222	0.244	0.264	0.284	0.304	0.324	0.344	0.364
4	1.108	1.058	1.008	0.958	0.908	0.858	0.808	0.754	0.704	0.654	0.604	0.554	0.554	0.608	0.658	0.708	0.758	0.808	0.858	0.908
5	1.120	1.070	1.020	0.970	0.920	0.870	0.820	0.760	0.710	0.660	0.610	0.560	0.560	0.620	0.670	0.720	0.770	0.820	0.870	0.920
6	1.120	1.070	1.020	0.970	0.920	0.870	0.820	0.760	0.710	0.660	0.610	0.560	0.560	0.620	0.670	0.720	0.770	0.820	0.870	0.920
7	1.120	1.070	1.020	0.970	0.920	0.870	0.820	0.760	0.710	0.660	0.610	0.560	0.560	0.620	0.670	0.720	0.770	0.820	0.870	0.920
1+	0.734	0.701	0.668	0.635	0.602	0.569	0.536	0.498	0.465	0.433	0.400	0.367	0.367	0.405	0.438	0.471	0.504	0.536	0.569	0.602

Appendix to Table 6.4.1. Simulation parameters.

Starting population and selectivities:

Age	Number	Weight	Selectivity 1	Selectivity 2
1	10 000	1.86	.001	.005
2	4 270	5.53	.2	.1
3	1 820	8.80	.4	.2
4	780	11.0	1	.4
5	330	12.3	1	1
6	140	13.6	1	1
7	60	14.5	1	1

Constant catchability coefficients: $q_1 = 0.001$

$q_2 = 0.0002$

Effort:

Year	E_1	E_2	q_1 Variable	q_2 Variable
1960	1 100	100	.001	.0003
1961	1 050	100	.00102	.0003
1962	1 000	100	.00105	.0003
1963	950	100	.00108	.0003
1964	900	100	.00110	.0003
1965	850	100	.00113	.0003
1966	800	100	.00116	.0003
1967	750	50	.00119	.0003
1968	700	50	.00122	.0003
1969	650	50	.00125	.0003
1970	600	50	.00128	.0001
1971	550	50	.00131	.0001
1972	550	50	.00134	.0001
1973	600	100	.00138	.0001
1974	650	100	.00141	.0001
1975	700	100	.00145	.0001
1976	750	100	.00148	.0001
1977	800	100	.00152	.0001
1978	850	100	.00156	.0001
1979	900	100	.00160	.0001

Table 6.4.2. Parameters of the equation relating effort to fishing mortality and biomass to catch per unit effort for pure data, data with noise and data with changes in "q".

Relationship	Pure Data r^2	Data with Random Noise (20%) r^2	Change in "q" (No Noise) r^2
$\bar{F}$ vs E (Total catch/$Cpue_1$)	1.000	.393	.447
$\bar{F}$ vs E (Total catch/$Cpue_2$)	.810	.464	.236
F_p vs E (Gamma)	.024	.000	.002
$\bar{F}$ vs E (Gamma)	1.000	.397	.536
$\bar{F}_{wc}$ vs E (Gamma)	.318	.107	.075
$\bar{F}_{wn}$ vs E (Gamma)	.044	.003	.006
$\bar{F}_{wc}$ vs E (Total catch/$Cpue_1$)	.320	.109	.058
$\bar{F}_{wn}$ vs E (Total catch/$Cpue_1$)	.044	.003	.002
Cpue vs Exploited biomass	1.000	.746	.943
Cpue vs Spawning stock biomass	.902	.680	.836
Cpue vs Total biomass	.638	.440	.537
$Cpue_1$ vs Exploited biomass	1.000	.745	.923
$Cpue_2$ vs Exploited biomass	.907	.443	.115

Table 6.4.3. Coefficients of determination (r^2) for wider dynamic range of effort and change in selectivity and "q".

Relationship	Pure Data	Change in "q"	Change in "s"
$\overline{F}$ vs E_1	1.000	.789	.988
$\overline{F}$ vs E_2	.929	.231	.888
F_p vs E (Gamma)	.133	.080	.086
$\overline{F}$ vs E (Gamma)	1.000	.895	.984
$\overline{F}_{wc}$ vs E (Gamma)	.560	.349	.613
$\overline{F}_{wn}$ vs E (Gamma)	.195	.119	.156
$\overline{F}_{wc}$ vs E_1	.567	.292	.628
$\overline{F}_{wn}$ vs E_2	.197	.084	.163
Ypue vs B_{exp}	1.000	.987	1.000
Ypue vs B_{ss}	.909	.879	.874
Ypue vs B_t	.742	.670	.732
$Ypue_1$ vs B_{exp}	1.000	.974	1.000
$Ypue_2$ vs B_{exp}	.942	.155	.962

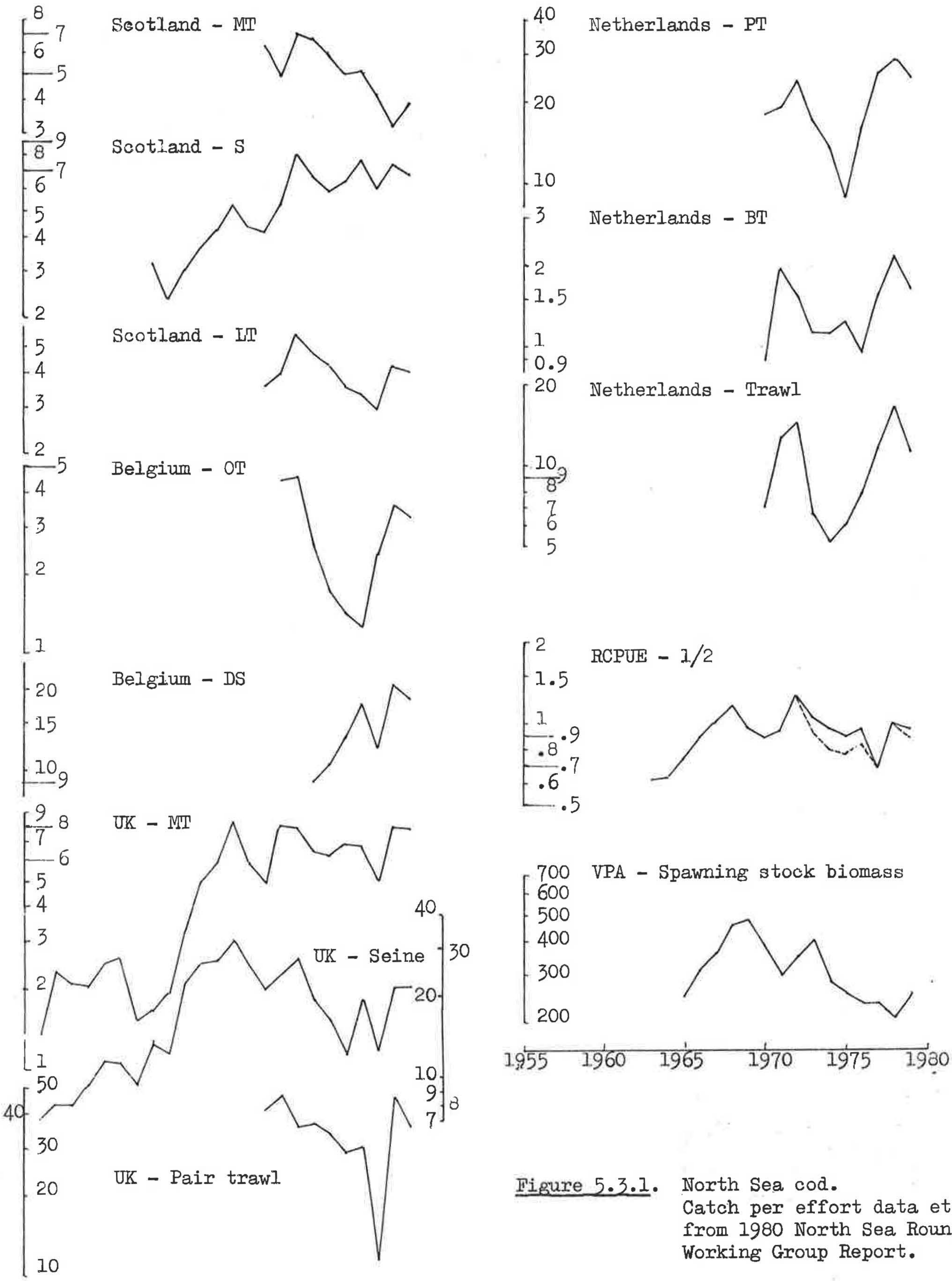


Figure 5.3.1. North Sea cod.
Catch per effort data etc.
from 1980 North Sea Roundfish
Working Group Report.

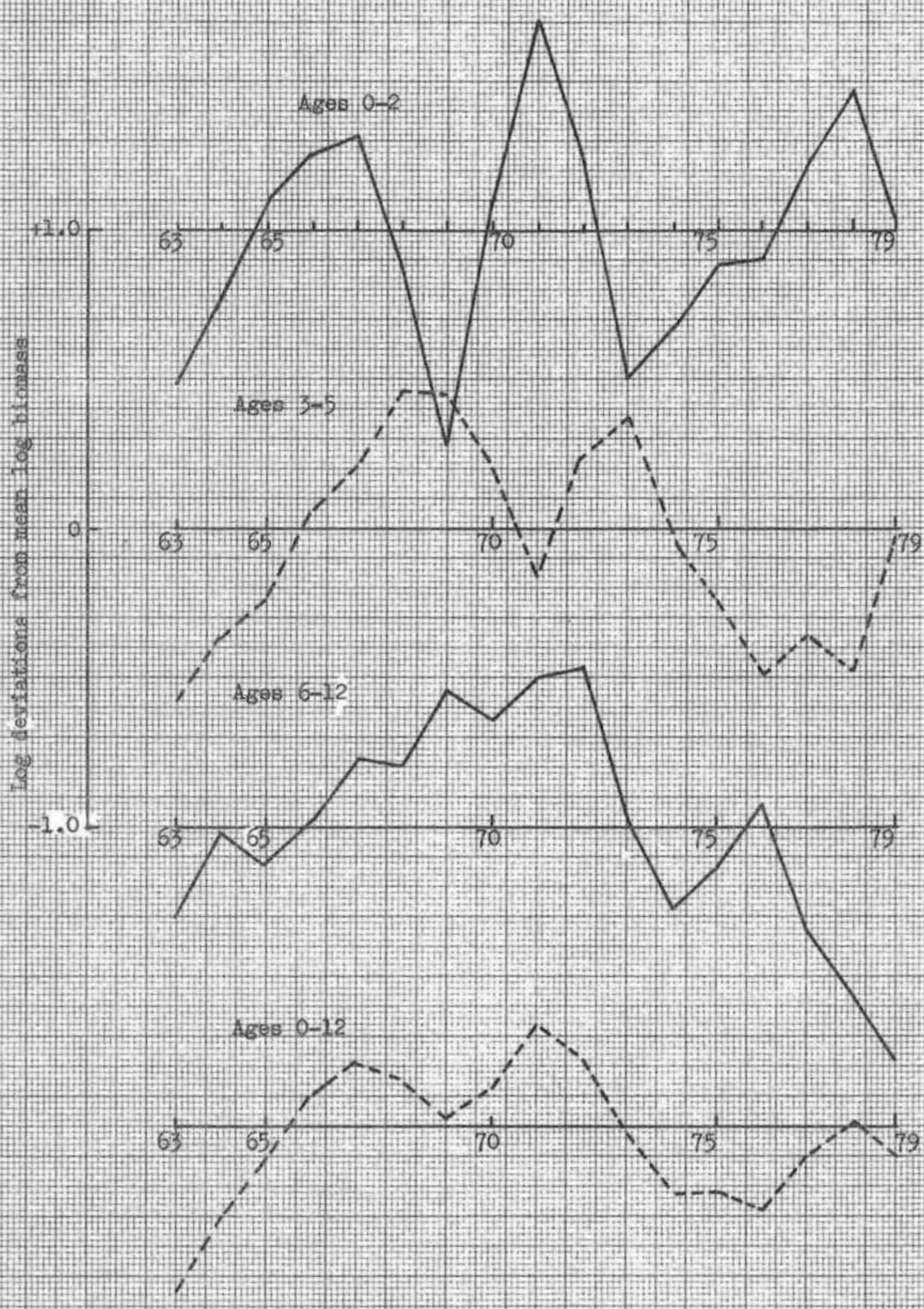


Figure 5.3.2. North Sea cod.
Biomass from VPA for various age ranges.
Beginning of year values. 1980 Working Group Report.

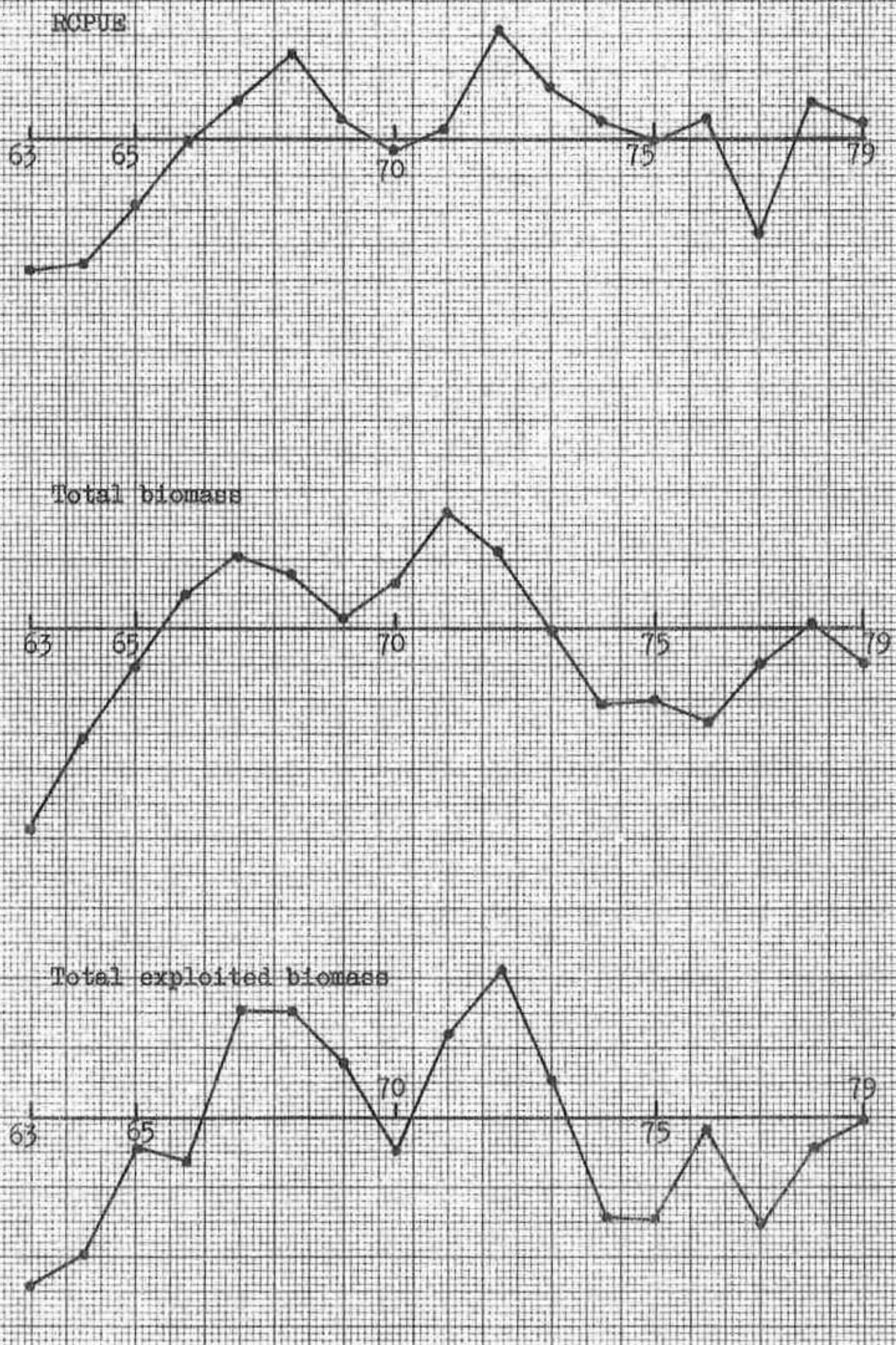
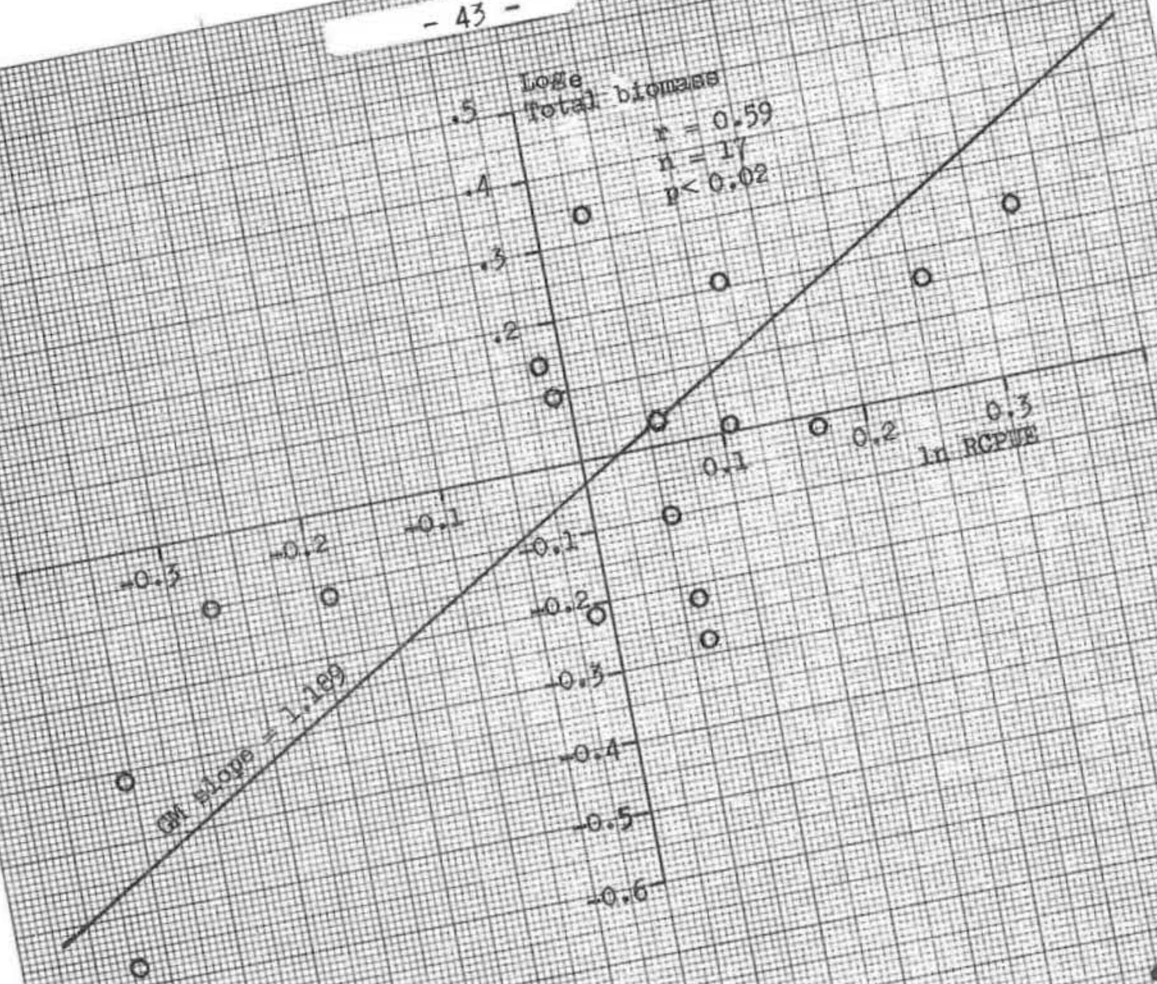


Figure 5.3.3. North Sea cod, ln RCPUE, ln B and ln TEB from 1980 Working Group Report.



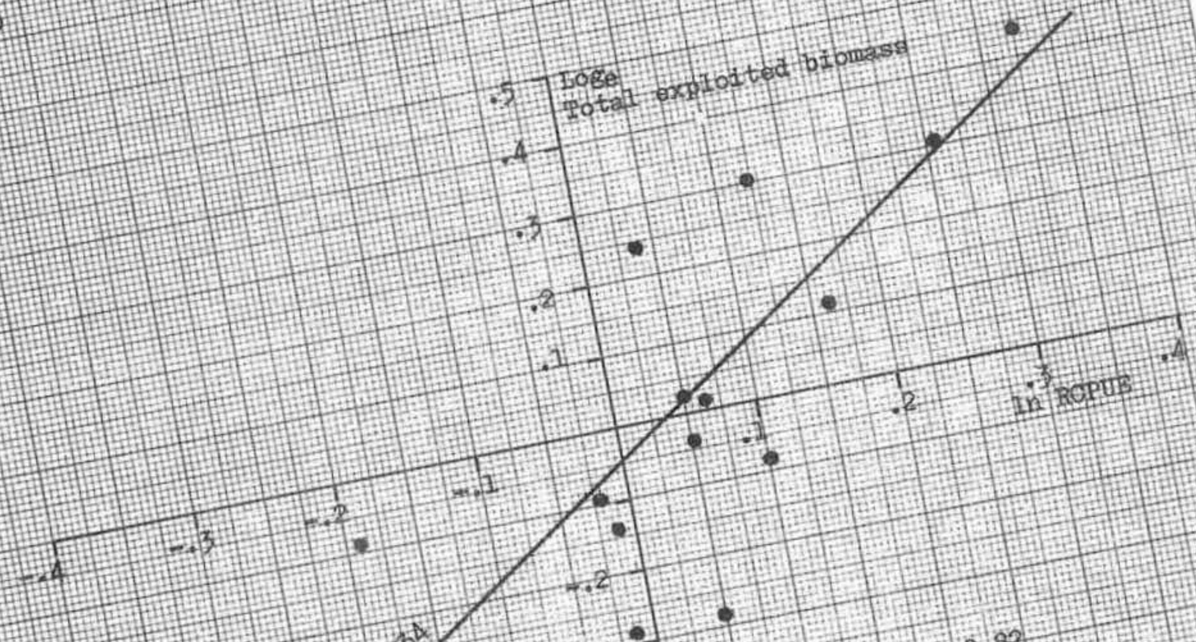


Figure 5.3.4. North Sea cod. Regression of ln B and ln TEB on ln RCPUE. 1980 Working Group Report.

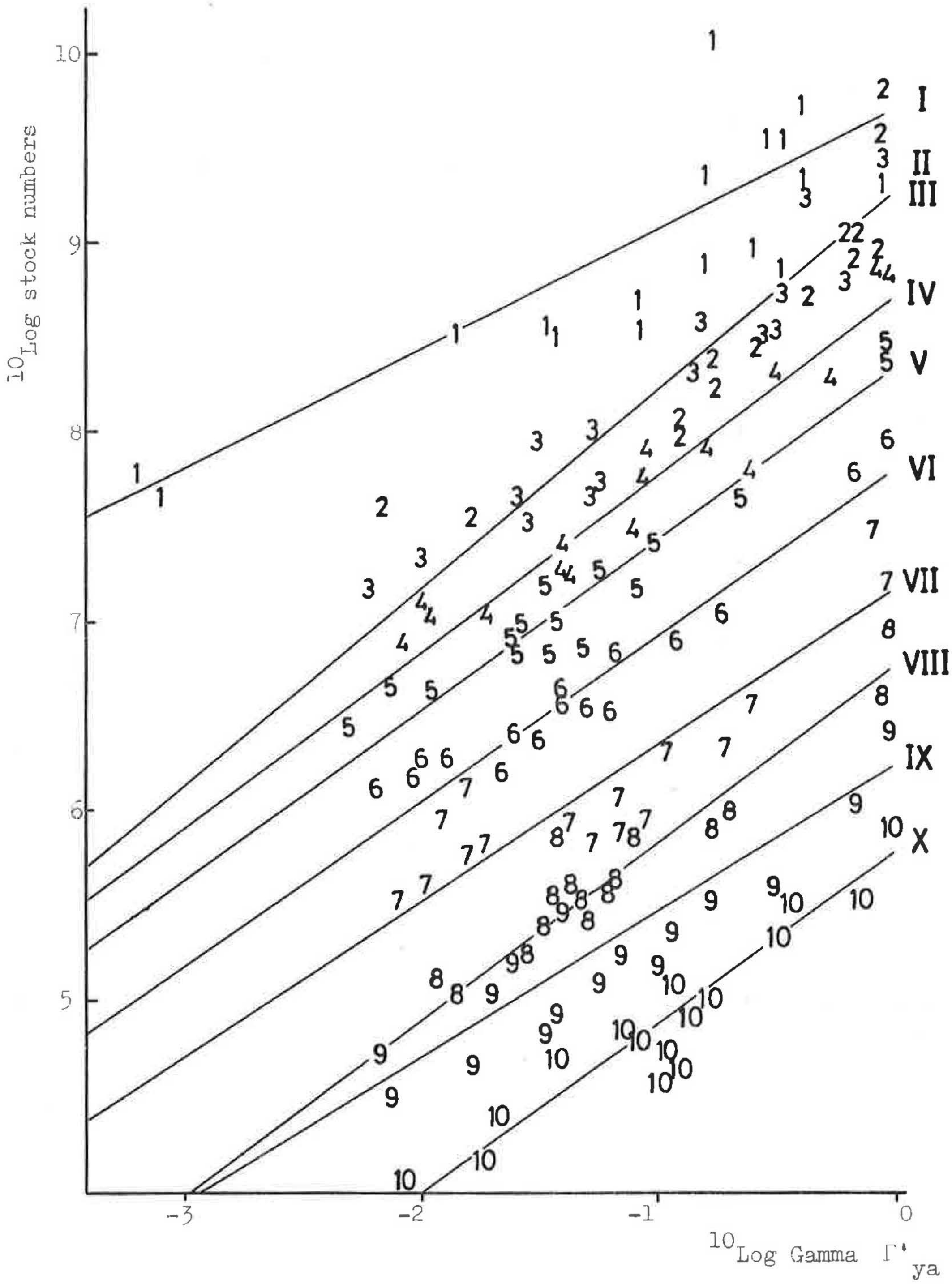


Figure 6.1.1. Γ'_{ya} vs Log (N^{VPA}_{ya}) for North Sea haddock for ages 1 to 10.

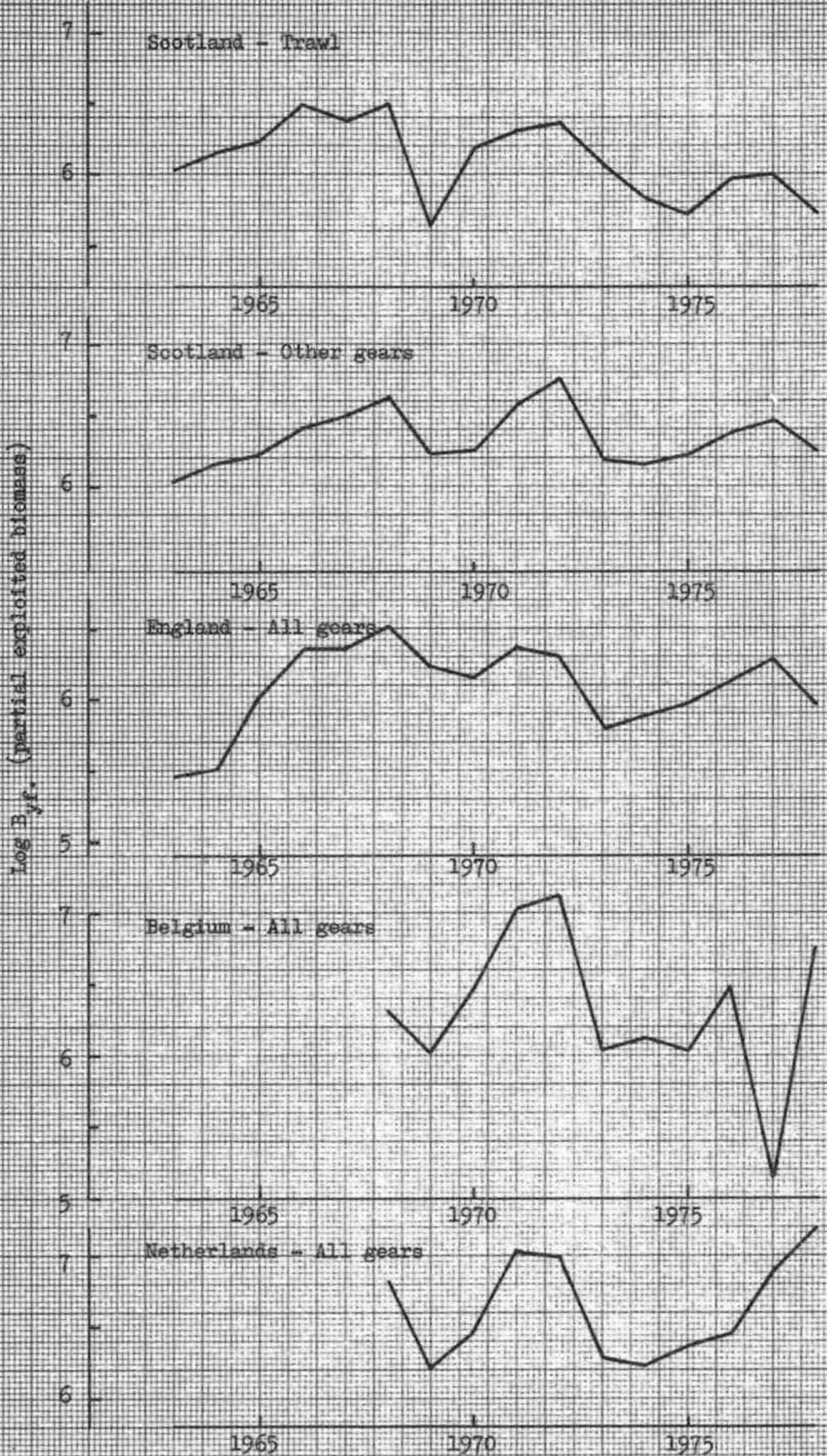


Figure 6.2.1. North Sea cod. ln PEB/years.

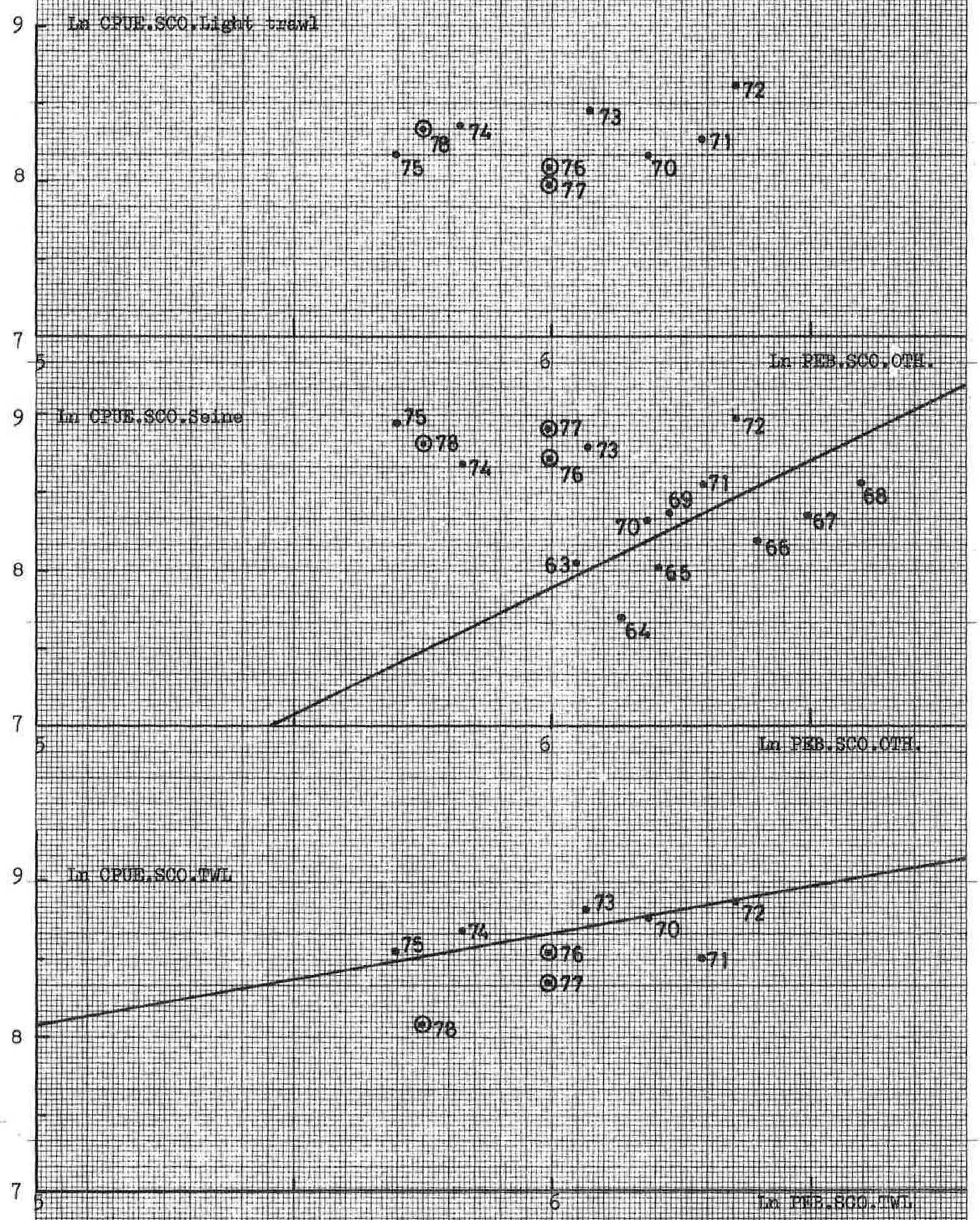


Figure 6.2.2. North Sea cod. Ln of CPUE/Ln of PEB.

