NORTHWEST ATLANTIC FISHERIES ORGANIZATION

Scientific Council Studies
Number 36

Workshop on Assessment Methods

2003

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Foreword

In accordance with its mandate to disseminate information on fisheries research to the scientific community, the Scientific Council of NAFO publishes the *Journal of Northwest Atlantic Fishery Science*, which contains peer-reviewed primary papers and notes on original research, and *NAFO Scientific Council Studies*, which contains review papers of topical interest and importance. Each year since 1981, the Scientific Council has held at least one Special Session on a topic of particular interest, and many of the contributions to those sessions have been published in either of these NAFO publications. For 2000, the Scientific Council initiated this Special Session titled *Workshop on Assessment Methods*, as a specific topic of interest to the Scientific Council in June 1999. The Council invited D. Rivard (Canada) and C. Darby (EU-United Kingdom) to design and to conduct a workshop on assessment methods as a Scientific Council Special Session in conjunction with the September 2000 Annual Meeting. It was suggested that the focus should be on techniques and tools routinely (or increasingly) used by the Scientific Council in the context of stock assessments, risk analyses and the development of the Precautionary Approach.

During 13–15 September 2000, the Scientific Council held the Special Session in conjunction with the 22nd Annual Meeting of NAFO, at the Boston Back Bay Hilton, Boston, Massachusetts, United States of America. D. Rivard (Canada) and C. Darby (EU-United Kingdom) were conveners, and R. K. Mayo (USA) played a key role in the preparation of the Workshop and the presentation of tutorials.

At its meeting of 18–22 September 2000, the Council evaluated this Workshop as a very informative and a valuable contribution to the work of the Scientific Council. While recommending that a workbook should be published in the *Scientific Council Studies* series, the Council noted the publication could constitute previously published information as well as public domain material. While there was a considerable time lapse in the preparation of the final texts and tutorials for this publicaiton, the comprehensive coverage achieved in this publication is believed to be timely and important for scientists throughout the world dealing with stock assessments.

May 2003

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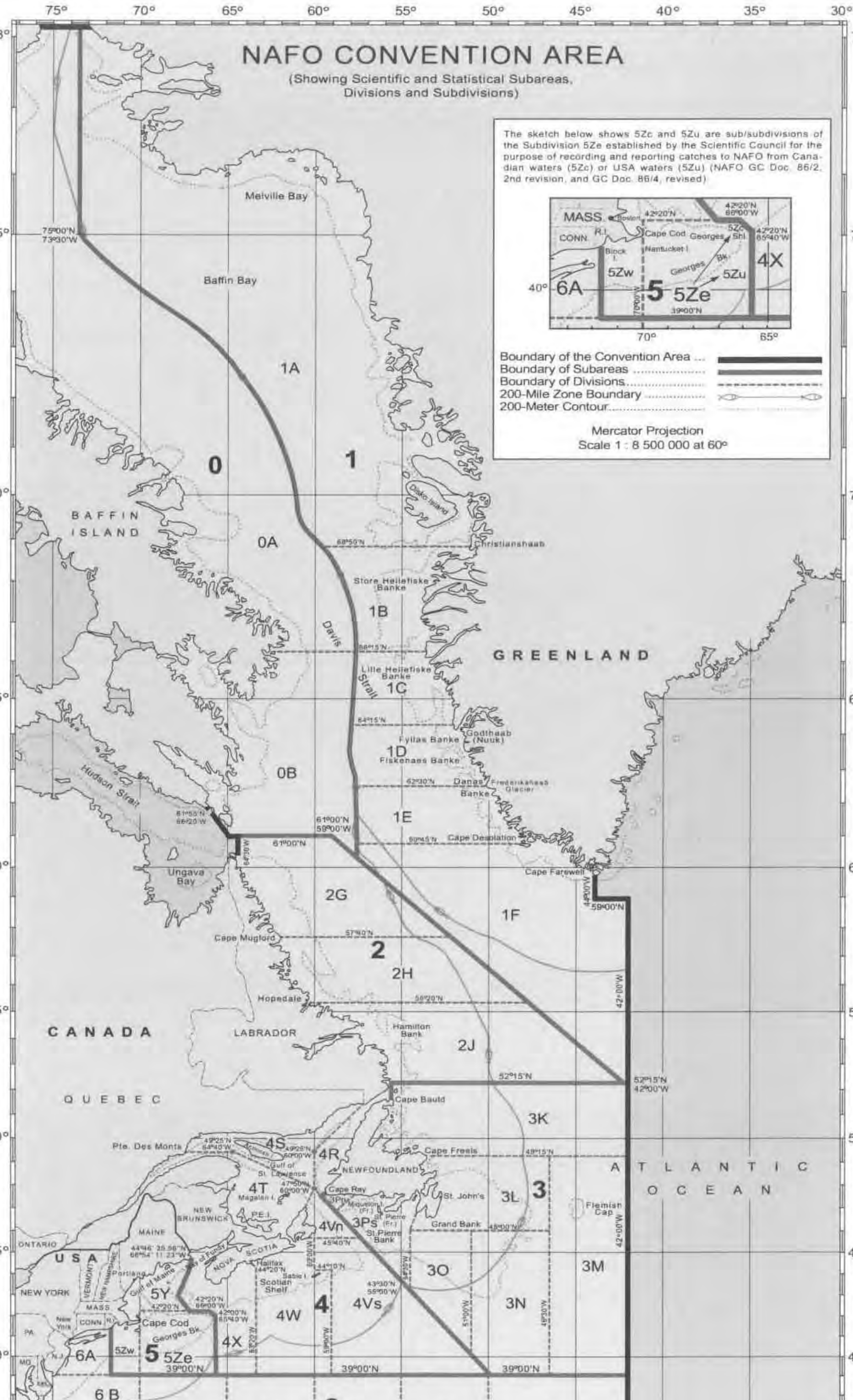
NAFO CONVENTION AREA
(Showing Scientific and Statistical Subareas, Divisions and Subdivisions)
The sketch below shows 5Zc and 5Zu are sub/subdivisions of the Subdivision 5Ze established by the Scientific Council for the purpose of recording and reporting catches to NAFO from Canadian waters (5Zc) or USA waters (5Zu) (NAFO GC Doc. 86/2, 2nd revision, and GC Doc. 86/4, revised)
Boundary of the Convention Area
Boundary of Subareas
Boundary of Divisions
200-Mile Zone Boundary
200-Meter Contour
Mercator Projection
Scale 1 : 8 500 000 at 60°
Melville Bay
Baffin Bay
BAFFIN ISLAND
GREENLAND
CANADA
LABRADOR
QUEBEC
USA
ATLANTIC OCEAN
Davis Strait
Hudson Strait
Ungava Bay
NEWFOUNDLAND
Cape Farewell
Cape Desolation
Cape Bauld
Cape Freels
Cape Cod
Cape Hatteras
Hamilton Bank
Grand Bank
Flemish Cap
Scotian Shelf
Georges Bk.
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Introduction and Objective of the Workshop

The Scientific Council Special Session, *Workshop on Assessment Methods*, was held at the Boston Back Bay Hilton, Boston, Massachusetts, United States of America, with co-conveners D. Rivard (Canada) and C. Darby (EU-United Kingdom) during 13–15 September 2000. R. K. Mayo (USA) also played a key role in the preparation of this Workshop and the presentation of tutorials. There were 31 participants from Canada, Denmark (in respect for Greenland and Faroe Islands), European Union (Portugal, Spain and United Kingdom), Japan, Russia Federation and the United States of America.

The Workshop was opened by W. B. Brodie (Canada), Chair of Scientific Council, who on behalf of the Scientific Council welcomed participants to Boston and to the Workshop. D. Rivard welcomed the participants, and gave a general outline of the Workshop, particularly noting the hands-on nature of the activities, which limited the Workshop to about 30–35 participants (the list of participants is given at Annex 1).

This Workshop was designed to provide an opportunity for the members of the Scientific Council to explore assessment techniques and the various tools available for their application. In particular, the Workshop was to focus on tools to perform age-structured analyses and stock abundance estimations, calculate reference points in the context of the Precautionary Approach and carry out risk analyses.

Each session was designed to begin with a brief comment on the theory and common practices, followed by demonstrations or tutorials making use of a common data set, and working sessions inviting participants to apply these tools to specific data sets (see Annex 2).

Co-conveners of Workshop: D. Rivard (Canada) and C. Darby (EU-United Kingdom) assisted by R. K. Mayo (USA).

The Report of the *Workshop on Assessment Methods*

by

D. Rivard, C. Darby and R. K. Mayo

1. Age-structured Analyses and Stock Abundance Estimation

1.1 The Lowestoft Tuning Suite (Appendix 1 – see Tutorials 1–8)

1.1.1. Introduction: principles of VPA tuning (see Tutorial 1 – Reported by C. Darby)

The evolution of VPA tuning from *ad hoc* age-aggregated methods to age-disaggregated methods employing a specific objective function with least squares minimization was presented. VPA tuning methods have evolved considerably over the past 2–3 decades, but current state-of-the-art techniques still do not account for all of the uncertainty in data (e.g. sampling uncertainty for which measurements exist, and variability of survey indices).

In this tutorial, the Lowestoft VPA suite of assessment programs was introduced. These include Separable VPA, *ad hoc* tuning and Extended Survivors Analysis methods. The structure of the data files required for performing an assessment was examined and a basic example, the running of a VPA with user defined starting values, was used to illustrate the reading of input data files, specification of key fishery summary statistics and the output of results.

1.1.2. Separable VPA (see Tutorial 2 – Reported by C. Darby)

The development of the Separable VPA has been described by Pope (1977, 1979), and Pope and Shepherd (1982). Separable VPA determines values of fishing mortality from a matrix of catch-at-age data, on the assumption that the exploitation pattern is constant over time. The method provides a useful filter for examining catch-at-age before tuning; high individual residuals may indicate data anomalies. By partitioning the data (e.g. fitting the model for a specific period, the method can be used to investigate changes in the exploitation pattern over time). However, the information contained within the data matrix is insufficient for the determination of a unique solution. In addition to natural mortality, the user must specify a 'reference age for unit selection', against which the selection values for other ages will be scaled; and values for:

a) the fishing mortality on a reference age in the last year, and

b) the terminal selection value, i.e. that for the oldest independent age in the data range (used for all years). Selection-at-age is the fishing mortality at age relative to that on the reference age.

1.1.3. Laurec-Shepherd tuning method (see Tutorial 3 – Reported by C. Darby)

The Laurec-Shepherd VPA tuning method is one of many *ad hoc* tuning algorithms, which derive estimates of fishing mortality at age in the final year from an analysis of the logarithms of fleet catchabilities. They are based on the assumption that catchability (q) is separable by fleet and by age within a fleet. The *ad hoc* methods have been reviewed and tested by Pope and Shepherd (1985). The algorithms have no formal statistical basis and are based on an iterative process, which relies solely on the convergence properties of V.

An iterative algorithm is used to derive estimates of fleet catchability-at-age in the final year. Fleet catchabilities and effort in the final year are used to calculate partial F-at-age: the fraction of overall F-at-age contributed by each fleet. Fleet partial Fs are then 'raised' by the ratio of the total catch-at-age and the fleet catch-at-age to give fleet based estimates of total F-at-age. Final year Fs for each new VPA iteration are derived from a weighted average of the fleet-based estimates. The Laurec-Shepherd method assumes constant catchability with respect to time for each fleet.

1.1.4. **Extended Survivor Analysis** (see Tutorial 4, 5 – Reported by C. Darby)

Extended Survivor Analysis (XSA) (Shepherd 1999), an extension of Survivors Analysis (Doubleday 1981), focuses on the relationship between catch per unit effort and population abundance, allowing the use of a more complicated model for the relationship between CPUE and year-class strength at the youngest ages. The XSA algorithm performs:

a) a cohort analysis of the total catch-at-age data to produce estimates of population abundance-at-age, and fishing mortalities,

b) adjustment of the CPUE values for the period of fishing into CPUE values corresponding to the beginning of the year,

c) calculation of fleet-based population abundance-at-age from the adjusted CPUE values and fleet catchabilities, which are assumed to be constant with respect to time, or dependent on year-class abundance and

d) calculation of a least squares estimate (weighted mean) of the terminal population (survivors at the end of the final assessment year) for each cohort in the tuning range using the fleet-derived estimates of population abundance-at-age.

The technique allows for weighting the survivors estimates using various methods. It also allows for shrinkage towards the mean. The detailed algorithm is presented in Darby and Flatman (1994).

1.2 **Integrated Catch Analysis (ICA)** (see Appendix 1 – Reported by C. Darby)

In the ICA model, the last years of the available catch-at-age matrix are fitted by a separable model. The earlier years in the data set are modeled by a conventional VPA, estimated backwards using the first year of the separable model as the starting point. In the separable model, the fishing mortality at each age in each year is partitioned into a year effect, which may change with changing effort, and an age effect, which represents the susceptibility to fishing. Parameters for the separable model are estimated by minimizing the squared differences between observed and predicted catch at age. In the VPA model, F on the last age that is required to drive the VPA is derived from the Fs at earlier ages and the (assumed constant) selection-at-age vector.

Tuning indices may be age-structured or based on age-aggregated measures of spawning stock biomass. The assumed relationship between a given index and the corresponding separable or conventional VPA estimate of expected stock size can be selected to be absolute, linear, or non-linear. Weighting of indices in the separable model may be manual, based on prior information, or by inverse-variance re-weighting. A Beverton-Holt stock-recruitment relationship may be imposed on the model fit, with appropriate weighting, and a VPA may be 'shrunk' to a mean.

Two methods of estimating uncertainty in parameter estimates are available: traditional statistical methods using the variance-covariance matrix of the estimated parameters, and a Bayesian method using analyses of the parameter posterior distributions.

1.3. Adaptive Framework (ADAPT)

1.3.1. Introduction to ADAPT VPA tuning

ADAPT is an age-structured, adaptable framework for estimating historical stock sizes of an exploited population. It is not a rigidly defined model in the mathematical sense, but rather a flexible set of modular tools designed to integrate all available data that may contain useful information on population size.

The statistical basis of the ADAPTive approach is to minimize the discrepancy between observation of state variables and their predicted values. The observed state variables are usually (but are not limited to) age-specific indices of population size, e.g. from commercial catch-effort data, research surveys, mark-recapture experiments, etc. The predicted values are a function of a vector of estimated population size (age-specific) and catchability parameters; and standard population dynamics equations (usually Gulland's (MS 1965) VPA). Nonlinear least squares objective functions are employed to minimize the discrepancies.

The ADAPT VPA model uses the application of a statistical technique, non-linear least squares, to determine the most appropriate estimate of the population matrix. Gavaris (1988) initially describes the ADAPT objective function in general terms, as a minimization of the difference between observation of variables and the values of those variables predicted as functions of the population matrix (i.e. as function of the catch-at-age).

1.3.2. The Woods Hole version of ADAPT/VPA: Fishery Assessment Compilation Toolbox (FACT)

(see Appendix 2 – Reported by R. K. Mayo)

FACT is the Fishery Assessment Compilation Toolbox and the successor to the Woods Hole's Assessment Toolbox. Several existing fishery software programs have been added to FACT making it a powerful and user-friendly tool. The assessment programs had previously existed in a DOS or UNIX version. These programs now have a user-friendly interface that makes editing of inputs and completion of assessment more intuitive.

This is the VPA implementation using the ADAPT approach towards minimizing sums of squares in a specified objective function. In ADAPT, there is a calibration block and an estimation block. The calibration block is the set of indices, which are used to 'calibrate' the VPA terminal populations. A value of q is estimated for each index in the calibration block.

The estimation block is the set of ages for which you are estimating a terminal population stock size. In ADAPT, these are considered as survivors at the end (December 31) of the terminal year of the catch-at-age matrix, or at the beginning (January 1) of the year following the terminal year.

Input

The ADAPT module requires the following input: catch at age, mean catch weights-at-age, mean stock weights-at-age, tuning indices, natural mortality, and maturity schedules. There are also several initialization specifications to be set before the VPA can run.

Diagnostics

- In addition to the residuals, one can look for a retrospective pattern in the estimates of F, stock size-at-age, and SSB. The retrospective may be selected from the Diagnostics dialog box.
- The final formulation of the VPA may be run through a bootstrap procedure in which a normalized residual is drawn at random from the pool, and subtracted from an observed

normalized survey index. This is done for each index in the calibration block. Generally, between 500 and 1 000 bootstrap runs are performed. This may take time, so 100 is recommended for the Workshop

Output

After the VPA has run successfully, formatted output will be written by default to a file based on the name of the input file. This file should be brought into a word processor for viewing and printing. If a Retrospective Analysis has been selected, the results will be appended to the end of this file.

An ASCII 'Flat File' may also be output as an option. This file contains VPA results and residuals selected by the user. This file should be brought into a spreadsheet for further analysis, tabulation, and plotting. After the Bootstrap procedure has run successfully, formatted output containing a summary of all bootstrapped variables will be written to a file, which should also be brought into a word processor for viewing and printing.

The Bootstrap procedure allows the user to keep track of key biological measures including:

1. Fully recruited F in terminal year of the VPA
2. Estimated stock sizes at age at the end of the terminal year
3. Spawning Stock Biomass in all years of the VPA
4. Mean Stock Biomass in the terminal year of the VPA
5. Beginning-year Biomass in the terminal year of the VPA
6. Biomass-weighted F in the terminal year of the VPA

This information may be brought into a spreadsheet for further analysis, tabulation, and plotting.

1.3.3. **St. Andrews (S. Gavaris) version of ADAPT: Estimation of Population Abundance** (see Appendix 3 – Reported by D. Rivard)

This tutorial aimed at introducing the use of version 2.1 of the software developed by S. Gavaris, St. Andrews Biological Station (New Brunswick, Canada), who introduced the concept of the ADAPTive framework in the late-1980s. The framework was introduced to allow flexibility in the exploration of various formulations for the estimation of stock abundance from fisheries and survey data. The ADAPTive framework uses a non-linear least-squares fit to calibrate a virtual population analysis against independent indices of abundance. This software has served both as a research tool for exploring various aspects of parameter estimation and as a production tool for stock assessment.

The tutorial used a data set mimicking a gadoid stock having four indices of abundance exhibiting various anomalies (trends in catchability, year effects, and conflicting trends in indices). The tutorial outlined working procedures that would permit a user to analyze the results using the various diagnostics available and to explore the impact of various formulations of the estimation problem.

To assist in the preparation of data for using ADAPT, a template was provided in the form of a computer spreadsheet, which includes data validation and pre-formatting. Essentially, the spreadsheet operates as a front-end to the ADAPT program which implements the non-linear estimation procedure, procedure that has been so far easier to handle outside the spreadsheet environment because of its complexity. Essentially, the template provides placeholders for your input data and output data. It also provides a means to display data in a graphical form or to carry out additional analyses using the spreadsheet graphical and statistical functions.

The tutorial highlighted the importance of verifying the sensitivity of the results to initial assumptions regarding survey catchability and the constraints imposed to reduce the dimensionality of the estimation problem (e.g. by imposing a functional relationship for the calculation of the oldest age-group in each year). It also highlighted the need to inspect the result carefully using the diagnostic tools available: i.e. variance and correlation matrix of parameter estimates, distribution of residuals, retrospective analyses, etc.

2. **PA Reference Points**

In this session, the functionality of FISHLAB was explained through a demonstration. This followed by a demonstration, and a hands-on session, on the PA software.

2.1 **FISHLAB** (Demonstration): FISHLAB (MRAG. 1997) provides a series of functions for use in Excel for simulations and sketching assessment problems.

FISHLAB is a set of fisheries tools developed at the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) with partial funding from the European Union. The tools are in the form of Excel add-ins and functions as well as routines that can be called from Visual Basic. Standard assessment methods such as Separable VPA, ADAPT, XSA and the calculation of reference points are provided as well as routines to allow the evaluation of management under uncertainty.

This software package was developed to assist in the modeling of uncertainty in fish stock assessment and management. It is essentially a library of functions that can be called from Excel or Visual Basic, although interfaces to other packages have also been developed. The intention was to make existing commercial applications more suitable for fisheries modeling by adding specialist routines. It is assumed that the average user would be familiar with Excel particularly in the use of functions. Whilst the more advanced user would be familiar with Visual Basic. A comprehensive help system is provided which should be consulted for use and documentation of FISHLAB methods

2.2 **PA software** (Demonstration and hands-on)

A key concept in implementing a precautionary approach is defining limit and target reference points. Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits, whilst Target reference points are intended to meet management objectives. The PA software was developed at CEFAS (Smith and Kell, 1998) to enable ICES working groups to estimate limit and precautionary reference points for fishing mortality and spawning. It is in the form of an Excel add-in and functions that can be used from Excel or Visual Basic.

3. **Risk Analyses** (see Appendix 4 – Reported by D. Rivard)

These sessions explored newly developed tools for producing risk analysis and long-term simulations.

3.1. **Long-term Simulations Based on Excel Spreadsheets Using @Risk** (see Appendix 5 – Reported by D. Rivard)

This session was intended as a tutorial to explore risk analysis using spreadsheets. The tutorial used @Risk (Anon., 2000a), an Add-in to the Excel spreadsheet software (Anon., 2000b) to add risk analysis capabilities to models. The Add-in provides a framework to handle probability distributions for any variable or input parameter to a model. It also provides tools to analyze the distribution of the results, i.e. any calculated field (or cell) dependent upon your input.

The tutorial covered various aspects of the @Risk software, including how to use @Risk functions and menus for setting up simulations, how to develop models and run simulations, and how to explore simulation results using the @Risk interface.

These tools were applied to a fisheries model allowing long-term projections in the context of the Precautionary Approach. The use of @Risk, in combination with this model, allows someone to specify uncertainty in initial conditions of the state variables and in certain population dynamic parameters (we focussed on the definition of the stock-recruit relationship). Many authors have suggested various ways to capture both the dynamics and the uncertainties of the recruitment process by re-sampling the recruit-SSB scatter points. In this spreadsheet, one option available is to split the observed range of SSB into quartiles and to resample the observed recruitment within these quartiles. Since this approach is based on re-sampling observations, it does not require making assumptions about the recruitment probability density function (pdf). The resulting model provides a framework to calculate the probability of achieving limits or targets in the simulation years, to calculate the time it takes to reach these targets and to evaluate other elements of interest to managers (e.g. number of closures after re-opening, recovery time).

As the participants were lead through the tutorial, they were asked to discuss how such a model could be modified to account for uncertainty in other population dynamic parameters, or to account for regime shifts and uncertainties related to management implementation. The take-home message is that long-term projections make a number of assumptions on the "realization" of key population dynamics parameters in future years; while some of the variability is taken into account, projection models rarely capture all possible sources of uncertainty or the full dynamic range of the possible outcomes. Consequently, actual trajectories may deviate substantially from the model results, even when these are expressed in terms of probabilities. For this reason, when long-term projections are used to investigate the impact of various approaches, the results should be interpreted in relation to the results of other scenarios rather than in absolute terms.

3.2. **Woods Hole AgePro Stochastic Simulations (AGEPRO)** (see Appendix 6 – Reported by R. K. Mayo)

The AGEPRO program performs stochastic projections of the abundance of an exploited age-structured population over a time horizon of up to 25 years. The primary purpose of the AGEPRO model is to characterize the sampling distribution of key fishery system outputs such as landings, spawning stock biomass, and recruitment under uncertainty. The acronym "AGEPRO" indicates that the program performs age-structured projections in contrast to size- or biomass-based projection models. In this framework, the USER chooses the level of harvest that will be taken from the population by setting quotas or fishing mortality rates in each year of the time horizon.

There are three elements of uncertainty incorporated in the AGEPRO model: recruitment, initial population size, and natural mortality. Recruitment is the primary stochastic element in the population model in AGEPRO, where recruitment is either the number of age-1 or age-2 fish in the population at the beginning of each year in the time horizon. There are a total of nine stochastic recruitment submodels that can be used for population projection. It should be noted that it is possible to simulate the case of deterministic recruitment with AGEPRO through a suitable choice of recruitment submodel and input data. Initial population size is a second potential source of uncertainty in AGEPRO that can be incorporated into population projection. To use this feature, the USER must have an initial distribution of population sizes that can be projected through the time horizon. Alternatively, the USER can choose to base the projections on a single estimate of initial population size. A third potential source of uncertainty in the AGEPRO model is natural mortality. In particular, the instantaneous natural mortality rate is assumed to be equal for all age classes in the population. The USER can choose to have a constant or a stochastic natural mortality rate. In the stochastic case, the natural mortality rates are taken to be realizations from a uniform distribution specified by the USER.

Stock sizes-at-age estimated at the end of the terminal year of the VPA are used as input for the forward projection. The stochastic aspect of the projection is based on 2 sets of input data:

1. The results of the Bootstrap procedure run in ADAPT.
2. The incoming recruitment estimated for each year in the projection time horizon.

AGEPRO is generally used to forecast catches several years ahead, based on an input set of annual fully recruited instantaneous fishing mortality rates. AGEPRO can also iteratively solve for *F*, given an input set of annual catches. It is also possible to specify a target SSB level, and AGEPRO will determine the probability of exceeding the target in each year of the projection time horizon.

Input

The age-based forward projection starts in the year immediately following the terminal year of the VPA. In addition to the initial stock sizes at age and incoming recruitment, many of the same input data used in the VPA are required in AGEPRO, including: mean catch weights-at-age, mean stock weights-at-age, natural mortality, maturation and partial recruitment-at-age.

In the case of AGEPRO, however, these data are input as smoothed multi-year averages that are judged to be representative of the projection time horizon.

There are 9 recruitment models in AGEPRO, but only 4 are included in the workshop tutorial.

Output

After AGEPRO has run successfully, formatted output will be written to a file named during the run by the user. These files should be brought into a word processor for viewing and printing.

3.3. ADAPT-based Short-term Projections

This tutorial explored the functions available within the St. Andrews implementation of the ADAPTive framework to carry out stock forecasts and analyses of the risks associated with various scenarios. This implementation provides for two types of projections: deterministic and stochastic. Deterministic projections make forecasts of stock characteristics from the point estimates of stock abundance and from fishery scenarios that are specified by the user. Stochastic projections make forecasts using the point estimates as well as a measure of their precision. The measure of precision can either be obtained analytically, or through a bootstrap procedure.

The most common practice is to use the bootstrap procedure (as opposed to the analytical approach) for calculating risk curves from ADAPT results. While it takes longer to obtain results because of the re-sampling procedure, bootstrap is believed to give a better appreciation for the shape of the risk curve (assuming, of course, a sufficient number of replicates). In the current version of ADAPT, the bootstrap is performed by re-sampling all residuals assuming that they are independent and identically distributed (i.i.d.).

The discussion highlighted the point that, despite efforts to make the residuals i.i.d when calibrating VPAs, residuals often show significant departures from this assumption. It was noted that research is ongoing on possible refinements to bootstrap procedures for age-structured models so as to take such factors into account.

3.4 **Lowestoft Projection Software** (see Appendix 1 – Reported by C. Darby)

Projection software currently under development at Lowestoft was presented. This software integrates in a single environment the functionality of a number of programs used by ICES Working Groups to perform medium-term projections. The software was designed to be used in conjunction with the Lowestoft VPA tuning programs and offers features that are similar to the other projection programs explored during this Workshop.

4. General Discussion

The Workshop aimed not only at showing how the various software programs work but also at establishing good working practices to analyze the results. Discussion sessions were held throughout the Workshop.

They served to clarify technical questions on the use of the software programs and to discuss common practices in stock assessment.

It was noted that the age-structured models explored during this workshop are based on the same population dynamics equations. However, the estimation problem (i.e. the problem of estimating population abundance in the most recent year) is defined differently in each of these models. The differences mainly lie in the assumptions (or constraints) that are imposed to reduce the number of parameters. When these methods are applied using (or forcing) similar assumptions, they essentially give similar results. The fact is that in their default mode, different methods make widely different assumptions to facilitate the estimation of stock abundance within their estimation framework. Some of the assumptions can free up parameters.

4.1. Estimation – Strengths and Weaknesses of the Various Methods

Extended Survivor Analysis (XSA). This method estimates one survivor for each cohort represented in the indices of abundance without requiring constraints for the fishing mortality applied at the oldest age-group. Instead, the coefficients representing the catchability of the indices-at-age are assumed to be similar (i.e. reaching a plateau) for all fleets after a pre-determined age. The practice is to define the beginning of the plateau as the youngest age where the virtual population analysis has converged sufficiently to provide some stability in the estimation of population numbers without distorting the catchability pattern at age.

The extended Survivor Analysis allows for "Inverse variance weighting" of the indices. This self-weighting procedure has the advantage of ensuring that the estimation gives higher weight to the indices that are more precise. However, the procedure can lead to an assessment being tuned to a single age-group or survey. That would be fine if this index is unbiased but experience shows that indices with apparent high precision are often biased to a significant degree, which can seriously affect final estimates of stock abundance. To avoid this situation, the software provides an option, which allows the user to set the maximum weight allowed for any given index/value. The maximum weight is specified in that option as a minimum value for the "standard error of any observation".

As the convergence of the extended Survivor Analysis to a solution depends upon the convergence property of the underlying virtual population analysis, this method could be difficult to apply reliably at low F values. The same is true when there is a high degree of variability in the indices. Nevertheless, the method performs well in a wide range of situations where multiple indices of abundance are available.

ADAPT. As the ADAPTive framework is based in a non-linear least-squares procedure, it benefits from a suite of diagnostics and tools that are well known to statisticians. For instance, the approach provides algorithms for calculating the variance and the correlation of parameter estimates. One drawback is that non-linear estimation is based on an iterative process that needs monitoring to avoid pitfalls such as local minimum, over-specifying the number of unknown parameters, etc.

The framework provides flexibility in formulating the estimation problem. For instance, the constraints in natural mortality could be relaxed by estimating it as an additional parameter. While such flexibility could be an advantage in research, it could also lead to over-parameterization of the estimation problem (i.e. trying to estimate too many parameters in relation to the information content of your data). We recommend being "parsimonious" in defining the number of parameters for your models. When a model is over-parameterized, the correlation of the parameters estimates becomes very high (e.g. absolute values in the range of 0.9 to 1.0). Inspect the correlation matrix at the end of the estimation process to ensure that this situation does not occur.

Another advantage of ADAPT in its current form is that it allows the use of aggregated indices, together with your age-disaggregated indices. This is a feature that is not available at present in many of the other methods.

ICA. The Integrated Catch Analysis (ICA) has been developed to address specific situations of pelagic species. The method invokes the "separability" assumption, at least for a pre-specified time period, an assumption that may not be met in many situations. The approach is generally computer-intense because of the number of parameters requiring estimation. The approach produces diagnostics typical of non-linear approaches based on least-squares or maximum likelihood.

4.2. Estimation – Diagnostics

All methods produce a wide range of diagnostics to evaluate the validity and "quality" of the results.

Residuals. All methods provide log-normal residuals. Residuals should be independent and identically distributed. Do distribution plots of the residuals. It is also important to inspect the residuals (graphically or through analysis) for year effects, age effects, as well as for trends (with time, stock size, etc.). Outliers (i.e. large residuals) should be identified and their influence on the population size estimates should be investigated. High leverage observations should be given special attention and investigated in "sensitivity" runs.

Variance of parameter estimates. The variance of parameter estimates provides information on the precision of the results. Typically, results would be considered satisfactory when the coefficient of variation for most estimates of population abundance at age is below 40%. In a risk analysis context (where both the estimate and a measure of its precision is used), higher coefficients of variation could be used but the model formulation should be investigated carefully before using such results. Often, high variance is the result of residuals that are not i.i.d (e.g. much larger residuals for younger ages, which corrupts the calculation of the variance for other ages).

Correlation matrix of parameters. High correlation between parameter estimates is an indication of over-parameterization (trying to estimate too much for the information content of the data). This could be corrected by adding structure or constraints to the model (e.g. assumptions on survey catchability, on determination of fishing mortality for oldest age groups, etc.).

Functional form for catchability of each index. Assumption of constant q for commercial fleets can be a problem. Catchability estimates should be inspected for time trends (usually graphically). While time trends or power curves can be fitted to catchability, use these options sparingly. Keep the model as simple as possible and do not go for power models or temporal trends at the beginning of your exploration. Use different techniques to investigate the possibility of changes in catchability through time. For instance, look at your indices with a separable model.

Bias-correction. Because of the non-linear nature of the estimation problem, the estimates obtained through the procedures described above are generally biased. Some methods provide a bias-correction to be applied to the estimates of population abundance for the most recent year. In ADAPT, this correction is also done for historical estimates of population abundance and fishing mortality. Some methods do the bias correction only for the final estimate of population abundance and such estimates are not directly comparable to historical reconstruction of stock abundance. Recent research sponsored by the EU suggests that bias correction is necessary.

Inverse weighting. The weights used in some methods (e.g. XSA) to individual indices of abundance combined should provide a balanced contribution from each index. Extreme values should be investigated with the aim of limiting the undue influence of indices that are potentially biased.

Retrospective analysis. Such analyses apply the estimation procedure repeatedly to data sets that are truncated of their most recent observations to determine if the estimation procedure has a tendency to either over- or under-estimate population abundance. There has been a tendency for many models to over-estimate abundance in the most recent year. Changes in catchability (e.g. due to learning or technological innovations for indices based on commercial catch rates; change in survey gear for research surveys), trends/changes in reporting practices (mis-reporting), changes in natural mortality, shifts in geographical distribution, as well as immigration or emigration can lead to retrospective patterns. When strong retrospective patterns are present, the condition that lead to such patterns must be identified and accounted for in model formulation.

Sensitivity analysis. As indicated above, the influential points should be investigated through sensitivity runs.

4.3. Estimation – Model formulation

Catchability. The "power function" available in most models should only be used when for species/ages where a contagious distribution is suspected (e.g. youngest ages). Contagious distributions are the result of the tendency for some species or age groups to aggregate. The current practice in some areas is use only the most recent years (e.g. 10 or 15 years) to do the calibration. Short time series (e.g. less than 10 years) are not sufficient for fitting power models. The truncation of the time series is also used frequently when abrupt changes in catchability are suspected (e.g. resulting from a change in survey gear); short series may result in the estimate of stock abundance for the terminal year being poorly determined. Regarding "time trends" in catchability, it is generally not possible to estimate such trends for all indices; catchability of at least one index has to be kept time invariant as the estimation procedure confounds time trends in catchability with trends in population abundance.

How many parameters? The number of parameters that could be estimated in a given situation depends on a number of factors, including the convergence properties of the virtual population analysis, the contrast or information content of the data, the length of the index series, the consistency of the series, etc. It is advisable to attempt to estimate as few parameters as required (the principle of "parsimony").

How much shrinkage? Some methods (e.g. XSA) implement shrinkage to improve the stability of the estimation. In essence, shrinkage biases the results towards the mean and too much shrinkage may result in substantial biases.

