This Report not to be quoted without prior reference to the Council[x)]

International Council for the
Exploration of the Sea

C.M.1983/Assess:17

REPORT OF THE WORKING GROUP ON METHODS OF FISH STOCK ASSESSMENT

ICES Headquarters 20 - 26 May 1983

This document is a report of a Working Group of the International Council for the Exploration of the Sea and does not necessarily represent the views of the Council. Therefore, it should not be quoted without consultation with the General Secretary.

[x)] General Secretary,
ICES,
Palægade 2-4,
DK-1261 Copenhagen K
Denmark.

TABLE OF CONTENTS

Page

Table of Contents (ctd)

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
R Borodin	USSR
R M Cook	U.K. (Scotland)
J L Durand	France
G Gudmundsson (part-time)	Iceland
H J L Heessen	Netherlands
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 (Interpreter)
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 greatfully 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.

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 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 automate 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 of F in 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 population) 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 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 <u>not</u> 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 considers input 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 the analyses. A paper has been presented to the Working Group which intends 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 intergrated 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 $\frac{C(y,f,a)}{E(y,f)} = q(f,a)\ \bar{N}(f,a)$, 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 so 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

$$q(f,a) = 1\alpha E_{(y,f)}^{\beta}$$

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 the 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 criteria. 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 informations. 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, used 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.

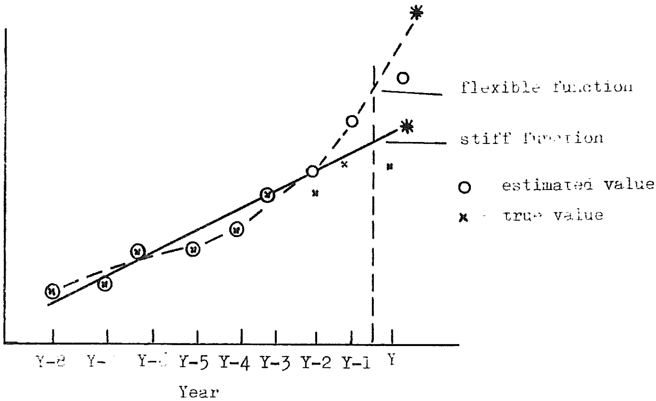
4.4 Problems raised by the Existence of Trends in Catchability with Time

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 respectively 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.

On the other hand 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 more close 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 so) 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. Consideration should be given 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, sampling areal 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	1.6
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 three of the four stocks the current F is at or exceeds F_{high}. 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.

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.

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).

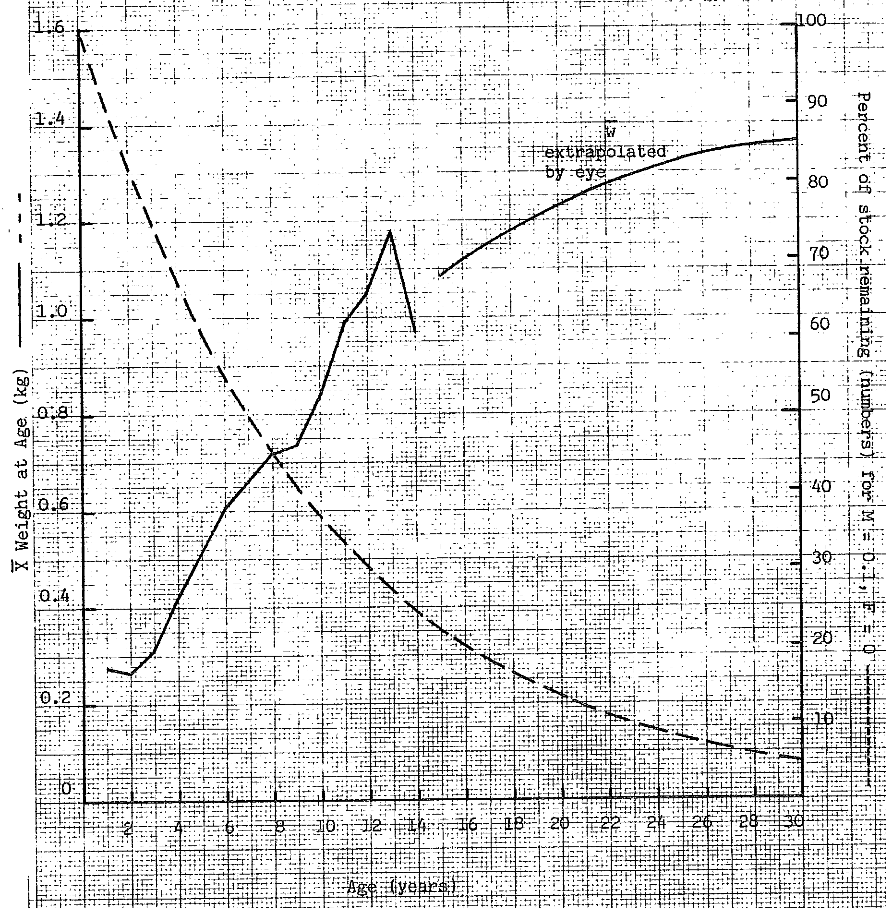


Figure 5.1.2 North Sea PLAICE (M = 0.1)
The effect of truncating the age range on the value of F_{max} and $F_{0.1}$. Relative $S_{(J)}$, exploitation pattern used.

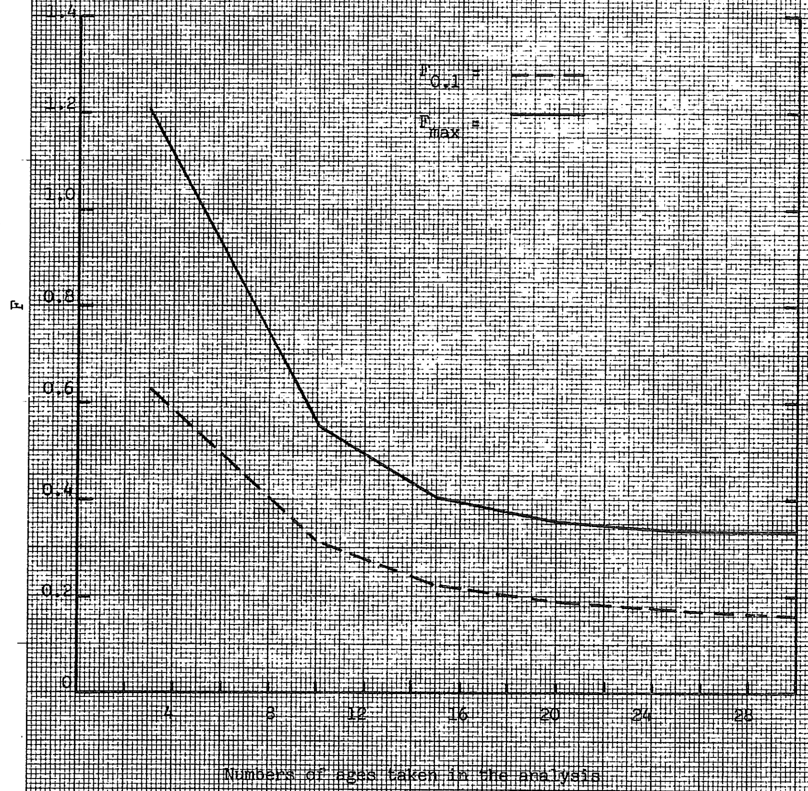


Figure 5.1.3 North Sea PLAICE (M = 0.1).
The effect of truncating the age range on the yield per recruit at different levels of fishing mortality rate.