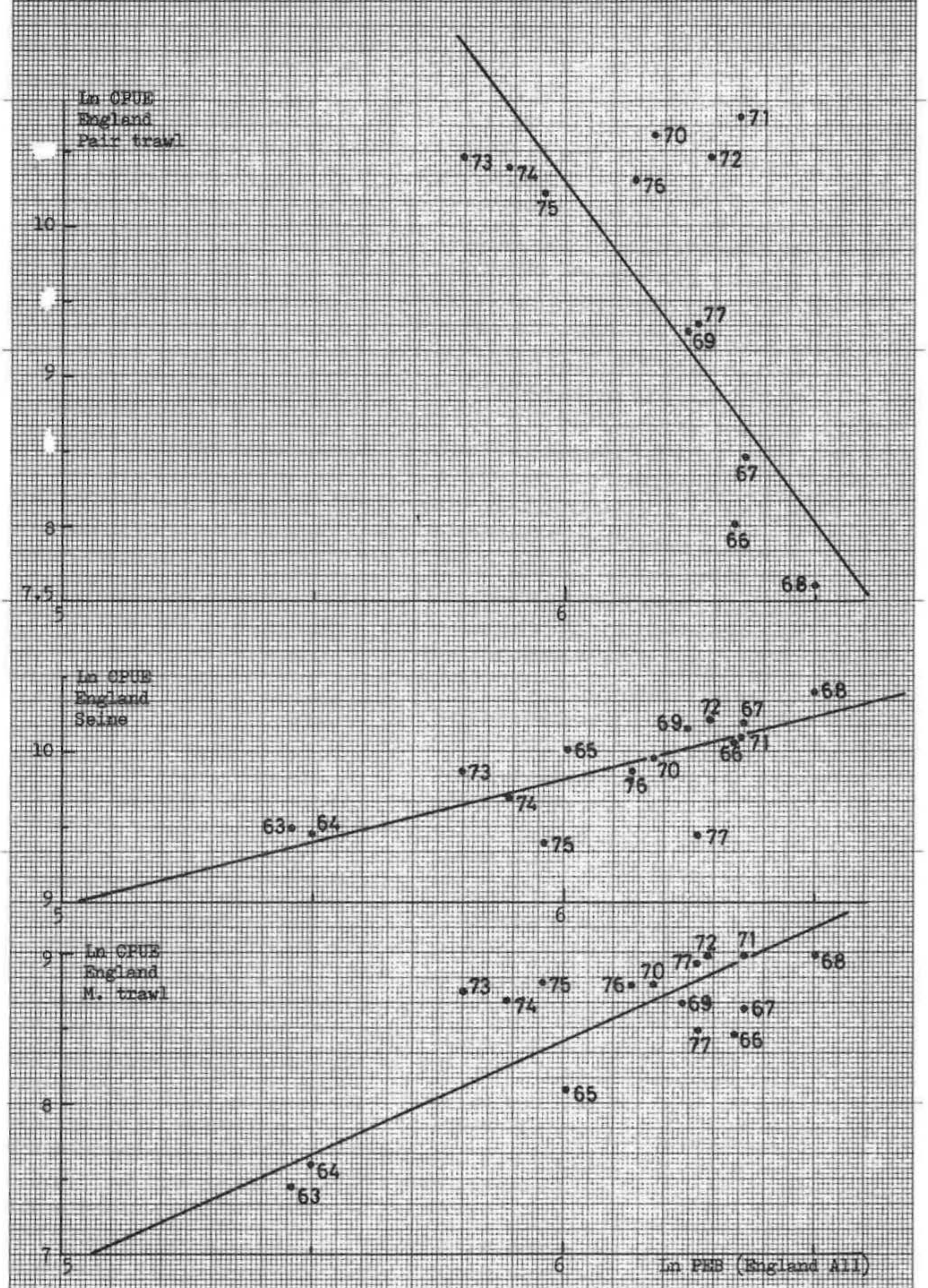
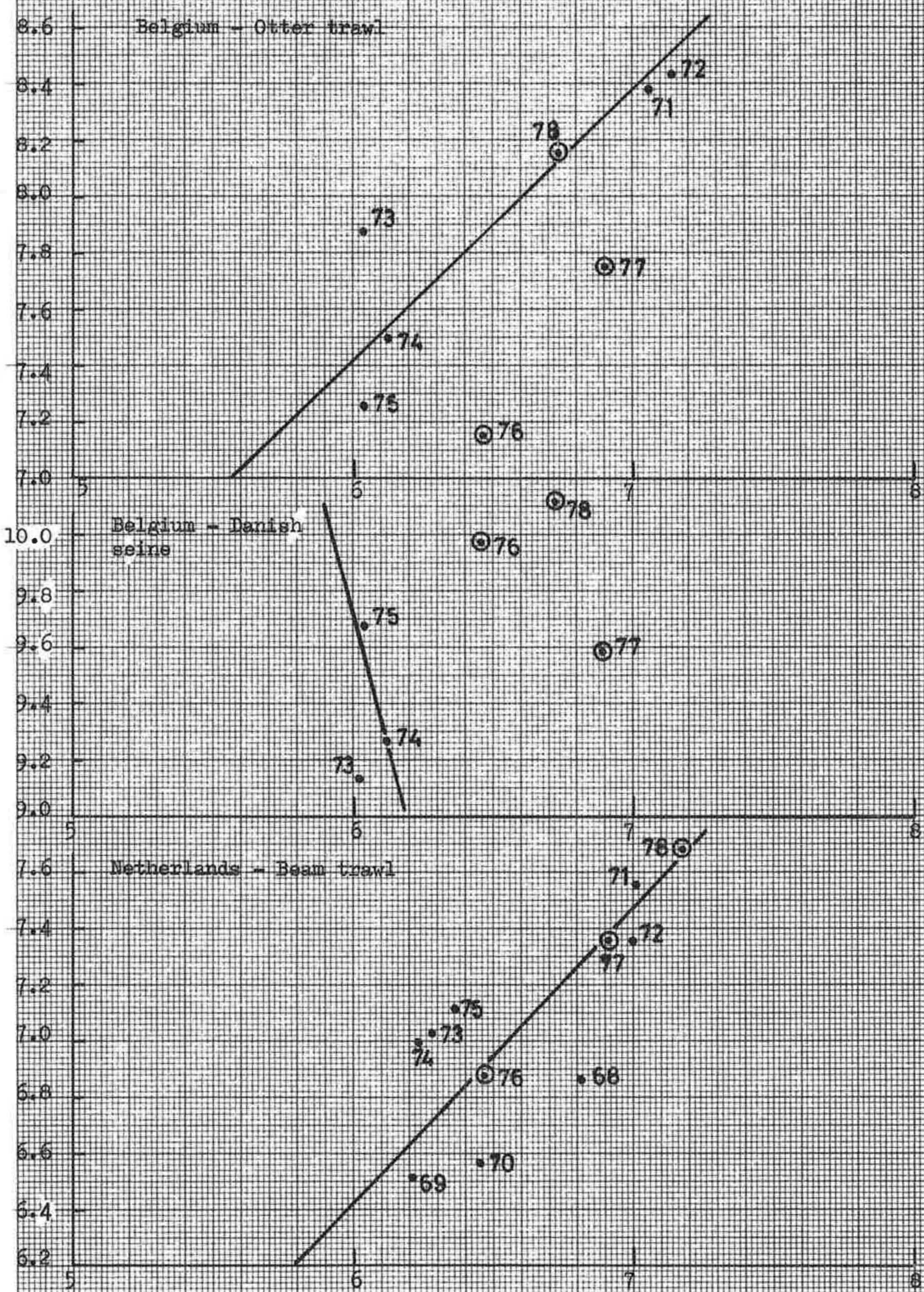


Figure 6.2.3. North Sea cod. Ln of CPUE/Ln PEB.



<u>Figure 6.2.4</u>. North Sea cod. ln of CPUE/ln of PEB.

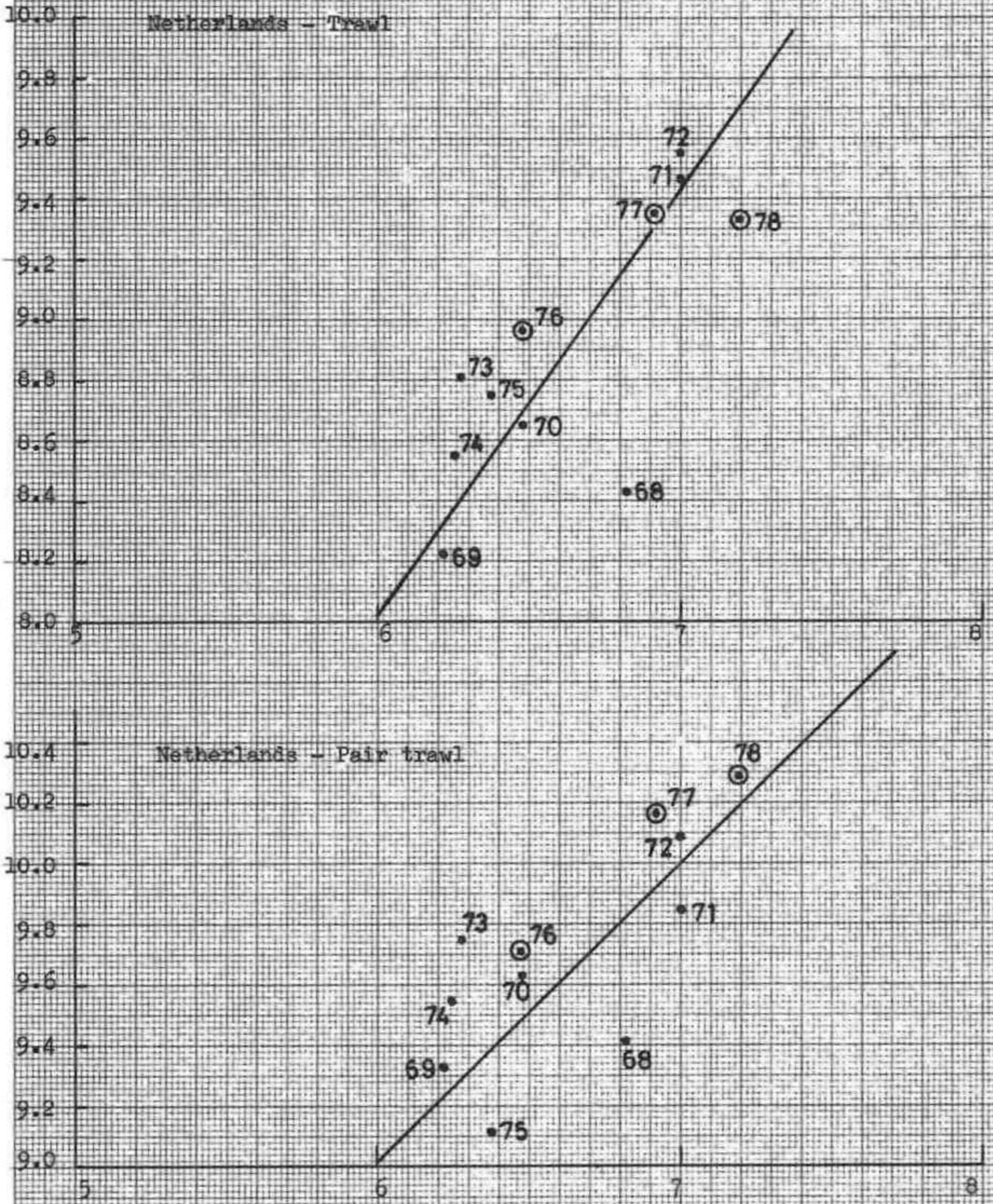


Figure 6.2.5. North Sea cod. ln of CPUE/ln of PHD.

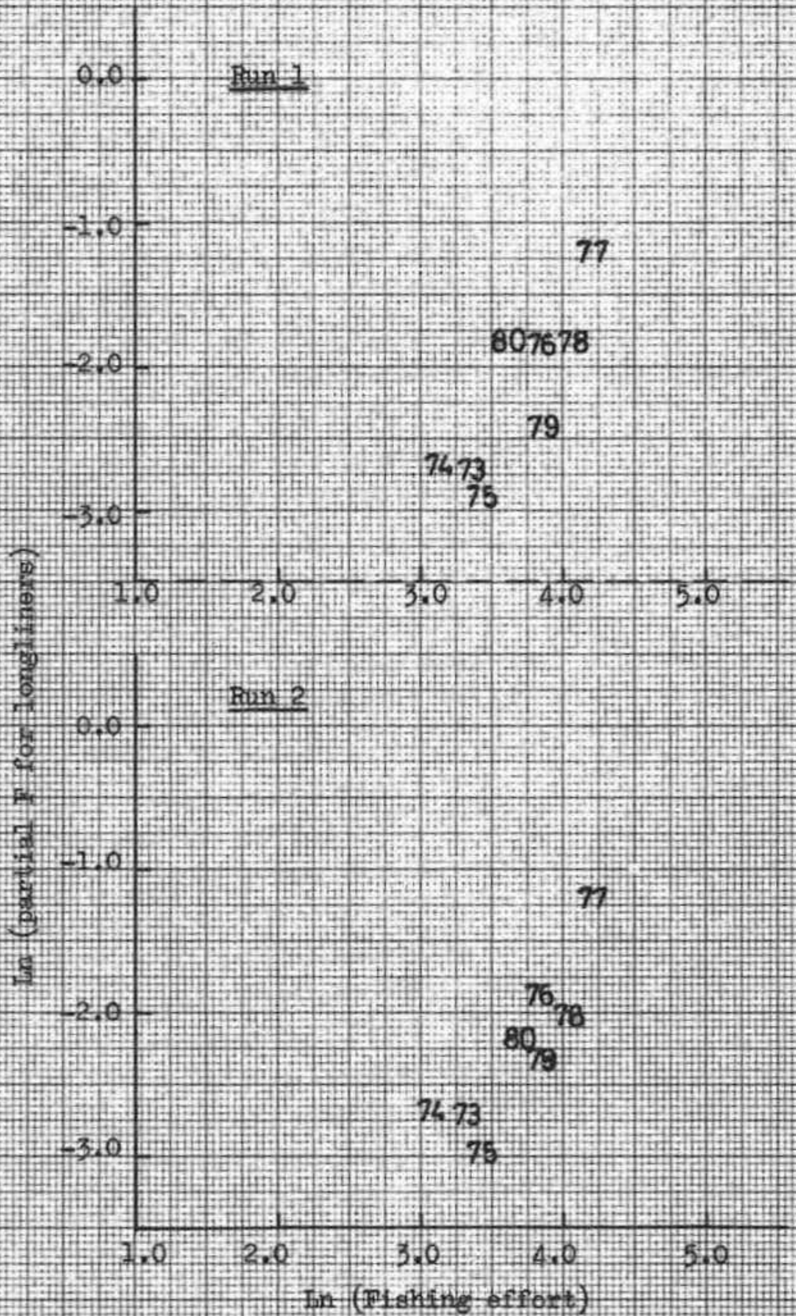


Figure 6.3.1. Cod in ICES Sub-division Vb.
Ln (partial F) vs Ln (effort).

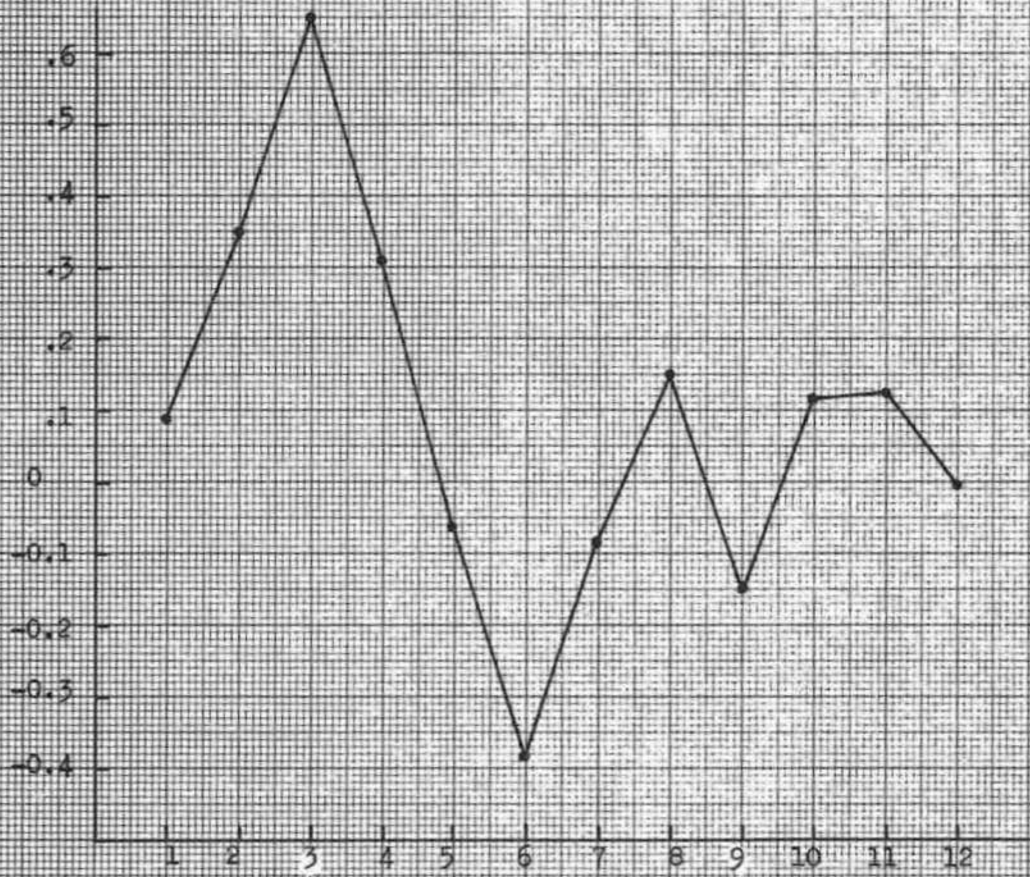


Figure 6.3.2. Relative monthly abundance (in logs).
(Data : Total catch/total effort)

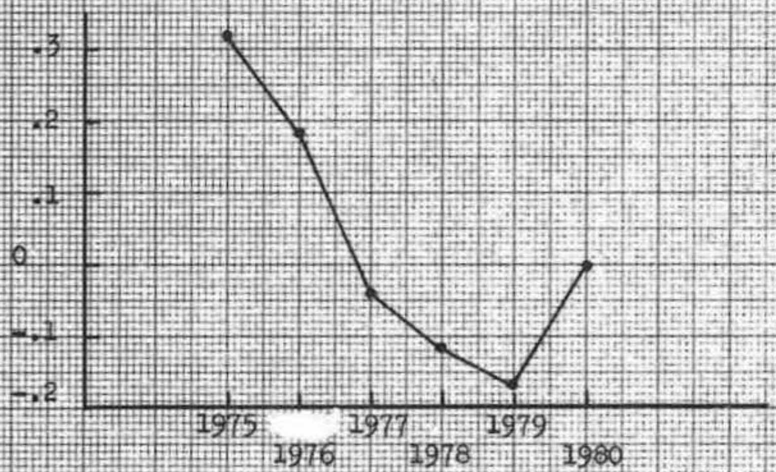


Figure 6.3.3. Relative yearly abundance (in logs).
(Data : Total catch/total effort)

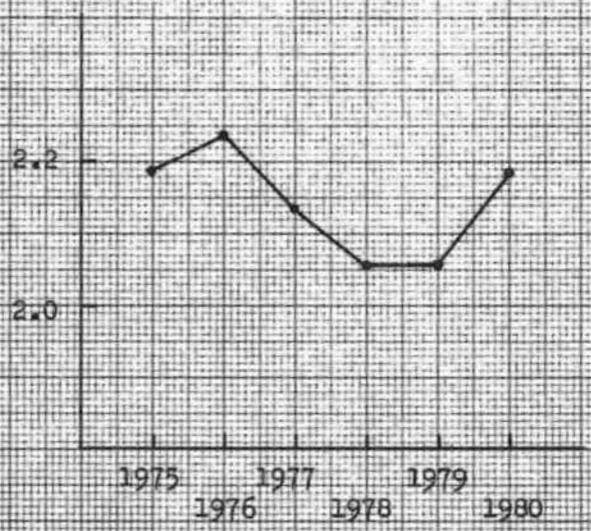


Figure 6.3.4. Log ($C/_E$). Faroese line boats.

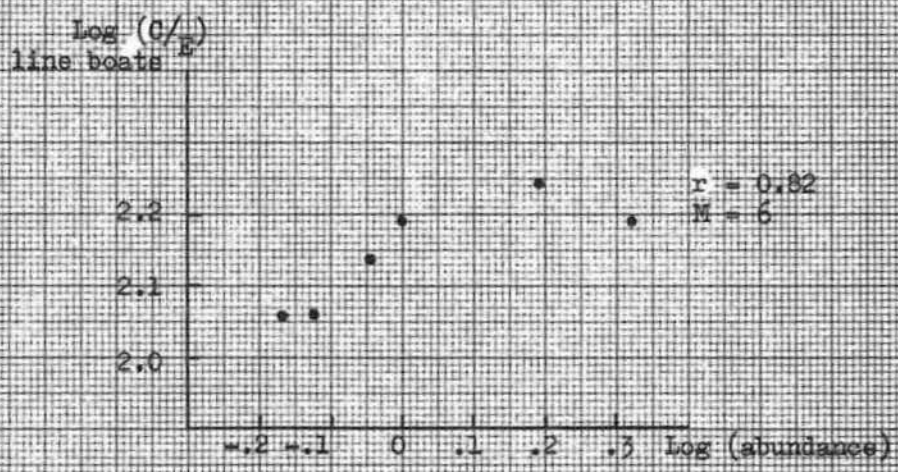


Figure 6.3.5. Log ($C/_E$) of line boats vs log (abundance) multiplicative model.

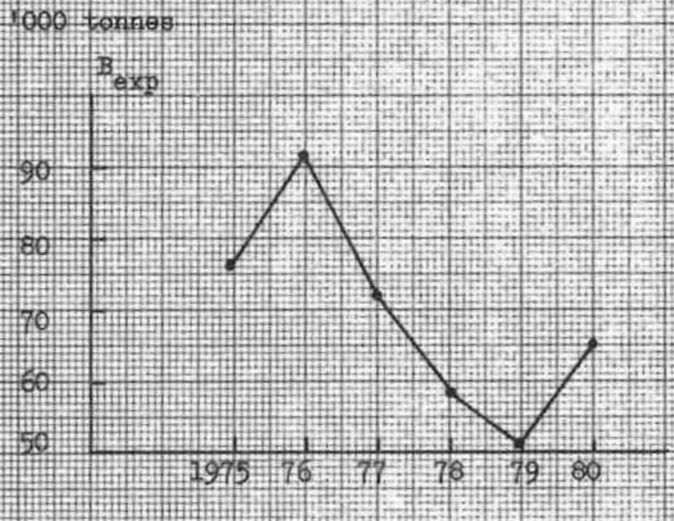


Figure 6.3.6. Cod. Faroese Plateau.
Exploited biomass.

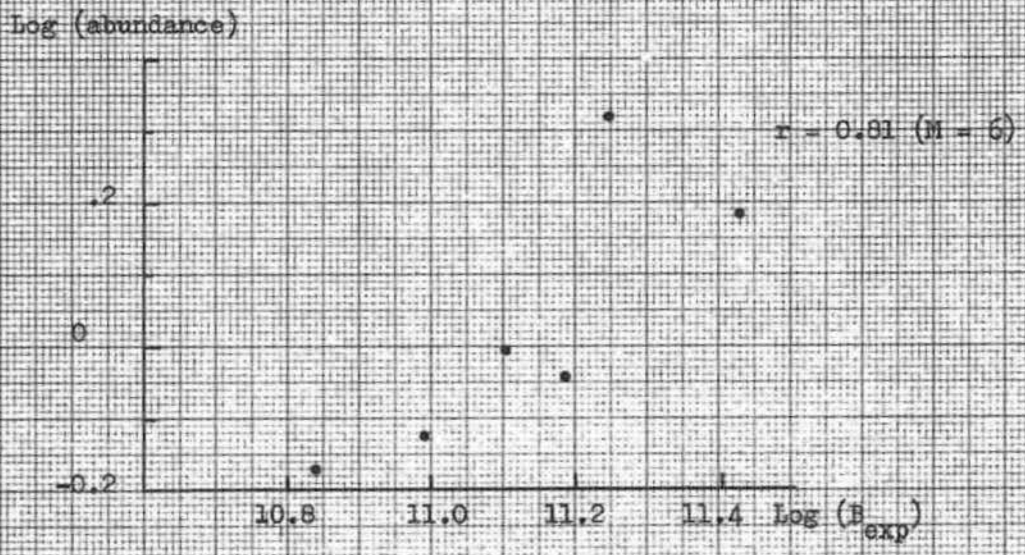


Figure 6.3.6. Log (B_{exp}) vs Log (abundance).

APPENDIX A

CATALOGUE OF EFFORT DATA

ICES CATALOGUE OF EFFORT DATA

Country: BELGIUM

Years: 1950 ?

Areas: North Sea, English Channel, Celtic Sea, Irish Sea, Iceland

Ports: Oostende, Zeebrugge, Nieuwport

Vessels: all categories

Gears: all types specified

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Statistics Office Ostend		x
Form of Data	Listings		x
TYPE OF DATA			
No. of Vessels	yes		x
No. of Voyages	yes		x
Days (specify)	Days at sea, days fishing		x
Level A (e.g. hours)	Fishing hours		x
DISAGGREGATION			
Fishing Area	Rectangles		x
Location Landing	Belgian harbours, Foreign harbours		x
Vessel Size	Gross tonnage		x
HP ?	yes		x
Gear	Otter trawl, beam trawl, pair trawl		x
Fishing Power Corr. ?	possible		
Time of Year	Date of landing		x
ASSOCIATED DATA			
Catches	Splitting species by market categories		x
Length Composition Age Composition	North Sea: sole, plaice, whiting, cod, haddock		x
	English Channel, Irish Sea, Celtic Sea: sole and plaice		x

ICES CATALOGUE OF EFFORT DATA

Country: DENMARK | Areas: All | Vessels: All

Years: 1973 - 1.6.1978 | Ports: Esbjerg, Hanstholm, Hirtshals, Skagen, Thyborøn, Bagenkop, Nexö | Gears: All

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Charlottenlund		
Form of Data	Magnetic tape		
TYPE OF DATA	Sample of total landings*		
No. of Vessels			
No. of Voyages	For individual landings:		
Days (specify)	No. of hauls/nets		
Level A (e.g. hours)	Time trawling Total catch by species		
DISAGGREGATION			
Fishing Area	ICES int. square		
Location Landing			
Vessel Size	BRT, HP, Mean of fabrication	Card register	1977 vessel file on magnetic tape merged with effort file
HP ?			
Gear , Mesh size	Yes		
Fishing Power Corr. ?	No		
Time of Year	Date		
ASSOCIATED DATA	Some consumption with biological samples (industrial landings only)		
Catches			
Length Composition			
Age Composition			

*) % coverage of all landings

Esbjerg	95%
Hanstholm Hirtshals Skagen	30-40%
Thyborøn	15%
Bagenkop Nexö	30-40%

ICES CATALOGUE OF EFFORT DATA

Country: England & Wales Areas: All Vessels: >40 ft

Years: 1972 - Ports: All Gears: All

	Most detailed Data which exist		Data which are easily accessible
Location of Data	MAFF Lowestoft		MAFF Lowestoft
Form of Data	Computer File		Manual Tabulations
TYPE OF DATA			
No. of Vessels	-		-
No. of Voyages	Yes		Yes
Days (specify)	Days absent		Days absent
Level A (e.g. hours)	Yes		Yes
DISAGGREGATION			
Fishing Area	(Sub)rectangles		Divisions
Location Landing	Ports		Ports
Vessel Size	Length, GRT		Length Groups
HP ?	Unreliable		No
Gear	Yes		Trawl, Seine, Other
Fishing Power Corr. ?	No		Ton-hours
Time of Year	Date of Landing		Months
ASSOCIATED DATA			
Catches	Yes		For main species
Length Composition	Yes		Yes
Age Composition	Yes		Yes

ICES CATALOGUE OF EFFORT DATA

Country: FAROE ISLANDS Areas: V_{b_1}, V_{b_2} Vessels: All (13) categories

Years: 1973 - 1980 Ports: Gears: Line, gillnet, trawl handline

All Species caught

	Most detailed Data which exist		Data which are easily accessible
Location of Data	NEUCC, Copenhagen		Fiskirannsóknarstovan, Tórshavn
Form of Data	Computer File		Computer file
TYPE OF DATA			
No. of Vessels	x		
No. of Voyages	x		
Days (specify)	x		
Level A (e.g. hours)	Level A		Level A
DISAGGREGATION			
Fishing Area	Rectangles 15 mile x 15		Stock area
Location Landing			
Vessel Size	By vessel		x
HP ?			x
Gear	x		x
Fishing Power Corr. ?	-		-
Time of Year	All year		By months
ASSOCIATED DATA			
Catches	x		x
Length Composition			x
Age Composition			x

ICES CATALOGUE OF EFFORT DATA

Country: FAROE ISLANDS Areas: Va Vessels: All

Years: 1973 - 1980 Ports: Gears: Trawl, longline, handline

	Most detailed Data which exist		Data which are easily accessible
Location of Data	NEUCC, Copenhagen		
Form of Data	Computer file		
TYPE OF DATA			
No. of Vessels	x		
No. of Voyages	x		
Days (specify)	x		
Level A (e.g. hours)	Level A		
DISAGGREGATION			
Fishing Area	Rectangles 1^{o} Longitude, $1/2^{o}$ Lat.		
Location Landing			
Vessel Size	By vessel		
HP ?			
Gear	x		
Fishing Power Corr. ?	-		
Time of Year	All year		
ASSOCIATED DATA			
Catches	x (Landings)		
Length Composition			
Age Composition			

ICES CATALOGUE OF EFFORT DATA

Country: FAROE ISLANDS | Areas: | Vessels: All

Years: 1973 - 1980 | Ports: | Gears: All

For Faroese Fishery in ICES Areas I, II, III, IV, VI,and XIV

	Most detailed Data which exist		Data which are easily accessible
Location of Data	NEUCC, Copenhagen		
Form of Data	Computer file		
TYPE OF DATA			
No. of Vessels			
No. of Voyages			
Days (specify)			
Level A (e.g. hours)	Level A		
DISAGGREGATION			
Fishing Area	Rectangles		
Location Landing	-		
Vessel Size	By vessel/haul		
HP ?			
Gear	x		
Fishing Power Corr. ?	-		
Time of Year	All year round		
ASSOCIATED DATA			
Catches	Reported catches, Wt Landings		
Length Composition			
Age Composition			

ICES CATALOGUE OF EFFORT DATA

Country: FRANCE | Areas: All | Vessels: *)

