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REPORT OF THE WORKSHOP ON METHODS OF FISH STOCK ASSESSMENT

Reykjavik, 6-12 July 1988

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THE METHODS
GEYSIR

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1.2 Terms of Reference

At the 75th Statutory Meeting of ICES (1987), it was decided (C. Res.1987/2:11) that:

"As part of the preparatory process for the next meeting of the Working Group on Methods of Fish Stock Assessments, a Workshop will be held in Reykjavik from 6-12 July 1988 (Chairman: Mr A. Laurec) for the purpose of testing software methods which perform statistical integrated analysis of catch-at-age data and auxiliary information, and constructing and implementing appropriate test data sets. Results of these methods will be contrasted with output from equivalent ad hoc VPA tuning methods. Local arrangements for the Workshop will be co-ordinated by Dr G. Stefansson."

Following this resolution, Mr Laurec found that, because of other commitments, he could not act as Chairman and it was decided at the November 1987 meeting of ACFM to offer the Chairmanship to Mr D.W. Armstrong.

2 INTRODUCTION

2.1 Interpretation of "Stock Assessment"

For the purposes of this report, the meaning of "fish stock assessment" is restricted to any procedure by which the historical and current state of a fish stock is estimated. This definition includes no reference to prediction of possible future states of the stock and no attention was given to prediction in the course of this meeting.

It should also be noted that, in real-life assessments, recruitment estimates for the most recent data years are often obtained by techniques additional to those used to analyze the catch-at-age and auxiliary data. No attention was given to such methods at this meeting.

2.2 Requirement for Testing Methods of Assessment

Particularly during the past 4-5 years, considerable development of new methods for fish stock assessment has occurred. In many instances, the new methods have not been extensively tested and the first application of many of them has often taken place during stock assessment working group meetings when the results are of material importance to non-scientists. In some instances, use of different methods to assess the same stock has produced considerably different results leading to confusion.

Furthermore, development of new techniques has taken rather different routes in Europe and North America. In North America, the focus has been on fitting formal mathematical models by standard statistcal techniques (minimization of an objective function). In Europe, much more attention has been given to developing socalled ad hoc "tuning" methods in which non-standard techniques are used to find a solution for the last data year which is con- sistent with historical parameter estimates.

Given this background, it was felt essential that the various methods should be tested at least to identify those which produce unacceptably poor results. Ultimately, the aim of the testing procedure should be to identify an overall best method or a best method contingent on the nature of the stock being assessed.

2.3 Methods Tested

The 18 methods listed below were tested.

Number	Name of Method	Acronym
1	Hybrid	HYBRID
2	Laurec-Shepherd	LS
3	Armstrong-Cook 1	AC1
4	Armstrong-Cook 2	AC2
5	Armstrong-Cook 3	AC3
6	Armstrong-Cook 4	AC4
7	Alternative Estimation of Fishing Mortalities	AEFM
8	Corrected Catch Per Unit Effort	CCPUE
9	Survivors	SURVIV
10	Extended Survivor Analysis	XSA
11	Catch at Age Analysis	CAGEAN
12	Adaptive Approach	ADAPT
13	General Linear Model	GLM
14	Collie-Sissenwine	COLSIS
15	Time Series 1	TSER1
16	Time Series 2	TSER2
17	Separable VPA	SVPA
18	Conventional VPA	CONVEN

A description of each of these methods together with details of the way in which they were applied, an account of the ease (or otherwise) of application, and references to further descriptions in the scientific literature are given in Annex 2.

Methods 1-8 in the list above are ad hoc tuning methods. Methods 11-14 are the integrated methods. Methods 9 and 10 incorporate some features of both the ad hoc and the integrated approach. Methods 17 and 18, unlike the others, cannot make use of auxiliary data (CPUE) and were tested to indicate the improvement which may be obtainable by the appropriate use of such data.

The methods are listed in the order in which they appear in the tabulations included in this report. The acronyms listed above are used to indicate the methods in these tables.

The assumptions inherent in each of the methods are summarized in Table 2.1. It should be noted that the assumptions listed are those incorporated to produce the results presented in this report. Within many of the methods, these assumptions can be modified. The various tuning methods can be regarded as the same method run under different assumptions. Similarly, the difference between the two Time Series methods is that TSER1 analyzes only the total catch-at-age data, whereas TSER2 also analyzes CPUE data from one of the research vessels. The adaptive approach is specifically designed to allow modification of assumptions and incorporation or exclusion of various data sets.

3 PROCEDURE FOR TESTING METHODS

3.1 Simulated Data Sets

The basic approach adopted was to investigate how well each method estimated certain parameters employed in creating simulated data sets. Details of the simulation method and the input parameters for each simulation are provided in Annex 1. By appropriate choice of the values of the input parameters, it is possible to simulate different types of fisheries exploiting different types of stocks, and hence, for each combination of fishery and stock, to produce data of the type commonly analyzed by stock assessment.

The output from the simulation process consisted of estimates of catch at age for each of seven fleets, four of which were commercial fisheries (two trawler fleets, one liner fleet, and one fleet of fixed nets), and the other three were research vessels. Estimated fishing effort was provided for the research vessels, for liners, and for one of the trawler fleets. Catch-at-age data were provided for ages 3-12 for a period of 30 years for all fleets.

Noise was added to the output data sets in the form of process error and measurement error as described in Annex 1. These errors were different for different age groups and fleets.

Mean weight at age and proportion mature at age were assumed to be constant and known. Natural mortality rate was assumed to be 0.2 for all ages and years and known.

Six data sets were assessed the main features of which are described cribed below (see Annex 1 for full details).

Data Set 1:	No trends in catchability in any fleet. Total international F about 0.4 for the whole of the 30-year period. Process and measurement errors log-normal. Separable F at age for each fleet.
Data Set 2:	No trends in catchability in any fleet. Total international F about 1.0 for the whole of the 30-year period. Process and measurement errors log-normal. Separable F at age for each fleet.
Data Set 3:	Catchability trends in the two commercial fleets for which effort data available. No catchability trends in other commercial fleets or in research vessels. Total international F around 0.4, but with steadily increasing trend. Process and measurement errors log-normal. Separable F at age for each fleet.
Data Set 4:	Catchability trends in all fleets for which effort data are available (including research vessels). Total international F around 0.8 in year 1 increasing to about 1.2 in year 30. Process and measurement errors log-normal. Separable F at age for each fleet.

These four data sets were sent to the assessors in advance of the meeting. Having carried out their assessments, all of the assessors considered that the data were too "clean". In particular and when the method of simulation and the precise nature of these data sets was revealed, it was suggested that:

i) the research vessel data should have higher variances,

ii) separability assumptions for each fleet may be violated in reality,

iii) errors in catch-at-age data may be gamma-distributed rather than log-normally distributed,

iv) some methods assumed exponential trends in catchability and, since this assumption is incorporated in those data sets where catchability is allowed to change, these methods would be in an advantageous position when assessing data of the type provided,

v) research vessel effort data varied considerably from year to year.

Accordingly, during the meeting, two other data sets were prepared in an attempt to overcome these criticisms.

Data Set 5: Same as Data Set 3 except that gamma-distributed process noise used on F-at-age and catch-at-age data (log-normal noise retained on fishing effort). Level of noise increased compared to Data Sets 1-4.

Data Set 6: Noise treated in the same way as Data Set 5. F-at-age not separable for any fleet for the whole of the simulated time period.

It should stressed that, ideally, the assessors would have carried out extensive exploratory analysis of the data sets prior to producing their results. Many of the methods routinely produce diagnostic statistics (HYBRID, LS, CAGEAN, ADAPT, TSER) and some methods (especially ADAPT) actively encourage intervention by the operators. However, in the time available, only cursory reference to diagnostics was possible. Because of this, the results from these methods presented in this report may not be the best attainable.

These data sets are large, and it has been decided that they will not be tabulated in this report. Copies of them can be obtained on IBM-formatted disk from

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3.2 Estimation of Parameters of the Last Data Year in Simulated Data Sets

One of the most important results arising from a stock assessment is an appreciation of the state of the stock in the last data year since short-term conservation measures (TACs, effort and mesh regulations, etc.) are highly dependent on the current state of the stock. The current state of the stock is describable by estimating the parameters for the last data year of an appropriate fisheries model.

3.2.1 Procedure for comparison of methods

Because the simulation method incorporates stochastic processes, it is possible to produce many different realizations of the outputs for any constant set of input parameters. In principle, this property could have been used in a Monte Carlo test of each assessment method in which a large number of realizations of a data set could be analyzed to obtain the mean value (expectation) and variance of each parameter. These quantities could be used to compare the efficiency of the methods.

In practice, however, such an approach would have been extremely time-consuming to implement and logistically difficult to set up. It was, therefore, decided that a simpler approach should be adopted.

In advance of or during the meeting, a single realization of each of the six data sets was supplied to a number of nominated stock assessors. Each stock assessor was requested to apply a method which he had originated or which he is accustomed to using to each of the data sets. The true input parameter values were not provided to the assessors at this stage.

The assessors were asked to:

i) apply their method to data for years 2-21 and estimate parameter values for year 21,

ii) apply the method to years 3-22 and estimate parameters of year 22,

iii) repeat for years 4-23, 5-24, ..., 11-30.

The assessors were asked to record their estimates of:

i) number at age,

ii) F at age and mean F for ages 5-9,

iii) total and spawning biomass,

iv) catchability at age for each fleet for which effort data were provided.

(It should be noted that, in the time available, it was not possible to analyze estimates of catchability.)

The estimates were then compared to the true values used in producing the data sets supplied to the assessors. (In this context, the true values are the "realized" values referred to in Annex 1). Two comparisons were made:

i) The percentage discrepancy between estimate and truth was calculated as

$$PD = 100[(Estimate/Truth)-1]$$

For each of the parameters listed above, ten discrepancies can be calculated (e.g., for each data set, there are ten estimates of F at age 4 to be compared with corresponding true values). The discrepancies are presented as frequency distributions in Tables 3.1, et seq.

It should be noted that in some of the frequency distributions of percentage discrepancies, the frequencies do not add to 10. There are three reasons for this:

a) True values of N at age were truncated to the nearest million by the program producing the frequency distributions. In simulations incorporating high mortality rates, the true number in the sea sometimes becomes less than 0.5 million at high age. In this case, the truncated value is zero and it is, therefore, not possible to calculate a precentage discrepancy.

b) Some of the assessment methods estimated values of zero or infinity for fishing mortality rates (and associated catchabilities). Such values were not included in the frequency distributions.

c) In the case of the Collie-Sissenwine and Time Series methods, it was possible in the time available only to make estimates of parameters in one last data year. The frequency distributions in these cases, therefore, consist of only one frequency of unity.

Some assessors found it impossible in the time available to apply their allocated method to some of the data sets and in these cases the associated table of histograms is blank. Estimates which were ignored or non-computable for the reasons described above were also excluded when calculating mean logarithmic ratios and associated root mean square deviations referred to below.

ii) Indicators of bias and precision of the estimates were calculated.

The mean of the logarithms of the ratio of estimate to truth was calculated as a measure of bias in the estimates. The logarithmic transformation was adopted to reduce the effect of estimates which departed widely from truth. Lower absolute values indicate less biassed results.

$$MLR = 1/10\Sigma[\ln(Estimate) - \ln(Truth)]$$

The root mean square of the logarithms of the ratio of estimate to truth was calculated as an indicator of the precision of the cision of the estimates. Lower values indicate more precise results.

$$\text{RMS} = \left[1/10\Sigma[\ln(\text{Estimate}) - \ln(\text{Truth})]^2\right]^{1/2}$$

Values of 100MLR and 100RMS are presented in Tables 3.2, 3.2, et seq.

In the time available, it was not possible to perform the above-mentioned analyses on estimates of catchability.

To present the true values required to carry out the calculations indicated above would require a prohibitively large number of tables. Copies of the true values can be obtained on IBM-formatted disk from D.W. Armstrong or G. Stefansson at the addresses shown in Section 3.1.

3.2.2 Problems with the simplified procedure

The procedure adopted is, from the statistical point of view, less satisfactory than the full Monte Carlo approach in that the successive data sets are not statistically independent even though they are analyzed separately and the number of estimates achieved (10) is too small for precise statistical conclusions to be drawn. However, since the important factor to be investigated is the relative performance of the methods, statistical independence between trials is probably not a crucial point.

3.3 Estimation of Historical Trends in Simulated Data Sets

The description of the current state of the stock is a very important product of stock assessment techniques, but the utility of this information is greatly enhanced by the perspective on the historical state of the stock which assessment methods also provide. If the current state of the stock can be observed in relation to previous states, conservation advice intended to rectify immediate and longer-term problems can be provided more readily.

It is, of course, important to be confident that an assessment is not providing an erroneous impression of historical states, i.e., assessment methods should be capable of detecting changes when they exist and should not suggest the existence of changes which have not occurred. This aspect is particularly important for results for years close to the last data year because of the greater influence which they will exert in deciding on changes required in the future in the state of the stock.

To investigate this aspect of assessment methodology, the assessors were also requested to present an assessment for the whole of the 30-year period of Data Sets 4 and 6. From these outputs, time series for the last 10 years of estimates of recruitment (N at age 3), spawning biomass, and mean F for ages 5-9 were plotted. True values of these quantities were plotted on the same graphs to allow comparison between estimates and truth. In addition, the estimate of each quantity obtained as a last-data-year value, as described in Section 3.2, was also plotted.

3.4 Estimation of Parameters in Last Data Year for Real Data Sets

As stated in Section 2.2, application of different methods to the same data set has, on some occasions, produced rather different and confusing results. It was, therefore, decided to apply the methods implemented at this Workshop to real data sets to demonstrate the kind of differences which can arise.

The assessors were provided with real data sets for North Sea cod and haddock comprising catch at age for commercial and research vessels, associated mean weight at age, fishing effort where available, and estimates of natural mortality rate and proportion mature at age.

The assessors were requested to carry out an assessment using each of these data sets and to record their estimates for 1986 (the last data year) of N at age, mean F ages 5-9, spawning biomass and total biomass.

A summary of the data available for each stock is given in the text table below. As with the simulated data, no tabulation of the data sets are included in this report. Copies may be obtained from D.W. Armstrong or G. Stefansson at the addresses indicated in Section 3.1.

Fleet	Cod	Haddock
England Seine	*	
England Trawl	*	
Scotland Seine	*	*
Scotland Trawl	*	*
Scotland Light Trawl	*	*
Scotland Nephrops Trawl	*	*
Other nations all gears	*	*
International Young Fish Survey	*	*
English Groundfish Survey	*	*
Dutch Groundfish Survey	*	
Scottish Groundfish Survey	*	*

4 INTERPRETATION OF RESULTS

Because it was necessary to analyze Data Sets 5 and 6 during the meeting, relatively little time could be spent discussing the results of the analyses. The interpretation presented below is an attempt to reflect the points raised in discussion, but also includes other suggestions received by correspondence or which became apparent during the writing of the report.

4.1 Estimates of Parameters in the Last Data Year of Simulated Data Sets

4.1.1 Frequency distributions of percentage deviations from truth

Data Sets 1-4

For Data Sets 1-4, most of the methods performed well. Most of the estimates of N at age and F at age are within 30% and many of them are within 10% of the true values. This result is to be expected given the low variance of the data in these sets. In addition, many of the methods assume log-normal errors and/or changes in catchability following an exponential function, and both of these properties are included in these data sets.

However, even on these excellent data, all of the methods can produce estimates which depart widely from truth, especially at the higher ages. Greater attention to any available diagnostics would probably have resulted in improved results, but careful handling of F and/or catchability at high age is clearly indicated.

Results for the current version of Extended Survivor Analysis (XSA) demonstrate trends with age in Data Sets 1,2, and 4. A similar problem exists with results from the General Linear Model (GLM) for Data Sets 3 and 4. Both of these methods are still under development and problems of this type may be resolved in the future.

A note of caution should be given about the results of the CAGEAN analysis of Data Sets 1-3. As explained more fully in Annex 2, these results are possibly better than they should be since they are conditioned by prior knowledge obtained by running the method on the full 30-year data set. The results presented for Data Set 4 are perhaps more typical of possibilities which can occur. It appears that, in this case, CAGEAN was initiated with levels of F far lower than the true values and subsequently failed to converge towards the true values.

Conventional VPA and Separable VPA, neither of which employ auxiliary data, both performed poorly on Data Sets 1-4 and failed to track changes in fishing mortality rate or numbers at age as well as the other methods. This confirms the desirability of obtaining and using auxiliary data to allow improved estimation of mortality rate and stock size in the most recent years.

However, the Time Series method applied only to total catch-at-age data and ignoring auxiliary information (TSER1) also performed well. Unfortunately, only one set of parameters was estimated by this method for these data sets, but the results suggest that this method may be worth considering if auxiliary data are not available. The performance of the Time Series method appears to be improved if auxiliary data are included in the analysis (TSER2).

Estimates of total biomass, spawning biomass, and mean F tended to cluster closer around true values than did the estimates of N at age and F at age. This is probably because the biomass and mean F values are aggregates over age groups and errors at age tend to cancel.

Data Sets 5 and 6

Estimates of N at age and F at age are much less closely clustered around the true values as expected given imprecise data which do not comply with the assumptions of the analytical methods.

Trends in the results for N and F at age are still evident for the Extended Survivors and General Linear Model methods (XSA and GLM). CAGEAN performed better on these data sets than on Set 4 perhaps because the initiating value of F used was reasonably close to the true value.

Comparison of the results from the Armstrong-Cook methods indicates a possible advantage in using a logarithmic transform in that AC1 and AC2, which use log-transformed data, performed better than AC3 and AC4 which use untransformed data.

4.1.2 Bias and precision indicators (MLR and RMS)

Because of limited time, no interpretation was attempted at the meeting of MLR and RMS of the N- and F-at-age data, but subsequent inspection of these results revealed nothing that has not already been referred to in Section 4.1.

During the meeting, a preliminary attempt was made to rank the methods in order of performance. This procedure was confined to results from Data Sets 5 and 6 since these were considered to be the most realistic sets. Within the results from each data set, the methods were ranked according to the values of bias and precision indicators calculated for mean F for ages 5-9 and for spawning biomass. The latter quantities were selected since they are formed by aggregating over age groups and thus may represent a more reasonable representation of the overall performance of the methods than analogous rankings on an age-by-age basis. The rankings are shown in Table 4.1.

Subsequent to the meeting, the ranking procedure was modified and extended to all data sets. A 2-way classification is presented in which methods are assigned to intervals of both MLR and RMS. The results of the modified procedure are shown in Tables 4.2-4.13. Methods listed in the top left-hand area of the tables exhibit better performance.

For Data Sets 1-4, the 2-way tables confirm the generally poor performance of Separable and Conventional VPA, although for Data Set 3, both of these methods would be judged good performers according to the criteria adopted. The problems mentioned above with Extended Survivors Analysis, the General Linear Model, and CAGEAN are also reflected in these tables.

For Data Sets 5 and 6, Extended Survivors Analysis and CAGEAN are among the highest ranked performers in estimating spawning stock biomass, but perform less well in estimating mean F. Overall, the Laurec-Shepherd method exhibits the least erratic high rankings for these data sets.

It should be added that many of the participants expressed severe reservations over attempting to rank the methods in the manner indicated. It should be recalled that it was not possible to implement the full diagnostic features associated with many of the integrated methods and that these may, therefore, have performed less well than would otherwise be possible. In addition, it is by no means certain that the criteria for the rankings are the most appropriate or valid.

4.2 Estimates of Historical Trends in Simulated Data Sets

4.2.1 Data Set 4: Tuning methods (Figures 4.1-4.8)

The advantage of using tuning methods when catchabilities are changing is obvious in these results. All tuning methods produced quite similar results as may be expected since the methods employed at this meeting are all variations on the same theme.

HYBRID, AC1, and AC2 performed best because the trend in catchability assumed by HYBRID corresponds exactly to that used in the data simulation model, while the catchability trend assumed in AC1 and AC2 is sufficiently flexible to take a shape close to the true one. For AC3 and AC4, the assumed trend in catchability approximates less well to truth, and these methods exhibited a poorer performance.

Techniques which assume local constancy in catchability also performed less efficiently on this data set. The Laurec-Shepherd method produced biassed results, in that it tended to underestimate fishing mortality and overestimate spawning biomass. Results from AEFM and CCPUE do not exhibit this consistent bias.

4.2.2 Data Set 4: Survivors and Extended Survivors (Figure 4.9)

Survivors reproduced the major features of the data set for early years, but underestimated fishing mortality and overestimated spawning biomass in the later years.

Extended Survivors Analysis, as applied to this data set, overestimated fishing mortlaity and underestimated spawning biomass in the later data years.

4.2.3 Data Set 4: Integrated methods (Figures 4.10-4.13)

It was not possible to run the Time Series and Collie-Sissenwine methods on the full 30-year data set during the meeting.

All the other integrated techniques appear to have performed less efficiently than the tuning methods. CAGEAN failed to reproduce both the historical trends and the last-data-year values which perhaps implies that considerable care should taken in choosing the quantities used to initiate this method.

ADAPT produced better results when a trend in catchability was taken into account, but even in this case, the results were poorer than those produced by tuning methods. The GLM method reproduced the early years' historical trend reasonably well, but underestimated mean F and overestimated spawning biomass in the later years.

4.2.4 Data Set 4: Conventional and Separable VPA (Figures 4.14-4.15)

In both cases, the effects of convergence of the VPA can be observed, in that the estimates correspond well to truth in the earlier data years, but less well in the later years. In fact, true catchabilities (and hence fishing mortalities) were increasing. These methods tended to underestimate the fishing mortality in the last data year and hence overestimated biomass.

4.2.5 Data Set 6: Tuning methods (Figures 4.16-4.21)

None of the methods produced really satisfactory results. The main features of the time series are reproduced by AC1, LS, and, to a lesser extent, CCPUE, but these and all other tuning methods erroneously estimated a sharp reduction in F in the last data year. This was because, by chance, the CPUE estimates in the last data year for three of the fleets which had, until then, provided the most reliable data were subject to large positive measurement error which resulted in the underestimation of fishing mortality. Such a result would be very unfortunate in a real assessment since it would indicate a better situation than that which actually exists.

Techniques such as HYBRID, which permit catchability changes in all fleets, will probably always perform poorly on data sets such as this where the level of noise is high and, consequently, the estimation of the parameters descriptive of trends is difficult. Difficulties are also encountered when the assumptions implicit in the analytical method (e.g., probability distribution of errors, functional form of catchability trends, assumption of separability) do not conform to truth. This is the case for all of the tuning methods applied to this data set.

Probably the safest approach in these circumstances is to employ one of the more constrained techniques. If it is thought (or if diagnostics can indicate) that changes in catchability are not important for any fleet in recent years, methods such as LS seem appropriate. If recent years' catchability can be assumed constant only for some fleets, mixed methods such as AC1 and AC2 may provide a reasonable approach.

4.2.6 Data Set 6: Survivors and Extended Survivors (Figure 4.22)

Survivors tended to overestimate fishing mortality and underestimate spawning biomass. (Reference to diagnostics on the results obtained identified this problem and indicated that one of the research vessel surveys had produced data of very high variance which should be excluded from the analysis.) The Extended Survivors Analysis gave good results for this data set.

4.2.7 Data Set 6: Integrated methods (Figures 4.23-4.25)

It was not possible to apply the Collie-Sissenwine method to this data set and, of the time series methods, only TSER1 (omitting the use of auxiliary data) could be implemented.

TSER1 performed efficiently on this data set and estimated fishing mortality and biomass in the last data year with no important discrepancy from the true values. This is, at least partly, because TSER1 does not use auxiliary data and was, therefore, not affected by the misleading CPUE values for the last data year which created problems for the tuning methods. All other integrated methods, which make use of auxiliary data, underestimated fishing mortality in the last data year.

4.2.8 Data Set 6: Separable VPA (Figure 4.26)

This method produced satisfactory results purely because the arbitrarily chosen inputs to initiate the computations happened to approximate closely to truth.

4.3 Applications to Real Data Sets

Estimates of numbers at age, F at age, total and spawning stock biomass, and mean F for 1986 for North Sea cod and haddock are given in Tables 4.3.1 and 4.3.2, respectively. (No estimates are available for seven of the methods tested at this meeting - see tables for details.)

Estimates of these parameters made by the 1988 North Sea Roundfish Working Group are also included in the tables for comparison. The North Sea Roundfish Working Group's data base included data for 1987, and estimates of F at age and associated N at age for that year were obtained for fish of ages greater than 1 by the Laurec-Shepherd method. The results shown in the tables for 1986 are derived by VPA from the estimates for 1987.

The Collie-Sissenwine method produced implausible results. Estimates of F for cod were either very high (age 2) or very low (other ages) when compared with recent historical values obtained by the Roundfish Working Group. No estimate of F was obtained for many age groups of haddock because this method estimated values of N at age less than the observed catch.

Results for CAGEAN and Survivors were more plausible and it would be difficult to demonstrate that they were not correct. However, the results are, in many cases, very different from those obtained by the Roundfish Working Group both for 1986 and for other recent years. This is particularly the case for the results from CAGEAN for haddock where the estimated values of F are low and correponding values for N are high. It is doubtful that the Roundfish Working Group would accept such estimates.

The range of results from the *ad hoc* tuning methods exemplifies the difficulties encountered by the Roundfish Working Group in deciding on final estimates of F and N at age in the last data year. In many cases, the estimates obtained are in reasonable than the VPA-based methods and lengthy run times may not be able to be accommodated in the ICES working group environment unless some means can be found for extending the time available to carry out the required assessments. The main difference between integrated and ad hoc methods is that the former are capable of allowing for errors in the total catch-at-age data. For stocks where these errors are smaller than the errors in the commercial CPUE and survey series, the extra complexity and effort involved in implementing integrated methods may not be worthwhile in terms of parameter estimation.

At present, therefore, there is no indication that any of the methods which use auxiliary data clearly and consistently performs much better than any of the others. It has yet to be demonstrated that full implementation of integrated methods produces enhanced results. Equally, it has not yet been demonstrated that, except on the grounds of computational speed, it is preferable to use ad hoc methods. Further testing of both types of method against realistic data sets (e.g., Data Sets 5 and 6) is clearly required before decisions can be made on which type of method is preferable. Finally, it was suggested that modifications of some of the integrated methods may be desirable. In particular, CAGEAN may perform better if initial parameter estimates are obtained using an ad hoc method.

5 FUTURE TESTING OF ASSESSMENT METHODS

Testing of methods, as performed at this meeting, was based on studying how estimation procedures behave on simulated data sets. This procedure could serve as the general approach to verifying new methods before they are applied for assessment of real fish stocks.

The approach which has been taken when simulating data sets is:

a) define a plausible underlying deterministic model to describe the fishery;

b) stochastically perturb (some of) the parameter values incorporated in this model i.e., add process error to the underlying parameter values to produce realized parameter values;

c) produce catch-at-age and effort data associated with the realized parameter values;

d) add measurement error to catch-at-age and effort data.

The realized parameter values are regarded as "truth". The efficiency of an assessment method is tested by how well it estimates a subset of the realized parameters.

When applying an assessment method to a data set, it is believed, at least temporarily, that the underlying fisheries model is known and that the method is appropriately specified with respect to process and measurement error (or perhaps to the combination of both types of error). However, even if this is the case, increased errors will increase the difficulty in obtaining good agreement. However, occasional "wild" values occur (e.g., high estimates of F at ages 3 and 4 for haddock when using AC2) and it is difficult to select the results of any one of these methods as being the best.

Estimates of F and N at age are most variable for the youngest age groups (0 and 1 for haddock, 1 for cod). This indicates the continued requirement mentioned in Section 2.1 to use additional methods to estimate these values.

4.4 General Comments

None of the variants of *ad hoc* tuning is obviously preferable in all circumstances to any of the others. This is not surprising since, as stated previously, all the variants tested are closely related. The Laurec-Shepherd and Hybrid methods are the longest established of the tuning variants and diagnostic outputs are well developed for these methods. The Laurec-Shepherd method generally has lower prediction error (RMS) and higher bias (MLR) than the Hybrid method when there are strong changes in catchability for some fleets and generally appears to be more robust, in line with theoretical expectations. In practice, however, examination of diagnostics often leads to reformulation of the method. An example of this is referred to in the last paragraph of Section 1 of Annex 2 where an analysis was initiated using the Laurec-Shepherd method, but the final formulation incorporated a mixture of that method and the Hybrid method allowing for trends in catchability in some fleets and constant catchability in others. Where such procedures are required, there would be considerable benefit from obtaining good standardized commercial effort data or survey data so that catchability can unambiguously be held constant for as many fleets as possible in a mixed analysis.

The integrated methods have a more respectable statistical basis than the *ad hoc* methods in that integrated methods utilize standard and generally accepted statistical methods for parameter estimation. The properties of these estimators are understood, at least asymptotically, and some approximations for their precision are available. Furthermore, most of the integrated methods produce copious diagnostic statistics and, especially in the case of the adaptive framework, users are encouraged to modify their model specification in the light of diagnostic outputs.

Judging by their performance at this meeting, the integrated methods seem to be intermediate in performance among the tuning variants and no major advantage in using integrated methods was demonstrated. However, as previously, in the time available, it was not possible to make full use of diagnostic features. In all cases, it was necessary to choose a model specification *a priori* and to produce results dependent on this specification. For this reason, many of the applications of the integrated methods incorporated misspecified models (e.g., assuming constant catchability, separability, etc. for data sets where such assumptions were not valid). In these circumstances, it is perhaps surprising that integrated methods did well at all.

The integrated methods are computationally much more demanding parameter estimates. Furthermore, within an assessment method, the specification of the underlying fisheries model or of the probability density functions of the errors may be incorrect. If this is the case, the estimation of parameters may also be adversely affected.

One possibility for quantifying the effects of the factors referred to above is to test each method against a set of simulated data organized as a factorial design. One such design is indicated in the text table below.

	Test no.											
	1	2	3	4	5	6	7	8	9	10	11	12
Measurement error												
None	*	*					*	*				
Correct specification			*	*					*	*		
Incorrect specification					*	*					*	*
Underlying model												
Correct specification	*		*		*		*		*		*	
Incorrect specification		*		*		*		*		*		*
Process error absent	*	*	*	*	*	*						
Process error present							*	*	*	*	*	*

Such an approach is attractive, but it should be recognized that it could be very labour-intensive since multiple runs would be required within those tests incorporating measurement or process error so that the effects of increasing level of error could be evaluated. In addition, since no method can be expected to perform well in all circumstances, it would probably be necessary to subject each method to the tests above for each of a number of types of fishery.

Furthermore, within such an approach, it is difficult to define a single incorrectly specified underlying model. This is because the model for simulating the data and the model implicit in an assessment method are both comprised of various sub-models. The specification of any of these sub-models in the simulation and in the assessment method may or may not differ.