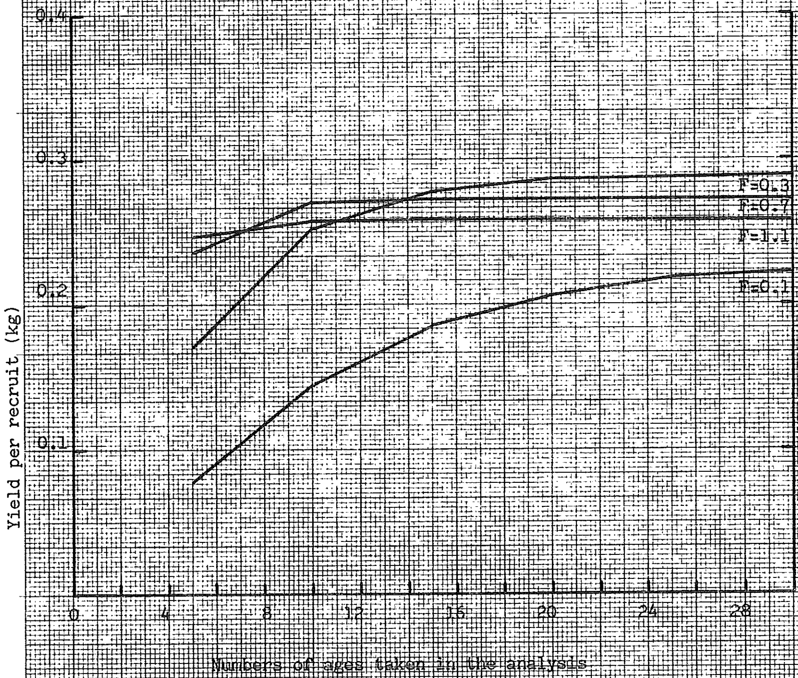


Table 5.2.1 FAROE - SAITHE

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	129	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 tonnes)	105	116	131	149	165	175	191	188	219	247	260	258	275	243	236	218	202	192	(172)	(148)	(150)	(148)	(153)

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

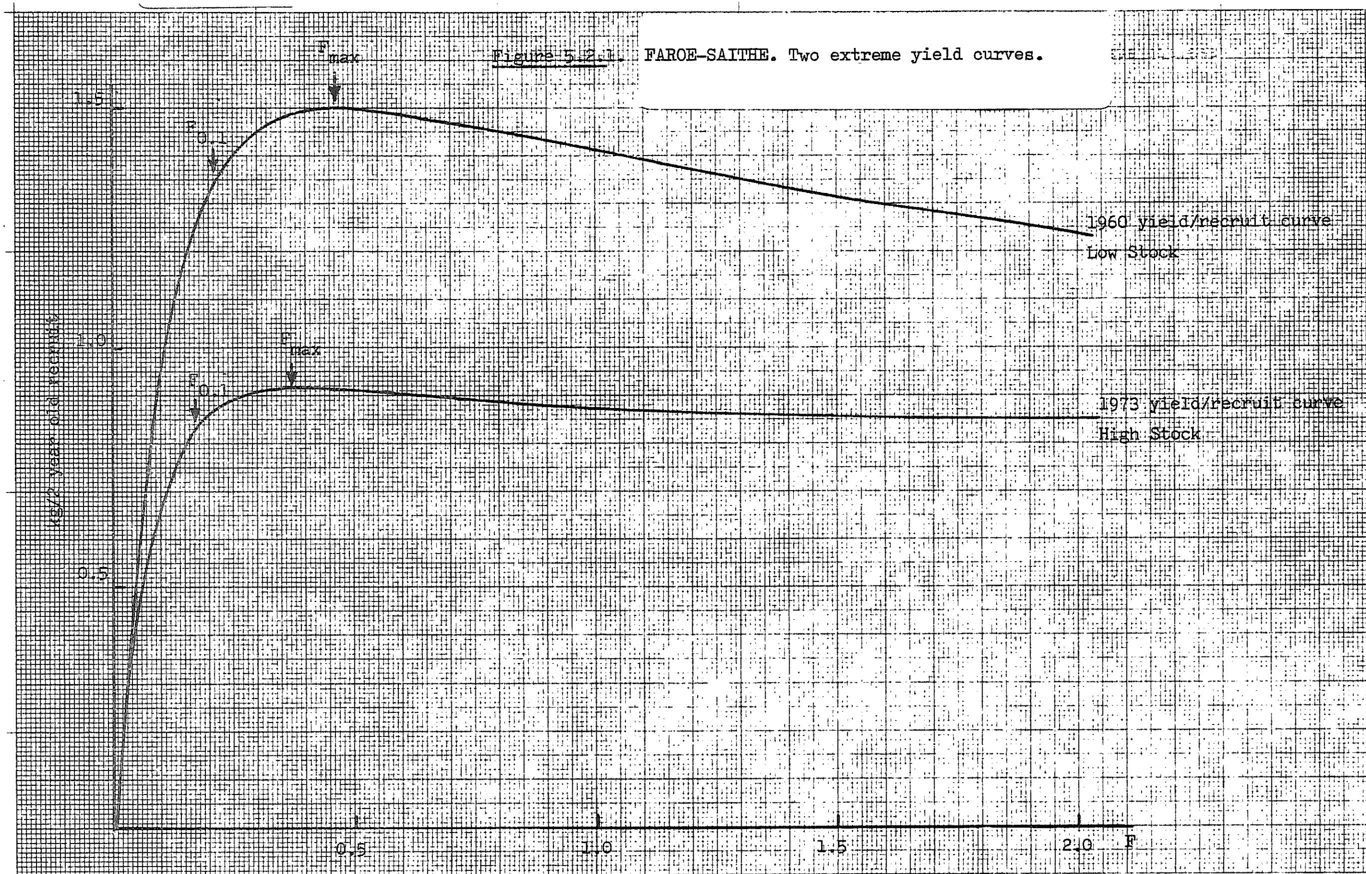


Figure 5.2.2 FAROE SAITHE. Yield per recruit at F_{max} versus biomass 1960-1977 period.