Years: 1979 → | Ports: La Rochelle, Les Sables d'Olonne only | Gears: All

	Most detailed Data which exist		Data which are easily accessible
Location of Data	ISTPM		ISTPM
Form of Data	Computer files		Tabulations
TYPE OF DATA			
No. of Vessels	-		-
No. of Voyages	Yes		-
Days (specify)	Days fishing		Days fishing
Level A (e.g. hours)	Fishing time		
DISAGGREGATION			
Fishing Area	Sectors		Divisions
Location Landing	Ports		Ports
Vessel Size	Length, GRT		Vessel type
HP ?	Yes (kW)		Yes
Gear	Yes		Yes
Fishing Power Corr. ?	No		Sometimes
Time of Year	Date of landing		Month
ASSOCIATED DATA			
Catches	Yes		
Length Composition	Market categories		
Age Composition	No		

*) only if landings via an auction market

ICES CATALOGUE OF EFFORT DATA

Country: ICELAND | Areas: Div. Va | Vessels: Trawls

Years: 1960-1980 | Ports: All concerned | Gears: Shrimp trawl, Nephrops trawl, Danish seine

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Reykjavik		
Form of Data	Catch ports		
TYPE OF DATA			
No. of Vessels	Yes)	Known for approx.	
No. of Voyages	Yes)	80% of effort	
Days (specify)	)		
Level A (e.g. hours)	Yes (hours trawling))		
DISAGGREGATION			
Fishing Area	Fishing rectangles around Iceland		
Location Landing	Yes		
Vessel Size	Yes		
HP ?	in HP		
Gear	Length of handline + mesh size		
Fishing Power Corr. ?	only some		
Time of Year	All year or season (date of landing)		
ASSOCIATED DATA			
Catches	Yes, by rectangular areas and total		
Length Composition	For all main areas, length composition is known		
Age Composition	Only estimated ages		

ICES CATALOGUE OF EFFORT DATA

Country: ICELAND | Areas: Div. Va | Vessels: Dredgers

Years: 1972 - 1980 | Ports: All concerned | Gears: Scallop dredges

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Reykjavik		
Form of Data	Catch reports		
TYPE OF DATA			
No. of Vessels	Known for about 50% of the effort		
No. of Voyages	Known for about 50% of the effort		
Days (specify)	Yes		
Level A (e.g. hours)	Hours fishing		
DISAGGREGATION			
Fishing Area	Fishing rectangles around Iceland		
Location Landing	Yes		
Vessel Size	Yes in HP		
HP ?			
Gear	Breadth of dredge in feet		
Fishing Power Corr. ?			
Time of Year	All year or season (Date of landing)		
ASSOCIATED DATA			
Catches	Yes, by rectangular areas		
Length Composition	For some areas length composition is known		
Age Composition	Only estimated ages		

ICES CATALOGUE OF EFFORT DATA

Country: IRELAND

Areas: Celtic Sea VIIj, VIa, VIIa, VIIb

Vessels: Herring trawlers

Years: 1958 onwards (Celtic Sea, later for other fisheries)

Ports: Dunmore East, Castletownbere, Killybegs, Burtonport, Howth, Galway, Rossaveal

Gears: Paired midwater trawl

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Fisheries Res. Centre, Dublin		
Form of Data	Notebooks, Summary sheets, also ICES W.G. Reports		
TYPE OF DATA			
No. of Vessels	x		x
No. of Voyages	x		x
Days (specify)			
Level A (e.g. hours)	Catch per landing per pair		
DISAGGREGATION			
Fishing Area	ICES Divisions		x
Location Landing	Ports		x
Vessel Size	x		
HP ?	x		
Gear	x		x
Fishing Power Corr. ?	No		
Time of Year	Date of landing		Date for season
ASSOCIATED DATA			
Catches	x		x
Length Composition	x		x
Age Composition	x		x

ICES CATALOGUE OF EFFORT DATA

Country: SCOTLAND

Years: 1960 - present

Areas: Faroe, IV, VI

Ports: Possible, but not readily accessible

Vessels:

Gears: Pelagic gears, trawl, seine, light trawl, *Nephrops* trawl

	Most detailed Data which exist		Data which are easily accessible
Location of Data	Aberdeen		
Form of Data	1960 - present on disk for demersal gears. Pelagic data on bits of paper - a mess		
TYPE OF DATA			
No. of Vessels			
No. of Voyages			
Days (specify)			
Level A (e.g. hours)	Hours (ton hours possible for recent years but not really in state of readiness)		
DISAGGREGATION			
Fishing Area	Stat. square		
Location Landing	Possible, but not really accessible		
Vessel Size	Possible, but not really accessible		
HP ?	Tonnage		
Gear	Trawl, seine, L trawl, *Nephrops* trawl, & pelagic and shellfish		
Fishing Power Corr. ?	No		
Time of Year	Months		
ASSOCIATED DATA			
Catches	Yes) for cod, haddock, whiting, saithe, plaice		
Length Composition	Yes) lemon sole, megrim and pelagic and shellfish		
Age Composition	Yes)		

ICES CATALOGUE OF EFFORT DATA

Country: NETHERLANDS
Areas: North Sea
Vessels:

Years: ? - 1968/1978
Ports: All
Gears: Beam trawl, otter trawl, pair trawl

	Most detailed Data which exist	Partly analysed Data	Data which are easily accessible
Location of Data	Ijmuiden	Ijmuiden	ICES
Form of Data	Listings	Charts	Stat. Newsletters
TYPE OF DATA			
No. of Vessels	By ship	-	-
No. of Voyages	By trips	-	-
Days (specify)	-	-	-
Level A (e.g. hours)	Hours fishing	Hours fishing	Hours fishing
DISAGGREGATION			
Fishing Area	Stat. rectangle	Stat. rectangle	Total NS and by sub-areas
Location Landing	By port	-	-
Vessel Size +	{Can in principle	-	-
HP ? +	(be combined	-	-
Gear	By gear	By gear	OT, BT, PT
Fishing Power Corr. ?	-	-	-
Time of Year	By month	By month	By quarter
ASSOCIATED DATA			
Catches	By species*	By species*	By species*
Length Composition	-	-	Yes
Age Composition	-	-	Yes

*) Cod
Haddock
Whiting
Plaice
Sole
Saithe

PART II: REPORT OF THE WORKING GROUP ON METHODS OF FISH STOCK ASSESSMENT

1. PARTICIPANTS AND TERMS OF REFERENCE

1.1 Participants

E Aro	Finland
V Anthony	USA
D W Armstrong	U.K. (Scotland)
F A van Beek	Netherlands
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G Gudmundsson (part-time)	Iceland
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M. Hildén	Finland
T Jakobsen	Norway
A Laurec	France
J J Maguire	Canada
B Mesnil	France
R Mohn	Canada
S Murawski	USA
N A Nielsen	Denmark
J G Pope	U.K. (England)
N Prusova	USSR
A Rijnsdorp	Netherlands
J G Shepherd (Chairman)	U.K. (England)
S A Schopka	Iceland

Mr W Panhorst, ICES Systems Analyst also participated in the meeting.

1.2 Terms of Reference (C. Res. 1982/2:4)

"To continue the work of the ad hoc Working Group on the Use of Fishing Effort Data in Stock Assessments, and to examine problems of methodology referred to it by ACFM".

The topics identified for consideration at the 1983 meeting were

(i) the use of effort data in assessments,

(ii) the application of separable VPA,

(iii) factors which may invalidate yield per recruit calculations and the derivation of biological reference points.

2. INTRODUCTION

The Working Group considered that although there were many problems of methodology which required examination, it would not be possible to deal with more than two or three at any one meeting. The topics should be identified as early as possible, to permit sufficient time for investigations to be carried out, and should be finalised immediately after the Statutory Meeting each year. A list of possible topics is given in Appendix C.

The Working Group was fortunate in having available a substantial number of working papers, several prepared specifically for the meeting, which enabled a rapid start to be made on the items of business. These are listed in Appendix A, together with an indication as to whether they are available elsewhere, are to be presented at the Statutory Meeting, or have been incorporated into the report in some form.

The Working Group agreed that the report of the ad hoc Working Group on the Use of Effort Data in Assessments (hereafter referred to as the Effort Working Group) (ICES CM 1981/G:5) should be regarded as a basic working document and taken as read.* The standardisation of notation adopted by the Effort Working Group was considered to be helpful, and with minor changes has been adopted by this Working Group. The standard notation is listed in Appendix B, with minor useages defined in the text.

The work of the Working Group was considerably assisted by the availability on the ICES computer system of several programs developed by members. The implementations were largely the result of work by R G Houghton and W Panhorst, whose effort and assistance is gratefully acknowledged.

3. SEPARABLE VPA

3.1 General Discussion

The technique known as separable VPA was introduced by Pope and Shepherd, 1982, and its implementation has been described in a user's guide by Shepherd and Stevens, 1983. The name derives from the assumption that the two-dimensional array of fishing mortalities $F(y,a)$ determined from a set of catch number at age data $C(y,a)$ should approximate as closely as possible to the product of two one-dimensional arrays, the overall fishing mortality in each year $F_S(y)$, and the average selection at age (or exploitation pattern), $S(a)$. This is equivalent to the mathematical technique of separation of variables. Here index "y" denotes years, index "a" denotes age groups, and the suffix S on overall fishing mortality indicates both that it is the separable estimate thereof, and that it is conditional on the estimated exploitation pattern. The notation here is slightly different from that in the papers cited, in an attempt to clarify possible obscurities.

Using a tilde (~) to indicate an estimate, separable VPA therefore consists of an algorithm to fit the model

$$F(y,a) \cong \tilde{F}(y,a) \equiv F_S(y)\ S(a) \qquad (1)$$

Note that the estimates of fishing mortality $F(y,a)$ are not forced to fit the separable assumption exactly, only to approximate to it. The 'terminal' values $F_S(t)$ for the most recent year, and $S(g)$ on the greatest (oldest) age group must be specified, as must mortality M (assumed constant).

Different assumptions concerning $F_S(t)$, $S(g)$ and M lead in practice to equally satisfactory representations of the data, judged by the goodness of fit to the separable pattern, which therefore provides no basis for choosing between them.

*This report now appears as Part I of this Cooperative Research Report.

With the exception of natural mortality, the separable method requires the input of only two unknowns, but the inclination to believe that the estimated values are any more reliable than those calculated from a conventional VPA must be weighed against the strong assumption of constancy in the exploitation pattern. If the assumption can be validated or shown to be tenable then there is a real improvement in the problem of indeterminancy from m+n-1 (i.e., one value of terminal F for each cohort with m years and n ages) for a traditional VPA to 2 for a separable VPA. Indeed, in these circumstances the separable technique is to be preferred because it reduces the work in finding a suitable exploitation pattern. Furthermore, the estimates of F obtained in this way should be more reliable because they are less sensitive to random noise than those emerging from a conventional VPA and will be more appropriate for Y/R calculations and perhaps for catch forecasts. In addition, the technique provides estimates at the overall level of fishing mortality ($F_S(y)$), which may be used for correlation with indices of international effort. In the absence of any knowledge about the exploitation pattern, the deviations of the $F(y,a)$ (which correspond exactly with the catch data) from the separable estimates $\tilde{F}(y,a)$ (which do not) clearly include both random fluctuations (e.g., those due to sampling errors) and systematic changes of exploitation pattern, if any. Whether or not one wishes to use the $\tilde{F}(y,a)$ as smoothed estimates from which the random fluctuations have been to some extent removed is a matter of choice.

The disadvantages of separable VPA fall into two classes: those which are fundamental, and those which are merely technical. The main fundamental difficulty is that there is no guarantee of the validity of the principal assumption, that the exploitation pattern of the total international fishery has remained more or less constant for some period of time, say five to ten years. Indeed, where the total fishery is composed of several disparate sectors, whose relative importance has changed, the assumption may be implausible.

With the method as implemented at present (Shepherd and Stevens, 1983) this difficulty can be ameliorated only by reducing the span of years over which separability is assumed, and breaking the total span into several sections. This usually involves making some more or less tendentious assumptions about terminal F's in earlier years, and in practice the inconsistencies which arise (e.g. in estimated biomasses) at the junctions of the sections create difficulties. In the longer term, a multiple fleet version of the method is under development in which the separable assumption <u>needs</u> to be applied only to one fleet or sector of the fishery (though it may be applied to all in order to reap the benefits of the useful summary provided thereby). Preliminary results of this work are reported by Stevens (1983). When fully developed it should remove the main criticism levelled against separable VPA, and permit a much better job to be made of the correlation of fishing mortality and fleet effort data.

There seems to be little independent experimental evidence which can be adduced to determine what the true exploitation pattern is or whether it has changed. Thus, while one may reasonably be dubious that the assumption of separability applies, to disprove that null hypothesis may be difficult. Meanwhile, the analysis provided by separable VPA is objective and explicit and hence probably worthwhile.

There can also be technical difficulties in the use of separable VPA. The most common arise when there are large residuals between the estimated $F(y,a)$ and the separable pattern $\tilde{F}(y,a)$. These arise from fluctuations in the catch-at-age-data, which may be real, or may simply be due to random noise in the sampling procedure: there is usually no way to tell. Large fluctuations are particularly common on very young and very old age groups, and it is usually desirable to exclude these from consideration when fitting the separable model: there is provision to do this in the present implementation. A logical extension of this would be to allow for some weighting of the residuals, so that most weight is given to the well-sampled age groups which constitute the bulk of the catch, and less to others. This modification has not yet been tried.

The effect of such large residuals is to introduce discrepancies between alternative and prima facie equally sensible ways of computing quantities of interest, thereby causing confusion. For example, the overall measure of fishing mortality $F_S(y)$ provided by separable VPA may not show the same trend as other measures such as arithmetic average F (over a restricted age range), or the $\bar{F}_C$ measure proposed by Shepherd (1982). Even the signs of changes may differ in extreme cases (Brander and Houghton, pers. comm.): in such cases it is not clear which estimate should be used for correlation with effort data. Similar discrepancies may appear between estimates of exploitable biomass obtained using the average exploitation pattern $S(a)$, and those using the 'exact' $F(y,a)$ normalized by some measure of overall F.

It is not yet clear what is the best procedure to adopt in such cases. If the fluctuations are simply due to random error, one can argue that the 'smoothed' estimates provided by the separable technique should be preferred. If, on the other hand, the fluctuations are real, the more variable 'exact' estimates should give better results. This matter requires further investigation. It is likely that weighting the residuals in carrying out the separable analysis, as suggested above, would serve to reduce the discrepancies between $F_S(y)$ and $\bar{F}_C$, in particular, since the latter is frankly weighted to favour age groups contributing most to the catches. Even so, however, perfect agreement is never to be expected. The problem lies of course in the variability inherent in the data, and is merely exposed, not created, by the separable technique. Therefore some decisions on the best procedure to adopt, which will be largely determined by what one is trying to achieve, will still be required.

A related difficulty may arise when one wishes to use the results of separable VPA to initiate a catch forecast. If year class strengths are determined by the recommended procedure (involving a fit to the catch data over the whole cohort), the fishing mortalities in the most recent year diverge from the separable exploitation pattern. For forecast purposes it is best to use the separable pattern, since future departures from it are generally unpredictable. This means, however, that the exploitation patterns used in the most recent year differs from those in the intermediate and forecast years, albeit only in detail. If there are large residuals, there may be significant discrepancies between alternative estimates of the increase or decrease of fishing mortality involved. Once again, further investigation is required to determine the best procedure in these circumstances. The discrepancies can be removed by forcing the fishing mortalities in the final year to fit the separable pattern (an option is in fact provided to do this), but only at the expense of larger residuals elsewhere. Since there is no reason to suppose that deviations from the separable pattern should be any smaller in the most recent year than at other times, this procedure is not recommended. It merely sweeps under the carpet a real problem which should rather be faced squarely, and a resolution sought.

3.2 Practical Description of Method

Separable Virtual Population Analysis is currently on the ICES computer as SEP and has been used by several Working Groups. A Users Guide (Shepherd and Stevens, 1983) is available at ICES which fully explains the procedure. The SVPA merely automates the procedure of generating an internally consistent VPA in the sense that the exploitation pattern is more or less constant, given the starting assumptions of M, terminal F and selection on the oldest age in the last year. The program provides a listing of the catch matrix, the mean weights at age and the apparent coefficient of variation of the catch data along with a table of residuals of log catch ratios which is very useful for judging the quality of the input data. The initial and final values of the sum of squares of residuals of the log catch ratio matrix are also printed. The SVPA calculates a constant pattern (S) of exploitation for any series of years and ages and extends the results to neighbouring years and ages which are poorly represented in the basic catch matrix. This extension to the entire catch matrix is done in two ways; 1) populations are determined from the entire data set according to the separable model which are then extended to other ages and years by cohort, and 2) the terminal Fs from the separable pattern are adopted for the last year. Both procedures may then be used to produce a standard VPA using actual catch data beginning in the last year. The first extension (that from terminal populations) fits the catch data exactly but, of course, produces Fs which deviate from the strict separable pattern because of noise in the data. These deviations are printed (along with the detailed VPA) as F (EXT) - F (SEP) and are useful in judging how the traditional VPA differs from the strict separable exploitation pattern. It is common for F in the extended analysis to differ noticeably from the separable pattern. This may be due to errors in the catch data or in changes in the recent selection pattern. A decision must be made from external evidence whether the deviation is real or not. The percentage differences between F (EXT) and F (SEP) are commonly on the order of the C.V. If the catch changes are real and not random, one should not abandon the separable exploitation pattern unless one is sure that the new situation will continue. Since there is no reason to suppose that the deviation of F in the recent year should be any less than in any other year, there is no reason to force F in the final year to fit the separable pattern exactly. The terminal populations estimated and used in the extended analysis are based on a fit of all data available for each cohort and, therefore, are likely to be more reliable than those based on catch data in the last year with the average exploitation pattern as would be the case in the second method of extension.

The present version of SVPA, then, can produce two conventional VPAs along with estimation of biomass, effective age at first capture, $\bar{F}_c$ (which may be tested against effort) and $\bar{F}_p$ (an index of exploitation) (Shepherd, 1982). The separable exploitation pattern may be used in catch predictions and in yield per recruit analyses. The present version has had to be truncated slightly to fit the ICES computer, so that the biomasses are based on weights in the catch only, and should therefore be used with caution.

SVPA is not a method for determining F in the last year, only for examining the consequences of various assumptions. It does not allow for a major systematic change in exploitation pattern (but see Appendix E.3) or consider data from fishery-independent surveys. It is especially useful for examining the variability of the catch at age matrix and the assumption of constant exploitation.

It should be remembered that the SVPA requires that 3 parameters be specified (the natural mortality, terminal F and terminal S) and that each choice produces an alternative interpretation of the data. There is usually little basis for choosing between the alternatives using goodness-of-fit as a criterion, and external evidence must be used as with any traditional VPA.

3.3 Recommendations

In using the separable VPA, the following is recommended:

1. A minimum of 5 years should be chosen.

2. The most recent year should be used in the analysis so that the analysis is not extended forward in time, since this results in divergence of fishing mortality estimates with this as with any other method of VPA.

3. The SVPA should be run for a series of age ranges to determine the age range to be used, using the residual Table as a guide to suitability. The selection of the age span in the analysis is important since all ages are at present given equal weight in the analysis. Residuals of 2 $\log_e$ (1 + C V/100) or larger from the log catch ratio may be an indication of excess noise in the catch data, and may indicate where to restrict the data set. Such high values are likely to occur at very old or young ages due to sampling problems. Ages should not however be discarded, in general, if they provide a significant proportion of the catch, in spite of the noise.

   If the log catch ratio residuals fluctuate widely with no constant pattern one should question the quality of the basic catch data and improve the reporting procedures and the sampling which produces the age structure of the catches. Total catches may be in error due to underreporting or misreporting but the catch at age matrix should be consistent except for noise and occasional systematic change that may be caused by changes in fishery regulations.

4. After the age span is set, the SVPA should be run for a series of years to examine the assumption of constant exploitation pattern over time. If external evidence is available that indicates a change in the exploitation pattern due to a change in mesh size, for example, these years may have to be discarded. Probably five to ten of the most recent years of reliable data are sufficient for SVPA.

5. The age chosen for the unit selection in the exploitation pattern should contribute significantly to the total catch.

6. An appropriate value of relative fishing mortality, S(g), on the last age which levels out the exploitation patterns on the older age groups should be chosen. It should not be small without very good reason since a low F inhibits convergence, of all VPAs, so that one should err on the high side.

7. There is no information in the SVPA which provides guidance in the selection of fishing mortality in the terminal year. The SVPA will have to be tuned using standard procedures. The SVPA provides estimates of $\overline{F}_c$ (Shepherd, 1982) and $F_S(y)$ which may be used for tuning. There are up to three sets of $\overline{F}_c$ produced by the program. If $\overline{F}_c$ is to be used, the estimates from the extended analysis using terminal populations should be preferred. When a restricted age range has been used in the separable VPA because of inconsistencies and excess noise on certain ages, the information derived from the restricted age range should be adequate for tuning. There is no advantage in extrapolating over the entire data set before tuning.

8. The terminal Fs from the extended analysis using terminal populations (as opposed to that using the separable Fs in the last year), modified if necessary, should be used for input to standard VPA programs. The extended version from terminal Fs should not normally be used. The extension using terminal populations fits the catch data exactly and the deviations of F from the strict separable pattern are printed in a table of F (EXT) - F (SEP). These residuals should be examined very carefully for inconsistencies, especially in the last year.

   The SVPA cannot select an F for the youngest age in the final year and this as well as Fs on other neighbouring age groups should be determined from fishery-independent estimates of recruitment if possible.

9. The exploitation pattern (S) may be used for catch prognosis and yield per recruit analyses, with additional smoothing and modifications if this is judged to be necessary.

4. ANALYSIS OF CATCH AND EFFORT DATA

Numerous attempts have been made in recent years to incorporate effort data in analyses of catch-at-age data. A paper was presented to the Working Group which attempted to clarify the existing techniques and to compare their results, through simulations (Pope and Shepherd, 1983). The alternatives between comparing fishing mortality and effort or cpue and biomass have also been addressed by Mohn, 1983.

Beyond comparisons between existing techniques, new ones have also been suggested in several papers presented or discussed during the meeting (Pope and Shepherd, 1983; Armstrong and Cook, 1983; Lewy, 1983; Nielsen, 1982 a,b.; Gudmundsson *et al.*, 1983).

The discussion, however, focussed on problems more than on individual papers. In this respect it must be noted that the various techniques can be examined, first from the point of view of the underlying model they implicitly or explicitly use. This is discussed in Section 4.1. Then the estimation of the parameters can be conducted either by direct fitting of the integrated models (Section 4.2), or through the iterative use of VPA combined with tuning techniques (Section 4.3).

The very important problems of changes in catchability with time is addressed in Section 4.4.

In Appendix F appears Table F.1, which can be used as a framework for the comparison of the various existing and possible techniques. Appendix D refers to further tests on tuning methods.

4.1 The Relationship between Fishing Mortality and Effort

Choice of an appropriate definition of fishing effort

All the techniques which make use of fishing effort data rely upon some model relating the fishing mortality for each fleet for each age in each year $F(y,f,a)$ to the corresponding value of fishing effort $E(y,f)$.

The simplest model may be written as

$$F(y,f,a) = q(f,a)\ E(y,f) \text{ where } q(f,a) \text{ is constant.}$$

(This model is totally equivalent to the model $\frac{C(y,f,a)}{E(y,f)} = q(f,a)\ \overline{N}(y,a)$, and there is thus no difference in principle between relating F and fishing effort and relating cpue and stock numbers).

More sophisticated models are conceivable, allowing for changes in catchability with time, year, season, effort and exploited biomass. The building of such catchability models is described in Appendix F.

Simple relationships may be introduced between catchability and time (Armstrong and Cook, 1983; Pope and Shepherd, 1983; Gudmundsson et al., 1983). It is equally possible to propose a relationship between q(f,a) and biomass or between q(f,a) and the level of fishing effort using a global measure of fishing effort. Nielsen used a relationship of the type

$$q(f,a) = \alpha E(y,f)^{\beta}$$

The "fishing pattern" in terms of variation in q(f,a) with age can also be described by a simple model, e.g., some polynomial (Nielsen, 1982a; Gudmundsson et al., 1983). Interaction effects can even be introduced (Gudmundsson et al., 1983).

The global quality of the estimation of the level of fishing mortality in the last data year of a VPA or of the estimate of catches at age will depend upon the validity and the goodness-of-fit of the proposed relationship between mortality and effort. Increasing the level of sophistication employed in fitting the model will not per se reduce problems caused by "noise" in the data. In this context the use of some appropriate measure of effective fishing effort rather than crude measures of nominal fishing effort are likely to increase the goodness-of-fit to the model.

The definition of effective effort must take account of

(i) problems of standardization of fishing power

(ii) the distribution of effort in space and time.

To achieve the former end, adequate data on effort and catch at age disaggregated by vessel types, by area, and by time period must be available. Such data must be analysed using classical methods for the standardization of fishing power.

Two approaches to take into account variable distribution of effort in time and space were suggested. The first of these (Armstrong and Cook) related q(f,a) to the proportion of the total fishing effort expended in each of six areas in each year for the period 1963-80 by means of a linear (multiple regression) model. (The basic model employed in this method was complicated somewhat by replacing the underlying data on fishing effort by synthetic variates obtained via an orthogonal rotation of the original axes.)

The second method suggests fitting a multiplicative model (Anon, 1981a) which estimates for each time period and area a combination of the proportion of each age group present and the relative catchability of this part of the age group. The effort allocated to the different combinations of time period and area are then weighted by relative catchability and fraction of the age groups to produce standardized effort data. No comparison has yet been made of the relative utility or validity of the two methods referred to above.

4.2 Direct Fitting of Integrated Models

Two examples of this approach, one referring to the Danish fishery for sandeel in the North Sea (Nielsen, 1982 a,b), the other referring to the Icelandic fishery for cod (Gudmundsson et al., 1983), were presented to the meeting. One of the major points of interest to emerge from these papers is the possibility of including in a model various well-defined items of information related to the fishery under investigation.

In the two cases presented, standardization of fishing effort data was carried out prior to fitting the model. Nielsen (1982a) chose to achieve this standardization by use of simple functions relating insurance value, gross registered tonnage and horse power to fishing effort.

Nielsen's model assumes constant year to year catchability while Gudmundsson's model allows for variation of catchability with time, this variability being described by a polynomial function the parameters of which are estimated and tested for significance with the model. Gudmundsson's model also allows for the possibility of using available data within time periods of less than one year. (See Table F.1 and Appendix F.)

In principle, models of the type referred to above can be fitted either by maximum likelihood methods or by least squares methods. Nielsen chose to use maximum likelihood methods, while Gudmundsson used weighted least squares fitting. Reference should be made to the appropriate papers for details of the fitting procedures and problems encountered.

Two points of general interest may be made concerning Gudmundsson's model. First, the model and separable VPA are related in that they both use the log catch ratio matrix. (The separable VPA, however, makes no use of effort data). Second, the estimation of mortality rates at age in the last data year is achieved using a polynomial function which is prevented from being "too flexible" by means of an associated penalty function. The desirability of this property within various tuning methods is discussed in Section 4.4.

Finally, it must be noted that approximate variances for the estimated parameters and derived quantities may be obtained in both studies.

4.3 Iterative Tuning of VPA

4.3.1 General principles

If values of historical fishing mortalities are obtained from some VPA initiated by inputting arbitrary values of fishing mortality in the last data year and at the highest age and given an appropriate model for the relationship between fishing mortality and fishing effort, then it is possible to iteratively revise the assumption for fishing mortality at age in the last data year. This possibility (according to various assumptions about the constancy or otherwise of catchability with time) has been exploited by Armstrong and Cook (1983); Lewy (1983); Pope and Shepherd (1983) and also (but with somewhat inadequate methodology - see Section 4.3.2) the gamma (Anon, 1981b) and rho methods (Anon, 1982a).

At present there exists no theoretical basis from which it is possible to decide whether the iterative processes within each of the techniques cited will produce results which are optimal according to some definable criterion. Theoretical investigations of this approach are therefore required.

Techniques of this type produce final estimates of fishing mortality in the last data year after a finite and definable number of iterations (see Armstrong and Cook, 1983) provided that some decision can be made on the value of fishing mortality at the highest age. This decision must be made according to arbitrary criteria which will depend to a great extent on the nature of the data set being investigated.

4.3.2 Technical aspects

Each fleet and year within a data series provides an ordered pair of values of mortality and effort for each age which may be used to evaluate an apparent catchability. The problem thus arises of how to combine such information. Combination within years and across fleets can be achieved two ways:

(i) Combination of data on mortality and effort across fleets within each year, to provide a single index of catchability which can then be fitted by means to be discussed below;

(ii) fitting models to data on catchability for each fleet separately and then combining the results.

The second option is to be preferred on the basis of both theory (Laurec and Shepherd, 1982; Laurec, 1983), as confirmed by simulation techniques (Pope and Shepherd, 1983) and by common sense. Only by taking this approach is it possible to observe the dispersion of the data points for each fleet and hence to judge the pertinence of the models being fitted. In addition, the quality of the fit for each fleet can be used as weighting factors when combining the estimates of fishing mortality for each fleet in the last data year. The most obvious way to do this is to form a weighted mean where the inverses of the variances of the catchabilities are used as weighting factors (Laurec and Shepherd 1982). Laurec (1983), however, suggests methods of weighting using the elements of the inverses of the variance-covariance matrix of residuals from the fitted catchability.

Several methods evolved in the past, however, using the first system of combinations, viz. Saville, Hoydal-Jones, Gamma, Rho (see Table F.1) and their use is therefore to be avoided if possible. The methods of Armstrong, Armstrong and Cook, Laurec and Shepherd, Shepherd and Pope, and partial exploitable biomass employ the second method of combination and are to be preferred on this basis.

Laurec's technique can, assuming certain hypotheses, lead to the definition of confidence intervals, for the derived estimate of catchability in the last data year, but this technique has not yet been implemented on real data.

The partial exploitable biomass method involves a combination of data across ages within years. The theoretical implications of this procedure have not been sufficiently well studied to allow advice to be given on its acceptability. Various improvements and developments of this method are possible and could be explored.

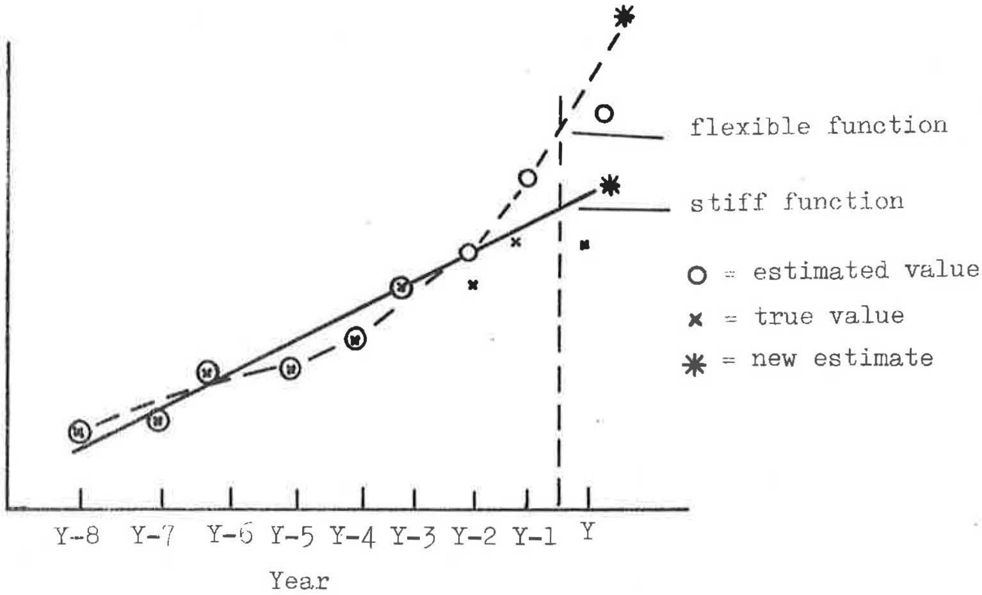
4.4 Problems raised by the Existence of Trends in Catchability with Time

In some cases it has been demonstrated that catchability varies (usually in a systematic manner) with time (Anon, 1982a). If this is the case, and if we wish to tune a VPA to be consistent with these changes we must evolve some method for estimating catchability in the last data year. The best way to do this is to find a set of appropriate variates which are not connected with time and use these to explain the observed changes in catchability. To date only the technique of Armstrong and Cook (1983) has attempted to do this and even in this case the required condition that the explanatory variates should not be connected with time could not be fulfilled because of the nature of the actual data available to them.

All other attempts to tune VPAs under the assumption of changing catchability have fitted some empirical function to values of catchability plotted as a time series over a period of years up to but not including the last data year. This empirical function is then extrapolated to give a revised estimate of catchability and hence fishing mortality in the last data year so that a revised VPA can be initiated.

The fact that the extrapolation to the last data year is made with a function of arbitrary form can give rise to a number of problems.