Similarly, it is also difficult to define an appropriate "incorrect" probability density function for measurement and/or process errors. (Most assessment methods assume that the measurement errors are normally or log-normally distributed, and it was suggested that the gamma distribution could be used as the incorrect specification.) Further thought needs to be given to these problems by the Methods Working Group.

An alternative suggestion on the future testing of methods was that a number of standard data sets could be created against which new and existing methods could be tested so that a preliminary ranking of methods can be obtained. The Group recognized that Data Sets 1-4 produced for this meeting are not suitable for this purpose. Data Sets 5 and 6 offer a more stringent test and may serve in the immediate future as standard sets. However, more thought needs to be given to producing appropriate data sets against which to test assessment methods. One possibility in this context is that the simulated data might be based on the fishery for which the method is intended. Few, if any, fisheries have been modelled with respect to creating a realistic error structure in the observations (as compared to adding errors derived from some conventional probability density function). In particular, it might be advantageous to produce the estimated catch-at-age data by simulating the biological sampling procedures used on that fishery. This should add measurement error of more or less the correct statistical form.

One of the major aspects of a good method is its ability to detect, by means of good diagnostics, when unreliable parameter estimates are being produced. Whatever method of testing is finally decided upon, the Group suggests that, wherever possible, the estimated variance-covariance matrix of the parameter estimates should be presented as the basis for an efficient set of diagnostics. In addition, serial correlations in the differences between the observations and their fitted values should also be made available along with the variances of the residuals for each age group. (It is recognized that this may be difficult in the case of ad hoc methods.) Variances of residuals for each year and for each fleet should also be made available to provide the user with hints, e.g., of badly sampled fleets, the data for which can then be down-weighted. These outputs should be arranged as a year-by-age table for each fleet.

In future testing, it would be useful to categorize methods according to their two components, i.e., estimation procedure and model specification, and to test these separately. With respect to estimation procedure, the methods examined fall into two broad categories, i.e, statistically-founded approaches and ad hoc approaches. It is possible that certain ad hoc estimation procedures correspond to realizations of statistically-founded procedures and clarification of this possibility is required. With respect to model specification, there is a varying degree of flexibility among the methods tested, and opinions ranged from advocating complete flexibility to specifying a single model. The success of a flexible approach hinges on the adequacy of diagnostics to define appropriate models, while a single model approach relies on the robustness of the specified model. Attempts should be made to determine whether, given the same underlying model, the statistically-founded approach works better or worse than the ad hoc approach and thereby discriminate between estimation procedure and model formulation.

The Group is also of the opinion that, since there is already a proliferation of new methods, authors should restrain themselves from publicizing new methods until they can demonstrate that some real advantage can be gained from their use.

Finally, it should not be forgotten that the ability to estimate the current and historical state of the stock is only one part of the assessment process. The desired end product of an assessment is often advice on an appropriate total allowable catch and this requires methods to predict how changes in fisheries will affect stock size and yield. This aspect of assessment was not dealt with during the meeting. It is, however, of considerable importance and should be the topic of future meetings of the Methods Working Group.

Table 2.1 Assumptions of the methods

Method	HYBRID	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVIV	XSA	CAGEAN	ADAPT	GLM	COLSIS	TSER1	TSER2	SVPA	CONVEN
Separable model for fishing mortality	No	Each fleet	Some fleets	Some fleets	Some fleets	Some fleets	Each fleet	Each fleet	Yes	Some fleets	Each fleet	No	Each fleet	No	No	No	Sum of fleets	No
Time trends - catchability											Step-wise				Markov	Markov	n.a.	n.a.
Regress log(q) vs year	Yes																	
Regress log(q) vs log(yr)			Yes	Yes														
Regress q vs year					Yes	Yes												
Assumed absent		Yes					Yes	Yes	Yes	Yes		Yes	Yes	Yes				
Assumes existence of process error	<------------ Not explicit ------------>						Not explicit		No	No	No	No but can do	Not explic	Yes	Yes	Yes	Yes-added to catch error	
Assumes no Error in Catch-at-Age	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	log-normal	log-normal	log-normal	log-normal	log-normal	No	log-normal	log-normal	log-normal	Yes
Weight for fleets										No					n.a.	n.a.	n.a.	n.a.
1 / Var(q)	Yes	Yes	Yes	Yes	Yes	Yes												
1 / Var(N)								Yes										
1 / Var(residuals)											Yes	Yes	Yes					
1 / Var(survivors)									Yes									
Externally specified														Yes				
F Constrained for Older Ages	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	Yes	Yes	Yes
Can handle multiple fleets CPUE data	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	n.a.	n.a.
Down-weights early-years data	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	n.a.	Yes	n.a.	n.a.	No	n.a.	No	No	n.a.	n.a.
Estimate of CPUE in last data year assumed exact	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	n.a.	n.a.
Estimate of catch-at-age in last data year assumed exact.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes in VPA calcns	Yes in VPA calcns	No	Yes	n.a.	No	No	No	Yes in VPA calcns	Yes

Table 3.1 : Simulated Data Set 1 : Frequency Distributions of Percentage Deviation of Estimates of N at age from True Values

Methd	HYBRID									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50									1	
30	1							3	1	2
<¦10¦	8	10	10	10	9	9	8	3	5	4
-30	1				1	1	2	4	3	3
-50										1
-70										
< -70										

Methd	LS									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50									1	
30								1	1	1
<¦10¦	10	10	10	10	10	10	10	8	8	6
-30								1		3
-50										
-70										
< -70										

Methd	AC1									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50									1	
30	1						1			1
<¦10¦	8	10	10	10	10	10	9	8	8	5
-30	1							2	1	4
-50										
-70										
< -70										

Methd	AC2									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50									1	
30	1						1		1	1
<¦10¦	8	10	10	10	10	10	9	8	7	5
-30	1							2	1	4
-50										
-70										
< -70										

Methd	AC3									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50									1	
30	1						1		1	2
<¦10¦	9	10	10	10	10	10	9	9	8	4
-30								1		4
-50										
-70										
< -70										

Methd	AC4									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50									1	
30	1						2	1	1	1
<¦10¦	9	10	10	10	10	10	8	8	7	5
-30								1	1	4
-50										
-70										
< -70										

Methd	AEFM									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50									2	2
30	5							1	2	3
<¦10¦	4	9	9	9	8	9	8	5	3	
-30	1	1	1	1	2	1	2	3	3	5
-50								1		
-70										
< -70										

Methd	CCPUE									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										1
30									1	2
<¦10¦	9	10	10	10	10	10	8	8	5	3
-30	1						2	2	4	4
-50										
-70										
< -70										

Methd	SURVIV									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30	2								2	5
<¦10¦	7	10	10	10	10	10	10	10	8	4
-30	1									1
-50										
-70										
< -70										

Methd	XSA									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30										
<¦10¦	3	1								
-30	7	9	10	10	10	8	2	1		
-50						2	8	8	8	2
-70								1	2	8
< -70										

Methd	CAGEAN									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30										1
<¦10¦	10	10	10	10	10	10	10	10	8	7
-30									2	2
-50										
-70										
< -70										

Methd	ADAPT									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30	2						2		1	3
<¦10¦	6	10	10	10	10	9	7	9	7	2
-30	2					1	1	1	2	4
-50										1
-70										
< -70										

Methd	GLM									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30	2		1	1				1	6	1
<¦10¦	7	10	9	9	10	10	9	7	4	5
-30	1						1	2		4
-50										
-70										
< -70										

Methd	COLSIS									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30										
<¦10¦								1		1
-30		1		1	1	1	1		1	
-50										
-70										
< -70			1							

Methd	TSER1									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30										
<¦10¦			1		1					
-30		1		1		1	1	1	1	
-50										
-70										
< -70										

Methd	TSER2									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30										
<¦10¦		1	1	1						
-30					1	1	1	1	1	
-50										
-70										
< -70										

Methd	SVPA									
Age	3	4	5	6	7	8	9	10	11	12
> 70	3	4	2	1	2	2	1	3	5	2
70		3	3	4	2	3	4	3		1
50	3		2	2	3	2	1			2
30							1	1	1	2
<¦10¦	1	1	1	2	2	1	2	2	3	2
-30	2	2	2	1	1	2	1			1
-50	1							1	1	
-70										
< -70										

Methd	CONVEN									
Age	3	4	5	6	7	8	9	10	11	12
> 70	4	5	4	4	3	5	3	4	5	4
70	1		1		2		3	1		1
50	1	2	1	3	2	1		1		
30	1		1			1				1
<¦10¦			1			1	1	1	2	1
-30		1		1	1		1	1	1	1
-50	1	1	1	1	1	1	1	1	1	1
-70	1	1	1	1	1	1	1	1	1	1
< -70	1									

Table 3.2 : Simulated Data Set 1 : Mean Log Ratio of Estimates of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	-1	-1	-1	-1	-2	-2	-2	-4	-1	-7
LS	1	1	0	0	-0	-1	1	-3	4	-6
AC1	0	0	0	0	-0	-1	2	-3	3	-9
AC2	0	0	0	0	-0	-1	2	-3	4	-9
AC3	2	1	0	1	0	1	3	-0	6	-6
AC4	1	1	1	1	-0	-0	3	-1	5	-7
AEFM	6	-3	-2	-2	-4	-3	-2	-10	4	1
CCPUE	1	-2	-2	-2	-2	-4	-2	-8	-3	-0
SURVIV	3	2	2	2	2	2	4	2	5	5
XSA	-13	-14	-17	-21	-26	-32	-40	-54	-71	-87
CAGEAN	0	-0	-0	-0	-2	-2	-2	-3	-4	-2
ADAPT	-1	-1	-2	-1	-2	-2	-2	-3	-5	-7
GLM	-1	1	-1	-0	-1	-0	-2	-1	10	-6
COLSIS		-12	-241	-17	-16	-13	-13	-7	-19	0
TSER1		-31	-11	-15	-6	-14	-14	-17	-13	
TSER2		-11	-5	-11	-12	-14	-14	-17	-13	
SVPA	28	35	31	28	27	29	28	29	30	28
CONVEN	29	37	28	28	25	26	24	23	18	18

Table 3.3 : Simulated Data Set 1 : Root Mean Square Log Ratio of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	8	6	6	6	7	7	7	14	14	19
LS	4	3	2	3	3	3	4	9	11	15
AC1	6	3	2	2	2	3	6	8	11	16
AC2	6	3	2	2	2	3	6	8	12	16
AC3	6	3	3	3	3	4	6	6	12	18
AC4	6	3	3	3	3	3	7	8	13	17
AEFM	12	6	5	5	8	7	7	19	18	22
CCPUE	5	3	4	4	4	5	6	11	11	19
SURVIV	9	5	4	3	3	3	5	6	8	11
XSA	14	15	17	21	26	33	40	55	72	89
CAGEAN	4	2	2	2	3	3	3	5	7	8
ADAPT	9	6	6	4	5	7	11	7	10	20
GLM	9	5	6	5	5	6	6	11	13	14
COLSIS		12	241	17	16	13	13	7	19	0
TSER1		31	11	15	6	14	14	17	13	
TSER2		11	5	11	12	14	14	17	13	
SVPA	61	49	43	42	39	43	40	47	49	40
CONVEN	89	71	63	63	60	62	60	66	66	61

Table 3.4 : Simulated Data Set 1 : Frequency Distributions of Percentage Deviation of Estimates of F at age from True Values

Methd: HYBRID Age	3	4	5	6	7	8	9	10	11	12
> 70										
70	1									
50										2
30	1	1	2	2	2	5	2	4	2	4
<¦10	7	9	7	8	8	5	8	4	7	1
-30	1		1					2	1	3
-50										
-70										
< -70										

Methd: LS Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50	1							1		
30	1		1			1	1	1	1	5
<¦10	5	10	8	10	10	9	8	7	7	2
-30	3		1				1	1	2	3
-50										
-70										
< -70										

Methd: AC1 Age	3	4	5	6	7	8	9	10	11	12
> 70										
70	1									
50										
30	2		1			1	1	4	2	6
<¦10	4	10	8	10	10	9	8	5	5	3
-30	3		1				1	1	3	1
-50										
-70										
< -70										

Methd: AC2 Age	3	4	5	6	7	8	9	10	11	12
> 70										
70	1									
50										
30	2		1			1	1	4	2	6
<¦10	4	10	8	10	10	9	8	5	5	3
-30	3		1				1	1	3	1
-50										
-70										
< -70										

Methd: AC3 Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50	1									
30			1				1	2	1	5
<¦10	6	10	8	10	10	10	8	7	6	3
-30	3		1				1	1	3	2
-50										
-70										
< -70										

Methd: AC4 Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50	1							1		
30	1		1			1	1	2	2	5
<¦10	5	10	8	10	10	9	7	6	5	3
-30	3		1				2	1	3	2
-50										
-70										
< -70										

Methd: AEFM Age	3	4	5	6	7	8	9	10	11	12
> 70										
70								2		1
50							1	1		2
30	3	2	3	1	1	4	1	2	3	1
<¦10	3	8	7	9	9	6	8	4	4	4
-30	4							1	3	
-50										2
-70										
< -70										

Methd: CCPUE Age	3	4	5	6	7	8	9	10	11	12
> 70										
70	1									1
50								2		1
30	1		2		1	4	2	1	2	2
<¦10	5	10	8	10	9	6	8	6	6	4
-30	3							1	2	1
-50										1
-70										
< -70										

Methd: SURVIV Age	3	4	5	6	7	8	9	10	11	12
> 70										
70	1									
50										
30	1		1					2	1	
<¦10	4	9	9	9	10	10	10	7	6	8
-30	4	1		1				1	3	2
-50										
-70										
< -70										

Methd: XSA Age	3	4	5	6	7	8	9	10	11	12
> 70							2	8	10	10
70	1					5	8	2		
50		1	1	2	9	5				
30	5	8	9	8	1					
<¦10	4	1								
-30										
-50										
-70										
< -70										

Methd: CAGEAN Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50	1									
30	5	1	1	1			3	2	3	2
<¦10	1	9	9	9	10	10	7	5	5	8
-30	3							3	2	
-50										
-70										
< -70										

Methd: ADAPT Age	3	4	5	6	7	8	9	10	11	12
> 70										
70	1									
50							1		1	1
30	1	2	1	2	2	4	1	5	1	2
<¦10	5	8	9	8	8	6	7	3	8	7
-30	3						1	2		
-50										
-70										
< -70										

Methd: GLM Age	3	4	5	6	7	8	9	10	11	12
> 70										
70	1									
50										
30	3	1	2	3	3		3	2	2	4
<¦10	3	7	6	5	7	10	7	5	1	6
-30	3	2	2	2				3	7	
-50										
-70										
< -70										

Methd: COLSIS Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50				1						
30		1	1		1	1	1			
<¦10								1	1	1
-30										
-50										
-70										
< -70										

Methd: TSER1 Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50		1							1	
30			1	1	1	1		1		
<¦10							1			
-30										
-50										
-70										
< -70										

Methd: TSER2 Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50									1	
30		1	1	1	1	1	1	1		
<¦10										
-30										
-50										
-70										
< -70										

Methd: SVPA Age	3	4	5	6	7	8	9	10	11	12
> 70	1									
70								1		
50	2	1	1	1	1	1			1	
30		1	1	1		1	1			1
<¦10		1	1	1	2	1	2	2	3	2
-30	3				2	2	2	1	1	2
-50	1	6	6	6	5	5	5	6	3	5
-70	3	1	1	1					2	
< -70										

Methd: CONVEN Age	3	4	5	6	7	8	9	10	11	12
> 70	2	1	2	1	1	1	1	1	1	1
70		1		1	1	1	1	1		1
50	1								1	
30			1	1	1	1	1	1	2	1
<¦10		1					1			1
-30	2		1	1	1	2		1	1	1
-50	2	3	3	3	3	2	4	3	2	3
-70	2	4	3	3	3	3	2	3	3	2
< -70	1									

Table 3.5 : Simulated Data Set 1 : Mean Log Ratio of Estimates of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	3	2	2	2	3	5	4	6	1	8
LS	1	0	1	0	0	4	-1	6	-4	6
AC1	1	1	0	0	0	4	-1	6	-3	7
AC2	1	1	0	0	0	3	-1	6	-3	7
AC3	-1	-0	-0	-1	-0	2	-3	3	-6	5
AC4	0	0	0	-0	0	3	-2	4	-5	6
AEFM	-5	4	2	2	4	6	4	14	-3	2
CCPUE	1	3	3	2	3	8	3	11	2	6
SURVIV	-1	-1	-1	-2	-2	0	-2	-0	-5	-3
XSA	15	16	20	24	30	40	48	66	83	117
CAGEAN	8	-3	-0	3	4	3	5	-3	-1	3
ADAPT	3	2	3	2	2	5	4	5	5	9
GLM	7	-4	2	1	2	1	4	-3	-12	6
COLSIS		17	11	28	26	25	16	6	10	-9
TSER1		36	23	21	22	20	6	19	33	
TSER2		22	19	21	18	20	10	19	36	
SVPA	-26	-37	-34	-31	-29	-29	-29	-31	-33	-28
CONVEN	-28	-38	-31	-30	-27	-26	-23	-23	-20	-19

Table 3.6 : Simulated Data Set 1 : Root Mean Square Log Ratio of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	18	7	11	7	8	12	9	17	12	21
LS	15	4	8	4	3	7	8	14	11	15
AC1	17	3	7	4	3	7	9	13	13	13
AC2	17	3	7	4	3	7	9	13	14	14
AC3	16	4	8	4	3	7	8	12	14	12
AC4	17	4	7	4	3	7	9	13	15	13
AEFM	15	7	9	6	9	9	11	25	16	31
CCPUE	16	5	7	5	5	10	9	18	13	27
SURVIV	20	7	6	5	4	6	6	9	11	12
XSA	23	17	20	25	31	41	48	67	84	119
CAGEAN	21	8	8	7	6	4	8	13	14	7
ADAPT	19	9	5	7	6	11	13	12	13	15
GLM	22	10	12	11	8	6	9	12	21	10
COLSIS		17	11	28	26	25	16	6	10	9
TSER1		36	23	21	22	20	6	19	33	
TSER2		22	19	21	18	20	10	19	36	
SVPA	57	52	51	47	43	45	42	47	52	38
CONVEN	87	74	74	71	66	67	65	69	71	60

Table 3.7 : Simulated Data Set 1 : Frequency Distributions of Percentage Deviations of Estimates of Total Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70																	3	4
70																	1	1
50																	3	1
30																		1
<10	8	10	10	10	10	10	10	10	10		10	10	10				1	
-30	2									10							2	1
-50																		1
-70																		1
< -70																		

Table 3.8 : Simulated Data Set 1 : Frequency Distributions of Percentage Deviations of Estimates of Spawning Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70																	3	3
70																	2	2
50																	1	1
30																	1	1
<10	9	10	10	10	10	10	9	10	10		10	9	10				2	
-30	1						1			7		1					1	1
-50										3								1
-70																		1
< -70																		

Table 3.9 : Simulated Data Set 1 : Frequency Distributions of Percentage Deviations of Estimates of Mean F (Ages 5-9) from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70										8								1
70										2								1
50																	1	
30	4	1	1	1		1	4	3				2		1	1	1		1
<10	5	9	9	9	9	8	6	7	10		10	8	8				2	
-30	1				1	1							2				2	2
-50																	5	2
-70																		3
< -70																		

Table 3.10: Simulated Data Set 1 : Mean Log Ratio of Estimates of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	-2	-2	4
LS	0	-0	1
AC1	-0	-0	2
AC2	-0	-0	2
AC3	1	1	-1
AC4	1	1	0
AEFM	-1	-2	6
CCPUE	-2	-3	6
SURVIV	2	2	-2
XSA	-27	-36	56
CAGEAN	-1	-2	1
ADAPT	-3	-3	5
GLM	-0	-0	-2
COLSIS			17
TSER1			20
TSER2			21
SVPA	30	28	-31
CONVEN	28	24	-24

Table 3.11 : Simulated Data Set 1 : Root Mean Square Log Ratio of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	7	8	10
LS	3	3	6
AC1	3	3	6
AC2	3	3	6
AC3	4	4	6
AC4	3	4	7
AEFM	4	6	10
CCPUE	4	5	9
SURVIV	3	3	3
XSA	27	37	56
CAGEAN	2	2	4
ADAPT	4	5	6
GLM	5	5	8
COLSIS			17
TSER1			20
TSER2			21
SVPA	45	41	45
CONVEN	66	62	67

Table 3.12 Simulated Data Set 2 : Frequency Distributions of Percentage Deviation of Estimates of N at age from True Values

Methd	HYBRID									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50							1	2		
30	1				1			1		
<10	7	10	10	10	9	10	8	5	7	5
-30	2						1	1		
-50									1	
-70										
< -70										

Methd	LS									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50							1	2	1	
30	2					1	1	1		
<10	7	10	10	10	10	9	7	5	7	5
-30	1						1	1		
-50										
-70										
< -70										

Methd	AC1									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50							1	2	1	
30	2				1	1	1	1		
<10	6	10	10	10	9	9	7	5	7	4
-30	2						1	1		
-50										1
-70										
< -70										

Methd	AC2									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50							1	2	1	
30	2					1		1		
<10	6	10	10	10	10	9	8	5	7	4
-30	2						1	1		
-50										1
-70										
< -70										

Methd	AC3									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50							1	2	1	
30	2		1		1	2	1	1		
<10	8	10	9	10	9	8	8	6	7	4
-30										
-50										1
-70										
< -70										

Methd	AC4									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50							1	2	1	
30	2					1	1	1		
<10	8	10	10	10	10	9	8	5	7	4
-30								1		
-50										1
-70										
< -70										

Methd	AEFM									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50								3	2	
30	2									
<10	6	8	9	7	7	6	8	6	5	4
-30	2	2	1	3	3	3	1			
-50						1	1		1	1
-70										
< -70										

Methd	CCPUE									
Age	3	4	5	6	7	8	9	10	11	12
> 70								1		
70										
50							1	1		
30								1		
<10	6	8	9	9	9	10	7	5	7	4
-30	4	2	1	1	1		2	1		
-50									1	1
-70										
< -70										

Methd	SURVIV									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50	1						1	1	1	
30	2	1						1		
<10	6	9	10	10	10	10	9	6	7	5
-30	1							1		
-50										
-70										
< -70										

Methd	XSA									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50							1	1	1	
30	1							1		
<10	5	8	6	8	8	7	7	7	6	5
-30	4	2	4	2	2	3	1			
-50							1		1	
-70										
< -70										

Methd	CAGEAN									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50								2		
30	2					2		1		
<10	7	10	10	10	10	8	10	6	8	5
-30	1									
-50										
-70										
< -70										

Methd	ADAPT									
Age	3	4	5	6	7	8	9	10	11	12
> 70						1	3	2	1	
70						1	1			
50			1		2	2		1	1	
30	2	1		1	4			1		
<10	6	8	9	8	2	4	3	3	4	5
-30	2	1		1	2	2	2			
-50							1	2	2	
-70										
< -70										

Methd	GLM									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50							1			
30	1	1		1						
<10	5	7	8	8	10	9	7	6	6	2
-30	4	2	2	1		1	2	2		
-50								1	2	1
-70										
< -70										

Methd	COLSIS									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30										
<10			1				1			
-30		1		1	1					
-50						1				
-70										
< -70										

Methd	TSER1									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50								1	1	
30			1	1	1	1				
<10		1					1			
-30										
-50										
-70										
< -70										

Methd	TSER2									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30										
<10		1	1	1	1	1	1	1	1	
-30										
-50										
-70										
< -70										

Methd	SVPA									
Age	3	4	5	6	7	8	9	10	11	12
> 70	6	2	3	3	1	1	2	1	2	
70	1	4	2	1	1	1	1			
50		3	3	3	5	4	3	3	1	
30	2	1	2	3	2	4	4	1		
<10	1				1			4	5	5
-30										
-50										
-70										
< -70										

Methd	CONVEN									
Age	3	4	5	6	7	8	9	10	11	12
> 70	3						1		1	
70							1			
50	2	6	5	3	3	3	1	4	1	
30	2	4	5	6	6	5	1	1		
<10	2			1	1	2	6	4	6	4
-30	1									
-50										1
-70										
< -70										

Table 3.13: Simulated Data Set 2 : Mean Log Ratio of Estimates of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	-2	1	3	2	0	0	3	7	-9	0
LS	-1	2	2	1	-1	2	5	7	5	0
AC1	-1	1	3	2	2	3	4	7	5	-14
AC2	-1	1	3	1	0	3	3	7	5	-14
AC3	1	3	5	3	4	5	8	10	5	-14
AC4	-0	2	3	1	0	2	7	7	5	-14
AEFM	-1	-4	-3	-7	-6	-8	-8	11	1	-14
CCPUE	-7	-5	-3	-5	-4	-0	-0	13	-9	-14
SURVIV	5	1	1	-3	-1	2	5	4	5	0
XSA	-5	-5	-5	-7	-6	-6	-4	7	-4	0
CAGEAN	-1	-0	1	-0	1	3	0	10	0	0
ADAPT	0	-2	3	-1	12	13	22	22	1	0
GLM	-4	-2	0	-1	-4	-4	1	-9	-17	-23
COLSIS		-14	-11	-24	-25	-40	0			
TSER1		7	13	17	16	17	10	29	29	
TSER2		4	3	7	4	5	0	0	0	
SVPA	54	44	45	39	32	32	37	22	22	0
CONVEN	33	27	26	22	18	20	18	19	14	-14

Table 3.14: Simulated Data Set 2 : Root Mean Square Log Ratio of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	10	6	5	4	5	0	15	19	25	0
LS	9	5	5	3	4	5	15	19	14	0
AC1	10	5	5	3	4	6	15	19	14	31
AC2	9	5	5	3	2	6	15	19	14	31
AC3	9	6	6	5	5	8	15	18	14	31
AC4	9	5	5	4	2	6	14	19	14	31
AEFM	12	9	6	9	11	16	23	20	32	31
CCPUE	13	7	5	7	7	4	15	33	25	31
SURVIV	15	8	5	4	5	4	13	17	14	0
XSA	14	9	9	11	9	10	26	15	28	0
CAGEAN	10	6	4	3	2	6	0	18	0	0
ADAPT	12	9	12	9	20	33	56	57	54	0
GLM	12	9	7	7	5	6	16	17	35	40
COLSIS		14	11	24	25	40	0			
TSER1		7	13	17	16	17	10	29	29	
TSER2		4	3	7	4	5	0	0	0	
SVPA	65	46	49	42	36	35	44	32	38	0
CONVEN	46	28	28	24	21	21	30	26	28	31

Table 3.15 : Simulated Data Set 2 : Frequency Distributions of Percentage Deviation of Estimates of F at age from True Values

Methd	HYBRID										LS										AC1										AC2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	1									1	1								1		1								1		1								1	
70									2																															
50							1	2											1	1							1		1								1	2	1	
30	1	1	1		1	2	2	1	2	3	1	1	1		1	2	3	3	2	1	1	1	1		1	2	2	2	2	2	1	1	1		1	2	2		2	3
<¦10	2	6	9	10	8	8	7	4	4	4	2	7	9	10	8	8	7	3	4	3	2	6	9	10	8	7	7	5	4	7	2	7	9	10	8	7	7	5	4	6
-30	6	3			1			3	1	1	6	2			1			4	2	4	6	3			1	1		3	2	1	6	2			1	1		3	2	1
-50									1	1										1																				
-70																																								
< -70																																								

Methd	AC3										AC4										AEFM										CCPUE									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70											1										1					1	2				1								1	1
70	1																		1										1	1							2	1		
50									1								1	1	1			1	1	4	2		1		1	2			1	1	1		1		1	1
30	1		1				2		2	2	1	1	1		1	2	1	1	2	2	1	1	5	1	2	6		2	1	1	1	1	7	4	1	4	2	2	3	3
<¦10	2	7	9	10	9	8	8	3	4	7	2	7	9	10	8	8	8	4	3	8	3	7	4	5	5	3	6	4	3	3	4	9	2	5	8	5	3	3	3	4
-30	6	3			1	2		7	3	1	6	2			1			4	2		4	1			1		1	2	2	1	4					1	2	2	1	
-50																			1		1							2	2	2								2	1	1
-70																																								
< -70																																								

Methd	SURVIV										XSA										CAGEAN										ADAPT									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	1								1	1	1			1																	1						1	3	3	
70										1			1				2	1	1																	1	1	1	2	
50			1				1	1				1	1	1	2	1	1		1														1			1	1			
30		1	3	4	1	2	2	3	2	1		2	3	3	2	3	1	4		1			1						2	3		2	2	2	3	1				1
<¦10	3	7	5	6	7	7	4	3	5	2	4	7	5	5	5	6	4	2	4	3	7	9	9	10	10	10	10	10	7	7	4	6	5	7	1	2	3	2	2	2
-30	5	2	1		2	1	3	2	2	4	4				1		2	3	3	2	3	1							1		4	2	2	1	4	2		2		6
-50	1							1		1	1								1	3											1				2	2			1	1
-70																				1																1	4	1	1	
< -70																																						1	1	

Methd	GLM										COLSIS										TSER1										TSER2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70									2	6				1		1																								
70									6	1					1																									
50						1		1		2			1				1																							
30	1	3	4	4	2	2	3	7	2	1																														
<¦10	6	5	5	5	7	6	6	2				1								1					1							1	1	1	1	1	1			
-30	2	2	1	1	1	1	1															1	1	1		1	1	1	1									1	1	
-50	1																																							
-70																																								
< -70																																								

Methd	SVPA										CONVEN									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																				
70																				
50																				
30																			1	1
<¦10									1	1	1					1	1	1	3	1
-30	2	2	4	4	4	5	3	5	6	4	2	7	9	8	8	8	8	7	6	7
-50	4	5	3	3	3	3	6	3	3	4	7	3	1	2	2	1	1	2		1
-70	4	3	3	3	3	2	1	2		1										
< -70																				

Table 3.16 : Simulated Data Set 2 : Mean Log Ratio of Estimates of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	-4	-2	4	0	-3	2	7	-1	6	6
LS	-5	-3	5	1	-3	0	2	-5	8	-9
AC1	-5	-3	4	1	-3	-1	4	-5	4	4
AC2	-5	-2	5	1	-3	0	4	-4	5	5
AC3	-7	-4	2	-2	-7	-5	-2	-12	-2	-1
AC4	-5	-3	5	1	-3	-0	3	-5	1	4
AEFM	-5	4	13	14	8	13	14	-9	-6	-2
CCPUE	2	5	13	9	5	6	16	-8	6	10
SURVIV	-11	-2	7	7	-2	1	5	-1	5	-5
XSA	-1	5	16	15	8	10	11	3	-5	-31
CAGEAN	-6	0	3	-0	-1	-1	-2	1	1	4
ADAPT	-6	1	6	5	-18	-14	-20	6	10	-16
GLM	-7	1	6	2	2	6	-0	15	46	54
COLSIS		4	31	59	44	75	33			-6
TSER1		-13	-13	-15	-9	-15	-14	-26	-29	
TSER2		-7	-2	-4	0	-4	-3	-13	-16	
SVPA	-64	-51	-47	-47	-46	-45	-45	-43	-32	-42
CONVEN	-41	-32	-25	-27	-27	-25	-21	-23	-9	-18