Functional relationship for fishing mortality for the oldest age-group. It is common practice to reduce the number of parameters to be estimated by assuming a functional relationship for the fishing mortality for the oldest age group in each year. For instance, the oldest age group could be defined as the mean of fishing mortality estimates for a range of younger ages. It is recommended to keep the age-groups used for such calculation as close as possible to the oldest age-group to avoid forcing a flat top partial recruitment pattern when a dome is in fact present.

Age truncation. In many situations, the youngest age groups and oldest age groups of an index are inherently more variable than the age groups, which are targeted by the survey or fishing gear leading to the index. Because of this variability, including these ages in a model that assumes the same error structure for all ages may inflate the variance estimates of the ages of interest. It is common practice to truncate these ages from the indices. A better approach would be to account for this difference in error structure but current implementations do not include such a feature.

4.4. Forecasts

Retrospective patterns. There is no universal rule on how to account for retrospective effects in short term forecasts. As suggested above, someone should first attempt to understand the processes that leads to the retrospective effect and correct for it in the formulation of the model. In many cases, the cause(s) of the retrospective pattern cannot be readily identified. In some cases, the retrospective effect has been accounted for by adjusting the forecast accordingly but there is no guarantee that this will bring the results closer to the underlying "true value".

Regime shifts. Temporal shifts in biological parameters are often evidenced in maturity data, growth data or stock-recruitment data. In short-term forecasts, shift in biological parameters can be captured (with a lag) by using the most recent observations on these quantities (e.g. averaging the last three years). In long term simulations to assess harvest strategies, regime shifts have been investigated using sensitivity runs but other techniques are also possible.

Risk analyses. Most forecasts account only for some of the uncertainty in the processes being simulated. For instance, in the programs used in this workshop, the variance of population estimates in the starting year and the variability of the recruitment process was taken into account. Some programs (not reviewed here) also account for variability in other biological parameters (e.g. growth) or control parameters (partial recruitment or selection pattern). How to account for biases (as opposed to variance) from various sources in such forecasts is still unclear. In recent years, scientists have gained some experience in evaluating and communicating the risks associated with various management actions. However, more work is needed to evaluate the sensitivity of forecasts to plausible biases and directional shifts in biological parameters. Another approach might be to adhere to management approaches that are more robust so as to reduce the dependency upon the accuracy of annual assessments.

Biological metrics. While simulations have typically focussed on stock trends and fishery trends, they should capture other biological aspects as well (e.g. age structure).

4.5. Suggestions for improving software tools

It was observed that software tools are becoming easier to use, thanks to improvements in the user interface and to the improvements in computing technology. For instance, bootstrap procedures are now more accessible than they used to be, thanks both to the computing power and to their availability as options in current software implementations.

It was also observed that software programs are converging so as to offer the same functionality. Despite this convergence, the learning curve of these software tools remains steep in part because of the lack of standards for user interfaces, and input/output formats. Data entry remains a challenge when using these models.

It was noted that all of the software programs used during this workshop would benefit from improving the user-interface. Simple modifications could also enhance their usefulness or functionality. Suggestions for improvements included the following:

- User interface: Programs should allow the user to correct errors in input windows without having to restart the input process. Output files are often cryptic and difficult to read and would benefit from labels strategically placed to identify table contents (e.g. name of parameters being estimated, etc.).
- Input formats: All methods essentially require the same type of data in input. Users would benefit greatly from a common format for input data common to all programs.
- Bootstrap: Capture Recruitment-SSB pairs from the bootstrap, together with the corresponding estimates of population size, to allow re-sampling from them in forecasts or to allow further analyses on them (e.g. to determine correlation).

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(See also *NAFO Scientific Council Reports*, 2000. List of Research and Summary Documents, of the 13–22 September 2000 Scientific Council Meeting Report.)

Scientific Council Workshop on Assessments Methods, 13–15 September 2000, Boston, Masschussetts, USA

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Annex 2. Timetable

Time	Topic	Lead	Software tools
	Wednesday, 13 September		
09:00–10:00	Registration, and network setup and software installation		
10:00–10:30	Introduction, Principles of VPA tuning and separable VPA	C. Darby	Lowestoft tuning suite
10:30–11:00	Work session	C. Darby	Lowestoft tuning suite
11:00–11:20	Laurec-Shepherd	C. Darby	Lowestoft tuning suite
11:20–12:10	Work session	C. Darby	Lowestoft tuning suite
12:10–12:30	ADAPTive framework: theory, use of software, output overview	R. Mayo	Woods Hole Fishery Assessment Compilation Toolbox (FACT)
Lunch break			
14:00–15:15	Work session	R. Mayo	Woods Hole FACT
Health break			
15:30–16:15	ADAPT demo/tutorial	D. Rivard	ADAPT: Gavaris implementation
16:15–17:00	Discussion	All participants	
	Thursday, 14 September		
9:00–9:45	Extended Survivor Analysis: theory, use of software, output overview	C. Darby	Lowestoft tuning suite (XSA)
9:45–10:45	Working Session	C. Darby	Lowestoft tuning suite (XSA)
Health break			
11:00–11:30	ICA: theory, use of software, output overview	C. Darby	ICA
11:30–12:30	Work session	C. Darby	ICA
Lunch break			
14:00–15:00	Discussion	All participants	
Health break			
15:15–16:00	FISHLAB (demo)	C. Darby	FISHLAB
16:00–16:30	PA Software (demo)	C. Darby	PA Software
16:30–17:30	Work session	C. Darby	PA Software
	Friday, 15 September		
9:00–9:45	Long term simulations using @Risk	D. Rivard	Excel, @Risk
9:45–10:45	Work session	D. Rivard	Simulation Excel spreadsheet, @Risk
Health break			
11:00–11:30	Stochastic projections	R. Mayo	Woods Hole AgePro
11:30–12:30	Work session	R. Mayo	Woods Hole AgePro
Lunch break			
14:00–14:45	ADAPT-based risk analyses (Demo/tutorial)	D. Rivard	ADAPT Sofware
14:45–15:30	Stochastic projections	C. Darby	Lowestoft Projection Software
Health break			
15:45–16:15	Work session	C. Darby	Lowestoft Projection Software
16:15–17:00	Discussion	All participants	

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Appendix 1: The Lowestoft Stock Assessment Suite

Tutorial 1

Data file input and User-defined VPA

by

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Abstract

This document is the first in a series of tutorials that provide an introduction to fitting stock assessment models within the Lowestoft VPA Suite stock assessment software package, and prediction programs that utilise the results. This tutorial takes the user through the input of data files, running a VPA with user defined fishing mortalities and the printing of data and results.

Introduction

This document takes the user through the process of entering data into the Lowestoft VPA suite program and running a "user-defined" traditional VPA (virtual population analysis) using file and keyboard input of terminal F values (the fishing mortality occurring at the oldest cohort age). The tutorial assumes that the user has installed the VPA program described in Darby and Flatman (1994), that the required data files have been placed in a directory c:\vpas\data and that the example assessment index file (Blackfin.ind) contains path names which point to the appropriate input files within that directory.

In the following text **action to be taken by the user** is highlighted in bold. The symbol ↵ is used to represent the Return or Enter key on the keyboard.

Data Input

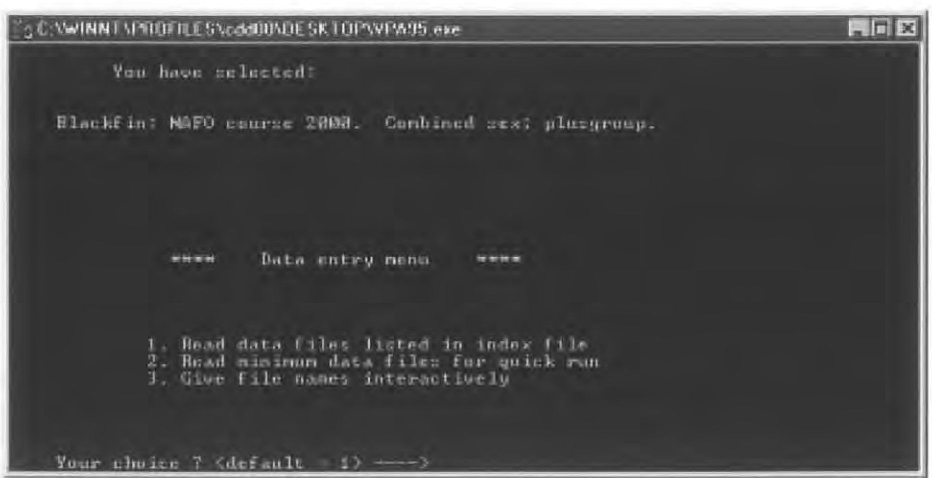
Start the VPA suite from the program file VPA95.EXE or at the windows icon.

The program should open and present the VPA suite introductory screen shown below

If the data files were installed in the recommended directory then

Type in the directory path and index file name C:\VPAS\DATA\BLACKFIN.IND ↵

Otherwise type in the directory in which the data files were placed. The program will then present the data file entry screen.



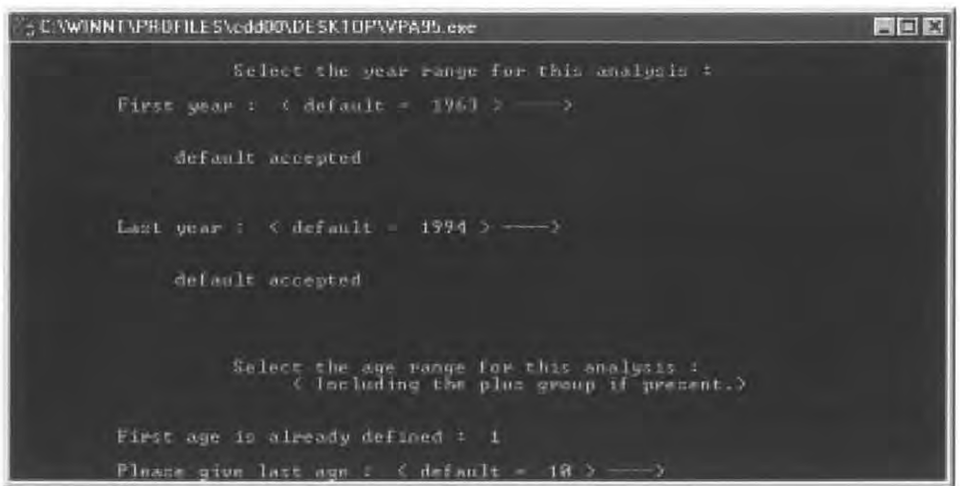
The title from the index file is displayed, for reference, at the top of the screen. Three options are available for input of the data files. Selecting option (1) reads the first eight stock data files from the index file list. Option (2) only reads the catch numbers and natural mortality files from the index file list; the option is used if the other data are not readily available. Runs with this option will only calculate population numbers and fishing mortality rates. Option (3) allows the user to type the path and name of each file interactively; the defaults are taken from the appropriate file name in the index file list.

Type 3 ↵
Type ↵ at each prompt and select the default data files.

Note that the program reads through the list of files provided within the index file list; each is presented so that the user can replace them with alternatives if required. Typing return at each question takes the offered default file.

After selecting the data files that we wish to use in the assessment the program the prompts the user for the selection of the year and age ranges over which the assessment is to be calculated. The subset of data years used for the assessment can be selected from the complete range specified in the data files.

Type ↵ and select the default at each of the year prompts.



When selecting the age range for the assessment, the only restriction imposed on the user is that the first assessment age must be that defined in the data files. If the oldest age selected is less than the oldest defined within the data files, a plus group will be created. The plus group catch weights, stock weights and proportion mature are automatically calculated as catch number weighted means.

The next question defines the use of the oldest age. The program initiates all VPA and Cohort analyses from the oldest **true** age. Stock numbers for the plus group are estimated independently using the plus group catch number and the F on the oldest true age in the same year.

Type ↵ and select the default oldest age.

If the selected age was less than the number of ages in the original data files **the oldest age entered at this prompt will be a plus group**. After selecting the oldest age for the analysis, the user must then inform the program whether the oldest age defined in the data files was created as a plus group. If the oldest age selected by the user is younger than the oldest age defined in the data files, a new plus group is automatically created by summing the catch data of the selected age with the data for older ages. The new plus group catch, stock weights and other data attributes are recalculated as catch-number-weighted means. The age preceding the plus group age becomes the oldest true age for the analysis.

If the user wishes to perform a run without a plus group, the full age range defined within the header section of the original data files **must** be used. The data files should be edited to specify required age range. Data for older ages outside of the range will be ignored. During interactive input, select the default values offered for the age range (the data file values) and answer 'No' to the question asking whether the oldest age in the data files is a plus group.

In this example the original data set listed in the index file does have a plus group at age 10.

Type ↵ to take the default.

We have now completed the specification of the data structures used in the assessment.

Specification of Assessment Summary Table Means

In the next series of selections we define the range of ages used for the fishing mortality and population summary means printed in the result tables when the assessment is completed. This procedure is carried out prior to calculating assessments so that it does not have to be repeated for each assessment run.

Initially we are presented with a screen, shown below, that lists the options available for specifying the summary means.

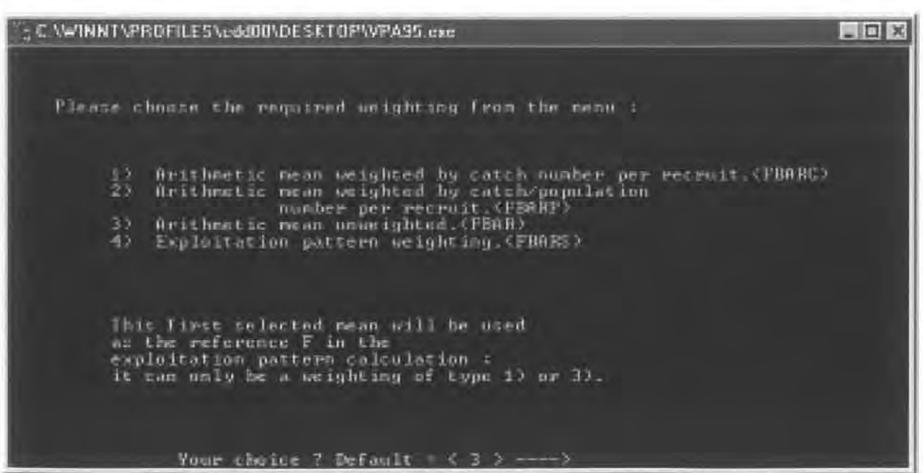
Taking the default option (1) will calculate an unweighted arithmetic mean for each year (across ages). If the number of assessment ages selected by the user is greater than 5, the age range is (firstage +2) to (lastage -2), otherwise the average is calculated over all ages. Row means for each age (across years) are calculated as unweighted arithmetic mean with the year range: (lastyear -2) – last year.

In this example we will define two means for the annual fishing mortality. The first is an arithmetic mean F calculated over ages 3–7. The second is an average in which, at each age, the fishing mortality is weighted by the ratio of the catch numbers to the estimated population numbers.

Type 2 ↵ To select user definition of the fishing mortality column means.

We will specify two means for each column (year) of the output summary table.

Select two means by typing 2 ↵

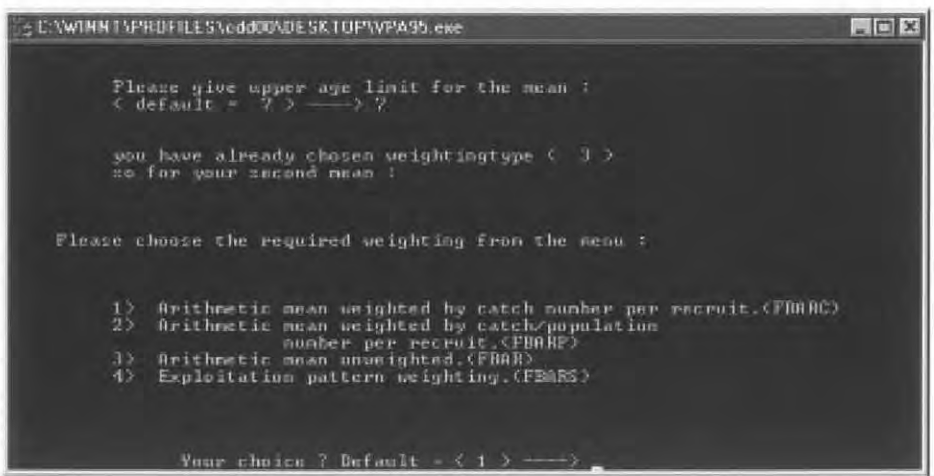


At the next screen we select the format of the first mean.

Type 3 for the arithmetic mean or just press enter for the default.

Select the defaults offered for the range of ages over which the arithmetic mean is to be calculated.

This completes the specification of the unweighted arithmetic mean. We now specify the catch / population weighted mean.



Type 2 for the catch/population weighted mean

The mean is a weighted average of the catch numbers to the population numbers calculated at each age and there is therefore no requirement to specify the age range for the calculations.

This completes the specification of the summary means and brings us to the central menu for the program.

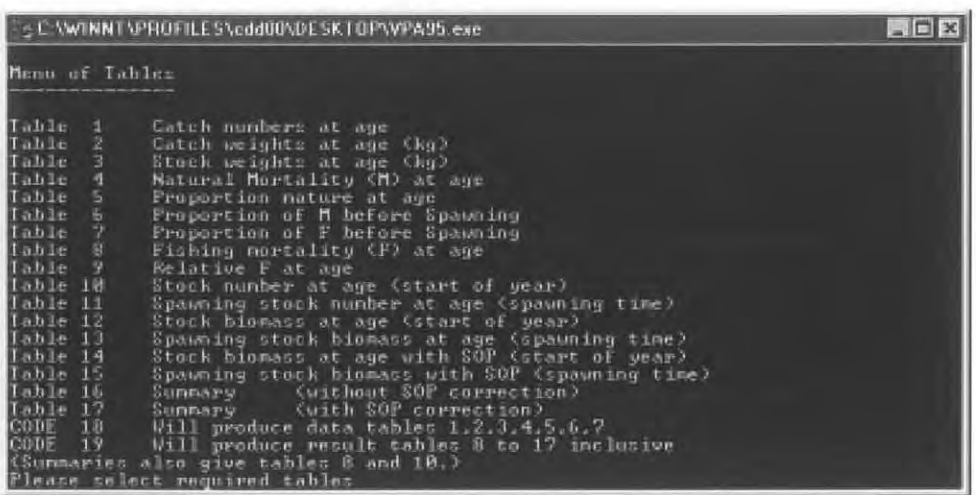
The VPA Suite Central Menu

At the program central menu we can select assessment models and print tables of data or results. After each assessment model has been fitted to a data set, the program will return to this menu. This allows the user to undertake a series of exploratory trials and examine the results of the assessments in an editor or spreadsheet package without having to re-specify the data and summary age or year ranges.

Printing Data and Result Tables

Type 9 ↵

This screen presents a list of the tables available for printing from the program. At the current stage in the tutorial we have not run an assessment model so that there are no results available for printing. We can only print the input data sets 1–7.



Type 1, 2, 3, 4, 5, 6, 7 ↵

Type an output path followed by a file name with a .csv extension ↵

After pressing return you should be back at the central menu. Note the star indicating that we have used the printing section. Examine the results file in a suitable spreadsheet or word processing package; there is no need to close the VPA program. The use of the .csv file extension produces spreadsheets that are automatically formatted when loaded into e.g. Microsoft Excel.

The VPA Suite Input Data Output File Format

Tables 1 – 7 present the Blackfin input data files that are printed as output from the VPA suite. They are:

Table	Contents
1	Catch at age in numbers (thousands)
2	Catch weight at age (kg)
3	Stock weight at age (kg)
4	Natural mortality
5	Maturity ogive
6	Proportion of F before spawning
7	Proportion of M before spawning

Note that for this stock the catch weights have also been used for the stock weights at age. Stock weights at age are used to calculate the spawning stock biomass and ideally should be the values recorded at that time of year.

The first two lines of each output table are consistent between tables. The first line is the run title, taken from the title of the assessment data index file. It is generally used to identify the stock, year and type of data. The second line is the date and time at which the data files were printed.

Table 1 presents the catch numbers at age data used in the assessment model. In this instance the data have been tabulated in thousands, the unit that the program assumes for all calculations. Note however that the output table is formatted for ease of printing and the output unit, as detailed in the first line of each section, may change.

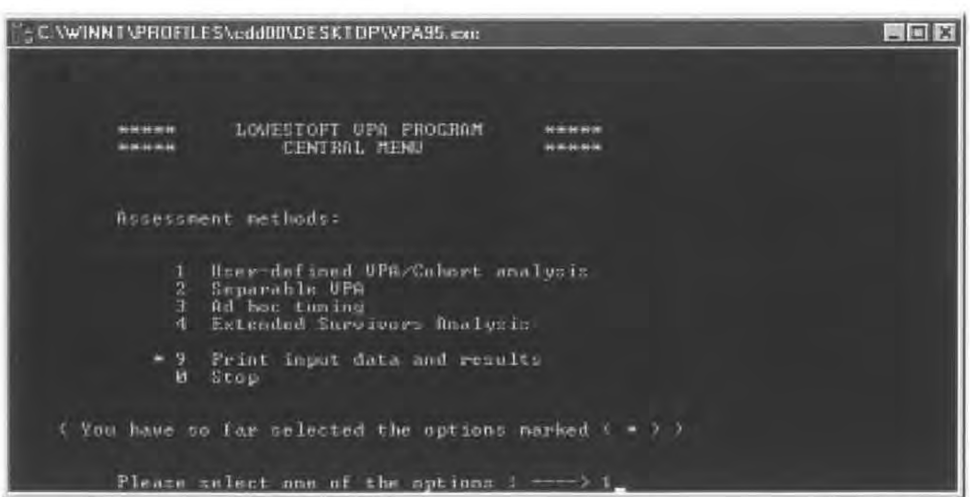
The data are tabulated in columns by year with totals presented for each column. Beneath the total numbers are the landings data time series from the first input file and a sum of products (SOP) cross check. The SOP value indicates the factor, given as a percentage, by which the sum of the products of the catch numbers and catch weights at age has to be raised to match the total landings. In Table 1 the SOP of the catch weights and catch numbers at age for 1963 is 6% lower than the landings weight. The SOP value is taken as an indication of the quality of the sampling used in the estimation of the numbers at age. In many ICES assessment working groups the catch weights are scaled, to correct for the difference, prior to the fitting of the assessment models (this is the case with this data set for recent years). However, if required the correction can be applied within the program during the printing of the results. The SOP value is also presented in Table 2: the catch weight at age data.

Analysis of the dynamics of the population and the characteristics of the fishery does not have to start with the fitting of assessment models. The structure of the catch at age data can be very informative. In the case of the Blackfin example, throughout the time series there has been a change in the peak age of the catch moving towards the youngest ages in the landings. During 1965–69 the distribution of the catch at age peaked at age 4. As the fishery has progressed there has been a gradual reduction in the dominant age towards age 3 in the late 1970's and 1980's to ages 2 and 3 in the most recent years. During the early years there were very few catches recorded at age 1, whereas more recently this age group has formed a substantial proportion of the catch. The pattern could result from high mortalities removing fish before they reach the older ages or from a change in selection by the fishery.

The catch weight at age data demonstrates trends during the available time series. During the period 1967–71 catch weight at age 5 averaged 2.2 kg; it increased during 198–84 to an average of 3.0 kg, and then decreased to less than 2.0 kg during 1987–93. The changes could be the product of the changes in selection by the fishery, such as changes in discard practices, or result from changes in growth rates.

Note that stock weights are a repeat of the catch weights for this fishery. If spawning takes place at a specific time of year catch weights from that time of year or from surveys could be used. Natural mortality is assumed constant at age and invariant through time. Maturity varies with age and is also constant in time. The proportion of fishing mortality and natural mortality that take place before spawning are set to zero so that SSB is calculated at the beginning of the year.

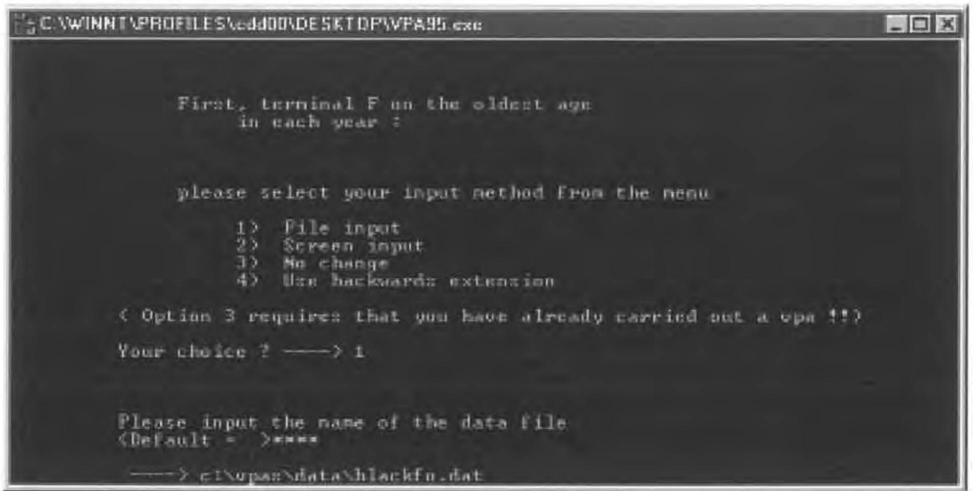
User-Defined VPA



Select Option 1 at the main menu

Four methods are available for the input of terminal fishing mortality values at the oldest age. Option 3 takes F values from a previous run of any of the assessment methods. Option 4 calculates an average of the fishing mortalities at younger ages.

Select option 1 for file input



Note the four stars in the default. This indicates that a filename was not specified in the index file and user input is required.

Type the path and file name C:\VPAS\DATA\BLACKFO.DAT ↵

The program reads the fishing mortality values stored in the data file and will use them to calculate population abundance for each of the cohorts terminating at the oldest age prior to the final year.

At the next menu select the "Screen Input" option and type the following values for each successive age (0.01 0.03 0.09 0.10 0.12 0.18 0.15 0.15 0.15).

Select 1 for the Exact VPA method.

After running the VPA we return to the main menu. A star now highlights the user-defined method that we have just used.

The program has now calculated a time series of population abundance and fishing mortality at each age. We can therefore print the time series of spawning and stock biomass and fishing mortalities.

Type 9 and select table 19. Specify a directory path and a file name with a .csv extension.

The VPA Suite Results Output File Format

Tables 8–17 present the output files derived from the previous run and printed using the VPA suite menu option 9.

Table	Contents
8	Fishing mortality at age
9	Relative fishing mortality at age
10	Stock number at age, calculated at the start of the year
11	Spawning stock number at age, calculated at the time of spawning
12	Stock biomass at age, calculated at the start of the year, without SOP correction
13	Spawning stock biomass at age, calculated at the time of spawning, without SOP correction
14	Stock biomass at age, calculated at the start of the year, with SOP correction
15	Spawning stock biomass at age, calculated at the start of the year, with SOP correction
16	The assessment stock summary table without SOP correction
17	The assessment stock summary table with SOP correction

The first line of each table is the run title. It is taken from the title of the assessment data index file and is generally used to identify the stock, year and type of data. The second line is the date and time at which the data files were printed.

Table 8 presents the fishing mortality (F) at age matrix, calculated using the user inputs for the F in the final year, F at the oldest age from the input file, the natural mortality and the catch at age input data. The table layout is similar to the data file tabulation, with columns containing the results for a year and the rows the results for each age. Note that the plus group fishing mortality is defined to be equal to that at the oldest age.

The two fishing mortality means specified by the user are presented in the rows below the results for each age. In this instance we have defined an unweighted average F (FBAR), calculated over the age range 3–7, and a catch/population weighted average calculated across all ages (FBARP). The average values are also presented as time series in summary tables 16 and 17. The final column of the table presents an average fishing mortality for each age calculated over a user-defined range of years. As with the column means, the user can define the type of average and the year range over which it is calculated when specifying the assessment structure.

Pope (1972) has shown that the historic fishing mortality and population numbers calculated using VPA are insensitive to the values used to initiate the cohort calculations if the cumulative fishing mortality back up the cohort is greater than 1.0 (conditional on the value of M); the estimates are considered to be "converged". In Table 8 this generally holds for ages 7 and younger in the years 1963–91. Calibration models fitted to the Blackfin catch at age data set are therefore primarily estimating the level of fishing mortality and population abundance at all ages for the years 1992–94 and at ages 8 and 9 in earlier years.

Table 9 presents the relative fishing mortality at age, that is the ratio of the fishing mortality estimated at each age and the first user defined mean (Fbar 3–7). It is used to detect changes in selection at age such as the increased selection for age 2 and 3 that occurred after 1973.

Table 10 presents the population numbers at age calculated from the VPA transformation of the catch at age data with the two row (age) means. The number of means, the year range and the method of calculation are user defined. In this case the defaults were selected and they are a geometric and arithmetic mean calculated over all years except the final three.

Table 11 presents the spawning stock numbers calculated at spawning time. The populations are brought forward to spawning time using the proportions of fishing and natural mortality that take place before spawning, defined by the user within the input files.

Two tables of stock biomass at age (12, 14) and spawning stock biomass at age (13, 15) are available. The stock biomass is calculated at the beginning of the year, spawning stock biomass at spawning time. Tables 12 and 13 are the biomass without SOP correction and Table 14 and 15 present the biomasses scaled by the SOP factor which corrects for sampling error and which was discussed previously in relation to the catch data.

Two output summary tables are available. Table 16 is not SOP corrected and Table 17 has the SOP corrected biomasses. Both tables present the time series of recruitment to the first age of the assessment, total and spawning stock biomass, landings, yield (landings) / SSB which is a proxy for fishing mortality and the time series of user defined fishing mortality means specified at the start of the run.

References

DARBY, C. D. and S. FLATMAN. 1994. Virtual Population Analysis: version 3.1 (Windows/DOS) user guide. *Info. Tech. Ser.*, MAFF Direct. Fish. Res., Lowestoft, **1**: 85 p.

POPE, J. G., 1972. An Investigation of the Accuracy of Virtual Population Analysis Using Cohort Analysis. *ICNAF Res. Bull.*, **9**: 65–74.

TABLE 1. The VPA suite catch numbers-at-age output table for the Blackfin example data set.