Estimates of fishing mortality in the last data year will always be less well determined than those for previous years. This means that values of catchability estimated for years Y-1, Y-2 etc. will deviate from the true values to a retrospectively decreasing extent, i.e., the situation will be as exemplified in the figure below



Some empirically chosen function is then fitted to the observed values. If the function chosen is sufficiently "flexible" (e.g. a high-degree polynomial) it is very probable that the end result will be as depicted in the text figure above, i.e. the estimate of fishing mortality in the last data year may be farther from the true value than an original guess. In this case divergence from the true value will occur. Another contingency which could be envisaged, depending on the data set being analysed, is one where the flexible function recovers the original input value and nothing is achieved.

On intuitive grounds, therefore, it appears more desirable to fit a "stiff" function (e.g. a polynomial of first degree) which does not permit much curvature in the most recent data years. This is likely to underestimate changes of catchability. The results on data with varying q will be biassed to some extent. This bias can be minimised by ensuring that data are standardized and aggregated carefully, in order to make changes of q as small as possible.

At the same time, the extra freedom allowed by permitting changes of catchability is likely to increase the variance of the estimates, compared with that of relatively restrictive models (such as those assuming constant catchability), and this feature will be exacerbated if the use of flexible function is permitted.

It appears from the results of Pope and Shepherd (1983)that in the case of the rho, Armstrong and Hybrid method the functional forms of the equations used to re-evaluate catchability in the last data year are sufficiently stiff to ensure convergence to an iterative value whose expectation is close to the true value, i.e. several methods give slightly biassed estimates of time catchability in the last data year. At present, however, this result has only been demonstrated by Monte-Carlo methods and has not been investigated at an analytical level. The latter investigation is required.

A possible alternative course of action, given the presence of a trend in apparent catchability, is to attempt to validly standardize effort data in such a way to eliminate this trend. This procedure may, however, be as difficult to implement in practice.

4.5 Conclusions and Recommendations

4.5.1 Conclusions

In the past a number of poor results have been in evidence from various attempts to employ catch and effort data to estimate terminal fishing mortalities. There are several identifiable reasons for this:

i) Failure to recognize the true nature of the problem (e.g., the use of methods assuming constant catchability in situations where catchability has changed);

ii) Use of improper or inefficient techniques leading to the underutilization of the information in available data sets (e.g., techniques which aggregate cpue data before fitting the model);

iii) Use of data sets which on closer inspection should have been excluded from the analysis (e.g., the use of data for Scottish Nephrops trawlers);

iv) In some cases the original concept of a technique has been insidiously (but not deliberately) altered (e.g., the original gamma concept did not involve log-transformation of the data. Logarithmic transformation was carried out only in order to allow the graphs presented in the Effort Working Group to be presented more conveniently).

To a great extent all of these shortcomings have been the result of failing to critically examine the available data and the proposed techniques in advance of their use in Assessment Working Groups. An Assessment Working Group is a very sub-optimal environment for evolving such techniques.

Nevertheless, encouraging results have been presented and the conceptual framework of the problems to be faced is now much better understood. Essentially, the angels may now walk with relative safety in the mire but only on the bodies of the fools who have rushed in before them.

In particular, it is now apparent (see e.g. Pope and Shepherd, 1983) that a reasonable way to judge the performance of a technique is to evaluate the overall quality of for example the TAC prediction or biomass estimated by it. It should be recognized that every effort should be made to develop methods which precisely estimate terminal fishing mortalities in the last data year. However, it is unlikely that a high degree of precision of the point estimators of these quantities can be obtained because there will always be some degree of unexplained variability irrespective of how sophisticated the method or how good the data.

Interest in relationships between effort and fishing mortality should not be restricted only to problems related to setting TACs. There is also intrinsic interest in determining the "average" relationship between effort and fishing mortality as a possible means of implementing management by effort regulation.

4.5.2 Recommendations

4.5.2.1 Action in the short term

1. Studies on the relationships between fishing mortality and fishing effort should be continued.

2. Much effort should be devoted to finding the best possible estimator of fishing effort.

3. Where methods deal with catchability values derived from prior VPA, the catchability should be evaluated for individual fleets of vessels which are as homogenous as possible.

3.1 If trends are apparent in the catchability values formed in (3)

i) The degree to which this trend is contingent upon the terminal fishing mortalities input to initiate the VPA should be investigated;

ii) If possible, explanatory variates (preferably uncorrelated with time) should be found and relationships between such variates and catchability should be established;

iii) If no such explanatory variates are forthcoming empirical functions may be fitted to the time series of catchabilities BUT READ AND UNDERSTAND SECTION 4.4 BEFORE DOING SO.

3.2 If catchability values and hence estimates of terminal mortalities are available for more than one fleet some method of combining these values using goodness-of-fit criteria should be employed.

3.3 Further consideration should be given to modelling the relationships between fishing mortality and effort by Monte-Carlo methods. The idea here would be to create artificial but totally defined data sets which exhibit the same degree of noise as those observed in some real data set. Some empirical measure of the variance of the various estimated values could be obtained from such data.

4.5.2.2 Action in the long term

1. Attempt to disaggregate available data to an even higher degree than that currently in evidence (e.g., data disaggregated to season, gear, and sampling area level would be most interesting).

2. Work towards evolving the best possible modelling of the relationship between effort and fishing mortality (i.e., the model which produces the lowest residual variance and the highest degree of precision in prediction).

3. If standardization of nominal fishing effort data is to be carried out provide clear documentation of the methods used. If the raw data involved are not too numerous they should be compiled and submitted to ICES as a part of the general data base on catch and effort.

4. Modelling such as that of Nielsen (1982 a,b) and Gudmundsson et al. (1983) is to be encouraged. While it is recognized that such models will inevitably embody some aspects unique to the data sets to which they are applied, every attempt should be made to follow and elucidate clear common principles.

5. Attention should be given to achieving parsimony of parameters involved in any mortality/effort model (i.e., find some way of critically excluding parameters which do not serve to explain variability in observed catchability or catch).

6. Think about the problems of statistical inference and the problems of estimating confidence limits.

7. Theoretical studies should be carried out to elucidate what quantity is being optimized by current and any future iterative techniques.

5. COMPUTATION AND USE OF YIELD PER RECRUIT

5.1 Technical Problems and Standardization

5.1.1 Introduction

Working documents prepared by Anthony (1982) and Scumacher (1982) emphasize potential discrepancies in Y/R computations based on the number of age groups included in the calculations. The three documents illustrate for a variety of North Atlantic and Arctic stocks that by not accounting for potential yields of relatively old age groups in the population (for which there may be inadequate sampling of mean weight at age), calculations of $F_{0.1}$ and F_{max} and absolute Y/R may (in some cases) be seriously misestimated. In general, these biases result in an overestimation of the position of $F_{0.1}$ and F_{max} and under-estimation of yield per recruit at particular F values. The impact of such a bias on calculation of Y/R at F_{max} or $F_{0.1}$ would, however, be to some extent compensating. This can be seen in the redfish example of Schumacher. The value of $F_{0.1}$ is estimated to be 0.04 if the plus group is included (age 30+), and 0.08 if the plus group is ignored. However, the Y/R values for F = 0.04 with a plus group and F = 0.08 without the plus group differ by only 3% (.268, .275 kg). However, the practical result of overestimation of $F_{0.1}$ by 50% in the redfish example is that the recommended TAC values, if one were to proceed immediately to $F_{0.1}$, would be excessive by 80% (15 000, 27 000 tonnes).

Since the two working papers attempted to account for the yields of older age groups in the population in different ways, analyses of the two methods were undertaken by the Working Group, using the same data set, to investigate the adequacy and comparability of the methods. Examination of the method for extrapolating the age range over an arbitrary number of age groups based on the assumed pattern of natural mortality, as suggested by Anthony, was undertaken for North Sea plaice (Anon., 1983a). Similarly, examination of effects of including plus groups in the Y/R computations, as in the Schumacher documents, was also performed, for the same stock and for North Sea saithe. Descriptions of the two methods, their assumptions, properties, and results of Y/R calculations undertaken by the Working Group are described in Section 5.1.2 and 5.1.3.

The Working Group also discussed another technical problem in the Y/R calculation related to the existence of more than one local maximum in the function of Y/R versus F. The problem has been seen in the North Sea saithe Y/R calculation, and is probably related to peculiarities in the observed weight at age. A substantial decline in mean weight from one age to the next apparently causes the phenomenon. Since values of $F_{0.1}$ and F_{max} are computed in the ICES yield program under the assumption of a monotonic Y/R function with F, in some circumstances a solution for these values cannot be computed. The ICES System Analyst intends to investigate potential solutions to be implemented in the software.

5.1.2 Standardization based on the expected age distribution of the virgin stock

The thesis of the Anthony paper is that given a particular assumption of M, the number of age groups comprising a significant portion of the virgin population is potentially much larger than the number of age groups that may appear in populations under exploitation. By failing to include age groups that would theoretically be present (based on the assumed M value) potential biases in calculations of $F_{0.1}$, F_{max} and Y/R may exist (i.e., overestimate of $F_{0.1}$ and F_{max}, underestimate of Y/R). As a guide for standardization of the number of ages to be included in the Y/R computations, Anthony suggested the age at which a 95% reduction in initial population numbers would be observed under virgin conditions. This number is equivalent to a cumulative M (over ages) of 3.0. Thus for M = 0.1 the number of ages to be included is 30; for M = 0.2 it is 15, and so on. The relationship between the number of ages to be included in the Y/R calculations under the 95% rule, and M is given in the following text table:

M	0.1	0.2	0.3	0.4	0.6	1.1	1.5
No. of ages$^{x)}$	30	15	10	8	5	3	2

$^{x)}$Number of ages to be included in the Y/R analysis is given by 3.0 M.

Thus, although the notion of such extreme ages for particular stocks may appear to be nonsense (30 ages at M = 0.1), if the assumed M value is correct then under virgin equilibrium conditions 5% of the stock will be 30+ years old. If this is unacceptable, the assumed M values should be re-evaluated (e.g., for possible senescent mortality).

An example of Y/R calculations incorporating this suggested standardization rule was worked for North Sea plaice, based on current estimates of vital population parameters given in the 1983 North Sea Flatfish Working Group report (Anon., 1983a, p. 57). The value of M is given as 0.1 for the stock, thus the number of suggested ages to be included for Y/R is 30.

Mean weights at age and the theoretical population reduction curve under the condition of F = 0 are given in Figure 5.1.1. Since mean weights at age are unavailable for ages in excess of 15, values for ages 15-30 were estimated by eye. Results of yield per recruit analyses with 30 age groups included in the calculations were compared to similar analyses with truncated age spans to assess the degree of bias in $F_{0.1}$, F_{max}, and Y/R. The effect of truncating the age range on $F_{0.1}$ and F_{max} for North Sea plaice is given in Fig. 5.1.2. By including only those age groups for which data were available from the Working Group report, the value of $F_{0.1}$ is overestimated by 30% relative to the inclusion of 30 age groups (0.23, 0.16), F_{max} is overestimated by 20% (0.41, 0.33). The effect of the bias is progressively reduced by increasing the number of ages from 15 to 30.

Effects on the absolute value of Y/R of increasing the numbers of age classes in the analysis is given in Fig. 5.1.3. For relatively low F values, the bias imparted by a truncated age range is larger than at relatively high F values. A similar conclusion was reached by Anthony for a variety of western Atlantic stocks.

Data contained in these analyses are also useful for judging the adequacy of the 95% rule as opposed to another arbitrary standard (e.g., 90%, 99%). If the rule were 90%, then 23 age groups would be included in the calculations for M = 0.1; 46 age groups would be appropriate for a 99% rule. Clearly, the 99% rule results in little improvement in the results, as marginal changes in $F_{0.1}$, F_{max}, and Y/R were small as the number of ages used approached 30. The difference in $F_{0.1}$ values between using 23 and 30 ages was about 11% (0.18, 0.16), F_{max}, however, decreased only 4% (0.34, 0.33). If a 10% difference in $F_{0.1}$ is judged to be significant, then the 5% rule is preferable to the 10% rule, for North Sea plaice.

One of the difficulties of implementing such a methodological standardization is that weight at age data may not be available for many of the ages considered when an extended age range is included. In the North Sea plaice example, weight at age data were extrapolated for ages 15-30 which were unavailable in the Working Group report. Since results of the analysis are likely to be at least somewhat sensitive to the assumed mean weights, then any data available which help to determine the general shape of the growth curve for the extrapolated ages would be important.

5.1.3 Inclusion of plus groups in Y/R calculations

The effect of the plus group on the Y/R curve was investigated by the Working Group for North Sea plaice and North Sea saithe. Data were taken from Anon., 1983a and Anon., 1983b.

Y/R curves were calculated for different age ranges with and without the plus group. The values of $F_{0.1}$ and F_{max} for both stocks are shown in the text tables below.

North Sea plaice

				Without plus group, No. of ages			
	5+	10+	15+	4	9	14	30
$F_{0.1}$	.19	.17	.16	.94	.34	.24	.16
F_{max}	.45	.33	.33	2.00	.60	.43	.33

North Sea saithe

				Without plus group, No. of ages		
	5+	10+	15+	4	9	14
$F_{0.1}$	.26	.19	.18	1.00	.30	.22
F_{max}	.54	.32	.32	1.55	.47	.35

The differences in $F_{0.1}$ and F_{max} between the two methods decrease asymptotically as more ages are added to the calculation not using plus groups.

In the examples, $F_{0.1}$ and F_{max} were well approximated at smaller age ranges when plus groups were added. The estimates of $F_{0.1}$ and F_{max} with a 10+ and a 15+ age range do not differ significantly. If no plus groups are used there are still considerable differences. The examples suggest that the use of these groups is necessary.

When $F_{0.1}$ and F_{max} are found at low F levels, the situation becomes different. The contribution of the plus grups to the Y/R increases with decreasing F, and is quite substantial at low F levels. This contribution is also likely to be dependent on the weight of the plus group.

In case of a high F, the numbers in the plus group are low, and since the mean age in the plus group is low, the mean weight is low. In the case of a low F, the mean age in the plus group is high, and the mean weight is high.

In the computations for North Sea plaice, estimates of $F_{0.1}$ and F_{max} were identical when the 15+ group was used, and when 30 age groups were included in the calculations without the plus group ($F_{0.1} = 0.16$, $F_{max} = 0.33$). The assumed mean weight of the plus group was in this case approximately correct for Z = 0.2 - 0.5. However, it is likely that these computations are somewhat sensitive to assumed mean weights.

Thus, it appears that if relatively good data on the weight of the plus group are available, then the two methods (95% rule, inclusion of plus groups) yield nearly identical estimates of $F_{0.1}$ and F_{max}. However, if the mean weight of the plus group cannot be estimated with reasonable confidence, then even crude approximations of the form of the growth curve for older ages will yield reasonable estimates of $F_{0.1}$ and F_{max} with the 95% rule, and is thus preferred.

When a plus group is used, sufficient explicit age groups should therefore still be included, so that the mean weight for the plus group is not seriously in doubt (say by more than 10%).

In both analyses, the necessity of reasonable data on growth patterns of relatively old individuals (for which sampling data may be scarce) is emphasized. Thus, as far as practical it is recommended that ages be determined for all fish sampled including those individuals usually lumped into the plus group, for which a reliable age can be determined.

5.2 Density-Dependence and Related Problems

5.2.1 Effects of density-dependent and density-independent changes in vital population parameters on results of yield per recruit

- A general overview

Working papers presented by Ulltang and Hildén discuss some general aspects of effects of presumed density dependence of vital population rates on the results of yield per recruit calculations. In general, the influence of a significant relationship between stock biomass and growth rate will influence the absolute level of Y/R at particular F levels, and will shift the position of $F_{0.1}$ and F_{max} at stock biomass changes. Similarly, if natural mortality rate is a function of stock density, calculations of yield per recruit could also be significantly influenced. Other factors which may affect the results include density-dependent maturity-fecundity effects, which in turn may influence the calculations of spawning stock biomass per recruit.

Age dependence of natural mortality can also significantly alter results of Y/R analysis from the constant M over ages that is normally assumed. However, age dependence of M is very difficult to determine given current data sources.

In general, data with which to estimate density effects on population parameters will be of a circumstantial nature and may result in spurious conclusions if based only on statistical correlation. In the Icelandic cod stock, for example, growth decreases which coincide with increases in stock biomass are probably related to a collapse of the capelin stock and not to density-dependent influences (Schopka, pers.comm.).

Nevertheless, even if trends in vital population rates are density-dependent or independent, trends in their variability over time will influence results of yield per recruit and subsequent management advice. Thus, it appears important to periodically update Y/R calculations and management advice based on them if trends in the rates are apparent.

The Working Group considered the special case of Faroe Saithe (data from Anon., 1983b) where a significant negative correlation between growth and stock biomass has been observed, and the resulting influence on advice for management (i.e., $F_{0.1}$, F_{max}). These analyses are presented in Section 5.2.2.

5.2.2 Density-dependence and density-independence in growth and its effects on Y/R

In some fish stocks there is circumstantial evidence for density-dependence in growth. Such a relationship has been shown in Icelandic summer spawning herring (Anon., 1983c) and for all the major saithe stocks in the NE-Atlantic (Jones, 1980). In order to analyse the effect of changes in growth rate on the yield per recruit curve the Working Group carried out calculations on the Faroe saithe which was the only saithe stock available with a sufficiently long data series for such a study. The total stock biomasses were derived from a VPA assuming the same input F values as used in 1983 Saithe Working Group Report (Anon., 1983b). For each year during the period 1960-82 a yield/recruit curve was calculated by assuming the 1982 exploitation pattern throughout the whole period, and changing weight at age based on values observed in each year.

The results are given in Table 5.2.1 and Figures 5.2.1 and 5.2.2. As can be seen from these calculations the highest yield (1.5 kg per 2 year old recruit at F_{max}) was estimated in 1960 when the stock was at the lowest recorded level (105 000 tonnes). On the other hand, the lowest yield at F_{max} of only 0.92 kg per 2 year old recruit was estimated at one of the highest stock levels (243 000 tonnes) in 1973 (Figures 5.2.1). In these two extreme cases the difference in Y/R at F_{max} is more than 60%.

Figure 5.2.2 shows the relationship between the yield per recruit at F_{max} level and the total stock biomass (2 plus) derived from the VPA. When the total biomass increased from 105 000 tonnes in 1960 to a peak of 275 000 tonnes in 1972 the yield per recruit at F_{max} declined from 1.5 kg to 0.99 kg, this being partly compensated by higher recruitments of year classes in the late 1960s. Since 1973 the yield per recruit has been increasing by a simultaneous decrease of the stock. The correlation between these two parameters is highly significant ($r = -0.94$).

As the stock biomass increases the $F_{0.1}$ value and F_{max} values shift to the left side of the curve as mean weights at a decrease even though this is not as pronounced at the decline in the yield per recruit (Figure 5.2.1).

Circumstantial growth changes apparently not related to density-dependence may also occur as was the case recently for Icelandic cod (Schopka, unpubl.). These may be linked to lack of food (i.e., the collapse of the capelin stock in 1979-80) or other environmental factors as for example downward trends in sea temperature in Icelandic waters since 1976. Compared to the 1977-79 level the present decrease in yield per recruit for Icelandic cod is about 15%.

Thus, where trends in growth patterns over time exist, yield per recruit may have to be re-evaluated in the light of the directions and rate of change in vital population parameters. It should be noted, however, that an annual re-calculation of the Y/R curve should be avoided since this implies year-to-year variations in management advice based on an equilibrium model. Forecasting the trends of growth rate and Y/R over a moderate number of years would lead to more consistent advice while accounting for systematic changes in growth parameters.

5.3 Extensions of Yield per Recruit Analysis

Yield per recruit analysis typically balances somatic growth with mortality as functions of age to give yield as a function of fishing mortality. It is also customary that the F-value at maximum yield (F_{max}) and at the point tangential to one tenth the initial slope ($F_{0.1}$) are specified in the analysis. There is no formal reason why the analysis should be limited to growth. It could be, and occasionally is, in terms of meat weight, economic value or gonad weight. Also the usual computation supplies expected stock numbers or biomass per recruit which when multiplied by a maturity ogive gives spawning stock numbers and biomass. In the following an attempt is presented to relate yield per recruit analysis with stock-recruit data in order that some other interesting reference points may be determined for acceptable levels of fishing mortality. Four stocks supply the data for this study: North Sea cod, herring, plaice and sole.

The principle method investigated involves the examination of spawning biomass per recruit. The reciprocal of this quantity (recruitment per unit biomass) is a measure of the level of recruitment which a stock needs to be able to maintain in order to perpetuate itself at any level of fishing mortality. Some information on this quantity may be derived from plots of stock and recruitment data, by drawing straight lines through the origin which bracket the bulk of the data. Such lines represent constant values of recruitment per unit biomass. A line leaving only 10% of the data exhibiting higher values of R/B represents a level, for which there is very little evidence in the data that the stock can sustain a higher level. Values of F higher than that (F_{high}) which produce this level of R/B <u>may</u> therefore involve significant danger of stock collapse. F_{high} may therefore be a useful biological reference point. On the other hand, a line for which 90% of the data exhibit higher values represents a level of R/B which there is much evidence that the stock can support, so that fishing mortalities lower than the corresponding value (F_{low}) are likely to involve very little danger of stock collapse. The value of fishing mortality (F_{med}) corresponding to the median value of R/B is intermediate and represents a level at which one is reasonably happy that the stock can reproduce itself comfortably.

Although four stocks are used we will proceed with a detailed description of the techniques on data from the North Sea plaice stock and the other stocks will be described in much less detail. Figure 5.3.1 A is the yield per recruit analysis produced by the ICES computer program. The weights at age, natural mortality and selectivity pattern are the 1982 values from the 1983 Flatfish Working Group Report (Anon., 1983a). Two curves are shown in Figure 5.3.1 A as functions of F, the yield per recruit and the spawning stock biomass per recruit. The yield per recruit is seen to have its maximum at an F level of 0.33 and the $F_{0.1}$ level is 0.16. The spawning stock biomass and recruits of the following year as defined by VPA is shown in Figure 5.3.1 B for the period 1957 to 1979. The spawning stock biomass is rather stable throughout this period while the recruitment varies by a factor of four. Lines were drawn from the origin to approximate the 10%, 50% and 90% percentiles in order to define the range spanned by available data. These lines correspond to 2.16 recruits/kg spawning stock biomass at the upper level and 0.68 at the lower level with a median of 1.42. In order to relate these values to the Y/R results they are inverted to give kg spawning biomass per recruit values which can be found on the spawning stock biomass per recruit curve. These points may be seen in Figure 5.3.1 A and are labelled low, median and high.

Taking advantage of the stability of the spawning stock biomass, two other methods were used to relate the Y/R and stock-recruit data. The thirteen years period from 1960 to 1972 was seen to represent a stable period in the spawning stock biomass having a mean of 392 000 tonnes with a coefficient of variation of less than 9%. For the same period the fishing mortality on age four has a mean of 0.35. This gives a point to link the two graphs. An F_4 of .35 corresponds to a spawning stock biomass per recruit of 1.1 which, in turn, represents a spawning stock biomass of 392 000 tonnes. The largest and smallest spawning stock biomass from the VPA are 454 000 and 324 000 tonnes which would scale to 1.27 and .91 spawning stock biomass per recruit. These values in turn would correspond to F levels of 0.3 and 0.6. In Figure 5.3.1 A strong assumption about stability has been made to relate the two relationships, but the range of F levels of the observed biomasses is well away from $F_{0.1}$ showing that it is outside observed recruitments as well as growth data.

A somewhat similar test on the plaice data was performed by looking along cohorts which are complete in the data set. The 3+ biomass of the cohort was divided by the number of one year olds. The resulting spawning stock biomass per recruit values showed a range of .33 to .48 agreeing well with the range defined by the other analyses.

The North Sea sole stock was essentially identical to plaice in terms of growth and mortality and therefore $F_{0.1}$ and F_{max}. However, as is seen in Figure 5.3.2 B, the stock-recruit data show a wide range of spawning stock biomass and a relatively constant recruitment except for a few exceptional year classes. The ratio of the estimate of the 10% slope to the 90% slope is greater than 8 whereas for plaice it was less than 4. This was the only stock of the four tested that had $F_{0.1}$ within the range of F_{low} and F_{high}.

Because of the similarity of the two flatfish stocks growth characteristics, two roundfish stocks were also tried. The first one was cod, and the data are shown in Figure 5.3.3. The Y/R curve peaks at lower values of F and has a more distinct peak than the flatfish. The stock-recruit data show no obvious pattern but the ratio of the upper and lower 10% limits is fairly close, less than 4. Again both F_{max} and $F_{0.1}$ are outside the probable range of the VPA data.

The Y/R model was checked also for North Sea cod using 1962 year class and 1974-76 year classes. (Data from Anon., 1982a). The 1962 year class had a fishing mortality of about half that of the fishing mortality for the year classes 1974-76. The Fs, mean weights at age and calculated numbers from VPA for each cohort were used. The 1962 cohort's exploitation pattern was used for year classes 1974-76 and vice versa.

The predicted decreases in Y/R agreed quite well with the observed ones. The calculations showed also that the Y/R model corresponds closely to reality on the observed range of fishing mortality (Fs 0.46 - 1.10), although all points fall to the right of $F_{0.1}$ and F_{max}.

Results and data for the herring stock are shown in Figure 5.3.4. For the other three examples the selectivity pattern was taken from the most recent year of the VPA. In the case of herring the exploitation pattern in 1982 was unusual in having the highest mortality on the 0-group. Therefore, in this case a selectivity was assumed to be zero at age zero, .5 at age 1, and unity for age 2 and older. The results are similar to those of the flatfish except that the Y/R curve fall off more rapidly after its maximum.

The following text table summarizes these results and shows that for all the stocks the current F level is in excess of F_{max} and also that for two of the four stocks the current F is at or exceeds F_{med}. F_{high} may be considered to define the onset of a warning zone in which high levels of recruitment would be required to maintain the stock.

	Stock	F_{82}	$F_{0.1}$	F_{max}	F_{low}	F_{med}	F_{high}
North Sea	Plaice	0.45	.16	.33	.26	.50	.68
"	Sole	0.55	.16	.34	.10	.49	.80
"	Cod	1.23*	.13	.20	.46	.90	1.05
"	Herring	.86+	.13	.27	.22	.53	.86

*1981 value. +0-group only.

5.4 The Utility of Yield per Recruit Analysis

There are many social, technical and economic factors involved in the determination of long-term strategies for the management of fisheries which are beyond the competence of this Group.

The determination of biological reference points is nevertheless relevant to the choice of strategy, and one needs to take account of the long-term considerations (so far as these can be estimated) in yield per recruit and related analyses.

The Working Group therefore briefly discussed the utility of Y/R analysis as a tool in attempting to determine appropriate long-term strategies for the management of fisheries.

Traditional biological reference points are generally F_{max} and $F_{0.1}$. These need in no sense be regarded as goals of management, but attempt to provide biological reference points for the level of fishing mortality at which high yields may probably be taken without unneccessary expenditure of effort. F_{max} is less useful because it sometimes does not exist, and it may in some circumstances be very sensitive to the details of assumptions made about exploitation pattern and weight at age. There are in any case several reasons for preferring a fishing mortality slightly lower than F_{max} (rather than higher), because this permits more year classes to contribute to the fishery (reducing fluctuations of yield) and a larger stock size, with probably higher catch rates and less chance of recruitment failure.

$F_{0.1}$ is therefore, although arbitrary, not unreasonable, and it is generally to be preferred to F_{max}. Switching from one to the other causes confusion and should be avoided. If $F_{0.1}$ is to be adopted at all as a biological reference point, it should be used always*, and not only when F_{max} does not exist.

The other biological reference point which the Group considered may be useful is that (F_{high}) defined in Section 5.3, which gives an estimate of F beyond which there may be significant chance of recruitment failure. Some stocks are much nearer to this level than to $F_{0.1}$, which may be relevant to their management.

As discussed in Section 5.2, the computation of these biological reference points usually neglects factors such as age dependence of natural mortality, and density dependence of vital parameters, which might prove to be quite important, if appropriate data were available. Although the Working Group recommends procedures for their computation which are intended to be precise and unambiguous, this is of course to prevent inconsistencies and confusion. There is no pretence that the estimates so made are anything other than fairly rough estimates of the true values.

For this reason, and because there are many other relevant factors to be considered, these biological reference points should not be considered by themselves as targets of management. They may, however, serve as signposts, and give some indication of what consequences may lie in certain directions, on account of biological factors.

5.5 Recommendations on Use

1. Weight at age data should extend as far as possible into the older ages. As a guideline to the number of ages to be included (if plus groups are not used) it is recommended that the cumulative natural mortality should be at least three (i.e., the 95% rule).

2. Either the plus group should be included in the Y/R calculation or alternatively the weight at age (and mortalities) may be extrapolated beyond the observed data. However, the analysis with plus groups is sensitive to the assumed mean weight value.

3. Frequency of Analysis - In stocks for which the growth and mortality characteristics are not changing, average values may be used in the Y/R, and the results are applicable for long periods. However, in those stocks which display growth and mortalities that are changing in time it is recommended that the values used to estimate the Y/R be chosen to anticipate the perceived trend. $F_{0.1}$ estimates would then be updated only after monitoring has revealed that the underlying data are no longer appropriate. These comments would apply whether or not the changes were caused by density dependence.

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* Editor's note: "always" here means regularly, for stocks for which it is considered to be a suitable reference point - not for all stocks.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 The Working Group endorses the conclusions and recommendations of the *ad hoc* Working Group on the Use of Effort Data in Assessment, which are copied in Appendix G for easy reference. The report of that Working Group remains a useful document, which should, if possible, be reproduced in the Cooperative Research Reports series.*

6.2 The reports of this Working Group should be published in the Cooperative Research Reports series, and distributed to all members of Assessment Working Groups, in order to ensure the effective dissemination of the results.

6.3 Separable VPA is a technique which, carefully applied with proper attention to the quality of the data, may be useful to Assessment Working Groups, especially in the exploratory analysis of their data.

6.4 Fishing mortalities for the most recent year are essentially undetermined (as in a normal VPA) and must of course be "tuned" using effort data (or otherwise) in the usual manner. Separable VPA may give misleading results if the central hypothesis of separability is inadequate, and the analysis of variance described in Appendix E3 may assist in examining this point.

6.5 Recruitment estimated for the most recent cohorts are usually unreliable and should be modified in the light of independent information in the usual way.

6.6 Detailed recommendations on the use of separable VPA are given in Section 3.3

6.7 Working Groups should continue in their efforts to use effort data paying special attention to the need for good quality control and careful data processing.

The importance of using appropriate levels of aggregation and proper standardization cannot be overemphasized. One should avoid aggregating data from different fleets before examining time series of apparent catchability, and methods which do this should be discarded, if possible.

6.8 Great care is necessary in allowing for possible changes of catchability with time. These should be treated so far as possible using appropriate explanatory variables.

6.9 Careful attention should be paid to the structure of the model being used explicitly or implicitly for the behaviour of catchability, and the assumptions being made should be stated as clearly as possible.

6.10 Further work aimed at a better theoretical understanding of the methods of analysis should be encouraged, and better techniques for fitting models, having an appropriate structure should be developed.

6.11 Further work on the estimation of confidence limits of the predictions made is required, and will be facilitated by the use of methods which have a sound statistical basis.

6.12 Data disaggregated to the level of fleet, area, and season are required for proper analysis, and the collection of such data should be expedited.

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* Appendix G is not included in this publication - refer to Section 7 of Part I, which is the publication recommended.

6.13 The Working Group considered the new method of Armstrong and Cook, but was not able to test it by simulation methods in the time available. The method is more soundly based than other current methods which could be applied to data usually available to Working Groups. It would be expected to give results generally similar to the rho-method, but more reliable, and the Group recommends that it be tried out in practice as soon as possible.

6.14 Long-term goals for fishery management should not be deduced from Y/R analyses. Biological reference points may, however, be determined.

6.15 $F_{0.1}$ is preferable to F_{max} as a biological reference point at which high yields may be obtained without unnecessary expenditure of effort, since F_{max} may not exist, and may in some circumstances be much more sensitive to details of the assumptions made.

6.16 Yield per recruit and biomass per recruit calculations should always include a plus-group, or at least 3/M explicit age groups.

6.17 Sufficient age groups should be included explicitly in the calculation that further changes of weight, maturity and fishing mortality within the plus group are small (say less than 10%).

6.18 The principle factors likely to invalidate the usual computations of biological reference points are (a) variation of natural mortality with age (especially high predation mortality on young ages and senescent mortality on old ages), (b) systematic variation (for example, with stock density) of growth, maturity, and fecundity. However, variation of recruitment at low stock size may have a greater effect on the overall state of the stock.