Table 3.17 : Simulated Data Set 2 : Root Mean Square Log Ratio of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	25	10	7	5	9	8	13	21	28	24
LS	25	8	8	5	8	8	12	20	26	21
AC1	25	9	7	6	8	8	13	20	25	11
AC2	25	9	7	6	8	8	13	22	26	11
AC3	24	8	6	5	8	8	9	16	20	11
AC4	25	9	8	5	8	8	11	20	27	11
AEFM	31	11	16	21	19	21	29	26	33	33
CCPUE	27	10	15	15	12	11	27	33	37	34
SURVIV	33	12	13	12	10	8	18	21	26	34
XSA	32	12	22	23	17	15	27	23	31	43
CAGEAN	11	6	6	6	4	5	5	4	8	12
ADAPT	26	11	16	12	29	42	67	94	121	24
GLM	18	12	13	11	12	15	10	17	48	59
COLSIS		4	31	59	44	75	33			6
TSER1		13	13	15	9	15	14	26	29	
TSER2		7	2	4	0	4	3	13	16	
SVPA	69	55	51	52	51	49	49	48	37	47
CONVEN	44	32	26	28	29	26	24	25	16	23

Table 3.18: Simulated Data Set 2 : Frequency Distributions of Percentage Deviations of Estimates of Total Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70																	4	
70																	2	
50																	3	4
30												1					1	6
<10	10	10	10	10	10	10	10	10	10	10	10	9	10					
-30																		
-50																		
-70																		
< -70																		

Table 3.19: Simulated Data Set 2 : Frequency Distributions of Percentage Deviations of Estimates of Spawning Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70																	2	
70																	2	
50												1					3	1
30					1							1					3	9
<10	10	10	10	10	9	10	10	10	10	10	10	8	10					
-30																		
-50																		
-70																		
< -70																		

Table 3.20: Simulated Data Set 2 : Frequency Distributions of Percentage Deviations of Estimates of Mean F (Ages 5-9) from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70												2						
70												1						
50								1		1			1					
30	3	2	1	2		2	6	3	1	1		2	7					
<10	7	8	9	8	9	8	3	6	8	8	10	4	2	1		1		3
-30					1		1		1			1			1		5	7
-50																	4	
-70																	1	
< -70																		

Table 3.21 : Simulated Data Set 2 : Mean Log Ratio of Estimates of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	2	2	4
LS	2	2	2
AC1	2	3	1
AC2	2	2	2
AC3	4	5	-5
AC4	2	2	0
AEFM	-3	-3	7
CCPUE	-4	-3	8
SURVIV	1	1	3
XSA	-4	-4	8
CAGEAN	1	1	-0
ADAPT	2	8	22
GLM	-2	-2	15
COLSIS			3
TSER1			-19
TSER2			-7
SVPA	45	39	-42
CONVEN	26	22	-21

Table 3.22: Simulated Data Set 2 : Root Mean Square Log Ratio of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	3	3	10
LS	3	3	9
AC1	3	3	8
AC2	3	3	8
AC3	5	6	7
AC4	3	3	8
AEFM	4	5	13
CCPUE	5	4	14
SURVIV	3	2	10
XSA	6	6	12
CAGEAN	2	2	3
ADAPT	5	12	38
GLM	5	5	19
COLSIS			3
TSER1			19
TSER2			7
SVPA	47	42	47
CONVEN	28	23	23

Table 3.23: Simulated Data Set 3 : Frequency Distributions of Percentage Deviation of Estimates of N at age from True Values

Methd	HYBRID										LS										AC1										AC2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																																								
70																																								
50																			1																					
30	2				1				1		2				1		3	2	3		2								2		2								2	
¦<¦10¦	7	8	9	9	7	6	5	2	5		7	10	10	10	9	10	6	7	4	6	7	10	10	10	10	10	9	5	4	3	7	10	10	10	10	10	9	5	4	3
-30	1	2	1	1	2	4	4	8	3	2	1						1	1	2	1	1						1	5	4	2	1						1	5	4	2
-50							1		1	8										3										5										4
-70																																								1
< -70																																								

Methd	AC3										AC4										AEFM										CCFUE									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																													1											
70									1										1										1											
50									1										1									1		1						1			3	1
30	4		1	1	1		1	3	3		4	1		1	1		1	3	3		4	1		1		1	1	2	1		3			1	2	2	2	2		1
¦<¦10¦	6	10	9	9	8	9	8	4	2	4	5	9	10	9	9	9	8	4	2	4	4	9	10	9	10	6	7	3	4	4	6	10	10	9	6	4	6	2	3	3
-30					1	1	1	3	3	2	1					1	1	3	3	2	2					3	2	4	3	1	1				2	3	2	6	4	
-50										4										3										3										4
-70																				1																				1
< -70																														1										

Methd	SURVIV										XSA										CAGEAN										ADAPT									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																																							3	
70										1	1																										1	1	1	
50	1								3	3	1	1																			1					2	2	5	2	1
30	3	2	1	1	2	2	3	4	4		1	1	2	2	2	1					3	2							1		2	2	2	3	6	5	3	1	1	
¦<¦10¦	4	6	9	9	8	8	7	5	3	5	7	8	8	8	8	8	9	5	3		7	8	10	10	10	10	10	8	7	8	5	7	8	6	3	2	2	2	1	6
-30	2	2						1								1	1	4	6	3								2	2		2	1		1	1	1	1	1	2	
-50										1								1	1	7										2							1			3
-70																																								
< -70																																								

Methd	GLM										COLSIS										TSER1										TSER2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																																								
70	1																																							
50	1								2																															
30	5	4	3	3	2			2																																
¦<¦10¦	3	6	7	7	8	9	5	5	1	1												1	1	1	1	1	1					1	1	1	1	1	1	1	1	
-30						1	5	3	3	1																		1	1											
-50									4	6																														
-70										2																														
< -70																																								

Methd	SVPA										CONVEN									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	2								1		1								1	
70	1	1							1		1									
50	1		1					3			2	1							1	
30	3	6	4	5	4	3	2			1	2	2	2		1		1	2	1	
¦<¦10¦	2	3	5	5	6	6	6	5	4	2	1	6	7	10	8	5	5	3	2	2
-30	1					1	2	2	3	2	2	1	1		1	5	4	3	2	2
-50									1	5	1							2	2	6
-70																			1	
< -70																				

Table 3.24 : Simulated Data Set 3 : Mean Log Ratio of Estimates of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	-0	-3	-3	-3	-6	-9	-13	-18	-12	-52
LS	5	3	3	4	3	-0	4	-1	7	-18
AC1	1	0	-0	1	-1	-5	-3	-13	-5	-34
AC2	1	0	-0	1	-1	-5	-3	-13	-5	-41
AC3	8	2	1	3	-0	-2	-0	-4	8	-27
AC4	6	2	1	3	-0	-2	1	-4	9	-34
AEFM	5	4	3	5	-0	-4	-3	-6	8	-28
CCPUE	3	-0	2	3	0	-2	-1	-12	-2	-29
SURVIV	4	2	4	5	5	7	9	7	17	12
XSA	11	10	8	7	4	1	-3	-16	-21	-48
CAGEAN	2	2	2	1	2	0	-0	-4	-1	-8
ADAPT	1	2	2	5	9	14	12	20	28	-11
GLM	15	9	7	6	3	-2	-12	-5	-24	-59
COLSIS										
TSER1		4	-1	1	-6	0	-8	-22	-29	
TSER2		7	4	2	-4	0	0	-7	0	
SVPA	25	16	10	12	9	2	-2	1	-1	-32
CONVEN	12	5	2	2	-0	-5	-7	-14	-13	-38

Table 3.25 : Simulated Data Set 3 : Root Mean Square Log Ratio of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	10	7	6	7	11	10	18	21	23	55
LS	10	5	4	6	6	2	11	9	18	30
AC1	10	5	4	4	4	6	9	16	18	44
AC2	10	5	3	4	4	6	9	16	18	54
AC3	11	5	6	7	8	6	10	16	25	38
AC4	12	6	5	7	8	6	11	16	26	50
AEFM	13	8	4	7	4	9	12	21	25	53
CCPUE	10	5	6	6	9	17	14	22	26	52
SURVIV	15	8	7	6	6	7	10	12	21	28
XSA	19	13	10	8	8	8	9	20	26	51
CAGEAN	10	6	4	4	3	3	3	7	8	18
ADAPT	18	11	8	10	14	23	27	31	44	31
GLM	22	12	10	9	9	6	15	15	42	66
COLSIS										
TSER1		4	1	1	6	0	8	22	29	
TSER2		7	4	2	4	0	0	7	0	
SVPA	37	19	15	14	12	9	13	23	35	44
CONVEN	32	14	10	6	7	10	15	30	43	45

Table 3.26: Simulated Data Set 3 : Frequency Distributions of Percentage Deviation of Estimates of F at age from True Values

Methd	HYBRID									
Age	3	4	5	6	7	8	9	10	11	12
> 70							1		1	2
70	2						1	1	1	1
50					1		2	3	3	2
30	2	2	2	1	7	7	4	4	1	3
<¦10¦	3	7	8	9	1	3	1	1	3	2
-30	3	1			1		1	1		
-50									1	
-70										
< -70										

Methd	LS									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50	2						1		1	1
30	1	2			1	1	1	1		
<¦10¦	3	6	9	8	8	8	6	7	6	4
-30	3	2	1	2	1	1	2	2	2	5
-50	1								1	
-70										
< -70										

Methd	AC1									
Age	3	4	5	6	7	8	9	10	11	12
> 70									1	1
70							1			1
50	3						1	2		1
30	1	2			3	4	2	4	5	4
<¦10¦	3	7	9	10	7	6	5	2	1	2
-30	2	1	1				1	2	3	1
-50	1									
-70										
< -70										

Methd	AC2									
Age	3	4	5	6	7	8	9	10	11	12
> 70									1	1
70	1						1	1		1
50	2						1	1		1
30	1	2	1		3	4	1	3	6	4
<¦10¦	3	7	8	10	7	6	6	3		2
-30	2	1	1				1	2	2	1
-50	1								1	
-70										
< -70										

Methd	AC3									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70									1	2
50	1						1			1
30	2	1			3	1	3	4	1	3
<¦10¦	3	8	9	9	6	8	5	4	3	2
-30	3	1	1	1	1	1	1	2	4	2
-50	1								1	
-70										
< -70										

Methd	AC4									
Age	3	4	5	6	7	8	9	10	11	12
> 70									1	
70							1			2
50	2									1
30	1	2			3	1	3	3	1	3
<¦10¦	3	7	9	9	6	8	5	6	4	2
-30	3	1	1	1	1	1	1	1	3	2
-50	1								1	
-70										
< -70										

Methd	AEFM									
Age	3	4	5	6	7	8	9	10	11	12
> 70									1	1
70							1	1		
50	1						2			
30	4	1	1	1	3	2	1	1	1	3
<¦10¦	1	8	9	5	7	8	5	5	2	4
-30	3	1		4			1	3	4	
-50	1								2	2
-70										
< -70										

Methd	CCPUE									
Age	3	4	5	6	7	8	9	10	11	12
> 70										3
70									1	
50	1					1	2	2	2	1
30	5	2		1	5	3	4	4	2	1
<¦10¦	1	7	10	6	4	5	1	3	2	3
-30	3	1		3	1	1	3	1	1	1
-50									2	1
-70										
< -70										

Methd	SURVIV									
Age	3	4	5	6	7	8	9	10	11	12
> 70									1	
70										
50	2						1			
30	2	2			1		1			
<¦10¦	3	7	7	7	8	7	4	6	1	1
-30	2	1	3	3	1	3	4	3	5	4
-50	1							1	3	5
-70										
< -70										

Methd	XSA									
Age	3	4	5	6	7	8	9	10	11	12
> 70							1	1	1	2
70	1								3	4
50							1	2		1
30	2				2	2	2	2	2	2
<¦10¦	3	6	6	7	7	5	5	4	3	
-30	3	4	4	3	1	3	1	1	1	1
-50	1									
-70										
< -70										

Methd	CAGEAN									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										2
30		1	3			1	2		4	3
<¦10¦	6	7	5	8	10	8	7	5	2	4
-30	4	2	2	2		1	1	5	4	1
-50										
-70										
< -70										

Methd	ADAPT									
Age	3	4	5	6	7	8	9	10	11	12
> 70									1	
70	1						1			
50	1				1	1	1			1
30	3	3		1	1	1	1	2		1
<¦10¦	2	5	8	6	5	2	1	2	1	3
-30	2	2	2	3	3	4	5	2	2	4
-50	1					2	1	3	2	1
-70								1	4	
< -70										

Methd	GLM									
Age	3	4	5	6	7	8	9	10	11	12
> 70									2	1
70										3
50							2	2	1	2
30					1	4	6		3	3
<¦10¦	4	4	5	8	8	3	2	3	3	1
-30	4	6	5	2	1	3		3	1	
-50	2							2		
-70										
< -70										

Methd	COLSIS									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50										
30										
<¦10¦										
-30										
-50										
-70										
< -70										

Methd	TSER1									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50									1	
30						1		1		
<¦10¦		1	1	1	1		1			
-30										
-50										
-70										
< -70										

Methd	TSER2									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										
50									1	
30										
<¦10¦			1	1	1	1	1	1		
-30		1								
-50										
-70										
< -70										

Methd	SVPA									
Age	3	4	5	6	7	8	9	10	11	12
> 70										
70										1
50									3	1
30			1			1	5	1	1	5
<¦10¦	4	3	3	5	8	7	5	7	3	1
-30	5	6	6	5	2	2		2	3	2
-50	1	1								
-70										
< -70										

Methd	CONVEN									
Age	3	4	5	6	7	8	9	10	11	12
> 70								1	1	1
70								1	2	1
50							1	1	1	1
30	2		2		2	4	5	1	1	4
<¦10¦	4	8	7	9	8	6	4	5	3	2
-30	3	2	1	1				1	1	1
-50	1								1	
-70										
< -70										

Table 3.27 : Simulated Data Set 3 : Mean Log Ratio of Estimates of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	6	4	4	3	15	12	21	21	18	30
LS	0	-2	-3	-4	3	2	1	-1	-5	-7
AC1	4	1	0	-2	8	7	9	10	9	20
AC2	4	1	0	-2	8	7	9	10	9	20
AC3	-2	-1	-2	-3	7	4	6	1	-5	14
AC4	-1	-0	-1	-4	7	4	6	1	-5	14
AEFM	0	-3	-3	-5	7	5	9	5	-8	6
CCPUE	2	2	-2	-3	7	4	7	13	2	16
SURVIV	1	-1	-4	-6	0	-6	-4	-11	-20	-42
XSA	-5	-8	-9	-8	1	-1	10	14	25	37
CAGEAN	-11	-3	-0	-6	1	2	4	-11	-6	8
ADAPT	5	-0	-3	-6	-4	-15	-8	-25	-29	-11
GLM	-20	-13	-8	-8	1	2	19	-9	20	32
COLSIS										
TSER1		-9	6	3	7	11	5	15	39	
TSER2		-17	1	0	1	6	-1	10	36	
SVPA	-20	-15	-12	-13	-4	-2	9	-4	2	13
CONVEN	-6	-4	-2	-2	7	6	14	14	18	22

Table 3.28 : Simulated Data Set 3 : Root Mean Square Log Ratio of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	26	11	7	7	19	16	29	27	37	36
LS	22	8	7	6	8	8	17	13	23	19
AC1	25	9	6	4	11	10	19	20	27	30
AC2	25	9	6	5	11	10	19	20	28	31
AC3	22	8	6	7	11	10	19	14	28	28
AC4	24	9	6	8	12	11	20	14	32	29
AEFM	25	9	7	10	9	10	21	20	38	47
CCPUE	23	10	6	10	14	17	23	20	30	48
SURVIV	25	10	8	9	7	9	17	19	38	46
XSA	25	13	11	10	10	12	22	26	42	43
CAGEAN	15	11	12	9	6	9	9	18	20	21
ADAPT	29	13	7	14	17	29	31	40	71	25
GLM	25	17	13	12	10	13	21	27	32	37
COLSIS										
TSER1		9	6	3	7	11	5	15	39	
TSER2		17	1	0	1	6	1	10	36	
SVPA	25	18	16	16	8	10	13	16	22	25
CONVEN	18	10	11	7	9	9	17	26	37	33

Table 3.29 : Simulated Data Set 3 : Frequency Distributions of Percentage Deviations of Estimates of Total Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70																		
70																		
50																		
30					1	1		1	1			4	2				6	
<10	9	10	10	10	9	9	10	9	9	10	10	6	8				4	10
-30	1																	
-50																		
-70																		
< -70																		

Table 3.30 : Simulated Data Set 3 : Frequency Distributions of Percentage Deviations of Estimates of Spawning Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70																		
70																		
50																		
30		1			1	1		2				10					1	
<10	9	9	10	10	9	9	10	6	10	10	10		10				9	9
-30	1							2										1
-50																		
-70																		
< -70																		

Table 3.31 : Simulated Data Set 3 : Frequency Distributions of Percentage Deviations of Estimates of Mean F (Ages 5-9) from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70												1						
70										1								
50	3		1	1			1	1										2
30	5	2	5	5	3	3	1	5	1	6			5		1		1	2
<10	1	7	3	3	6	6	8	2	6	3	10	5	5			1	9	6
-30	1	1	1	1	1	1		2	3			2						
-50												2						
-70																		
< -70																		

Table3.32 : Simulated Data Set 3 : Mean Log Ratio of Estimates of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	-5	-9	19
LS	3	2	1
AC1	-1	-3	10
AC2	-1	-3	10
AC3	1	-1	3
AC4	1	-0	4
AEFM	2	-0	6
CCPUE	0	-1	8
SURVIV	6	7	-6
XSA	5	1	14
CAGEAN	1	0	-3
ADAPT	10	14	-11
GLM	4	-1	7
COLSIS			
TSER1			15
TSER2			10
SVPA	11	5	-0
CONVEN	1	-3	12

Table 3.33: Simulated Data Set 3 : Root Mean Square Log Ratio of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	8	11	24
LS	4	4	10
AC1	2	4	15
AC2	2	4	15
AC3	5	6	13
AC4	5	7	14
AEFM	4	3	14
CCPUE	7	10	17
SURVIV	7	8	12
XSA	5	3	20
CAGEAN	3	2	5
ADAPT	10	15	29
GLM	7	5	10
COLSIS			
TSER1			15
TSER2			10
SVPA	12	7	8
CONVEN	4	6	17

Table 3.34: Simulated Data Set 4 : Frequency Distributions of Percentage Deviation of Estimates of N at age from True Values

Methd	HYBRID										LS										AC1										AC2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																	1																							
70																																								
50						1	1				1					2	3	2								1	1	1								1	1	1		
30	1				1	2	2				4	7	8	6	5	5	2				3	3	2		1	3	2				3	3	2		1	3	2			
<10	8	10	10	10	9	6	7	6	5	1	5	3	2	4	5	3	4	5	5	1	7	7	8	10	9	6	7	6	5	1	7	7	8	10	9	6	7	6	5	1
-30	1					1																																		
-50								1																																
-70																																								
< -70																																								

Methd	AC3										AC4										AEFM										CCPUE									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70									1										1								1													
70																																								
50	1					1	2	2			1					1	2	1								2	3	2								1	1	1		
30	4	5	3	3	3	5	3				5	6	3	1	3	2	1				2	2	3	1	2	2					3	1	2	1	2	2	1			
<10	5	5	7	7	7	4	5	5	5	1	4	4	7	9	7	7	7	6	5	1	3	8	6	7	7	4	5	5	6	1	5	9	8	9	7	6	8	6	6	1
-30																					5		1	2	1	2					2				1	1				
-50																											1													
-70																																								
< -70																																								

Methd	SURVIV										XSA										CAGEAN										ADAPT									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70							1										1	2	1		3					2	5	4	2											
70																					4	3	1	4	3	4	3													
50	1					2	1	2								1	6	2			3	7	8	6	7	4	1	3												
30	4	3	4		4	6	3							1	5	6							1																	
<10	5	7	6	10	6	2	5	5	6	1	2	2	7	7	3	2	3	3	5	1							1		4	1										
-30											6	7	3	2	2	1																								
-50											1	1																												
-70											1																													
< -70																																								

Methd	GLM										COLSIS										TSER1										TSER2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70							1																																	
70																																								
50						1	3																																	
30			2	5	5	5	2																1			1														
<10	4	3	8	5	5	3	4	6	4	1														1	1		1	1	1				1	1	1	1		1	1	
-30	4	6				1																1										1					1			
-50	2	1						1																																
-70																																								
< -70																																								

Methd	SVPA										CONVEN									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70						1	2	1	1		1						2	2	1	
70	1	1																		
50	1	2	3	3	3	1	2				1	2		1		2	2	1		
30	4	2	4	4	3	6	2				2	3	7	6	6	4	2			
<10	1	4	3	3	4	2	3	5	4	1	4	5	3	3	4	4	4	3	4	1
-30	3	1									2									
-50							1	1										1		
-70																				
< -70																				

Table 3.35: Simulated Data Set 4 : Mean Log Ratio of Estimates of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	-2	1	3	1	1	7	8	-10	0	0
LS	10	13	13	11	10	16	21	12	0	0
AC1	8	7	6	4	4	9	8	6	0	0
AC2	7	7	6	3	4	9	8	6	0	0
AC3	13	11	9	8	7	12	13	12	12	0
AC4	13	10	9	7	7	8	10	6	12	0
AEFM	-7	3	5	-3	3	7	11	12	0	0
CCPUE	2	4	5	3	2	6	6	6	0	0
SURVIV	11	9	9	1	8	16	17	12	0	0
XSA	-26	-21	-8	-3	4	14	27	31	12	0
CAGEAN	47	37	36	38	41	48	51	57	23	0
ADAPT										
GLM	-20	-16	4	11	9	11	21	-10	0	0
COLSIS										
TSER1		-14	19	3	0	16	0	0	0	
TSER2		-14	3	-6	-6	-8	-22	0	0	
SVPA	13	15	20	17	14	21	22	0	14	0
CONVEN	8	13	12	13	11	15	25	16	14	0

Table 3.36 : Simulated Data Set 4 : Root Mean Square Log Ratio of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	9	4	4	3	6	16	16	26	0	0
LS	14	14	14	12	11	20	30	22	0	0
AC1	12	8	7	5	6	15	16	15	0	0
AC2	12	8	7	5	6	15	16	15	0	0
AC3	17	12	10	9	9	17	19	22	28	0
AC4	17	11	10	7	9	15	18	15	28	0
AEFM	16	8	12	8	9	18	37	22	0	0
CCPUE	11	6	8	5	8	16	13	15	0	0
SURVIV	14	10	9	3	9	20	28	22	0	0
XSA	37	28	12	11	12	21	35	43	28	0
CAGEAN	48	37	37	38	41	49	55	59	40	0
ADAPT										
GLM	26	18	7	13	11	19	30	26	0	0
COLSIS										
TSER1		14	19	3	0	16	0	0	0	
TSER2		14	3	6	6	8	22	0	0	
SVPA	26	23	23	22	20	28	39	37	31	0
CONVEN	24	16	15	16	12	20	36	48	31	0

Table 3.37: Simulated Data Set 4 : Frequency Distributions of Percentage Deviation of Estimates of F at age from True Values

Methd	HYBRID										LS									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70									1											
70																			1	
50	1						1	1	2	1									1	
30	2	1	1	1			1	1	2	4	1						1	1	3	2
<¦10	3	7	9	9	10	10	5	5	4	2	3	3	5	4	1	4	2	3	3	3
-30	3	2					3	3	1	3	3	7	5	6	9	6	6	5	2	5
-50	1										3						1	1		
-70																				
< -70																				

Methd	AC1										AC2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70									1										1	
70									1										1	
50								1									1	1		
30	1						1		3	2	1			1				1	3	2
<¦10	3	7	10	8	6	9	3	4	4	8	3	7	10	7	6	9	4	3	4	8
-30	4	3		2	4	1	6	4	1		4	3		2	4	1	5	4	1	
-50	2							1			2							1		
-70																				
< -70																				

Methd	AC3										AC4									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																				
70																			1	
50																	1	1	1	
30							1	1	3										1	1
<¦10	3	3	8	6	4	7	2	3	5	10	3	4	8	7	5	7	3	3	5	9
-30	4	7	2	4	6	3	7	6	2		4	6	2	3	5	3	6	5	1	
-50	3										3							1	1	
-70																				
< -70																				

Methd	AEFM										CCPUE									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70							2		1	1							1		1	1
70	1		1															1		
50	1	1		2		1			1	1			1						1	1
30	1		1	1	1	2	1	4	1	1	2	1		1	1	1	2	1	3	3
<¦10	3	7	3	5	7	5	2	1			3	6	5	7	7	8	4	3	2	2
-30	3	2	5	2	2	2	3	3	6	6	5	3	4	2	2	1	3	4	1	1
-50	1						2	2	1	1								1	2	2
-70																				
< -70																				

Methd	SURVIV										XSA									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70											1	2	1							
70											1		1	1						
50								1	2		3	1	2	2	1		1			
30	2			2			1			1	2	4	2	1	1	1			1	
<¦10	2	6	6	7	2	1	3	1	2	1		3	3	4	3	2	2	3	1	
-30	4	4	4	1	8	9	4	7	5	6	3		1	2	5	7	3	1	4	1
-50	2						2	1	1	2							3	5	2	5
-70																	1	1	2	4
< -70																				

Methd	CAGEAN										ADAPT									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																				
70																				
50																				
30																				
<¦10																				
-30			1																	
-50	9	10	9	10	9	9	9	5	4											
-70	1				1	1	1	5	6	9										
< -70										1										

Methd	GLM										COLSIS									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																				
70																				
50																				
30	1								2	3										
<¦10	7	6	6	3	1	1		1	8	7										
-30	2	4	4	7	9	9	8	9												
-50							2													
-70																				
< -70																				

Methd	TSER1										TSER2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																				
70																				
50																				
30																		1	1	
<¦10			1	1	1	1	1	1	1				1	1	1	1	1			
-30																				
-50		1										1								
-70																				
< -70																				

Methd	SVPA										CONVEN									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																				
70																				
50																				
30							1		2	2									1	
<¦10	3	3	3	3	3	3	3	3	4	3	2	3	5	4	1	1	1	1	8	4
-30	5	7	5	4	4	4	3	3	4	2	8	7	5	6	9	9	9	9	1	6
-50	2		2	3	3	3	3	4		3										
-70																				
< -70																				

Table 3.38 : Simulated Data Set 4 : Mean Log Ratio of Estimates of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	-5	-1	3	2	-3	-2	-4	-3	13	3
LS	-17	-16	-12	-13	-17	-15	-16	-14	7	-7
AC1	-14	-9	-2	-2	-8	-5	-8	-7	15	3
AC2	-14	-8	-1	-1	-8	-5	-7	-7	16	4
AC3	-20	-13	-6	-7	-13	-10	-13	-12	1	-4
AC4	-20	-12	-5	-5	-11	-7	-10	-10	2	-1
AEFM	1	-4	0	9	-6	3	1	-10	-10	-8
CCPUE	-8	-5	-1	1	-5	-1	1	-5	5	7
SURVIV	-18	-11	-5	2	-15	-17	-18	-17	-9	-17
XSA	21	27	18	11	-4	-13	-22	-37	-39	-67
CAGEAN	-57	-52	-49	-55	-60	-61	-64	-72	-71	-100
ADAPT										
GLM	-3	-5	-8	-15	-21	-21	-28	-19	5	6
COLSIS										
TSER1		-63	-6	-8	-6	-7	-6	-4	-2	
TSER2		-48	4	9	10	9	10	11	13	
SVPA	-20	-18	-20	-20	-23	-25	-20	-25	-9	-15
CONVEN	-15	-15	-10	-15	-20	-18	-19	-20	-0	-11

Table 3.39: Simulated Data Set 4 : Root Mean Square Log Ratio of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	21	10	7	7	5	5	17	17	27	17
LS	26	18	14	14	18	16	23	21	24	17
AC1	24	13	5	7	10	7	19	21	27	8
AC2	25	13	6	8	9	6	19	22	30	9
AC3	27	15	9	10	14	11	19	19	19	7
AC4	27	15	10	9	12	9	20	20	25	7
AEFM	27	15	19	19	12	17	38	29	33	32
CCPUE	19	12	13	11	10	8	24	26	49	49
SURVIV	28	15	10	8	16	17	26	27	27	23
XSA	35	39	28	23	18	22	37	46	51	74
CAGEAN	58	53	50	56	61	61	64	72	72	101
ADAPT										
GLM	9	9	10	16	22	23	29	20	10	11
COLSIS										
TSER1		63	6	8	6	7	6	4	2	
TSER2		48	4	9	10	9	10	11	13	
SVPA	25	23	24	26	30	32	29	33	21	25
CONVEN	16	17	13	17	21	19	21	22	9	13

Table 3.40 : Simulated Data Set 4 : Frequency Distributions of Percentage Deviations of Estimates of Total Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70																		
70											7							
50											3						3	1
30		7	1	1	5	5	1	1	4								2	4
<10	10	3	9	9	5	5	9	9	6	5			8				5	5
-30										4			2					
-50										1								
-70																		
< -70																		

Table 3.41 : Simulated Data Set 4 : Frequency Distributions of Percentage Deviations of Estimates of Spawning Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70																		
70											6							
50											4						2	
30		8			3	2			2	4			3				5	7
<10	10	2	10	10	7	8	10	10	8	4			7				3	3
-30										2								
-50																		
-70																		
< -70																		

Table 3.42: Simulated Data Set 4 : Frequency Distributions of Percentage Deviations of Estimates of Mean F (Ages 5-9) from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70																		
70																		
50								2										
30	1		1	1			2									1		
<10	9	6	8	8	6	7	6	6	4	2			4		1		4	3
-30		4	1	1	4	3	2	2	6	8			6				3	7
-50											9						3	
-70											1							
< -70																		

Table 3.43 : Simulated Data Set 4 : Mean Log Ratio of Estimates of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	1	2	2
LS	12	12	-10
AC1	6	5	-1
AC2	6	5	-1
AC3	10	9	-9
AC4	9	7	-6
AEFM	1	2	-1
CCPUE	4	4	2
SURVIV	8	8	-14
XSA	-10	2	-20
CAGEAN	41	41	-65
ADAPT			
GLM	-3	6	-16
COLSIS			
TSER1			-5
TSER2			10
SVPA	15	16	-20
CONVEN	11	12	-15

Table 3.44: Simulated Data Set 4 : Root Mean Square Log Ratio of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	3	3	6
LS	13	12	11
AC1	7	6	7
AC2	7	5	8
AC3	11	9	10
AC4	10	8	9
AEFM	7	5	12
CCPUE	7	5	15
SURVIV	9	8	16
XSA	17	10	23
CAGEAN	41	41	66
ADAPT			
GLM	7	8	18
COLSIS			
TSER1			5
TSER2			10
SVPA	20	21	28
CONVEN	14	14	17