Run title : Blackfin: VPA course. Combined sex; plusgroup.
At 1/02/2002 8:47

Table 1 Catch numbers at age Numbers*10**-3

YEAR	1963	1964
AGE		
1	0	0
2	155	117
3	1483	2136
4	688	2340
5	327	700
6	215	339
7	73	159
8	149	42
9	50	49
+gp	49	93
TOTALNUM	3190	5975
TONSLAND	6594	13596
SOPCOF %	106	105

Table 1 Catch numbers at age Numbers*10**-3

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	2	0	0	0	57	350	897
2	231	68	385	49	335	33	382	3973	7753	3374
3	3327	2838	2053	2435	1983	2857	1385	8419	7665	6062
4	3060	4909	2885	2287	4618	2335	4444	3894	5251	2417
5	1757	1220	1934	1197	1498	1805	1891	2256	1946	2158
6	512	693	268	621	507	599	1085	456	883	617
7	271	135	454	148	568	240	465	333	468	949
8	92	39	91	126	106	196	362	160	336	925
9	69	27	44	29	79	41	300	92	199	502
+gp	137	48	75	58	71	122	238	162	472	869
TOTALNUM	9457	9977	8189	6952	9765	8228	10552	19803	25322	18769
TONSLAND	18395	18584	16034	12787	17124	14536	19863	29219	33832	35973
SOPCOF %	98	100	102	98	99	99	98	100	93	97

Table 1 Catch numbers at age Numbers*10**-3

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	25	36	160	38	10	46	154	43	35	157
2	2592	2826	1257	4452	1000	1023	2490	1403	3519	3026
3	6672	8274	4680	4278	1836	3351	3932	4633	4761	5590
4	2546	2782	2734	2362	1205	954	1981	1687	2574	2407
5	1328	1806	1687	1306	1181	685	588	1250	834	880
6	873	1122	743	701	724	638	410	574	764	685
7	1013	662	562	293	372	471	341	388	509	302
8	711	518	386	244	157	194	223	247	158	140
9	198	586	290	163	191	91	154	136	105	57
+gp	343	1365	922	1326	757	817	673	461	506	160
TOTALNUM	16300	19979	13421	15163	7433	8270	10947	10824	13765	13404
TONSLAND	30800	41747	27210	31370	21604	22102	23574	23884	28890	21641
SOPCOF %	98	97	96	97	99	100	98	99	102	99

Table 1 Catch numbers at age Numbers*10**-3

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	6	232	1	21	22	58	153	28	15	3
2	2288	773	1698	3591	759	1485	1243	861	2511	2408
3	5122	7101	2194	5702	7291	5595	3594	1773	2668	2029
4	3051	8441	6967	3518	5703	3729	2946	3093	2827	1080
5	1459	3787	1928	2627	2255	1194	1175	968	1185	492
6	1230	1399	1359	1051	1400	786	607	354	270	280
7	610	1056	779	892	376	525	424	107	112	109
8	187	470	454	698	258	245	235	61	56	65
9	105	186	261	330	157	132	96	54	43	50
+gp	225	347	210	329	184	157	223	93	83	110
TOTALNUM	14283	23792	15850	18759	18406	13906	10697	7392	9768	6627
TONSLAND	26595	39886	31369	34178	25577	19865	16995	11804	13943	10429
SOPCOF %	99	95	106	99	95	96	101	100	100	99

TABLE 2. The VPA suite catch weights-at-age output table for the Blackfin example data set.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:47

Table 2 Catch weights at age (kg)

YEAR	1963	1964
AGE		
1	0	0
2	0.92	0.8
3	1.3	1.45
4	1.769	2.01
5	2.35	2.76
6	3.21	3.76
7	4.17	4.27
8	3.759	5.06
9	5.309	6.26
+gp	7.542	7.297
SOPCOFAC	1.0558	1.0476

Table 2 Catch weights at age (kg)

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	0.48	0	0	0	0.508	0.31	0.309
2	0.74	0.65	1.07	0.63	0.78	0.6	0.65	0.748	0.62	0.589
3	1.16	1.09	1.19	1.19	1.04	1.08	0.95	1.082	1.089	0.973
4	1.68	1.74	1.581	1.68	1.43	1.419	1.26	1.708	1.374	1.607
5	2.47	2.74	2.24	2.19	2.28	1.98	1.79	2.474	2.487	1.716
6	3.85	3.229	3.53	2.989	2.95	2.949	2.74	2.521	3.025	3.522
7	4.48	4.62	3.761	4.05	3.511	3.67	3.51	2.908	3.605	4.519
8	5.431	5.81	5.26	4.47	4.931	4.879	4.701	4.889	4.736	4.985
9	6.791	6.549	5.951	5.28	5.73	6.259	5.28	6.014	6.681	6.012
+gp	7.504	8.069	7.233	7.386	7.578	7.158	7.344	8.088	8.105	8.276
SOPCOFAC	0.9839	0.9952	1.0223	0.9841	0.9873	0.9871	0.9842	1.0037	0.9289	0.9715

Table 2 Catch weights at age (kg)

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0.463	0.444	0.459	0.481	0.51	0.415	0.399	0.432	0.38	0.471
2	0.736	0.686	0.659	0.502	0.697	0.65	0.677	0.714	0.674	0.726
3	0.928	1.019	0.844	1.129	1.318	1.165	1.105	1.07	1.251	1.108
4	1.491	1.458	1.396	1.697	1.974	1.928	1.717	1.768	1.841	1.791
5	2.573	2.786	2.252	2.639	2.391	2.645	2.997	2.722	3.089	2.671
6	3.483	3.298	3.259	3.891	3.341	3.552	4.095	3.874	3.656	3.522
7	4.774	4.264	4.339	4.816	4.583	4.555	5.182	5.29	5.04	4.743
8	5.587	5.038	5.132	5.48	5.784	5.533	6.362	6.143	6.315	5.837
9	6.533	5.905	5.946	6.137	6.951	6.525	7.353	7.752	6.985	7.672
+gp	8.554	7.915	7.907	8.572	9.326	9.652	9.944	10.679	10.867	10.877
SOPCOFAC	0.981	0.9737	0.9607	0.9688	0.9936	0.9955	0.9843	0.9895	1.023	0.9853

Table 2 Catch weights at age (kg)

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	0.403	0.671	0.453	0.56	0.5	0.55	0.564	0.524	0.615	0.632
2	0.702	0.736	0.608	0.7	0.74	0.747	0.865	0.791	0.852	0.939
3	1.047	0.866	0.955	1.034	0.929	0.891	0.969	1.123	1.102	1.168
4	1.67	1.333	1.184	1.344	1.159	1.229	1.235	1.34	1.434	1.612
5	2.61	2.199	1.985	1.706	1.597	1.849	1.797	2.04	1.974	2.322
6	3.23	3.14	3.054	3.21	2.577	2.618	2.366	2.717	2.893	2.998
7	4.301	4.112	4.421	4.414	4.387	3.771	3.249	4.164	3.888	4.377
8	5.979	5.148	5.65	5.545	5.665	5.696	4.64	5.043	4.937	5.381
9	7.352	6.368	7.236	7.176	6.946	6.952	6.536	6.509	6.372	6.397
+gp	11.052	9.469	10.973	9.959	8.75	8.864	8.705	9.744	8.547	8.861
SOPCOFAC	0.9906	0.9478	1.0614	0.9921	0.9481	0.9613	1.0075	1.0019	0.9995	0.995

TABLE 3. The VPA suite weights-at-age output table for the Blackfin example data set.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:47

Table 3 Stock weights at age (kg)

YEAR	1963	1964
AGE		
1	0	0
2	0.92	0.8
3	1.3	1.45
4	1.769	2.01
5	2.35	2.76
6	3.21	3.76
7	4.17	4.27
8	3.759	5.06
9	5.309	6.26
+gp	7.542	7.297

Table 3 Stock weights at age (kg)

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	0.48	0	0	0	0.508	0.31	0.309
2	0.74	0.65	1.07	0.63	0.78	0.6	0.65	0.748	0.62	0.589
3	1.16	1.09	1.19	1.19	1.04	1.08	0.95	1.082	1.089	0.973
4	1.68	1.74	1.581	1.68	1.43	1.419	1.26	1.708	1.374	1.607
5	2.47	2.74	2.24	2.19	2.28	1.98	1.79	2.474	2.487	1.716
6	3.85	3.229	3.53	2.989	2.95	2.949	2.74	2.521	3.025	3.522
7	4.48	4.62	3.761	4.05	3.511	3.67	3.51	2.908	3.605	4.519
8	5.431	5.81	5.26	4.47	4.931	4.879	4.701	4.889	4.736	4.985
9	6.791	6.549	5.951	5.28	5.73	6.259	5.28	6.014	6.681	6.012
+gp	7.504	8.069	7.233	7.386	7.578	7.158	7.344	8.088	8.105	8.276

Table 3 Stock weights at age (kg)

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0.463	0.444	0.459	0.481	0.51	0.415	0.399	0.432	0.38	0.471
2	0.736	0.686	0.659	0.502	0.697	0.65	0.677	0.714	0.674	0.726
3	0.928	1.019	0.844	1.129	1.318	1.165	1.105	1.07	1.251	1.108
4	1.491	1.458	1.396	1.697	1.974	1.928	1.717	1.768	1.841	1.791
5	2.573	2.786	2.252	2.639	2.391	2.645	2.997	2.722	3.089	2.671
6	3.483	3.298	3.259	3.891	3.341	3.552	4.095	3.874	3.656	3.522
7	4.774	4.264	4.339	4.816	4.583	4.555	5.182	5.29	5.04	4.743
8	5.587	5.038	5.132	5.48	5.784	5.533	6.362	6.143	6.315	5.837
9	6.533	5.905	5.946	6.137	6.951	6.525	7.353	7.752	6.985	7.672
+gp	8.554	7.915	7.907	8.572	9.326	9.652	9.944	10.679	10.867	10.877

Table 3 Stock weights at age (kg)

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	0.403	0.671	0.453	0.56	0.5	0.55	0.564	0.524	0.615	0.632
2	0.702	0.736	0.608	0.7	0.74	0.747	0.865	0.791	0.852	0.939
3	1.047	0.866	0.955	1.034	0.929	0.891	0.969	1.123	1.102	1.168
4	1.67	1.333	1.184	1.344	1.159	1.229	1.235	1.34	1.434	1.612
5	2.61	2.199	1.985	1.706	1.597	1.849	1.797	2.04	1.974	2.322
6	3.23	3.14	3.054	3.21	2.577	2.618	2.366	2.717	2.893	2.998
7	4.301	4.112	4.421	4.414	4.387	3.771	3.249	4.164	3.888	4.377
8	5.979	5.148	5.65	5.545	5.665	5.696	4.64	5.043	4.937	5.381
9	7.352	6.368	7.236	7.176	6.946	6.952	6.536	6.509	6.372	6.397
+gp	11.052	9.469	10.973	9.959	8.75	8.864	8.705	9.744	8.547	8.861

TABLE 4. The VPA suite natural mortality-at-age output table for the Blackfin example data set.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:47

Table 4 Natural Mortality (M) at age

YEAR	1963	1964
AGE		
1	0.2	0.2
2	0.2	0.2
3	0.2	0.2
4	0.2	0.2
5	0.2	0.2
6	0.2	0.2
7	0.2	0.2
8	0.2	0.2
9	0.2	0.2
+gp	0.2	0.2

Table 4 Natural Mortality (M) at age

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
6	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
8	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
9	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
+gp	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table 4 Natural Mortality (M) at age

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
6	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
8	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
9	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
+gp	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table 4 Natural Mortality (M) at age

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
6	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
8	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
9	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
+gp	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

TABLE 5. The VPA suite maturity-at-age output table for the Blackfin example data set.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

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Table 5 Proportion mature at age

YEAR	1963	1964
AGE		
1	0	0
2	0	0
3	0	0
4	0	0
5	1	1
6	1	1
7	1	1
8	1	1
9	1	1
+gp	1	1

Table 5 Proportion mature at age

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1
+gp	1	1	1	1	1	1	1	1	1	1

Table 5 Proportion mature at age

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1
+gp	1	1	1	1	1	1	1	1	1	1

Table 5 Proportion mature at age

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1
+gp	1	1	1	1	1	1	1	1	1	1

TABLE 6. The VPA suite proportion of fishing mortality before spawning output table for the Blackfin example data set.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:47

Table 6 Proportion of M before Spawning

YEAR	1963	1964
AGE		
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
+gp	0	0

Table 6 Proportion of M before Spawning

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
+gp	0	0	0	0	0	0	0	0	0	0

Table 6 Proportion of M before Spawning

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
+gp	0	0	0	0	0	0	0	0	0	0

Table 6 Proportion of M before Spawning

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
+gp	0	0	0	0	0	0	0	0	0	0

TABLE 7. The VPA suite proportion of natural mortality before spawning output table for the Blackfin example data set.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

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Table 7 Proportion of F before Spawning

YEAR	1963	1964
AGE		
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
+gp	0	0

Table 7 Proportion of F before Spawning

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
+gp	0	0	0	0	0	0	0	0	0	0

Table 7 Proportion of F before Spawning

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
+gp	0	0	0	0	0	0	0	0	0	0

Table 7 Proportion of F before Spawning

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
+gp	0	0	0	0	0	0	0	0	0	0

TABLE 8. The fishing mortality-at-age calculated for the Blackfin stock using Traditional VPA.

Run title : Blackfin: VPA course. Combined sex; plusgroup.
At 1/02/2002 8:46

Traditional vpa using screen input for terminal F

Table 8 Fishing mortality (F) at age

YEAR	1963	1964
AGE		
1	0	0
2	0.0133	0.0052
3	0.148	0.2523
4	0.2404	0.3656
5	0.2208	0.4106
6	0.3218	0.3742
7	0.1649	0.4171
8	0.3774	0.1348
9	0.1582	0.2053
+gp	0.1582	0.2053
FBAR 3- 7	0.2192	0.364
FBARP	0.1061	0.1395

Table 8 Fishing mortality (F) at age

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	0.0001	0	0	0	0.0018	0.012	0.0299
2	0.0162	0.0048	0.0167	0.0029	0.0126	0.0017	0.0133	0.1622	0.3485	0.1528
3	0.199	0.2808	0.1965	0.1394	0.155	0.1414	0.0905	0.4416	0.5319	0.5061
4	0.6903	0.5024	0.5124	0.3491	0.4231	0.2753	0.3391	0.3912	0.5486	0.3166
5	0.5173	0.6624	0.3778	0.4151	0.4065	0.2904	0.3755	0.2883	0.3459	0.458
6	0.6019	0.3961	0.293	0.1992	0.3099	0.2816	0.2843	0.1447	0.1745	0.175
7	0.5837	0.3113	0.4908	0.2605	0.2825	0.2367	0.3682	0.132	0.2167	0.2872
8	0.4553	0.1495	0.3578	0.2421	0.3007	0.1479	0.668	0.2079	0.1909	0.8633
9	0.3433	0.2288	0.255	0.1842	0.2375	0.1808	0.3529	0.3525	0.4304	0.4805
+gp	0.3433	0.2288	0.255	0.1842	0.2375	0.1808	0.3529	0.3525	0.4304	0.4805
FBAR 3- 7	0.5184	0.4306	0.3741	0.2727	0.3154	0.2451	0.2915	0.2796	0.3635	0.3486
FBARP	0.1665	0.1594	0.1454	0.1181	0.1319	0.1071	0.122	0.1816	0.2475	0.207

Table 8 Fishing mortality (F) at age

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0.0011	0.0023	0.0095	0.0021	0.0005	0.0016	0.0057	0.0012	0.001	0.004
2	0.1131	0.1653	0.103	0.3874	0.0686	0.061	0.1137	0.0657	0.1296	0.1062
3	0.505	0.6219	0.4493	0.5928	0.2729	0.3412	0.3475	0.3186	0.3285	0.3115
4	0.4132	0.4082	0.4295	0.4304	0.3279	0.2222	0.3474	0.2462	0.294	0.2749
5	0.2879	0.5834	0.4666	0.3759	0.3986	0.3139	0.2077	0.3858	0.1846	0.1543
6	0.3388	0.4209	0.5081	0.36	0.3693	0.3905	0.3144	0.3211	0.4323	0.2275
7	0.4802	0.467	0.386	0.385	0.33	0.4384	0.3743	0.5533	0.5249	0.303
8	0.3627	0.4864	0.5503	0.288	0.3682	0.286	0.3837	0.5116	0.46	0.2645
9	0.4484	0.5774	0.5585	0.4746	0.3835	0.3794	0.386	0.4291	0.4267	0.2951
+gp	0.4484	0.5774	0.5585	0.4746	0.3835	0.3794	0.386	0.4291	0.4267	0.2951
FBAR 3- 7	0.405	0.5003	0.4479	0.4288	0.3397	0.3412	0.3183	0.365	0.3528	0.2542
FBARP	0.1922	0.2254	0.1967	0.2588	0.1542	0.1517	0.1664	0.1559	0.1666	0.1462

Table 8 Fishing mortality (F) at age

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	FBAR 92-94
AGE											
1	0.0003	0.0084	0	0.0011	0.0011	0.0031	0.006	0.0007	0.0002	0.01	0.0036
2	0.0745	0.0484	0.0786	0.1722	0.0475	0.0951	0.0835	0.0418	0.0836	0.03	0.0518
3	0.2627	0.3451	0.188	0.4059	0.621	0.5696	0.3479	0.1643	0.1758	0.09	0.1434
4	0.2793	0.9123	0.6757	0.5158	0.9326	0.7685	0.6789	0.5722	0.425	0.1	0.3657
5	0.267	0.6645	0.5415	0.5893	0.7477	0.5054	0.5913	0.4961	0.4493	0.12	0.3551
6	0.3341	0.442	0.5354	0.6495	0.7365	0.6431	0.525	0.3541	0.2485	0.18	0.2609
7	0.3247	0.5356	0.4745	0.8315	0.5118	0.6916	0.8954	0.1615	0.1793	0.15	0.1636
8	0.3126	0.4471	0.4654	1.0727	0.6161	0.7545	0.7864	0.2988	0.1191	0.15	0.1893
9	0.324	0.5863	0.4804	0.7424	0.7567	0.7601	0.7767	0.4138	0.3502	0.15	0.3047
+gp	0.324	0.5863	0.4804	0.7424	0.7567	0.7601	0.7767	0.4138	0.3502	0.15	
FBAR 3- 7	0.2936	0.5799	0.483	0.5984	0.7099	0.6356	0.6077	0.3496	0.2956	0.128	
FBARP	0.1432	0.2022	0.1764	0.2152	0.2287	0.225	0.2	0.1531	0.1466	0.0755	

TABLE 9. The relative (to the reference mean) fishing mortality-at-age calculated for the Blackfin stock using Traditional VPA.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:46

Traditional vpa using screen input for terminal F

Table 9 Relative F at age

YEAR	1963	1964
AGE		
1	0	0
2	0.0605	0.0143
3	0.6752	0.6932
4	1.0966	1.0044
5	1.0075	1.1281
6	1.4683	1.0283
7	0.7523	1.146
8	1.7218	0.3703
9	0.7218	0.5641
+gp	0.7218	0.5641
REFMEAN	0.2192	0.364

Table 9 Relative F at age

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	0.0003	0	0	0	0.0064	0.0329	0.0858
2	0.0313	0.0112	0.0447	0.0107	0.0399	0.0068	0.0456	0.5803	0.9587	0.4384
3	0.3839	0.6521	0.5252	0.5113	0.4915	0.5768	0.3105	1.5797	1.4632	1.4519
4	1.3315	1.1666	1.3697	1.2803	1.3415	1.1234	1.1631	1.3994	1.5091	0.9083
5	0.9977	1.5384	1.01	1.5223	1.2888	1.1849	1.2882	1.0311	0.9517	1.3138
6	1.161	0.9199	0.7831	0.7305	0.9825	1.1491	0.9752	0.5175	0.4799	0.502
7	1.1259	0.723	1.3119	0.9555	0.8957	0.9658	1.263	0.4723	0.596	0.824
8	0.8782	0.3471	0.9565	0.8879	0.9532	0.6036	2.2917	0.7435	0.525	2.4766
9	0.6622	0.5313	0.6816	0.6756	0.753	0.7377	1.2106	1.2609	1.184	1.3785
+gp	0.6622	0.5313	0.6816	0.6756	0.753	0.7377	1.2106	1.2609	1.184	1.3785
REFMEAN	0.5184	0.4306	0.3741	0.2727	0.3154	0.2451	0.2915	0.2796	0.3635	0.3486

Table 9 Relative F at age

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0.0027	0.0046	0.0211	0.0048	0.0014	0.0048	0.0179	0.0033	0.0027	0.0159
2	0.2793	0.3304	0.2299	0.9034	0.2018	0.1786	0.3573	0.1799	0.3673	0.4177
3	1.2469	1.2431	1.0031	1.3825	0.8033	0.9998	1.092	0.8728	0.9309	1.2251
4	1.0202	0.816	0.9589	1.0038	0.9651	0.6512	1.0916	0.6744	0.8331	1.0814
5	0.7108	1.1661	1.0418	0.8766	1.1733	0.9198	0.6526	1.057	0.5232	0.6069
6	0.8365	0.8414	1.1345	0.8394	1.0871	1.1444	0.9878	0.8799	1.2252	0.895
7	1.1856	0.9335	0.8617	0.8978	0.9713	1.2848	1.176	1.5158	1.4876	1.1916
8	0.8956	0.9721	1.2287	0.6715	1.0837	0.8381	1.2057	1.4017	1.3037	1.0403
9	1.1071	1.1541	1.2469	1.1068	1.1288	1.1118	1.2129	1.1757	1.2093	1.1608
+gp	1.1071	1.1541	1.2469	1.1068	1.1288	1.1118	1.2129	1.1757	1.2093	1.1608
REFMEAN	0.405	0.5003	0.4479	0.4288	0.3397	0.3412	0.3183	0.365	0.3528	0.2542

Table 9 Relative F at age

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	MEAN 92-94
AGE											
1	0.0009	0.0146	0.0001	0.0018	0.0016	0.0048	0.0098	0.0021	0.0005	0.0781	0.0269
2	0.2538	0.0834	0.1628	0.2878	0.0669	0.1496	0.1374	0.1196	0.2828	0.2344	0.2123
3	0.8949	0.5951	0.3892	0.6783	0.8747	0.8961	0.5725	0.4698	0.5949	0.7031	0.5893
4	0.9516	1.5732	1.3988	0.8619	1.3136	1.209	1.1171	1.6366	1.4379	0.7812	1.2852
5	0.9095	1.1458	1.1211	0.9848	1.0532	0.795	0.973	1.4189	1.52	0.9375	1.2921
6	1.1381	0.7622	1.1085	1.0854	1.0375	1.0117	0.864	1.0128	0.8407	1.4063	1.0866
7	1.106	0.9237	0.9824	1.3895	0.7209	1.0881	1.4734	0.4618	0.6066	1.1719	0.7468
8	1.0648	0.7711	0.9634	1.7925	0.8679	1.187	1.2941	0.8548	0.4031	1.1719	0.8099
9	1.1037	1.011	0.9946	1.2406	1.0659	1.1958	1.2781	1.1836	1.1848	1.1719	1.1801
+gp	1.1037	1.011	0.9946	1.2406	1.0659	1.1958	1.2781	1.1836	1.1848	1.1719	
REFMEAN	0.2936	0.5799	0.483	0.5984	0.7099	0.6356	0.6077	0.3496	0.2956	0.128	

TABLE 10. The population number-at-age calculated for the Blackfin stock using Traditional VPA

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:46

Traditional vpa using screen input for terminal F

Table 10 Stock number at age (start of year) Numbers*10**-3

YEAR	1963	1964
AGE		
1	30399	19306
2	13025	24888
3	11869	10523
4	3540	8381
5	1815	2279
6	859	1191
7	527	510
8	520	366
9	378	292
+gp	365	551
TOTAL	63296	68288

Table 10 Stock number at age (start of year) Numbers*10**-3

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	18969	31238	22737	36038	26343	39047	35655	35364	32388	33584
2	15807	15531	25575	18615	29503	21568	31969	29192	28902	26202
3	20271	12733	12654	20592	15196	23853	17629	25829	20321	16700
4	6695	13601	7873	8512	14665	10655	16955	13184	13597	9774
5	4760	2748	6738	3861	4916	7864	6624	9890	7299	6432
6	1238	2324	1160	3781	2087	2680	4816	3725	6069	4229
7	671	555	1280	709	2537	1254	1656	2967	2639	4173
8	275	306	333	642	447	1566	810	938	2129	1740
9	262	143	216	191	412	271	1106	340	624	1440
+gp	516	260	365	381	367	813	877	600	1477	2493
TOTAL	69464	79438	78931	93322	96474	109571	118095	122029	115446	106767

Table 10 Stock number at age (start of year) Numbers*10**-3

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	24954	17320	18737	20363	23306	31208	29894	38984	40439	43073
2	26686	20408	14148	15196	16638	19072	25509	24336	31878	33077
3	18412	19512	14163	10450	8445	12719	14692	18640	18659	22928
4	8243	9098	8577	7399	4729	5263	7404	8497	11098	10999
5	5831	4464	4952	4570	3939	2790	3450	4283	5439	6772
6	3331	3580	2040	2543	2569	2165	1669	2295	2384	3702
7	2906	1944	1924	1005	1452	1454	1199	998	1363	1267
8	2564	1472	997	1071	560	855	768	675	470	660
9	601	1461	741	471	657	317	526	428	331	243
+gp	1039	3400	2356	3843	2605	2835	2305	1446	1595	689
TOTAL	94566	82659	68634	66910	64901	78678	87416	100582	113656	123410

Table 10 Stock number at age (start of year) Numbers*10**-3

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	GMST 63-92	AMST 63-92
AGE													
1	22048	30484	30508	22052	22043	20945	28479	42159	109779	280	0	27946	28936
2	35123	18046	24748	24977	18035	18027	17096	23179	34492	89866	227	22081	22899
3	24353	26692	14077	18730	17215	14081	13420	12876	18200	25975	71401	16286	16941
4	13748	15332	15476	9550	10219	7575	6522	7759	8945	12498	19436	9240	9831
5	6841	8512	5041	6447	4668	3292	2876	2708	3585	4788	9259	4687	5070
6	4752	4288	3586	2402	2928	1810	1626	1303	1350	1873	3477	2489	2771
7	2414	2785	2257	1719	1027	1148	779	788	749	862	1281	1375	1597
8	766	1429	1335	1150	613	504	471	260	549	513	608	743	890
9	415	459	748	686	322	271	194	175	158	399	361	408	491
+gp	893	855	603	684	378	322	450	301	306	871	894		
TOTAL	111352	108883	98379	88396	77447	67975	71913	91509	178112	137923	106944		

TABLE 11. The spawing stock number-at-age calculated at spawning time for the Blackfin stock using Traditional VPA.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:46

Traditional vpa using screen input for terminal F

Table 11 Spawning stock number at age (spawning time) Numbers*10**-3

YEAR	1963	1964
AGE		
1	0	0
2	0	0
3	0	0
4	0	0
5	1815	2279
6	859	1191
7	527	510
8	520	366
9	378	292
+gp	365	551

Table 11 Spawning stock number at age (spawning time) Numbers*10**-3

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	4760	2748	6738	3861	4916	7864	6624	9890	7299	6432
6	1238	2324	1160	3781	2087	2680	4816	3725	6069	4229
7	671	555	1280	709	2537	1254	1656	2967	2639	4173
8	275	306	333	642	447	1566	810	938	2129	1740
9	262	143	216	191	412	271	1106	340	624	1440
+gp	516	260	365	381	367	813	877	600	1477	2493

Table 11 Spawning stock number at age (spawning time) Numbers*10**-3

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	5831	4464	4952	4570	3939	2790	3450	4283	5439	6772
6	3331	3580	2040	2543	2569	2165	1669	2295	2384	3702
7	2906	1944	1924	1005	1452	1454	1199	998	1363	1267
8	2564	1472	997	1071	560	855	768	675	470	660
9	601	1461	741	471	657	317	526	428	331	243
+gp	1039	3400	2356	3843	2605	2835	2305	1446	1595	689

Table 11 Spawning stock number at age (spawning time) Numbers*10**-3

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	6841	8512	5041	6447	4668	3292	2876	2708	3585	4788
6	4752	4288	3586	2402	2928	1810	1626	1303	1350	1873
7	2414	2785	2257	1719	1027	1148	779	788	749	862
8	766	1429	1335	1150	613	504	471	260	549	513
9	415	459	748	686	322	271	194	175	158	399
+gp	893	855	603	684	378	322	450	301	306	871

TABLE 12. The stock biomass-at-age calculated at the start of the year (without SOP correction) for the Blackfin stock using Traditional VPA.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:46

Traditional vpa using screen input for terminal F

Table 12 Stock biomass at age (start of year) Tonnes

YEAR	1963	1964
AGE		
1	0	0
2	11983	19911
3	15429	15259
4	6262	16845
5	4265	6290
6	2757	4480
7	2200	2177
8	1953	1853
9	2004	1826
+gp	2756	4021
TOTALBIO	49609	72661

Table 12 Stock biomass at age (start of year) Tonnes

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	17298	0	0	0	17965	10040	10378
2	11697	10095	27366	11728	23013	12941	20780	21835	17919	15433
3	23515	13879	15059	24504	15804	25761	16748	27947	22129	16249
4	11247	23666	12447	14301	20971	15119	21363	22519	18683	15707
5	11758	7531	15094	8456	11208	15571	11857	24467	18154	11037
6	4765	7503	4096	11301	6158	7904	13195	9392	18359	14893
7	3006	2564	4815	2870	8906	4601	5812	8629	9515	18860
8	1494	1780	1751	2868	2205	7639	3808	4586	10082	8673
9	1779	935	1286	1006	2363	1696	5837	2045	4168	8658
+gp	3875	2095	2637	2815	2778	5820	6439	4852	11974	20630
TOTALBIO	73135	70049	84549	97147	93404	97052	105839	144236	141023	140518

Table 12 Stock biomass at age (start of year) Tonnes

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	11553	7690	8600	9795	11886	12951	11928	16841	15367	20287
2	19641	14000	9323	7628	11597	12397	17270	17376	21486	24014
3	17087	19883	11953	11798	11131	14818	16235	19945	23342	25404
4	12290	13264	11974	12556	9335	10147	12712	15023	20431	19700
5	15002	12438	11152	12061	9418	7378	10341	11657	16801	18088
6	11602	11805	6647	9893	8585	7689	6833	8891	8716	13040
7	13875	8287	8347	4838	6656	6623	6215	5277	6869	6008
8	14325	7416	5119	5868	3237	4730	4886	4149	2966	3853
9	3925	8624	4406	2891	4569	2069	3866	3321	2316	1863
+gp	8885	26915	18626	32940	24293	27368	22924	15443	17334	7496
TOTALBIO	128186	130324	96149	110267	100707	106171	113208	117923	135628	139752

Table 12 Stock biomass at age (start of year) Tonnes

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	8885	20455	13820	12349	11021	11520	16062	22092	67514	177
2	24656	13282	15047	17484	13346	13466	14788	18334	29387	84384
3	25497	23115	13444	19367	15992	12546	13004	14459	20056	30339
4	22959	20438	18323	12836	11843	9309	8055	10397	12827	20147
5	17854	18719	10007	10998	7455	6088	5168	5525	7076	11117
6	15348	13466	10952	7709	7545	4737	3848	3541	3906	5615
7	10384	11453	9977	7587	4505	4328	2530	3280	2912	3774
8	4580	7355	7541	6375	3471	2871	2183	1313	2709	2758
9	3050	2922	5413	4924	2237	1883	1268	1142	1008	2551
+gp	9866	8098	6620	6813	3306	2856	3914	2932	2619	7714
TOTALBIO	143081	139302	111144	106441	80723	69604	70820	83016	150013	168575

TABLE 13. The spawning stock biomass-at-age calculated at spawning time (without SOP correction) for the Blackfin stock using Traditional VPA.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:46

Traditional vpa using screen input for terminal F

Table 13 Spawning stock biomass at age (spawning time) Tonnes

YEAR	1963	1964
AGE		
1	0	0
2	0	0
3	0	0
4	0	0
5	4265	6290
6	2757	4480
7	2200	2177
8	1953	1853
9	2004	1826
+gp	2756	4021
TOTSPBIO	15935	20647

Table 13 Spawning stock biomass at age (spawning time) Tonnes

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	11758	7531	15094	8456	11208	15571	11857	24467	18154	11037
6	4765	7503	4096	11301	6158	7904	13195	9392	18359	14893
7	3006	2564	4815	2870	8906	4601	5812	8629	9515	18860
8	1494	1780	1751	2868	2205	7639	3808	4586	10082	8673
9	1779	935	1286	1006	2363	1696	5837	2045	4168	8658
+gp	3875	2095	2637	2815	2778	5820	6439	4852	11974	20630
TOTSPBIO	26677	22409	29678	29316	33616	43231	46948	53971	72252	82751

Table 13 Spawning stock biomass at age (spawning time) Tonnes

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	15002	12438	11152	12061	9418	7378	10341	11657	16801	18088
6	11602	11805	6647	9893	8585	7689	6833	8891	8716	13040
7	13875	8287	8347	4838	6656	6623	6215	5277	6869	6008
8	14325	7416	5119	5868	3237	4730	4886	4149	2966	3853
9	3925	8624	4406	2891	4569	2069	3866	3321	2316	1863
+gp	8885	26915	18626	32940	24293	27368	22924	15443	17334	7496
TOTSPBIO	67615	75486	54298	68491	56758	55858	55064	48738	55002	50348

Table 13 Spawning stock biomass at age (spawning time) Tonnes

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	17854	18719	10007	10998	7455	6088	5168	5525	7076	11117
6	15348	13466	10952	7709	7545	4737	3848	3541	3906	5615
7	10384	11453	9977	7587	4505	4328	2530	3280	2912	3774
8	4580	7355	7541	6375	3471	2871	2183	1313	2709	2758
9	3050	2922	5413	4924	2237	1883	1268	1142	1008	2551
+gp	9866	8098	6620	6813	3306	2856	3914	2932	2619	7714
TOTSPBIO	61083	62012	50509	44405	28519	22763	18911	17734	20229	33529

TABLE 14. The stock biomass at age calculated at the start of the year (with SOP correction) for the Blackfin stock using Traditional VPA.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:46

Traditional vpa using screen input for terminal F

Table 14 Stock biomass at age with SOP (start of year) Tonnes

YEAR	1963	1964
AGE		
1	0	0
2	12651	20859
3	16290	15985
4	6611	17647
5	4503	6590
6	2911	4693
7	2322	2280
8	2062	1941
9	2116	1913
+gp	2909	4212
TOTALBIO	52376	76120

Table 14 Stock biomass at age with SOP (start of year) Tonnes

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	17024	0	0	0	18031	9327	10082
2	11508	10046	27975	11541	22720	12774	20451	21916	16646	14993
3	23136	13812	15394	24116	15603	25428	16482	28050	20557	15785
4	11066	23552	12724	14074	20705	14924	21024	22602	17355	15259
5	11569	7495	15430	8322	11065	15370	11669	24557	16864	10722
6	4688	7467	4187	11122	6080	7802	12986	9426	17054	14468
7	2957	2552	4922	2825	8792	4541	5720	8661	8838	18322
8	1470	1772	1790	2822	2177	7540	3748	4603	9366	8426
9	1751	931	1314	990	2333	1674	5745	2052	3872	8411
+gp	3812	2085	2696	2770	2742	5745	6337	4870	11123	20041
TOTALBIO	71956	69712	86431	95605	92217	95799	104162	144770	131003	136510

Table 14 Stock biomass at age with SOP (start of year) Tonnes

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	11334	7488	8262	9489	11810	12893	11740	16665	15720	19989
2	19267	13632	8957	7390	11523	12342	16998	17194	21980	23661
3	16761	19360	11484	11430	11060	14752	15979	19736	23878	25030
4	12056	12916	11503	12164	9276	10102	12512	14866	20900	19410
5	14717	12111	10714	11685	9358	7345	10178	11535	17187	17821
6	11382	11495	6386	9584	8530	7655	6725	8798	8916	12848
7	13611	8069	8019	4687	6614	6594	6117	5222	7027	5920
8	14052	7221	4918	5684	3217	4709	4809	4105	3034	3797
9	3851	8398	4233	2801	4540	2060	3806	3286	2369	1835
+gp	8716	26207	17894	31912	24138	27246	22563	15282	17733	7386
TOTALBIO	125746	126897	92371	106827	100064	105698	111426	116691	138744	137696

Table 14 Stock biomass at age with SOP (start of year) Tonnes

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	8802	19387	14669	12251	10449	11074	16182	22133	67483	176
2	24424	12589	15971	17345	12653	12944	14898	18369	29374	83959
3	25257	21908	14269	19213	15162	12060	13101	14487	20047	30186
4	22742	19371	19448	12734	11229	8949	8115	10417	12821	20045
5	17686	17742	10621	10911	7068	5852	5206	5535	7073	11061
6	15203	12763	11624	7648	7153	4554	3876	3548	3904	5586
7	10287	10855	10590	7527	4271	4160	2549	3286	2911	3755
8	4537	6971	8004	6324	3291	2759	2199	1316	2708	2744
9	3022	2769	5745	4885	2120	1810	1278	1144	1007	2538
+gp	9773	7675	7026	6759	3135	2745	3943	2938	2617	7675
TOTALBIO	141731	132030	117968	105595	76532	66908	71349	83173	149945	167727

TABLE 15. The spawning stock biomass-at-age calculated at spawning time (with SOP correction) for the Blackfin stock using Traditional VPA.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:46

Traditional vpa using screen input for terminal F

Table 15 Spawning stock biomass with SOP (spawning time) Tonnes

YEAR	1963	1964
AGE		
1	0	0
2	0	0
3	0	0
4	0	0
5	4503	6590
6	2911	4693
7	2322	2280
8	2062	1941
9	2116	1913
+gp	2909	4212
TOTSPBIO	16824	21630

Table 15 Spawning stock biomass with SOP (spawning time) Tonnes

YEAR	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	11569	7495	15430	8322	11065	15370	11669	24557	16864	10722
6	4688	7467	4187	11122	6080	7802	12986	9426	17054	14468
7	2957	2552	4922	2825	8792	4541	5720	8661	8838	18322
8	1470	1772	1790	2822	2177	7540	3748	4603	9366	8426
9	1751	931	1314	990	2333	1674	5745	2052	3872	8411
+gp	3812	2085	2696	2770	2742	5745	6337	4870	11123	20041
TOTSPBIO	26246	22301	30338	28851	33189	42673	46205	54170	67118	80391

Table 15 Spawning stock biomass with SOP (spawning time) Tonnes

YEAR	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	14717	12111	10714	11685	9358	7345	10178	11535	17187	17821
6	11382	11495	6386	9584	8530	7655	6725	8798	8916	12848
7	13611	8069	8019	4687	6614	6594	6117	5222	7027	5920
8	14052	7221	4918	5684	3217	4709	4809	4105	3034	3797
9	3851	8398	4233	2801	4540	2060	3806	3286	2369	1835
+gp	8716	26207	17894	31912	24138	27246	22563	15282	17733	7386
TOTSPBIO	66328	73501	52165	66354	56396	55609	54197	48229	56265	49607

Table 15 Spawning stock biomass with SOP (spawning time) Tonnes

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
AGE										
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	17686	17742	10621	10911	7068	5852	5206	5535	7073	11061
6	15203	12763	11624	7648	7153	4554	3876	3548	3904	5586
7	10287	10855	10590	7527	4271	4160	2549	3286	2911	3755
8	4537	6971	8004	6324	3291	2759	2199	1316	2708	2744
9	3022	2769	5745	4885	2120	1810	1278	1144	1007	2538
+gp	9773	7675	7026	6759	3135	2745	3943	2938	2617	7675
TOTSPBIO	60507	58775	53611	44052	27039	21881	19052	17767	20220	33360

TABLE 16. The stock summary table (without SOP correction) for the Blackfin Traditional VPA.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 1/02/2002 8:46

Table 16 Summary (without SOP correction)

Traditional vpa using screen input for terminal F

	RECRUITS Age 1	TOTALBIO	TOTSPBIO	LANDINGS	YIELD/SSB	FBAR 3- 7	FBARP
1963	30399	49609	15935	6594	0.4138	0.2192	0.1061
1964	19306	72661	20647	13596	0.6585	0.364	0.1395
1965	18969	73135	26677	18395	0.6896	0.5184	0.1665
1966	31238	70049	22409	18584	0.8293	0.4306	0.1594
1967	22737	84549	29678	16034	0.5403	0.3741	0.1454
1968	36038	97147	29316	12787	0.4362	0.2727	0.1181
1969	26343	93404	33616	17124	0.5094	0.3154	0.1319
1970	39047	97052	43231	14536	0.3362	0.2451	0.1071
1971	35655	105839	46948	19863	0.4231	0.2915	0.122
1972	35364	144236	53971	29219	0.5414	0.2796	0.1816
1973	32388	141023	72252	33832	0.4683	0.3635	0.2475
1974	33584	140518	82751	35973	0.4347	0.3486	0.207
1975	24954	128186	67615	30800	0.4555	0.405	0.1922
1976	17320	130324	75486	41747	0.553	0.5003	0.2254
1977	18737	96149	54298	27210	0.5011	0.4479	0.1967
1978	20363	110267	68491	31370	0.458	0.4288	0.2588
1979	23306	100707	56758	21604	0.3806	0.3397	0.1542
1980	31208	106171	55858	22102	0.3957	0.3412	0.1517
1981	29894	113208	55064	23574	0.4281	0.3183	0.1664
1982	38984	117923	48738	23884	0.49	0.365	0.1559
1983	40439	135628	55002	28890	0.5253	0.3528	0.1666
1984	43073	139752	50348	21641	0.4298	0.2542	0.1462
1985	22048	143081	61083	26595	0.4354	0.2936	0.1432
1986	30484	139302	62012	39886	0.6432	0.5799	0.2022
1987	30508	111144	50509	31369	0.6211	0.483	0.1764
1988	22052	106441	44405	34178	0.7697	0.5984	0.2152
1989	22043	80723	28519	25577	0.8968	0.7099	0.2287
1990	20945	69604	22763	19865	0.8727	0.6356	0.225
1991	28479	70820	18911	16995	0.8987	0.6077	0.2
1992	42159	83016	17734	11804	0.6656	0.3496	0.1531
1993	109779	150013	20229	13943	0.6892	0.2956	0.1466
1994	280	168575	33529	10429	0.3111	0.128	0.0755
Arith. Mean	30566	108445	44524	23125	0.5532	0.3893	0.1691
Units	(Thousands)	(Tonnes)	(Tonnes)	(Tonnes)			

NAFO Sci. Coun. Studies, 36: 49–61

Appendix 1: The Lowestoft Stock Assessment Suite

Tutorial 2

Separable VPA

by

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Abstract

This document is the second in a series of tutorials designed to assist users of the Lowestoft VPA Suite assessment software and prediction programs that utilise the results. This tutorial takes the user through fitting a Separable VPA model to catch at age data and analysis of the diagnostic output.