6.19 The computations of yield per recruit may easily be modified to take account of these factors as and when relevant data are available. The utility (or otherwise) of the concept is not affected.

6.20 Working Groups should be asked to indicate clearly on plots of long-term yield or yield per recruit the ranges of fishing mortality corresponding to levels of recruitment per unit spawning stock biomass which there is little evidence that the stock can support indefinitely. The biological reference point F_{high} defined in Section 5.3 may be useful for this purpose.

6.21 Detailed recommendations concerning the computation of yield per recruit are given in Section 5.5.

6.22 The Working Group considered which of the many possible topics (see Appendix C) it would be appropriate to treat at its next meeting. It was agreed that

(a) methods for estimating recruitment in the short term

(b) simpler methods for computing TACs

(c) linear regression in fish stock assessment

were topics on which progress could probably be made, and should be seriously considered.

7. REFERENCES

(see also list of Working Documents: Appendix A)

Anon., 1981a. Report of the *ad hoc* Working Group on the Use of Effort Data in Assessment. ICES, C.M. 1981/G:5.

Anon., 1981b. Report of the North Sea Roundfish Working Group. ICES, C.M. 1981/G:8.

Anon., 1982a. Report of the North Sea Roundfish Working Group. ICES, C.M. 1982/Assess:8.

Anon., 1983a. Report of the North Sea Flatfish Working Group. ICES, C.M. 1983/Assess:11.

Anon., 1983b. Report of the Saithe (Coalfish) Working Group. ICES, C.M. 1983/Assess:16.

Anon., 1983c. Herring Assessment Working Group for the Area South of 62°N. ICES, C.M. 1983/Assess:9.

Anthony, V. 1982. The calculation of $F_{0.1}$: a plea for standardization. NAFO Scr. Doc. 82/VI/64.

Gudmundsson, G, Helgason, Th. and Schopha, S.A. 1982. Statistical estimation of fishing effort and mortality by gear and season for the Icelandic cod fishery in the period 1972-1979. ICES, C.M. 1982/G:29.

Mohn, R.K. 1983. The effects of error in catch and effort data on tuning cohort analysis. Reference: In press.

Nielsen, N.A. 1982a. Estimation of the relation between nominal effort and fishing mortality in the fishery for sandeels. ICES, C.M. 1982/G:49.

Nielsen, N.A. 1982b. Production functions for the Danish fishery in the North Sea: an empirical example. Internal Report. Danmarks Fiskeri- og Havundersøgelser.

Pope, J.G. and Shepherd, J.G. 1982. A simple method for the consistent interpretation of catch-at-age data. J. Cons. int. Explor. Mer, 40(2): 176-184.

Shepherd, J.G. and Stevens, S.M. 1983. Separable VPA: 'Users Guide'. Internal Report, Lowestoft Lab.

Sparre, P. 1982. A comment to the 1982 North Sea Roundfish Working Group Report. ICES, C.M. 1982/G:48.

Table 5.2.1 FAROE - SAITHE

Yield/2-year old recruit (kg) assuming the same (1982) exploitation pattern throughout the period 1960-1982

																		Not used in the graphs				
F \ Year	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
0.1	1.00	0.98	0.93	0.96	0.93	0.93	0.91	0.84	0.82	0.77	0.74	0.71	0.72	0.68	0.73	0.76	0.78	0.82	0.86	0.82	0.97	0.88	0.92
0.2	1.34	1.31	1.24	1.28	1.24	1.22	1.21	1.09	1.05	1.00	0.95	0.90	0.92	0.87	0.94	0.98	1.02	1.07	1.17	1.08	1.29	1.18	1.21
0.3	1.46	1.41	1.35	1.39	1.35	1.32	1.30	1.18	1.11	1.07	1.01	0.95	0.98	0.91	1.00	1.04	1.11	1.16	1.29	1.16	1.40	1.28	1.29
0.5	1.50	1.47	1.38	1.42	1.37	1.35	1.32	1.19	1.11	1.08	1.02	0.94	0.98	0.97	1.26	1.06	1.13	1.17	1.37	1.18	1.42	1.33	1.29
1.0	1.41	1.39	1.28	1.33	1.27	1.25	1.25	1.12	1.06	1.03	0.97	0.87	0.89	0.87	1.01	1.01	1.07	1.09	1.36	1.12	1.31	1.26	1.20
F_{max}	1.50	1.47	1.39	1.43	1.38	1.35	1.33	1.20	1.12	1.09	1.03	0.96	0.99	0.92	-	1.07	1.14	1.18	1.38	1.19	1.43	1.34	1.31
$F_{0.1}$ value	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.19	0.18	0.19	0.18	0.17	0.18	0.17	0.19	0.19	0.20	0.20	0.23	0.20	0.21	0.21	0.19
F_{max} value	0.46	0.47	0.45	0.45	0.43	0.43	0.44	0.42	0.38	0.42	0.40	0.35	0.40	0.37	-	0.43	0.46	0.42	0.63	0.44	0.43	0.49	0.39
Total stock biomass (2^+) from trad. VPA ('000 t.)	105	116	131	149	165	175	191	188	219	247	260	258	275	243	236	218	202	192	(172)	(148)	(150)	(148)	(153)

Figure 5.1.1 North Sea PLAICE (M = 0.1)
$Age_{95\%}$ = 30 (see text). Mean weight at age.
Stock reduction with no fishing.
$\overline{W}$ from 1983 North Sea Flatfish Report (Anon., 1983,a).

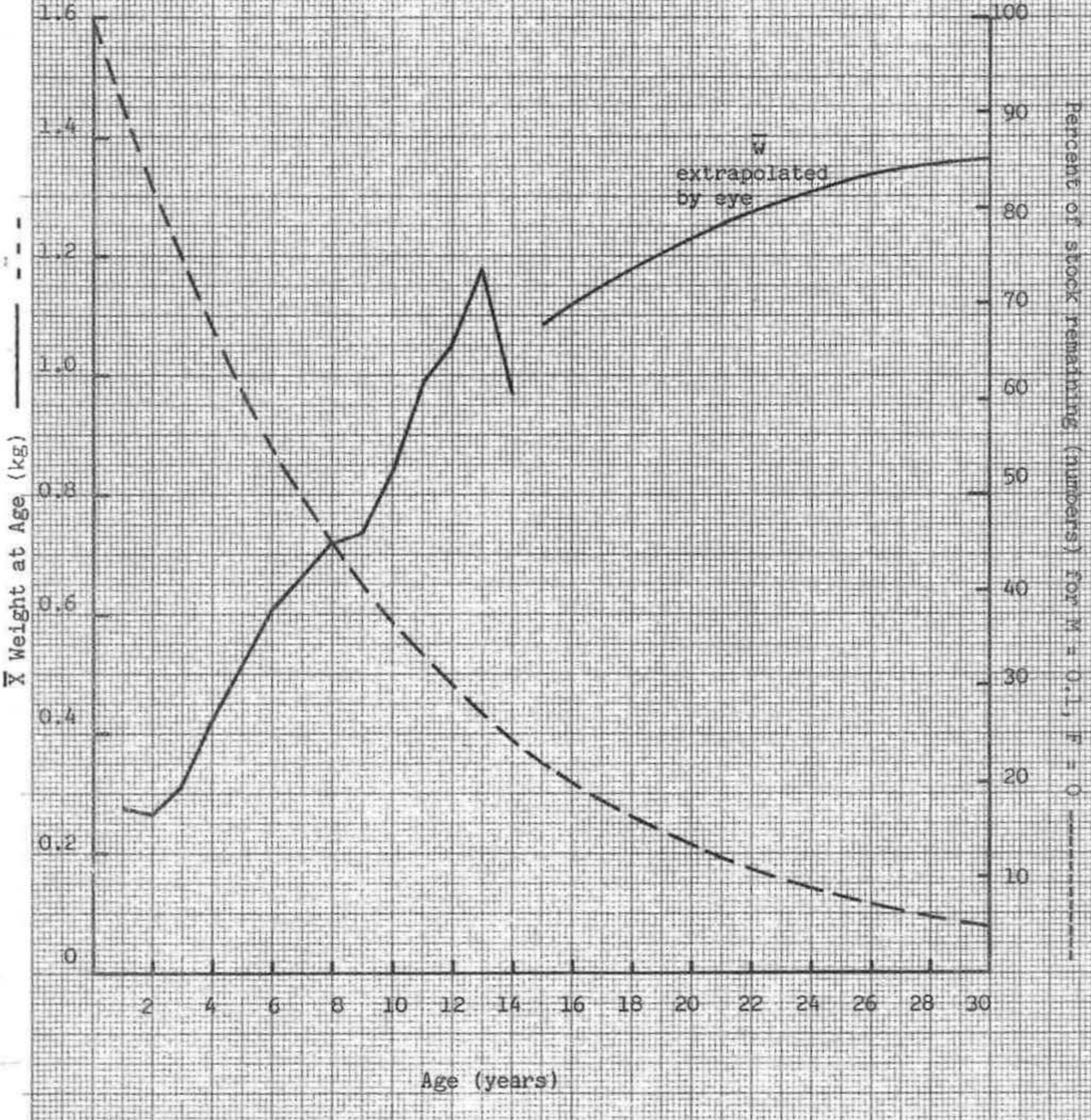


Figure 5.1.2 North Sea PLAICE (M = 0.1)

The effect of truncating the age range on the value of F_{max} and $F_{0.1}$. Relative $S_{(J)}$, exploitation pattern used.

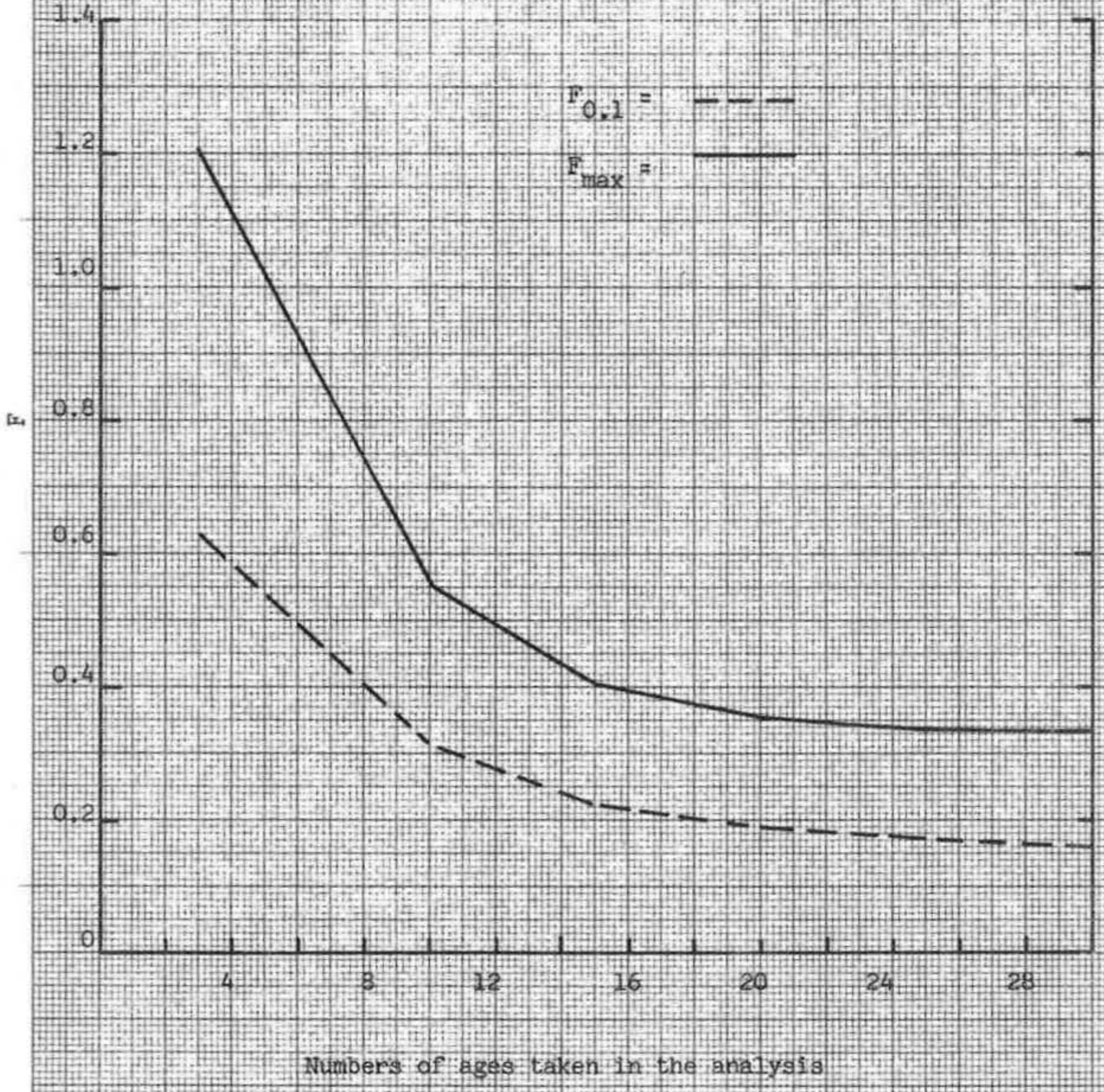
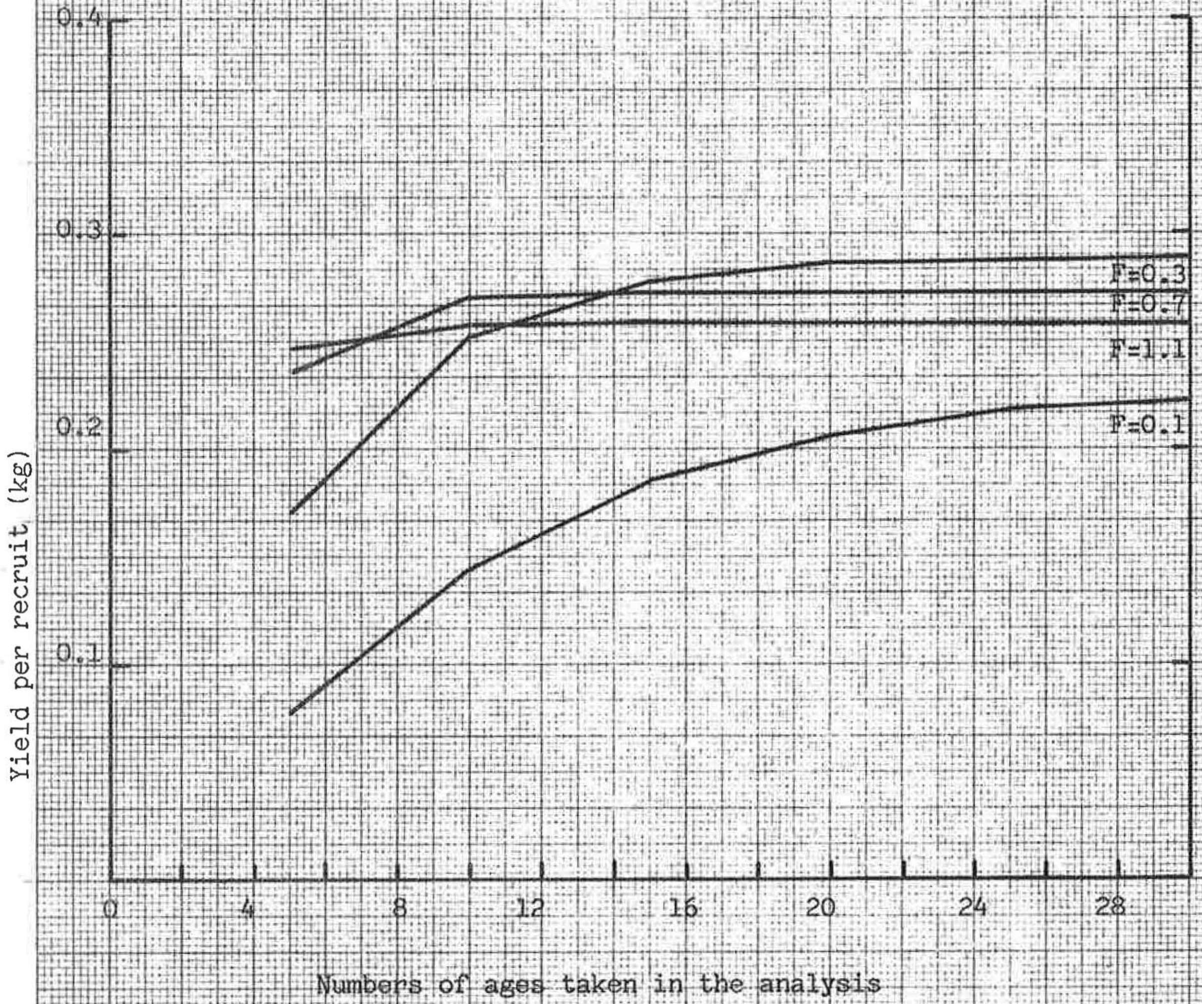


Figure 5.1.3 North Sea PLAICE (M = 0.1).
The effect of truncating the age range on the yield per recruit at different levels of fishing mortality rate.



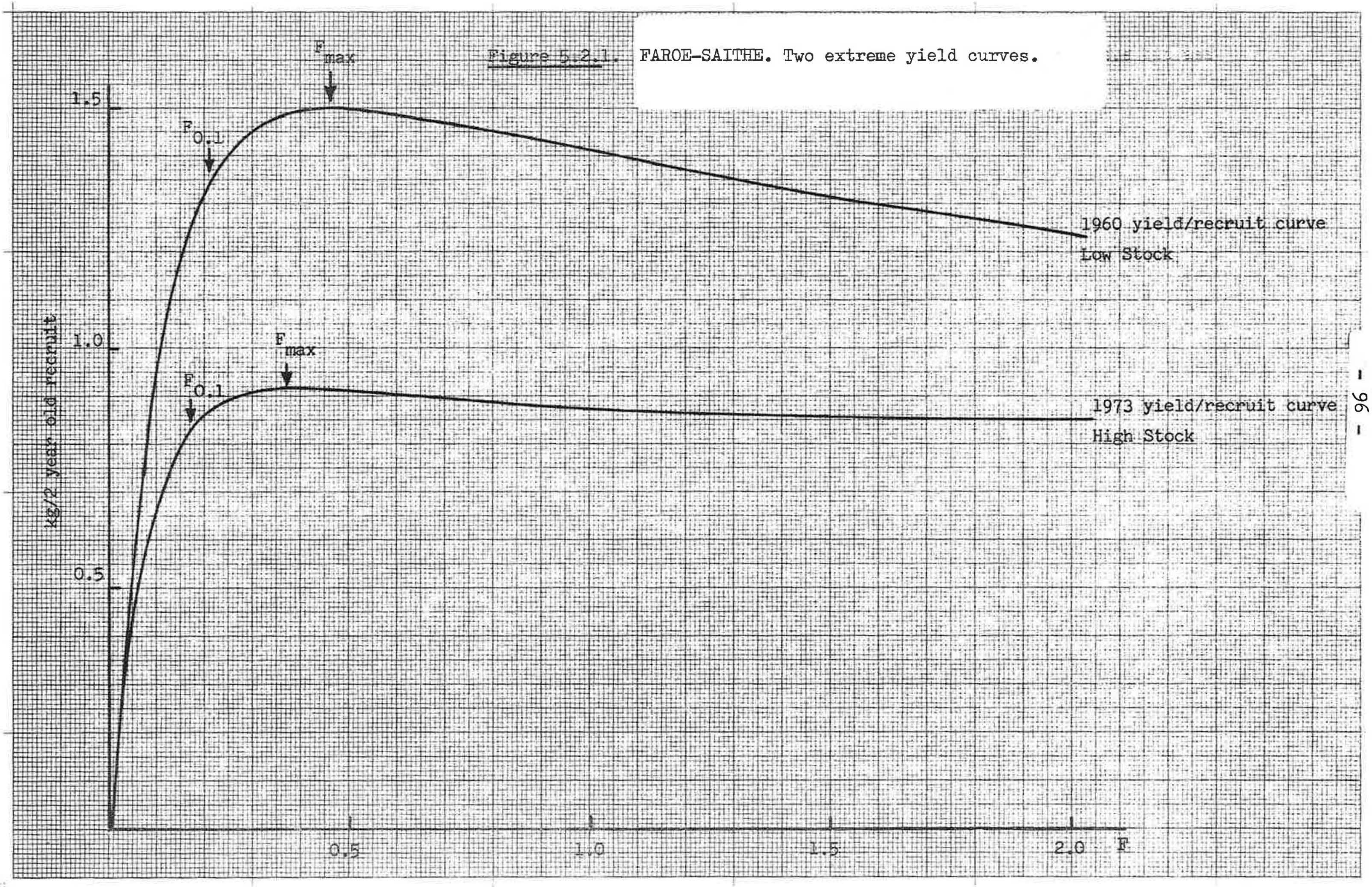


Figure 5.2.1. FAROE-SAITHE. Two extreme yield curves.

Figure 5.2.2 FAROE SAITHE. Yield per recruit at F_{max} versus biomass 1960-1977 period.

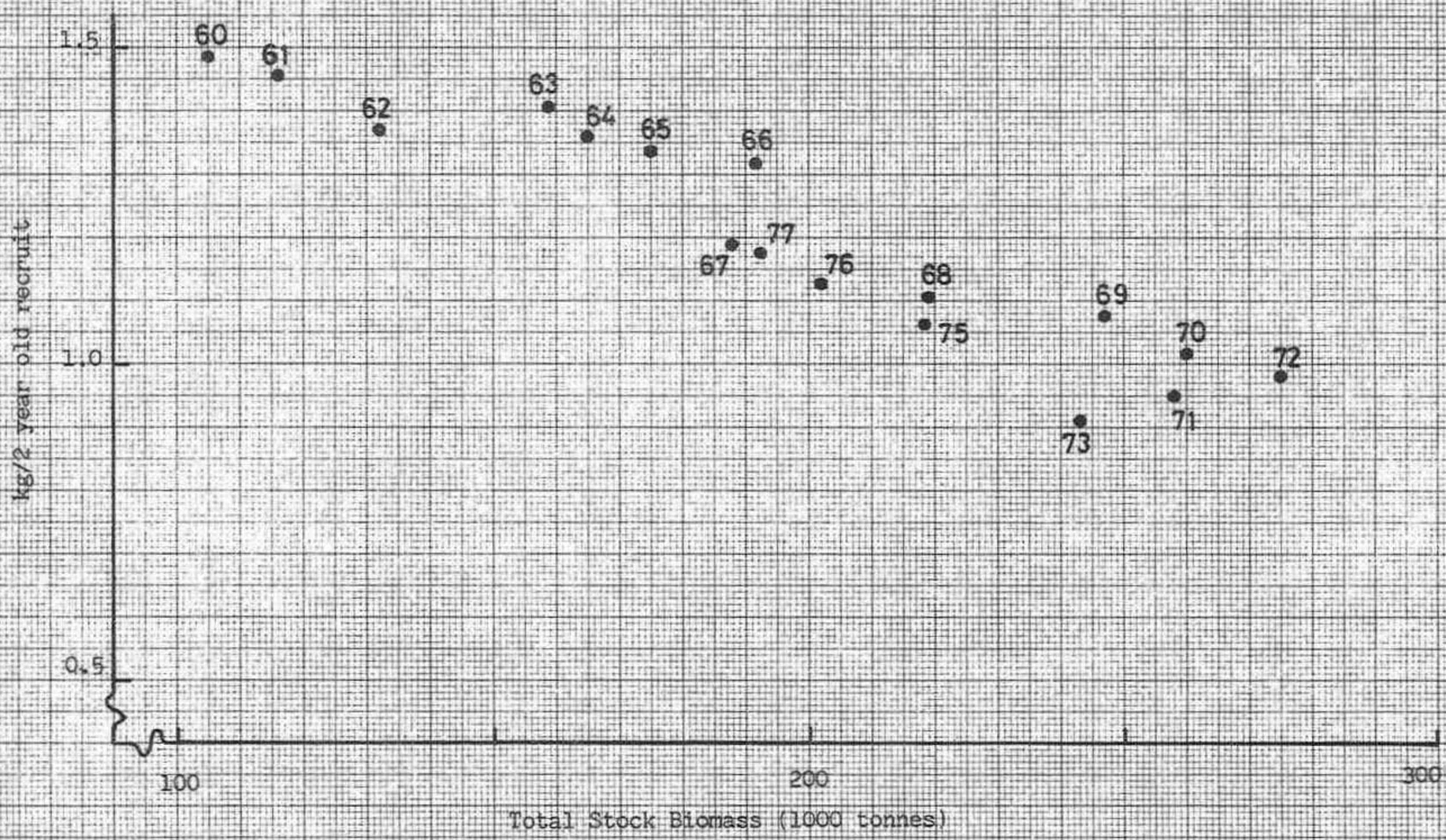
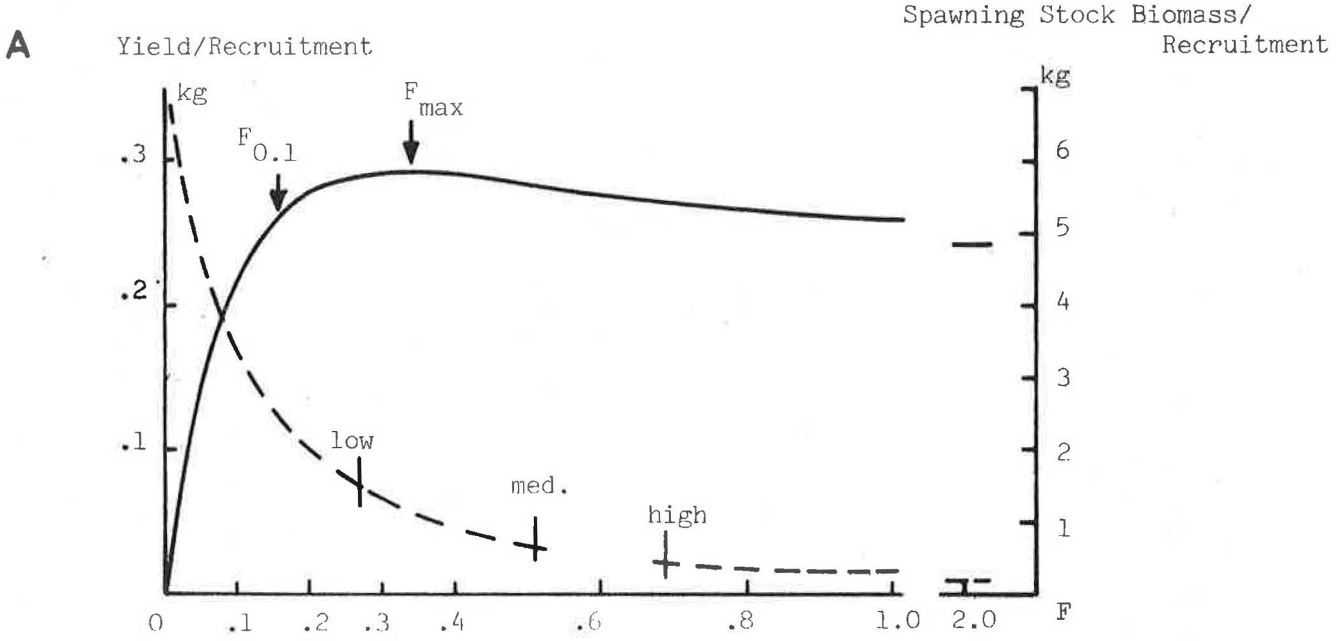
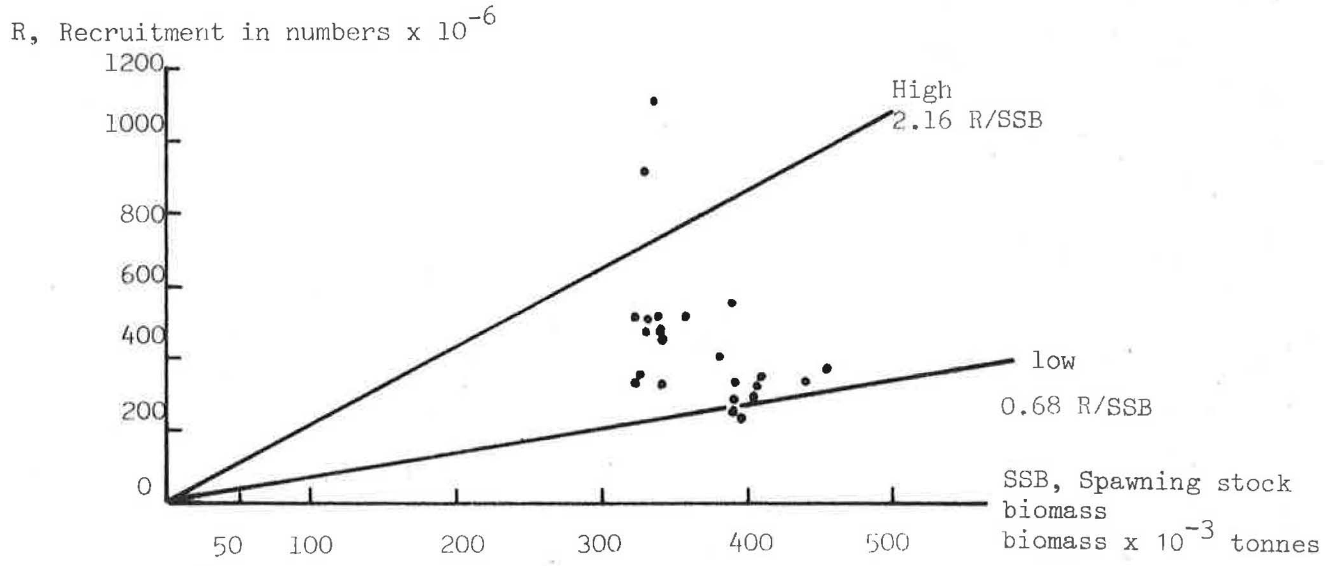


Figure 5.3.1 North Sea PLAICE

A



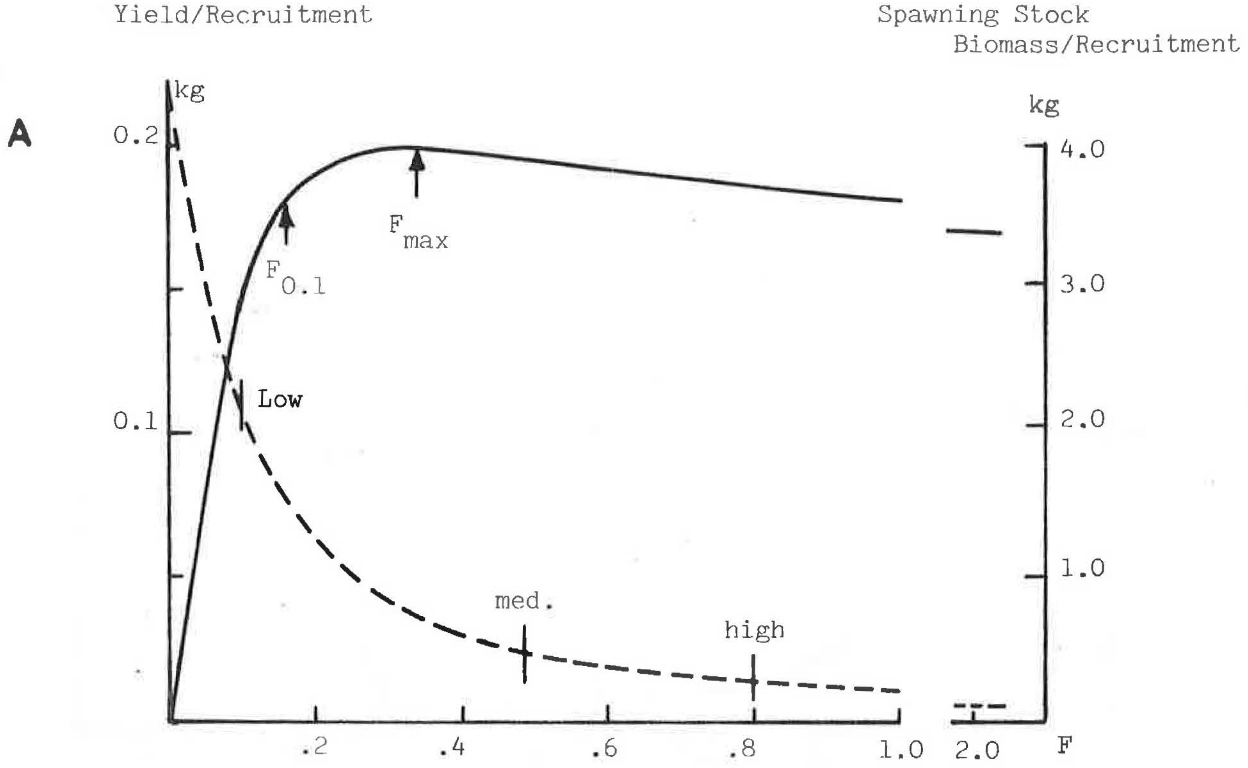
B



(High slope $\frac{1080 \times 10^6}{500 \times 10^3} = \underline{2.16 \times 10^3/t}$ | ~ 2.16 R/SSB = .46 SSB/R)