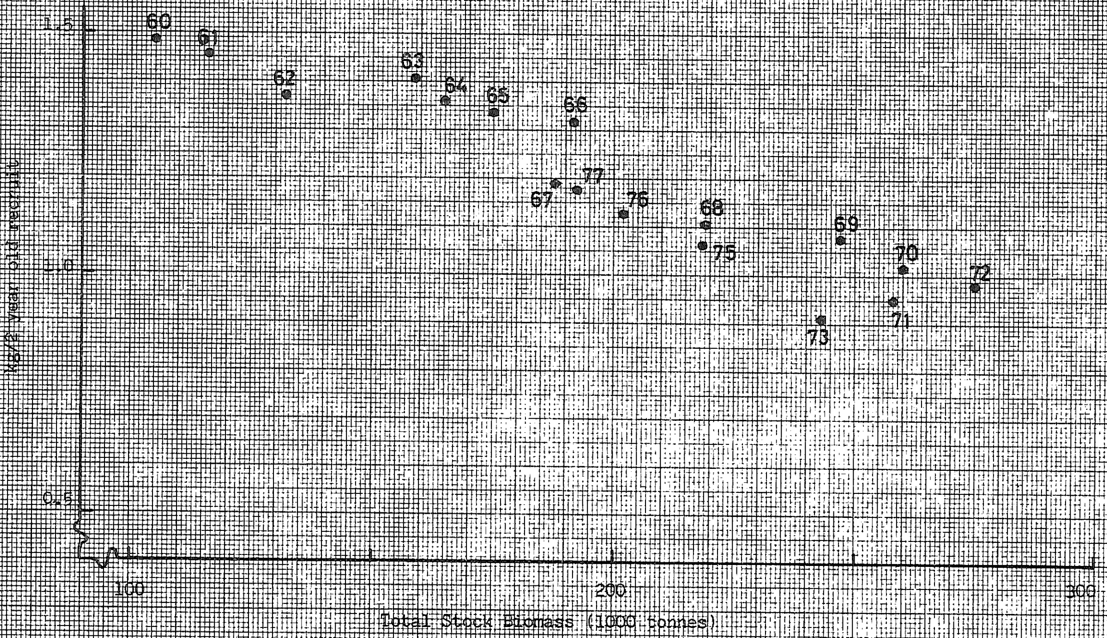
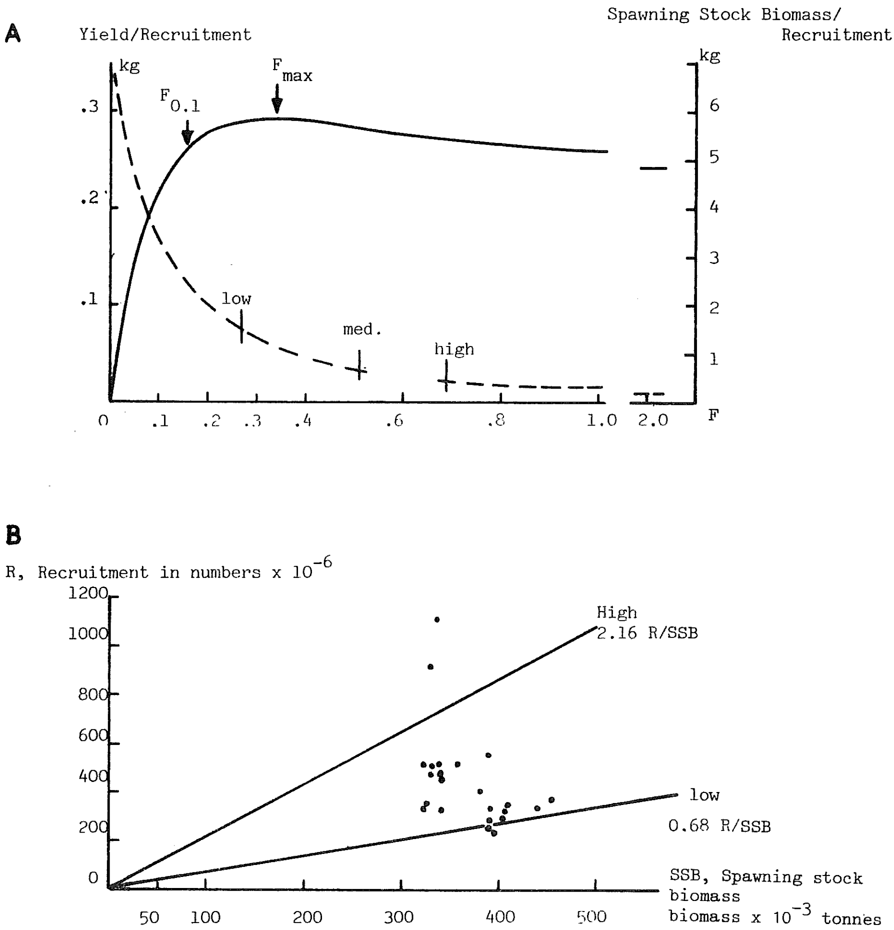