Introduction

This tutorial assumes that the user has installed the VPA program described in Darby and Flatman (1994), that the required data files have been placed in a directory c:\vpas\data and that the assessment index file (Blackfin.ind) contains path names which point to the appropriate files.

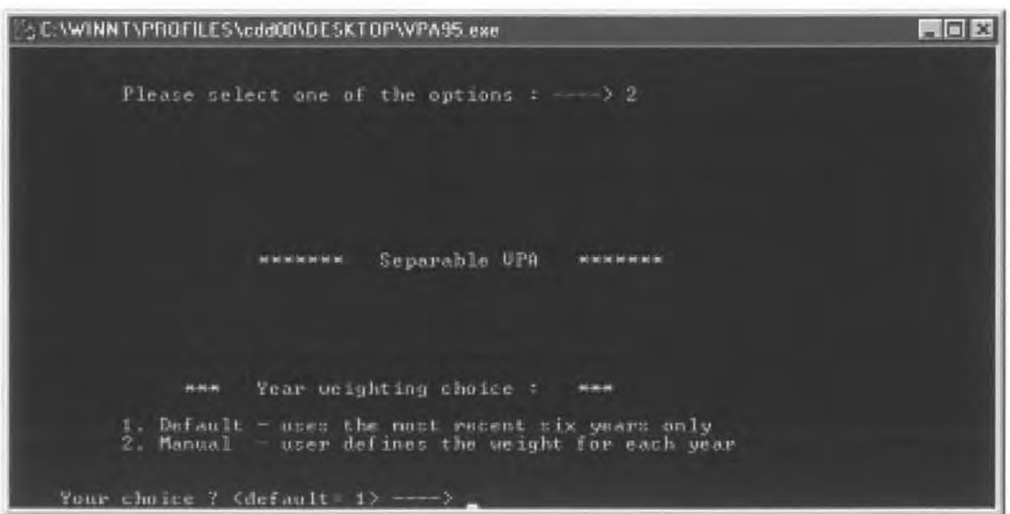
In the following text **action to be taken by the user** is highlighted in bold. The symbol ↵ is used to represent the Return or Enter key on the keyboard.

Separable VPA

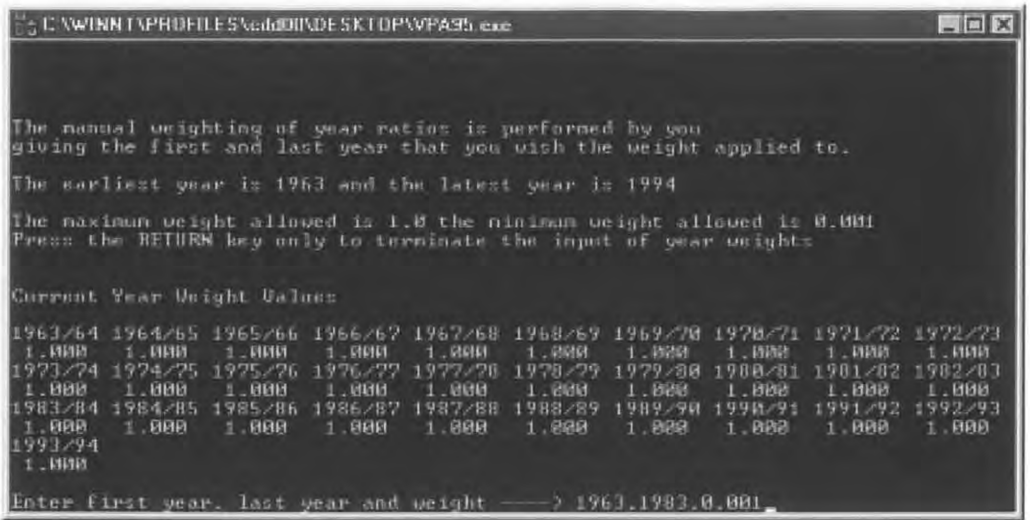
Open the program and read in the index file C:\VPAS\DATA\BLACKFIN.IND. Use the default year, age and summary means settings until the main menu is reached.

At the main menu **Type 2 ↵** to select Separable VPA.

The first input screen is used to define the year weights for the log catch ratios to which the model is fitted. Usually the default settings, which utilise the data from the most recent six years, provide a suitable model for an assessment. However to demonstrate the use of year weighting we shall use the last 11 years.



Type 2 ↵

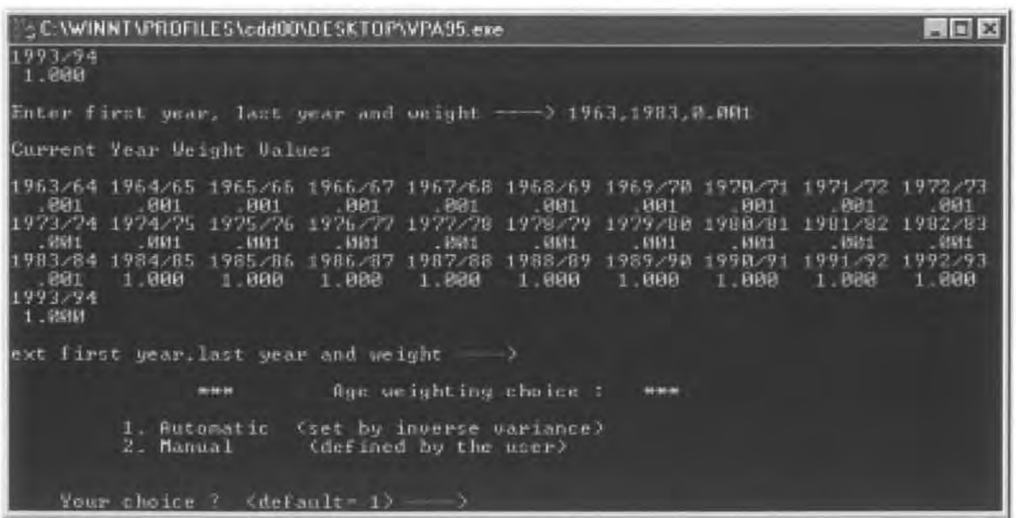


In order to select the most recent years for fitting the model we down-weight data from the early years.

Type 1963, 1983, 0.001↵

This can be repeated until all of the years have been weighted as required.

Type ↵ to exit year weighting.



The next screen presents the options for user-defined age weighting. This would merit a tutorial on its own, and further information on using the option is contained in the referenced user guide. In general it is best left to the program and here we shall take the default and let the program calculate the weights.

Type ↵ To take the default Automatic weighting

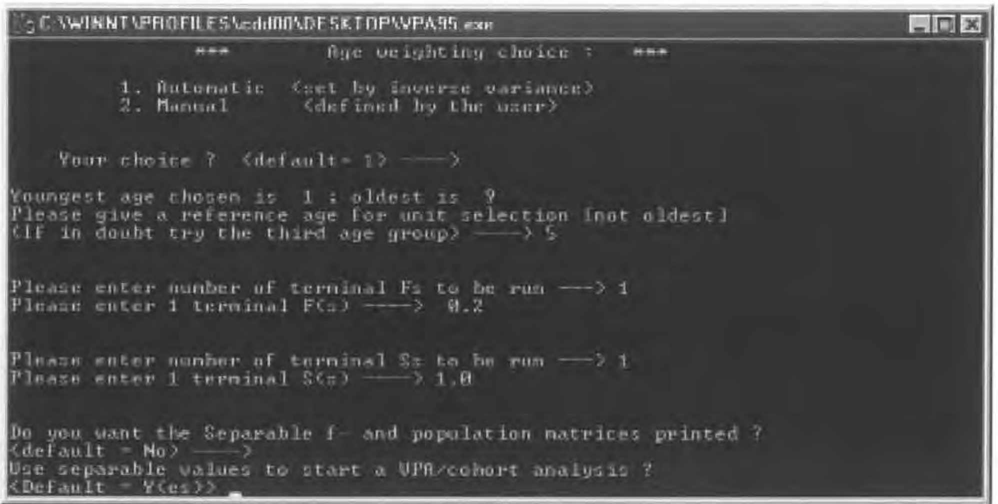
Input is now required for the reference age for unit selection (full recruitment). The selection at each age will be scaled relative to the estimate for this age. The choice as to which age to use is not usually critical and an age in the middle of the range is suitable.

Type 5 ↵

The program allows up to 3 terminal F values to be fitted for each of 3 terminal selection values. Here we shall only run one of each. A terminal F of 0.2 and a selection at the oldest age of 1.0

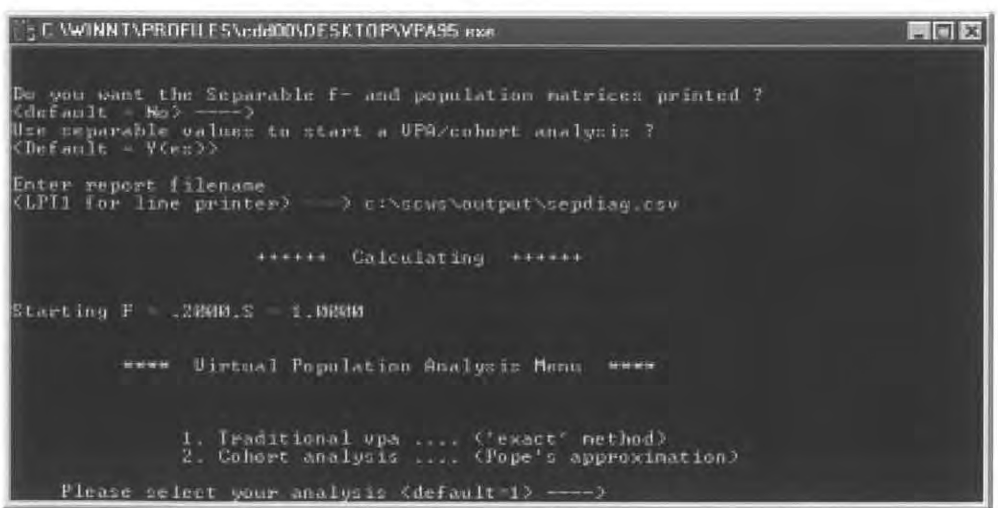
Type 1 ↵ for a single terminal F value
Type 0.2 ↵ the terminal F value to be used in fitting the model

Type 1 ↵ for a single selection value
Type 1.0 ↵ the terminal selection value to be used in fitting the model (make sure it is **1. 0** bug/feature)



Type Y ↵ to print the separable F's and population numbers.
Type ↵ to take default option to use the separable results to start a VPA.

Type a directory path and filename for the Separable VPA diagnostics file ↵
Type↵ to run exact VPA



This completes the fitting of the separable model to the catch at age data and the calculation of a VPA based on the marginal fishing mortalities. To output the SSB and biomass values resulting from the run option 9 must be selected from the main menu.

The Separable VPA Diagnostic File

The separable method produces a diagnostic output file which is listed in Tables 1–5 and illustrated in Figures 1–4. The bracketed numbers within each of the following paragraphs refer to the reference numbers **(x)** added to the tables and figures.

The printed output consists of:

The title, time and date of the run (1), the year and age range of the data and the terminal F and terminal S value for this run (2) (Table 1).

The number of iterations taken to reach the solution (3), and the initial and the final sum of squared **unweighted** residuals (SSQ). This provides a measure of the fit to the separable model and should be reduced in the final solution. For the Blackfin model the sum of squares is reduced from 1160 to 221: a significant reduction on the sum of squares indicating a good fit to the catch data set. The final value can be used to derive the root mean square residual (≡ standard error) of the fit to the log catch ratios, an approximation for the coefficient of variation implied if all the lack of fit were due to uniform random variation in the catch-at-age data.

$$\text{Model RMSE} \equiv \text{catch-at-age data CV} \approx \sqrt{\frac{\text{Final SSQ}}{2((a-1)(y-1)-2}}$$

where a is the number of ages and y the number of years of catch-at-age data. The variance of the fit to the log catch ratios is 2× that of the fit to the catch-at-age data. Often the lack of fit is not due to uniform variation and a few residuals contribute a significant proportion.

The matrix of residuals showing the difference between the observed log catch ratio and the estimated log catch ratio (4). Positive values indicate that the model expects a greater change in the catches between years than observed. Row and column totals of **weighted** residuals are given (5), as is the grand total (6), which the algorithm is attempting to minimize. The row and column totals should be near zero. If they are not the analysis is a poor fit. Row and column weights are printed at the edges of the table.

Often the SSQ value is the result of a few high residuals which indicate poor data for that year and age; these may occur with poorly sampled age groups. The automatic weighting should cope with this adequately, but occasionally it may be necessary to either (i) exclude the age groups by removing younger ages from the analysis or incorporating the older ages in the plus group, or (ii) down-weight specific years manually.

Pattern in the residuals may indicate systematic lack of fit to the model (i.e. a changing selection pattern). Figure 4 illustrates some of the ways in which the residuals can be plotted in order to detect patterns. The figure presents a bubble plots for each age within a year and time series for all ages combines and at each age. Look for year effects running down the columns, age effects across the rows and year class effects which follow the cohort diagonals. If the selection pattern has changed a chequered flag effect can result with positive residuals in diagonally opposed quadrants and negative residuals in the other two.

The fully exploited fishing mortality Fo(y) for each year (7) (Table 2), referred to the reference age, is plotted in Figure 2. The exploitation pattern S(a) for each age (8), referred to unity on the reference age, and set to the user-defined value on the oldest age, is plotted in Fig. 3.

The Separable model fishing mortalities (9) (Table 3) for each cell in the age/year matrix are obtained from the product of the overall fully-exploited fishing mortality for the year, Fo(y), and the selection-at-age value for the particular age S(a). These are the smoothed model estimates of fishing mortality derived from the fit to the log catch ratios.

The Separable VPA populations-at-age (10) (Table 4) are derived by calculating the recruitment (i.e. initial population for each cohort) values that would, using the separable F values, give the best fit to the catch-at-age data over the whole cohort.

After a run with only one value for terminal F and terminal S, the user can choose whether to run a VPA or Cohort analysis. The terminal F starting values for the run are calculated using the raw catch data (including errors), along with the 'smooth', Separable VPA-generated, terminal population abundances (estimated at the start of the year). The F and population numbers tables generated by the VPA or Cohort analysis (Tables 8 and 10 from option 9 of the main menu) are produced by an exact fit to the raw catch data. They will exhibit differences from the 'smoothed' Separable VPA tables ((9) and (10)). The differences in fishing mortality are given in (11) (Table 5), the F residuals ($F_{sep} - F_{vpa}$).

Terminal Fishing Mortality and Selection at the Oldest Age

Each of the user-specified values for the fishing mortality at the reference age in the final year, and selection at the oldest age, result in model fits that are equally good interpretations of the data (as judged by the final sum of squares); each statistically valid. The choice as to which is the appropriate interpretation can only be made using additional information e.g. trends in effort over time, groundfish survey data, assumptions about exploitation patterns, etc. An appropriate example is the Separable VPA assessment carried out for the Western mackerel by Anon. (MS 1993). Spawning stock biomasses (SSB) generated by a Separable VPA were 'tuned' to estimates of SSB derived from triennial egg surveys and the sum of squares between estimated and observed biomasses minimised to find a value for the terminal year fishing mortality. Selection at age was assumed to be constant over the oldest ages.

By definition S on the reference age is 1.0. Using the same value for S on the oldest age, without thought, can lead to: an increasing trend in F with age for the older ages if one has a dome shaped selection pattern (Fig. 1a); or a spuriously domed exploitation pattern if one has selected a reference F at a partially recruited age group (Fig. 1b).

The values of natural mortality-at-age and of selection-at-age are confounded within the separable model. Therefore, the user-defined pattern of natural mortality-at-age can influence the shape of the selection-at-age pattern derived from the analysis. If natural mortality varies with age, the influence of the variation on the selection pattern must be taken into consideration.

The final choice is made on the basis of the user's perception of the most likely shape of the selection-at-age curve. In the absence of any prior information, and if natural mortality is considered to be constant for the oldest ages, it may be prudent to choose a terminal selection value that produces a level exploitation pattern for the oldest ages.

References

ANON. MS 1993. Report of the Working Group on the Assessment of Mackerel, Horse Mackerel Sardine and Anchovy. *ICES C.M. Doc.*, No. 1993/Assess:19, 274 p. (mimeo).

DARBY, C. D. and S. FLATMAN. 1994. Virtual Population Analysis: version 3.1 (Windows/DOS) user guide. Information Technology Series. MAFF Directorate of Fisheries Research, Lowestoft, **1**: 85 p.

POPE, J. G., and J. G. SHEPHERD. 1982. A simple method for the consistent interpretation of catch-at-age data. *ICES J. Cons.*, **40**: 176–184.

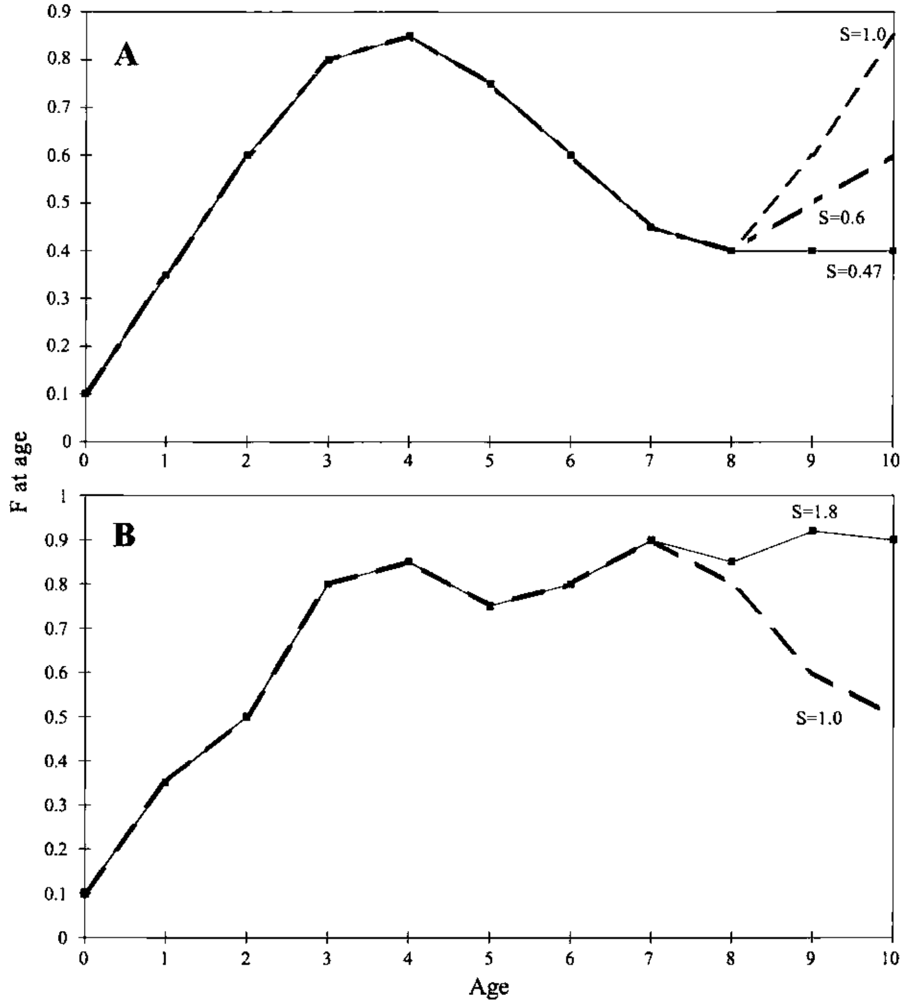


Fig. 1. (**A**) an illustration of the effects on estimated F-at-age of an inappropriate selection for the value of S on the oldest age (Reference age = 4, terminal F = 0.85) and (**B**) an illustration of the effects on estimated F-at-age of an inappropriate selection for the value of S on the oldest age (Reference age = 24, terminal F = 0.5).

TABLE 1. The Separable VPA diagnostic file : model specification and log catch ratio residuals.

```
Title : Blackfin: VPA course. Combined sex; plusgroup.                          (1)
At  4/02/2002  13:48

Separable analysis                                                              (2)
from 1963 to 1994 on ages  1 to  9
with Terminal F of  .200 on age  5 and Terminal S of 1.000

Initial sum of squared residuals was  1160.180 and                              (3)
final sum of squared residuals is      221.386 after 126 iterations

Matrix of Residuals

Years,  1963/64,                                                                (4)
Ages
1/ 2,  -2.594,
2/ 3,  -1.308,
3/ 4,   -.008,
4/ 5,   -.305,
5/ 6,   -.157,
6/ 7,    .165,
7/ 8,    .441,
8/ 9,   1.108,

TOT ,    .000,
WTS ,    .001,

Years,  1964/65,1965/66,1966/67,1967/68,1968/69,1969/70,1970/71,1971/72,1972/73,1973/74,

1/ 2,  -3.037, -2.718, -3.948, -2.319,  -.717, -1.852, -3.388, -6.398,  -.689,  1.853,
2/ 3,  -1.833, -1.889, -2.279, -1.123, -2.403, -1.366, -2.078, -2.105,   .505,  1.294,
3/ 4,    .253,  -.684,   .224,  -.271,  -.228,  -.266,   .327,  -.992,   .673,  1.212,
4/ 5,    .162,  -.155,   .423,  -.044,   .096,   .079,   .250,  -.053,   .127,   .162,
5/ 6,    .361,   .040,  1.180,   .388,   .702,   .231,   .719,   .878,   .559,   .618,
6/ 7,    .255,   .425,   .072,  -.171,  -.087,   .041,   .447,   .621,  -.417,  -.614,
7/ 8,    .610,  1.076,   .072,   .548,   .189,   .392,  -.185,   .542,  -.365, -1.186,
8/ 9,   -.332,   .481,  -.346,   .520,   .425,   .394,  -.095,   .953,  -.468,  -.799,

TOT ,    .000,   .000,   .000,   .000,   .000,   .000,   .000,   .000,   .000,   .000,
WTS ,    .001,   .001,   .001,   .001,   .001,   .001,   .001,   .001,   .001,   .001,

Years,  1974/75,1975/76,1976/77,1977/78,1978/79,1979/80,1980/81,1981/82,1982/83,1983/84,

1/ 2,   2.886,  -.483,   .425,   .525,   .538,  -.625,   .052,  1.917,  -.390,  -.786,
2/ 3,    .194,   .004,   .367,  -.456,  1.638,  -.244,  -.354,   .446,  -.270,   .167,
3/ 4,    .748,  1.028,   .937,   .432,  1.039,   .663,   .561,   .945,   .562,   .360,
4/ 5,   -.322,  -.286,  -.488,  -.333,  -.338,  -.206,  -.259,  -.217,  -.109,  -.045,
5/ 6,    .186,  -.262,   .112,   .016,  -.241,   .035,  -.040,  -.462,  -.126,  -.729,
6/ 7,  -1.226,  -.164,  -.093,   .059,  -.211,  -.165,   .060,  -.443,  -.510,  -.010,
7/ 8,   -.404,   .269,  -.204,   .003,  -.185,   .094,   .216,  -.140,   .303,   .389,
8/ 9,    .956,  -.105,  -.058,   .141,  -.452,   .093,  -.190,   .136,   .369,   .238,

TOT ,    .000,   .000,   .000,   .000,   .000,   .000,   .000,   .000,   .000,   .000,
WTS ,    .001,   .001,   .001,   .001,   .001,   .001,   .001,   .001,   .001,   .001,        (5)

Years,  1984/85,1985/86,1986/87,1987/88,1988/89,1989/90,1990/91,1991/92,1992/93,1993/94, TOT,  WTS,

1/ 2,   1.447,  -.331,  1.826, -3.592,   .451,  -.201,   .955,  1.680,  -.623, -1.590,  .000, .149,
2/ 3,    .569,   .384,  -.316,   .083,   .148, -1.163,  -.033,  -.044,  -.307,   .693,  .000, .290,
3/ 4,    .777,   .033,  -.286,  -.230,  -.268,   .375,   .356,  -.615,  -.612,   .462,  .000, .537,
4/ 5,   -.089,  -.432,   .344,   .437,  -.677,   .410,   .011,  -.542,   .021,   .518,  .000,1.000,
5/ 6,   -.743,   .012,   .105,   .272,  -.260,   .135,  -.233,  -.221,   .532,   .397,  .000, .694,
6/ 7,   -.307,   .112,  -.343,   .081,   .136,   .059,  -.292,   .311,   .398,  -.153,  .000, .842,
7/ 8,    .085,   .255,  -.042,  -.190,   .396,  -.445,  -.058,   .553,  -.074,  -.483,  .000, .718,
8/ 9,    .008,   .102,  -.189,   .116,   .749,  -.105,   .173,   .198,  -.246,  -.808,  .000, .656,

TOT ,    .000,   .000,   .000,   .000,   .000,   .000,   .000,   .000,   .000,   .000,     -21.683,
WTS ,   1.000,  1.000,  1.000,  1.000,  1.000,  1.000,  1.000,  1.000,  1.000,  1.000,        (6)
```

TABLE 2. The Separable VPA diagnostic file: Fishing mortality at the reference age and selection at age.

Fishing Mortalities (F) (7)

,	1963,	1964,								
F-values,	.1445,	.1883,								
,	1965,	1966,	1967,	1968,	1969,	1970,	1971,	1972,	1973,	1974,
F-values,	.3150,	.2106,	.2343,	.1696,	.2190,	.1671,	.3265,	.3269,	.3991,	.4439,
	1975,	1976,	1977,	1978,	1979,	1980,	1981,	1982,	1983,	1984,
F-values,	.4137,	.5330,	.5150,	.4371,	.3531,	.3494,	.3559,	.3958,	.3936,	.2728,
,	1985,	1986,	1987,	1988,	1989,	1990,	1991,	1992,	1993,	1994,
F-values,	.3004,	.5460,	.4474,	.6912,	.7091,	.7147,	.7376,	.4003,	.3449,	.2000,

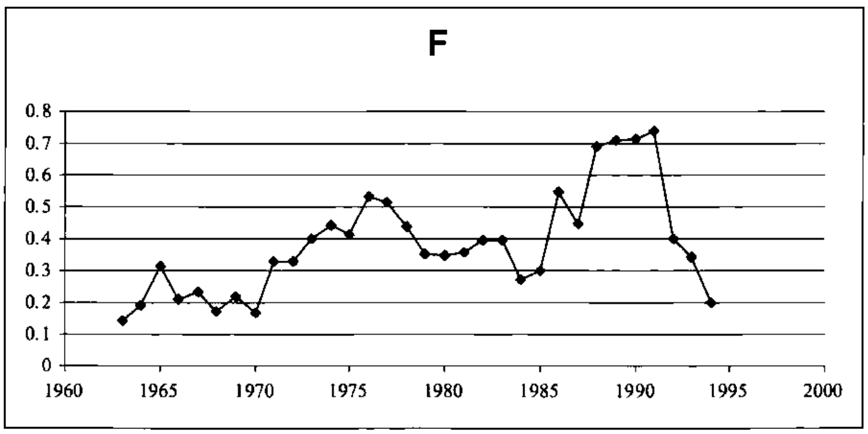


Fig. 2. Fishing mortality at the reference age, by year, for the Blackfin data set as estimated by Separable VPA.

Selection-at-age (S) (8)

,	1,	2,	3,	4,	5,	6,	7,	8,	9,
S-values,	.0026,	.1841,	.6919,	1.1884,	1.0000,	.9778,	.9324,	.9099,	1.0000,

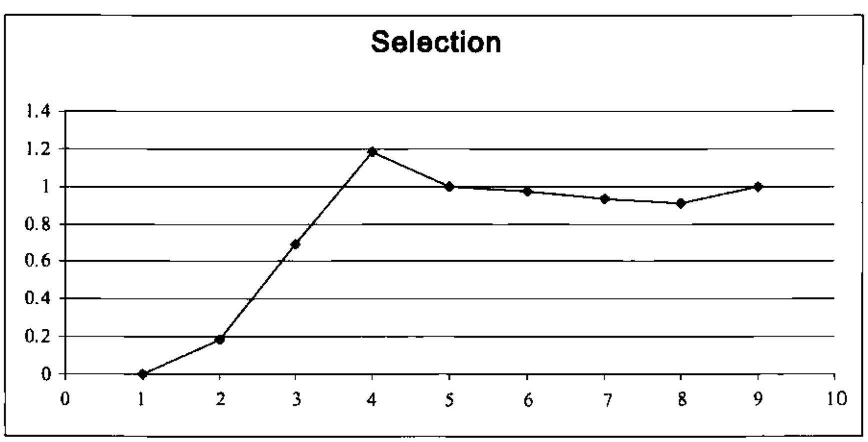


Fig. 3. Selection (y-axis) at age (x-axis) for the Blackfin data set as estimated by Separable VPA.

TABLE 3. The Separable VPA diagnostic file : Separable model estimates of fishing mortality at age.

Run title : Blackfin: VPA course. Combined sex; plusgroup.
At 4/02/2002 13:48

Traditional vpa Terminal populations from weighted Separable populations

SEPARABLY GENERATED FISHING MORTALITIES (9)

YEAR, AGE	1963,	1964,
1,	.0004,	.0005,
2,	.0266,	.0347,
3,	.1000,	.1303,
4,	.1717,	.2238,
5,	.1445,	.1883,
6,	.1413,	.1841,
7,	.1347,	.1756,
8,	.1315,	.1713,
9,	.1445,	.1883,

YEAR, AGE	1965,	1966,	1967,	1968,	1969,	1970,	1971,	1972,	1973,	1974,
1,	.0008,	.0006,	.0006,	.0004,	.0006,	.0004,	.0009,	.0009,	.0010,	.0012,
2,	.0580,	.0388,	.0431,	.0312,	.0403,	.0308,	.0601,	.0602,	.0735,	.0817,
3,	.2179,	.1457,	.1621,	.1173,	.1515,	.1156,	.2259,	.2262,	.2761,	.3072,
4,	.3743,	.2502,	.2785,	.2015,	.2602,	.1986,	.3880,	.3885,	.4743,	.5276,
5,	.3150,	.2106,	.2343,	.1696,	.2190,	.1671,	.3265,	.3269,	.3991,	.4439,
6,	.3080,	.2059,	.2291,	.1658,	.2141,	.1634,	.3192,	.3197,	.3902,	.4341,
7,	.2937,	.1963,	.2185,	.1581,	.2042,	.1558,	.3044,	.3048,	.3721,	.4139,
8,	.2866,	.1916,	.2132,	.1543,	.1993,	.1521,	.2971,	.2975,	.3631,	.4039,
9,	.3150,	.2106,	.2343,	.1696,	.2190,	.1671,	.3265,	.3269,	.3991,	.4439,

YEAR, AGE	1975,	1976,	1977,	1978,	1979,	1980,	1981,	1982,	1983,	1984,
1,	.0011,	.0014,	.0013,	.0011,	.0009,	.0009,	.0009,	.0010,	.0010,	.0007,
2,	.0762,	.0981,	.0948,	.0805,	.0650,	.0643,	.0655,	.0729,	.0725,	.0502,
3,	.2862,	.3688,	.3563,	.3025,	.2443,	.2417,	.2463,	.2738,	.2724,	.1887,
4,	.4916,	.6334,	.6120,	.5195,	.4196,	.4152,	.4230,	.4703,	.4678,	.3241,
5,	.4137,	.5330,	.5150,	.4371,	.3531,	.3494,	.3559,	.3958,	.3936,	.2728,
6,	.4045,	.5211,	.5035,	.4274,	.3452,	.3416,	.3480,	.3870,	.3849,	.2667,
7,	.3857,	.4969,	.4802,	.4076,	.3292,	.3258,	.3319,	.3690,	.3670,	.2543,
8,	.3764,	.4849,	.4685,	.3977,	.3212,	.3179,	.3238,	.3601,	.3581,	.2482,
9,	.4137,	.5330,	.5150,	.4371,	.3531,	.3494,	.3559,	.3958,	.3936,	.2728,

YEAR, AGE	1985,	1986,	1987,	1988,	1989,	1990,	1991,	1992,	1993,	1994,
1,	.0008,	.0014,	.0012,	.0018,	.0019,	.0019,	.0019,	.0010,	.0009,	.0005,
2,	.0553,	.1005,	.0824,	.1273,	.1305,	.1316,	.1358,	.0737,	.0635,	.0368,
3,	.2078,	.3778,	.3096,	.4782,	.4906,	.4945,	.5104,	.2770,	.2387,	.1384,
4,	.3570,	.6489,	.5317,	.8214,	.8427,	.8493,	.8766,	.4757,	.4099,	.2377,
5,	.3004,	.5460,	.4474,	.6912,	.7091,	.7147,	.7376,	.4003,	.3449,	.2000,
6,	.2937,	.5339,	.4375,	.6758,	.6933,	.6988,	.7212,	.3914,	.3373,	.1956,
7,	.2801,	.5091,	.4172,	.6445,	.6612,	.6664,	.6878,	.3733,	.3216,	.1865,
8,	.2733,	.4968,	.4071,	.6289,	.6452,	.6503,	.6711,	.3643,	.3138,	.1820,
9,	.3004,	.5460,	.4474,	.6912,	.7091,	.7147,	.7376,	.4003,	.3449,	.2000,

TABLE 4. The Separable VPA diagnostic file : Separable model estimates of population numbers at age.