Table 3.45 : Simulated Data Set 5 : Frequency Distributions of Percentage Deviation of Estimates of N at age from True Values

Methd	HYBRID										LS										AC1										AC2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	2									2	1		1							1	1	1			1						1	1	1		1					
70		1	1	1	1				1		1	2	1	1	2							1	1	1			1					1	1	1	1		1			
50		1		1			1		1	1	1		3	1	1	1	2			1		1	4		3					1		1	3		2		1			1
30	1	1	3	1	3	3	2	2	1		2	3	1	1	2	3	1	3	1		3	1	1	2	1	1	1	3	1	1	3	1	1	2	1	1		3	1	1
<¦10¦	2	4	2	2	3	1	3	2	1	3	4	4	4	5	5	2	2	4	3	4	3	2	3	4	4	5	3	4	4	4	3	2	3	3	4	5	3	4	4	4
-30	4	2	4	4	3	5	3	3	4		1			2		4	5	2	5		3	3	1	1		4	5	2	2	1	2	3		2		4	5	2	1	1
-50	1	1		1		1	1	3	2	3		1						1	1	3				2	1			1	3	2	1		1	2	1			1	4	2
-70										1										1		1								1		1								1
< -70																																								

Methd	AC3										AC4										AEFM										CCPUE									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	2	1			1				2		2	2	1		2				2		2	1			1		2	1			2				1	1	1	1	1	2
70	1	1	2		1		1				1		2			1	1				1		1										1							
50	1	1	2	3	2	1	2		1	5	1	1	2	3	4		2	1	1	5		2	1		3	2	1			1	1	2	1	1	3	1	1	1		
30	1	1	4	2	3	4	2	8	1			2	3	2	1	2	1	5					3	4	1			3		1	1	5	4	3	1	1	1	1	1	
<¦10¦	4	4	1	4	2	3	2		3	3	4	3	1	3	2	4	2	2	4	2	5	6	3	2	2	2	1	1	2	1	3		3	2	3	2	2	4	3	2
-30	1	2	1	1	1	1	2	1	3		2	2	1	2	1	2	4	2	2	1	2			1	2	4	5	2	2		3	2	1	4	2	4	4	1	3	1
-50						1	1	1		1						1			1	1		1	2	2	1	1		1	5	6		1				1	1	2	2	4
-70										1										1				1		1	1	2	1	1										1
< -70																																								

Methd	SURVIV										XSA										CAGEAN										ADAPT									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	2										1										1																			
70			1								1																		1											
50	2	1	2		1							2	1	2	1			1			3	2	1	1	1	1	1	1	1	4										
30	2	5	2	3		1		4	1		2	2	5	1	1						2	3	4	4	3	4	3	5	5	2										
<¦10¦	3	2	1	2	2	2	7	4	4	5	5	4	3	6	6	8	6	4	3	2	3	4	4	3	6	3	6	3	2	4										
-30	1		2	3	6	6	3	1	3	2	1	2	1	1	2	2	4	4	4			1	1	2		2		1	1											
-50		2	2	2	1	1		1	2	3									2	7	1																			
-70																		1		1																				
< -70																			1																					

Methd	GLM										COLSIS										TSER1										TSER2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																													1											
70	2	1			1																																			
50		1	1	1																		1	1	1	1	1	1	2	1											
30	2	1	3	2	1		1															3	1	1	1	1	2		1											
<¦10¦	3	2	5	2	4	3	1	1														2	3	5	4	3	2	2												
-30	2	4	1	4	4	5	6	1	1													2	4	3	3	2	1	2	2											
-50	1	1		1		2	2	6	8	7												2	1		1	3	4	3	4											
-70								2	1																			1	1											
< -70										3																														

Methd	SVPA										CONVEN									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																				
70																				
50																				
30																				
<¦10¦																				
-30																				
-50																				
-70																				
< -70																				

Table 3.46 : Simulated Data Set 5 : Mean Log Ratio of Estimates of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	4	-1	0	-3	3	-11	-5	-19	-9	-10
LS	18	8	23	7	17	2	-3	-5	-14	-21
AC1	6	-1	17	-3	12	-8	-7	-5	-16	-19
AC2	6	-1	20	-4	15	-8	-7	-4	-18	-19
AC3	23	14	21	10	20	1	6	8	18	8
AC4	20	17	27	10	25	2	5	7	15	2
AEFM	22	4	2	-10	10	-16	-6	-18	-42	-44
CCPUE	16	5	13	1	14	1	-0	1	-9	-16
SURVIV	26	1	-1	-13	-16	-20	-12	-4	-15	-24
XSA	14	8	10	6	3	-4	-8	-14	-35	-58
CAGEAN	15	9	8	7	8	7	11	12	14	20
ADAPT										
GLM	3	-4	3	-6	-5	-22	-21	-55	-58	-94
COLSIS										
TSER1		-10	-8	-6	-8	-13	-16	-23	-27	
TSER2										
SVPA										
CONVEN										

Table 3.47: Simulated Data Set 5 : Root Mean Square Log Ratio of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	42	31	24	27	22	25	26	31	32	65
LS	35	28	30	22	25	15	21	21	23	58
AC1	35	38	29	27	29	17	25	23	26	47
AC2	36	39	33	28	32	17	25	23	28	47
AC3	37	28	28	20	31	21	29	21	53	42
AC4	39	31	35	23	37	24	27	20	57	48
AEFM	61	30	30	40	38	41	46	46	50	62
CCPUE	34	30	24	21	33	32	31	37	48	75
SURVIV	42	30	36	27	24	26	17	21	28	36
XSA	28	19	20	17	16	13	15	32	54	66
CAGEAN	29	21	18	17	14	15	16	19	24	28
ADAPT										
GLM	27	29	18	23	21	26	27	60	63	102
COLSIS										
TSER1		29	24	18	24	29	34	40	53	
TSER2										
SVPA										
CONVEN										

Table 3.48 : Simulated Data Set 5 : Frequency Distributions of Percentage Deviation of Estimates of F at age from True Values

Methd	HYBRID										LS										AC1										AC2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	1							1	2	3	1								2	2	1	1		1	1			1	3		1	1		1	1			1	3	
70	1	1		2	1	1		1										1	1					1			1			1				2			1			1
50			2	1	1	2	3		4	1	1	1		1			1	1	1	2	1			1		3	1	1	2	2	1		1			2	1	1	2	2
30	2	2	1	1		2	2							3	1	1	3		2	1	2	1	2	1	1		2	1		4	2	1	1	1	1	1	2	1		4
<¦10¦	1	2	2	3	5	2	3	5			1	2	3		2	4	3	3	1		2	3		3	3	5	4	2	2	1	2	3		3	2	5	4	2	2	1
-30	4	2	3	1	2	2	2	3	2	4	3	3	2	4	5	4	3	3	2	4	1	2	5	2	2	2	2	2	1	2	1	2	5	2	3	2	2	2	1	2
-50		3	2	2	1	1			1	1	3	4	5	2	2	1		2	1	1	2	2	3		3			3	1		2	2	3		3			3	1	
-70	1								1	1	1										1	1		1					1		1	1		1					1	
< -70																																								

Methd	AC3										AC4										AEFM										CCPUE									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70									1		1								1		1		1	3		1	2	3	4	4	2							1	3	4
70	1													1		1		1				1			1	2		1	1	2		1		1	1		1	1	1	
50				1		2					1				1	1				1	2		1		1		1		1	1						1				1
30	1			1	1		3	1	1	2			1	1			3	2	1	2	1		1	1	2	2	2		1	1			1	3	1	4	4	1	1	2
<¦10¦	1	3	2	3	3	3	3	3	4	4	1	3	1	4	3	4	3	1	4	3	1	1	1	1	1	3	1	1	3	1	2	2	2	2	3	1	1	2	3	1
-30	2	2	5	3	3	4	3	2	1	3	2	3	2	2	2	3	3	1	1	3	1	6	4	2	3		2	1		1	1	3	4	3	3	2	3	2		
-50	4	4	2	2	2	1	1	3	1	1	4	3	5	1	3	1	1	4	1	1	1	2	2	3	1	2	2	3			4	4	3	1	1	1	1	2		
-70	1	1	1		1			1	1		1	1	1	1	1			1	1		2				1			1			1				1	1		1	1	1
< -70									1										1		1																		1	1

Methd	SURVIV										XSA										CAGEAN										ADAPT									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70							1	1	2	1	1						1	3	5	4																				
70	1	1	3	4	2	3		1		1						1				2																				
50				1	3	1	2	1	2	2				1	2			1	1	1																				
30	1	1			2	3	3	1		3	1		1	1		1	4			2					1															
<¦10¦	4		2	3	1	2	1		3	2	3	2	3	3	4	5	2		2		1	4	4	2	1	1	3	1												
-30		7	3	1	2	1	3	3	2		1	6	4	4	4	3	2	4	2	1	3	3	6	8	7	8	6	5	3	1										
-50		1	2	1				3	1	1	3	2	2	1			1	1			6	3			1		1	4	6	8										
-70	4										1							1								1			1	1										
< -70																																								

Methd	GLM										COLSIS										TSER1										TSER2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70							1	2	1	9																2		1	2											
70					1	1	1	4	3																3		2	1	1											
50				2	1	3	2	2	2													1		1		2	3	1												
30		3	2	2	2	3	2	1	3	1												2	4	2	1	3	1	2	2											
<¦10¦	2	3	3	3	4	2	3	1	1													3	4	4	3	1	1	3	3											
-30	5	2	5	2	2	1	1															3	1	3	2	1	2	1												
-50	3	2		1																		1	1		1	1	1	1	2											
-70																																								
< -70																																								

Methd	SVPA										CONVEN									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																				
70																				
50																				
30																				
<¦10¦																				
-30																				
-50																				
-70																				
< -70																				

Table 3.49 : Simulated Data Set 5 : Mean Log Ratio of Estimates of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	-6	-14	-5	2	-4	9	6	6	9	4
LS	-20	-23	-30	-10	-20	-7	3	-11	16	12
AC1	-8	-14	-24	3	-14	6	8	-9	16	12
AC2	-8	-14	-27	4	-17	5	8	-10	17	12
AC3	-26	-30	-28	-13	-24	-6	-7	-26	-25	-9
AC4	-22	-33	-35	-13	-29	-6	-7	-23	-21	-6
AEFM	-25	-19	-7	12	-11	16	8	14	54	63
CCPUE	-18	-21	-19	-3	-17	-5	1	-15	11	19
SURVIV	-29	-16	-4	14	18	19	14	-10	12	18
XSA	-16	-24	-16	-9	-5	0	9	6	35	53
CAGEAN	-37	-24	-16	-15	-18	-26	-16	-30	-48	-55
ADAPT										
GLM	-30	-10	-5	0	8	19	17	40	30	79
COLSIS										
TSER1		-4	-1	2	8	16	15	11	11	
TSER2										
SVPA										
CONVEN										

Table 3.50 : Simulated Data Set 5 : Root Mean Square Log Ratio of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	49	34	30	32	28	27	24	31	59	52
LS	47	36	39	29	30	19	19	33	44	44
AC1	50	40	35	39	37	21	22	37	54	25
AC2	50	42	39	41	42	22	24	40	55	25
AC3	46	39	35	29	36	29	20	38	62	20
AC4	54	43	43	34	44	32	24	45	69	23
AEFM	74	33	34	58	44	52	45	84	83	92
CCPUE	49	36	31	28	41	37	27	53	71	76
SURVIV	55	31	39	36	30	27	33	45	48	32
XSA	41	28	26	25	21	17	36	57	55	72
CAGEAN	40	31	21	17	24	31	21	34	50	56
ADAPT										
GLM	36	28	18	24	23	27	30	45	35	83
COLSIS										
TSER1		24	25	18	32	39	35	33	38	
TSER2										
SVPA										
CONVEN										

Table 3.51: Simulated Data Set 5 : Frequency Distributions of Percentage Deviations of Estimates of Total Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70																		
70								1										
50	1	2	1	1	1	3	2	1										
30	2	3	3	3	7	5	2	3	1	1	3		2					
<¦10¦	3	4	2	3			3	2	5	9	7		5					
-30	3	1	3	2	2	2	2	2	3				2					
-50	1		1	1			1	1	1				1					
-70																		
< -70																		

Table 3.52: Simulated Data Set 5 : Frequency Distributions of Percentage Deviations of Estimates of Spawning Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70								1										
70																		
50					2	3	2											
30	3	4	2	3	4	4	1	4			4							
<¦10¦	1	5	6	5	2	1	4	2	4	8	6		4					
-30	6	1	2	2	2	2	2	3	6	2			5					
-50							1						1					
-70																		
< -70																		

Table 3.53: Simulated Data Set 5 : Frequency Distributions of Percentage Deviations of Estimates of Mean F (Ages 5-9) from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70							4						1					
70							2	1		1			1		3			
50	4					1		2	2									
30	2	4	6	6	2	1	1	2	7	6			6		3			
<¦10¦	1	4	2	2	1	2	2	2	1	3			1		2			
-30	3	2	2	2	6	5	1	2			9		1					
-50					1	1					1				2			
-70								1										
< -70																		

Table 3.54: Simulated Data Set 5 : Mean Log Ratio of Estimates of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	-4	-5	9
LS	9	6	1
AC1	0	-0	7
AC2	1	1	7
AC3	14	11	-14
AC4	17	14	-11
AEFM	1	-3	35
CCPUE	5	4	0
SURVIV	-10	-16	17
XSA	1	-4	18
CAGEAN	4	4	-27
ADAPT			
GLM	-10	-17	24
COLSIS			
TSER1			12
TSER2			
SVPA			
CONVEN			

Table 3.55: Simulated Data Set 5 : Root Mean Square Log Ratio of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	23	20	26
LS	19	14	14
AC1	20	13	19
AC2	21	14	20
AC3	21	20	22
AC4	24	23	24
AEFM	26	26	46
CCPUE	26	28	37
SURVIV	17	19	19
XSA	7	7	22
CAGEAN	11	9	28
ADAPT			
GLM	19	22	30
COLSIS			
TSER1			34
TSER2			
SVPA			
CONVEN			

Table 3.56: Simulated Data Set 6 : Frequency Distributions of Percentage Deviation of Estimates of N at age from True Values

Methd	HYBRID										LS										AC1										AC2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	1	1	1	2				2	1	1		1																		1										1
70		2		1	2	1	1					2	1	2								1										1								
50	1		2		1	2	2		1		1	1	2	2	1	1	1	1	1	3			1						1	1			1						1	1
30	3	2	2	2		1	2	1	1		1	5	5	1	3	4	3	1	2	1	2	1	3	3			1	2	1		2	1	3	4	1		1	2	1	
<¦10¦	3	1	3		4	3	1	2	4	9	4	1	2	3	3	3	4	3	2	5	3	3	2	3	4	3	3	1	1	2	3	3	2	1	3	3	3	1	1	2
-30	2	4	2	3	2	2	3	5	2		4			2	3	1	2	4	5	1	3	5	4	1	5	5	5	6	5		3	2	4	2	5	5	5	6	5	
-50				2	1	1	1		1							1		1			2			3	1	2	1	1	2	5	2	3		3	1	2	1	1	2	5
-70																														1										
< -70																																								1

Methd	AC3										AC4										AEFM										CCPUE									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	6	3	2	2	3	2	3	1	3	4	4	3	2	4	3	2	3	1	3	3	3	1	2			2		2		2		2			1	1				2
70		1		2	1	2		1			2	2				1				1				1	1				1	1	1			1	1					
50	1	2	2	2			1			2	1	1	3	1	1	1	1	3		2		2	1			1	2				2	2	1		1					1
30	2	1	3	1	2	3	1	3			3	1	3	2	2	3	3	1	1		1	1	1	1	1	1	1	1	1			1		1	2	2	1			
<¦10¦	1	3	3	3	4	2	4	3	3	1		2	2	2	3	2	3	3	2	1	4	2	3	3	2	1	1	4	3	3	2	2	5	4	3	2	2	4	3	2
-30						1	1	1	3	2		1		1	1	1		1	3	1	1	2	1		3		1		3	1	4	3	4	2	2	3	6	3	3	
-50								1	1	1								1	1	2	1	1	2	5	1	3	5	2	2	2	1			1		1	1	3	3	3
-70																									2	2		1		1				1		1			1	2
< -70																						1																		

Methd	SURVIV										XSA										CAGEAN										ADAPT									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	3										1										1									1										
70												1	1								3	1					1		1											
50		1									2	1		1	1	1	1		1			2	1			1		1		5										
30	3	2				1		1	1		2	3	4	3	2	2	1	3	2	1	3	2	4	5	4	3	4	8	6	2										
<¦10¦	2	3	5	4	4	3	4	2	2	4	3	3	5	5	6	5	7	4	3	7	1	3	5	5	6	5	5	1	2	1										
-30	2	3	4	3	2	2	5	3	4	2	2	2		1	1	2	1	3	4	1		2				1			1											
-50		1	1	3	4	4	1	4	2	3										1	2									1										
-70									1	1																														
< -70																																								

Methd	GLM										COLSIS										TSER1										TSER2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70	1	1	1				1																																	
70		1		1	1		1															1																		
50	2			1		1																	1				1													
30		1	1		1	1	1															1	2	4	1	1		2												
<¦10¦	1	3	7	4	2	2			2	2												6	5	3	4	5	3	1	2											
-30	5	4	1	3	6	4	6	4	6	1												2	2	2	5	2	4	4	5											
-50	1			1		2	1	5	2	6														1		2	2	3	3											
-70								1		1																														
< -70																																								

Methd	SVPA										CONVEN									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																				
70																				
50																				
30																				
<¦10¦																				
-30																				
-50																				
-70																				
< -70																				

Table 3.57: Simulated Data Set 6 : Mean Log Ratio of Estimates of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	11	15	11	8	2	5	6	3	5	11
LS	1	27	21	12	4	3	4	-6	-5	10
AC1	-14	-8	2	-14	-12	-24	-17	-14	-16	-23
AC2	-14	-13	2	-14	-13	-26	-16	-15	-16	-30
AC3	62	39	33	36	29	31	31	16	27	26
AC4	65	43	36	37	29	31	33	16	23	22
AEFM	23	-3	6	-19	-31	-12	-23	-5	-13	-3
CCPUE	-2	19	-5	-8	16	-9	-17	-20	-32	-17
SURVIV	29	-7	-13	-23	-23	-25	-18	-25	-33	-30
XSA	11	9	11	8	4	4	3	-0	-2	-5
CAGEAN	15	13	12	8	7	10	15	16	17	25
ADAPT										
GLM	-1	3	4	-5	-7	-9	-5	-49	-29	-54
COLSIS										
TSER1		2	2	-1	-8	-12	-19	-23	-29	
TSER2										
SVPA										
CONVEN										

Table 3.58: Simulated Data Set 6 : Root Mean Square Log Ratio of N at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	30	43	29	37	30	29	29	32	31	31
LS	16	33	25	27	16	22	18	22	21	23
AC1	26	23	18	33	20	32	24	25	31	56
AC2	27	30	20	34	23	33	24	25	31	70
AC3	76	57	49	47	45	53	53	40	74	54
AC4	78	62	52	51	48	52	49	37	67	59
AEFM	76	56	37	40	57	75	43	55	31	62
CCPUE	29	40	19	34	36	36	25	30	42	72
SURVIV	51	26	19	32	30	33	23	32	45	43
XSA	28	20	18	15	14	16	16	16	19	19
CAGEAN	40	26	18	12	12	18	22	17	24	36
ADAPT										
GLM	37	30	20	28	24	25	37	56	35	63
COLSIS										
TSER1		17	16	19	16	23	31	37	38	
TSER2										
SVPA										
CONVEN										

Table 3.59 : Simulated Data Set 6 : Frequency Distributions of Percentage Deviation of Estimates of F at age from True Values

Methd	HYBRID										LS										AC1										AC2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70									1	2									1	2				3	1	3	1	1	1	3				3	1	3	1	1	1	3
70		1	1		1	1			1	1						1						1		1			2			2		4		1	1		2			2
50		2		2	1	2		1		1				1	1	2	1	1		1	2	2	2		2		2	2			2	2	2		2	1	2	2		
30		1	1	3	2	1	3	2				1	1	2	3		1	3			3	3	3	1	2	5	1	2	2	1	3		3	2	1	4	1	2	2	1
<¦10¦	1	2	2	1	3	2	3	1			4	1	2	2	1	2	4	2	2	1	1	3		3	4	2	1	3	3	2	1	3		2	4	2		2	3	2
-30	5	2	4	2	1	2	2	3	1	3	3	7	3	4	5	3	2	2	3	2	2		3	1	1		3	2	3	2	2		3	1	1		4	3	3	2
-50	2	1	1	1	2	2	2	2	6	1	1		4			2	2	2	4	3	1	1	2	1							1	1	2	1						
-70	2	1	1	1				1	1	1	2	1		1						1									1										1	
< -70										1											1										1									

Methd	AC3										AC4										AEFM										CCPUE									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																						2	2	5	3	4	2	2	1	1				2		2	2	1	2	2
70																	1	1				1			2	1	1						1		1		1		1	1
50						1	1	1		1					1	1				1					1		1		1	1			2	1		1	1	3		1
30					1	2		1						1				1	1		2	1	2	1	1		2	1	1	2	2	3	2	2		2		1	1	1
<¦10¦		4	1	1	2			1	1	2		4	2	1	3	2		1	2	2	2	2	1	3			2	4	1	2	2	3	2	3	4	2	3	2	2	2
-30	1	2	5	5	3	3	2	3	5	3	1	2	4	4	3	2	2	2	1	4	2	3	2		2	3	2		4	1	2	3	2	1	2	2	3	3	3	
-50	3	2	2	2	2	2	5	2	1	3	3	1	2	1		3	5	3	3	2	1		2		1	1		1	1	2	3		1		2				1	3
-70	3	2	2	2	2	1	2	2	2	1	2	2	2	3	3	1	2	2	2	1	1	1	1	1				2	1	1	1	1		1	1	1				
< -70	3					1			1		4	1				1			1		2					1														

Methd	SURVIV										XSA										CAGEAN										ADAPT									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70		1		1	2	2	2	2	2	3									1																					
70			1	4	2	3	1	1		1						1	1			1																				
50		3	1	1		1	1	1	3	3			1		1		1			3																				
30	2	2	3	3	3	1	2	2		1	1	2		2	1	2	2	2	1					1																
<¦10¦	2	1	5		1	2	2	3		1	1	7	2	5	4	3	1	2		2		3	3	3	1	1	1	3												
-30		3		1	2	1	1	1	3	1	4		6	2	4	3	2	5	3	4	1	5	7	6	6	5	7	4		2										
-50	2						1		2		2	1	1	1		1	3	1	5		5	2			3	3	2	3	8	8										
-70	2										2										4					1			2											
< -70	2																																							

Methd	GLM										COLSIS										TSER1										TSER2									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70								6		4																1	1	1	2											
70					1	2	1																	1	1		1	1												
50				2				1		3												1	1	2		1	1	1	2											
30	1	3	3	2	3	3	3	1	2	1													1		4	4	4	2	5											
<¦10¦	1	4	5	3	3	3	2	1	3													7	6	7	3	3	3	4	1											
-30	2	2	1	2	1	1	2	1	4	1												2	2		2	1		1												
-50	5	1	1	1	2	1	1		1	1																														
-70	1						1																																	
< -70																																								

Methd	SVPA										CONVEN									
Age	3	4	5	6	7	8	9	10	11	12	3	4	5	6	7	8	9	10	11	12
> 70																				
70																				
50																				
30																				
<¦10¦																				
-30																				
-50																				
-70																				
< -70																				

Table 3.60: Simulated Data Set 6 : Mean Log Ratio of Estimates of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	-39	-10	-14	-4	-2	-5	-11	-15	-23	-10
LS	-30	-24	-25	-9	-5	-3	-8	-5	-17	-8
AC1	-15	14	-3	22	14	31	17	7	4	25
AC2	-15	20	-4	23	16	33	17	8	5	27
AC3	-93	-37	-38	-36	-33	-34	-40	-29	-56	-29
AC4	-93	-41	-41	-36	-33	-35	-41	-28	-51	-28
AEFM	-52	11	-7	29	43	24	25	-1	-1	1
CCPUE	-27	-14	4	15	-18	13	18	13	24	26
SURVIV	-58	14	13	32	28	31	19	21	15	36
XSA	-39	-5	-15	-5	-6	-5	-8	-12	-20	2
CAGEAN	-62	-18	-19	-12	-27	-34	-23	-24	-58	-44
ADAPT										
GLM	-39	-9	-4	-1	0	6	-7	52	-12	35
COLSIS										
TSER1		-4	3	8	9	15	22	18	23	
TSER2										
SVPA										
CONVEN										

Table 3.61 : Simulated Data Set 6 : Root Mean Square Log Ratio of F at age to True Values

Method	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12
HYBRID	51	46	36	40	35	37	24	36	63	69
LS	48	33	33	29	21	31	25	25	54	51
AC1	58	32	28	45	28	42	36	29	56	43
AC2	58	39	30	48	32	44	39	29	57	46
AC3	102	57	53	47	50	61	53	51	78	44
AC4	102	63	57	52	54	60	54	50	74	42
AEFM	86	69	46	55	75	100	46	73	52	53
CCPUE	41	38	28	46	39	50	46	36	71	76
SURVIV	89	31	23	41	42	43	43	33	65	47
XSA	55	21	26	20	20	24	36	26	58	30
CAGEAN	67	24	22	16	31	38	27	28	59	45
ADAPT										
GLM	51	25	23	28	26	30	38	64	25	56
COLSIS										
TSER1		17	14	20	18	29	28	31	30	
TSER2										
SVPA										
CONVEN										

Table 3.62 : Simulated Data Set 6 : Frequency Distributions of Percentage Deviations of Estimates of Total Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70	1				4	3	1											
70					1	2		1					1					
50	3	2			1	1	1			1	2		1					
30	1	5			2	2		2	1	1	5							
<|10|	3	2	7	7	2	2	4	6	2	8	3		3					
-30	2	1	2	2			2	1	7				5					
-50			1	1			2											
-70																		
< -70																		

Table 3.63 : Simulated Data Set 6 : Frequency Distributions of Percentage Deviations of Estimates of Spawning Biomass from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70					2	2	1											
70	1				1	1												
50	3				2	2	1	1			2		2					
30	1	5			3	3				2	4							
<|10|	3	4	5	5	2	1	2	7		8	4		2					
-30	1	1	4	4		1	4	2	9				6					
-50	1		1	1			2		1									
-70																		
< -70																		

Table 3.64: Simulated Data Set 6 : Frequency Distributions of Percentage Deviations of Estimates of Mean F (Ages 5-9) from True Values

Methd	HYBRI	LS	AC1	AC2	AC3	AC4	AEFM	CCPUE	SURVI	XSA	CAGEA	ADAPT	GLM	COLSI	TSER1	TSER2	SVPA	CONVE
> 70			1	1			4	3	2									
70			1	2			2						1		2			
50	2	1	2	1		1			1	1			2					
30	2	2	2	2	1		1	1	4				3		4			
<|10|	1	2	4	4	1	1	2	5	3	5			2		4			
-30	3	4			3	4				4	7		1					
-50	2	1			4	3		1			3		1					
-70						1	1											
< -70					1													

Table 3.65 : Simulated Data Set 6 : Mean Log Ratio of Estimates of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	11	8	-8
LS	12	8	-4
AC1	-10	-13	19
AC2	-12	-14	20
AC3	41	33	-36
AC4	43	34	-34
AEFM	2	-10	32
CCPUE	4	-2	18
SURVIV	-13	-22	27
XSA	6	4	-6
CAGEAN	15	15	-33
ADAPT			
GLM	-2	-8	11
COLSIS			
TSER1			17
TSER2			
SVPA			
CONVEN			

Table 3.66 : Simulated Data Set 6 : Root Mean Square Log Ratio of Biomass and Mean F to True Values

Method	TSB	SSB	FBAR
HYBRID	30	28	29
LS	19	15	19
AC1	18	18	30
AC2	19	19	32
AC3	52	47	51
AC4	53	47	48
AEFM	47	38	57
CCPUE	17	16	39
SURVIV	17	24	37
XSA	12	7	22
CAGEAN	20	18	34
ADAPT			
GLM	24	23	29
COLSIS			
TSER1			25
TSER2			
SVPA			
CONVEN			

Table 4.1: Ranking of Methods - Data Sets 5 and 6

	Ranking on MLR(Mean F)					Ranking on MLR(SSB)			
	Set 5		Set 6			Set 5		Set 6	
Rank	Method	MLR	Method	MLR	Rank	Method	MLR	Method	MLR
1	CCPUE	0	LS	-4	1	AC1	0	CCPUE	-2
2	LS	1	XSA	-6	2	AC2	1	XSA	4
3	AC1	7	HYB	-8	3	AEFM	-3	LS	8
4	AC2	7	GLM	11	4	CCPUE	4	HYBRID	8
5	HYBRID	9	TSER1	17	5	XSA	-4	GLM	8
6	AC4	-11	CCPUE	18	6	CAGEAN	4	AEFM	-10
7	TSER1	12	AC1	19	7	HYBRID	5	AC1	-13
8	AC3	-14	AC2	20	8	LS	6	AC2	-14
9	SURVIV	17	SURVIV	27	9	AC3	11	CAGEAN	15
10	XSA	18	AEFM	32	10	AC4	14	SURVIV	-22
11	GLM	24	CAGEAN	33	11	SURVIV	-16	AC3	33
12	CAGEAN	-27	AC4	34	12	GLM	-17	AC4	34
13	AEFM	35	AC3	36	?	TSER1	*	TSER1	*
?	ADAPT	*	ADAPT	*	?	ADAPT	*	ADAPT	*
?	COLSIS	*	COLSIS	*	?	COLSIS	*	COLSIS	*
?	TSER2	*	TSER2	*	?	TSER2	*	TSER2	*
?	SVPA	*	SVPA	*	?	SVPA	*	SVPA	*
?	CONVEN	*	CONVEN	*	?	CONVEN	*	CONVEN	*