Figure 5.3.1 North Sea PLAICE



(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

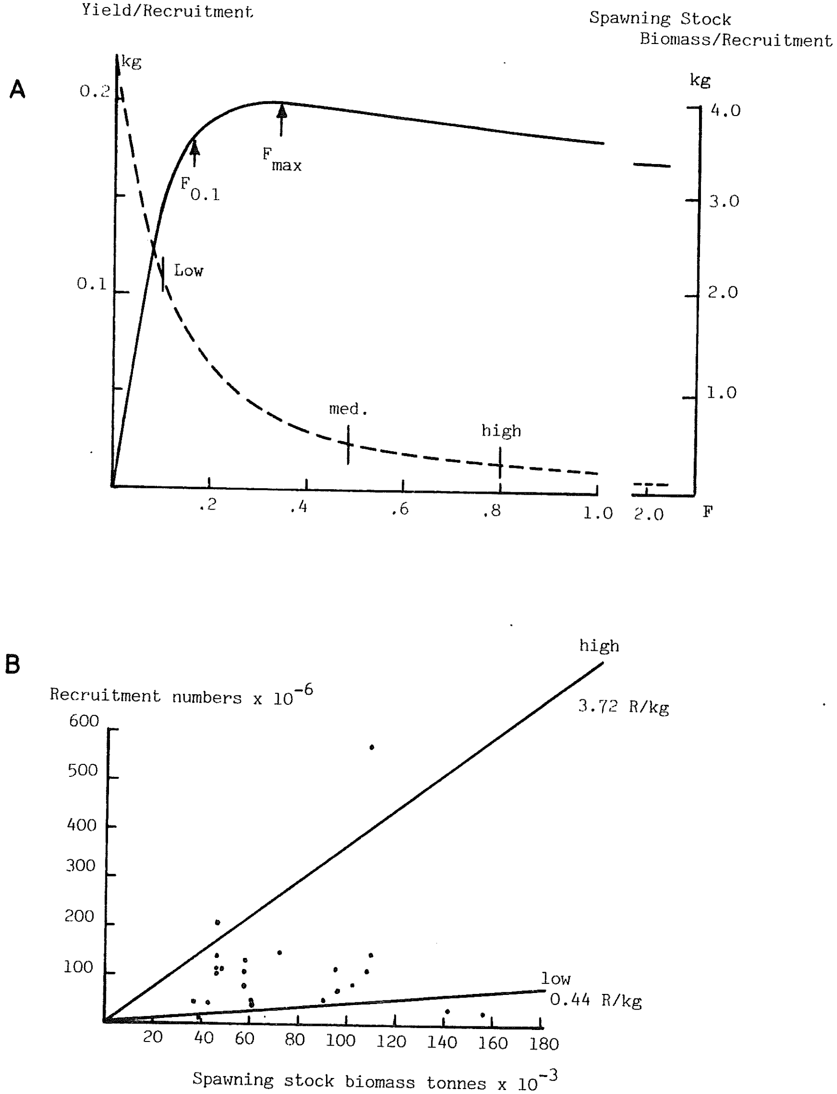


Figure 5.3.3 North Sea COD

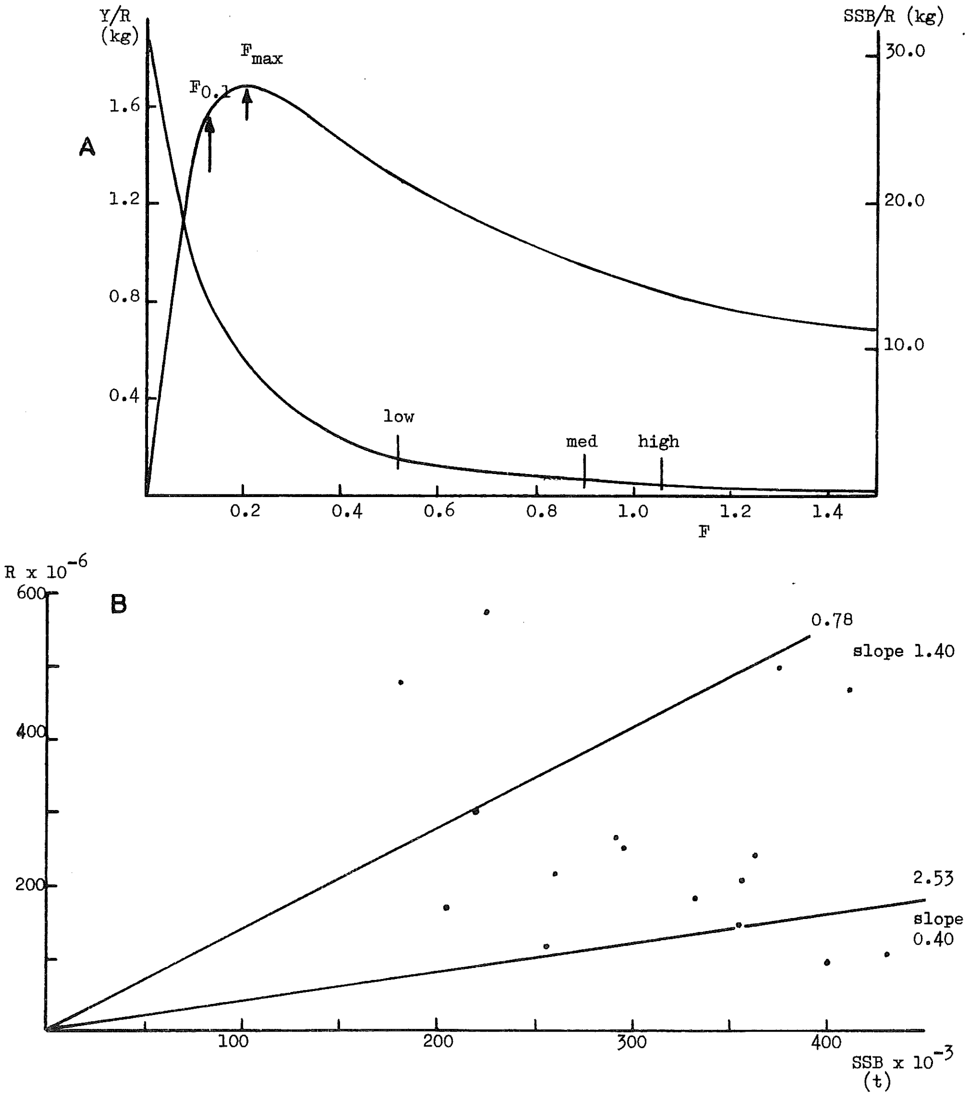
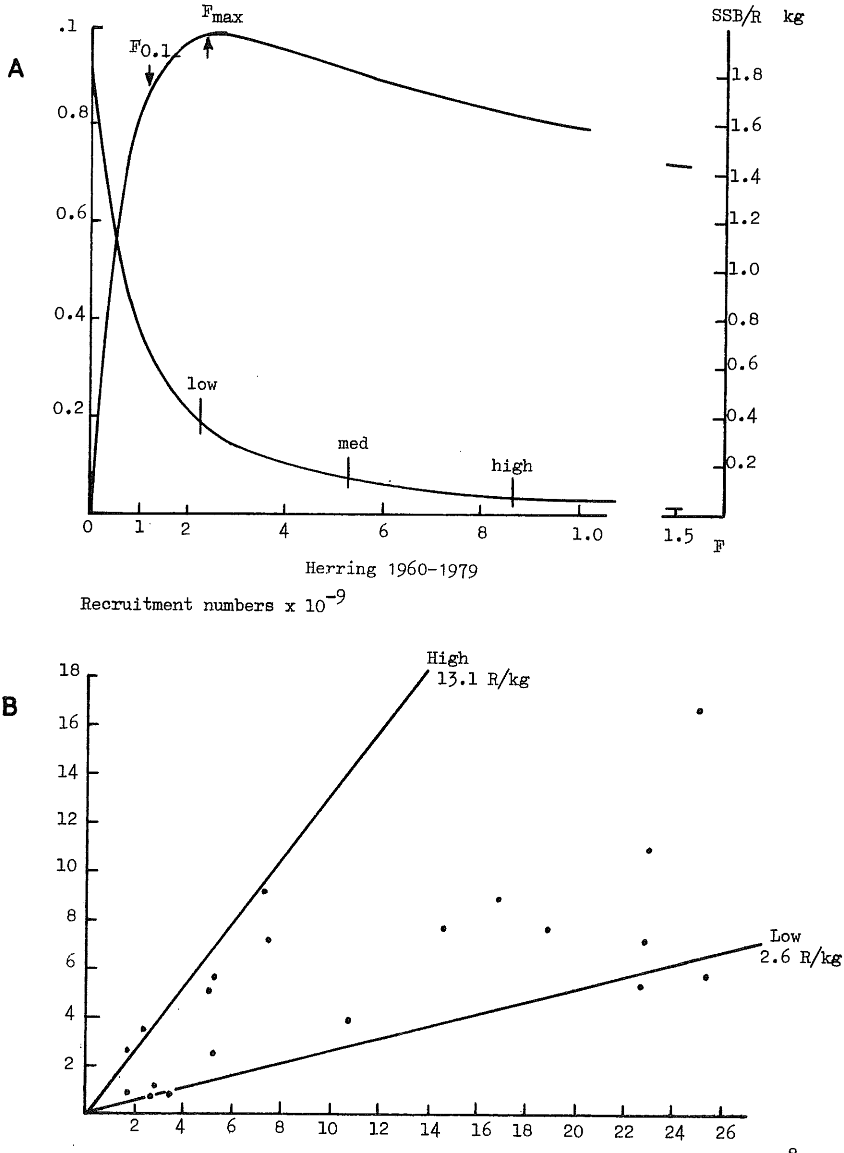


Figure 5.3.4 North Sea Herring



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.

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.

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 (terminal) year
g	"	oldest (greatest) 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 of recruitments	
8)	Methods for estimation of recruitment	
9)	Density-dependence (of growth, natural mortality, maturity, fecundity, recruitment, etc.)	
10)	Linear regression in assessments	

---

*) at meeting of ad hoc Working Group on the Use of Effort data in Assessments, Doc. C.M.1981/G:5

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 for this particular stock (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.