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 4/02/2002 13:48

Traditional vpa Terminal populations from weighted Separable populations

SEPARABLY GENERATED POPULATION NUMBERS **(10)**

YEAR,	1963,	1964,
AGE		
1,	24065,	15604,
2,	10245,	19695,
3,	11781,	8167,
4,	3641,	8728,
5,	1887,	2511,
6,	1076,	1337,
7,	534,	765,
8,	775,	382,
9,	411,	556,

YEAR,	1965,	1966,	1967,	1968,	1969,	1970,	1971,	1972,	1973,	1974,
AGE										
1,	14828,	22851,	17496,	33170,	22244,	28525,	27075,	26727,	32305,	33217,
2,	12769,	12130,	18699,	14315,	27145,	18202,	23344,	22148,	21863,	26421,
3,	15576,	9866,	9554,	14663,	11360,	21346,	14451,	17998,	17074,	16632,
4,	5870,	10255,	6982,	6651,	10676,	7993,	15568,	9439,	11752,	10606,
5,	5713,	3305,	6538,	4327,	4452,	6738,	5365,	8647,	5240,	5988,
6,	1703,	3414,	2192,	4234,	2990,	2928,	4667,	3169,	5105,	2878,
7,	911,	1025,	2275,	1427,	2937,	1976,	2036,	2777,	1885,	2829,
8,	526,	556,	689,	1497,	998,	1961,	1385,	1229,	1676,	1064,
9,	263,	323,	376,	456,	1050,	669,	1379,	842,	747,	954,

YEAR,	1975,	1976,	1977,	1978,	1979,	1980,	1981,	1982,	1983,	1984,
AGE										
1,	23809,	12172,	17935,	20008,	33649,	35767,	29760,	31543,	31867,	42547,
2,	27165,	19472,	9952,	14664,	16362,	27524,	29257,	24343,	25798,	26063,
3,	19934,	20610,	14453,	7411,	11077,	12553,	21131,	22434,	18530,	19645,
4,	10016,	12258,	11670,	8286,	4484,	7104,	8071,	13524,	13968,	11554,
5,	5124,	5016,	5327,	5181,	4035,	2413,	3840,	4329,	6918,	7163,
6,	3145,	2774,	2410,	2606,	2740,	2321,	1393,	2202,	2386,	3821,
7,	1527,	1718,	1349,	1193,	1392,	1588,	1350,	805,	1225,	1329,
8,	1531,	850,	856,	683,	650,	820,	939,	793,	456,	695,
9,	581,	861,	428,	439,	376,	386,	488,	556,	453,	261,

YEAR,	1985,	1986,	1987,	1988,	1989,	1990,	1991,	1992,	1993,	1994,
AGE										
1,	26575,	29947,	24098,	21306,	23627,	18269,	19298,	33853,	47221,	5329,
2,	34810,	21741,	24483,	19707,	17413,	19308,	14929,	15769,	27687,	38627,
3,	20294,	26967,	16097,	18460,	14207,	12512,	13859,	10671,	11993,	21274,
4,	13318,	13497,	15132,	9671,	9369,	7121,	6247,	6811,	6623,	7734,
5,	6841,	7630,	5775,	7280,	3482,	3303,	2494,	2129,	3465,	3599,
6,	4465,	4147,	3619,	3023,	2986,	1403,	1323,	976,	1168,	2010,
7,	2396,	2725,	1991,	1913,	1259,	1222,	571,	527,	540,	682,
8,	844,	1482,	1341,	1074,	822,	532,	514,	235,	297,	321,
9,	444,	526,	739,	731,	469,	353,	227,	215,	134,	178,

TABLE 5. The Separable VPA diagnostic file : Fishing mortality at age residuals $F_{sep} - F_{vpa}$

Run title : Blackfin: VPA course. Combined sex; plusgroup.

At 4/02/2002 13:49

Traditional vpa Terminal populations from weighted Separable populations

Fishing mortality residuals **(11)**

YEAR,	1963,	1964,
AGE		
1,	-.0004,	-.0005,
2,	-.0146,	-.0297,
3,	.0279,	.0943,
4,	.0290,	.0800,
5,	.0428,	.1343,
6,	.0936,	.1175,
7,	.0267,	.0964,
8,	.0998,	-.0398,
9,	-.0001,	-.0770,

YEAR,	1965,	1966,	1967,	1968,	1969,	1970,	1971,	1972,	1973,	1974,
AGE										
1,	-.0008,	-.0006,	-.0006,	-.0004,	-.0006,	-.0004,	-.0009,	.0009,	.0110,	.0283,
2,	-.0432,	-.0341,	-.0257,	-.0283,	-.0272,	-.0290,	-.0468,	.1067,	.2717,	.0714,
3,	-.0266,	.1068,	.0289,	.0290,	.0034,	.0326,	-.1323,	.2160,	.2777,	.1916,
4,	.2021,	.2250,	.1609,	.1350,	.1913,	.0765,	-.0277,	.0198,	.0755,	-.1908,
5,	.0783,	.2679,	.1129,	.1591,	.1665,	.1519,	.0486,	-.0135,	-.0310,	.0157,
6,	.1070,	.0589,	-.0480,	.0125,	.0109,	.0982,	.0035,	-.1752,	-.1961,	-.2443,
7,	.1271,	-.0142,	.0589,	-.0145,	.0417,	.0025,	.0285,	-.1501,	-.1558,	-.0848,
8,	-.0367,	-.0956,	-.0333,	-.0396,	-.0544,	-.0272,	.0799,	-.1153,	-.1325,	.4567,
9,	.0179,	-.1046,	-.0827,	-.0895,	-.1205,	-.0908,	-.0412,	-.1727,	-.0385,	.1902,

YEAR,	1975,	1976,	1977,	1978,	1979,	1980,	1981,	1982,	1983,	1984,
AGE										
1,	.0000,	.0009,	.0080,	.0009,	-.0005,	.0007,	.0047,	.0002,	-.0001,	.0033,
2,	.0352,	.0640,	.0076,	.3033,	.0027,	-.0035,	.0473,	-.0081,	.0563,	.0557,
3,	.2204,	.2392,	.0812,	.2857,	.0250,	.0940,	.1001,	.0418,	.0504,	.1202,
4,	-.0877,	-.2230,	-.1983,	-.1063,	-.0957,	-.1967,	-.0833,	-.2252,	-.1775,	-.0556,
5,	-.1004,	.0292,	-.0446,	-.0816,	.0220,	-.0408,	-.1525,	-.0222,	-.2100,	-.1209,
6,	-.0639,	-.0452,	-.0263,	-.0631,	-.0042,	.0157,	-.0409,	-.0744,	.0272,	-.0407,
7,	.1529,	-.0262,	-.0138,	-.0578,	.0065,	.0644,	-.0024,	.1648,	.1367,	.0286,
8,	.0640,	.1049,	.0891,	-.0186,	.0000,	-.0252,	-.0003,	.0623,	.0758,	.0009,
9,	.0322,	.2737,	.2788,	.0480,	.2256,	-.0363,	.0429,	-.0602,	-.0742,	-.0013,

YEAR,	1985,	1986,	1987,	1988,	1989,	1990,	1991,	1992,	1993,	1994,
AGE										
1,	-.0005,	.0073,	-.0011,	-.0007,	-.0008,	.0017,	.0070,	-.0001,	-.0006,	.0000,
2,	.0189,	-.0520,	-.0009,	.0495,	-.0817,	-.0376,	-.0382,	-.0101,	.0400,	.0320,
3,	.0540,	-.0342,	-.1207,	-.0535,	.1552,	.0974,	-.1675,	-.0806,	.0457,	-.0245,
4,	-.0807,	.2578,	.1391,	-.3023,	.1797,	-.0166,	-.1465,	.0835,	.1354,	-.0599,
5,	-.0415,	.1066,	.0874,	-.1098,	.0475,	-.1022,	-.0419,	.1664,	.0877,	-.0316,
6,	.0337,	-.1107,	.0810,	-.0406,	.0242,	-.0403,	.0209,	.0732,	-.0344,	-.0245,
7,	.0417,	.0102,	.0263,	.1365,	-.1690,	-.0099,	.2553,	-.1015,	-.0620,	.0055,
8,	.0119,	-.0555,	.0355,	.3017,	-.1005,	.0514,	.0365,	-.0362,	-.0904,	.0540,
9,	-.0012,	-.0364,	.0232,	-.0127,	-.1568,	-.1111,	-.0680,	-.0554,	.0545,	.1220,

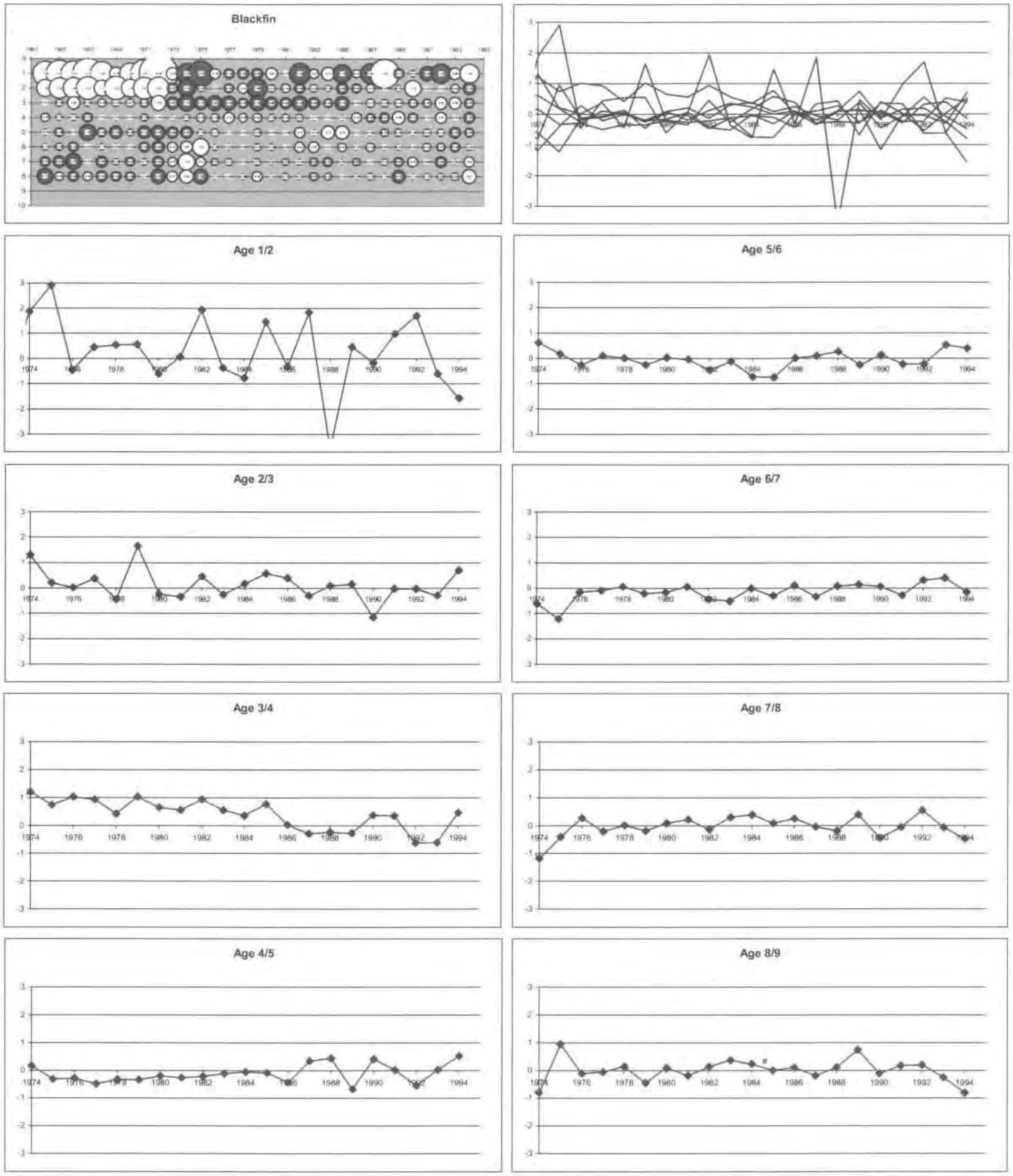


Fig. 4. The Separable VPA log catch ratio residuals illustrated using three diagnostic plotting approaches: bubble plots (solid circles positive) and time series plots of residuals at all ages and each age independently.

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Appendix 1: The Lowestoft Stock Assessment Suite

Tutorial 3

Ad hoc VPA tuning

by

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Abstract

This document is the third in a series of tutorials designed to assist users of the Lowestoft VPA Suite assessment software and prediction programs that utilize the results. The tutorial takes the user through the options required for running the Laurec-Shepherd and Hybrid *ad hoc* VPA tuning algorithms.

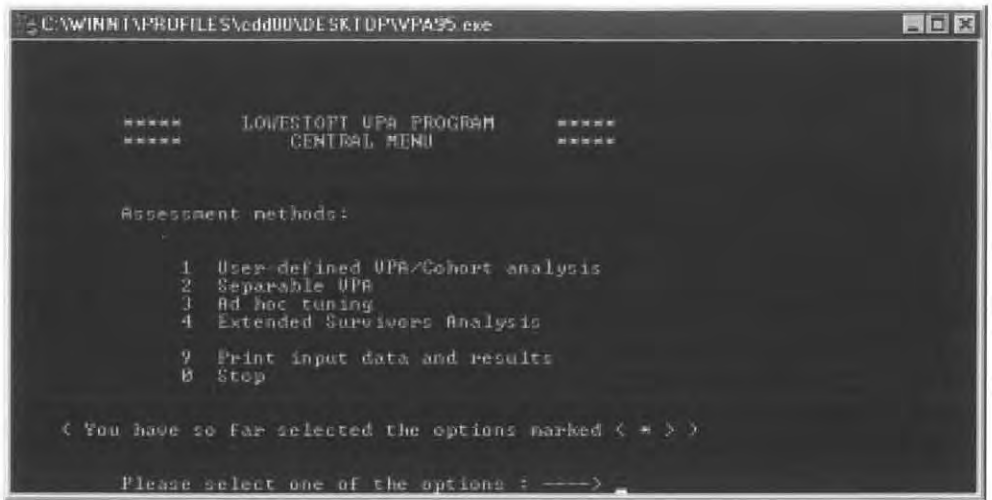
Introduction

This tutorial assumes that the user has installed the VPA program described in Darby and Flatman (1994), that the required data files have been placed in a directory c:\vpas\data and that the assessment index file (Blackfin.ind) contains path names which point to the appropriate files. This tutorial also assumes that the user has either read Tutorial 1which covers reading and selection of input data, or has previous experience of running the program.

In the following text **action to be taken by the user** is highlighted in bold. The symbol ↵ is used to represent the Return or Enter key on the keyboard.

Ad hoc VPA Tuning

Open the program and read in the index file C:\VPAS\DATA\BLACKFIN.IND. Take the default year, age and summary mean settings until the main menu is reached.

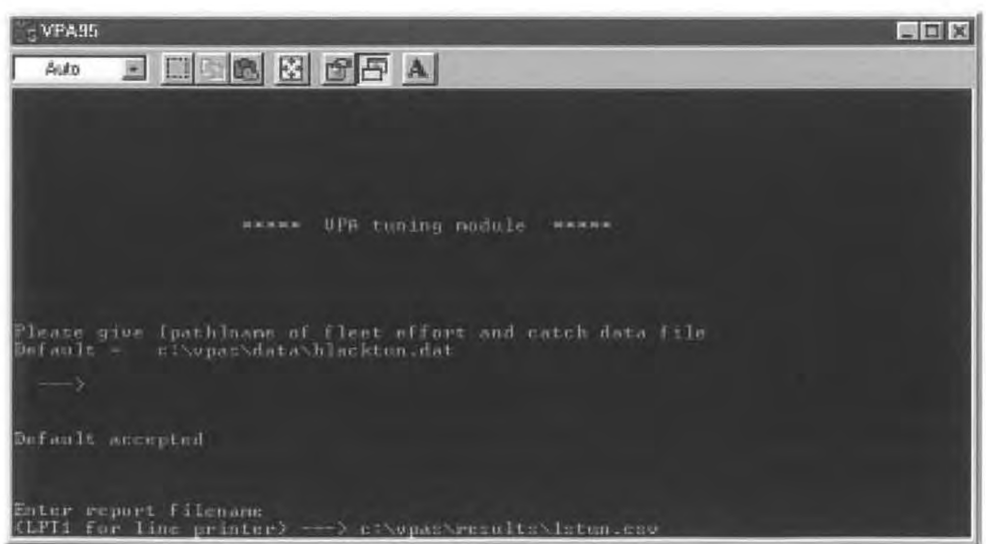


At the main menu **Type 3 ↵** to select *Ad hoc* VPA tuning.

The first two questions require input of the names for the data file containing the catch and effort data that will be used to calibrate the VPA and the diagnostics output file into which will be written the results of the calibration analysis.

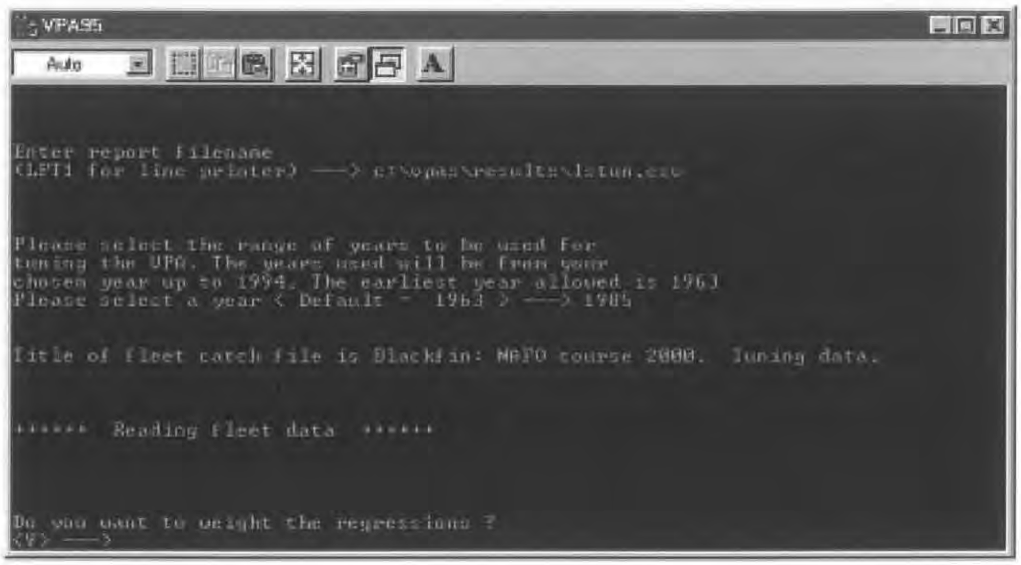
Type ↵ to take the default filename which has been read from the assessment index file

Type a path and filename for the tuning diagnostics output file.



We now have to select the range of data years from the index series to which we wish to fit the VPA. Current "accepted wisdom" is to take the last ten years of data. In general it is expected that catchability will have altered over a longer period.

Type 1985 ↵



The data file title is printed for cross-reference.

We are then asked whether we wish to apply a time series weighting to the model, down weighting the influence of historic tuning data in the fitted model. The models available are discussed in Darby and Flatman (1994). Since we have only taken ten years of tuning data for the calibration model we shall not down-weight historic data.

Type No ↵ , N ↵ or n ↵

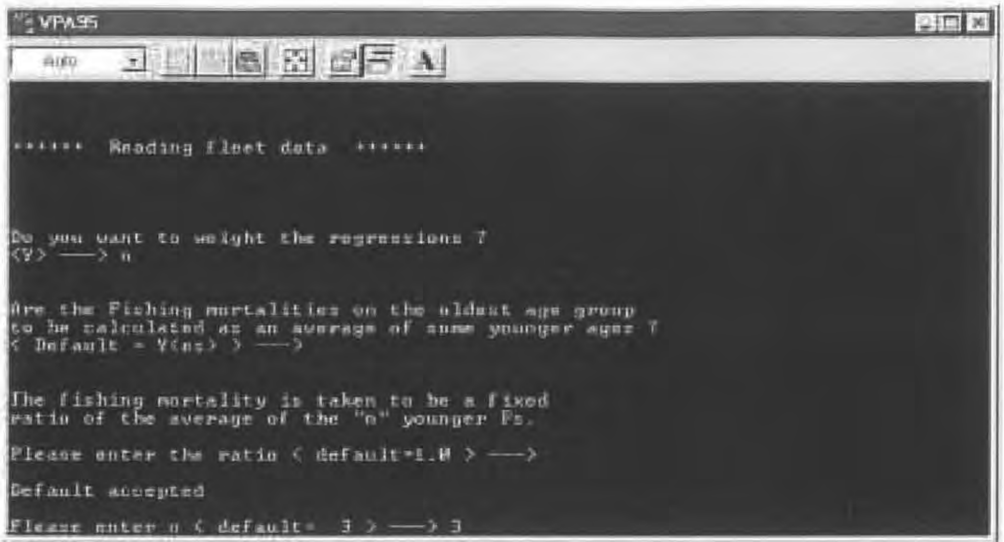
During the selection of the range of ages to be used in the assessment we used the default settings provided by the program, that is ages 1–10+. We have therefore opted for age 9 as the oldest true age.

In order to reduce the number of parameters that are estimated during the calibration of the VPA the *ad hoc* algorithms make the assumption that the fishing mortality at the oldest true age is a function (arithmetic mean) of the values calculated at younger ages in the same year. The program requires the number of ages over which we wish to calculate the average mortality and a scalar multiplier to be applied to that average (for example a value of 0.5 would apply half of the average fishing mortality). In this example we will calculate the fishing mortality at age 9 as the arithmetic mean of the values at ages 6, 7 and 8. Therefore the number of ages is 3 and the multiplier 1.0.

Type Yes ↵, Y ↵ or y ↵ to calculate the fishing mortalities as an average of younger ages

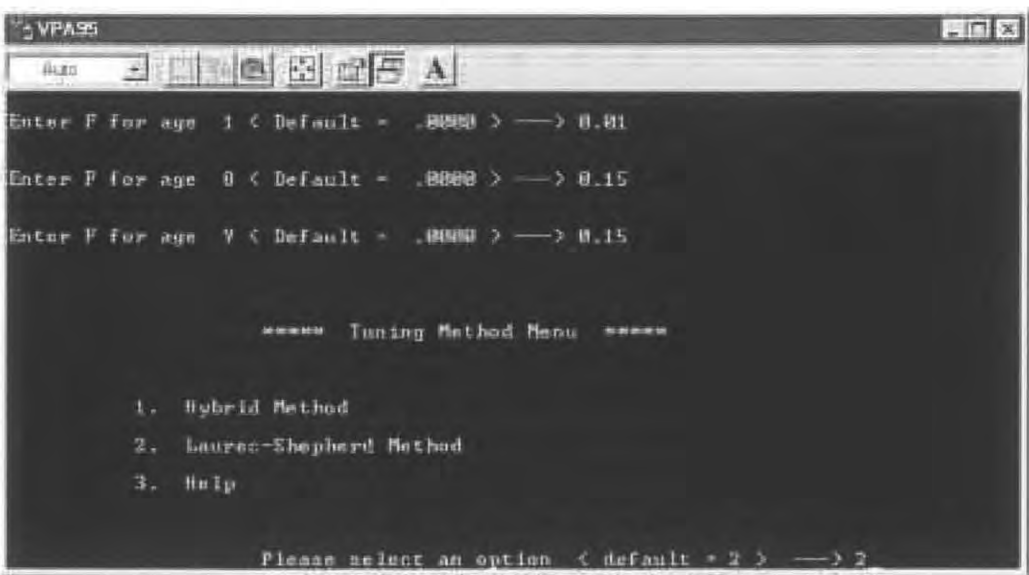
Type 1.0 ↵ for the scalar.

Type 3 ↵ for the number of ages used for the average fishing mortality.



Examination of the calibration data set C:\VPAS\DATA\BLACKFIN\BLACKTUN.DAT reveals that the final year cpue data value at ages 1, 8 and 9 is zero. Zero cpue values are considered to be missing data. Unlike XSA, the *ad hoc* algorithms do not use information from catches taken from the cohort at younger ages in the estimation of the terminal population; only final year cpue values are used. Therefore, in order to estimate the fishing mortality at these ages in the final VPA year, a similar constraint to that at the oldest ages is applied. The algorithm known as shrinkage is described later; but here we are required to supply starting estimates for the fishing mortality at the ages with missing data. The starting values will be replaced by shrinkage estimates in the fitted model.

Type the starting values 0.01 ↵, 0.15 ↵, 0.15 ↵



For the initial run we shall fit the constant catchability Laurec-Shepherd model to the data

Type 2 ↵

The program requires a threshold to be set for the minimum number of non-zero cpue values that are used for the calculation of catchability at each age. If, for any age, the fleet data set contains fewer values than the threshold, the fleet data will not be used in the overall weighted mean for the age. The recommended (default) value for the minimum number of data points is 5. This should prevent the assessment from being dominated by estimates from series with low standard errors, associated with small numbers of data points.

Type ↵ to take the default value for the minimum number of data points

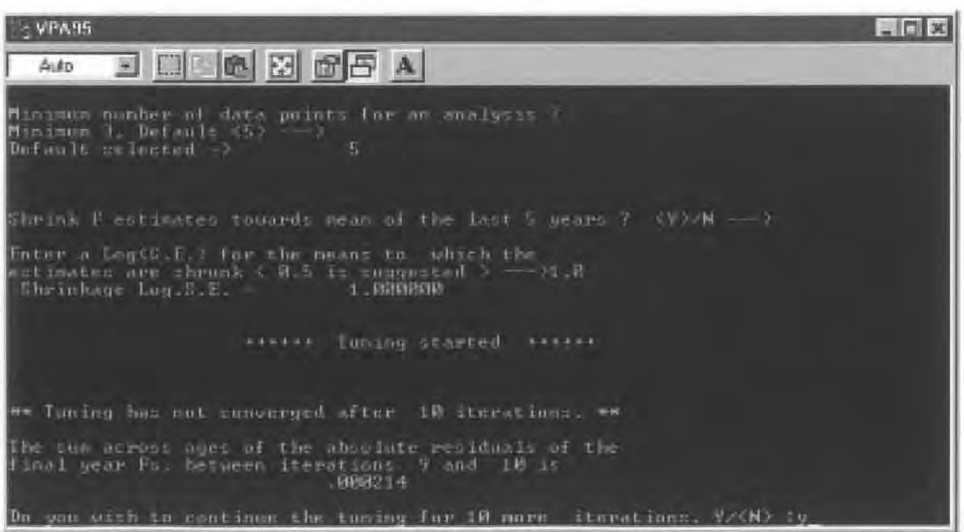
As described previously, we do not have calibration data for the final year at ages 1, 8, 9. Therefore we will use the average fishing mortality calculated over the preceding 5 years for the final year F at those ages, a constraint commonly called shrinkage.

Shrinkage is a constraint on the estimates derived from a time series of observations. The procedure can be described as making the assumption that, if a time series is being used to predict the current value of a particular parameter, e.g. F-at-age, and no major changes are known to have taken place, then as an initial starting value for the estimate, a mean of recent values of the parameter is appropriate. For the ages where we have no calibration information from the cpue series, we can only use the mean of the last few years. This is equivalent to the assumption used to estimate F at the oldest ages as an average of the values at younger ages. A more comprehensive description of the rationale behind shrinkage is given in Darby and Flatman (1994).

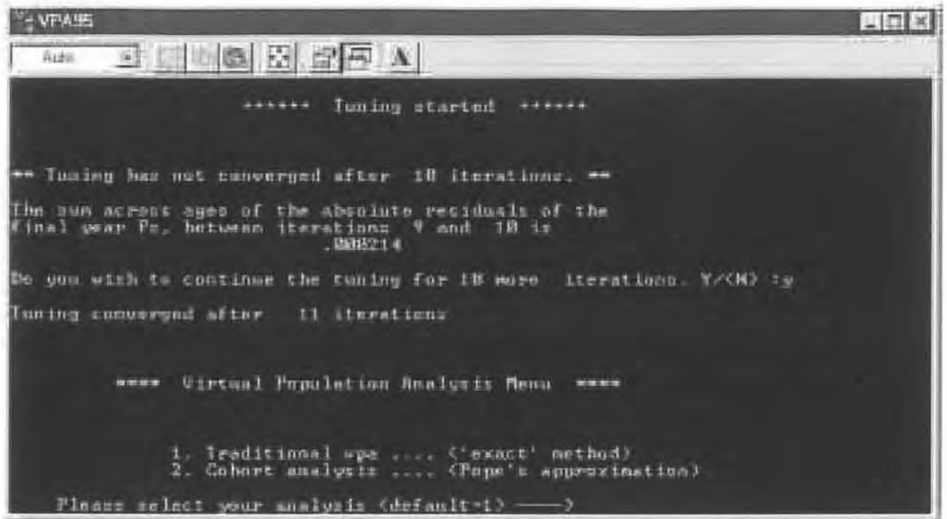
When using shrinkage at ages where fishing mortality estimates from the fleet tuning data series are available, the final year mortality is a weighted average of the estimates from the fleet series and the historic average fishing mortality. The weights for the fleet derived estimates are taken from the inverse of the variance of catchability at that age. The user must enter a weight for the average F. The value is given relative to the standard error of the log catchabilities; an approximation to the c.v. of the catchability. A shrinkage weight of 1.0 is a reasonable value for this data set (a 100% coefficient of variation). The estimate can be refined using retrospective analysis procedures to examine the influence of its magnitude on the consistency of the assessment estimates.

Type y ↵ to use shrinkage
Type 1.0 ↵ for the log standard error weight

This completes the specification of the *ad hoc* tuning algorithm and the program begins to fit the model. The algorithm runs for 10 iterations. If convergence of the final year F values has not been achieved after 10 iterations then the program seeks guidance as to whether to continue further, in batches of 10 iterations.



Type Y ↵, y ↵ or yes ↵ to continue the model fitting



There is no change in the terminal year fishing mortality values after 11 iterations and the calibration algorithm is complete. The program now offers a choice as to the method of calculation of the cohort population numbers and fishing mortalities at age: Exact VPA or cohort analysis.

Type y ↵ to use the default Exact VPA.

The program returns to the central menu. Note that we have calibrated the VPA using an *ad hoc* tuning algorithm (denoted by the star) and that we have a tuning diagnostics file for the Laurec-Shepherd method. However, we do not have tables of population numbers, SSB or fishing mortality at age; they are only printed after selecting option 9.

The *Ad hoc* Tuning Diagnostics file

The results from the current run should be in the file c:\vpas\results\lstun.csv. The file can be opened in a text editor word processing or spreadsheet package. The file lists the tuning data file used in the run, the selected range of ages, years and the model options chosen by the user.

Table 1 presents the results for the converged run. In the following text bold numbers **(x)** refer to labels added to the table. The file listing contains the date and time at which the run was performed, the tuning file used for calibrating the VPA **(1)**, a record of the selected assessment options **(2)**, and the convergence results **(3)**. If convergence was not achieved, the final year fishing mortality estimates from the last two iterations are printed. The fishing mortality values will indicate the ages that are varying between iterations and the degree of variation.

Examine the fishing mortality values resulting from the run **(4)**. Check for extreme values, especially those at the older ages that generally result from noise in poor quality catch at age or calibration data. This would indicate that the ages might better be incorporated into the plus group.

Examine the log catchability residuals for each age for all fleets **(5)**. An incidence of 99.99 indicates a missing (zero) fleet catch at age value. The values can indicate changes in the stock – fleet interactions. Look for year effects running down the columns, age effects across the rows and year class effects that follow the cohort diagonals. Recent and sudden changes in catchability may require removal of the fleet from the assessment. For each age, plots of the residuals against time can be used to reveal trends in log catchability. One way to achieve this is to give the tuning output file a comma separated file name extension (.csv) and import it into a spreadsheet package (Fig. 1, 2, 3, 4).

Note: If only one fleet data set is available and the Laurec-Shepherd constant log catchability model is used without shrinkage to the mean, the residuals in the final year will all be 0.0; the terminal F values are generated using the fleet's average catchability for the age. If shrinkage to the mean is selected or the assessment is tuned with more than one fleet, F in the final year is a weighted mean. The estimate of catchability derived for each age will differ from the fleet's mean and the final year residuals will not be zero.

The significance of any trends in time in log catchability noted from the residual tables can be tested using the diagnostics presented in the summary statistics **(6)**. As a quick check, look at the slope of the log catchabilities for each age **(8)**, for each fleet separately. Slopes which exceed twice their standard error consistently, for most of the important age groups, are considered significant and indicate that the assumption of constant catchability used to fit the model may not be correct. Changes in the sign of the slope across ages usually indicate noise in the data.