	Ranking on RMS(Mean F)					Ranking on RMS(SSB)			
	Set 5		Set 6			Set 5		Set 6	
Rank	Method	RMS	Method	RMS	Rank	Method	RMS	Method	RMS
1	LS	14	LS	19	1	XSA	7	XSA	7
2	SURVIV	19	XSA	22	2	CAGEAN	9	LS	15
3	AC1	19	TSER1	25	3	AC1	13	CCPUE	16
4	AC2	20	HYBRID	29	4	LS	14	CAGEAN	18
5	AC3	22	GLM	29	5	AC2	14	AC1	18
6	XSA	22	AC1	30	6	SURVIV	19	AC2	19
7	AC4	24	AC2	32	7	AC3	20	GLM	23
8	HYBRID	26	CAGEAN	34	8	HYBRID	20	SURVIV	24
9	CAGEAN	28	SURVIV	37	9	GLM	22	HYBRID	28
10	GLM	30	CCPUE	39	10	AC4	23	AEFM	38
11	TSER1	34	AC4	48	11	AEFM	26	AC3	47
12	CCPUE	37	AC3	51	12	CCPUE	28	AC4	47
13	AEFM	46	AEFM	57	?	TSER1	*	TSER1	*
?	ADAPT	*	ADAPT	*	?	ADAPT	*	ADAPT	*
?	COLSIS	*	COLSIS	*	?	COLSIS	*	COLSIS	*
?	TSER2	*	TSER2	*	?	TSER2	*	TSER2	*
?	SVPA	*	SVPA	*	?	SVPA	*	SVPA	*
?	CONVEN	*	CONVEN	*	?	CONVEN	*	CONVEN	*

Table4.2 : Simulated Data Set 1

MLR and RMS of Mean F for each Method

100*MLR

100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9	LS AC1 AC2 AC3 AC4 CCPUE SURVIV CAGEAN ADAPT GLM					
10-19	HYBRID AEFM					
20-29						
30-39						
40-49				SVPA		
>=50			CONVEN			XSA

Not included : COLSIS : TSER1 : TSER2

Table4.3 : Simulated Data Set 1

MLR and RMS of SSB for each Method

100*MLR

100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9	HYBRID LS AC1 AC2 AC3 AC4 AEFM CCPUE SURVIV CAGEAN ADAPT GLM					
10-19						
20-29						
30-39				XSA		
40-49			SVPA			
>=50			CONVEN			

Not included : COLSIS : TSER1 : TSER2

Table 4.4 : Simulated Data Set 2

MLR and RMS of Mean F for each Method

	100*MLR					
100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9	LS AC1 AC2 AC3 AC4 CAGEAN					
10-19	HYBRID AEFM CCPUE SURVIV XSA					
20-29		GLM	CONVEN			
30-39			ADAPT			
40-49					SVPA	
>=50						

Not included : COLSIS : TSER1 : TSER2

Table 4.5 : Simulated Data Set 2

MLR and RMS of SSB for each Method

	100*MLR					
100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9	HYBRID LS AC1 AC2 AC3 AC4 AEFM CCPUE SURVIV XSA CAGEAN GLM	ADAPT				
10-19						
20-29			CONVEN			
30-39					SVPA	
40-49						
>=50						

Not included : COLSIS : TSER1 : TSER2

Table 4.6 : Simulated Data Set 3

MLR and RMS of Mean F for each Method

	100*MLR					
100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9	CAGEAN SVPA					
10-19	LS AC3 AC4 AEFM CCPUE SURVIV GLM	AC1 AC2 CONVEN				
20-29		HYBRID XSA ADAPT				
30-39						
40-49						
>=50						

Not included : COLSIS : TSER1 : TSER2

Table 4.7 : Simulated Data Set 3

MLR and RMS of SSB for each Method

	100*MLR					
100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9	LS AC1 AC2 AC3 AC4 AEFM SURVIV XSA CAGEAN GLM SVPA CONVEN					
10-19	HYBRID CCPUE	ADAPT				
20-29						
30-39						
40-49						
>=50						

Not included : COLSIS : TSER1 : TSER2

Table 4.8 : Simulated Data Set 4

MLR and RMS of Mean F for each Method

	100*MLR					
100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9	HYBRID AC1 AC2 AC4					
10-19	AC3 AEFM CCPUE	LS SURVIV GLM CONVEN				
20-29			XSA SVPA			
30-39						
40-49						
>=50						CAGEAN

Not included : COLSIS : TSER1 : TSER2

Table 4.9 : Simulated Data Set 4

MLR and RMS of SSB for each Method

	100*MLR					
100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9	HYBRID AC1 AC2 AC3 AC4 AEFM CCPUE SURVIV GLM					
10-19	XSA	LS CONVEN				
20-29		SVPA				
30-39						
40-49				CAGEAN		
>=50						

Not included : COLSIS : TSER1 : TSER2

Table 4.10 : Simulated Data Set 5

MLR and RMS of Mean F for each Method

100*MLR

100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9						
10-19	LS AC1	SURVIV				
20-29	HYBRID AC2	AC3 AC4 XSA	CAGEAN			
30-39	CCPUE	TSER1	GLM			
40-49				AEFM		
>=50						

Not included : COLSIS : ADAPT : TSER2 : SVPA : CONVEN

Table 4.11 : Simulated Data Set 5

MLR and RMS of SSB for each Method

100*MLR

100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9	XSA CAGEAN					
10-19	LS AC1 AC2 SURVIV					
20-29	HYBRID AEFM CCPUE	AC3 AC4 GLM				
30-39						
40-49						
>=50						

Not included : COLSIS : ADAPT : TSER1 : TSER2 : SVPA : CONVEN

Table 4.12: Simulated Data Set 6

MLR and RMS of Mean F for each Method

	100*MLR					
100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9						
10-19	LS					
20-29	HYBRID XSA GLM					
30-39		AC1 CCPUE TSER1	AC2 SURVIV	CAGEAN		
40-49				AC4		
>=50			AEFM	AC3		

Not included : COLSIS : ADAPT : TSER2 : SVPA : CONVEN

Table 4.13: Simulated Data Set 6

MLR and RMS of SSB for each Method

	100*MLR					
100*RMS	0-9	10-19	20-29	30-39	40-49	>50
0-9	XSA					
10-19	LS CCPUE	AC1 AC2 CAGEAN				
20-29	HYBRID GLM		SURVIV			
30-39		AEFM				
40-49				AC3 AC4		
>=50						

Not included : COLSIS : ADAPT : TSER1 : TSER2 : SVPA : CONVEN

Table 4.14: Real Data Set : HADDOCK in North Sea

No estimates available for XSA, ADAPT, GLM, TSER1, TSER2, SVPA, CONVEN

Estimates of Number at Age in 1986

	Age										
Method	0	1	2	3	4	5	6	7	8	9	10
HYBRID	41095	3444	403	525	39	13	2	4	1	0	0
LS	40148	3602	448	513	40	15	2	4	1	0	0
AC1	17638	3726	391	469	36	14	2	3	1	0	0
AC2	17683	3733	380	405	33	14	3	3	1	0	0
AC3	85518	4346	460	524	41	14	2	4	1	1	0
AC4	86927	4346	452	481	39	14	2	4	1	1	0
AEFM	76601	4874	466	514	40	14	2	3	0	0	0
CCPUE	50182	3820	432	537	38	13	2	3	0	0	0
SURVIV	5584	2290	338	405	31	19	4	3	0	0	0
CAGEAN	na	6989	739	777	50	18	3	6	na	na	na
COLSIS	na	1924	249	202	39	*	*	*	*	*	*
WG(88)	36956	2959	322	485	39	16	3	4	1	0	0

Estimates of F at Age in 1986

	Age										
Method	0	1	2	3	4	5	6	7	8	9	10
HYBRID	3	99	735	1136	1457	1402	1055	757	428	496	485
LS	3	94	635	1184	1283	1105	887	734	503	748	871
AC1	8	91	768	1409	1682	1187	740	765	300	553	534
AC2	8	91	801	2013	2208	1219	597	753	257	557	522
AC3	2	78	612	1139	1283	1181	920	681	353	242	425
AC4	2	78	628	1341	1418	1256	1031	661	331	212	402
AEFM	2	69	602	1182	1331	1183	1057	993	960	865	865
CCPUE	3	89	667	1090	1441	1365	1091	912	959	864	864
SURVIV	24	151	959	2007	2529	757	411	1280	1280	1280	1280
CAGEAN	na	94	456	998	529	527	526	526	na	na	na
COLSIS	na	181	1710	*	1425	*	*	*	*	*	*
WG(88)	4	115	1033	1305	1493	1053	820	722	767	971	971

* indicates that catch bigger than estimated number in sea

Estimates of Total and Spawning Biomass and Mean F (ages 2-6) in 1986

Method	TSB	SSB	Mean F
HYBRID	1803	223	1156
LS	1808	226	849
AC1	787	208	1157
AC2	758	198	1368
AC3	905	232	1027
AC4	885	218	1134
AEFM	964	227	1071
CCPUE	1047	228	1131
SURVIV	570	194	1160
CAGEAN	1410	337	607
COLSIS	402	99	na
WG(88)	682	207	1141

Table 4.15: Real Data Set : COD in North Sea

No estimates available for XSA, ADAPT, GLM, TSER1, TSER2, SVPA, CONVEN

Estimates of Number at Age in 1986

	Age										
Method	1	2	3	4	5	6	7	8	9	10	11
HYBRID	732	33	48	6	4	1	1	0	0	0	0
LS	786	35	54	7	5	1	1	0	0	0	0
AC1	666	31	50	8	5	1	1	0	0	0	0
AC2	657	30	52	7	3	1	1	0	0	0	0
AC3	924	36	50	7	5	1	1	0	0	0	0
AC4	1010	37	52	7	5	1	1	0	0	0	0
AEFM	1029	38	55	7	5	1	1	0	0	0	0
CCPUE	615	33	53	6	5	1	1	0	0	0	0
SURVIV	595	28	59	7	3	1	1	0	0	0	0
CAGEAN	1271	50	54	6	4	1	1	na	na	na	na
COLSIS	na	23	121	19	15	6	5	3	3	3	3
WG(88)	581	37	52	8	5	1	1	0	0	0	0

Estimates of F at Age * 1000 in 1986

	Age										
Method	1	2	3	4	5	6	7	8	9	10	11
HYBRID	167	1184	1098	1176	1003	1353	1926	1801	1222	1409	3672
LS	154	1065	894	1025	850	1132	1840	1341	930	938	1066
AC1	184	1325	1014	789	800	777	873	804	819	790	1089
AC2	188	1496	967	848	1541	1084	2746	1368	1147	1417	1571
AC3	130	1063	1030	851	823	903	883	1024	970	1039	2035
AC4	118	990	971	888	902	1205	1161	1154	1026	1165	2347
AEFM	200	966	881	933	821	1107	981	937	869	613	609
CCPUE	201	1192	930	1042	941	1217	1481	1091	714	611	606
SURVIV	208	1677	804	930	1641	910	910	910	910	910	910
CAGEAN	102	1665	1380	974	974	974	974	na	na	na	na
COLSIS	na	3336	313	262	195	99	104	115	115	115	115
WG(88)	216	854	920	840	761	817	711	676	731	937	1528

Estimates of Total and Spawning Biomass and Mean F (ages 3-8) in 1986

Method	TSB	SSB	Mean F	
HYBRID	600	80	1393	
LS	651	88	1180	
AC1	583	95	842	
AC2	561	80	1425	
AC3	729	93	919	
AC4	778	90	1046	
AEFM	798	95	925	
CCPUE	550	87	1093	
SURVIV	533	80	1018	
CAGEAN	510	81	1055	(omits estimates for ages 8 and older)
COLSIS	539	313	181	(omits 1-group in biomass)
WG(88)	553	100	797	

Figure 4.1

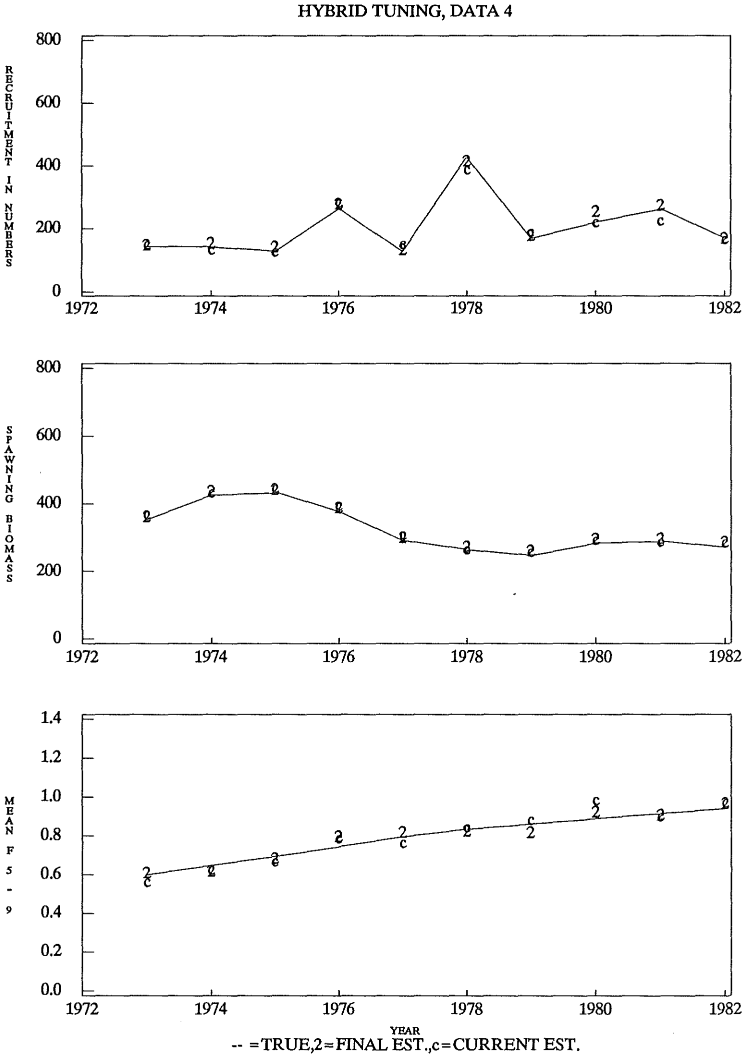

HYBRID TUNING, DATA 4
RECRUITMENT IN NUMBERS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
SPAWNING BIOMASS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
MEAN F 5-9
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.2

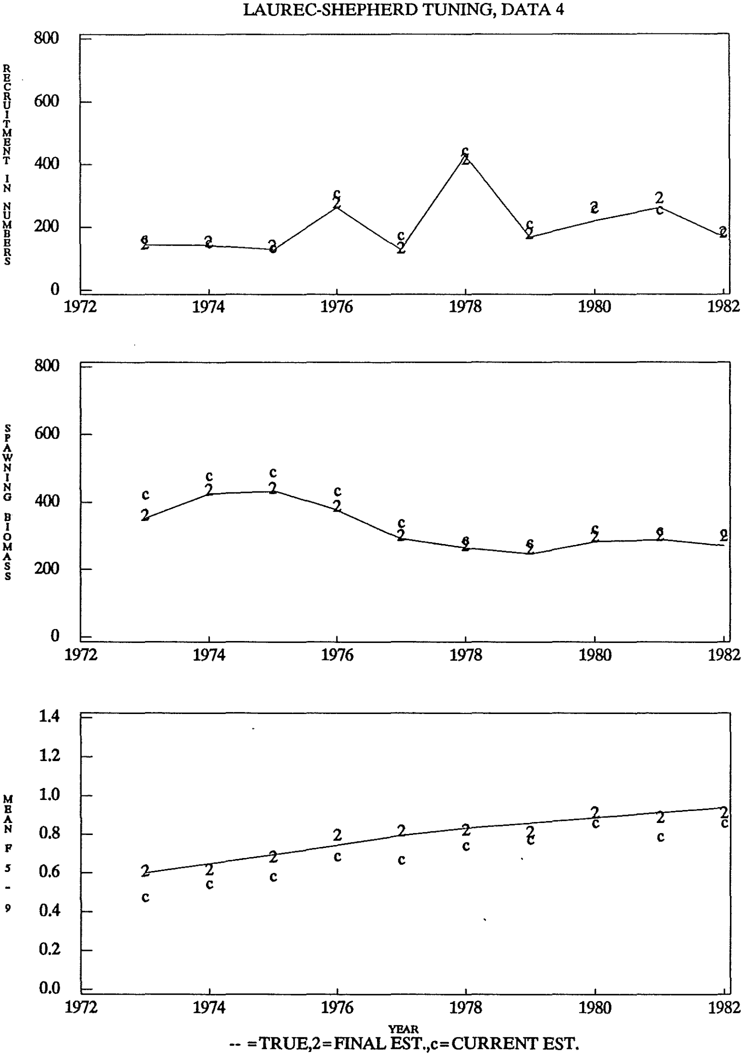

LAUREC-SHEPHERD TUNING, DATA 4
RECRUITMENT IN NUMBERS
0
200
400
600
800
1972
1974
1976
1978
1980
1982
SPAWNING BIOMASS
0
200
400
600
800
MEAN F 5 - 9
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.3

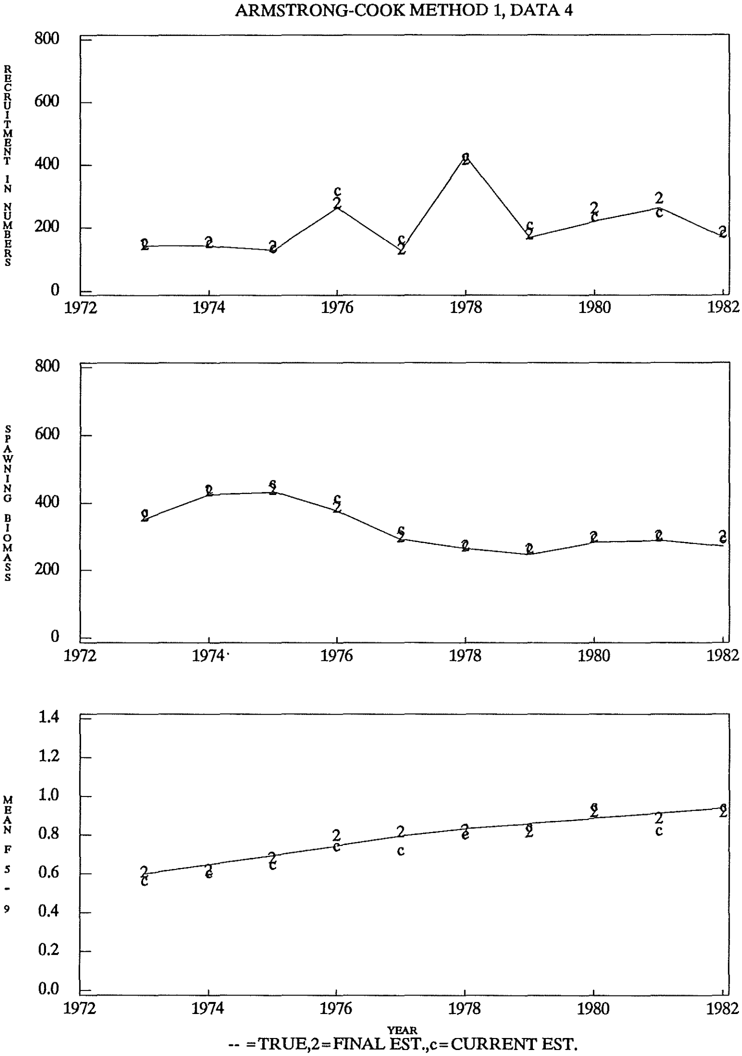

ARMSTRONG-COOK METHOD 1, DATA 4
RECRUITMENT IN NUMBERS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
SPAWNING BIOMASS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
MEAN F 5-9
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.4

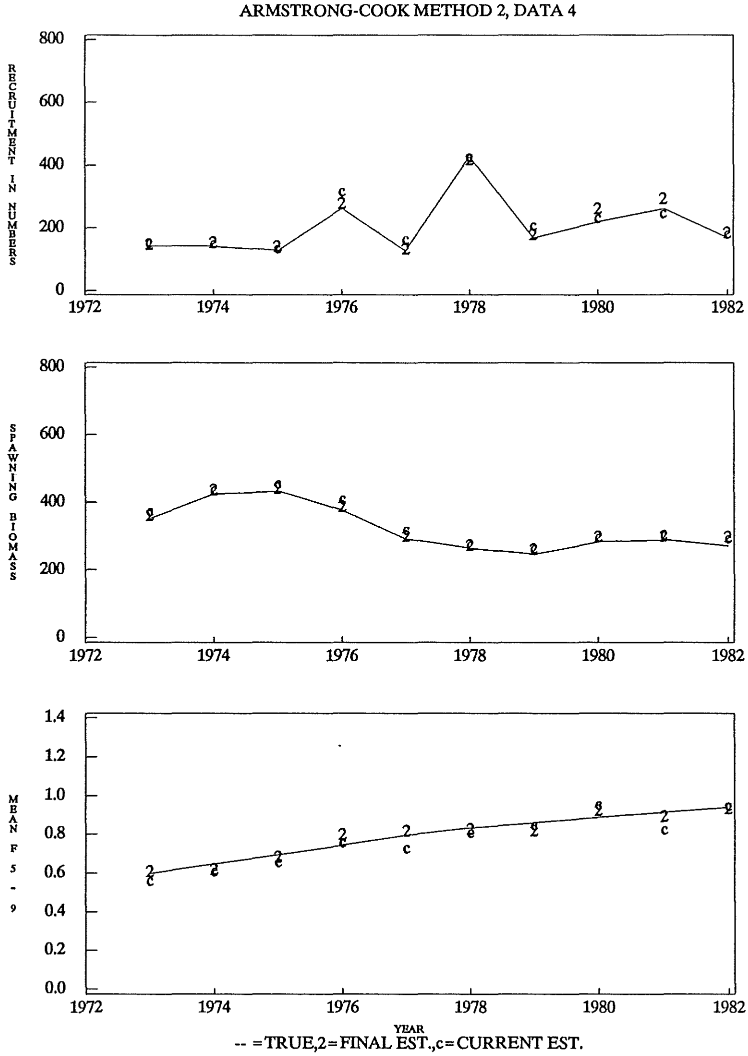

ARMSTRONG-COOK METHOD 2, DATA 4
RECRUITMENT IN NUMBERS
800
600
400
200
0
SPAWNING BIOMASS
800
600
400
200
0
MEAN F 5 - 9
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.5

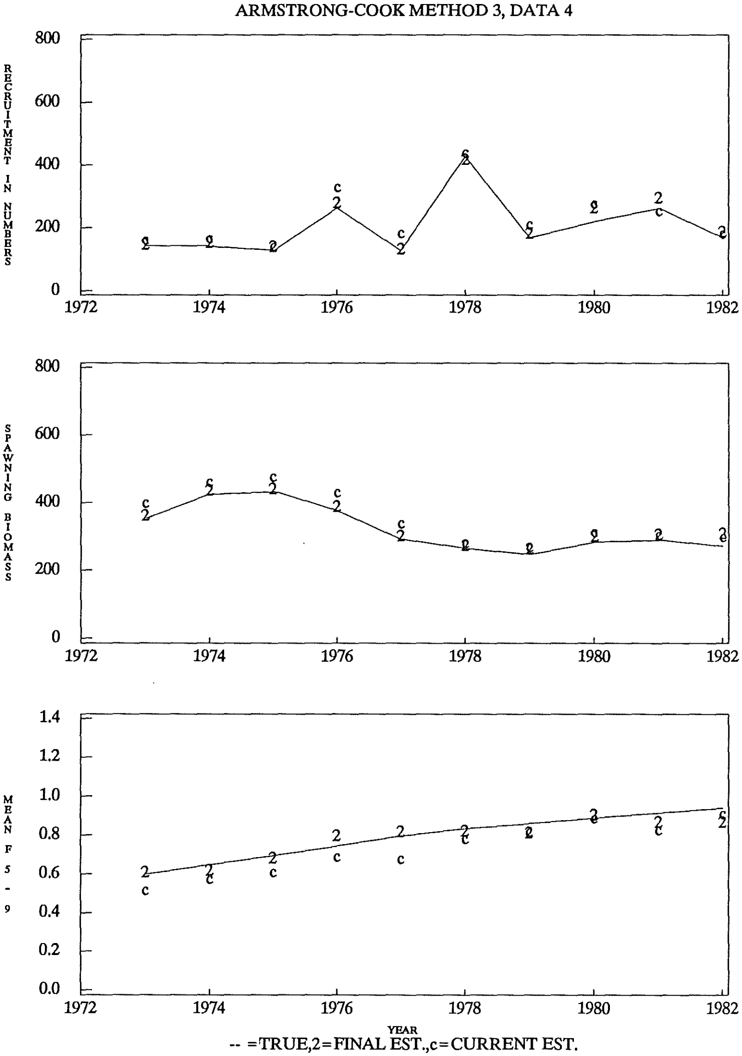

ARMSTRONG-COOK METHOD 3, DATA 4
RECRUITMENT IN NUMBERS
0
200
400
600
800
SPAWNING BIOMASS
0
200
400
600
800
MEAN F 5-9
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.6

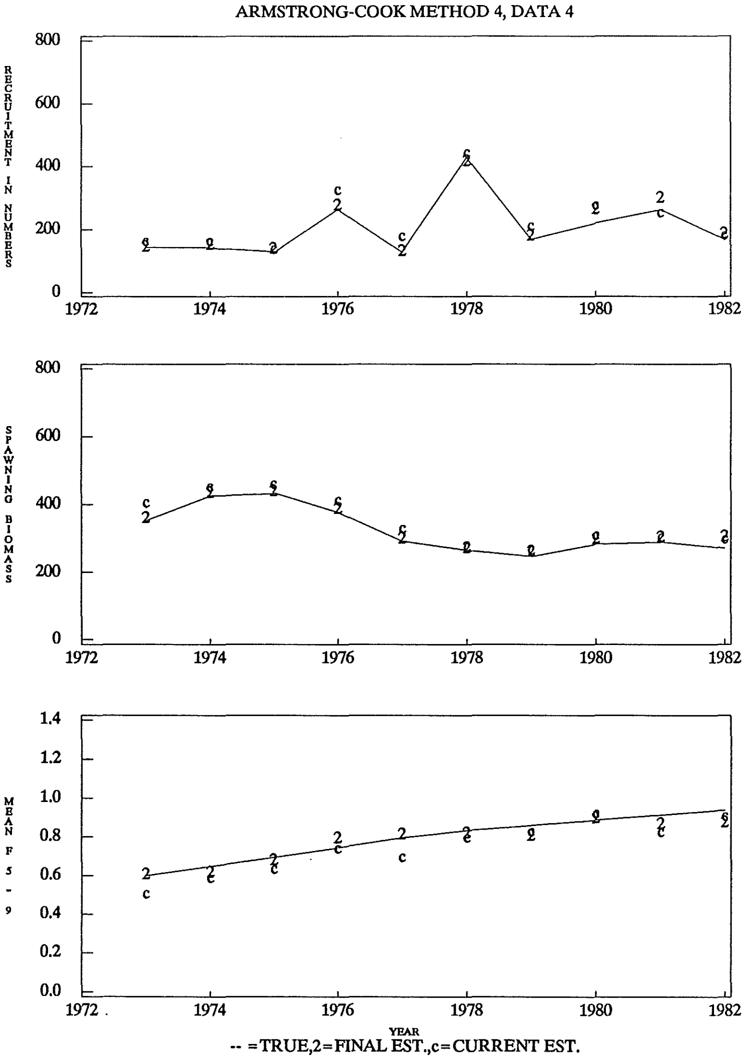

ARMSTRONG-COOK METHOD 4, DATA 4
RECRUITMENT IN NUMBERS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
SPAWNING BIOMASS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
MEAN F 5-9
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.7

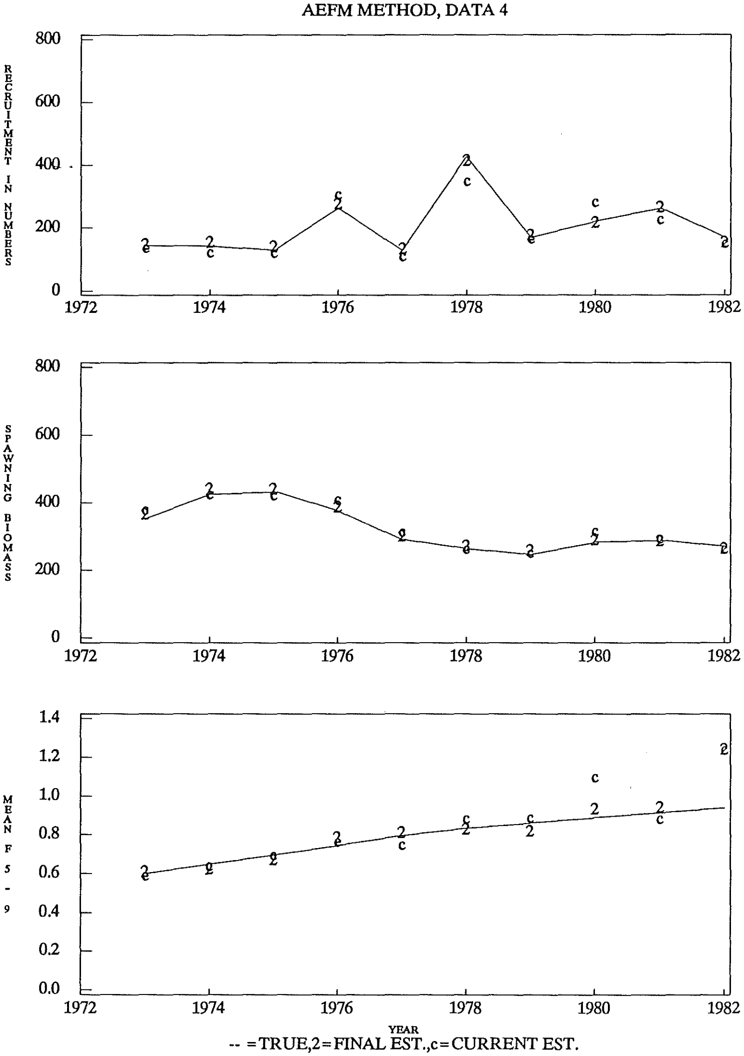

AEFM METHOD, DATA 4
RECRUITMENT IN NUMBERS
0
200
400
600
800
SPAWNING BIOMASS
0
200
400
600
800
MEAN F 5-9
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.8

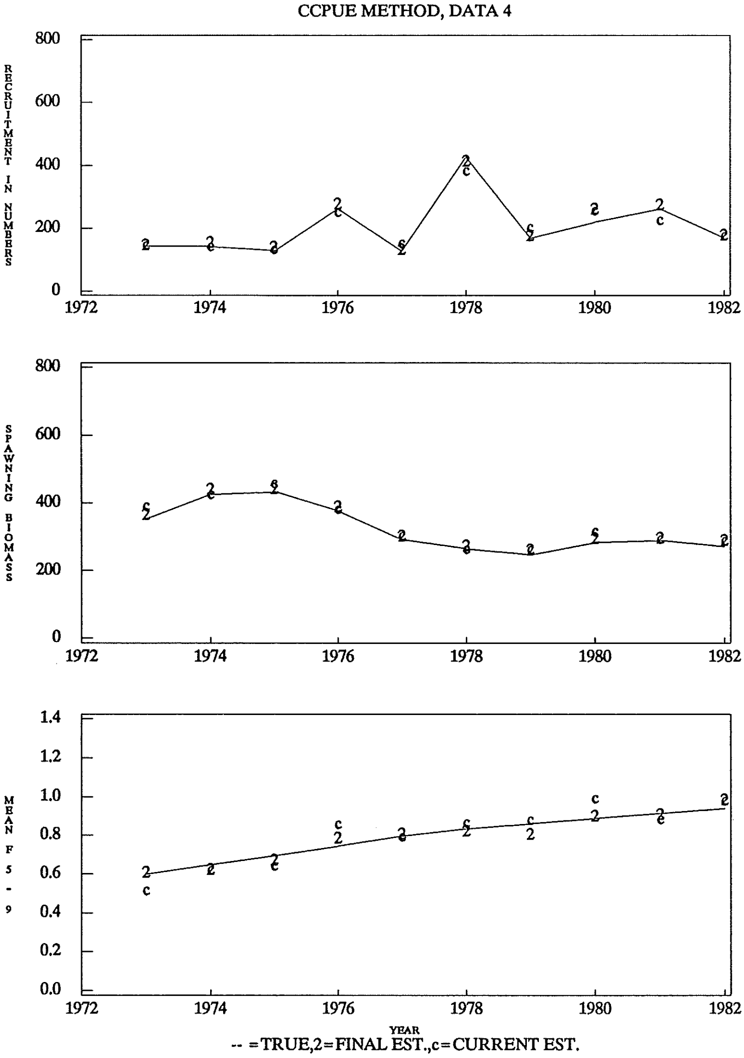

CCPUE METHOD, DATA 4
RECRUITMENT IN NUMBERS
0
200
400
600
800
SPAWNING BIOMASS
0
200
400
600
800
MEAN F 5 - 9
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.9

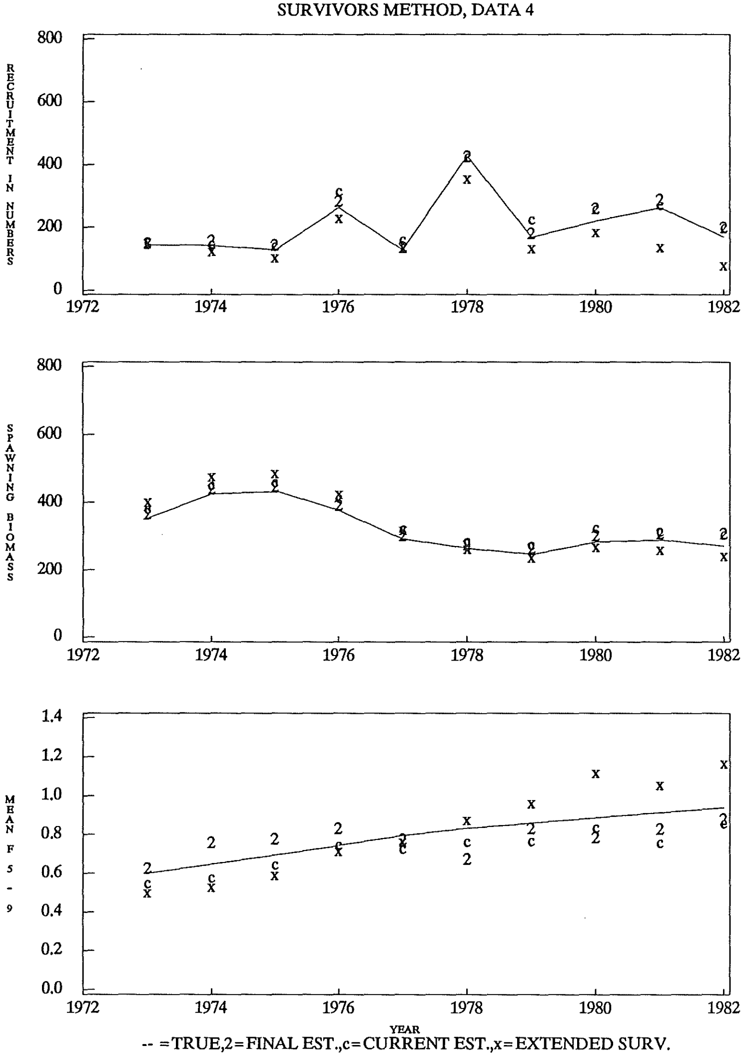

SURVIVORS METHOD, DATA 4
RECRUITMENT IN NUMBERS
800
600
400
200
0
SPAWNING BIOMASS
800
600
400
200
0
MEAN F 5-9
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.,x=EXTENDED SURV.