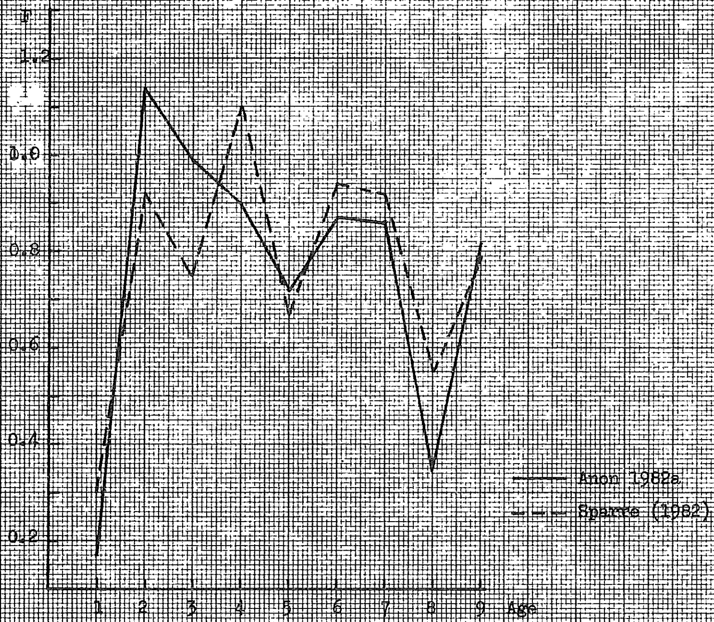
The values of fishing mortality at age obtained by various methods, and the "true" values, are plotted in Figure D.6. Also plotted are the ranges of uncertainty (one S.D.) due to using different tuning methods to determine the "true" values: these are large for the oldest ages, as expected.

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.

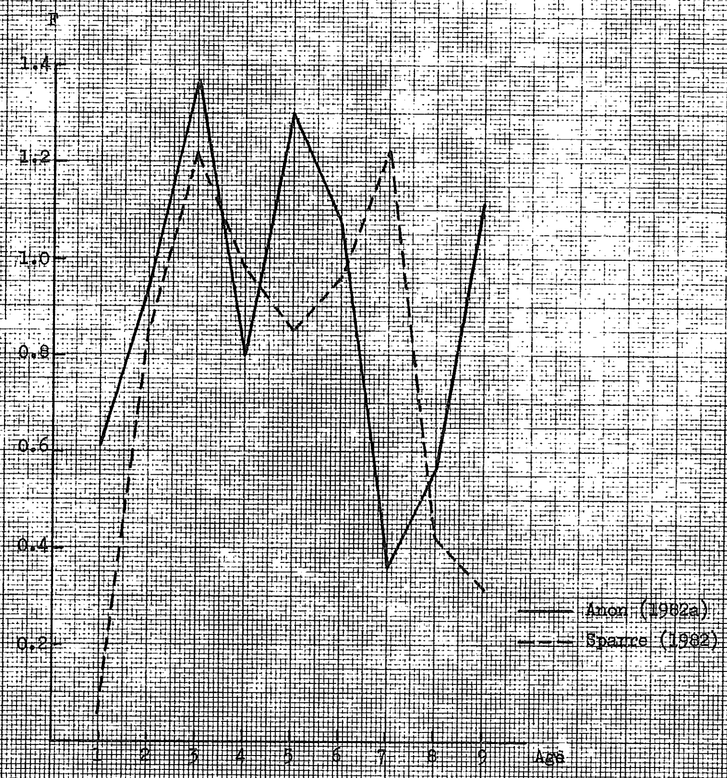
The results of two variable catchability methods are illustrated. The hybrid method arrives at the correct overall level of F, and reproduces some of the details, except for an overestimate of F on age 2. The Armstrong method achieves a very close correspondence for all ages except age 2, even reproducing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

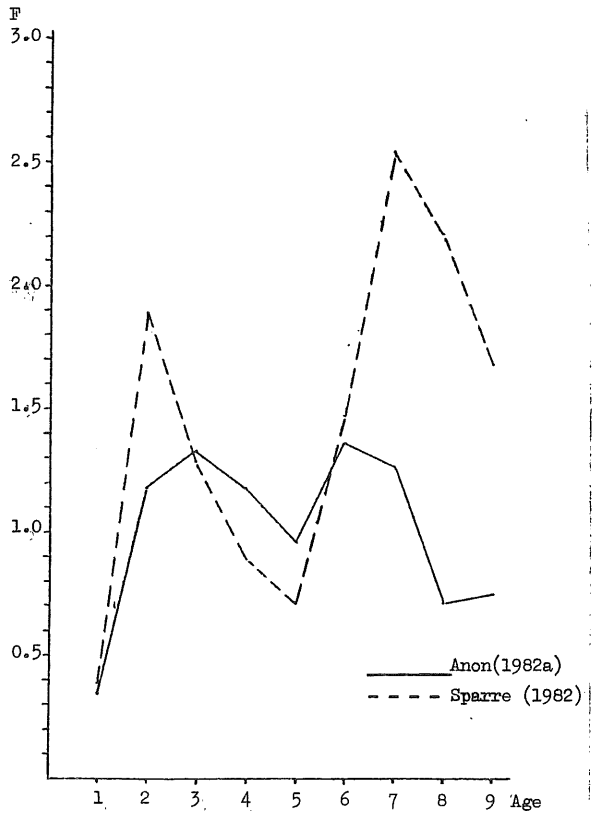
App. D. Figure 1 North Sea COD. F_{76} Rho Method.
Comparison of estimates F at age.



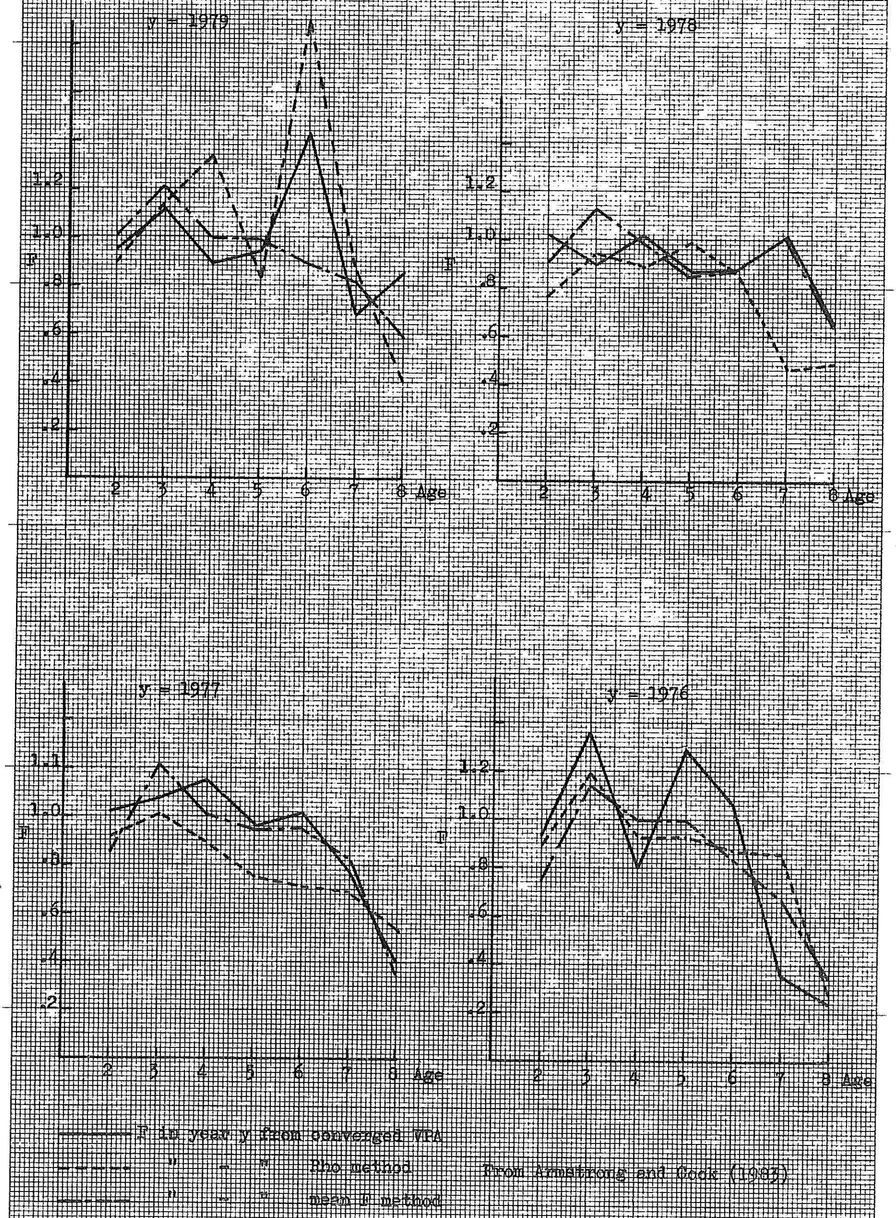
App. D. Figure 2 North Sea HADDOCK. F_{76} Rho Method.
Comparison of estimates of F at age.