If there are significant trends in the catchability of the fleets then the use of the Hybrid model could be appropriate. This model allows trends in catchability for selected fleets. If it is used, constant catchability should be maintained for as many fleets as possible. Remember that these are log catchabilities and that a trend with time indicates an exponential trend in catchability.

Examine the mean log catchability (pred. log q) and its standard error for each age and fleet **(7)**. The standard error of the log catchability is an indicator of the quality of the data (a fractional coefficient of variation). Values greater than 0.5 indicate problems with that age for the fleet. High standard errors for the older ages of all fleets indicate that the assessment should probably be re-run with the problem ages incorporated into a younger plus group.

When combining fleet-derived estimates of terminal F at each age, weighting by the inverse of the prediction variance of the log catchability will reduce the influence of poor fleet data. However, if for any fleet, the standard errors of the majority of the important ages are poor, the user may wish to remove the fleet from the analysis altogether.

The estimate of the partial F contributed by the fleet **(9)** and the raised F **(10)** are printed. Raised F's are the individual fleet predictions of overall F: the level that would have been recorded if the fleet had taken the whole of the international catch for that age. The values can be used to identify incompatible predictions from the individual fleet data sets.

For each age, the overall weighted mean terminal F is printed **(11)** along with its internal (SIGMA(int)) and external (SIGMA(ext)) log standard errors. Also given is the overall standard error (SIGMA(overall) **(12)**; it is the larger of the internal and external values.

The internal standard error for an age is calculated from the (prediction) standard errors of the fleet's final year log catchabilities; it corresponds to the within samples variance. The external standard error is calculated from the scatter of the logarithms of the raised F values; it corresponds to the between samples variance (Topping, 1978). If shrinkage to the mean has been selected, the internal and external standard errors include the F shrinkage value.

SIGMA(overall) is a good approximation to the fractional coefficient of variation of the mean F and should be used as a measure of the accuracy of the prediction. If it is large (greater than 0.3) for important age groups, then the assessment should be treated with caution.

If the values of the internal and external standard errors differ significantly, there is a discrepancy between the fleet estimates for overall F (the raised F's **(10)**). The variance ratio **(13)**, (external s.e.)^2/(internal s.e.)^2, may be tested as an F statistic with n and n -1 degrees of freedom, where n is the number of fleets contributing a raised F estimate. Values exceeding 3 imply conflicting signals from the fleets. Too small a value implies an unexpected correspondence of the tuning fleets in relation to the inherent noise.

Figures 1–4 present diagnostic plots for the fleets used to fit the Blackfin Laurec-Shepherd calibration model. In each figure the top left hand plot is a bubble plot of the log catchability residuals. This format is useful for looking for year and age effects in the estimates of log catchability. The top right plot presents the log catchability residuals as a time series for all ages together. Individual trends in log catchability at age are separated in the lower plots.

It is relatively obvious from the residual plots that the model assumption of constant catchability in time is being violated by the calibration series used in this fit.

- The Otter trawl residuals show a strong increase in the early period of the time series and a downward trend in recent years.
- The light trawl data are constant in time with no obvious pattern but are noisy.
- The prawn trawl cpue series shows a strong decrease in time.
- The seine data shows a strong increase in catchability in the recent years.

The trends in catchability are carried forward into differences in the estimates of terminal year fishing mortality derived from the four cpue series. Where a fleet has an increasing trend in catchability the assumption of constant catchability induces an under-estimate of the terminal fishing mortality. A downwards trend results in an over estimate of catchability. In the summary diagnostics for each age the difference is clearly illustrated at age 4. The two fleets with strong trends have marked differences in their estimates of the final year fishing mortalities (raised F). Fleet 3, the prawn trawlers, which have a downward trend in q contribute a terminal F estimate of 0.48 to the overall mean. Fleet 4, the seine netters, have an upward trend and F is consequently underestimated (0.05). The trends in residuals result in the estimates from these fleets having a high standard error in log catchability and they are therefore down-weighted in the final inverse-variance weighted estimate of fishing mortality.

In general the fitting of an assessment model to data series that violate the assumptions of the model is not ideal, and the fleets could be excluded from the model fit. Alternatively the Hybrid model, which is also available within the Lowestoft package, can be used to fit trends in time to the log catchability series. If this is carried out the fleet estimates of terminal fishing mortality are more consistent.

References

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POPE, J. G., and J. G. SHEPHERD. 1985. A comparison of the performance of various methods for tuning VPA's using effort data. *ICES J. Cons.*, **42**: 129–151.

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TABLE 1. The tuning diagnostic file for Laurec Shepherd tuning.

Lowestoft VPA Version 3.1

7/09/2000 23:31

Blackfin: VPA course. Combined sex; plusgroup.

CPUE data from file c:\vpas\data\blacktun.dat (1)

Catch data for 32 years. 1963 to 1994. Ages 1 to 10.

Fleet		First year	Last year	First age	Last age
Otter traw	1	1985	1994	2	6
Light trawl		1985	1994	2	7
Prawn trawl		1985	1994	2	4
Seine		1985	1994	2	5

Disaggregated Qs (2)
Log transformation
The final F is the (reciprocal variance-weighted) mean of the raised fleet F's.

No trend in Q (mean used)
Terminal Fs derived using L/S (with F shrinkage)

Shrinkage Log S.E = 1.000
Tuning converged after 11 iterations (3)

Regression weights

1	1	1	1	1	1	1	1	1	1

Oldest age F = 1.000*average of 3 younger ages.

Missing catch or tuning data at age 1 8 9

Fishing mortalities (4)

Age	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	0.000	0.008	0.000	0.001	0.001	0.003	0.011	0.001	0.001	0.010
2	0.073	0.047	0.078	0.172	0.048	0.084	0.091	0.076	0.159	0.208
3	0.261	0.339	0.182	0.405	0.621	0.581	0.301	0.181	0.355	0.186
4	0.276	0.900	0.657	0.495	0.927	0.769	0.704	0.459	0.487	0.237
5	0.259	0.652	0.527	0.559	0.692	0.499	0.591	0.530	0.319	0.144
6	0.337	0.424	0.517	0.619	0.667	0.555	0.515	0.354	0.274	0.115
7	0.324	0.544	0.445	0.776	0.471	0.572	0.667	0.157	0.179	0.169
8	0.270	0.447	0.477	0.936	0.539	0.649	0.549	0.185	0.115	0.150
9	0.311	0.471	0.480	0.777	0.559	0.592	0.577	0.232	0.189	0.145

TABLE 1 (Cont'd). The tuning diagnostic file for Laurec Shepherd tuning.

Log catchability residuals **(5)**

Fleet: Otter trawl

Age	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2	0.91	1.32	-1.01	0.33	-1.12	-1.6	1.14	0.05	0.16	-0.18
3	-1.65	-0.05	-1.52	0.29	0.88	1.38	0.56	0.11	0.08	-0.08
4	-2.4	-1.07	-0.24	0.28	0.61	2.49	1.19	0.08	-1.32	0.38
5	-2.82	-1.4	-1.10	0.67	0.34	2.74	1.63	0.72	-1.26	0.47
6	-1.54	-1.1	-0.56	-0.27	0.65	2.42	0.76	0.43	-0.55	-0.25
7	No data for this fleet at this age									

Fleet: Light trawl

Age	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2	-0.41	-1.16	0.97	0.32	-0.97	0.05	0.35	0.13	0.6	0.12
3	0.34	0.17	-0.50	-0.36	0.34	0.63	-0.24	-0.35	0.02	-0.04
4	0.47	0.64	-0.87	-0.79	-0.18	0.91	0.59	-0.1	-0.77	0.10
5	-0.80	0.75	-0.47	0.39	-0.40	0.36	1.10	0.15	-1.26	0.17
6	0.17	-0.39	-0.49	-0.65	0.12	0.11	0.49	0.02	0.37	0.26
7	-0.79	-0.01	-0.23	-1.09	-0.10	0.73	0.70	-0.19	0.60	0.37

Fleet: Prawn trawl

Age	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2	0.84	0.59	0.95	1.12	-1.11	0.29	-0.34	0.00	-0.76	-1.58
3	1.70	2.62	0.54	-1.39	1.46	-0.67	-0.89	-1.36	-1.19	-0.81
4	1.12	0.75	0.06	-1.94	0.19	1.13	0.13	-0.23	-0.49	-0.71
5	No data for this fleet at this age									
6	No data for this fleet at this age									
7	No data for this fleet at this age									

Fleet: Seine

Age	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2	-2.08	-1.16	0.48	-0.68	-1.43	-1.34	0.75	1.58	1.92	1.96
3	-0.87	-0.28	-1.56	-0.63	-0.29	-0.24	0.49	0.67	1.19	1.52
4	-0.56	0.67	-1.65	-0.82	-0.55	-0.41	0.27	1.48	-0.04	1.61
5	-1.67	1.10	-1.93	0.22	-1.31	-0.13	0.24	1.70	0.26	1.53
6	No data for this fleet at this age									
7	No data for this fleet at this age									

SUMMARY STATISTICS FOR AGE 2 **(6)**

Fleet	Pred **(7)** log q	se (log q)	Partial F **(9)**	Raised F **(10)**	Slope **(8)**	se Slope	Intrcpt	se Intrcpt
1	-14.93	1.041	0.0009	0.2483	-6.44E-02	1.14E-01	-14.928	0.314
2	-16.23	0.702	0.0156	0.1844	8.51E-02	7.21E-02	-16.230	0.212
3	-18.79	0.971	0.0026	1.0100	-2.36E-01	6.88E-02	-18.793	0.293
4	-15.81	1.594	0.0029	0.0294	4.11E-01	1.02E-01	-15.806	0.481

Fbar **(11)**	Sigma(int.)	Sigma(ext.)	Sigma(overall)	Variance ratio
0.208	0.476	0.5	0.5 **(12)**	1.102 **(13)**

TABLE 1 (Cont'd). The tuning diagnostic file for Laurec Shepherd tuning.

SUMMARY STATISTICS FOR AGE 3

Fleet	Pred. log q	se (log q)	Partial F	Raised F	Slope	se Slope	Intrcpt	se Intrcpt
1	-14.10	0.997	0.0021	0.2009	1.49E-01	9.78E-02	-14.099	0.301
2	-15.54	0.386	0.0312	0.1943	-1.87E-02	4.24E-02	-15.538	0.116
3	-19.11	1.536	0.0019	0.4181	-3.60E-01	1.14E-01	-19.107	0.463
4	-15.53	1.002	0.0038	0.0408	2.81E-01	5.08E-02	-15.529	0.302

Fbar	Sigma(int.)	Sigma(ext.)	Sigma(overall)	Variance ratio
0.186	0.331	0.288	0.331	0.757

SUMMARY STATISTICS FOR AGE 4

Fleet	Pred. log q	se (log q)	Partial F	Raised F	Slope	se Slope	Intrcpt	se Intrcpt
1	-14.69	1.439	0.0012	0.1618	1.78E-01	1.47E-01	-14.689	0.434
2	-15.73	0.683	0.0257	0.2136	-2.47E-02	7.55E-02	-15.735	0.206
3	-19.82	0.971	0.0009	0.4832	-1.18E-01	9.97E-02	-19.822	0.293
4	-15.71	1.078	0.0032	0.0475	2.04E-01	9.60E-02	-15.714	0.325

Fbar	Sigma(int.)	Sigma(ext.)	Sigma(overall)	Variance ratio
0.237	0.469	0.397	0.469	0.716

SUMMARY STATISTICS FOR AGE 5

Fleet	Pred. log q	se (log q)	Partial F	Raised F	Slope	se Slope	Intrcpt	se Intrcpt
1	-14.98	1.719	0.0009	0.0895	2.73E-01	1.65E-01	-14.979	0.518
2	-16.31	0.758	0.0145	0.1214	3.67E-03	8.44E-02	-16.307	0.229
3	No data for this fleet at this age							
4	-16.45	1.347	0.0015	0.0313	2.56E-01	1.20E-01	-16.45	0.406

Fbar	Sigma(int.)	Sigma(ext.)	Sigma(overall)	Variance ratio
0.144	0.617	0.326	0.617	0.279

SUMMARY STATISTICS FOR AGE 6

Fleet	Pred. log q	se (log q)	Partial F	Raised F	Slope	se Slope	Intrcpt	se Intrcpt
1	-14.72	1.178	0.0011	0.1473	1.54E-01	1.19E-01	-14.72	0.355
2	-16.46	0.401	0.0124	0.0893	7.31E-02	3.65E-02	-16.46	0.121
3	No data for this fleet at this age							
4	No data for this fleet at this age							

Fbar	Sigma(int.)	Sigma(ext.)	Sigma(overall)	Variance ratio
0.115	0.38	0.143	0.38	0.142

SUMMARY STATISTICS FOR AGE 7

Fleet	Pred. log q	se (log q)	Partial F	Raised F	Slope	se Slope	Intrcpt	se Intrcpt
1	No data for this fleet at this age							
2	-16.54	0.648	0.0115	0.1165	1.28E-01	5.62E-02	-16.541	0.195
3	No data for this fleet at this age							
4	No data for this fleet at this age							

Fbar	Sigma(int.)	Sigma(ext.)	Sigma(overall)	Variance ratio
0.169	0.648	0	0.648	0

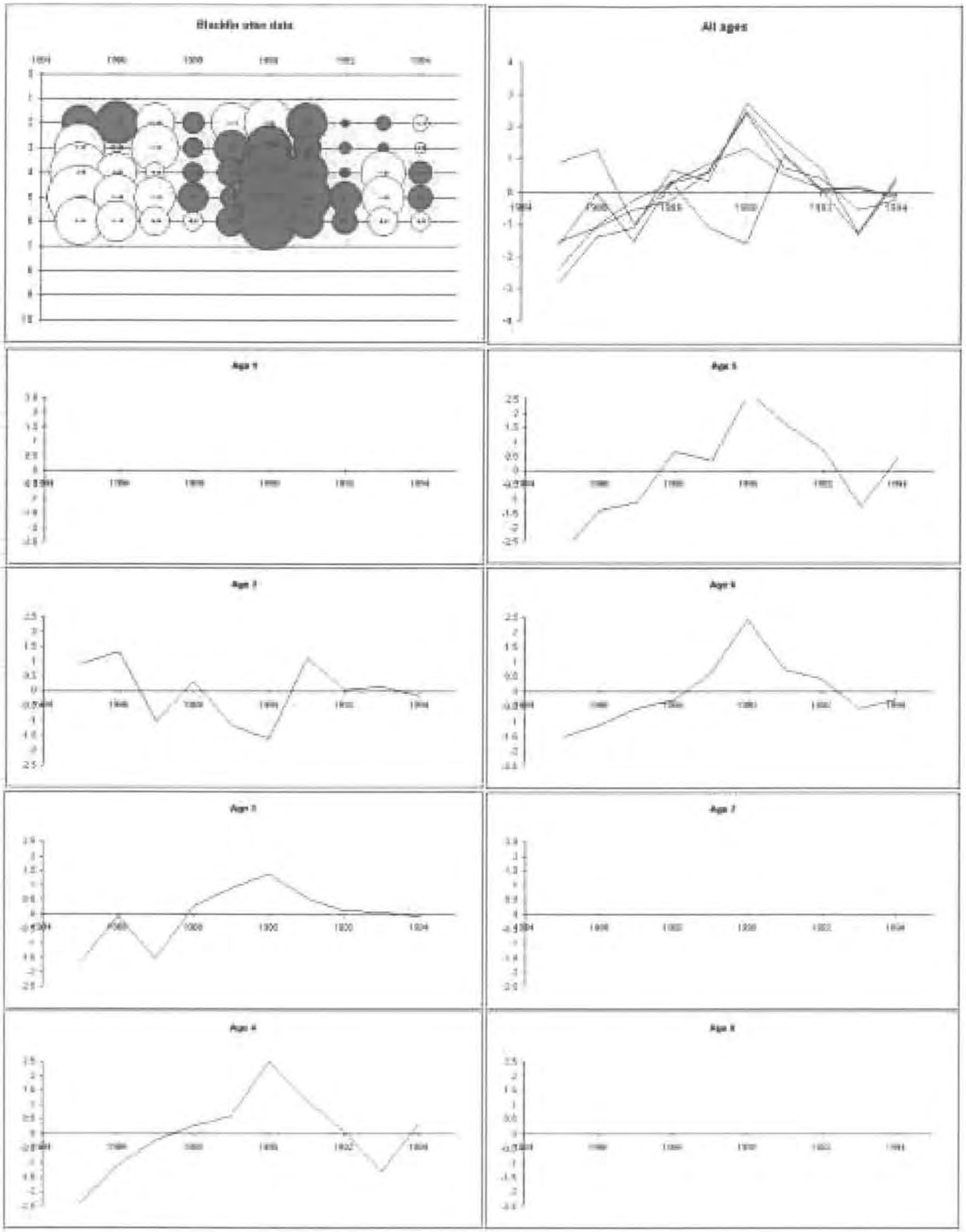

Fig. 1. The log catchability residuals for the Blackfin Otter trawl calibration data set.

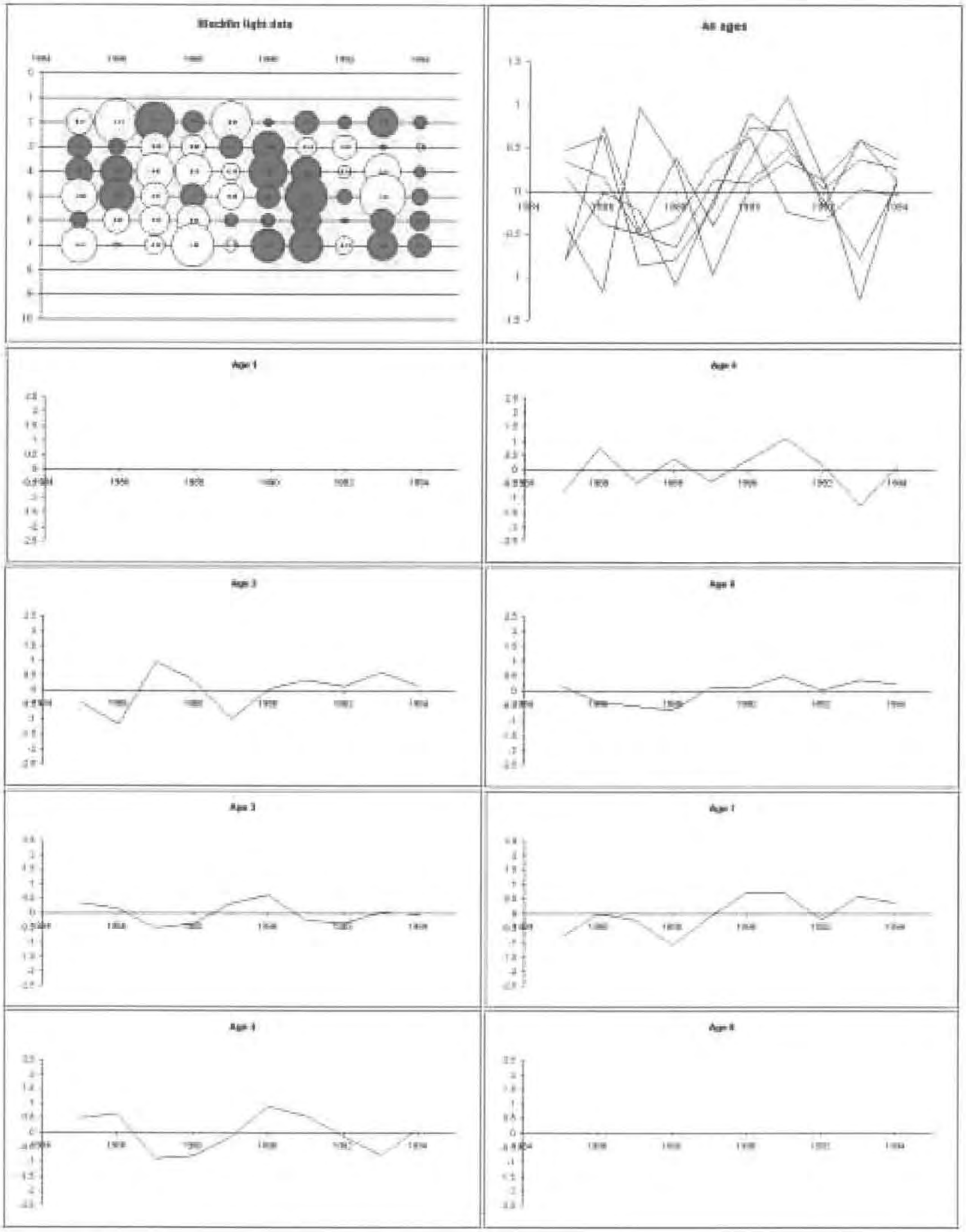

Fig. 2. The log catchability residuals for the Blackfin light trawl calibration data set.

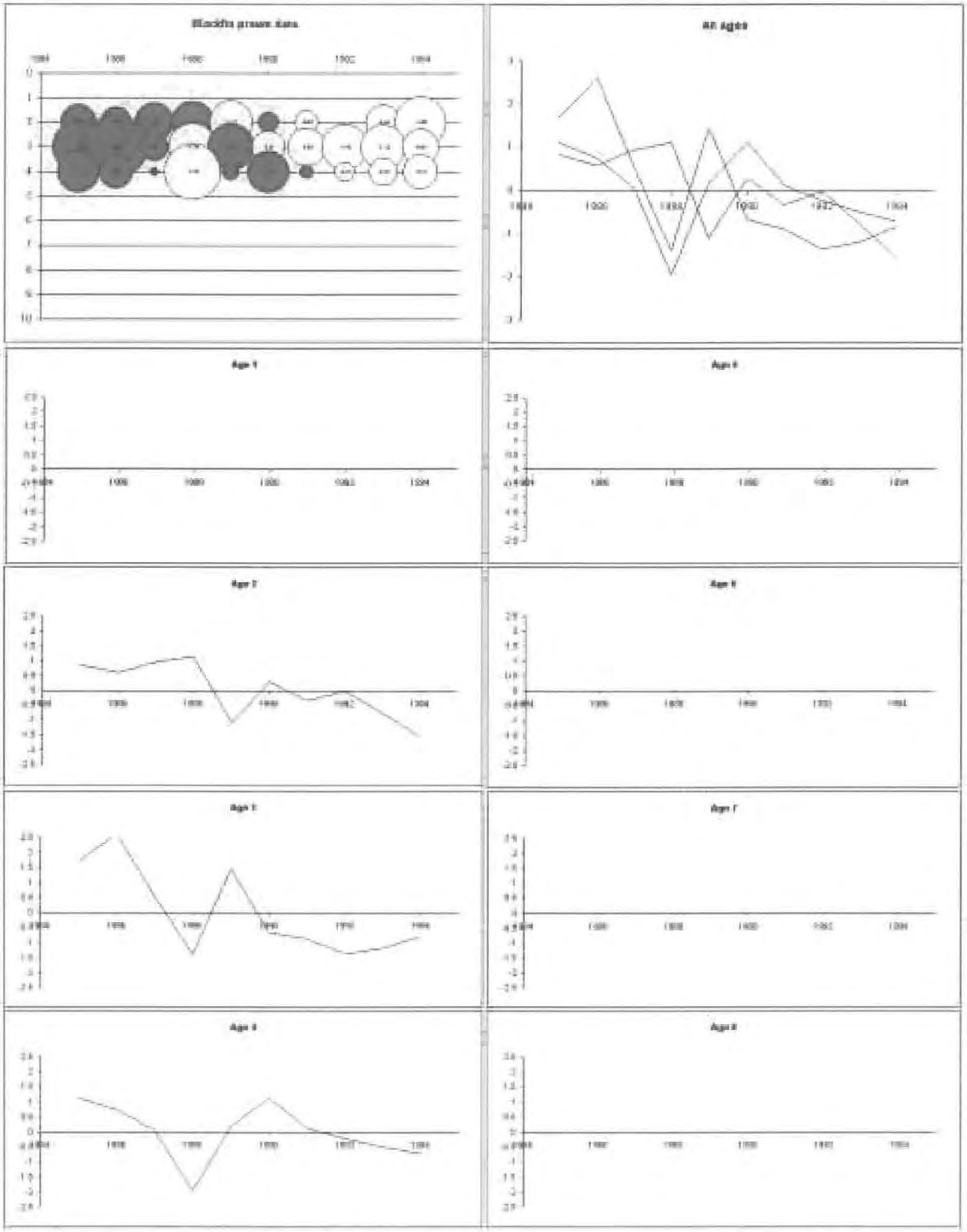

Fig. 3. The log catchability residuals for the Blackfin prawn trawl calibration data set.

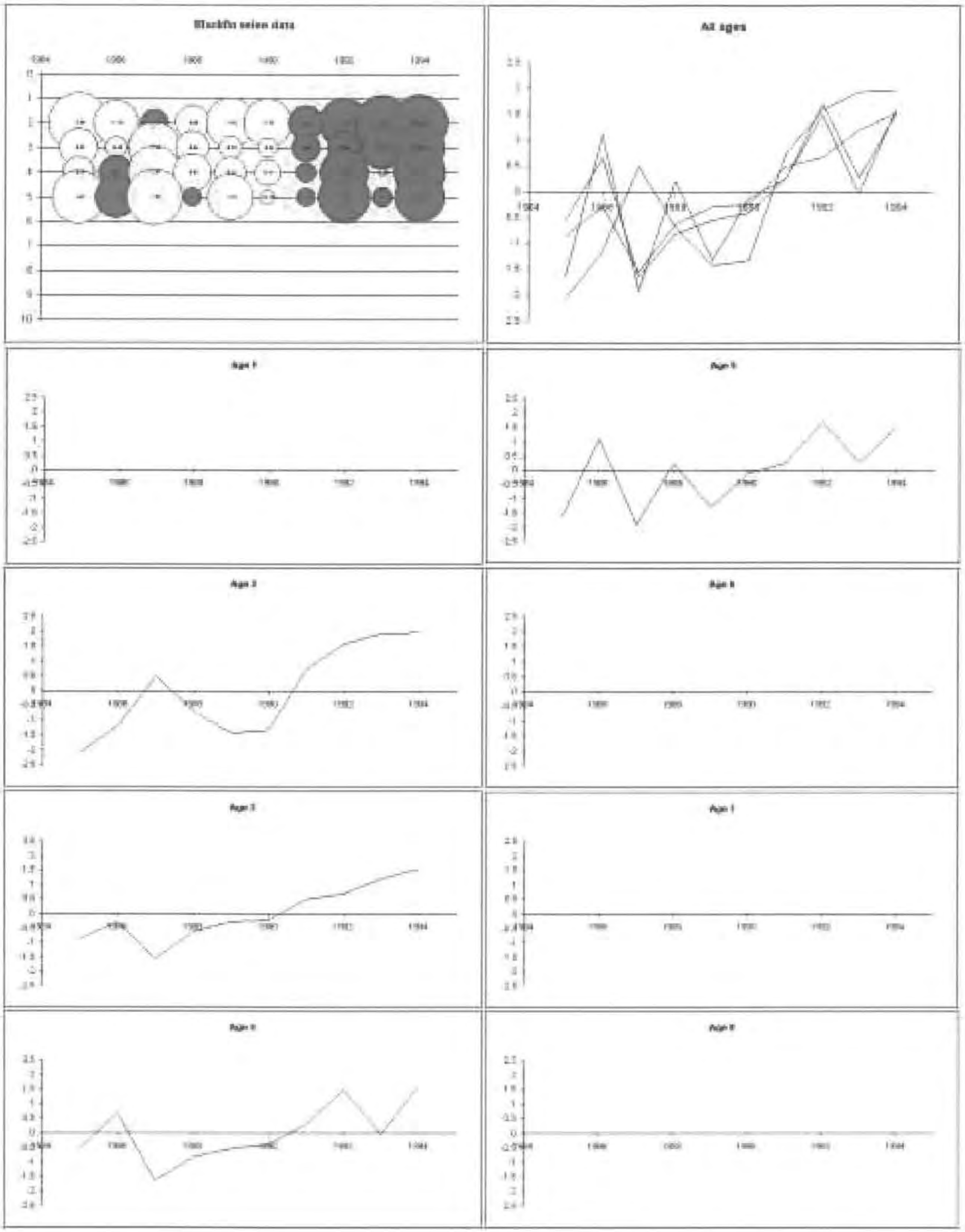

Fig. 4. The log catchability residuals for the Blackfin seine trawl calibration data set.

NAFO Sci. Coun. Studies, 36: 79–102

Appendix 1: Lowestoft Stock Assessment Suite

Tutorial 4

Extended Survivors Analysis (XSA)

by

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Abstract

This document is the fourth in a series of tutorials designed to assist users of the Lowestoft VPA Suite assessment software. The tutorial takes the user through the options required for running the Extended Survivors Analysis (XSA) assessment model.

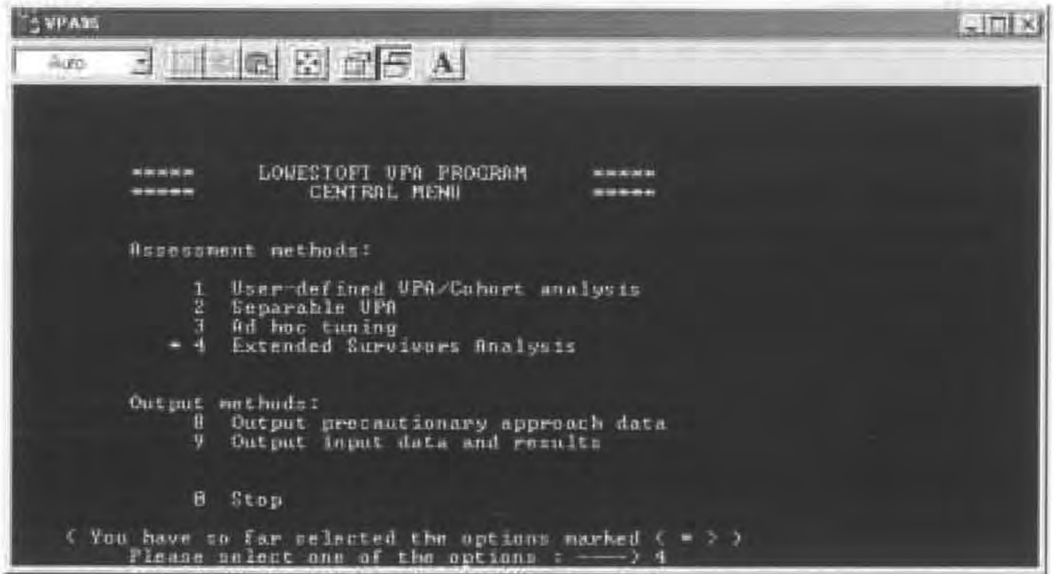
Introduction

This tutorial takes the user through the options required for running the Extended Survivors Analysis (XSA, Shepherd, MS 1992) tuning algorithm. Each of the tutorial series assume that the user has installed the VPA program VPA95.exe, described in Darby and Flatman (1994); that the required Blackfin data files have been placed in a directory c:\vpas\data\, and that the assessment index file (Blackfin.ind) contains path names which point to the appropriate files. This tutorial assumes that the user has either studied Tutorial 1which covers input of the data structures, or has previous experience of running the program.

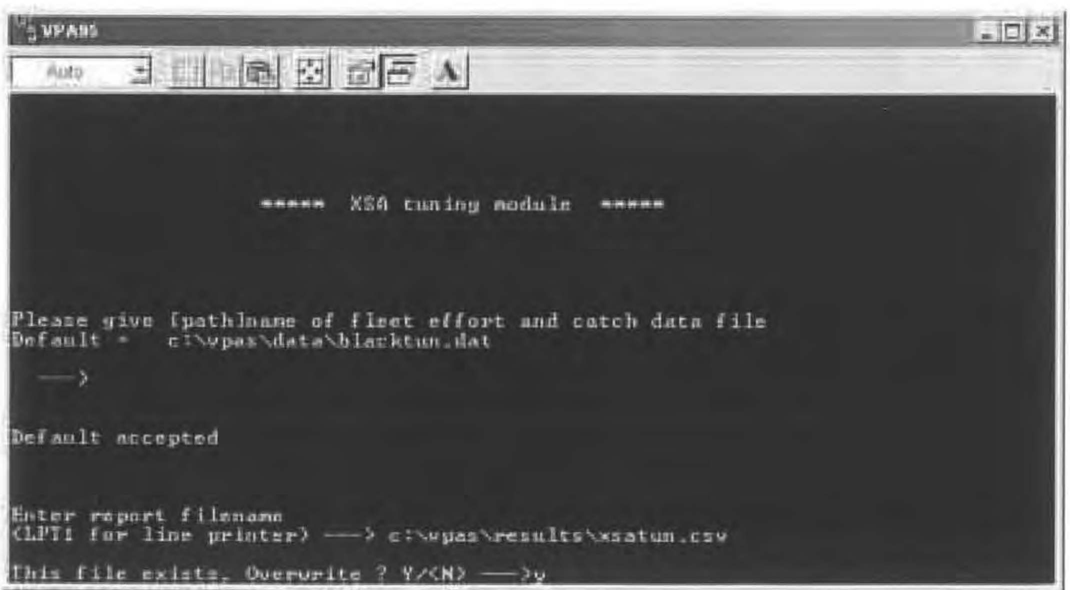
In the following text **action to be taken by the user** is highlighted in bold. The symbol ↵ is used to represent the Return or Enter key on the keyboard.

Extended Survivors Analysis

Open theVPA suite program and read in the index file C:\VPAS\DATA\BLACKFIN.IND. Take the default year, age and summary mean settings until the main menu is reached.

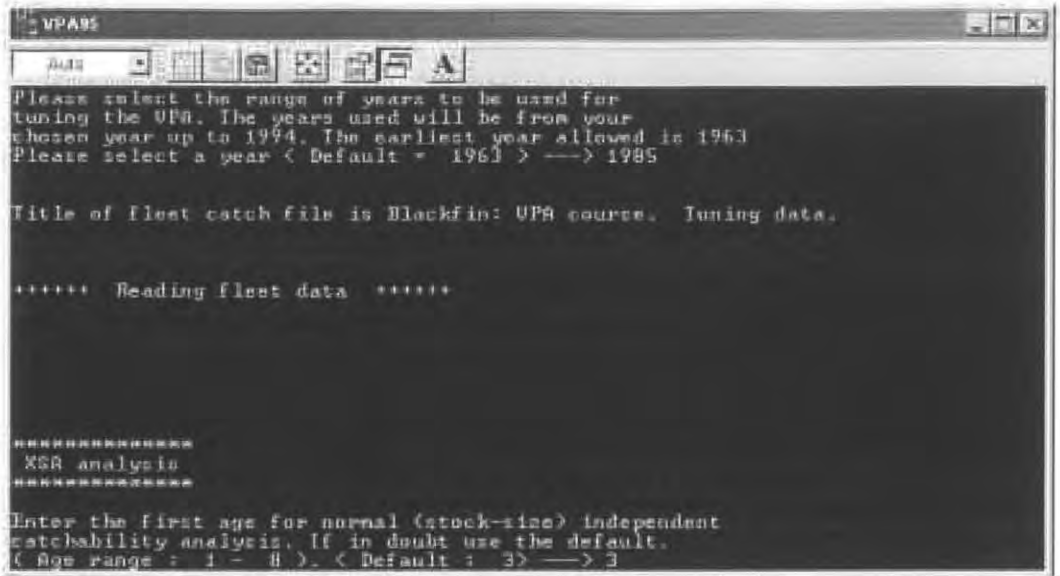


Type 4 ↵ to select the XSA model.
Type ↵ to select the default tuning data file, Blacktun.dat
Type a path and name for the tuning diagnostics output file. If a file of this name is located in the given directory, the program will ask for conformation of replacement.