(Low slope $\frac{340 \times 10^6}{500 \times 10^3} = 0.68 \times 10^3/t$ | ~ .68 R/SSB = 1.47 SSB/R)

Figure 5.3.2 North Sea Sole



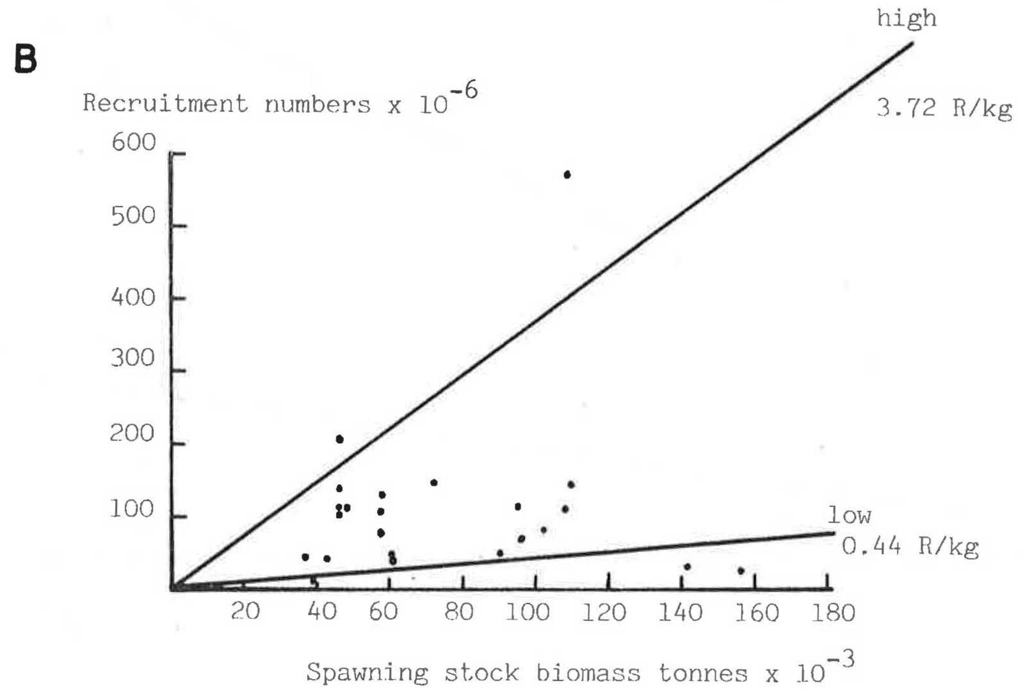


Figure 5.3.3 North Sea COD

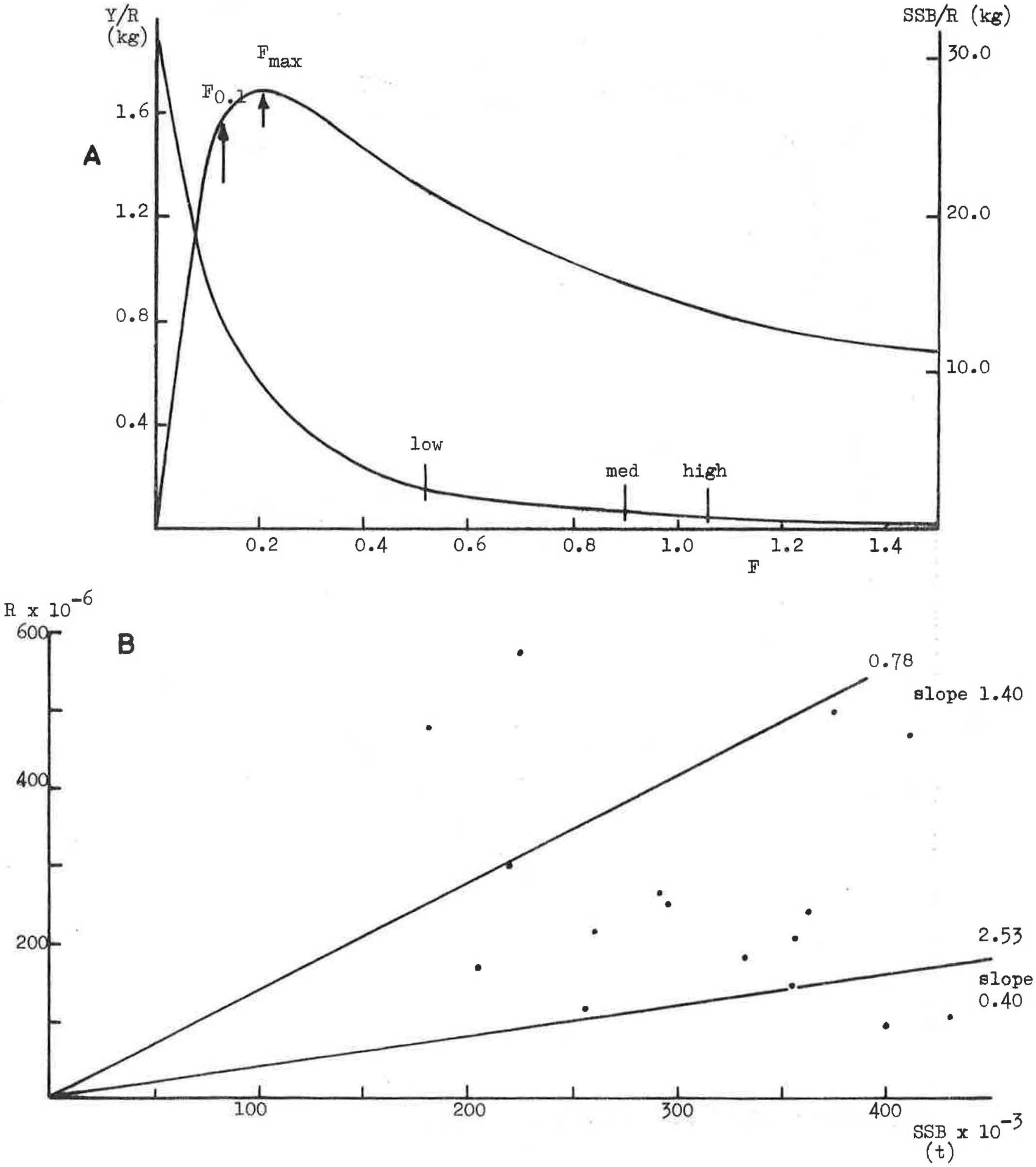
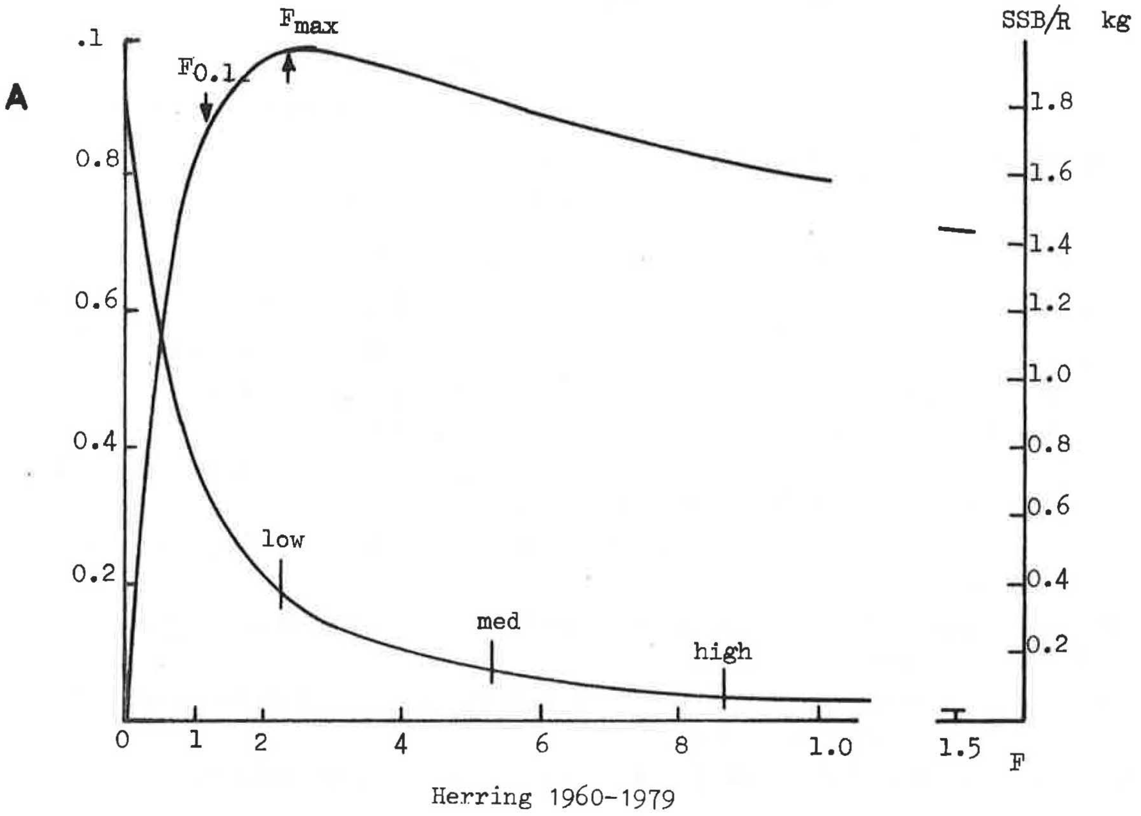
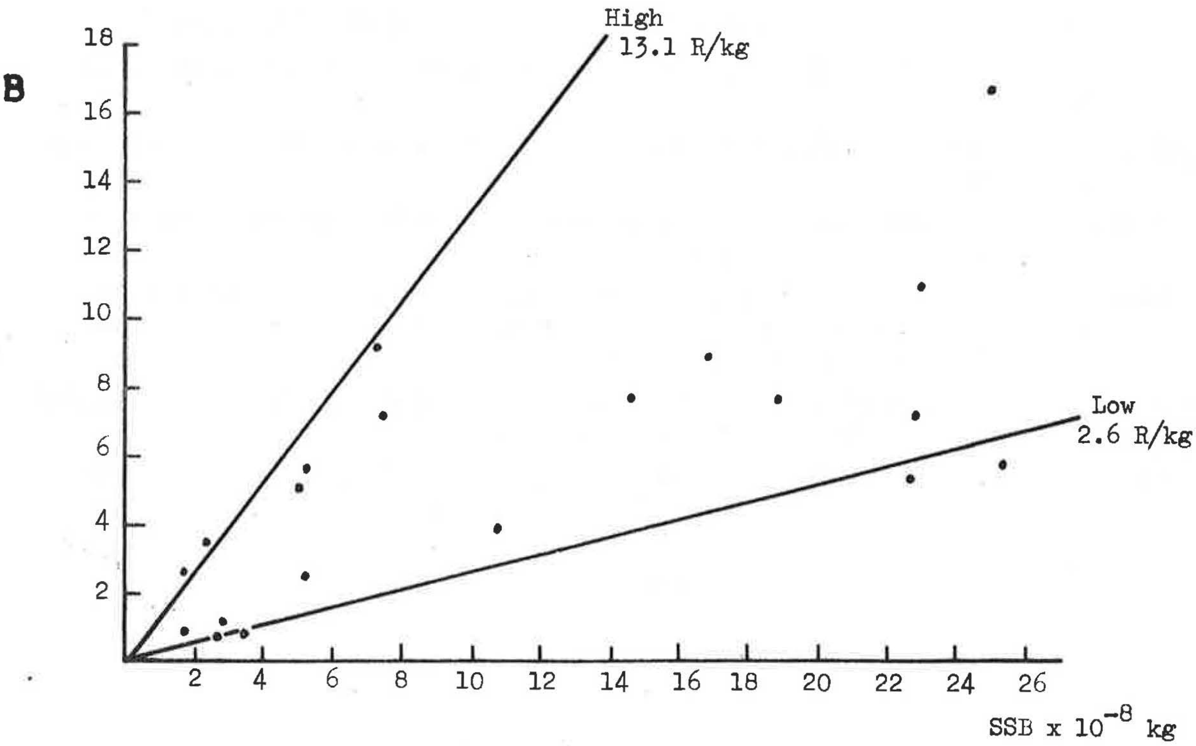


Figure 5.3.4 North Sea Herring



Recruitment numbers x 10^{-9}



APPENDIX A: WORKING PAPERS

Note (1) available elsewhere (see list of references)

(2) paper prepared specially for the meeting of the Working Group

(3) paper to be presented at Statutory Meeting

(4) paper substantially incorporated in text of report

Shepherd, J G and S M Stevens. Separable VPA: 'Users' Guide'. (1)

Shepherd, J G and J G Pope. 1983. The application of separable VPA. (2, 4)

Stevens, S M. 1983. The extension of separable VPAs to several fleets. (2, 3)

Pope J G and J G Shepherd. 1983. A comparison of the performance of various methods for tuning VPAs using effort data. (2, 3)

Laurec, A. 1983. Quelques calculs sur l'estimation par maximum du vraisemblance de mortalités de pêche terminales. (2)

Mohn, R K. The effects of error in catch and effort data on tuning cohort analysis. (1)

Armstrong, D W and R M Cook. 1983. Estimation of terminal F in Virtual Population Analysis. (2, 3)

Lewy, P. 1983. Determination of terminal fishing mortality rate based on catch and effort data. (2, 3)

Anthony, V. The calculation of $F_{0.1}$: a plea for standardization. (1)

Other Reference Material Available

Hildén, M. Some simple calculations with yield per recruit models.

Schumacher, A. Some examples of difficulties in the calculation of yield per recruit.

Redfish and Greenland Halibut WG Rep. 1982. Section 2.1: on calculations of yield per recruit.

Ulltang, Ø. Contribution to July 1982 meeting of ACFM, an application of the yield per recruit concept.

Gudmundsson, G, Th. Helgason and S A Schopka. Statistical estimation of fishing effort and mortality by gear and seasons for the Icelandic cod fishery in the period 1972-1979. (1)

Nielsen, N A. Estimation of the relation between nominal effort and fishing effort in the fishery for sandeels. (1)

Pope, J G and J G Shepherd. A simple method for the consistent interpretation of catch-at-age data. (1)

APPENDIX B: NOTATION

SUFFICES AND INDICES

y	indicates	year
f	"	fleet
a	"	age group
t	"	last (<u>t</u>erminal) year
g	"	oldest (<u>g</u>reatest) age group
ø	"	summation over all possible values of index (usually fleets)
#	"	summation over all fleets having effort data
@	"	an average (usually over years)
*	"	a reference value

QUANTITIES

C	(y,f,a)	Catch in number
E	(y,f)	Fishing effort
F	(y,f,a)	Fishing mortality
F_S	(y,f)	Separable estimate of overall fishing mortality
q		Catchability coefficient (in $F = qE$)
Y		Yield in weight (including discards)
L		Landings in weight (excluding discards)
W		Weight of an individual fish
B		Biomass
P		Relative fishing power of a fishing boat or fleet
E		Fishing effort
U		Yield or landings per unit of effort (see abbreviations)
C		Catch in numbers of fish (including discards)
T		Landed catch in numbers of fish
N		Stock in numbers of fish
F		Instantaneous fishing mortality
Z		Instantaneous total mortality
M		Instantaneous natural mortality
S		Selection coefficient defined as the relative fishing mortality (over age)

APPENDIX C

POSSIBLE TOPICS FOR CONSIDERATION BY ICES WORKING GROUP ON METHODS OF FISH STOCK ASSESSMENT

(with indication of dates when they have been examined)

		Date
1)	Application of separable VPA	1983
2)	Simpler methods for estimating TACs	
3)	Measures of overall fishing mortality	
4)	Use of effort data in assessments	(1981[*]) (1983
5)	Need for two sex assessments	
6)	Computation and use of yield per recruit	1983
7)	Inclusion of discards in assessments	
8)	Methods for estimation of recruitment	
9)	Density-dependence (of growth, natural mortality, maturity, fecundity, recruitment, etc.)	
10)	Linear regression in assessments	

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[*] at meeting of *ad hoc* Working Group on the Use of Effort data in Assessments, Doc. C.M.1981/G:5, reproduced as Part I of this Cooperative Research Report.

APPENDIX D

FURTHER TESTS OF TUNING METHODS

D.1 Tests of the Rho Method

Following the development and use of the rho method by the North Sea Roundfish Working Group (Anon., 1982a), Sparre (1982) and Armstrong and Cook (1982) carried out similar tests on the method. This involved comparing the predictions of the method on a truncated data set (extending to say 1976) with the "truth" obtained from the converged region of VPA on the full data set.

Figures D.1 to D.3 show some of the results obtained by Sparre (1982) for 3 North Sea stocks in 1976. The method gave best results for cod but with wide discrepancies in the Fs on the oldest age groups on haddock and whiting. Comparable results obtained by Armstrong and Cook (1982) are shown in Figure D.4, where the predicted terminal Fs are also compared with the "mean F" method. In this latter method, terminal F was calculated as a three year mean for the 3 years prior to the terminal year. Although there is fair qualitative agreement the rho method performs, if anything, slightly worse than the mean F method <u>for this particular stock</u> (see Figure D.5). The mean F method assumes that overall F on the stock is constant while the rho method allows for changes in F. The rho method should therefore perform better where F levels change from year to year.

In the test runs of Sparre (1982) the input Fs on the oldest fish were adjusted at each iteration to the mean of a range of younger fish in the same year. Armstrong and Cook (1983) held this value constant and this explains the difference between Figures D.2 and D.4. There is some reason to believe that the adjustment of Fs on the oldest fish using Sparre's technique may actually introduce greater variation in the predicted Fs on older fish (see Figures D.2 and D.3). In any event the Fs on these older fish should be interpreted with extreme caution and the rho method should not be used to estimate Fs on older fish in the region where VPA is still sensitive to input Fs.

Although the tests described above give some indication of the performance of the rho method it should be borne in mind that the truncated data set means that fewer data points are available in the regression. The historical performance of the method may therefore be worse than that which is potentially possible on current data. At present this problem cannot be resolved.

D.2 Further Tests of Other Tuning Methods

Following the suggestion of Sparre (1982) some further tests on tuning methods have been carried out by B W Jones (pers.comm.) on North Sea cod data. In these, a truncated data set extending only to 1977 was used, and the predictions based on these data were compared with the "truth" obtained from the converged region of VPA on the full data set.

The values of fishing mortality at age obtained by various methods, and the "true" values, are plotted in Figure D.6. Also plotted are the ranges of uncertainty (one S.D.) due to using different tuning methods to determine the "true" values: these are large for the oldest ages, as expected.

On this data set a reasonable constant catchability method (Laurec-Shepherd) performs well on the younger ages, but consistently underestimates F on the older ages. The gamma method on the other hand underestimates significantly on almost all ages.

The results of two variable catchability methods are illustrated. The hybrid method arrives at the correct overall level of F, and reproduces some of the details, except for an overestimate of F on age 2. The Armstrong method achieves a very close correspondence for all ages except age 2, even reproducing quite minor details.

The limited results must be treated with caution, but do suggest that variable catchability methods (especially that of Armstrong) are preferable, at least on this data set, and that their results are quite acceptable.

APPENDIX E

SEPARABLE VPA: TESTS OF METHOD

E.1 North Sea Sole

Separable VPA was applied to North Sea sole data, and Figure E.1.A shows that, given very different values of F_T, SVPA does converge quite rapidly, and that the same holds true for different values of S_T (Figure E.1.B). That figure also shows that the influence of S_T on F(I) and of F_T on S(J) although noticeable are probably negligible. This confirms the observations of Pope and Shepherd (1982). Figure E.1.2 compares the values of F(I) (year effect), F_{sc} (average fishing mortality from separable analysis) and $\bar{F}_c$ (average fishing mortality from extended analysis). As expected, F(I) and $\bar{F}_{sc}$ parallelled each other closely while $\bar{F}_c$ showed a smoothed average trend. No investigations of which one was the best to compare with fishing effort have been made.

The effect of the number of ages included in the separable VPA analysis was investigated by using the 1978 to 1982 North Sea sole catch at age data and F_T = .55 and S_T = .50. Some results are shown in the text table (p. 108). Ages having the largest residuals of log catch ratios were successively removed. The coefficient of variation went from 31% using all ages to 20.6% using ages 2-12 or 2-11. Using the CV and the absolute values of F(EXT)-F(s) for 1982 as an index of goodness-of-fit and in order to include as many ages as possible without introducing too much noise, ages 2-13 were felt to represent a good compromise. The text table also shows the estimated 1982 fishing mortalities (from extended analysis based on terminal population) for ages 3, 4 and 5. These are somewhat variable but not dramatically so, and there do not appear to be any obvious consistent trends. Figure E.1.3 shows the effect of age span on F(I) (A) and S(J)(B). F(I) 1978 increases gradually until ages 2-13 are used and then decreases slightly when ages 2-12 and 2-11 are used. The differences are largest between the runs with ages 1-14 and ages 2-13. Figure E.1.3.B shows the effect of age span on S(J) but the difference may be an artefact of using S_T = .50 for all runs. This could also have an effect on the F(I) of Figure E.1.3.A.

The effect of the number of years used on the separable VPA on the resulting 1982 fishing mortalities (based on terminal populations) for North Sea sole is shown in Figure E.1.4. The effect on ages 2-5 is minimal, but it is more pronounced for some of the older ages.Text table (p.109) shows some results of separable VPA for different numbers of years. It shows that the effect on fishing mortalities (from extended analysis, terminal populations used) is negligible. The coefficient of variation goes from 28.5% for 1966-82 to 22.3% for 1978-82.

An important assumption of separable VPA is that the selectivity at age pattern has remained relatively constant over the period studied. Figure E.1.5 shows the resulting S(J) for North Sea sole when sep. VPA is run on different periods. It shows that the selectivity pattern during 1968-72 is markedly different from that during 1978-82 with S(J)s for 1968-82 usually being somewhere between the two others. Table E.1.1.a shows the log catch ratios for the 1968-82 run and no obvious pattern indicating a change in selectivity can be seen thus suggesting that it could be difficult to identify changes in selectivities based on that table alone.

A related problem is that of the concentration of fishing effort (and thus fishing mortalities) on certain year classes. The basic assumptions of SVPA are that the catch at age data can be interpreted in terms of yearly fishing mortality effects and a constant age effect. It is thus conceivable that the comparison of F(EXT) (Standard VPA results produced from terminal populations from SVPA) and F(SEP) could give some indications of whether or not fishing effort does concentrate on certain year classes. For North Sea sole, the average of the F(EXT)-F(SEP) was calculated for one strong (1963), one average (1967) and one weak (1970) year class and did not indicate concentration of fishing effort on either of these year classes. This is based on a few observations, and it cannot be concluded that concentration of fishing effort does not occur.

The subject of changes in selectivities will be addressed further in Appendixes E.2 and E.3.

Text table North Sea Sole. Results of separable VPA. Years included in the analysis are 1978-82. The effect of age span is investigated.

	Age Span				
	1-14 all ages	2-14	2-13	2-12	2-11
Coeff. of variation	31.0	26.5	22.3	20.6	20.6
F_T	.55	.55	.55	.55	.55
S_T	.50	.50	.50	.50	.50
Average of absolute values of F(EXT)-F(s) for 1982	.086 (2-14)	.061(3-14)	.046(3-13)	.055(3-12)	.045 (3-11)
F(1982,3)	.408	.518	.502	.505	.511
F(1982,4)	.718	.613	.581	.597	.598
F(1982,5)	.605	.498	.460	.478	.469

Text table North Sea sole. Results of separable VPA. Investigation of the number of years used in the analysis (age span is 2-13).

	Year Span						
	1966-82	1968-82	1970-82	1972-82	1974-82	1976-82	1978-82
C.V.(%)	28.5	27.1	28.4	28.5	24.9	25.0	22.3
1982 extended from terminal pops.							
F_3	.519	.527	.516	.509	.502	.498	.502
F_4	.581	.590	.585	.578	.585	.580	.581
F_5	.459	.442	.442	.439	.455	.456	.460
$F_{(T)}$	.55 →						
S(g)	.5 →						
Av. of absolute values of F(EXT) -F(s)	.036	.034	.036	.042	.048	.041	.046

E.2 <u>North Sea Saithe</u>

In the period 1970-76, annually 12-27% of the saithe landings were from industrial fisheries. These catches were predominantly 2-4 year old fish. The industrial landings were abruptly reduced to about 10% of the former level from 1977 onwards, and this would be expected to have produced a significant change in the exploitation pattern, with lower relative fishing mortalities on the age groups 2-4. North Sea saithe, therefore, seemed a suitable stock for exploring the effects of a change in exploitation pattern on the separable VPA.

In the 1983 Saithe Working Group (Anon., 1983b) assessment of North Sea saithe, the 1982 input fishing mortalities were based on the average exploitation pattern for 1977-79, the underlying assumption being that there had been little change in the exploitation pattern after 1977. A separable VPA for the same period would therefore be expected to produce a similar result.

A number of separable VPA runs were made for the period 1970-82, using different combinations of terminal F and S values. However, the variation of these parameters did not appear to add any significant information about the effects of the change in exploitation pattern. The results presented here are therefore based on a run with values of F (= 0.36 at age 5) and S (= .722 at age 14) corresponding to the input fishing mortalities used by the Saithe Working Group. The age groups 2-14 were included in the analyses. The same input values were also used in a separable VPA for the period 1977-82.

In the separable VPA 1970-82 the log catch ratio residuals between 1976 and 1977 are very high for the three year classes which were subject to industrial fishing in 1976 (Table E.2.1). This is a strong indication of a change in the exploitation pattern from 1976-77.

Figure E.2.1 shows the exploitation patterns resulting from the two separable VPAs. The main difference is on ages 3-4 where S(J) is much higher in the 1970-82 run. It seems that in the 1970-82 run the high relative level of fishing mortalities on ages 3 and 4 in the earlier years are causing an overestimate of the F values on these age groups for the more recent years. This is in good accordance with what could be expected and gives an indication of the type of error resulting from using a separable VPA over a period when the exploitation pattern has changed abruptly. However, it is not clear why the same effect is not seen for age 2. In terms of stock numbers, the 1970-82 run indicates a lower level of recruitment for the year classes 1978 and 1979 which is a consequence of higher Fs on ages 3 and 4 in 1982.

Figure E.2.2 shows the fishing mortalities in 1982 resulting from the separable VPA for 1977 to 1982 and the input fishing mortalities in 1982 used by the Saithe Working Group. Although the fishing mortalities are based on the same assumption of a stable exploitation pattern from 1977, they are clearly different. The Saithe Working Group Fs are highest for ages 3 and 4, whereas the separable analysis Fs are highest for ages 5-8. The exploitation pattern for 1982 from the extended analysis (which is more appropriate for comparison with the Working Group assumption) has highest F values at ages 4-6 and seem to be approximately intermediate between the two others.

The exploitation pattern of the separable analysis is close to the average exploitation pattern for 1977-82 from the ordinary VPA and this might suggest that the exploitation pattern used for 1982 by the Saithe Working Group is wrong. However, there are also very large negative log catch ratio residuals between 1981 and 1982 for the youngest age groups (Table E.2.1), which suggest that the exploitation pattern changed from 1981 to 1982 and the Working Group may have arrived at a reasonable result, perhaps for the wrong reason. It seems clear that the basic assumption made by the Working Group about a stable exploitation pattern for 1977-82 is not entirely valid and the results of both the separable analysis and that of the Working Group should be used with caution However, there seems to be no reason to assume that the F values from the extended analysis are less reliable than those used by the Saithe Working Group, except that the former values have not in this exercise been adjusted according to information on effort.

E.3 Statistical Tests of Departure from the Separable Hypothesis

The central hypothesis of the separable VPA is that fishing mortality F(y,a) may be considered as the product of an age effect S(a) and a year effect $F_s(y)$. In practice fishing mortality is generated by a number of fishing fleets having different patterns of exploitation at age and different trends in fishing intensity. Moreover changes in mesh sizes alter exploitation pattern. It might therefore be supposed that total fishing mortality might in some cases prove to have an exploitation pattern which changes with time. In these circumstances the separable hypothesis would be insufficient to completely explain changes in fishing mortality and a more detailed model would be required. It is therefore important to consider this possibility when the separable VPA is used. The obvious way to investigate this is to examine the log catch ratio residual matrix for significant interaction effects. An indication of how such residuals would appear is given in Table E.3.1, which shows the log catch ratio residuals obtained when the non-separable exact data used to test the two fleet separable model (Stevens, 1983) were interpreted using separable VPA.

This shows that a systematic trend in exploitation pattern would show itself in negative residuals in two diagonally opposed quadrants and positive residuals in the other two diagonally opposed quadrants. This shows up clearly in this table due to the absence of noise on these artifically generated data, but in practice the same signals shown would almost certainly be drowned out if significant sampling error were imposed on the data. Since in practice this data set does not depart markedly from the separable hypothesis (see Table E.3.2 for comparison on separable and true Fs at age), this may not in this case be important.

A much more serious departure from the separability hypothesis can be seen in Table E.3.3, which shows the equivalent results from the Iceland cod stock (Gudmundsson et al., 1982). The chequered pattern of residuals shows clearly through the noise and there can be little doubt that the separable hypothesis will not be sufficient to adequately describe these data. It might, however, be used on a shortened data set. Since fitting the separable VPA is almost equivalent to performing an ANOVA on the log catch ratio matrix it is instructive to perform an ANOVA on this matrix and to include the obvious quadrant interaction term to show how important and significant departure from the separable hypothesis might be. Table E.3.4 shows the ANOVA table for the Stevens data while Table E.3.5 shows the ANOVA of the Iceland cod. In the former case the age and year effects which would be accounted for by the separable VPA account for almost 99% of the variance and are 500 times greater than the quadrant effect. While significant when viewed against the residuals estimated from these exact data, the mean squares of the quadrant effect would not be detectable if the residuals contained the usual amount of sampling error. In the case of the Iceland cod the quadrant effect is found to be both statistically significant and practically meaningful (8% of the variance). The year and age effects that the separable VPA accounts for explain 77% of the variance. The residual mean square for this stock would be consistent with a coefficient of variation of catch at age data of about 12%.

Similar ANOVAs were made for North Sea sole and North Sea saithe (Tables E.3.6 and E.3.7). Neither showed significant or important quadrant effects, while the age effect was always large and significant. This means that there is no significant shift from young to old age groups (or vice versa), but other more complex changes in exploitation pattern cannot thereby be ruled out. The combined age year effects accounted for 64% of the variance of log catch ratios for North Sea sole and 44% for North Sea saithe. The levels of residuals for these stocks indicate coefficients of variation of catch at age data of 24% and 33%, respectively.

In conclusion, therefore, it would seem that departures from the separability hypothesis may be detected where they are sufficiently strong to invalidate the use of separable VPA as in the case of the Iceland cod. In such circumstances a more detailed model will be required such as that of Gudmundsson, 1982. Using this particular test for the other two fish stocks investigated, the separable hypothesis appears adequate, but the results presented in Appendix E.1 and E.2 should be noted. The large proportion of the variance explained by age and year effects in each of these stocks indicates why the separable VPA is apparently a robust method of interpreting catch at age data. However, other tests of departure from separability should be actively sought.

APPENDIX F

CONCEPTUAL FRAMEWORK FOR CATCH AND EFFORT ANALYSES

The proliferation of VPA tuning techniques in recent years makes it difficult to clarify in which feature they do or do not differ. For this reason it would be useful if further techniques which may be created could be described in the way suggested by Pope and Shepherd (1983) Beyond this it appeared useful to build a table describing the conceptual framework of the problem of utilising effort data. This is the purpose of Table F.1.

F.1 General Principle

The left part of Table F.1. shows the definition of the catchability model. The right part of the table shows the fitting techniques.

F.1.1 The catchability model

Several possible influences can be taken into account:

age(a), year(y), effort(E), stock size in terms of exploited biomass(B) and interactions. Only possible interactions between age and year (a x y) and age and biomass (a x B) have been taken into account.

The presence of a zero means that the effect is not incorporated in the model. A "u" means that the effect is not restricted to be a simple function of age, but is described by a parameter at each age. A "R_n" means that a mathematical function describes the effects, with n parameters being associated to the shape of the function (regardless of the average value, which implies that the exact mathematical function may have n+1 parameters).