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

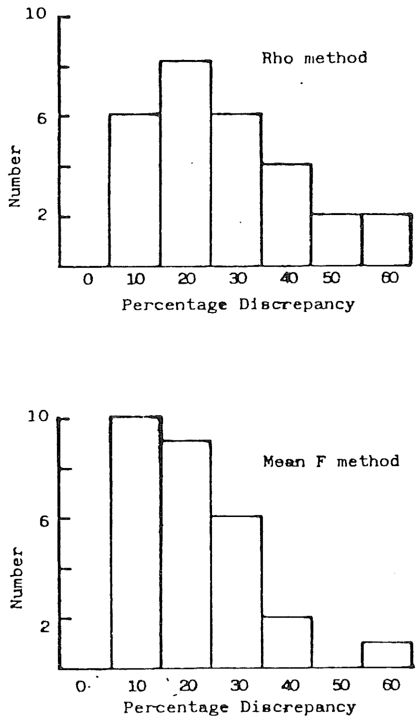


App. D. Figure 4 North Sea HADDOCK. Comparison of estimates of F at age

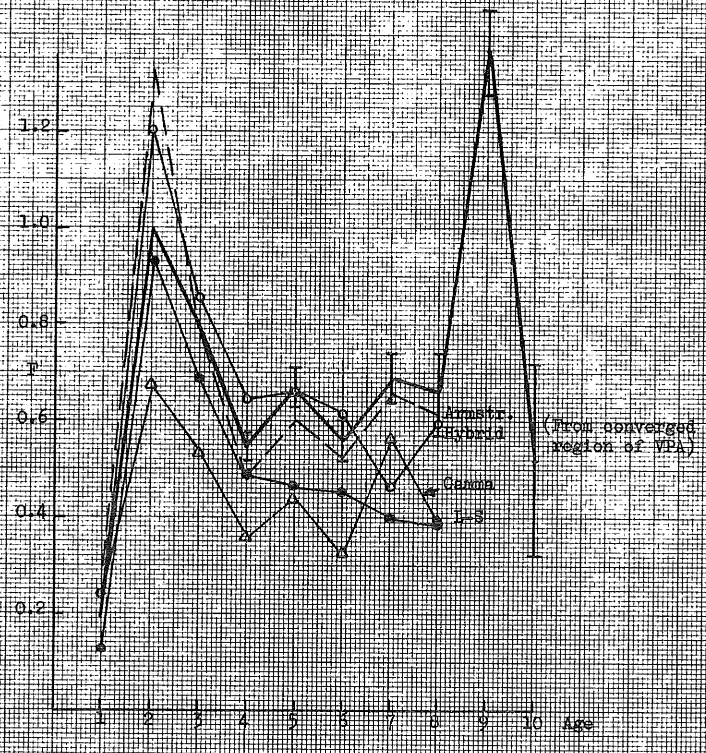


From Armstrong and Cook (1983)

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)



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 F_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.48). 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 does 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.49) 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

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

LOG CATCH RATIO RESIDUALS

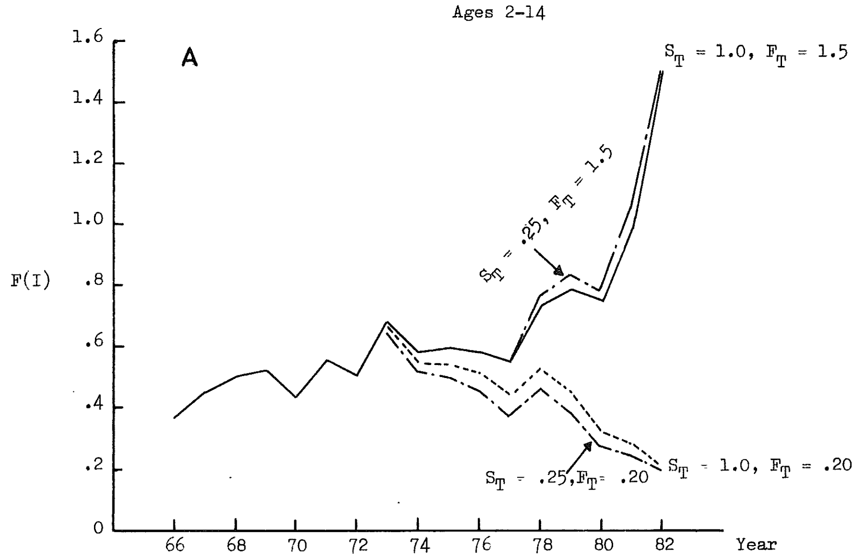
	68/69	69/70	70/71	71/72	72/73	73/74	74/75	75/76	76/77	77/78	78/79	79/80	80/81	81/82	
2/ 3	0.264	0.403	0.000	0.233	0.380	-0.273	-0.283	0.161	-0.819	0.453	-0.107	-0.109	-0.395	0.113	0.020
3/ 4	0.218	0.052	0.279	-0.225	0.499	-0.261	-0.275	-0.127	-0.163	0.252	-0.210	-0.033	0.045	-0.033	0.016
4/ 5	-0.061	0.172	0.206	-0.025	0.177	-0.260	0.002	-0.037	-0.226	0.324	-0.179	-0.176	0.124	-0.029	0.011
5/ 6	-0.053	0.426	-0.133	0.100	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	0.166	-0.138	0.505	0.058	-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	-0.448	-0.148	0.496	-0.196	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

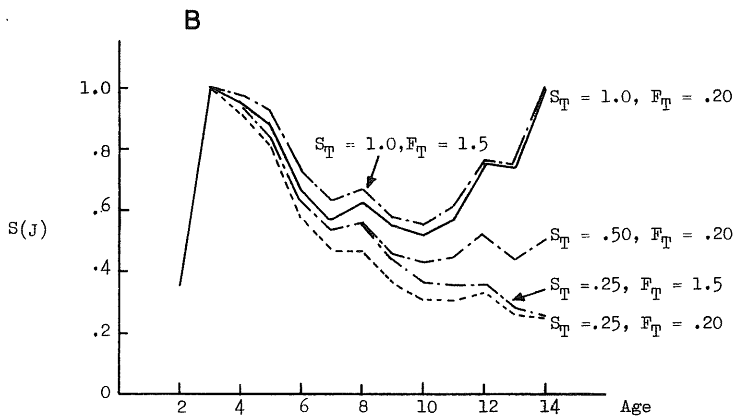
<u>Appendix E.1. Table 1.b.</u> North Sea sole. Table of residuals from the F table (extended based on terminal populations) and the F from SVPA.