Figure 4.10

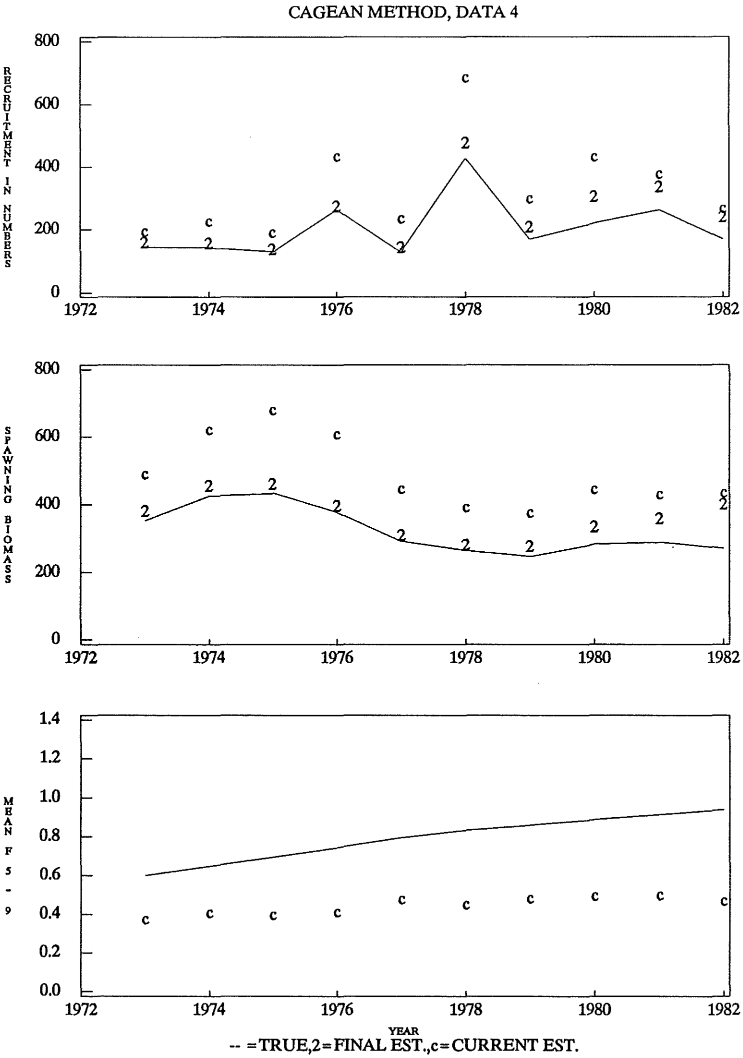

CAGEAN METHOD, DATA 4
RECRUITMENT IN NUMBERS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
SPAWNING BIOMASS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
MEAN F 5 - 9
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.11

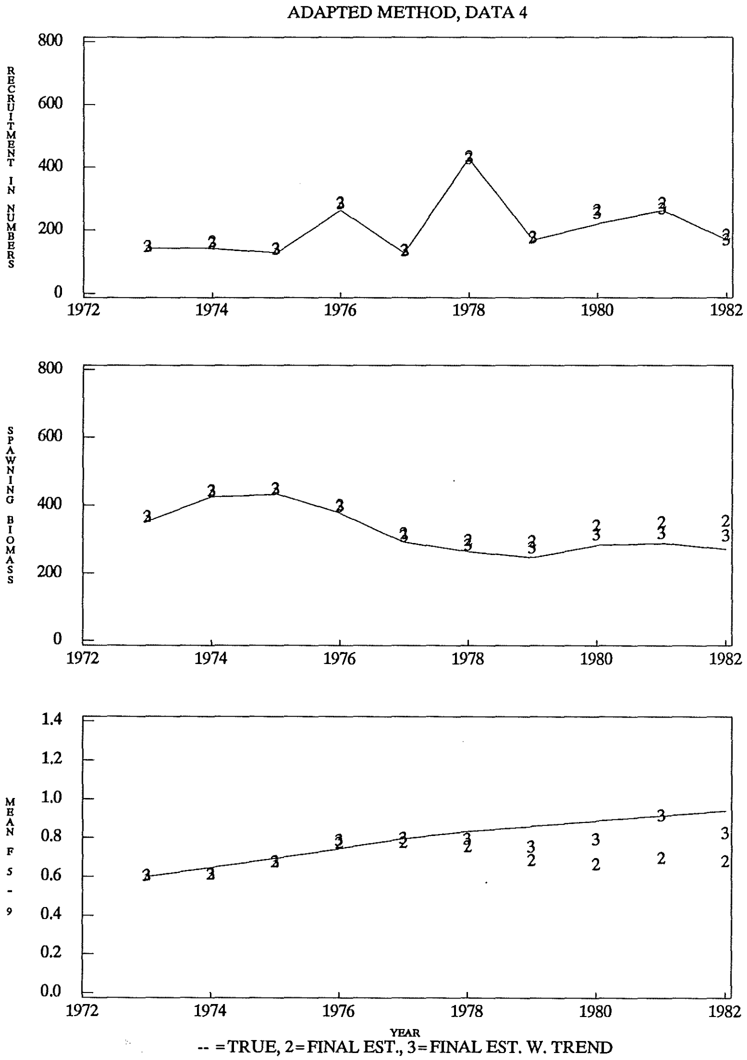

ADAPTED METHOD, DATA 4
RECRUITMENT IN NUMBERS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
SPAWNING BIOMASS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
MEAN F 5 - 9
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE, 2=FINAL EST., 3=FINAL EST. W. TREND

Figure 4.12

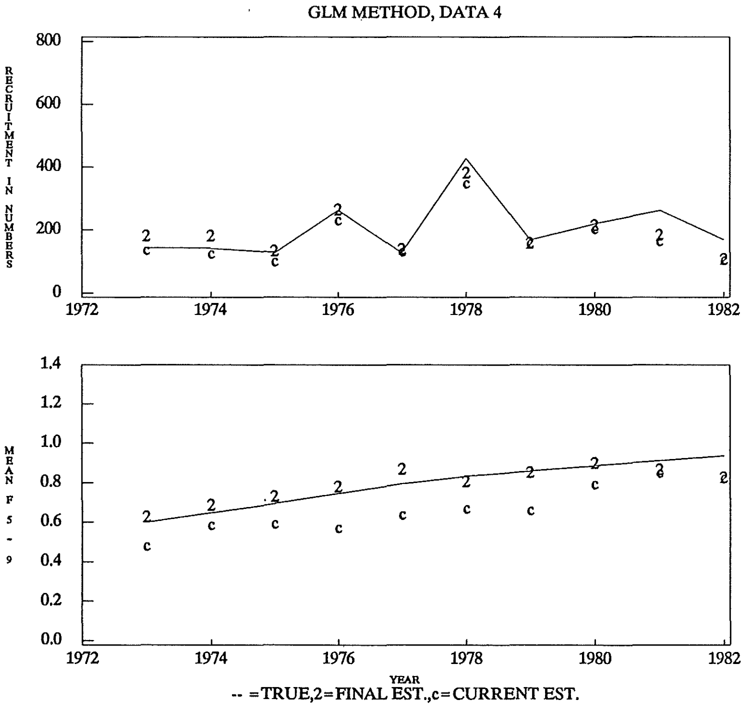

GLM METHOD, DATA 4
RECRUITMENT IN NUMBERS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
MEAN F 5-9
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.13

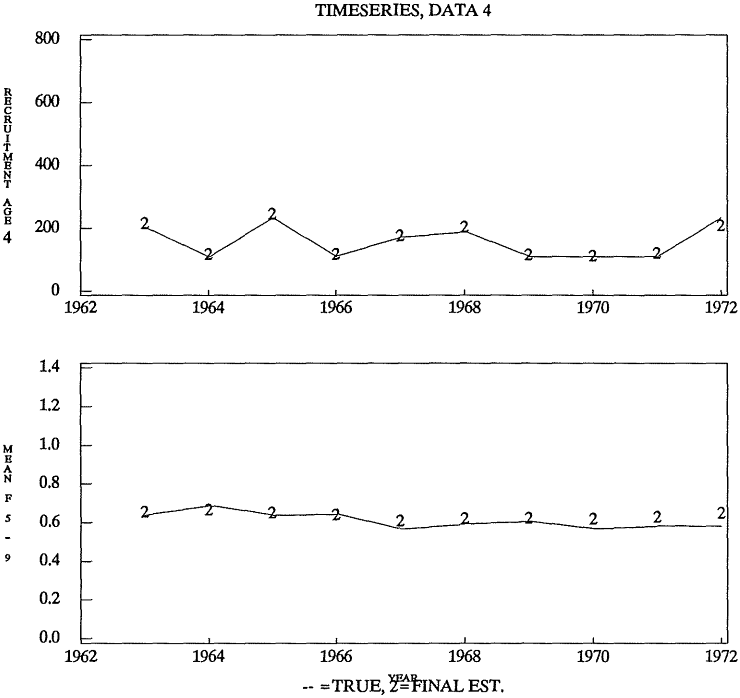

TIMESERIES, DATA 4
RECRUITMENT AGE 4
800
600
400
200
0
1962
1964
1966
1968
1970
1972
MEAN F 5-9
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
YEAR
-- =TRUE, 2=FINAL EST.

Figure 4.14

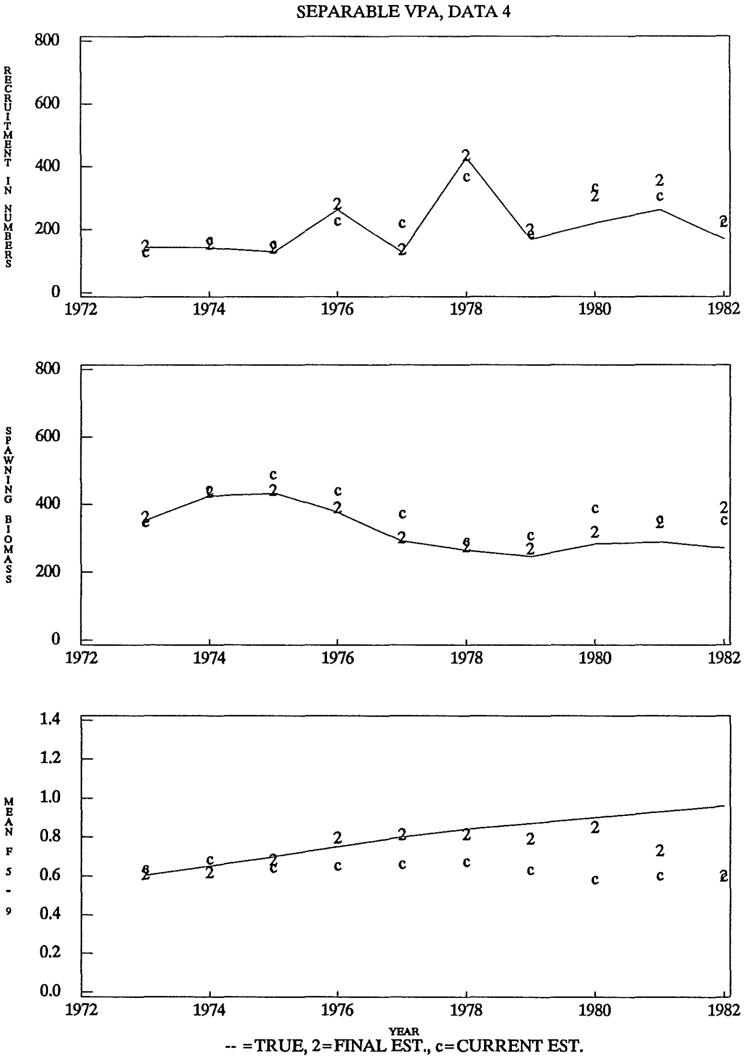

SEPARABLE VPA, DATA 4
RECRUITMENT IN NUMBERS
SPAWNING BIOMASS
MEAN F 5-9
800
600
400
200
0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE, 2=FINAL EST., c=CURRENT EST.

Figure 4.15

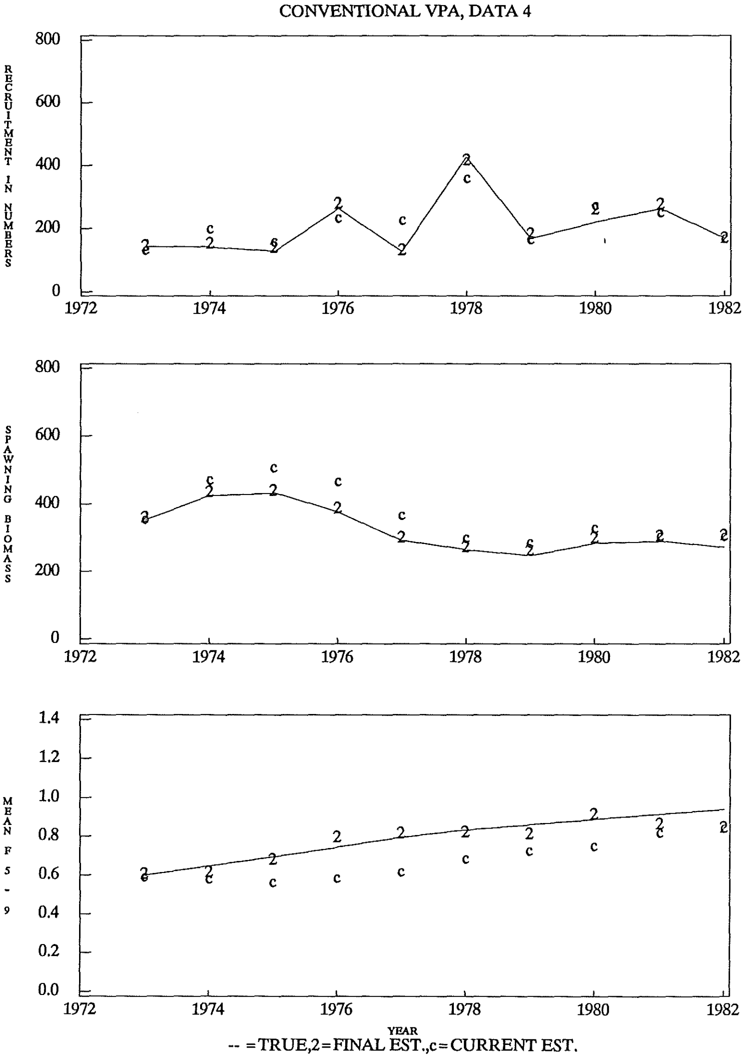

CONVENTIONAL VPA, DATA 4
RECRUITMENT IN NUMBERS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
SPAWNING BIOMASS
800
600
400
200
0
1972
1974
1976
1978
1980
1982
MEAN F 5 - 9
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- = TRUE, 2 = FINAL EST., c = CURRENT EST.

Figure 4.16

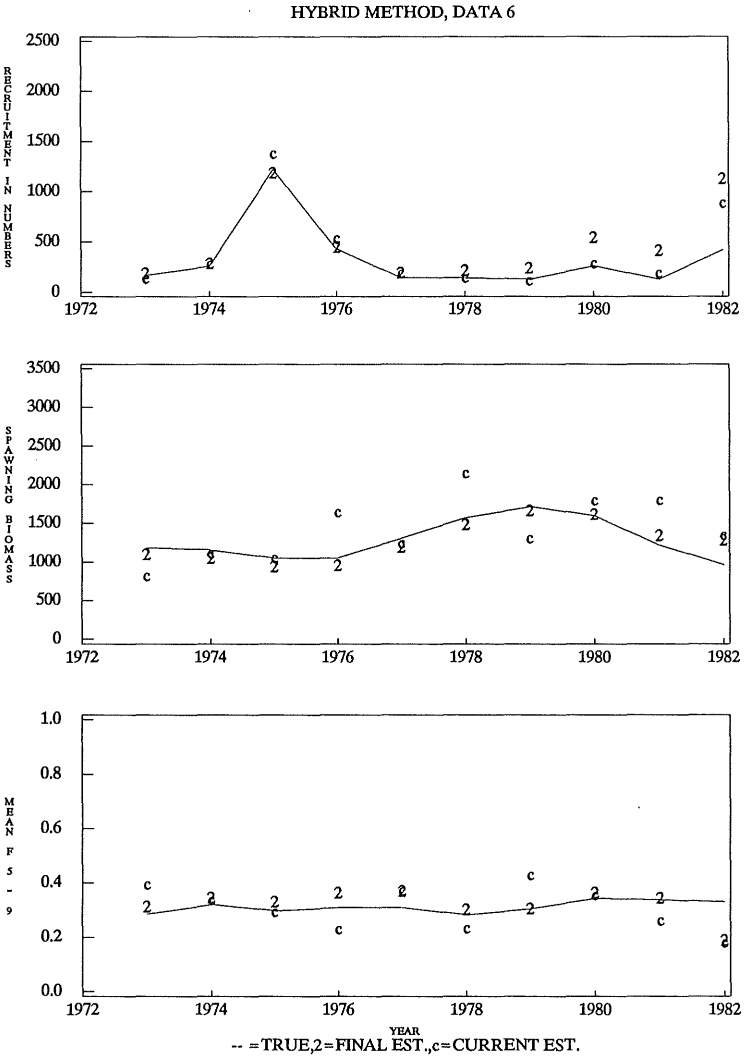

HYBRID METHOD, DATA 6
RECRUITMENT IN NUMBERS
2500
2000
1500
1000
500
0
SPAWNING BIOMASS
3500
3000
2500
2000
1500
1000
500
0
MEAN F 5 - 9
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.17

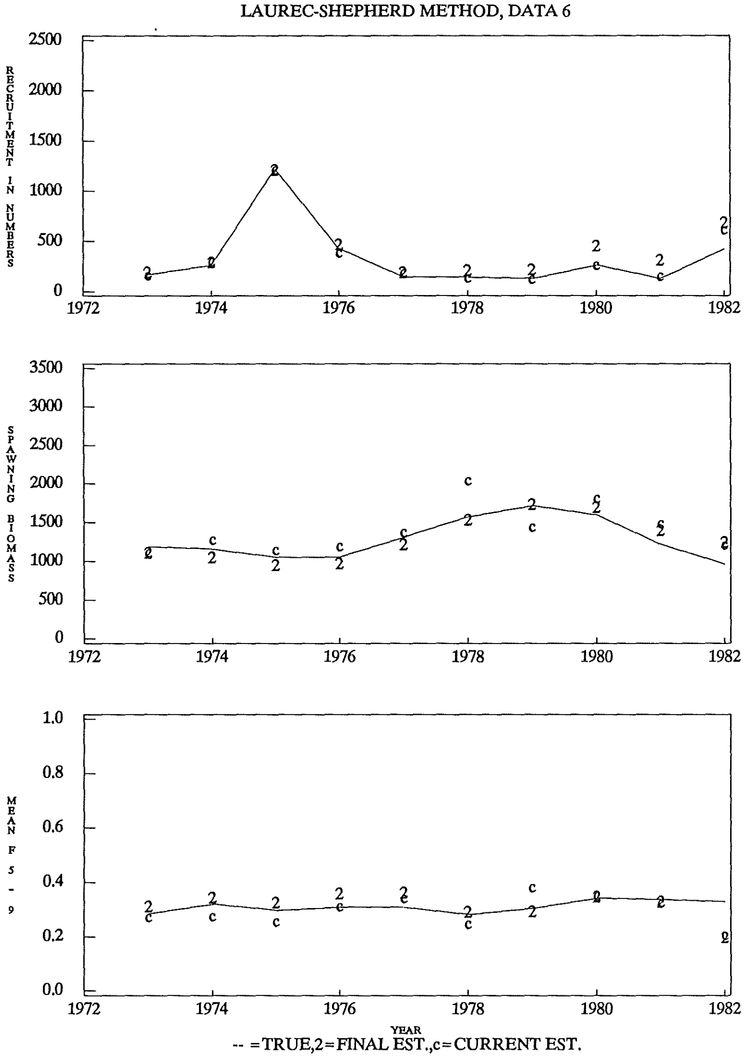

LAUREC-SHEPHERD METHOD, DATA 6
RECRUITMENT IN NUMBERS
2500
2000
1500
1000
500
0
SPAWNING BIOMASS
3500
3000
2500
2000
1500
1000
500
0
MEAN F 5 - 9
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.18

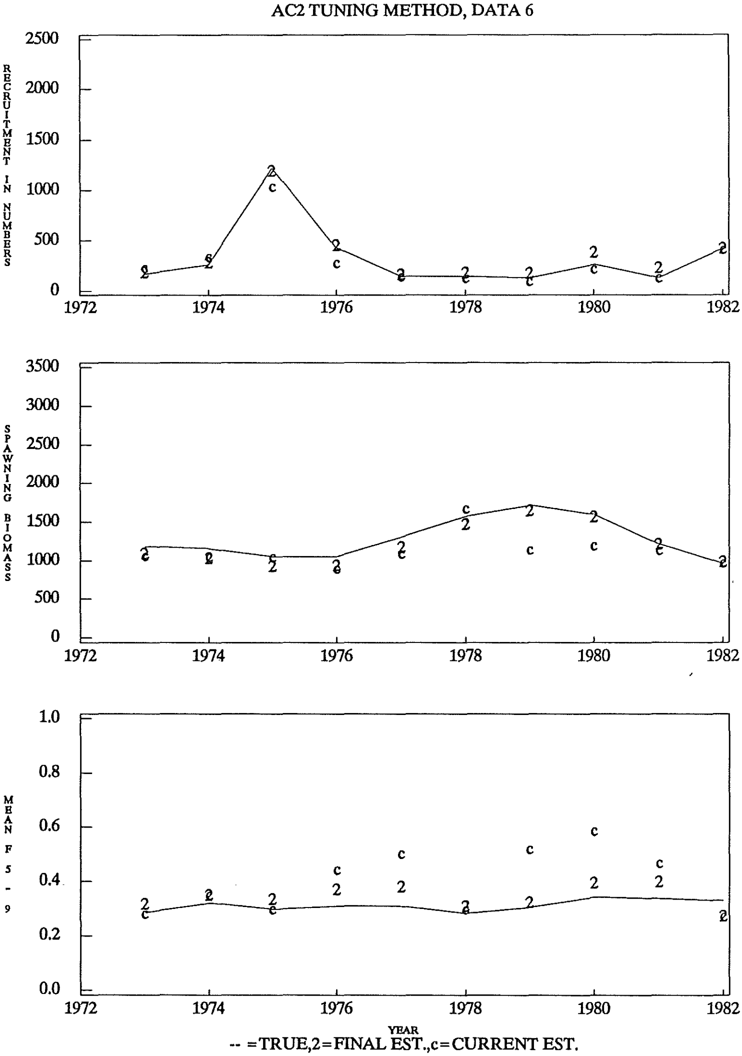

AC2 TUNING METHOD, DATA 6
RECRUITMENT IN NUMBERS
2500
2000
1500
1000
500
0
SPAWNING BIOMASS
3500
3000
2500
2000
1500
1000
500
0
MEAN F 5 - 9
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.19

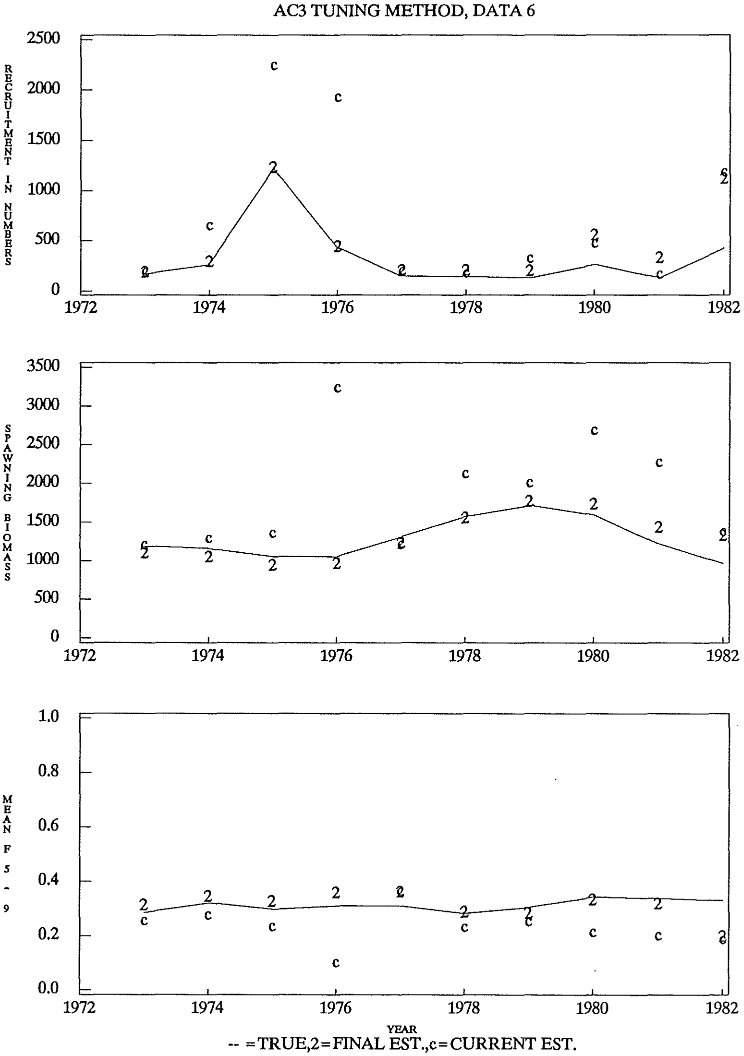

AC3 TUNING METHOD, DATA 6
RECRUITMENT IN NUMBERS
2500
2000
1500
1000
500
0
SPAWNING BIOMASS
3500
3000
2500
2000
1500
1000
500
0
MEAN F 5 - 9
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.20