The program reads the data file and then requires the user to select the range of years of cpue tuning data that will be used for calibrating the VPA. The current fad is to use only the last 10 years of data it is considered that technology creep will not have altered catchability substantially during this time period.

Type 1985 ↵

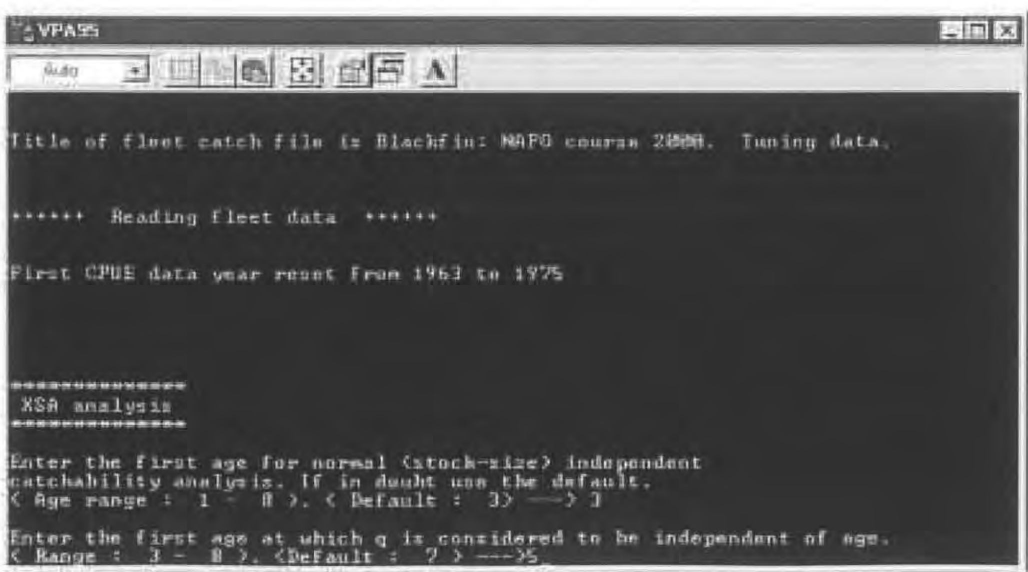


We now select the catchability models for each age. Two models are available:

direct proportionality or constant catchability cpue = q N
and the power model cpue = q N ^{p}

where q is catchability, N is population abundance and p the power coefficient. Unlike most formulations of ADAPT (Gavaris, MS 1988) and ICA (Patterson and Melvin 1996), which allow catchability models to be selected independently for each age within a cpue series, XSA currently fits all series with the specified catchability model at the selected age. If we use a power model at age 2, all calibration series will have this model fitted to the data at that age. In this tutorial we shall fit a power model for catchability at the first age, age 2. Note that the program requires us to input the first age at which the direct proportionality model is to be fitted, age 3.

Type 3 ↵ as the first age for the constant catchability model, that is, age 2 has a power model.



The next model specification required is the age at which we wish to constrain catchability. XSA reduces the number of parameters that are estimated by constraining catchability at the oldest ages to be equal to that at a younger age (the q plateau). Here we shall constrain catchability for ages greater than 5 to be equal to the value estimated at age 5. Once again this applies to all of the indices.

Type 5 ↵ so that catchability at ages older than 5 is set at that estimated at age 5.

The next screen presents the default settings for the XSA time series weights, the estimation of the regression model parameters, shrinkage and the minimum standard error threshold. For this assessment the default settings are not appropriate. We do not require the time series weights as we have reduced the time series for the indices to the data collected during the last 10 years. Also, the range of ages used for the fishing mortality shrinkage mean is also too large, extending into ages that are not fully recruited.

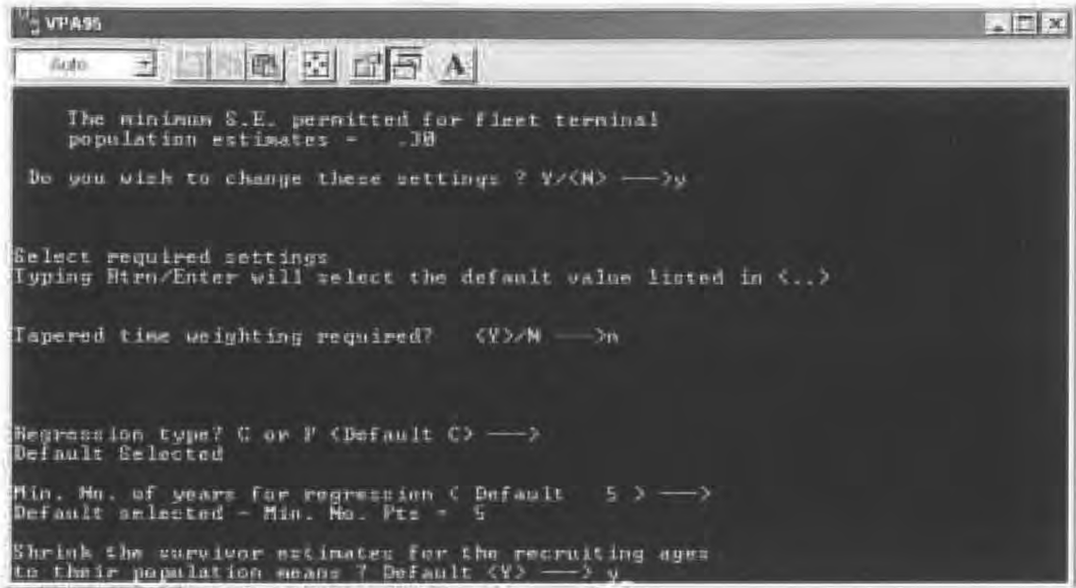
Type Y ↵ in order to change the default settings provided

The first question allows us to set time series weights in order to down - weight older data in the time series. In this example we have only selected the last 10 years and this is not required.

Type N ↵ to use all data in the 10 year time series with equal weight.

We now specify the regression model to be used to estimate the catchability parameters within the power model. We shall use Calibration regression, which assumes that the measurement errors are significantly larger in the survey observations than the estimated population abundance. Setting a minimum for the number of data points to which a regression model is fitted prevents the user from fitting regression models to times series of data that are too short and could therefore exhibit spurious correlation. In this case we can take the default option, as there are 10 years of data. Note that this does not equate to 10 data points in the regression, we could have zero cpue values, which are treated as missing in the analysis.

Type ↵ to take the default calibration regression model
Type ↵ to take the default of a minimum of 5 data points for the fitting of a regression model.



Within XSA two forms of shrinkage are used to provide constrained terminal population estimates. The first form of shrinkage is shrinkage to the population mean. This is described in detail in the user guide. It is only applied to the survivors estimated for the ages at which a power model is fitted. Terminal population estimates (calculated at the end of a year) for age a are shrunk to the time series weighted geometric mean of the population abundance estimates for age $a+1$ (calculated by the preceding VPA iteration, at the beginning of a year). The weight given to the shrinkage mean is the inverse of the variance of the time series weighted geometric mean population at the older age.

Rosenberg *et al.* (1992) have used simulation analysis to show that when estimating year class strength, prediction accuracy can be improved by the use of calibration regression with shrinkage to the population mean. The default settings supply this combination. If predictive regression is used, shrinkage to the population mean is equivalent to a double shrinkage and should be avoided.

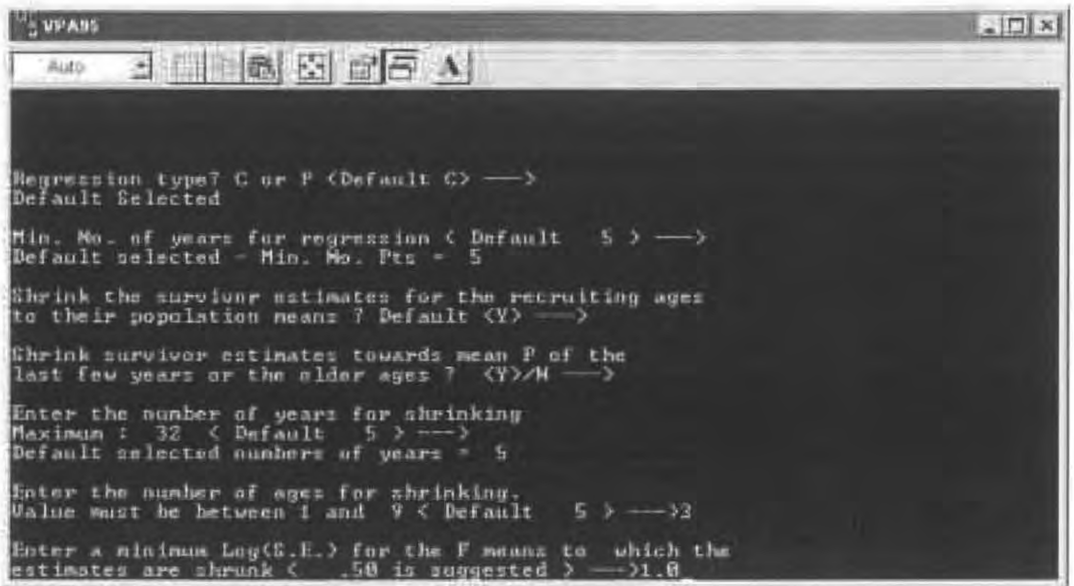
Type ↵ to take the default option of shrinkage to the population mean with the calibration model.

We are then asked whether we wish to use the mean F, calculated over recent years at each age and over the oldest ages to constrain the estimation process (F shrinkage). My personal preference is to start with a low shrinkage weight, allowing the cpue data to determine the survivors. The shrinkage constraint can then be increased later if required. Although it is not required to fit an XSA model, the main reason for keeping the shrinkage option is that we have years of catch data for which we wish to calculate a VPA but have no tuning data. If shrinkage is used, the terminal populations for the oldest age are calculated from the F values at younger ages, a procedure equivalent to the fixed exploitation pattern used within *ad hoc* tuning. By using F shrinkage with a low weight, cohorts without tuning data are initialised by survivor estimates derived from the average fishing mortality. In years for which there is calibration data the high c.v. minimises the influence of the fishing mortality mean. Note that the terminal population estimates are inverse variance weighted averages of the estimates from each cpue series. The weight given to the shrinkage mean (a user supplied value entered as a fractional c.v.) must be chosen relative to the c.v. of the values from the cpue series. A relatively high c.v. of 1.0 may still have a significant weight if the cpue series are noisy.

Type ↵ to take the default of using shrinkage to the mean fishing mortality.

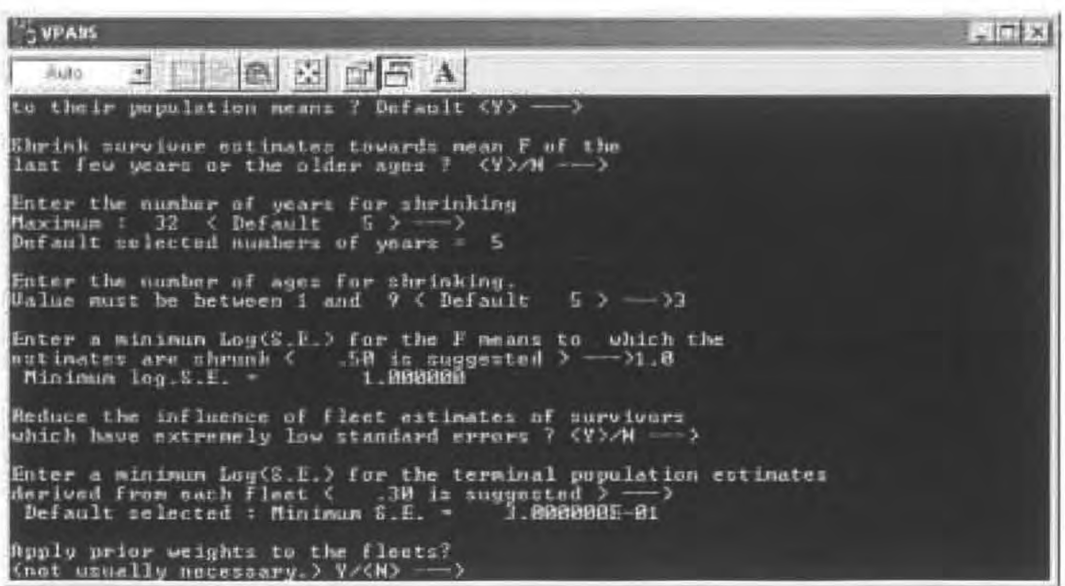
The range of ages over which we are fitting the assessment model is 2–9. The fishing mortality shrinkage mean is calculated over a user-defined range of ages that precede the oldest true age. If the range is too large we will include ages that are not fully recruited to the fishery and could force the assessment to have a dome-shaped selection pattern. We will use a mean taken over three ages.

Type ↵ to use 5 years in the mean across years.
Type 3 ↵ to use 3 ages in the mean across ages.
Type 1.0 ↵ for the weight to be used for the fishing mortality means.



We are using inverse variance weighting within the model fitting procedure. Occasionally one data set can have too great an influence on the fitted assessment and dominate the fit of the model. In order to prevent this we set a maximum for the weight that any observation can take. The weight is specified by entering a minimum for the standard error of any observation. The default value of 0.3 is suitable for this model.

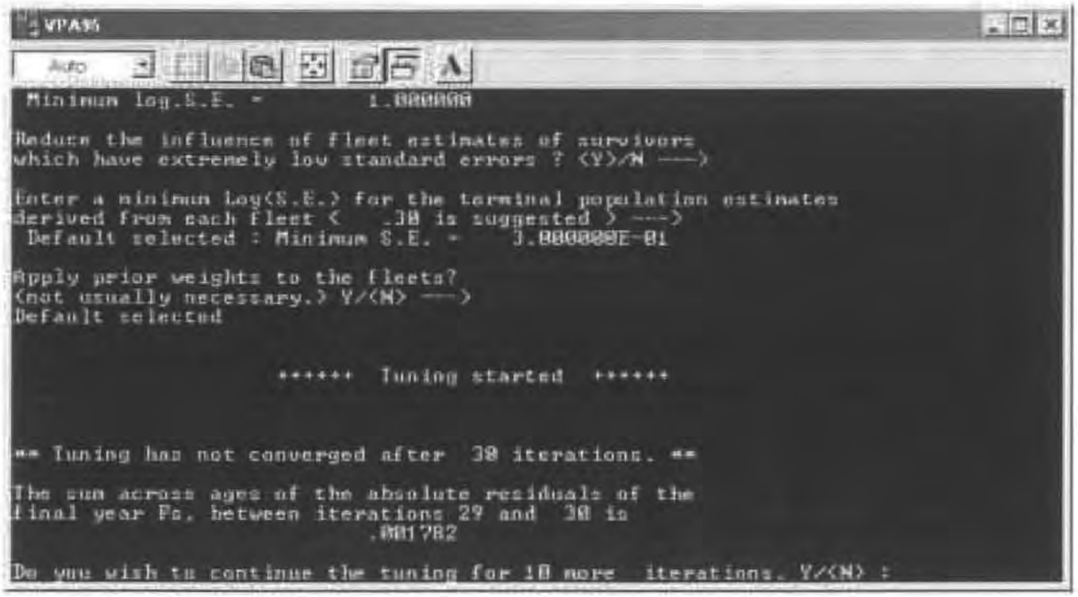
Type ↵ to use a minimum value for the standard error.
Type ↵ to set the minimum to 0.3.



Individual fleet weights can be used to down-weight, usually exclude, some indices from the analysis. In this preliminary run we do not wish to use this.

Type ↵ to take the default option of no individual fleet weighting.

The model now runs the iterative fitting algorithm. Initially 30 iterations are attempted and if convergence is not achieved, measured by the change in final year F values between iterations, then the model asks the user if they wish to run more iterations in batches of 10.



In this example convergence has not been achieved after 30 iterations. We could continue for more but as we are setting up a model it is better to stop the fitting process and examine the diagnostic output file before proceeding.

Once converged or the user has stopped the fitting process, the option is given to print a detailed breakdown of the estimates contributing to the population means. This can be useful in an understanding of which data series contribute most to the fitted model.

Type ↵ to stop the fitting algorithm
Type 1 ↵ to take the full diagnostics output.
Type y ↵ to print adjusted CPUE data.

We return to the main menu and can examine the diagnostics file in a spreadsheet package or text editor. Note that although we have fitted the assessment model we have not calculated the population biomass or printed any results tables. These are created using option 9 at the main menu.

The XSA Tuning Diagnostics File

The results from the current run should be in the file c:\vpas\results\xsatun.csv. The file can be opened in a text editor, word processing or spreadsheet package. The file lists the tuning data file used in the run, the selected range of ages, years and the model options chosen by the user.

Tables 1 - 12 present the results for the converged run; in the following text bold numbers **(x)** refer to labels added to the table. The file listing contains **(1)** the date and time at which the run was performed and the tuning file used for calibrating the VPA. **(2)** The ranges of the catch and calibration index data used to fit the XSA model. **(3)** The specification of the time series weights applied to down-weight older data. **(4)** The specifications for the catchability models. **(5)** The specification of the method for calculating the terminal population estimates. **(6)** The number of iterations performed to reach convergence, or if convergence was not achieved (as in the example), the differences between the final year F values for the last two iterations. **(7)** The time series weights used in down weighting historic data.

Following the model specifications is a selection of the model estimates. The tables are **(8)** the fishing mortality-at-age table for the final ten years of the assessment time series. **(9)** The estimated population numbers-at-age for the last ten assessment years; **(10)** the survivor estimates for the end of the final year (the terminal populations) and **(11)** the taper weighted geometric mean of the final VPA. If the population shrinkage option was selected, the terminal population estimates at the ages at which the power model was fitted were shrunk to the taper-weighted geometric mean population numbers of the next age. In the Blackfin example, the survivors for age 2, estimated at the end of the year, were shrunk to the mean of the population estimates at age 3 (calculated at the beginning of the year). The weight applied to the population shrinkage mean was the reciprocal of the square of the standard error **(12)** of the geometric mean population numbers.

The diagnostics tables from the run are used to examine the fit of the XSA model to the time series of indices at each age; each fleet **(13)** is presented in sequence. The log catchability residuals table **(14)** can be used to examine changes in the fleet – stock interactions (changes in catchability). An incidence of 99.99 indicates a missing (zero) total catch or fleet catch value. Look for year effects running down the columns (e.g. 1987 in the seine residuals), age effects, across the rows and year-class effects that follow the cohort diagonals (e.g. the 1984 cohort at age 2 in 1986 in the light trawl residuals). Recent and sudden changes in catchability may require removal of the fleet from the assessment since departures from the assumptions used in the catchability models can lead to biased estimates of population numbers and exploitation levels.

For the ages with constant catchability with respect to time, examine the log catchability means **(15)** and their standard error **(16)**. The standard error of the log catchability is an indicator of the quality of the data (a fractional coefficient of variation of the fleet's catchability for that age). Values greater than 0.5 indicate problems with that age in the fleet data. High standard errors for the older ages indicate that the assessment should probably be re-run with the problem ages incorporated in a younger plus group.

When combining estimates of terminal population derived from the fleet catches taken at each age, weighting by the inverse of the log catchability variance will reduce the influence of poor quality fleet data. However, if the standard errors of the majority of the important ages for a fleet are poor, the user may wish to remove the fleet from the analysis altogether.

Catchability on the oldest age is poorly determined and, to overcome this, the catchability values for the oldest ages are taken to be equivalent to that of a younger but fully recruited, age. In the initial Blackfin run log catchability at age 6 was constrained to the value at age 5 **(15)**. In order to introduce the greatest possible degree of stability to the assessment, it is necessary to set the age at which catchability is independent of age as low as possible in the fully recruited age range, without affecting the fit of the model at the older ages. The selection of the appropriate age is a process of model refinement. Examine the log catchability values for the ages with constant log catchability with respect to time **(15)** and their standard errors **(16)**. Fig. 2c plots catchability +/- one standard error against age. If, for the oldest ages, catchability does not exhibit large variation from age to age and there are no trends with respect to age, the youngest fully recruited age at which catchability appears to be independent of age is the preferred choice. At the selected age, examine the log catchability standard errors for each fleet; an alternative selection may be required if all of the fleets' log catchabilities, at the selected age, are poorly estimated by the model (s.e.'s >0.5). It is often seen that, if the age at which catchability is held constant is inappropriate, the catchability residuals for the subsequent ages generate blocks of all positive or negative values. Plots such as presented in Figures 2b – 5b aid the detection of problems.

If the log catchability standard errors are acceptable, a series of runs with a stepwise reduction in the age above which catchability is fixed, from the oldest true age-1 to the selected age, can be carried out and the log catchabilities and their standard errors compared with the standard run. Noticeable differences between runs should indicate when to stop.

One reason for choosing the penultimate age for the initial run is that if a trend in catchability with age exists, it is possible to force an inappropriate plateau by selecting too young an age. Also, large variations in catchability for all of the oldest ages in the assessment make it difficult to choose an appropriate age for fixing catchability. In either of these situations it is recommended that the assessment is carried out with catchability for the oldest age determined from the penultimate age. This removes the constraints on the older ages and allows the model to determine the majority of their catchability values independently. In addition, F shrinkage should be used, otherwise the model is badly under-determined and noisy. Due to the increased freedom within the model, the run may require more iterations to achieve a solution.

For each fleet, examine the regression statistics **(17)** for the ages with catchability dependent on year class strength, especially the slope **(18)**, the R square **(19)** and the overall regression standard error **(20)**. The slopes should be tested to see whether they are significantly different from 1.0, if not then catchability is constant with respect to population abundance (direct proportionality). The t-value **(21)** given in the table is derived from t = (slope - 1.0)/ se slope. It can be tested against the t statistic for the required confidence level, obtained from Student's t table with n-2 degrees of freedom – n is the number of data points used for the regression (No Pts) **(22)**.

The XSA algorithm fits the catchability proportional to year class abundance regression to all ages, regardless of whether the results are used within the analysis. This allows an examination of the regression slopes and standard errors for ages fitted with the catchability independent of year class strength model. The column labelled Mean Q **(23)** in the regression diagnostics lists the value of average log catchability derived independently at all ages. Comparison of values with the mean q values listed in **(15)** on the log or un-transformed scale (Fig. 2c–5c) will aid detection of inappropriate values for the age at which catchability is held constant with age.

If requested, XSA will print the final iteration's transformed CPUE values after a run **(40)**. Plotting the log of the CPUE values against the log of the VPA population abundance estimates given in **(9)**, allows an examination of the distribution of the data points about the fitted regression relationships. The graph can be used to examine whether one or two extreme values are dominating the relationships. This practice has also proved useful when examining the fleet CPUE data for ages at which calibration regression generates extreme values that are subsequently weighted out from the tuning process.

For each final year terminal population, the program prints the year class, the age of the cohort in the final year and the model used to derive catchability-at-age **(24)**. If the user selects the long format diagnostics output the program prints the estimate of the terminal population at the end of the final assessment year **(25)** and its raw weight **(26)** estimated for each fleet and each age in the cohort's history. The raw weights are used with the individual estimates of survivors to calculate the fleet-based and overall weighted means. Zero values indicate that the fleet has no data for the age. If the short diagnostics output is selected the individual fleet estimates at age will be omitted and only the following statistics will be tabulated:

A fleet-based weighted mean of the cohort's survivors **(27)**. This is derived from the estimates obtained from the fleet catches at each age in the cohort's history (the raw weights, printed in the long format output, can be used to identify the specific contribution of each estimate).

The internal standard error of the terminal population estimate obtained from a fleet **(28)**. It is derived by combining the standard errors associated with each estimate in the weighted mean and corresponds to the within samples variance of the fleet-based terminal population estimate.

The external standard error of the estimate of survivors obtained from each fleet **(29)**. This is the standard error of the terminal population estimates derived at each age; it corresponds to the between samples variance.

If the values of the internal and external standard errors differ significantly, this indicates a discrepancy between the individual estimates generated by the fleet catches. The variance ratio **(30)**, (external s.e.)^2/(internal s.e.)^2, may be tested as an F statistic with n-1 degrees of freedom. n is the number of estimates of terminal population abundance contributing to the mean, i.e. the number of years in which the fleet removed catches from the cohort. Values exceeding 3 imply that the independent estimates obtained at each age are providing conflicting signals. Too small a value implies an unexpected correspondence of the tuning fleets in relation to the inherent noise.

The scaled weights **(31)** are a measure of the proportional contribution of the fleet's estimates (for all ages) to the overall survivors estimate for the cohort. The weights are not actually used in the derivation of the overall mean, which is a weighted mean (using the raw weights **(26)**) of all the disaggregated (by fleet and age) estimates, including the population and F shrinkage means (if used). The scaled weight is given so that contributions from each fleet can be compared.

The terminal F that would be generated by using the estimate of survivors derived from the fleet to initiate the VPA **(32)** is equivalent to the fleet's raised F generated by the ad hoc tuning procedures. Discrepancies in the signals provided by the fleet data sets can be detected by comparing the F values or the survivor estimates.

If the age is a recruiting age in the assessment and shrinkage to the population mean has been selected, then the estimate of survivors used in the population shrinkage is printed with its standard error, scaled weight and F. The F shrinkage terminal population, the s.e. supplied by the user, scaled weight and F, are also given **(33)**.

The overall weighted geometric mean estimate of survivors at the end of the final year **(34)** is derived by combining all of the estimates of terminal population abundance; the estimates at each age from all fleets and the shrinkage estimates The raw weights used for the overall weighted mean are listed in **(26)**.

The internal standard error **(35)** and external standard error **(36)** of the overall mean, and the variance ratio **(38)** are printed. If the variance ratio exceeds 3, conflicting signals are being given by the disaggregated (by fleet and age) estimates of terminal population. The F test carried out for the individual fleet estimates can be repeated for the overall mean. In this case n is the summation, across fleets, of the number of years in which a fleet removed catches from the cohort. The individual estimates of terminal population abundance **(25)** and the fleet variance ratios **(30)** can be used to identify the fleets and/or ages that are causing problems.

The overall terminal F value for the cohort **(39)** is calculated using the overall weighted mean terminal population and the catch in the final year.

After the diagnostics for each age are printed an optional output of each fleet's corrected CPUE data is tabulated **(40)**. The data are transformed to the beginning of the year using the total fishing mortality values from the final iteration and the alpha and beta values entered in the diagnostics file. The data can be used to examine the distribution of data points about the fitted catchability regressions, as described previously.

The Blackfin example run

The otter trawl fleet cpue series has trends in time in the historic catchability residuals. Catchability increased during the late 1980's then declined during the early 1990's. This is inconsistent with the assumption of constant catchability in time and the large standard errors of log catchability reflect this mismatch. The catchability values are also inconsistent with the proportional to population abundance model, large standard errors and low R square correlation. The high standard errors will result in terminal population estimates from this fleet being heavily down-weighted in the final model estimates and therefore the fleet should be removed from the XSA model. However, the exclusion of the fleet from the model fit on the basis of the lack of correlation between the cpue data and the populations calculated from the catch at age data assumes that the fleet data does not reflect the stock dynamics. If the catch data is biased the VPA estimated populations will be biased and the fleet cpue may reflect the "truth".

The Light trawl cpue series has no trends in log catchability in time. There is a year class effect of low catchability values for the 1984 year class but the values are not extreme relative to the noise in the series. Given that the cohort effect does not reach the final assessment year it will add noise to the terminal population estimates but will not cause any bias. The power model (catchability dependent on population size) is not appropriate for the cpue data at age 2. The t-value indicates that the slope is therefore not significantly different from 1.0 (direct proportionality). The extra parameter fitted in the XSA model is not required. The age (five) at which catchability has been held constant, with respect to age, has resulted in some skew in the residuals calculated for ages 6 and 7 (Fig. 4b). This may be introducing bias at the oldest ages and the sensitivity of the results to this selection should be examined using a re-run with catchability at age seven constrained to that at age six. It would not be expected that the bias has a significant effect on the overall estimates since the catchability values at the older ages are not extremely different from the value at age five (Fig. 4c) and the population numbers at the oldest age are generally low.

The prawn trawl cpue series has pattern in the log-catchability residuals at the oldest ages and consequent high standard errors. Any pattern at the youngest age has been removed by fitting the power model at that age (see also Fig. 4b). The regression model statistics for the fitting of a power model at age 3 are provided even though the model was not used. They indicate that a power or proportional to population abundance model may be appropriate for the cpue at this age (t-value > 2.0, r-square > 0.5, low regression standard error).

The seine trawl cpue has a strong upward trend in catchability during the most recent years. The standard errors are high and for the ages with catchability constant in time have coefficients of variation of greater than 100% indicating that the estimates are poorly determined. Fitting of a power model at age 2 improves the fit of the model and reduces the standard errors through the introduction of the extra parameter. However the level of noise is still substantial. In addition, the slopes of the regression model are all negative, catchability increasing with decreasing population abundance. A clue to the underlying cause of the difficulty in fitting a catchability model is found in the values of R-square, the correlation coefficients for the regression points. The value is very low (close to zero) indicating poor correlation. We therefore have slopes that are potentially significantly different from 1.0 and yet low R-square. This can result from a cloud of data points with outliers that have high leverage, dominating the fitted regression model. Plotting the VPA estimated population abundance against the cpue data corrected to the beginning of the year could help resolve the issue. It would indicate that the data has no signal as to the trends in the stock (as estimated from the catch data) and that the fleet cpue series should not be used in the fitting of the XSA model.

Tables 7–11 present the detailed diagnostic output for the estimation of the terminal populations at the end of the final assessment year. Age 1 in the assessment has catch at age but no calibration or tuning data series. Therefore the estimate of the terminal population at age 2 in the following year is derived from two sources, the time series weighted geometric mean (population shrinkage) and the fishing mortality shrinkage mean. The two estimates of the terminal population differ by two orders of magnitude. This is reflected in the high external variance and the high variance ratio both characteristic of a difference in the estimates from the contributing data sources. The greatest weight (scaled weights) in the final estimate of the terminal population is contributed by the geometric mean. However, even at the low weight given to the fishing mortality shrinkage the very low value has a strong effect on the estimated survivors and raises a question as to the value of including age 1 in the assessment.

At age 2 (Table 7) the final estimate is dominated by the estimate of survivors from the Prawn trawl at age 2 and the population shrinkage geometric mean. This results from the relatively lower standard errors of the two series (Int se). At this age the population shrinkage estimate is higher than all of the fleet estimates and the overall mean is raised by the inclusion of the time series mean. After excluding the noisy fleet cpue series and changing the catchability models, as discussed above, the weighting of the estimates contributed from the series will change and this should be examined here.

Table 8 presents the results for ages 3 and 4. Note that, at these ages, catchability has been modelled as constant in time and therefore the population shrinkage is not used. The summary tables show that the weighted estimates are predominantly derived from the Light trawl and Prawn trawl series and the detailed breakdown shows that the contribution is mostly from ages 2 and 3. The dominance of estimates from separate ages and fleets reflects the poor fit of the catchability models at the youngest ages.

The XSA model should now be re-run and the model parameter and constraint selections altered to the optimum settings for the cpue series. The Otter trawl and seine fleets should be removed from the fitted model. The fastest way of achieving this is to give them a weight of zero using the prior fleet weighting option. In the current XSA program the selection of the age ranges at which the catchability models are applied is specified for all fleets concurrently. However, the most appropriate catchability model for the Light trawl fleet would be the simple proportionality model at all ages, whilst a power model seems appropriate for ages two and three of the Prawn trawl data. In order to fit a model that allows for both options we would go on to fit a power model at the first two ages. For the Prawn trawl fleet this is the required model, for the Light trawl fleet we estimate the slope and intercept rather than forcing them to be one and zero (we waste a parameter). The diagnostics of the new model fit should be examined for the fit of the regression to the Prawn trawl data at age three. Following the examination of the catchability models at the youngest ages, the age at which catchability is held constant with age should be re-evaluated. As noted previously there is a bias in the residuals when age 5 is used as the estimate for ages six and seven. Changes to this assumption should be examined for their effects on residual bias, standard errors and population estimates.

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TABLE 1. The XSA model specification for the Blackfin assessment.

Lowestoft VPA Version 3.1

2/02/2002 11:59 (1)

Extended Survivors Analysis

Blackfin: VPA course. Combined sex; plusgroup.

CPUE data from file c:\vpas\data\blacktun.dat

Catch data for 32 years. 1963 to 1994. Ages 1 to 10. (2)

Fleet	First year	Last year	First age	Last age	Alpha	Beta
Otter trawl	1985	1994	2	6	0	1
Light trawl	1985	1994	2	7	0	1
Prawn trawl	1985	1994	2	4	0	1
Seine	1985	1994	2	5	0	1

Time series weights : (3)

Tapered time weighting not applied

Catchability analysis : (4)

Catchability dependent on stock size for ages < 3

Regression type = C
Minimum of 5 points used for regression
Survivor estimates shrunk to the population mean for ages < 3

Catchability independent of age for ages >= 5

Terminal population estimation : (5)

Survivor estimates shrunk towards the mean F
of the final 5 years or the 3 oldest ages.

S.E. of the mean to which the estimates are shrunk = 1.000

Minimum standard error for population
estimates derived from each fleet = .300

Prior weighting not applied

Tuning had not converged after 30 iterations

Total absolute residual between iterations (6)
29 and 30 = .00178

Final year F values

Age	1	2	3	4	5	6	7	8	9
Iteration 29	0.0001	0.1885	0.2254	0.219	0.1901	0.1541	0.1489	0.1175	0.1368
Iteration 30	0.0001	0.1884	0.2253	0.2188	0.1898	0.1538	0.1487	0.1173	0.1365

Regression weights (7)

1	1	1	1	1	1	1	1	1	1

TABLE 2. The XSA estimates of fishing mortality and population numbers at age during the final 10 years of the assessment time series.