Finally, it should be noted that a catchability model is required for each fleet if several are to be considered. Some effects may be restricted to be similar from fleet to fleet, but for the sake of simplicity this has not been introduced in the table.

F.1.2 Fitting techniques

Direct fitting (D.F.) of the integrated models may be used, referring to a maximum likelihood (M.L.), to a least squares (L.S.) possibly weighted (W.L.S.), or approximate (A.L.S.). Beyond this, iterative tuning of VPA (It. VPA) can be used. These techniques fit either cpue against biomass (U/B on the table), or fishing mortalities against fishing effort (F/E on the table). They eventually need to combine information by year, fleet and ages. The ranking of the combinations used appears on the table with for instance f,y for a combination first over fleet, then over years, and a,y,f for a combination first over ages, then years, and finally fleets.

Finally, logarithms may be used (Y or N in the table for Yes or No) either prior to any combination (P in the table) or after some combination (A_f) for instance in the table if combinations over fleets are performed prior to logarithmic transformation.

F.1.3 Methods taken into account

The various methods discussed are described in reference papers. For the techniques varying in the rows from Saville to Armstrong techniques, they are described in Pope and Shepherd, 1983. Finally, a framework for further studies is suggested by the table, with for instance possible descriptions of the age effect varying from unrestricted description to a mathematical description with only a few parameters.

Such studies should pay special attention to the possible usefulness and dangers of the introduction of different levels of sophistication in the models. Only the suggested level of maximum flexibility appears for each possible effect, but in all cases the impact of not taking into account a possible effect should be explored.

Comparisons of the results from direct fitting and iterative tuning of VPA would be useful.

Summary of symbols used in Table F.1

- a,y,E,B	respectively age, year, effort and stock size effects
- a x y, a x B	interactions, respectively between age and year, age and biomass
- A	number of age groups
- o	effect not taken into account
- u	effect not mathematically restricted
- R_n	effect mathematically described with n 'shape parameters'
- D.F.	Direct Fitting
- M.L.	Maximum Likelihood
- (W),(A) L.S.	(weighted) (Approximate), least squares
- It. VPA	iterative VPA
- a,y,f	combination over ages, then years, then fleet
- U/B	fitting of relationships between cpue and exploited biomass
- F/E	fitting of fishing mortalities/effort relationship
- Y, N	Yes or No to logarithmic transformations
- P	transformation prior to any combination
- A_f	transformation after combination over fleets

Notes to Table F.1

(1) A degree three polynomial is used to describe the catchability pattern under age 8, catchability being considered as constant beyond age 8. A further constraint requires the first derivative of the polynomial to be zero at age 8, reducing the number of parameters to 2. On the other hand, within the year half-years are considered with separate models for each period so that the number of parameters should be multiplied by two (which explains the symbol 2 x 2 on the table).

(2) Restrictions on the derivatives reduces the number of parameters to 4. On the other hand, extra interaction between age and selectivity can be incorporated to take account of a change in the mesh size, introduced during the period considered.

(3) Separable VPA does not refer to catchability, but just to fishing mortality and cannot in this respect be strictly compared to the other techniques. It is, however, based on a model of very similar structure, and has therefore been included for comparison.

(4) The gamma method allows for a stock size effect on catchability with no restriction on the possible changes of this effect from age to age. So only interaction appears, with as many parameters as ages since for each age a model including one shape parameter is fitted. (The same is the case for the hybrid and rho methods as regards yearly effects). Finally, it must be noted that the stock size effect is affecting not individual catchability for each fleet, but an average catchability over fleet.

(5) Taking logarithms prior to any combination eliminates any difference between u vs B and F vs E techniques.

(6) This technique assumes constant catchability during the last three years, but does not restrict possible changes in earlier years.

(7) If no restriction is made of the age effect, this will lead to A-1 shape parameters. Restricted descriptions of the age effect should be particularly interesting to study, in terms of possible benefits of limiting n.

(8) If separate functions describe the yearly effect on catchability at each age, one parameter should be given to each for a total A. If a more "integrated" description for a x y interactions is to be used, proliferation in the number n of parameters should be avoided.

Appendix E.1. Table 1.a. North Sea sole. Log catch ratios for 1968 to 1982.

LOG CATCH RATIO RESIDUALS

	68/69	69/70	70/71	71/72	72/73	73/74	74/75	75/76	76/77	77/78	78/79	79/80	80/81	81/82	
2/ 3	0.264	0.403	0.000	0.233	0.380	-0.273	-0.233	0.161	-0.819	0.453	-0.107	-0.109	-0.395	0.113	0.020
3/ 4	0.218	0.052	0.279	-0.225	0.499	-0.261	-0.275	-0.127	-0.163	0.252	-0.210	-0.033	0.045	-0.033	0.016
4/ 5	-0.061	0.172	0.206	-0.025	0.177	-0.260	0.002	-0.037	-0.276	0.324	-0.179	-0.176	0.124	-0.029	0.011
5/ 6	-0.053	0.426	-0.133	0.106	0.391	-0.314	-0.284	-0.097	0.184	0.099	-0.110	-0.189	0.086	-0.103	0.002
6/ 7	-0.272	-0.087	0.060	0.240	0.151	-0.435	0.153	-0.021	0.438	-0.295	0.210	-0.386	-0.042	0.279	-0.008
7/ 8	0.156	-0.138	0.505	0.055	-0.505	-0.086	0.042	-0.137	0.084	-0.759	0.294	-0.337	0.653	0.146	-0.012
8/ 9	-0.036	0.068	-0.029	-0.399	-0.149	-0.052	-0.422	0.094	0.142	0.274	0.302	0.079	0.189	-0.071	-0.011
9/10	-0.235	-0.432	-0.914	-0.247	0.361	0.006	-0.073	0.312	0.134	0.081	-0.066	0.831	0.257	-0.020	-0.003
10/11	0.294	0.196	0.371	0.425	-0.443	-0.148	0.496	-0.195	0.437	-0.100	-0.119	-0.489	-0.821	0.110	0.008
11/12	-0.121	-0.300	-0.545	-0.335	-1.028	0.263	-0.163	0.279	0.146	-0.252	0.374	0.662	0.828	0.208	0.017
12/13	-0.158	-0.355	0.204	0.181	0.172	1.560	0.806	-0.231	-0.355	-0.069	-0.380	0.156	-0.917	-0.595	0.020
	0.006	0.005	0.005	0.004	0.003	0.001	-0.001	0.000	0.003	0.006	0.009	0.009	0.008	0.004	0.062

<u>Appendix E.1. Table 1.b.</u> North Sea sole. Table of residuals from the F table (extended based on terminal populations) and the F from SVPA.

TABLE OF F(EXT) - F(SEP)

AGE	YEAR 1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
2	0.089	0.143	-0.018	0.095	0.052	-0.091	-0.078	0.033	-0.104	0.061	-0.021	-0.017	-0.053	0.015	0.000
3	0.093	0.098	0.141	-0.082	0.136	-0.140	-0.108	-0.088	-0.010	0.045	-0.107	0.006	0.015	0.023	-0.023
4	0.106	-0.014	0.110	0.042	0.022	-0.187	-0.011	0.032	-0.048	0.092	-0.099	-0.026	0.028	-0.005	0.065
5	0.013	0.214	-0.084	0.042	0.070	-0.095	-0.081	-0.016	0.062	0.050	-0.054	-0.032	0.057	-0.024	0.009
6	-0.139	0.040	0.031	-0.064	0.103	-0.111	0.054	0.036	0.023	-0.005	0.026	-0.016	0.037	0.035	0.013
7	-0.083	-0.082	0.074	0.020	-0.117	-0.066	0.057	-0.001	0.048	-0.085	0.133	-0.044	0.122	0.065	-0.049
8	-0.060	-0.140	-0.059	-0.073	0.005	-0.038	-0.050	0.060	0.051	0.031	0.163	0.047	0.054	-0.058	0.037
9	-0.066	-0.055	-0.128	-0.070	0.035	0.087	-0.022	0.102	0.052	0.012	-0.046	0.063	0.022	0.008	-0.049
10	0.034	-0.013	0.046	0.019	-0.018	-0.074	0.097	-0.092	0.011	-0.000	-0.007	-0.033	-0.096	-0.034	0.015
11	-0.051	-0.041	-0.061	-0.043	-0.081	0.213	-0.048	-0.046	0.061	-0.078	0.036	0.029	0.105	0.039	-0.072
12	-0.026	-0.037	0.036	0.090	0.055	0.577	0.172	-0.010	-0.121	0.032	-0.073	-0.076	-0.117	-0.101	-0.013
13	0.000	0.020	0.067	-0.019	0.038	0.015	-0.119	-0.095	0.069	-0.057	0.086	0.035	-0.097	0.090	0.033

Appendix E.2. Table 1. North Sea Saithe

NATURAL MORTALITY = 0.200
TERMINAL F = 0.360
TERMINAL S = 0.722

REFERENCE AGE (FOR UNIT SELECTION) IS 5

NO. OF ITERATIONS CHOSEN IS 30
MINIMUM DIFFERENCE BETWEEN ITERATIONS IS 10**-5

ITERATION	SSQ
1	65.2740
30	33.3736

APPROX. COEFF. VARIATION OF CATCH DATA = 37.1 %

YEAR	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
F(I)	0.2731	0.3056	0.4111	0.4506	0.4606	0.5443	0.5159	0.5989	0.4395	0.3589	0.3742	0.4691	0.3600

AGE	2	3	4	5	6	7	8	9	10	11	12	13	14
S(J)	0.2623	0.8061	1.1646	1.0000	0.9716	0.9446	0.9686	0.8446	0.7354	0.7230	0.6736	0.6181	0.7220

LOG CATCH RATIO RESIDUALS

	70/71	71/72	72/73	73/74	74/75	75/76	76/77	77/78	78/79	79/80	80/81	81/82	
2/ 3	-2.294	-0.359	-0.062	0.013	-0.425	-0.527	0.800	-0.457	1.044	1.251	0.848	0.171	0.004
3/ 4	-0.365	0.198	0.018	0.155	0.793	-0.398	1.241	-0.841	0.275	-0.237	0.128	-0.960	0.006
4/ 5	0.359	0.399	0.201	0.173	0.534	-0.115	0.578	-0.147	-0.230	-0.279	-0.138	-1.329	0.006
5/ 6	0.804	0.089	-0.150	-0.473	0.063	-0.239	0.119	0.165	0.090	0.133	0.364	-0.958	0.005
6/ 7	0.640	-0.248	0.402	-0.587	-0.052	-0.084	-0.132	0.348	-0.458	-0.116	0.305	-0.017	0.003
7/ 8	0.005	0.002	0.211	-0.116	0.032	0.225	-0.423	0.100	-0.476	0.504	-0.026	-0.037	0.000
8/ 9	-0.387	-0.016	0.263	-0.499	-0.201	0.190	-0.356	0.278	-0.088	-0.071	-0.108	0.993	-0.001
9/10	-0.056	0.168	0.031	-0.230	-0.305	0.312	-0.175	0.478	0.056	-0.440	0.093	0.067	-0.002
10/11	0.065	0.240	0.212	0.384	-0.141	0.304	-0.272	0.174	-0.109	-0.514	-0.253	-0.091	-0.000
11/12	0.163	0.350	-0.464	0.391	0.032	0.193	-0.303	-0.205	-0.132	-0.026	-0.466	0.470	0.003
12/13	0.827	0.495	-0.030	0.123	-0.655	0.057	-0.793	-0.465	0.222	-0.019	-0.486	0.729	0.005
13/14	0.242	-1.316	-0.632	0.667	0.327	0.084	-0.282	0.578	-0.189	-0.181	-0.258	0.965	0.006
	0.003	0.002	0.002	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.004	0.002	0.034

<u>Appendix E.3. Table 1.</u> Log catch ratio residuals table from a separable VPA analysis made of Stevens exact test data for a two fleet separable VPA for years 2 to 10 and ages 1 to 9.

LOG CATCH RATIO RESIDUALS

		Years							
		2/ 3	3/ 4	4/ 5	5/ 6	6/ 7	7/ 8	8/ 9	9/10
	1/ 2	-0.034	-0.023	-0.013	-0.004	0.006	0.015	0.028	0.026
	2/ 3	-0.028	-0.019	-0.011	-0.003	0.005	0.013	0.024	0.020
	3/ 4	-0.036	-0.023	-0.012	-0.002	0.008	0.017	0.026	0.023
Ages	4/ 5	-0.013	-0.008	-0.004	0.000	0.004	0.007	0.009	0.006
	5/ 6	0.006	0.004	0.003	0.001	0.000	-0.002	-0.005	-0.006
	6/ 7	0.019	0.013	0.007	0.002	-0.003	-0.008	-0.015	-0.013
	7/ 8	0.039	0.026	0.014	0.002	-0.008	-0.018	-0.029	-0.025
	8/ 9	0.050	0.033	0.018	0.003	-0.011	-0.024	-0.038	-0.030

Appendix E.3. Table 2. Deviations of fishing mortality at age and year estimated by separable VPA

Ages \ Year	1	2	3	4	5	6	7	8	9	10	Average absolute deviation from truth
1	.014	.012	.007	.002	-.004	-.009	-.015	-.018	-.015	-.014	.011
2	.014	.012	.008	.003	-.002	-.007	-.011	-.014	-.010	-.007	.009
3	.015	.014	.010	.006	.002	-.003	-.007	-.009	-.004	.001	.007
4	.005	.006	.008	.008	.007	.008	.007	.009	.016	.027	.010
5	-.004	.001	.006	.011	.015	.019	.023	.030	.038	.056	.020
6	-.011	-.004	.005	.014	.021	.030	.038	.049	.056	.079	.031
7	-.019	-.009	.004	.016	.028	.040	.052	.066	.074	.101	.041
8	-.022	-.010	.006	.021	.035	.050	.065	.082	.090	.120	.050
9	-.025	-.010	.008	.026	.044	.061	.079	.099	.107	.140	.060
Average absolute deviation from truth	.014	.009	.007	.012	.018	.025	.033	.042	.046	.061	.027

Appendix E.3. Table 3. Log catch ratio residuals table from a separable VPA analysis made of Icelandic cod data from 1973 to 1979 and from ages 4 to 10.

LOG CATCH RATIO RESIDUALS

		Years					
		73/74	74/75	75/76	76/77	77/78	78/79
Ages	4/ 5	0.063	0.147	0.134	-0.052	-0.329	0.037
	5/ 6	0.192	0.061	0.019	-0.024	-0.043	-0.212
	6/ 7	0.235	-0.035	0.182	0.109	-0.275	-0.167
	7/ 8	0.105	0.096	-0.276	-0.098	0.253	0.023
	8/ 9	-0.144	0.071	-0.071	0.036	-0.075	0.184
	9/10	-0.358	-0.289	0.014	0.030	0.468	0.135

Appendix E.3. Table 4. ANOVA of Stevens' test data for years 2 - 10 and ages 1 - 9

Cause	D.F.	S. Sqs	M. Sq	F
Age	7	1.206	.1723	287
Year	7	1.308	.1868	311
Quadrant	1	0.005	.005	8.3
Residuals	48	0.027	.0006	
Total	63	2.546		

Appendix E.3. Table 5. ANOVA of Iceland Cod log catch ratio data for years 1973-1979 and age 4 - 10

Cause	D.F	S. Sqs	M. Sq	F	
Age	5	3.37	.674	23.44	P <.001
Year	5	.22	.044	1.53	NS
Quadrant	1	.36	.360	12.52	P <.001
Residuals	24	.69	.029		
Total	35	4.64			

Appendix E.3. Table 6. ANOVA of North Sea SOLE log catch ratio data for years 1972-1982 and for ages 2 - 12

Cause	D.F.	S. Sqs	M. Sq	F	
Age	9	14.517	1.613	13.68	P <.001
Year	9	2.736	.304	2.58	P <.05
Quadrant	1	.090	.090	.76	NS
Residuals	80	9.433	.118		
Total	99	26.776			

Appendix E.3. Table 7. ANOVA of North Sea SAITHE log catch ratio data for years 1972-1982 and for ages 2 - 12

Cause	D.F.	S. Sqs	M Sq	F	
Age	9	11.33	1.26	5.80	P < .001
Year	9	2.32	.26	1.20	NS
Quadrant	1	.19	.19	.88	NS
Residuals	80	17.37	.22		
Total	99	31.21			

Appendix Table F. 1 Description of different models using effort data for tuning VPAs

Technique \ Effect	Catchability Model Building						Fitting Technique			
	a	y	E	B	a x y	a x B	Basic Principle	Combi-nation	F/E U/B	Log.
Nielsen 1982 G:49	R_2	0	R_1	0	0	0	D.F. M.L.			
Nielsen 1982 G:50	0	0	R_1	0	0	0	D.F. M.L.			
Gudmundsson et al. (1983)	R_{2x2} (1)	R_{2x2}	R_{1x2}	0	R_{4x2} (2)	0	D.F. W.L.S.			
Separable VPA	u	u	(3)	0	0	0	D.F. A.L.S.			
Saville	u	0	0	0	0	0	It. VPA	f,y	F/E	No
Hoydal and Jones	u	0	0	0	0	0	"	f,y	F/E	No
Gamma	u	0	0	0	0	R_A (4)	"	f,y	U/B	Y,A_f
Modified Gamma	u	0	0	0	0	0	"	f,y	U/B	Y,A_f
Partial expl. biomass	u	0	0	0	0	0	"	a,y,f	U/B	No
Laurec/Shepherd	u	0	0	0	0	0	"	y,f	F/E(5)	Y,P
Hybrid	u	0	0	0	R_A	0	"	y,f	F/E (5)	Y,P
Rho	u	0	0	0	R_A	0	"	f,y	U/B	N
Log Rho	u	0	0	0	0	0	"	f,y	U/B	Y, A_f
Armstrong	u	(6)	0	0	0	0	"	y,f	F/E	N
Armstrong & Cook (1983)	u	Eliminated through an explan. variable	0	0	0	0	"	y,f	F/E	N
Further studies to be conducted (Maximum flexi-bility)	R_n (7) / u	R_1	R_1	R_1	R_n (8) / R_A	R_n (8) / R_A	W.L.S. / M.L. if possible for comparisons It. VPA with various methods			

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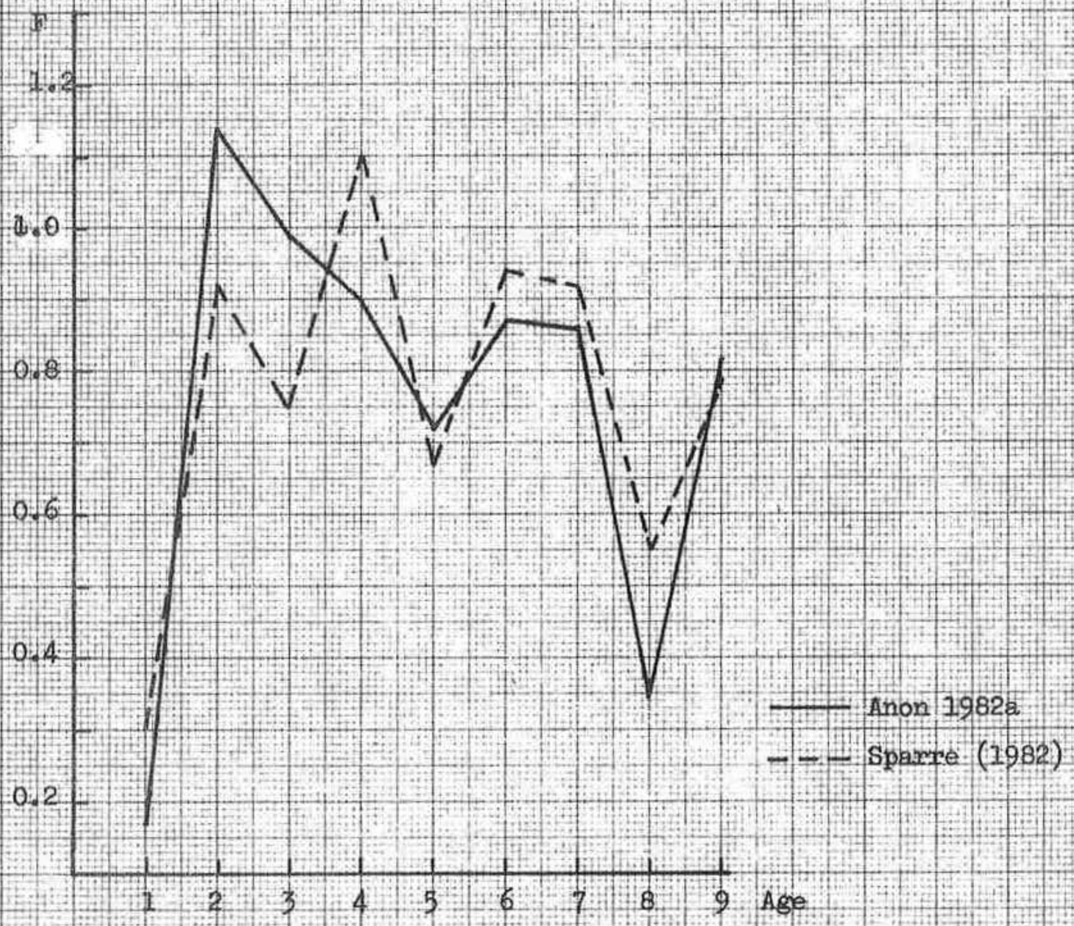
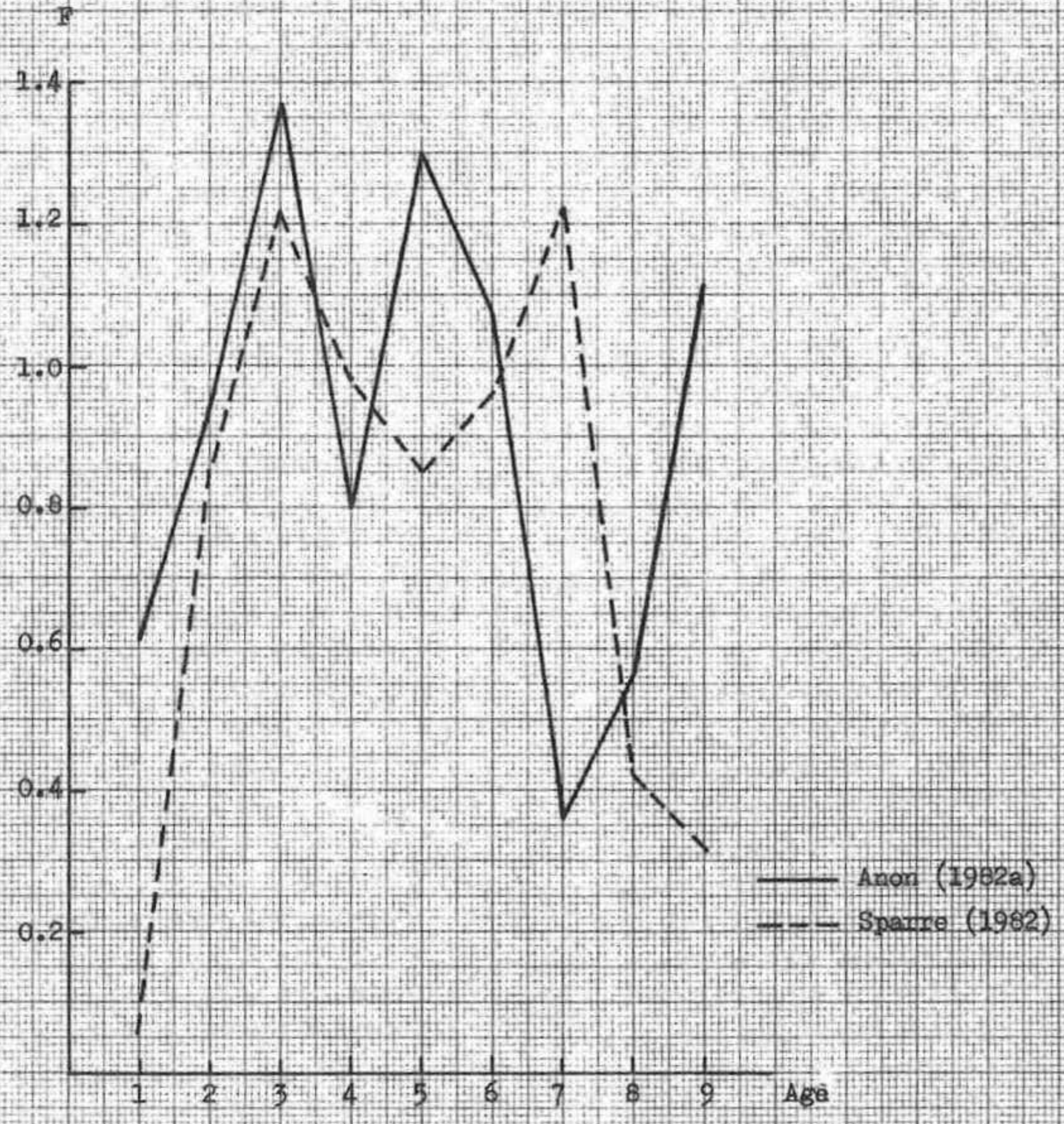
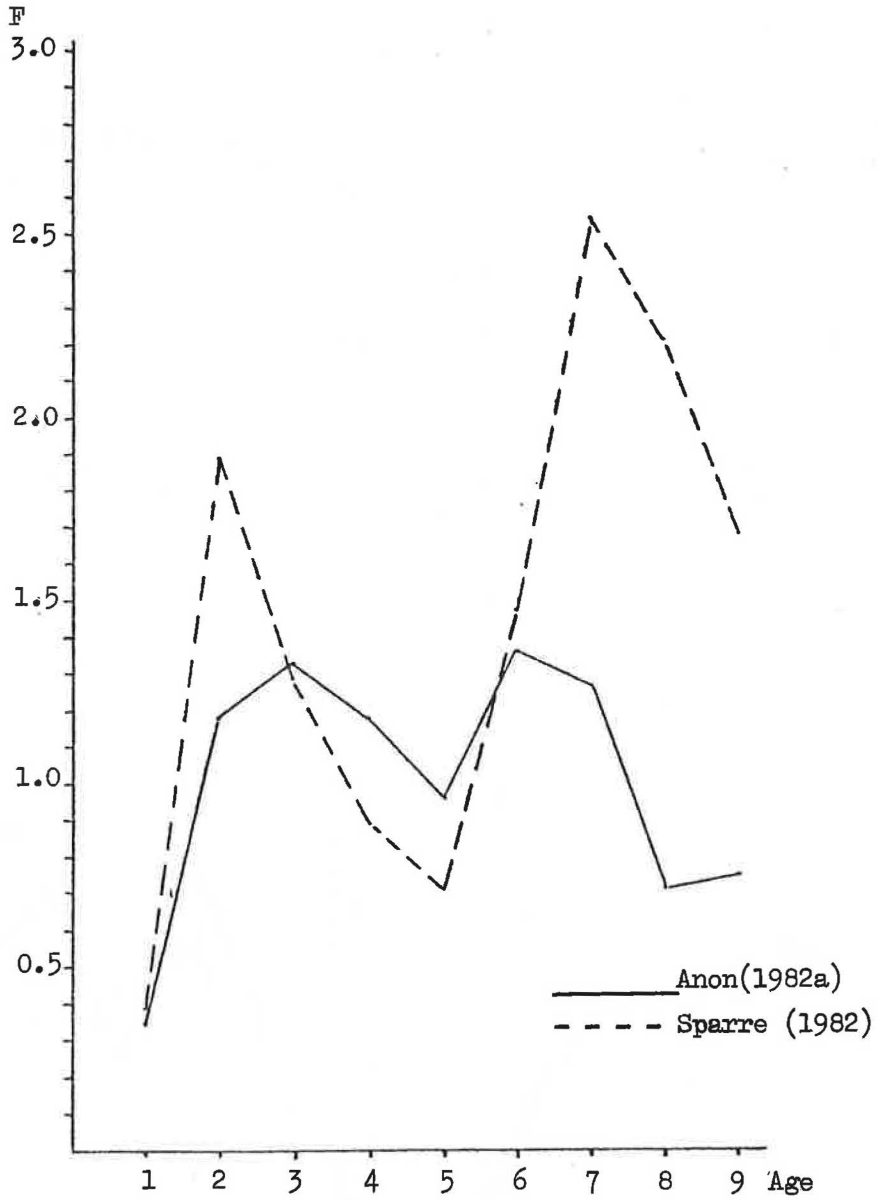
App. D. Figure 1 North Sea COD. F_{76} Rho Method.
Comparison of estimates F at age.



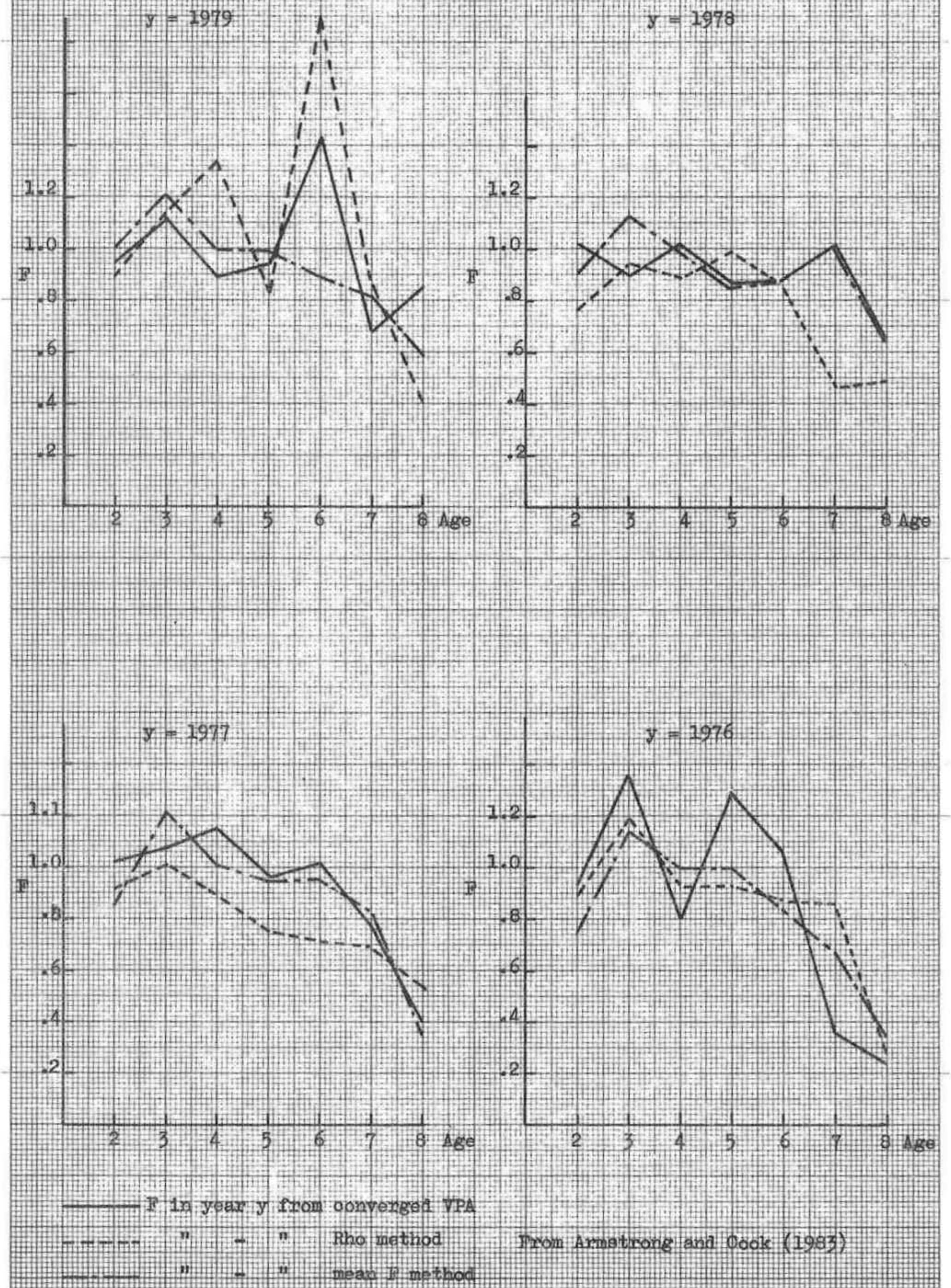
App. D. Figure 2 North Sea HADDOCK. F_{76} Rho Method. Comparison of estimates of F at age.