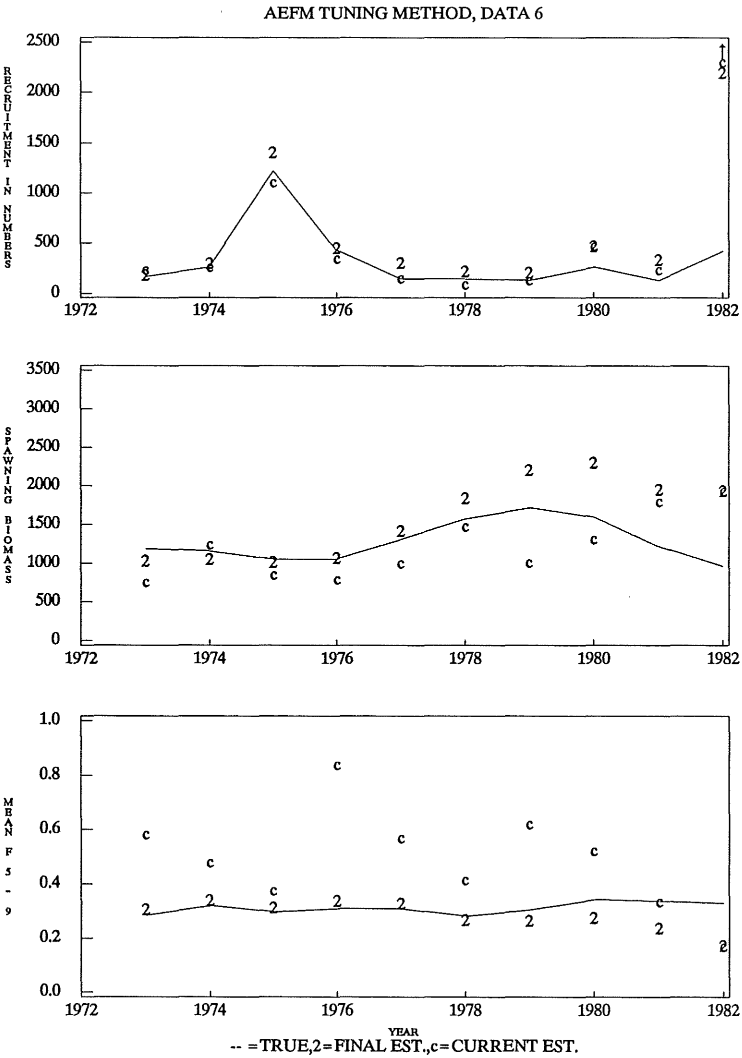

AEFM TUNING METHOD, DATA 6
RECRUITMENT IN NUMBERS
2500
2000
1500
1000
500
0
SPAWNING BIOMASS
3500
3000
2500
2000
1500
1000
500
0
MEAN F 5 - 9
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.21

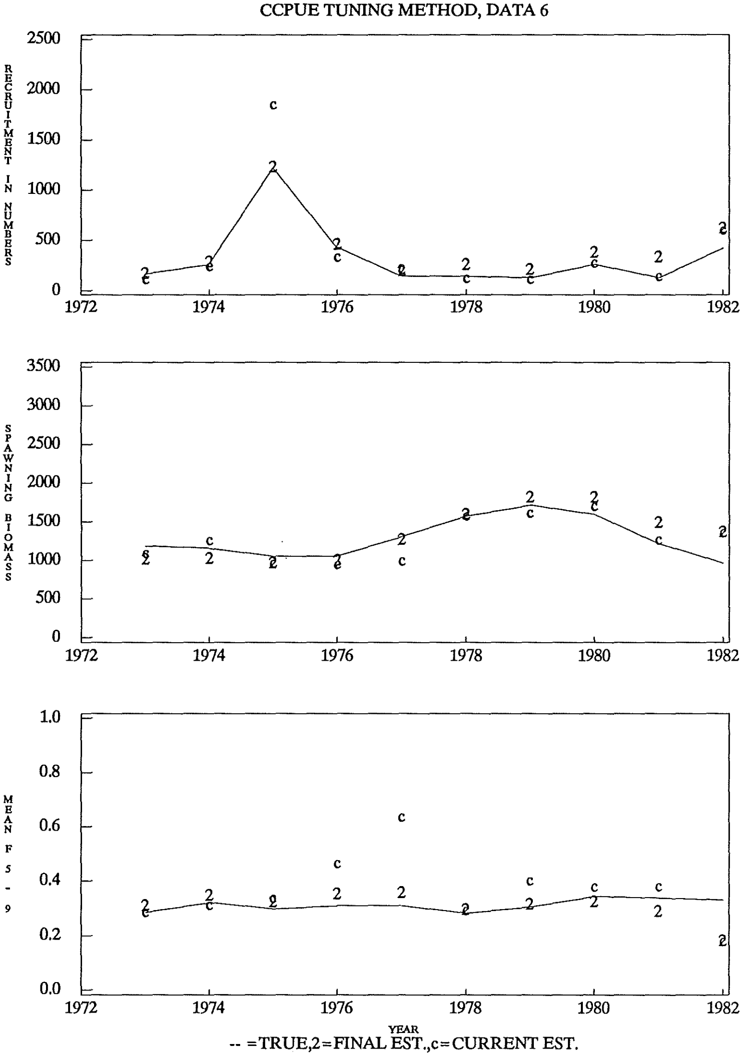
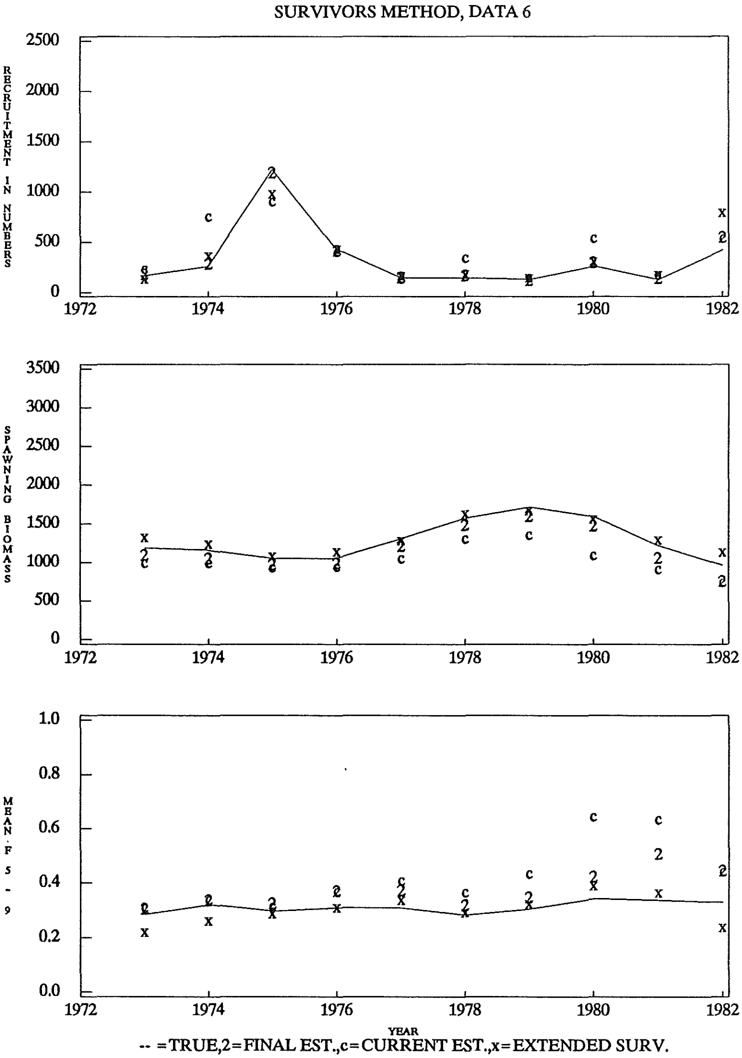

CCPUE TUNING METHOD, DATA 6
RECRUITMENT IN NUMBERS
2500
2000
1500
1000
500
0
SPAWNING BIOMASS
3500
3000
2500
2000
1500
1000
500
0
MEAN F 5 - 9
1.0
0.8
0.6
0.4
0.2
0.0
1972
1974
1976
1978
1980
1982
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.22



Final extended survivor estimate (XSA) was not computed.

Figure 4.23

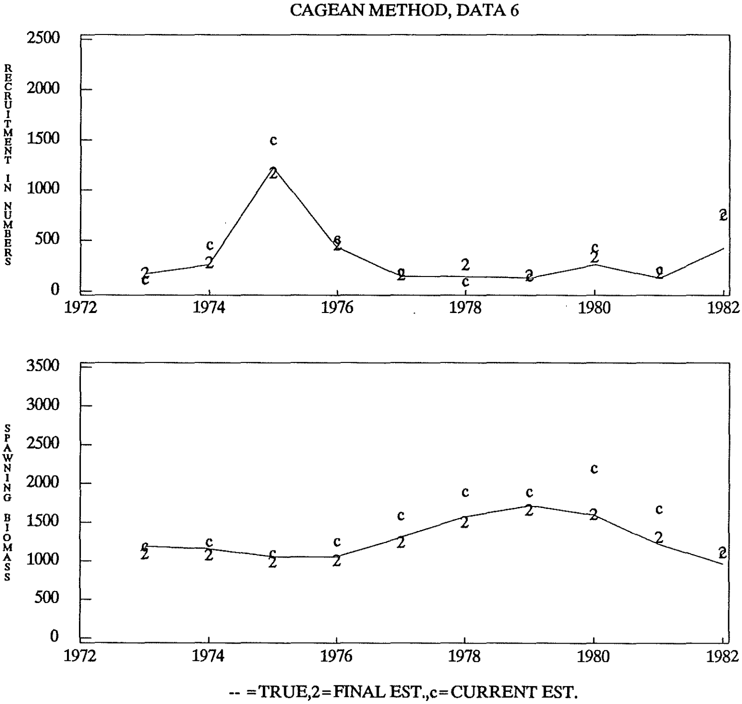

CAGEAN METHOD, DATA 6
RECRUITMENT IN NUMBERS
0
500
1000
1500
2000
2500
1972
1974
1976
1978
1980
1982
SPAWNING BIOMASS
0
500
1000
1500
2000
2500
3000
3500
1972
1974
1976
1978
1980
1982
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.24

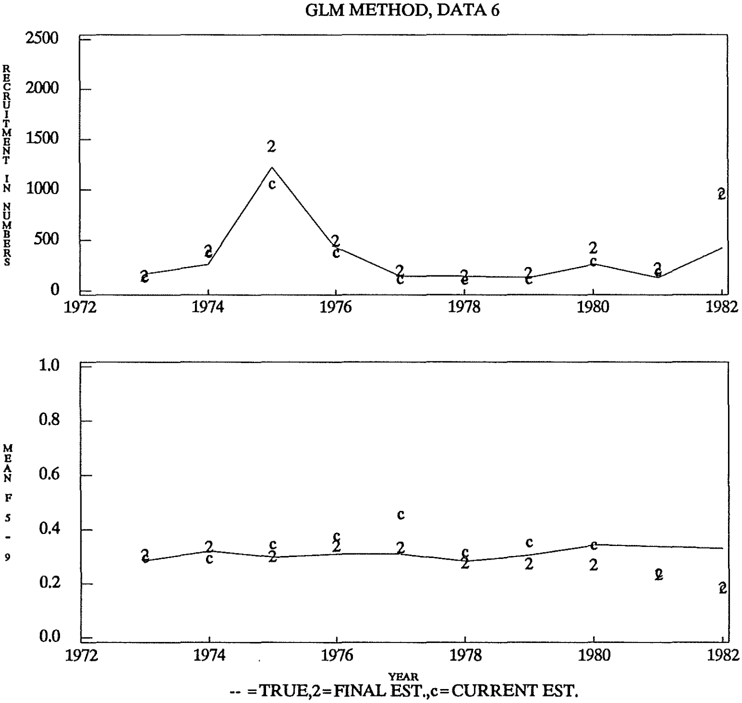

GLM METHOD, DATA 6
RECRUITMENT IN NUMBERS
2500
2000
1500
1000
500
0
1972
1974
1976
1978
1980
1982
MEAN F 5-9
1.0
0.8
0.6
0.4
0.2
0.0
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.25

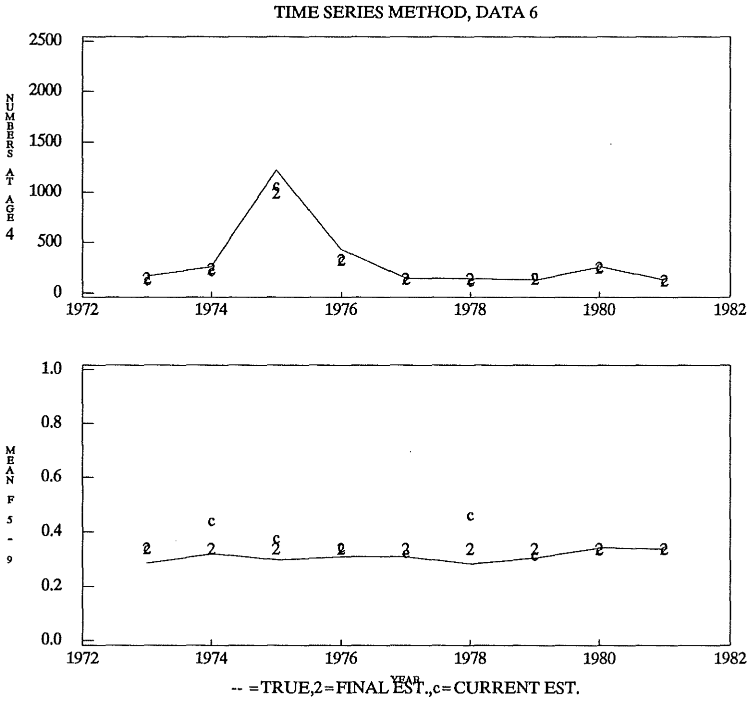
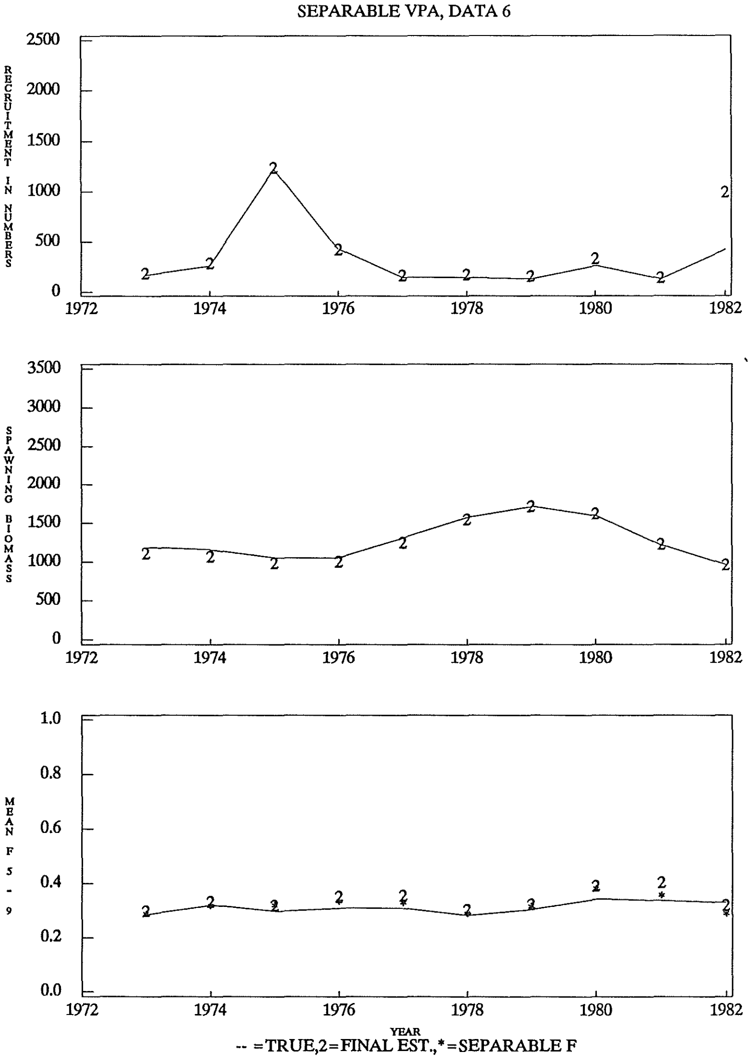

TIME SERIES METHOD, DATA 6
NUMBERS AT AGE 4
2500
2000
1500
1000
500
0
1972
1974
1976
1978
1980
1982
MEAN F 5 - 9
1.0
0.8
0.6
0.4
0.2
0.0
YEAR
-- =TRUE,2=FINAL EST.,c=CURRENT EST.

Figure 4.26


SEPARABLE VPA, DATA 6
RECRUITMENT IN NUMBERS
2500
2000
1500
1000
500
0
1972
1974
1976
1978
1980
1982
SPAWNING BIOMASS
3500
3000
2500
2000
1500
1000
500
0
MEAN F 5 - 9
1.0
0.8
0.6
0.4
0.2
0.0
YEAR
-- =TRUE,2=FINAL EST.,*=SEPARABLE F

ANNEX 1

SIMULATION OF DATA

1 INTRODUCTION

Six data sets were produced either before or during the meeting, and a description of the type of data generated is provided in Section 3.1. Assessment methods were applied to these data to estimate the "true" values of the parameters used to generate the data. Comparison of estimate with truth was used to judge the viability of the methods.

Because of the very large number of tables involved, reproduction of the true values in this report is not possible. Copies of the true parameter values can be obtained on IBM-formatted disk from D.W. Armstrong or G. Stefansson at the addresses cited in Section 3.1.

2 UNDERLYING (NON-STOCHASTIC) MODEL

The underlying model is the conventional fisheries model. If there were no errors involved, the following equations would hold true:

Let a = age (3-12)
y = year (30 years: 1953-1982)
f = fleet (7 fleets: 2 trawlers, 1 liner, 1 fixed net, and 3 research vessels)
C = catch in numbers
F = fishing mortality rate
M = natural mortality rate
N = stock size in numbers

Catches

$$C(a,y,f) = \frac{F(a,y,f)\{1-\exp[Z(a,y)]\}[N(a,y)]}{Z(a,y)}$$

where F(a,y,f) is the mortality induced by fleet f and

$$Z(a,y) = \text{total mortality rate} = \sum_f F(a,y,f) + M(a)$$

Stock

$$N(a+1,y+1) = N(a,y)\exp[-Z(a,y)]$$

Separability

The fishing mortality rate for each fleet is assumed to follow the separable model, so that

$$F(a,y,f) = F(A,y,f)S(a,f)$$

for some overall level of $F(A,y,f)$. For convenience, we take selection to be 1 at the maximum, or equivalently,

$$F(A,y,f) = \max F(a,y,f)$$

(For Data Set 6, we violated the assumption of separability for the commercial fleets. A detailed description of how this was done is provided in Section 3.1.)

Relationships between fishing effort and fishing mortality

The effort data for each fleet are related to fishing mortality in some simple fashion.

To simulate fleets in which catchability changes, we write

$$\ln E(y,f) = c(f) + d(f)y + \ln[F(A,y,f)]$$

To simulate a fleet which exhibits no change in catchability, we set $d(f)y = 0$ and hence

$$\ln E(y,f) = c(f) + \ln[F(A,y,f)]$$

(For Data Set 6, we altered the model relating effort and fishing mortality to the follwing form:

$$E(y,f) = F(A,y,f)[c(f) + d(f)y]$$

This corresponds to a trend in catchability described by the function

$$1/[c(f) + d(f)]$$

the convexity of which is opposite to the exponential funtion assumed in all other data sets.)

We refer to the above as the UNDERLYING model and, in particular, we refer to values of $F(a,y,f)$ as the underlying (nonstochastic) fishing mortalities.

This underlying model is assumed for all fleets including research vessels.

3 STOCHASTIC ADDITIONS

Process error of fishing mortality rates, realized values of F, N, and C

We introduce errors directly into the fishing mortalities.

$$\ln F'(a,y,f) = \ln F(a,y,f) + e(1,a,y,f)$$

This is equivalent to saying that a fleet has "decided" to induce a given level of fishing effort, but the target value has not been achieved due to random variations in weather and other factors.

For convenience, we have taken the errors $e(1,a,y,f)$ from a normal distribution (with different variances for different data sets and fleets). These errors are termed the PROCESS ERROR with variance $v(1,a,f)$.

The values $F'(a,y,f)$ are those which the fleet actually induces and are termed the REALIZED fishing mortalities.

The realized total mortality rate is, therefore

$$Z'(a,y) = \sum_{f} F'(f,a,y) + M(a)$$

The corresponding realized stock sizes are given by

$$N'(a+1,y+1) = N'(a,y)\exp[-Z'(a,y)]$$

The associated realized catches are given by

$$C'(a,y,f) = \frac{F'(a,y,f)\{1-\exp[-Z'(a,y)]\}N'(a,y)}{Z'(a,y)}$$

Note that an assessment method attempts to estimate the realized values (or some subset of them). It is the realized values that are, therefore, referred to as "truth" in the main body of this report.

Measurement error of catch at age, estimated catches

The realized catches $C'(a,y,f)$ are the quantities which are actually landed. These catches are sampled to produce ESTIMATED catches which incorporate MEASUREMENT ERRORS.

$$\ln\bar{C}(f,a,y) = \ln C'(f,a,y) + e(2,a,y,f)$$

The measurement error $e(2,a,y,f)$ is assumed to follow a normal distribution with variance $v(2,a,f)$ for Data Sets 1-4. For Data Sets 5 and 6, a gamma distribution parameterized to have a mean of 1 and a coefficient of variation between 0 and 1 was used to generate measurement errors in catch at age and process errors in the fishing mortalities.

Measurement error of effort data, estimated effort

It is unlikely, in reality, that effort data are exact. Errors will be incorporated as effort data are collected. To simulate this, a stochastic element is added to the relationship between effort and overall fishing mortality to produce the ESTIMATED effort data.

$$\ln\bar{E}(y,f) = c(f) + d(f)y + \ln F(A,y,f) + e(3,y,f)$$

For all data sets, the effort errors $e(3,y,f)$ are drawn from a normal distribution with variance $v(3,f)$ and are different for each fleet. This procedure was applied to all of the data sets.

4 TECHNICAL NOTES

(i) Random number generation was carried out using the Tausworthe shift-register generator.

(ii) Normal errors were generated using the Box-Mueller transform.

(iii) Gamma-distributed errors were generated by encoding an algorithm due to Knuth.

(iv) The program for simulating data sets can optionally generate log-normal or gamma-distributed errors and can include linear or exponential trends in effort.

5 GENERAL NOTES

(i) Changes in catchability are modelled by introducing a bias in the fishing effort data.

(ii) The estimated effort data are generated from the underlying fishing mortalities not from the realized fishing mortalities.

(iii) After analysis of Data Sets 1-4, it was found that the variances v(1,a,f) and v(2,a,f) included in the simulations were far too small for the research vessels. Caution is, therefore, required in interpreting the results from these data sets since many of the methods will perform better than they would on more realistic data.

(iv) For simulated Data Sets 1-4, the variance v(3,f) for research vessels was set at zero. Some higher value should have been used to allow simulation of the fact that research vessel catchabilities vary considerably from year to year.

(v) The model described above is used for all fleets including the research vessels. Differences between fleets are created by the choice of underlying fishing mortality rate, variances associated with the error terms, and the choice of changes in catchabilities reflected in c(f) and d(f)y. Stock numbers at the youngest age and for each age in the first simulated year were based on data for Icelandic cod and were not generated by a simulation process.

6 OVERVIEW OF THE CHARACTERISTICS OF DATA SETS 1-6

Process error and measurement error - general comments

An analysis of variance of log-catch data for North Sea and Icelandic cod indicated that the effects of process errors and measurement errors are almost additive into log-catch. However, no information is available on the degree to which the variance in log-catch is divisible between the two types of error. For this reason, the relative dimension of process and measurement error in each data set is arbitrary.

Process and measurement errors were given the highest values for the youngest and the oldest age groups.

Date Set 1

No bias in effort data [i.e., no trends in catchability, d(f)=0]. The level of the underlying fishing mortality rates for all fleets combined is about 0.4. Process error equal to measurement error. No effort error for research vessels.

Data Set 2

No bias in effort data for any fleet. Overall level of underlying fishing mortality is about 1.0. Process error = 0.5 x measurement error. No effort error for research vessels.

Data Set 3

Bias in effort data for two of the commercial fleets. Overall level of underlying fishing mortality about 0.4, but with a steadily increasing trend.

Data Set 4

Bias in effort data for all fleets. Overall level of underlying F about 0.8 in early years to about 1.2 in the last data year. No measurement error, only process error.

Data Set 5

Same underlying structure as Data Set 3, but process error on fishing mortalities and measurement error on catch at age derived from gamma distribution rather than log-normal distribution. Lognormal distribution retained for effort errors. Higher levels of noise used than in Data Sets 1-4. Catch measurement error coefficients of variation range from 14-70%, with higher values on the youngest and oldest age groups and on the research vessels' data. Process error coefficient of variation of 20% on all ages and fleets. Strong year class recruited in year 24 (1977) of abundance (1.2 billion) about an order of magnitude greater than the weakest year class.

Data Set 6

Based on Data Set 5, but some aspects of the underlying model altered. Changes to funtional form for trends of catchability with time explained in Section 2.

In addition, separability in commercial fleets no longer valid. For one of the commercial fleets, catchability increases on the two youngest age groups between years 14 and 20. Beyond year 21, catchability increases further on the young age groups and decreases on ages 9-12. This procedure simulates a progressive shift by this fleet towards fishing of younger fish.

For another of the commercial fleets, a shift towards fishing on older fish from year 18 onwards was simulated. This was achieved by increasing realized fishing mortality on ages 7-12 by the quantity 1+[0.2(age 6)].

Finally, it was assumed that all commercial fleets increased their catchability on a very large 1972 year class. The realized fishing mortalities at the appropriate years and ages were multiplied by 1.2 to simulate this effect.

ANNEX 2

DESCRIPTION OF METHODS

1 AD HOC TUNING OF VPA

The basic ad hoc tuning algorithm is outlined in the pseudocode below.

```
Guess F in last data year
Do VPA
Calculate catchability for each age and fleet
   For each age
      For each fleet
         Fit model to catchabilities
         Estimate terminal catchability and associated variance
         Calculate terminal F
      Next fleet
      Combine estimates of terminal F as weighted average value
   Next age
Iterate
```

The methods iterate to find a solution consistent with historical parameter estimates and do not seek to minimize any statistical objective function. For this reason, these methods are not regarded as being based on a formal statistical model.

The methods estimate catchablities for each age group and fleet separately. Some plausible model is then fitted to these estimates to allow estimation of catchability in the last data year. This value is then used in conjunction with the appropriate CPUE value to estimate population size. The population size is then used in conjunction with total catch-at-age data to estimate fishing mortality. The CPUE data and the total catch-at-age data are treated as exact. Errors in CPUE, therefore, affect both the population and F estimates while errors in the total catch-at-age data affect only the F estimates.

Ad hoc methods are simple to implement, computationally fast (run times of 1-2 minutes are typical) and rarely crash or give infeasible results.

Some of the ad hoc methods analyze the logarithm of catchability. In these cases, it makes no difference whether one analyzes the relationship between CPUE and abundance or that between fishing mortality and fishing effort (Laurec and Shepherd, 1983). Use of a logarithmic tranformation is also consistent with the non-negative, but highly skewed distributions of catch-at-age and CPUE-at-age data.

There is a family of ad hoc methods generated by choice among the following options:

(a) Use log-transform or not.

(b) Assume constant catchability or fit a regression (usually against time, but could also be against stock abundance, etc.).

(c) Combine estimates of terminal F using inverse variance weighting (usual procedure in recent years) or some other rule (becoming less popular).

(d) In addition, further variants may be generated by use of various procedures for down-weighting data for distant years and for shrinking estimates of terminal F (or N) towards some historical prior value.

The following eight methods were tested at this meeting:

(i) Laurec-Shepherd (Laurec and Shepherd, 1983; Pope and Shepherd, 1985). This uses a logarithmic transformation, applies a 20-year tricubic taper to down-weight historical data, assumes no linear trends in the log-catchabilities (locally constant catchability) and F on the oldest age group was iteratively reset to the average over the five next youngest ages.

(ii) Hybrid (Pope and Shepherd, 1985). This is identical to the Laurec-Shepherd method except that a linear time trend is fitted to the (down-weighted) log-catchabilities.

(iii) Armstrong-Cook methods. These are basically a mixture of the Laurec-Shepherd and Hybrid methods. Catchability is regressed against time for commercial fleets, but is assumed constant for research vessels. A 20-year tricubic taper with maximum weight applied 3 years before the last data year is used to down-weight. Estimates of terminal F are combined by inverse variance weighting. An additional option of shrinking estimates of terminal F towards the historic mean from VPA is also available.

Four variants of this method were tested:

AC1: Log-transformed catchabilities, shrink towards historical F

AC2: Log-transformed catchabilities, no shrinkage towards historical F

AC3: Untransformed catchabilities, shrink towards historical F

AC4: Untransformed catchabilities, no shrinkage towards historical F

(iv) Lewy's (1988) methods. These methods estimate stock numbers in the last data year by regressing numbers on corrected CPUE (CCPUE). No transformation of the data is used and catchability is assumed constant for the last 10 data years. Fishing mortality on the oldest age group is set equal to the average for the three next youngest age groups.

The CCPUE method combines predicted N values using inverse variance of the predicted Ns.

The AEFM method uses a different weighting procedure. Fitted values of fishing mortality and stock numbers are obtained for the last 10 years. These are used, via the conventional catch equation, to produce corresponding estimates of "fitted" catch. The inverse variance of the fitted and observed catches is used to weight the last data year estimates of N.

All the ad hoc tuning methods were run with no major problems on all six simulated data sets and the two real data sets for both the multiple realizations and the 30-year analysis. All of the methods recovered the main features of the data sets, especially in the case of Data Sets 1-4. The only computational difficulty encountered was that the AEFM method does not converge if the period when catchability is assumed constant includes the last data year. This method converges rapidly if the last two data years are excluded from the above-mentioned period.

The software developed to run the Armstrong-Cook methods was intended to run automatically without user intervention. If these methods are to be further developed, more attention needs to be given to diagnostic output. In the case of Data Set 6, examination of the slopes of the regressions through commercial catchablity estimates indicated that many of them did not appear significant.

The more highly-developed diagnostic features of the Laurec-Shepherd and Hybrid methods were particularly useful in analyzing Data Set 6. Large standard errors and significant conflicting trends in catchability were indicated and the Hybrid method indicated highly significant trends in catchability at all ages for all commercial fleets except one of the trawlers. A mixed analysis was, therefore, carried out by specifying catchability on this fleet. This indicated strong and highly consistent commercial catchability trends for almost all ages, especially for Fleet 3 and relatively weak but sometimes significant trends for the survey fleets. It was considered likely that it was the commercial rather than the survey fleets which exhibited real trends. A second mixed analysis was then run with fixed q for Surveys 1 and 2 (since the diagnostics for Survey 3 had indicated rather variable trends). This analysis revealed a weak but statistically significant negative trend for Survey 3, no significant trend for Commercial Fleet 1 and strongly significant positive trends for Commercial Fleet 3. This analysis was accepted even though it is probable that a mixed analysis with fixed q on all fleets except Commercial Fleet 3 would be preferable. (This level of confusion and inconsistency of results is considered by the assessor to be fairly typical of real life!)

2 SURVIVORS AND EXTENDED SURVIVORS

Survivor analysis

Survivor analysis combines catch-at-age information and a research vessel abundance index at age to produce estimates of stock size for each age at the end of the current year (i.e., survivors). The method is described by Doubleday (1981), and a computer implementation is provided by Rivard (1982).