TABLE OF F(EXT) - F(SEP)

AGE	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
2	0.089	0.148	-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	0.003	-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	-0.018	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	0.103	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

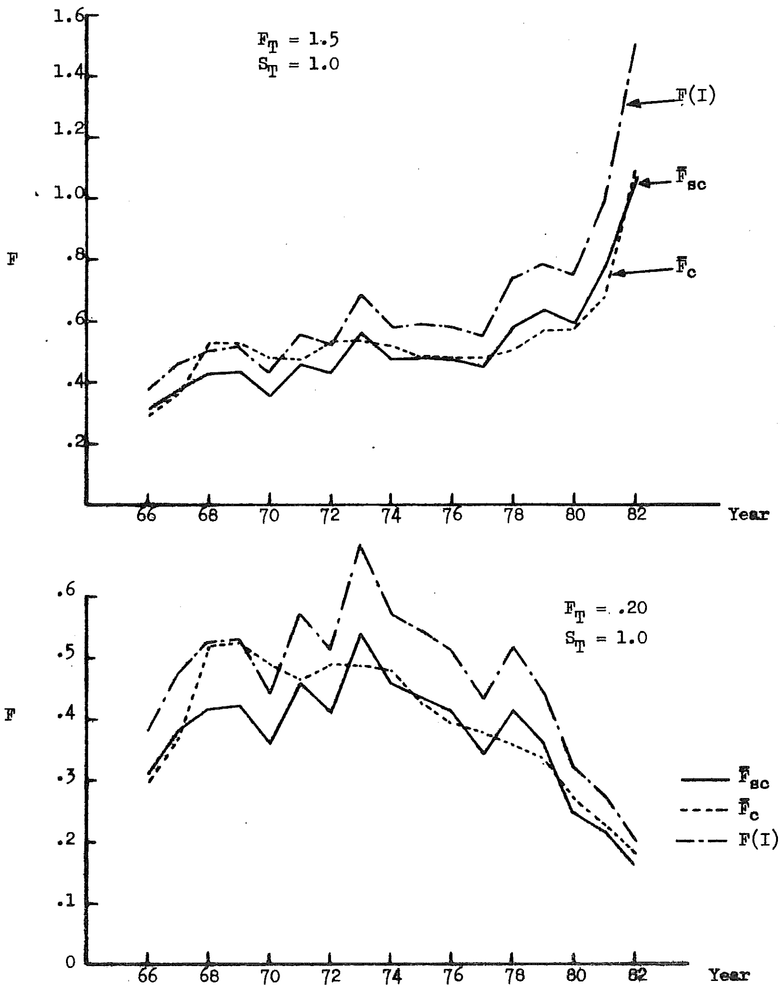
<u>App. E.1. Figure 1</u> North Sea SOLE. Convergence of F(I) and S(J) given different starting values and influence of S(J) on F(I) and vice-versa.



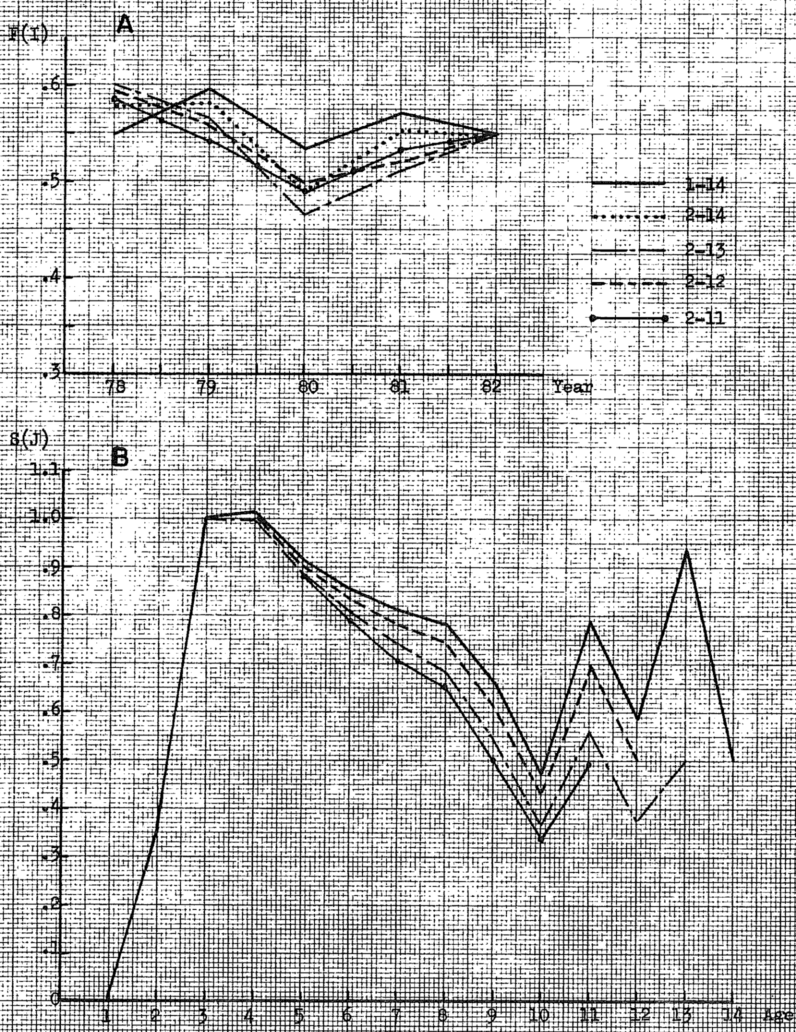


App. E.1. Figure 2 NORTH SEA SOLE. Comparison of F(I) with average fishing mortality from separable analysis ($\bar{F}_{sc}$) and average fishing mortality from extended analysis ($\bar{F}_c$).