App. D. Figure 3 North Sea WHITING. Rho Method
Comparison of estimates of F at age

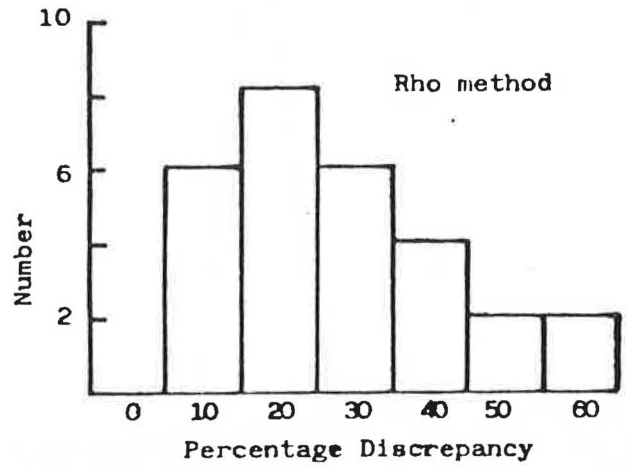


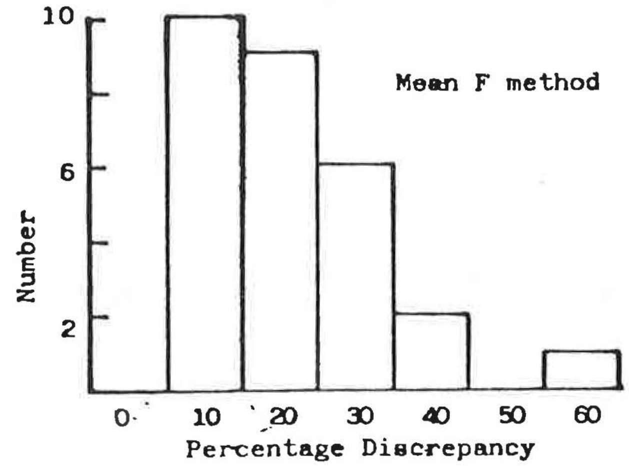
App. D. Figure 4 North Sea HADDOCK. Comparison of estimates of F at age



From Armstrong and Cook (1983)

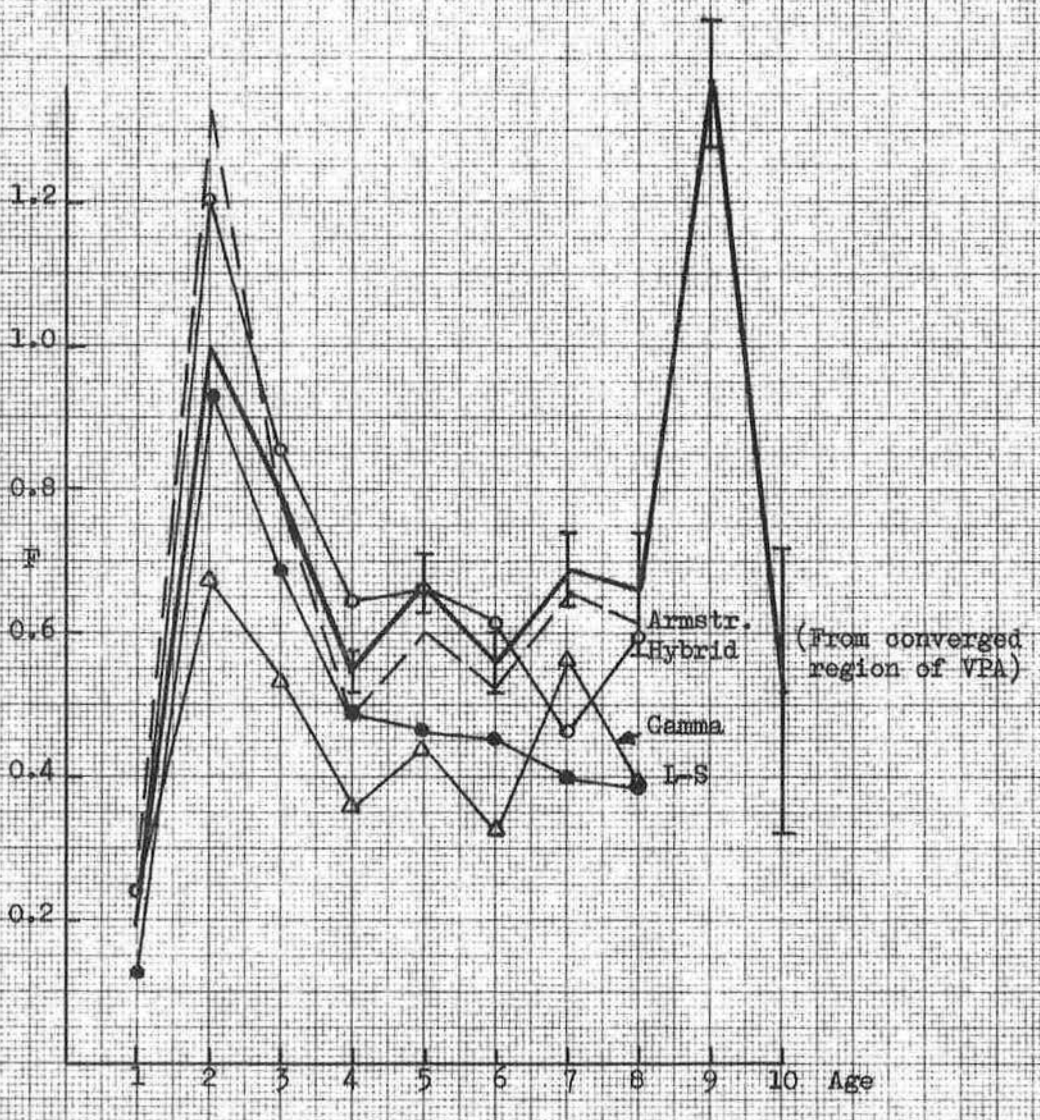
App. D. Figure 5 North Sea haddock
Comparison of Estimation Method for F-at-age



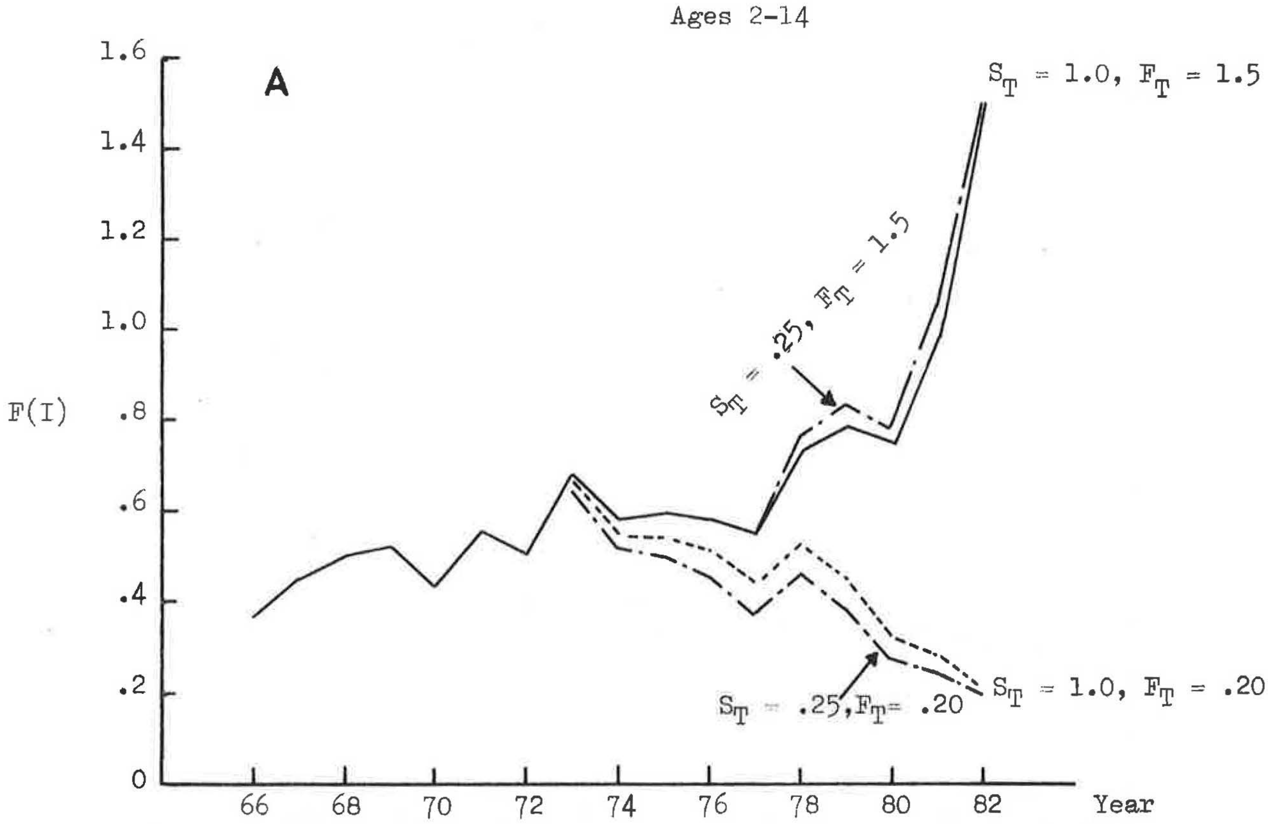


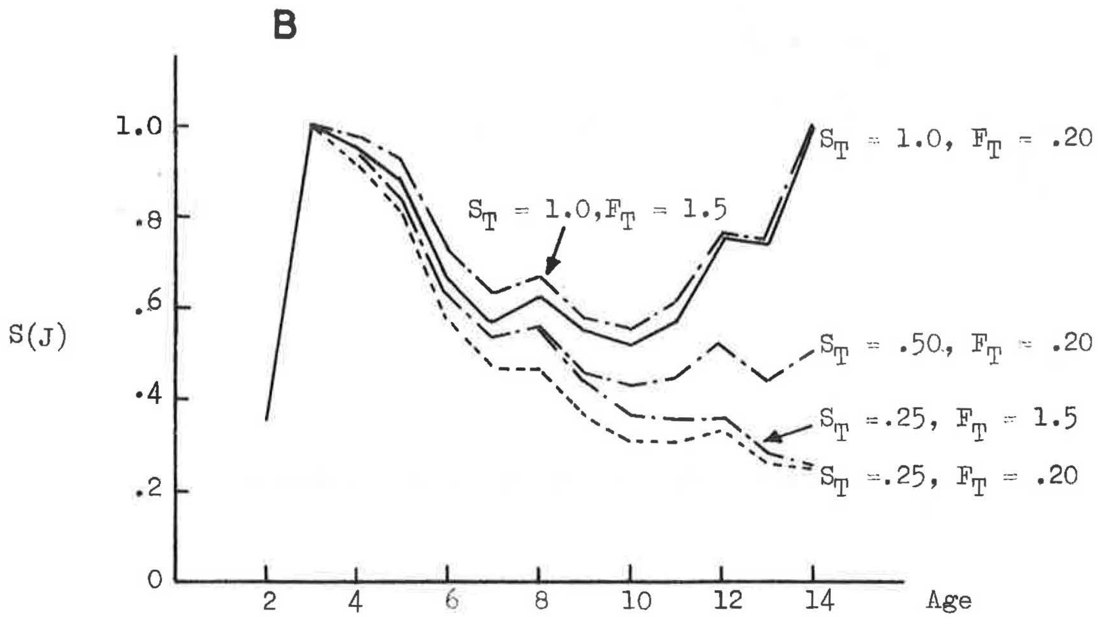
App. D. Figure 6 North Sea COD. Various methods for estimating F at age

(1977)



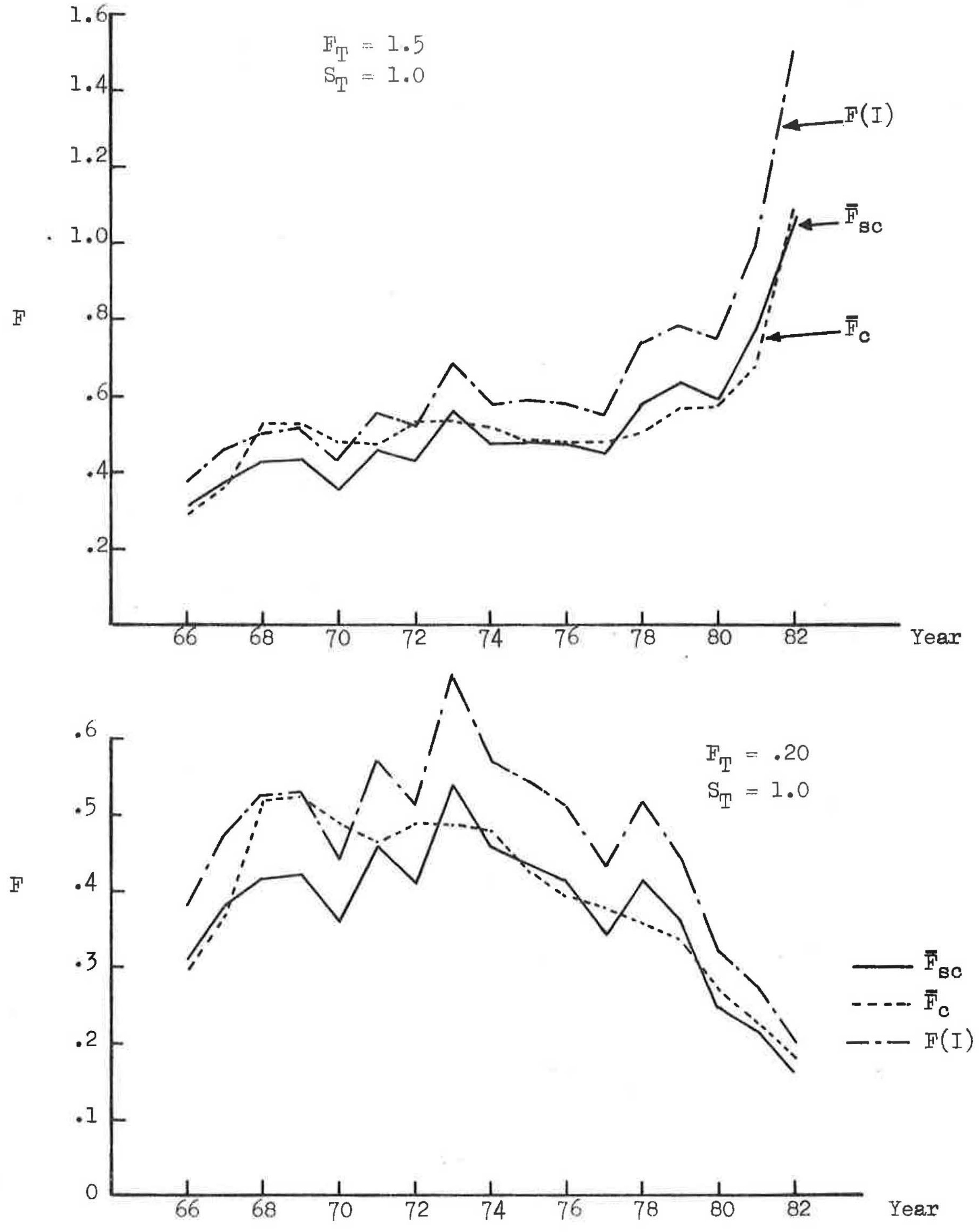
App. E.1. Figure 1 North Sea SOLE. Convergence of F(I) and S(J) given different starting values and influence of S(J) on F(I) and vice-versa.



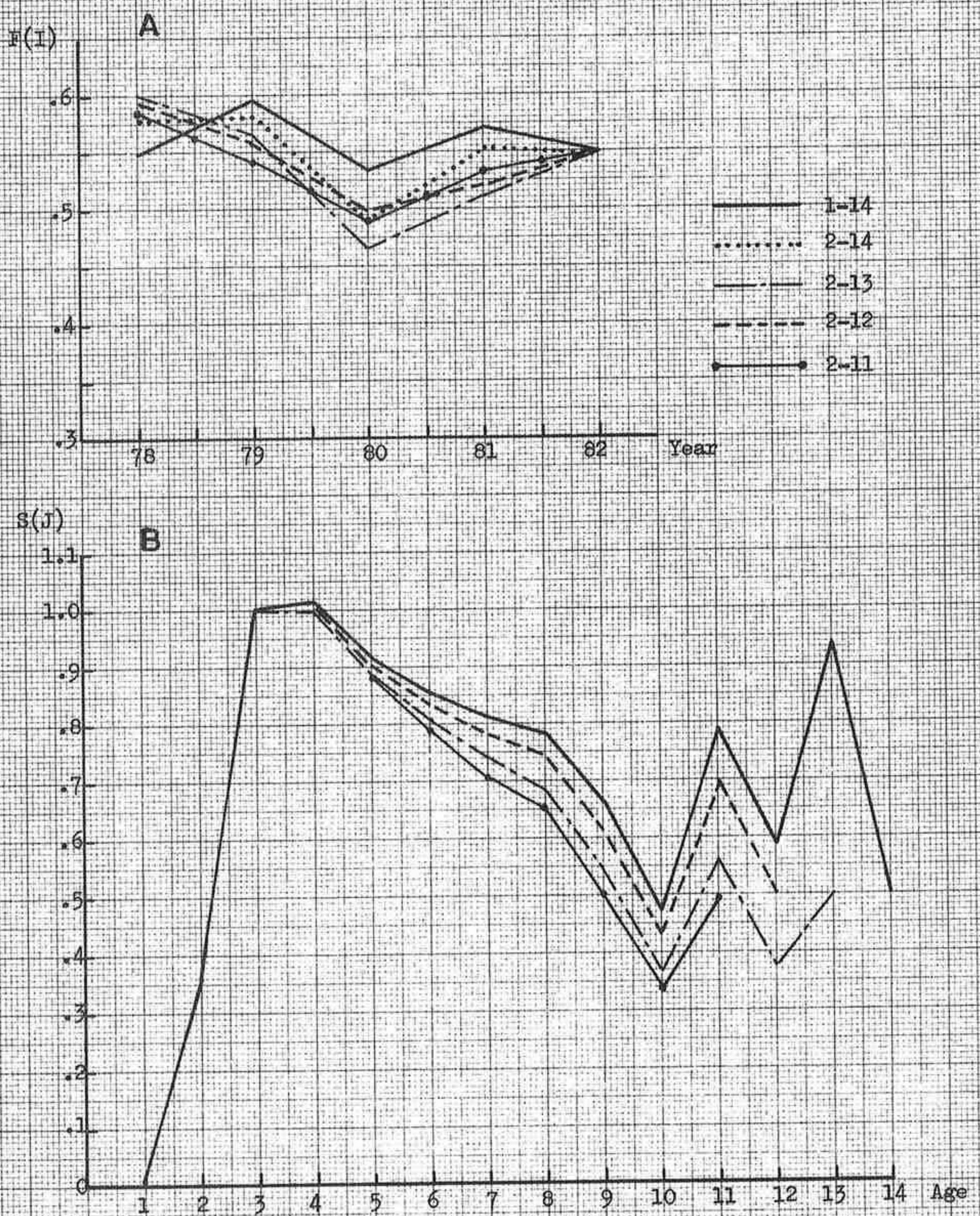


<u>App. E.1. Figure 2</u> NORTH SEA SOLE. Comparison of F(I) with average fishing mortality from separable analysis ($\bar{F}_{sc}$) and average fishing mortality from extended analysis ($\bar{F}_c$).

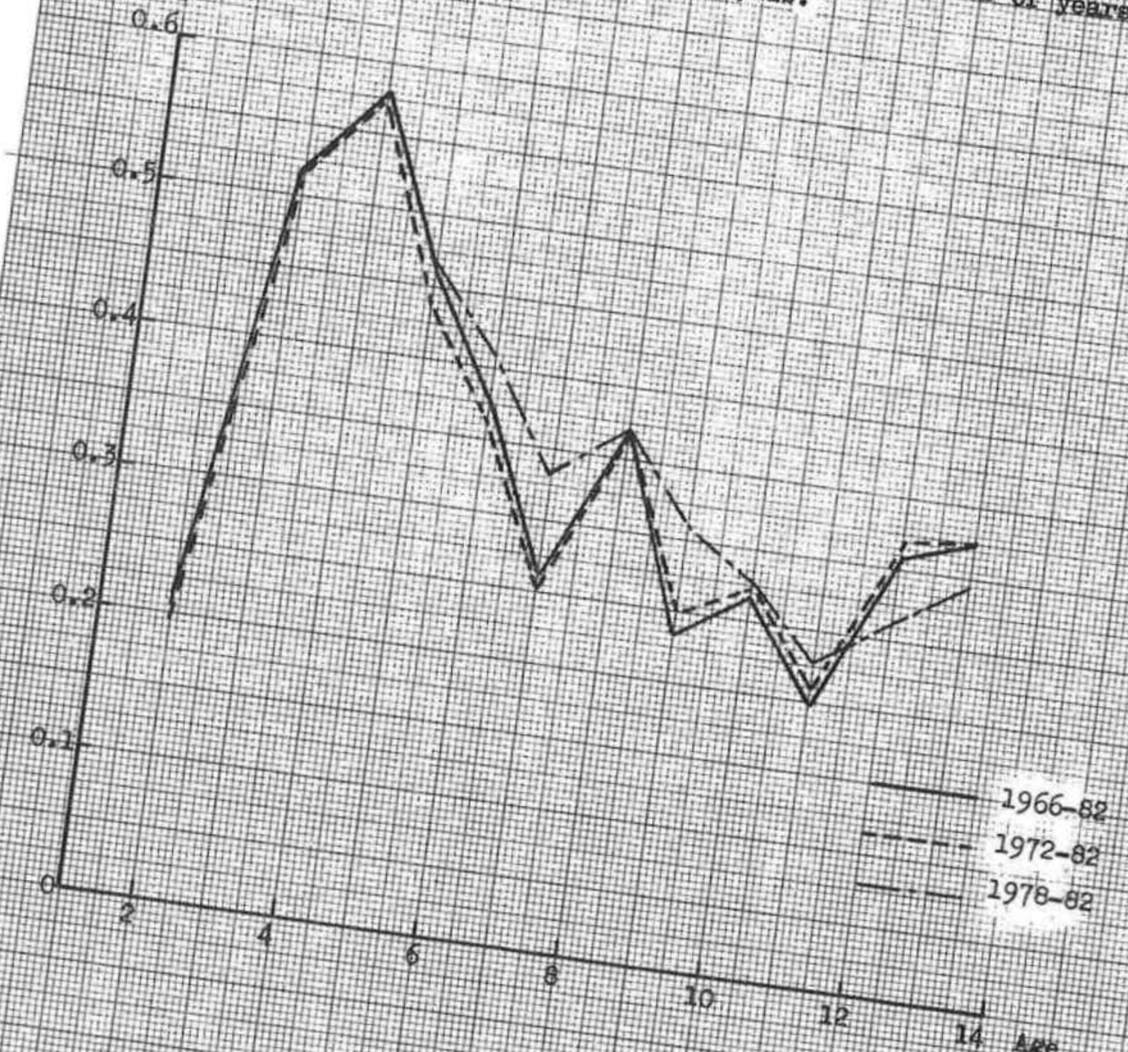
Ages 2-14



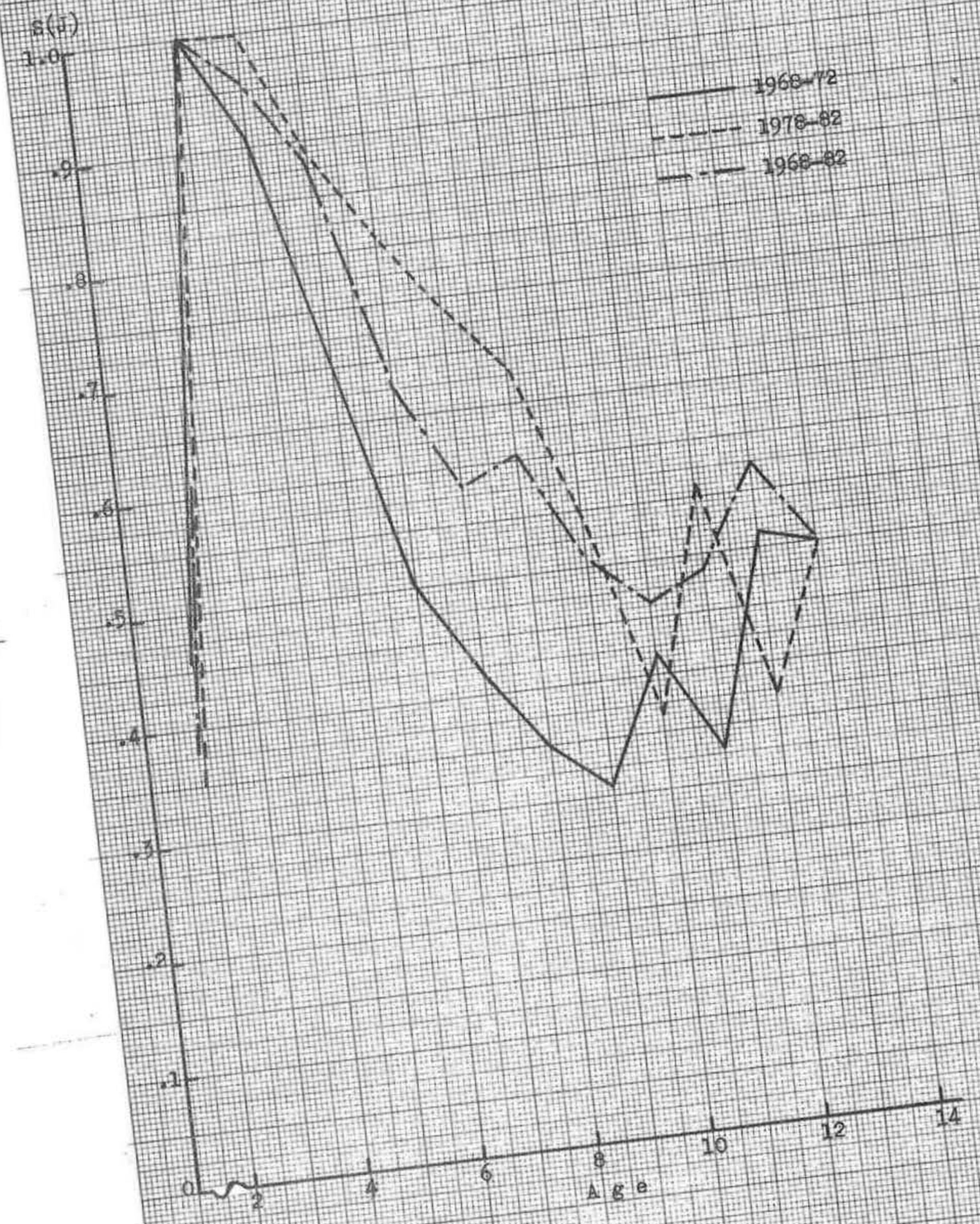
App. E.1. Figure 3 North Sea SOLE. Effect of age span on F(I) and S(J).



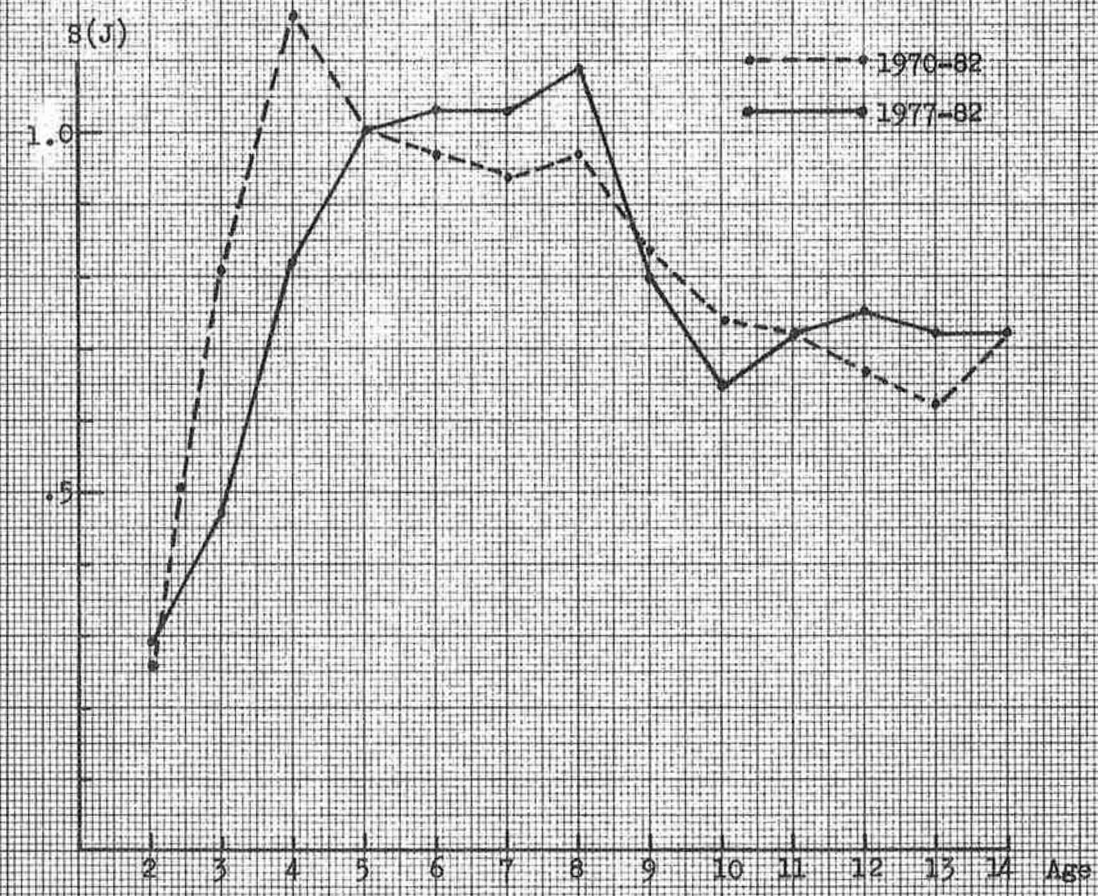
App. E.1. Figure 4 North Sea SOLE. 1982 fishing mortalities at age (age span 2-13) from extended analysis (terminal populations used) for different number of years included in the analysis.



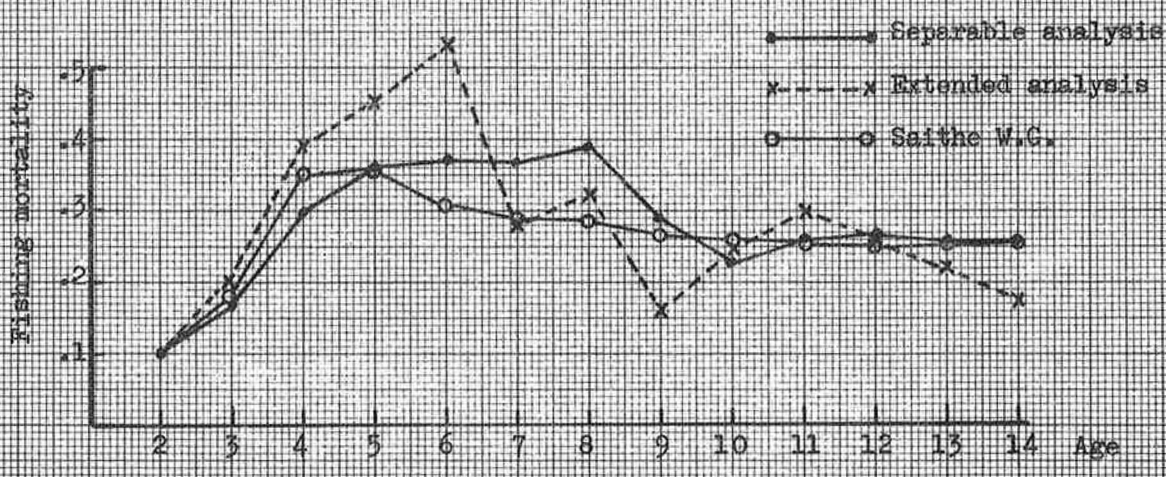
App. E.1. Figure 5 North Sea SOLE exploitation pattern using different periods of years.



App. E.2. Figure 1 North Sea SAITHE. Exploitation patterns from separable VPA for the periods 1970-82 and 1977-82.



App. E.2. Figure 2 North Sea SAITHE. Fishing mortalities in 1982 from separable VPA for the period 1977-82 and from the 1983 Saithe Working Group.



Indication of spine colours

Reports of the Advisory Committee on Fishery Management	Red
Reports of the Advisory Committee on Marine Pollution	Yellow
Fish Assessment Reports	Grey
Pollution Studies	Green
Others	Black

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