Underlying assumptions specify that

(a) catch is taken uniformly throughout the year,

(b) the research vessel abundance index is a mid-year estimate of numerical stock abundance,

(c) the natural mortality rate is a "known" constant applicable to all years and age groups represented in the catch-at-age data.

The research vessel abundance index is calibrated against VPA population numbers by defining calibration constants [say k(i)] within a pre-defined calibration block which correspond to the ages and years for which the VPA has converged. Within that block, the survey index at age [say A(i+0.5,t+0.5), where i+0.5, t+0.5 is used to identify the mid-year] is related to mid-year population abundance [say N(i+0.5,t+0.5)) as follows:

$$N(i+0.5,t+0.5) = k(i)A(i+0.5,t+0.5)e \qquad (1)$$

The calibration constant can thus be estimated as

$$\ln[k(i)] = \frac{\sum_{t=t0}^{t1} \ln N(i+0.5,t+0.5) - \ln A(i+0.5,t+0.5)}{t1 - t0 + 1} \qquad (2)$$

where t0 and t1 are the first year and the last year in the calibration block, respectively.

The mid-year population abundance is obtained from a generalized method of sequential population analysis in which the survivors appear explicitly as input parameters. This formulation allows estimation of the variance of the survivors, which is input to the catch projections, i.e.

$$N(i+0.5,t+0.5) = fS[i,t(f)] \qquad (3)$$

Consequently, from an initial estimate of survivors for the last year and for the oldest age-groups, we can estimate

$N(i+0.5,t+0.5)^1$ from equation (3)

and the calibration constants $k(i)^1$ are calculated from equation (2), where the superscript 1 identifies the first step of the iteration process. Then j independent estimates of the survivors in the final year, for age groups i, can be obtained from each survey index which provides an independent measure of stock size along a cohort, i.e.

$$S[i,t(f),j]^1 = (k(j)^1 A[j+0.5,t(f)-i+j+0.5] - f[C(i,t)])\exp(-M(i-j+0.5) \qquad (4)$$

The j independent estimates of the survivors along a cohort are then averaged as follows:

$$S[i,t(f)]^1 = \sum_j w[i,t(f),j]^1 S[i,t(f),j]^1 \qquad (5)$$

where $w[i,t(f),j]$ is a function of the variance of the estimated survivors.

$S[i,t(f)]^1$ becomes a new starting value for (3) and the calculations represented by (2), (4), and (5) are repeated in an iterative manner until the relative difference between the successive estimates of survivors is small (say <0.001).

This iterative process provides estimates of the survivors for the oldest age group in each cohort in the catch matrix together with corresponding variance estimates.

In practice, the method works well when the calibration block is extended to all years available. For the analysis of the simulated data sets, the calibration block was defined to include all years except the last data year and ages 3-9. Separate calibration constants were obtained for ages 3, 4, and 5, and a common calibration constant was estimated for ages 6-9. No attempt was made to evaluate the effect of the number of calibration constants on the results.

The Survivors Analysis was initially designed to accommodate the situation where no auxiliary information is available except that from a single survey estimate of abundance. The application of the methops to the simulated data (which provided the results of three independent surveys) required some pre- or post-processing.

(i) The commercial catch rate data were not utilized.

(ii) For Data Sets 1-3, where the survey data exhibited similar trends, the three survey indices were standardized and averaged to produce a single data set.

(iii) For Data Set 4, divergent trends were observed in the research vessel data. The analysis was applied using each data set and the results were averaged *a posteriori*.

(iv) For Data Sets 5 and 6, *a posteriori* averaging of results derived by using each survey series separately was also used. Diagnostics revealed that the assumption of log-normality of errors was incorrect for these data sets (large number of outliers in residuals and large proportion of residuals of the same sign in results obtained using Surveys 2 and 3, estimates of fishing mortality less variable than expected). For Data Set 5, the coefficients of variation (CVs) for survivor estimates for ages 4-7 were calculated.

Survey number	CV (%)
1	30-40
2	55-75
3	90-150

These estimates are inflated since they assume (actually non-existent) log-normality.

Survivor Analysis was also applied to the full 30-year data series for Data Sets 4 and 6.

For Data Set 4, comparison of stock abundance estimates and survey indices indicated an increasing catchability trend in Surveys 1 and 3 and a decreasing trend in Survey 2, and the survey indices were not tracking the trends in stock size. Also, in order to assess the effect of the changes that took place for the second research vessel in the 27th year, an analysis of catchability at age was made for that vessel. This led to the estimation of a conversion factor of 1.2 for the last four years of that series. Finally, a retrospective analysis (Rivard and Foy, 1987) was applied to the last 10 years of the time series. That analysis indicated that combining the three survey estimates led to a systematic overestimation of stock size. In view of these observations, Survivor Analysis was applied using Survey 2, multiplied by 1.2, for the last 4 years to account for the change in vessel efficiency, and Survey 1. Combining Surveys 1 and 2 had the same effect as removing the trend in catchability for each series. The retrospective analysis was applied again and indicated that a systematic overestimation of stock size was still present, but was reduced compared to the previous analysis.

For the analysis of the 30-year series of Data Set 6, the three survey series and stock abundance estimates were normalized and plotted against time. No obvious trends in catchability in any of the surveys were apparent. A retrospective analysis applied to the last 10 years of data indicated that combining the three surveys led to a systematic underestimation of stock biomass for older fish of 15-20%. Also, the coefficients of variation of Survivors for ages 6 and older estimated using Survey 3 were extremely high (120-180%). The logical step following from these observations would have been to re-analyze the data with Surveys 1 and 2 only and to apply diagnostic tools again to the new results. Lack of time prevented this, and the results referred to in Section 4.2 correspond to the application of the Survivor Analysis for the last 20 years by combining all three surveys. Thus, these results contain a bias of 15-20% which could have been eliminated by further analysis.

For the real data sets (North Sea cod and haddock), only one survey provided estimates for a sufficient range of ages and years under present implementation. The other sets could not be utilized.

Extended Survivor Analysis

Work in progress by Sun (pers. comm.) suggests that a major source of error in assessment calculations is sensitivity to errors in the data for the final year. Many of the assessment methods treat these data as being exact, but this is not necessary except in the VPA calculations of VPA-based techniques. The Survivors method of Doubleday (1981) allows estimates of terminal populations based on all data for each cohort to be used, which should reduce the sensitivity to final-year errors. The original method, however, allows auxiliary data for only one fleet to be analyzed and uses an estimation procedure for Survivors which is inconsistent with that used for catchability. In addition, the algorithm frequently produces negative estimates of survivors which are censored and replaced by zeroes.

Shepherd and Sun (pers. comm.) have recently developed an extended version of the same general procedure. This allows use of auxiliary data from multiple fleets and employs an exponential decline algorithm (rather than the original subtractive algorithm) which is consistent with the use of logarithmic mean catchability and avoids negative estimates.

A preliminary implementation of this method was available, although this did not include certain desirable features such as inverse variance weighting. By mistake, the method was run on Data Sets 1-3 with no constraint on catchability at the oldest ages, which leaves the solution ill-determined. For data sets 4-6, catchability was assumed to be constant on ages 10-12.

3 CAGEAN - CATCH-AT-AGE ANALYSIS

A well-documented description of CAGEAN can be found in Deriso *et al*. (1988) and references therein.

Some problems were identified in the approach taken to the estimation of last-data-year parameters for the period 1973-1972 (as specified in Section 3.2.1) for Data Sets 1-3. This work was carried out prior to the meeting. Essentially, the assessors conditioned the analysis of each 20-year data set by prior knowledge obtained from detailed analysis of the corresponding 30-year data sets. The final results from analysis of any 20-year data set was accepted only if estimated biomass agreed fairly closely with that obtained by analyzing the full 30 years data.

The original intention had been to perform an independent assessment on each 20-year data series. Because of lack of time, the assessors could not recompute the results for Data Sets 1-3, but Data Sets 4-6 were analyzed. The analysis was, in many ways, less rigorous than that which would be carried out given more time. It was only possible to analyze 10-year data sets. Some up-to-date software was not available at the meeting, and not enough time could be spent examining diagnostics and hence appropriately modifying the analyses. The comments in Section 4.1.1 on the apparent performance of CAGEAN should be read with these qualifications in mind.

Overall, it appears that the relative weighting given to each type of data and also the values used to initiate the computations need to be handled with considerable care. Different weightings can lead to substantially different results and careful consideration of diagnostics is required to obtain an acceptable assessment.

4 ADAPTIVE FRAMEWORK

Model

The basic framework is simply a mathematical expression for the application of a common statistical technique, least squares, to examine the discrepancy between observations of variables and the values of those variables estimated as functions of a population matrix, in order to determine the most appropriate estimate of that population matrix. That is, we require to find

$$\min \sum_{i} \{W(i)[O(i) - f(P,G)]\}^2 \qquad (6)$$

where $W(i)$ = weight for observed variable set i
$O(i)$ = observed variable set i
P = population matrix
G = matrix of any other required parameters

Note that O(i) and W(i) may be matrices of vectors (series). The W(i) are needed to accommodate differences in the reliability of the elements within an observed variable set as well as any differences in reliability between variable sets. Lacking such measures, transformations may be employed in attempting to stabilize variance. The summation is taken over all sets (i) as well as within each set.

The framework is adaptive in the sense that any observed variable which is a function of the population matrix can be accommodated by equation (6). Furthermore, various formulations of the structural relationships and statistical error models which link these observed variables with the population matrix may be invoked. This flexibility is considered essential given the wide range of situations encountered in stock assessment. Common statistical diagnostics, e.g., residual plots, standard errors, and correlation matrices of the parameters estimated, are used to select from among the formulations those which are most suitable for the particular conditions experienced. To elucidate the basic framework and to demonstrate the flexibility in the types of relationships which may be employed, two hypothetical scenarios are described.

Scenario A

The commercial catch has been sampled using a double sampling design and the estimated catch at age C(a,y) is available with the associated standard error CS(a,y). It is known that age determination for older ages is variable; therefore, ages 1-5 are treated individually, while ages 6 and older are aggregated. There are no reliable data on effort from the commercial fishery. A research vessel survey index of abundance at age, I(a,y), is available. The survey was conducted at the beginning of the year using a stratified random design, and the appropriate standard error for the index, IS(a,y), has been derived. There are no other relevant observed variables.

The expression to be minimized is:

$$\sum_{a=1}^{6+}\sum_{y=1}^{20}\left[\frac{1}{CS(a,y)}[C(a,y) - \hat{C}(a,y)]\right]^2 + \sum_{a=1}^{6+}\sum_{y=1}^{20}\left[\frac{1}{IS(a,y)}[\hat{I}(a,y) - I(a,y)]\right]^2 \qquad (7)$$

a = index for age
b = index for year (20 years of data)

Note that results from the beginning-of-the-year survey are available at the time the assessment is done.

In order to ensure that population size decreases along cohorts with time, the parameter set P is replaced by R, an estimate of the year-class size for each cohort, and F, the fishing mortality matrix.

The associated population matrix can then be calculated using the relationship:

$$Q(a,y) = Q(a+1,y+1)\exp[F(a+1,y+1) + M] \qquad (8)$$

where natural mortality rate, M, is assumed constant for all ages and years. The appropriate cohort year-class size, R, is substituted into Q as required.

The predicted catch can then be obtained using the conventional catch equation:

$$\hat{C}(a,y) = F(a,y)Q(a,y)\{1-\exp[-F(a,y) - M]\}/[F(a,y) + M] \qquad (9)$$

A linear relationship through the origin can be assumed between the abundance index and population size. Therefore, the predicted index is obtained from:

$$\hat{I}(a,y) = k(a)P(a,y) \qquad (10)$$

where k(a) = calibration coefficient for age a. The parameter set G consists of only k(a) in this scenario. Equations 7-10 can be used to solve for the least squares estimates of R, F, and k.

<u>Scenario B</u>

The commercial catch has been sampled, as in Scenario A above; however, the errors in the estimates of catch at age are considered negligible. A combined catch rate series, U(y), has been derived with a multiplicative model, and its associated standard error is US(y). There are two research survey abundance indices, I(1) and I(2), and their standard errors, IS(1) and IS(2), were computed on the basis of the respective survey designs. Survey I(2) is considered a recruitment index suitable for the first two ages only and is only available for the most recent 6 years. Both surveys are related to the beginning of year population.

The expression to be minimized is:

$$\sum_{a=1}^{10}\sum_{y=1}^{21}\left[\frac{1}{IS(1,a,y)}[I(1,a,y) - \hat{I}(1,a,y)]\right]^2 +$$

$$\sum_{a=1}^{2}\sum_{y=16}^{21}\left[\frac{1}{IS(2,a,y)}[I(2,a,y) - \hat{I}(2,a,y)]\right]^2 +$$

$$\sum_{y=1}^{21}\left[\frac{1}{US(y)}[U(y) - \hat{U}(y)]\right]^2 \qquad (11)$$

Since errors in the catch at age are considered negligible, the parameter set P is reduced to R, the year-class size of each cohort. The last year and the oldest age are used as the designate age for the year-class size. The population matrix can then be derived using:

$$Q(a,y) = C(a,y)\exp(M/2) + Q(a+1,y+1)\exp(M) \qquad (12)$$

where the appropriate cohort year-class size is substituted into Q as required.

Linear relationships are assumed for both survey indices. However, intercepts are accepted for survey index I(2) even though the mechanism to generate such a relationship has not been established. Therefore:

$$\hat{I}(1,a,y) = k(1,a)q(a,y) \qquad (13)$$

and

$$\hat{I}(2,a,y) = k'(2,a) + k(2,a)Q(a,y) \qquad (14)$$

A fishing mortality matrix is calculated from:

$$F(a,y) = \ln[Q(a,y)/Q(a+1,y+1)] - M \qquad (15)$$

The partial fishing mortality rate matrix for the otter trawl fleet was obtained as:

$$F(T,a,y) = F(a,y)C(T,a,y)/C(a,y) \qquad (16)$$

The annual fully-recruited fishing mortality for all trawlers was derived from:

$$F'(T,y) = \sum_{a=5}^{10} Q(a,y)F(T,a,y)/\sum_{a=5}^{10} Q(a,y) \qquad (17)$$

The annual partial recruitment for the trawler fleet is then obtained:

$$PR(T,y) = F(T,a,y)/F'(T,y) \qquad (18)$$

and used to calculate the average annual exploitable biomass:

$$\bar{B}'(T,y) = \bar{W}(a,y)(Q(a,y)\{1-\exp[-F(a,y) - M]\}/[F(a,y) + M]PR(T,y) \qquad (19)$$

A linear relationship through the origin is hypothesized for the otter trawl catch rate and the exploitable biomass:

$$\hat{U}(y) = k(3)\bar{B}'(Y,y) \qquad (20)$$

We now have the quantities required for minimization of expression (11).

Application of simulated data

Data Set 1

Errors in the catch-at-age data were assumed negligible. The three survey indices were used for individual ages 3, 4, and 5 and aggregated for ages 6 and older. The two commercial fleets for which effort data were available were employed by deriving a total catch rate in numbers for each fleet, i.e.

$$U(T,y) = \sum_{a=1}^{10} C(T,a,y)/E(T,y) \qquad (21)$$

No standard errors were provided and, therefore, logarithmic transformation of the survey indices and commercial CPUE was applied.

The expression minimized was:

$$\sum_{i=1}^{3} \sum_{a=3}^{6+} \sum_{y=1}^{20}[\ln I(i,a,y) - \ln I(i,a,y)]^2 + \sum_{T=1}^{2} \sum_{y=1}^{20}[\ln U(T,y) - \ln U(T,y)]^2 \qquad (22)$$

The population matrix was calculated using equation (12). However, because older ages appeared fully recruited, the population size for the oldest age was not included in the parameters R. Instead, the population was derived using catch equation (9), and a fully-recruited fishing mortality calculated as the weighted average for ages 6-9 inclusive.

With the population matrix available, relationships of the form of equation (13) were used to obtain predicted survey indices. The predicted catch rate indices were computed as for Scenario B [omitting the weights in equation (19) since the catch rates are in numbers].

A total of 23 parameters require to be estimated (9 year-class strengths at the end of year 20, catchability coefficients for ages 3, 4, 5, and 6+ for each of the three survey series, and catchability coefficients for each of the two commercial catch rate series.

The number of residuals calculated was 80 for each survey (4 age groups, 20 years), and 20 for each catch rate (20 years), giving a total of 280 residuals.

Convergence was rapid in all runs and no obvious problems were detected from analysis of residuals. Coefficients of variation for population size in the final year were of the order of 5-10%.

Data Set 2

The same formulation was used as for Data Set 1 except that the fully-recruited fishing mortality was calculated as the weighted averages of ages 7-10. Parameter estimation was difficult in the last few blocks of 20 years and in fact no suitable convergence criteria were obtained.

Coefficients of variation for the population size in the final year were 20-40% for the younger ages and higher for the older ages. The residuals revealed disturbing patterns suggesting that at least one of the indices did not conform to the model equations. Furthermore, the assumption of flat-topped exploitation pattern was questionable, especially in the later years. In conclusion, refinement of the model equations was indicated if the analysis of this data set was to be extended.

Data Set 3

The same model formulation as that for Data Set 1 was used with fully-recruited fishing mortality calculated as the average for ages 6-9. Convergence was not as rapid as for Data Set 1 (usually 7 iterations being required as compared to 3 for Data Set 1), but no basic problems in convergence were encountered.

Correlation between parameters was low, in the range 0.01-0.1. Coefficients of variation for population size in the last data year were 9-15% for ages 4-9 and higher for older ages. Residuals were not examined for trends.

Data Set 4

Only the analysis of the full 30-year data set was carried out. Initially, the same model formulation as that used for Data Set 2 was employed. Analysis of residuals revealed very strong patterns with time. Surveys 1 and 3 exhibited increasing catchability, while catchability in Survey 2 decreased. The model was modified to include a linear trend for catchability.

The coefficients of variation for the final year population estimates were lower (about 10% for younger ages and 20% for others) under the revised model. The slopes for the linear trends were highly correlated with the associated intercepts, but their coefficients of variation were only about 20%. There still remained, however, a significant trend in the residuals for the linear catch rates indicating that increases in catchability in some commercial gears may not have been adequately accounted for.

5 GENERAL LINEAR MODEL

This is a new method still in a state of development and testing. The method fits the General Linear Model (GLM):

$$\ln C(a,y,f) = A(a,f) + Y(y,f) + I(a,y) + e(a,y,f) \qquad (23)$$

$$\ln E(y,f) = Y(y,f) + n(y,f) \qquad (24)$$

where a, y, f are age, year, and fleet indices, respectively, A, Y, I are age X fleet, year X fleet, and age X year effects, and e(a,y,f), n(a,y,f) are error terms.

In the current implementation, the fit is done in the GLIM package of Baker and Nelder (1978) which allows the error structure to be any member of the exponential family of distributions (Normal, Poisson, Gamma, or Binomial). At present, the model is fitted assuming log-normality, but this could be easily modified. The parameter estimates obtained by the GLM described in equations (23) and (24) are adapted so that the fit to the data is unaffected, but the terms are reinterpreted in relation to the conventional fisheries catch and stock equations.

$$\ln C(a,y,f) = \ln q(a,f) + \ln E'(y,f) + \ln \bar{N}(a,y) \qquad (25)$$

$$\ln E(y,f) = \ln E'(y,f) \qquad (26)$$

where q, E', and $\bar{N}$ are catchability, effort, and average population terms, respectively.

This is done using factors d(a) and p(y) such that:

$$\ln q(a,f) = A(a,y) + d(a) \qquad (27)$$

$$\ln E'(y,f) = Y(y,f) + p(y) \qquad (28)$$

$$\ln \bar{N}(a,y) = I(a,y) - d(a) - p(y) \qquad (29)$$

The values of d(a) and p(y) are chosen such that a GLM of ln N(a,y)

$$\ln N(a,y) = \text{Year-class Effect}(y-a) + \text{Age Effect}(a) +$$

$$\text{Year Effect}(y) - k \times \text{CUMZ}(a,y) + \text{error}(a,y) \qquad (30)$$

has k = 1 and the age and year effects equal to zero. The age effects are fitted to ages up to 3 less than the oldest age in order to preserve constant values of q(a,f) on the last four ages of the last fleet. This fleet should, therefore, be chosen as one using a gear likely to have an exploitation pattern which is flat over these ages.

$$\text{CUMZ}(a,y) = \sum_{i<a} Z(i,y-a+i) + \ln \frac{1-\exp[-Z(a,y)]}{Z(a,y)} \qquad (31)$$

where $$Z(a,y) = M(a) + \sum_{\text{all } f} q(a,f)E'(y,f)$$

Suitable values of d(a) and p(y) are estimated by progressive iterations based on the GLIM fit. At each step j, we have:

$$d'(a,j) = 0.6k \times \text{Age effect}(a) \quad (32)$$

$$p'(y,j) = 0.6 \times \text{Year effect}(y) \quad (33)$$

where d(a,j) and p(y,j) sum to d(a) and p(y), respectively.

Preliminary runs of the model have been made giving uniform weighting to each component of Data Sets 1-4. The method would, therefore, probably give better results using appropriate weightings based upon the prior information provided and that gleaned from a study of the residuals.

Implementation time is about 20 minutes on an HP 9000-318 with 10 ages, 10 years, and 7 fleets included in the data sets.

The diagnostics which can be applied to the model results potentially comprise anything that can be done within the GLIM package and are, therefore, open-ended. The method routinely outputs tables, plots, and histograms of residuals with estimates of residual variation by fleets, ages, and years.

Most attention was given to the diagnostics when analyzing Data Set 6, which was one of the most difficult prepared for this meeting. Considerable departures from the assumed within-fleet separability were indicated, raising questions about the applicability of this manifestation of the method for analyzing this data set.

Work carried out for this meeting indicated that the present implementation could be improved in three important ways:

(i) Make into a tidy package.

(ii) Make fleet and age weighting automatic.

(iii) The means by which selection is fixed on the older ages could be arranged better.

Until these points are put into effect, it would be inappropriate to use this method to carry out a real assessment.

6 COLLIE-SISSENWINE METHOD

Collie and Sissenwine (1983) developed a modified DeLury method (DeLury, 1947; Allen, 1966) for estimating fish population size using a single relative abundance index and total catch data from the fishery. The method estimates a catchability coefficient for the index of abundance using non-linear regression techniques. In addition, it accounts for measurement error in the index by estimating an index of abundance for each year and age. Two models were proposed. One requires data on the age structure of the catch, while the other is a non-age-structured model. The age-structured model is of interest here.

Collie and Sissenwine fit the age-structured model to data from haddock populations (Georges Bank and NAFO Division 4X). The estimated population size at age agreed closely with results from VPA analyses. Despite these results, the method has not been widely used in practice.

One major reason for the lack of application is the assumptions and restrictions imposed by the model. In particular, the model assumes that the catchability (q) is constant over time and age, that natural mortality is constant for all ages, and allows only one index of abundance. Only minor modifications are required to account for age-specific natural mortality, but incorporating age- and/or year-specific qs and multiple indices of abundance requires fundamental changes to the model's structure.

In each of the real and simulated data sets considered at this meeting, multiple indices of abundance were available, catchability was thought to vary with age and/or time, and for the real data sets, natural mortality rates are age-specific. To examine the utility of the Collie-Sissenwine model structure, the method was extended to incorporate all of the above-mentioned aspects.

In extending the model, the Collie-Sissenwine concept of separating the process (or equation) error from the measurement error was maintained. The Collie-Sissenwine process error was generalized to incorporate age-specific qs and age-specific natural mortality. The measurement error term, a measure of the variability within an index of abundance, is essentially the same as that of the Collie-Sissenwine model except that log-normally distributed error was not assumed. This change allowed all terms in the objective function to be in the same units. A new consistency error term was developed which provides a measure of the variability between indices of abundance. Retention of the basic DeLury model, in which catch is assumed to be taken instantaneously at the start of the year, may induce bias in the estimates of N and F.

As with the Collie-Sissenwine model, parameters were estimated using a Levenberg-Marquadt algorithm an finite-difference Jacobian. An option to constrain all parameter estimates to be positive was also incorporated. All calculations were carried out using high-precision arithmetic.

The model estimates age-specific qs for each index and predicted indices for each year and age. The quotient of these estimates provides stock size numbers at age for each year. Using the mean stock size numbers, N(y,a), the catch, C(y,a), and the natural mortality rate, M(a), fishing mortality, F(y,a), is calculated from the conventional catch equation via a Newton-Raphson iteration. Total and spawning biomass are also calculated using N(y,a) in conjunction with input data on mean weight and proportion mature at age.

Implementation of the new model requires the estimation of a large number of parameters, and computer run time becomes a constraining factor (9 hours CPU time on a VAX 8800 is typical), but the use of some minimization method other than that of Levenberg-Marquadt may overcome this problem.

A single run was made on Data Set 1 using all ages and 20 years of data. Auxiliary data from the three research vessel surveys were used in fitting the model (commercial CPUE was ignored). Catchability was assumed constant with time, but age-specific estimates were made for ages 3, 4, 5, and 6+. All indices of abundance were given equal weight as were the three error types (measurement, process, and consistency errors). Measurement and process error residuals appeared to be well behaved and estimated q at age appeared to be similar for the three survey fleets.

A single run was made on Data Set 2 using all ages, 10 years of data, and three with the same assumptions on catchability as made for Data Set 1. The second research vessel index was given twice the weight applied to the others on the basis of "anecdotal" information supplied with the data set. Systematic patterns in the measurement and process error residuals indicated that this specification of the model may have been inappropriate.

Runs similar to those on Data Sets 1 and 2 were attempted on Data Sets 3 and 4, but no solution was obtained after extensive run times.

The model was applied to data on North Sea cod for the period 1971-1986 and for ages 1-8+. Four research vessel indices were used. For the first three indices, a single q was estimated for all ages for which data were available. For the last index, age-specific qs were estimated for ages 1, 2, and 3+. Run time was about 20 minutes.

Application to North Sea haddock data used data for years 1971-1986 and ages 0-8+. Three research vessel indices were used. Age-specific qs were estimated for ages 0, 1, and 2+. The Marquadt algorithm was constrained to providing only positive estimates by the implementation of a penalty function. Run time was about 20 minutes.

7 TIME SERIES METHOD

Full details of the estimation and application of this model are given in Gudmundsson (1987).

The main feature of this methods is that fishing mortality rates are modelled as time series, as follows:

$$\log F(a,y) = U(a,y) + V(a,y) + n1(a,y) \qquad (35)$$

where

$$U(a,y) = U(a,y-1) + n2(a,y) \qquad (36)$$

$$V(y) = V(y-1) + T1 + n3(y) \qquad (37)$$

$$\sum_{\text{all } a} U(a,y) = \text{constant} \qquad (38)$$

The residuals n1, n2, n3 are assumed to be serially uncorrelated and normally distributed with mean zero and covariances var1 x Q1, var2 x Q2, and var3, where Q1 and Q2 are given matrices.

The residuals n1 represent transient random variations. Equation (36) is associated with changes in selectivity, and equation (37) describes equal proportional changes in F at all ages.

Recruitment is represented by the equation:

$$N(1,y) = N0 + T2(\text{recruitment index}) + n4(y) \qquad (39)$$

(or N0 alone if no suitable recruitment index is available). The residuals have variance var4.

The measurement errors of catch-at-age observations are assumed to be serially uncorrelated with covariances s1 x H1, where H1 is a given matrix.

Initial values of the fishing mortality rates are represented by a function of three parameters, and the first year's observations are used to calculate corresponding stock estimates. The next year's Ns and Fs are predicted by means of the equations above and used to calculate catch predictions. The latter are compared to the actual catches, and the predictions of N and F updated by means of the Kalman filter before proceeding to predict the third year's values, etc.

Apart from the initial values, the unknown parameters in this model are var1, var2, var3, var4, T1, T2, and N0. These are estimated by maximizing the likelihood function of the catch prediction errors. Extensive diagnosis of residuals is performed.

Given the natural mortality rate, the estimation can be carried out with no further observations.

However, observed catch per unit effort can also be included in the estimation. Catch per effort is given as:

$$CPUE(a,y) = S(a)Cb(y)f[F(a,y)] + e2(a,y) \qquad (40)$$

f[F(a,y)] is a given function which depends on whether CPUE is obtained from a research vessel survey or a commercial fleet. S(a) describes variation of catchability with age, and is assumed constant. The residuals in this equation [e2(a,y)] represent measurement errors and irregular variations of CPUE. The residuals are assumed to be N(0,s2 x H2), where H2 is a given matrix.

Variations in catchability affecting all ages are modelled as

$$Cb(y) = W(y) + n5(y) \qquad (41)$$

$$W(y) = W(y-1) + n6(y) \qquad (42)$$

The residuals are assumed normally distributed, serially uncorrelated with zero mean and variances var5 and var6, respectively. In equation (41), the residuals represent transient variation, whereas each of the values of n6(y) affects all subsequent values of Cb(t).

With the present programs, estimation of the parameters for 10 years of data and 8 ages and ignoring CPUE data takes about 20 minutes on a VAX 8250. With 4 ages of CPUE data as well as total catches, the computational time increases to more than 1 hour.

The model was run on 10 years of data for ages 4-11 on Data Sets 1-4. Two runs were made on each data set, one run including and the other run excluding research vessel CPUE data. Only one set of CPUE data, selected by the assessor as the "best" set on the basis of trial runs, was used. For Data Sets 5 and 6, no CPUE data were included. In the latter case, it was found that much of the error in the last-year estimates was produced by T1, which is estimated with a high standard error. Addition of CPUE data should improve this situation.

8 CONVENTIONAL AND SEPARABLE VPA

The main purpose of the Workshop was to test the performance of various methods which utilize both total catch-at-age data and auxiliary (catch-per-effort) data. Conventional and separable VPA do not make use of auxiliary data, but were applied to Data Sets 1-4 mainly to demonstrate how they would perform in comparison to other methods as a basis for estimating the improvement which may be gained by the appropriate use of auxiliary data. Furthermore, work in progress (Man Sun, pers. comm.) shows that results from conventional and separable VPA can form the basis for reasonably accurate short-term catch predictions, and this might naively be taken to imply that there is no need to collect auxiliary data. However, conventional and separable VPA have no basis for estimation of true fishing mortality rates and stock size in recent years, and these quantities are important when formulating advice on conservation measures.

The conventional VPA was applied by iteratively replacing F in the last data year by average F computed for the previous 5 years and F at the highest age by average F computed for the 5 younger age groups. (This method is referred to as the JAM method; the acronym is variously expanded as the Judicious Averaging Method or Just Another Method.)

The separable VPA (Pope and Shepherd, 1982) was also applied by iteratively replacing F in the last data year by that obtained for four years previously. Terminal S was set equal to that obtained at age 7 (with unit selection at age 5).

In considering the results from these methods, it should be remembered that they are not tuning methods and should not be judged by the same criteria.

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