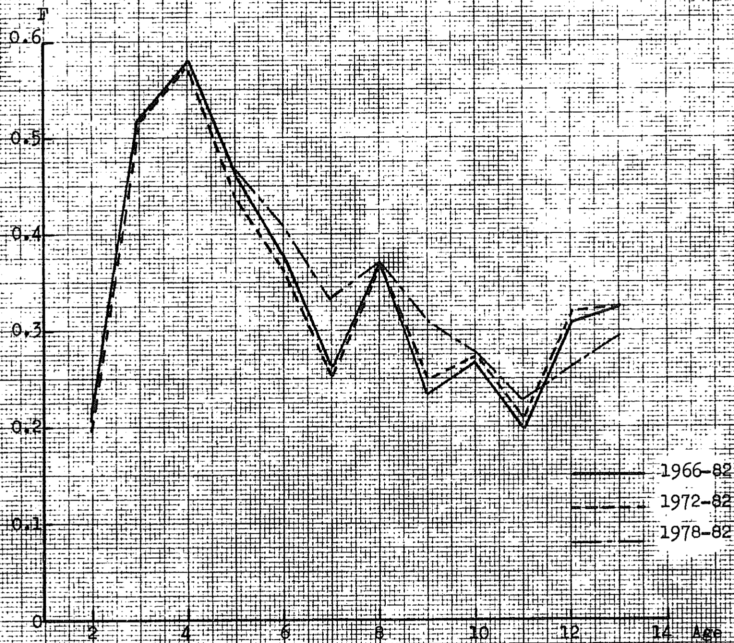
Ages 2-14



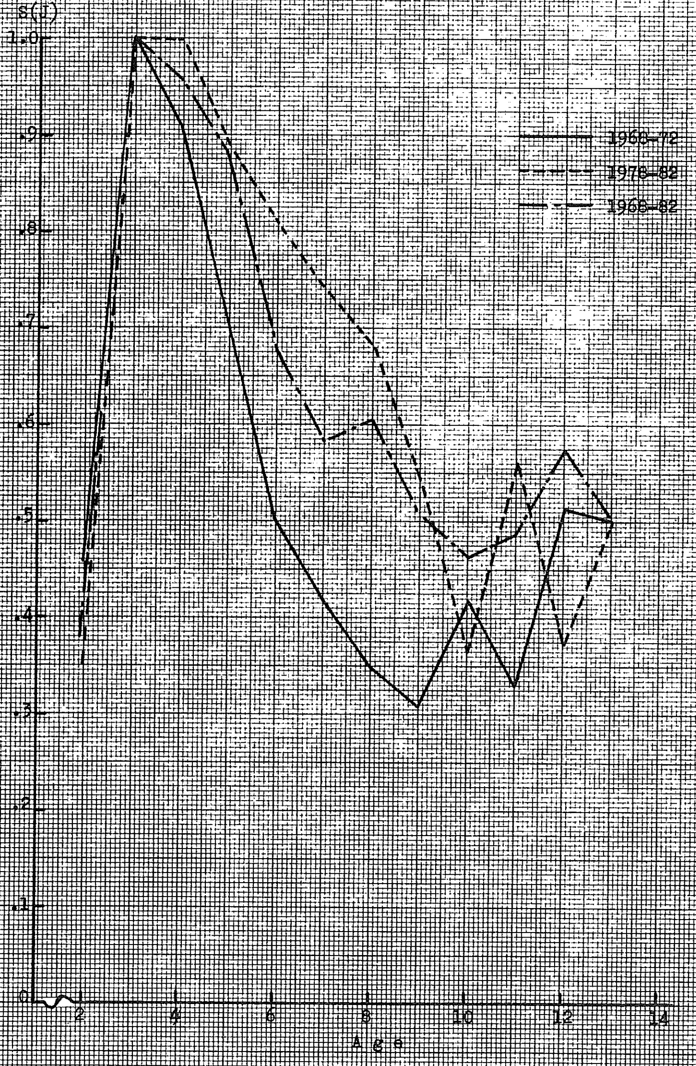
App. E.1. Figure 3 North Sea SOLE. Effect of age span on F(I) and S(J).



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.



E.2 North Sea Saithe

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 highermin 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.

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 %

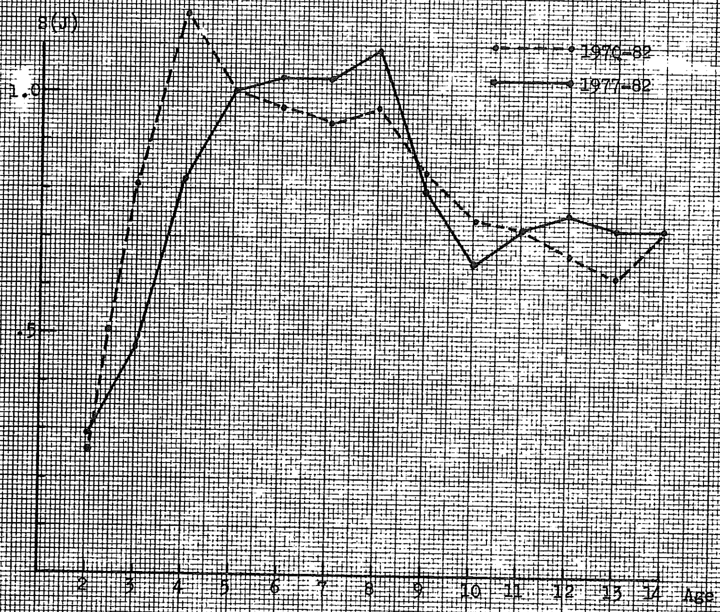
YEAR	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
F(I)	0.2731	0.3056	0.4111	0.4506	0.4606	0.5443	0.5159	0.5989	0.4395	0.3589	0.3742	0.4691	0.3600

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

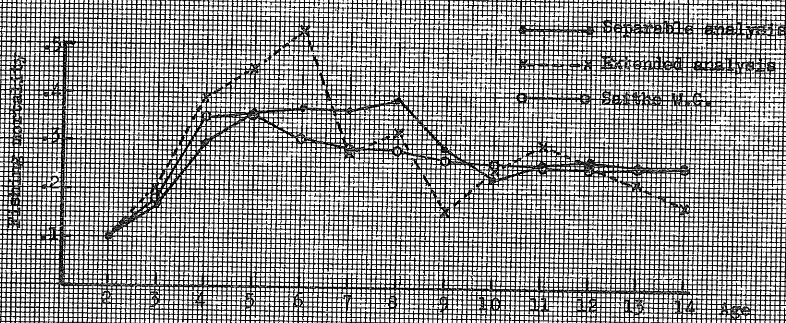
LOG CATCH RATIO RESIDUALS

	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	0.067	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

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.



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 E.3. Table 1. 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

Ages	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	0.02[illegible]	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
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

Ages	Years: 73/74	74/75	75/76	76/77	77/78	78/79
4/ 5	0.063	0.147	0.134	-0.052	-0.329	0.037
5/ 6	0.199	0.061	0.019	-0.024	-0.043	-0.212
6/ 7	0.235	-0.035	0.182	0.109	-0.273	-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	0.036	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 F

CONCEPTUAL FRAMEWORK FOR CATCH AND EFFORT ANALYSES

The proliferation of VPA tuning techniques in the 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 by a simple function of age, but is described by a parameter et 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.) eventually 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 (v) 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 areas, then years, at last 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 ignorance to unrestricted description or 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
- v	cpue
- 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 individually catchability for each fleet, but an average catchability over fleet.

(5) Taking logarithms prior to any combination eliminates any difference between v 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 Table F. 1 Description of different models using effort data for tuning VPAs

Technique \ Effect	Catchability Model Building: a	y	E	B	a x y	a x E	Fitting Technique: Basic Principle	Combination	F/E U/B	Log.
Nielsen 1982 G:49	R_2	0	R_1	0	0	0	D.F. M.L.			
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 flexibility)	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			

APPENDIX G

COPY OF CONCLUSIONS AND RECOMMENDATIONS OF *ad hoc* WORKING GROUP ON THE USE OF EFFORT DATA IN ASSESSMENTS

"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 <u>examples</u> 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."