Fishing mortalities (8)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	0	0.008	0	0.001	0.001	0.004	0.01	0.002	0.001	0
2	0.072	0.047	0.077	0.168	0.047	0.091	0.102	0.072	0.186	0.188
3	0.26	0.334	0.18	0.401	0.604	0.569	0.332	0.207	0.335	0.225
4	0.279	0.914	0.645	0.49	0.923	0.729	0.68	0.534	0.595	0.219
5	0.267	0.668	0.539	0.541	0.683	0.491	0.533	0.496	0.401	0.19
6	0.35	0.444	0.539	0.645	0.629	0.54	0.501	0.3	0.247	0.154
7	0.376	0.578	0.478	0.85	0.504	0.513	0.638	0.15	0.145	0.149
8	0.293	0.563	0.528	1.109	0.641	0.738	0.457	0.172	0.11	0.117
9	0.342	0.532	0.716	0.962	0.817	0.828	0.742	0.178	0.173	0.136

XSA population numbers (Thousands) (9)

YEAR	AGE 1	2	3	4	5	6	7	8	9
1985	2.30E+04	3.63E+04	2.47E+04	1.39E+04	6.88E+03	4.61E+03	2.15E+03	8.16E+02	4.00E+02
1986	3.10E+04	1.88E+04	2.76E+04	1.56E+04	8.59E+03	4.31E+03	2.66E+03	1.21E+03	4.99E+02
1987	3.14E+04	2.52E+04	1.47E+04	1.62E+04	5.11E+03	3.60E+03	2.27E+03	1.22E+03	5.64E+02
1988	2.23E+04	2.57E+04	1.91E+04	1.00E+04	6.95E+03	2.44E+03	1.72E+03	1.15E+03	5.90E+02
1989	2.30E+04	1.82E+04	1.78E+04	1.05E+04	5.04E+03	3.31E+03	1.05E+03	6.03E+02	3.11E+02
1990	1.74E+04	1.88E+04	1.42E+04	7.96E+03	3.40E+03	2.08E+03	1.45E+03	5.19E+02	2.60E+02
1991	1.68E+04	1.42E+04	1.41E+04	6.60E+03	3.14E+03	1.70E+03	9.93E+02	7.09E+02	2.03E+02
1992	2.00E+04	1.36E+04	1.05E+04	8.26E+03	2.74E+03	1.51E+03	8.46E+02	4.30E+02	3.68E+02
1993	1.90E+04	1.64E+04	1.04E+04	6.96E+03	3.96E+03	1.37E+03	9.15E+02	5.96E+02	2.96E+02
1994	2.00E+04	1.55E+04	1.11E+04	6.07E+03	3.14E+03	2.17E+03	8.73E+02	6.48E+02	4.37E+02

Estimated population abundance at 1st Jan 1995 (10)

0.00E+00	1.64E+04	1.05E+04	7.27E+03	4.00E+03	2.13E+03	1.53E+03	6.17E+02	4.73E+02

Taper weighted geometric mean of the VPA populations: (11)

2.68E+04	2.17E+04	1.62E+04	9.34E+03	4.80E+03	2.58E+03	1.42E+03	7.84E+02	4.23E+02

Standard error of the weighted Log(VPA populations) : (12)

0.2871	0.2954	0.3078	0.3797	0.4307	0.5088	0.6226	0.6843	0.7408

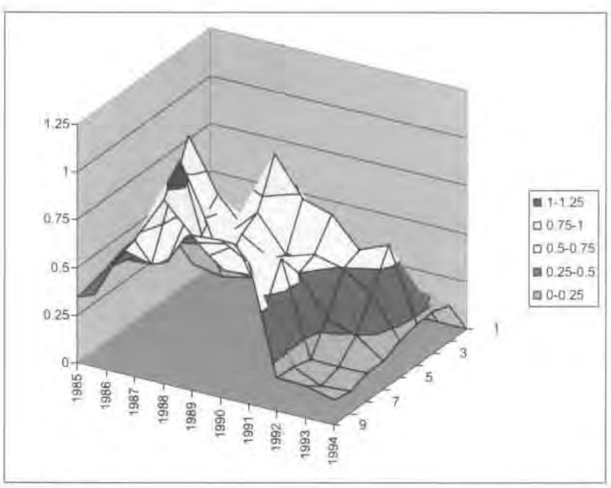

Fig. 1. Fishing mortality-at-age by year as estimated by XSA, note the very strong change in selection at the oldest ages in the most recent years.

TABLE 3. The Otter trawl log catchability residuals at age, the estimated log catchability and the power model regression diagnostics.

Log catchability residuals.

Fleet : Otter trawl **(13)**

(14)

Age	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2	0.77	1.21	-0.98	0.25	-1.06	-1.42	1.17	0.02	0.3	-0.25
3	-1.68	-0.09	-1.56	0.25	0.82	1.32	0.63	0.22	-0.01	0.09
4	-2.4	-1.08	-0.27	0.25	0.58	2.42	1.13	0.21	-1.14	0.29
5	-2.82	-1.42	-1.11	0.6	0.29	2.69	1.49	0.61	-1.06	0.72
6	-1.28	-0.83	-0.29	-0.01	0.82	2.61	0.96	0.49	-0.42	0.27
7	No data for this fleet at this age									

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Age	3	4	5	6	
Mean Log q	-14.0782	-14.6821	-14.954	-14.954	**(15)**
S.E(Log q)	0.9547	1.3325	1.6025	1.1215	**(16)**

Regression statistics : **(17)**

Ages with q dependent on year class strength

Age	Slope **(18)**	t-value **(21)**	Intercept	RSquare **(19)**	No Pts **(22)**	Reg s.e **(20)**	Mean Log q
2	0.93	0.067	14.56	0.1	10	0.98	-14.92

Ages with q independent of year class strength and constant w.r.t. time.

Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e	Mean Q **(23)**
3	5.63	-0.875	34.59	0	10	5.45	-14.08
4	-1.16	-1.641	2.76	0.07	10	1.42	-14.68
5	-0.62	-2.376	4.34	0.21	10	0.81	-14.95
6	-6.23	-1.472	-35.17	0.01	10	6.41	-14.72

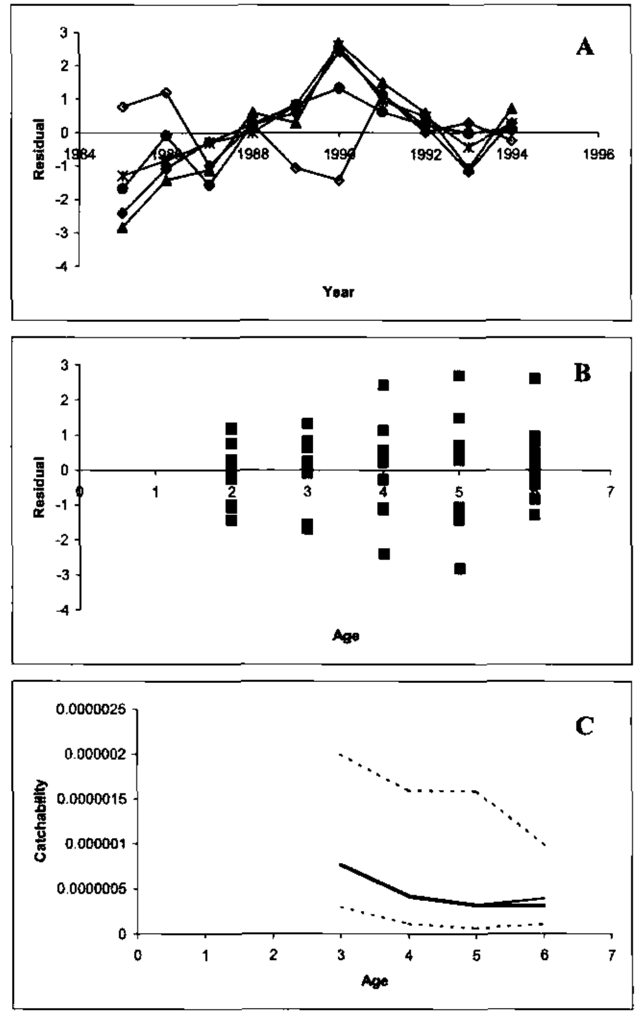

Fig. 2. The Otter trawl log catchability residuals plotted against (**A**) time and (**B**) age and (**C**) estimated catchability +/- one standard deviation.

TABLE 4. The Light trawl log catchability residuals at age, the estimated log catchability and the power model regression diagnostics.

Fleet : Light trawl

Age	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2	-0.4	-1.44	1.21	0.41	-1.23	0.13	0.49	0.01	0.87	-0.04
3	0.31	0.12	-0.54	-0.39	0.28	0.58	-0.17	-0.25	-0.06	0.12
4	0.46	0.63	-0.9	-0.81	-0.21	0.83	0.53	0.04	-0.59	0.01
5	-0.8	0.74	-0.48	0.32	-0.45	0.31	0.96	0.05	-1.06	0.42
6	0.02	-0.54	-0.64	-0.8	-0.13	-0.11	0.28	-0.33	0.09	0.36
7	-0.91	-0.22	-0.43	-1.28	-0.3	0.35	0.38	-0.5	0.13	-0.02

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Age	3	4	5	6	7
Mean Log q	-15.5176	-15.7286	-16.2817	-16.2817	-16.2817
S.E(Log q)	0.3457	0.6204	0.6706	0.4326	0.6058

Regression statistics :

Ages with q dependent on year class strength

Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e	Mean Log q
2	1.21	-0.22	17.58	0.12	10	0.89	-16.22

Ages with q independent of year class strength and constant w.r.t. time.

Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e	Mean Q
3	0.81	0.688	14.39	0.62	10	0.29	-15.52
4	1.24	-0.324	17.33	0.18	10	0.81	-15.73
5	1.28	-0.364	18.44	0.18	10	0.9	-16.28
6	1.49	-1.114	20.67	0.4	10	0.57	-16.46
7	2.07	-1.334	26.54	0.16	10	1.05	-16.56

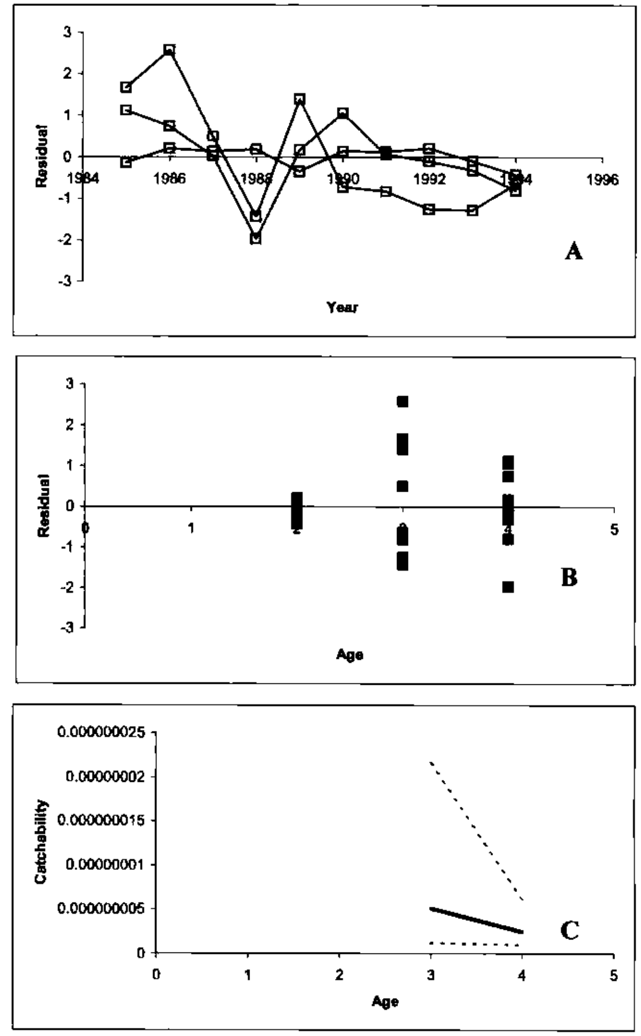

Fig. 3. The Light trawl log catchability residuals plotted against (**A**) time and (**B**) age and (**C**) estimated catchability +/- one standard deviation

TABLE 5. The Prawn trawl log catchability residuals at age, the estimated log catchability and the power model regression diagnostics.

Fleet : Prawn trawl

Age	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2	-0.14	0.21	0.14	0.18	-0.35	0.14	0.13	0.21	-0.09	-0.42
3	1.67	2.58	0.5	-1.43	1.4	-0.72	-0.82	-1.25	-1.28	-0.64
4	1.12	0.74	0.03	-1.97	0.17	1.06	0.07	-0.1	-0.31	-0.8
5	No data for this fleet at this age									
6	No data for this fleet at this age									
7	No data for this fleet at this age									

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Age	3	4
Mean Log q	-19.0864	-19.8161
S.E(Log q)	1.4344	0.9164

Regression statistics :

Ages with q dependent on year class strength

Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e	Mean Log q
2	0.34	2.446	12.86	0.63	10	0.25	-18.79

Ages with q independent of year class strength and constant w.r.t. time.

Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e	Mean Q
3	0.23	3.643	11.84	0.74	10	0.22	-19.09
4	0.55	0.975	14.98	0.37	10	0.5	-19.82

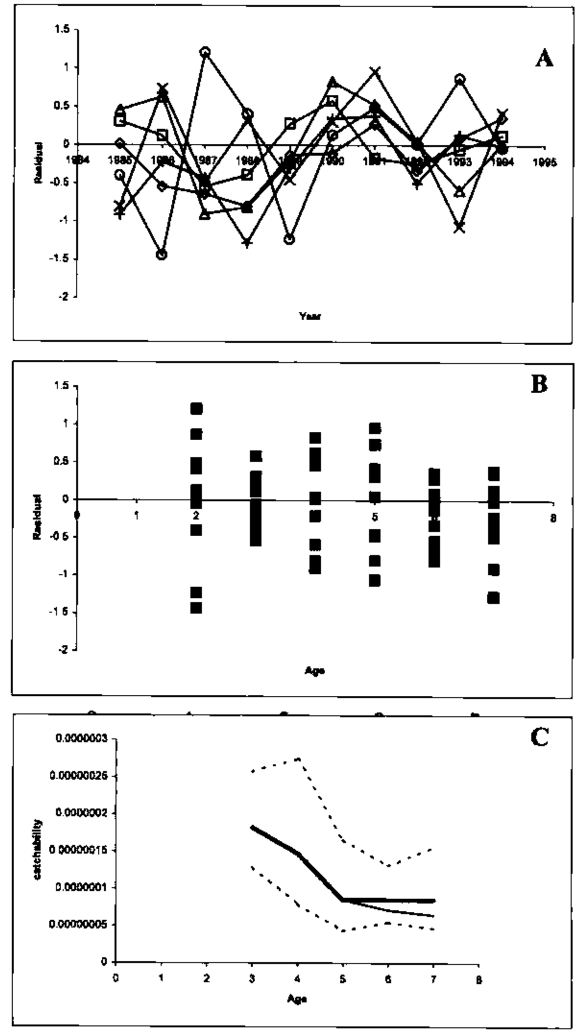

Fig. 4. The Prawn trawl log catchability residuals plotted against (**A**) time and (**B**) age and (**C**) estimated catchability +/- one standard deviation

TABLE 6. The Seine log catchability residuals at age, the estimated log catchability and the power model regression diagnostics.

Fleet : Seine

Age	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2	0.01	0.55	-0.57	-0.1	0.72	0.59	0.08	-0.15	-0.65	-0.48
3	-0.9	-0.32	-1.59	-0.67	-0.35	-0.29	0.56	0.78	1.11	1.68
4	-0.56	0.67	-1.69	-0.85	-0.58	-0.48	0.22	1.62	0.14	1.52
5	-1.67	1.09	-1.94	0.15	-1.36	-0.19	0.11	1.59	0.45	1.77
6	No data for this fleet at this age									
7	No data for this fleet at this age									

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Age	3	4	5
Mean Log q	-15.5078	-15.7074	-16.4243
S.E(Log q)	1.0043	1.0477	1.3153

Regression statistics :

Ages with q dependent on year class strength

Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e	Mean Log q
2	-0.43	-2.516	7.31	0.28	10	0.52	-15.8

Ages with q independent of year class strength and constant w.r.t. time.

Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e	Mean Q
3	-1.07	-2.485	3.37	0.15	10	0.86	-15.51
4	-1.75	-1.811	-2.26	0.05	10	1.64	-15.71
5	-3.52	-1.187	-19.71	0.01	10	4.52	-16.42

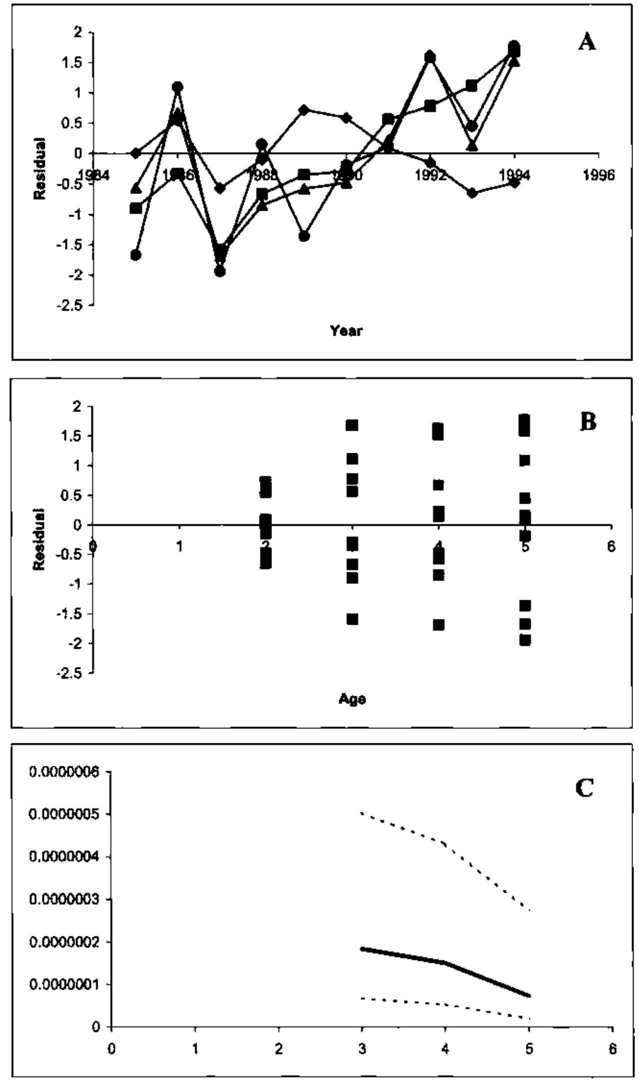

Fig. 5. The Seine log catchability residuals plotted against (**A**) time and (**B**) age and (**C**) estimated catchability +/- one standard deviation

TABLE 7. The XSA estimates of Blackfin terminal population numbers and fishing mortality and their standard errors at ages 1 and 2.

Fleet disaggregated estimates of survivors :

Age 1 Catchability dependent on age and year class strength

Year class = 1993

Otter trawl	
Age	1
Survivors	0
Raw Weights	0
Light trawl	
Age	1
Survivors	0
Raw Weights	0
Prawn trawl	
Age	1
Survivors	0
Raw Weights	0
Seine	
Age	1
Survivors	0
Raw Weights	0

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
Otter trawl	1	0	0	0	0	0	0
Light trawl	1	0	0	0	0	0	0
Prawn trawl	1	0	0	0	0	0	0
Seine	1	0	0	0	0	0	0
P shrinkage mean	21733	0.3				0.92	0
F shrinkage mean	657	1				0.08	0.003

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
16412	0.28	9.75	2	34.421	0

Age 2 Catchability dependent on age and year class strength

Year class = 1992

Otter trawl		
Age	2	1
Survivors	8174	0
Raw Weights	0.759	0
Light trawl		
Age	2	1
Survivors	10140	0
Raw Weights	0.936	0
Prawn trawl		
Age	2	1
Survivors	6904	0
Raw Weights	9.203	0
Seine		
Age	2	1
Survivors	6505	0
Raw Weights	2.387	0

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
Otter trawl	8174	1.045	0	0	1	0.031	0.236
Light trawl	10140	0.941	0	0	1	0.038	0.195
Prawn trawl	6904	0.3	0	0	1	0.37	0.274
Seine	6505	0.589	0	0	1	0.096	0.289
P shrinkage mean	16215	0.31				0.425	0.126
F shrinkage mean	20703	1				0.04	0.1

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
10518	0.19	0.26	6	1.372	0.188

TABLE 8. The XSA estimates of Blackfin terminal population numbers and fishing mortality and their standard errors at ages 3 and 4.

Age 3 Catchability constant w.r.t. time and dependent on age

Year class = 1991 **(24)**

Otter trawl				
Age	3	2	1	
Survivors	7940	9770	0	**(25)**
Raw Weights	0.796	0.62	0	**(26)**
Light trawl				
Age	3	2	1	
Survivors	8210	17278	0	
Raw Weights	6.073	0.712	0	
Prawn trawl				
Age	3	2	1	
Survivors	3814	6620	0	
Raw Weights	0.353	7.365	0	
Seine				
Age	3	2	1	
Survivors	39081	3781	0	
Raw Weights	0.72	1.824	0	

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F	
	(27)	**(28)**	**(29)**	**(30)**		**(31)**	**(32)**	
Otter trawl	8695	0.722	0.103	0.14	2	0.073	0.192	
Light trawl	8876	0.34	0.228	0.67	2	0.349	0.188	
Prawn trawl	6455	0.294	0.115	0.39	2	0.397	0.25	
Seine	7321	0.525	1.052	2	2	0.131	0.224	
F shrinkage mean	3599	1				0.051	0.412	**(33)**

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
7272	0.19	0.16	9	0.848	0.225
(34)	**(35)**	**(36)**	**(37)**	**(38)**	**(39)**

Age 4 Catchability constant w.r.t. time and dependent on age

Year class = 1990

Otter trawl				
Age	4	3	2	1
Survivors	5338	3955	4058	0
Raw Weights	0.411	0.573	0.495	0
Light trawl				
Age	4	3	2	1
Survivors	4045	3743	4027	0
Raw Weights	1.898	4.374	0.6	0
Prawn trawl				
Age	4	3	2	1
Survivors	1788	1112	4940	0
Raw Weights	0.87	0.254	5.941	0
Seine				
Age	4	3	2	1
Survivors	18174	12077	3429	0
Raw Weights	0.665	0.518	1.643	0

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
Otter trawl	4336	0.65	0.092	0.14	3	0.077	0.203
Light trawl	3849	0.304	0.026	0.09	3	0.357	0.226
Prawn trawl	4131	0.284	0.296	1.04	3	0.367	0.212
Seine	6396	0.463	0.528	1.14	3	0.147	0.142
F shrinkage mean	966	1				0.052	0.699

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
3997	0.18	0.16	13	0.867	0.219

TABLE 9. The XSA estimates of Blackfin terminal population numbers and fishing mortality and their standard errors at ages 5 and 6.

Age 5 Catchability constant w.r.t. time and dependent on age

Year class = 1989

Otter trawl					
Age	5	4	3	2	1
Survivors	4380	680	2648	6875	0
Raw Weights	0.293	0.234	0.37	0.291	0

Light trawl					
Age	5	4	3	2	1
Survivors	3229	1185	1666	3469	0
Raw Weights	1.672	1.077	2.82	0.38	0

Prawn trawl					
Age	5	4	3	2	1
Survivors	0	1560	607	2422	0
Raw Weights	0	0.494	0.164	3.719	0

Seine					
Age	5	4	3	2	1
Survivors	12545	2453	4636	2300	0
Raw Weights	0.435	0.378	0.334	1.088	0

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
Otter trawl	2899	0.643	0.462	0.72	4	0.08	0.143
Light trawl	1977	0.293	0.223	0.76	4	0.403	0.203
Prawn trawl	2189	0.283	0.204	0.72	3	0.297	0.185
Seine	3592	0.452	0.381	0.84	4	0.152	0.117
F shrinkage mean	644	1				0.068	0.525

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
2132	0.18	0.15	16	0.851	0.19

Age 6 Catchability constant w.r.t. time and age (fixed at the value for age) 5

Year class = 1988

Otter trawl						
Age	6	5	4	3	2	1
Survivors	2005	529	1886	2879	368	0
Raw Weights	0.62	0.203	0.172	0.241	0.169	0

Light trawl						
Age	6	5	4	3	2	1
Survivors	2191	528	1585	1287	1739	0
Raw Weights	4.164	1.161	0.795	1.838	0.251	0

Prawn trawl						
Age	6	5	4	3	2	1
Survivors	0	0	1385	671	1753	0
Raw Weights	0	0	0.364	0.107	2.45	0

Seine						
Age	6	5	4	3	2	1
Survivors	0	2398	7703	2669	2755	0
Raw Weights	0	0.302	0.279	0.218	0.666	0

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
Otter trawl	1424	0.637	0.357	0.56	5	0.094	0.164
Light trawl	1530	0.273	0.241	0.89	5	0.547	0.153
Prawn trawl	1644	0.284	0.135	0.48	3	0.195	0.144
Seine	3241	0.466	0.244	0.52	4	0.098	0.075
F shrinkage mean	451	1				0.067	0.447

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
1529	0.19	0.15	18	0.777	0.154

TABLE 10. The XSA estimates of Blackfin terminal population numbers and fishing mortality and their standard errors at ages 7 and 8.

Age 7 Catchability constant w.r.t. time and age (fixed at the value for age) 5

Year class = 1987

Otter trawl							
Age	7	6	5	4	3	2	1
Survivors	0	405	1137	1915	2315	213	0
Raw Weights	0	0.487	0.145	0.106	0.117	0.093	0
Light trawl							
Age	7	6	5	4	3	2	1
Survivors	604	671	645	1048	1095	181	0
Raw Weights	2.135	3.27	0.829	0.491	0.894	0.106	0
Prawn trawl							
Age	7	6	5	4	3	2	1
Survivors	0	0	0	663	300	436	0
Raw Weights	0	0	0	0.225	0.052	1.246	0
Seine							
Age	7	6	5	4	3	2	1
Survivors	0	0	3032	767	461	1266	0
Raw Weights	0	0	0.216	0.172	0.106	0.328	0

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
Otter trawl	658	0.694	0.392	0.57	5	0.079	0.14
Light trawl	694	0.278	0.115	0.41	6	0.643	0.133
Prawn trawl	458	0.288	0.119	0.41	3	0.127	0.195
Seine	1258	0.507	0.358	0.71	4	0.068	0.076
F shrinkage mean	205	1				0.083	0.393

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
617	0.21	0.13	19	0.6	0.149

Age 8 Catchability constant w.r.t. time and age (fixed at the value for age) 5

Year class = 1986

Otter trawl								
Age	8	7	6	5	4	3	2	1
Survivors	0	0	769	2094	5304	1074	608	0
Raw Weights	0	0	0.412	0.118	0.083	0.088	0.068	0
Light trawl								
Age	8	7	6	5	4	3	2	1
Survivors	0	536	339	1234	1086	625	708	0
Raw Weights	0	1.906	2.767	0.676	0.381	0.67	0.08	0
Prawn trawl								
Age	8	7	6	5	4	3	2	1
Survivors	0	0	0	0	1355	1916	562	0
Raw Weights	0	0	0	0	0.174	0.039	0.828	0
Seine								
Age	8	7	6	5	4	3	2	1
Survivors	0	0	0	524	291	331	428	0
Raw Weights	0	0	0	0.176	0.133	0.079	0.244	0

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
Otter trawl	1124	0.713	0.327	0.46	5	0.077	0.051
Light trawl	511	0.284	0.196	0.69	6	0.653	0.109
Prawn trawl	682	0.293	0.273	0.93	3	0.105	0.083
Seine	404	0.513	0.126	0.25	4	0.064	0.136
F shrinkage mean	110	1				0.101	0.426

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
473	0.22	0.17	19	0.744	0.117

TABLE 11. The XSA estimates of Blackfin terminal population numbers and fishing mortality and their standard errors at age 9.

Age 9 Catchability constant w.r.t. time and age (fixed at the value for age) 5

Year class = 1985

Otter trawl									
Age	9	8	7	6	5	4	3	2	1
Survivors	0	0	0	816	4597	560	400	117	0
Raw Weights	0	0	0	0.295	0.088	0.051	0.066	0.055	0
Light trawl									
Age	9	8	7	6	5	4	3	2	1
Survivors	0	0	189	412	426	253	211	1046	0
Raw Weights	0	0	1.667	1.981	0.505	0.234	0.505	0.055	0
Prawn trawl									
Age	9	8	7	6	5	4	3	2	1
Survivors	0	0	0	0	0	369	75	359	0
Raw Weights	0	0	0	0	0	0.107	0.029	0.683	0
Seine									
Age	9	8	7	6	5	4	3	2	1
Survivors	0	0	0	0	260	175	160	176	0
Raw Weights	0	0	0	0	0.131	0.082	0.06	0.197	0

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
Otter trawl	788	0.71	0.479	0.68	5	0.071	0.056
Light trawl	293	0.294	0.176	0.6	6	0.635	0.145
Prawn trawl	340	0.285	0.207	0.73	3	0.105	0.126
Seine	194	0.507	0.106	0.21	4	0.06	0.212
F shrinkage mean	303	1				0.128	0.14

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
313	0.24	0.12	19	0.502	0.136

TABLE 12. The Blackfin catch-per-unit effort data corrected to the beginning of the year using the estimated fishing mortalities and natural mortality.

(40)

Otter trawl

CPUE adjusted to start of year

YEAR	AGE 1	2	3	4	5	6	7	8	9
1985	0	0.02893	0.00354	0.00053	0.00013	0.00041	0	0	0
1986	0	0.02282	0.01939	0.00222	0.00067	0.00061	0	0	0
1987	0	0.00296	0.00238	0.00519	0.00054	0.00086	0	0	0
1988	0	0.01142	0.0188	0.00544	0.00408	0.00078	0	0	0
1989	0	0.00191	0.03114	0.00789	0.00215	0.0024	0	0	0
1990	0	0.00134	0.04116	0.03761	0.01603	0.0091	0	0	0
1991	0	0.01618	0.0204	0.00862	0.00447	0.00143	0	0	0
1992	0	0.00446	0.01001	0.00429	0.00162	0.00079	0	0	0
1993	0	0.00735	0.00789	0.00094	0.00044	0.00029	0	0	0
1994	0	0.00385	0.00934	0.00341	0.00207	0.00091	0	0	0

Light trawl

CPUE adjusted to start of year

YEAR	AGE 1	2	3	4	5	6	7	8	9
1985	0	0.0021	0.00613	0.00325	0.00026	0.0004	7.4E-05	0	0
1986	0	0.00052	0.0057	0.00434	0.00153	0.00021	0.00018	0	0
1987	0	0.00586	0.00156	0.00097	0.00027	0.00016	0.00013	0	0
1988	0	0.00308	0.00235	0.00066	0.00081	9.4E-05	4.1E-05	0	0
1989	0	0.0006	0.0043	0.00125	0.00027	0.00025	6.6E-05	0	0
1990	0	0.0019	0.00462	0.0027	0.00039	0.00016	0.00017	0	0
1991	0	0.00201	0.00216	0.00166	0.0007	0.00019	0.00012	0	0
1992	0	0.00131	0.00149	0.00127	0.00024	9.2E-05	4.4E-05	0	0
1993	0	0.0031	0.00177	0.00057	0.00012	0.00013	8.8E-05	0	0
1994	0	0.00141	0.00229	0.00091	0.0004	0.00026	7.3E-05	0	0

Prawn trawl

CPUE adjusted to start of year

YEAR	AGE 1	2	3	4	5	6	7	8	9
1985	0	0.00057	0.00067	0.0001	0	0	0	0	0
1986	0	0.00023	0.00187	8.1E-05	0	0	0	0	0
1987	0	0.00044	0.00012	4.1E-05	0	0	0	0	0
1988	0	0.00053	2.3E-05	3.5E-06	0	0	0	0	0
1989	0	4E-05	0.00037	3.1E-05	0	0	0	0	0
1990	0	0.00019	3.6E-05	5.7E-05	0	0	0	0	0
1991	0	7.8E-05	3.2E-05	1.8E-05	0	0	0	0	0
1992	0	8.9E-05	1.5E-05	1.9E-05	0	0	0	0	0
1993	0	6.2E-05	1.5E-05	1.3E-05	0	0	0	0	0
1994	0	2E-05	3E-05	6.7E-06	0	0	0	0	0

Seine

CPUE adjusted to start of year

YEAR	AGE 1	2	3	4	5	6	7	8	9
1985	0	0.00061	0.00185	0.00119	9.5E-05	0	0	0	0
1986	0	0.00079	0.00369	0.00457	0.00187	0	0	0	0
1987	0	0.00546	0.00055	0.00045	5.4E-05	0	0	0	0
1988	0	0.00173	0.0018	0.00065	0.0006	0	0	0	0
1989	0	0.00058	0.0023	0.00088	9.5E-05	0	0	0	0
1990	0	0.00073	0.00196	0.00074	0.00021	0	0	0	0
1991	0	0.00459	0.00453	0.00124	0.00026	0	0	0	0
1992	0	0.00855	0.0042	0.00629	0.00099	0	0	0	0
1993	0	0.0178	0.00577	0.00121	0.00046	0	0	0	0
1994	0	0.01349	0.01101	0.00417	0.00136	0	0	0	0

NAFO Sci. Coun. Studies, 36: 103–114

Appendix 1: Lowestoft Stock Assessment Suite

Tutorial 5

Retrospective Analysis (RETVPA00.EXE)

by

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Abstract

This document is number five in a series of tutorials designed to assist users of the Lowestoft VPA Suite assessment software and prediction programs that use the results. The tutorial takes the user through the options required for running the retrospective program RETVPA00.EXE.

Introduction

Retrospective studies have established that patterns of consistent under- or over-estimation bias in estimates of F and population numbers-at-age can be produced by the application of assessment methodologies to fish stock data (Sinclair *et al.*, MS 1990, ICES, MS 1991). Such biases may cause problems in the advice given to managers and therefore need to be examined and if possible removed from the assessment and subsequent predictions.

This tutorial takes the user through the options required for running the program RETVPA00.EXE and carrying out a retrospective analysis of an XSA model structure. The tutorial assumes that the required Blackfin data files have been placed in a directory c:\vpas\data\, and that the index file (Blackfin.ind) contains path names that point to the appropriate files.

Description of the method

For each stock and analysis procedure a series of assessments are performed with the terminal year decreased by one year at each run. This simulates the results of assessments with progressively shorter time series. All input parameters to the analysis are held constant, e.g. number of tuning data years, time series weights, reference ages. The values estimated by the most recent assessment, derived from all available data, are assumed to be the 'truth' and compared with the estimates from the runs which pre-date it. The accuracy of an assessment methodology is determined by its ability to consistently predict the 'truth'. Bias is the degree to which the method consistently under- or over-estimates the 'truth'. The analysis procedure usually involves the creation of retrospective time series plots for particular assessment estimates (e.g. F, population numbers-at-age, SSB) followed by a statistical or subjective analysis of the accuracy and bias of the method.

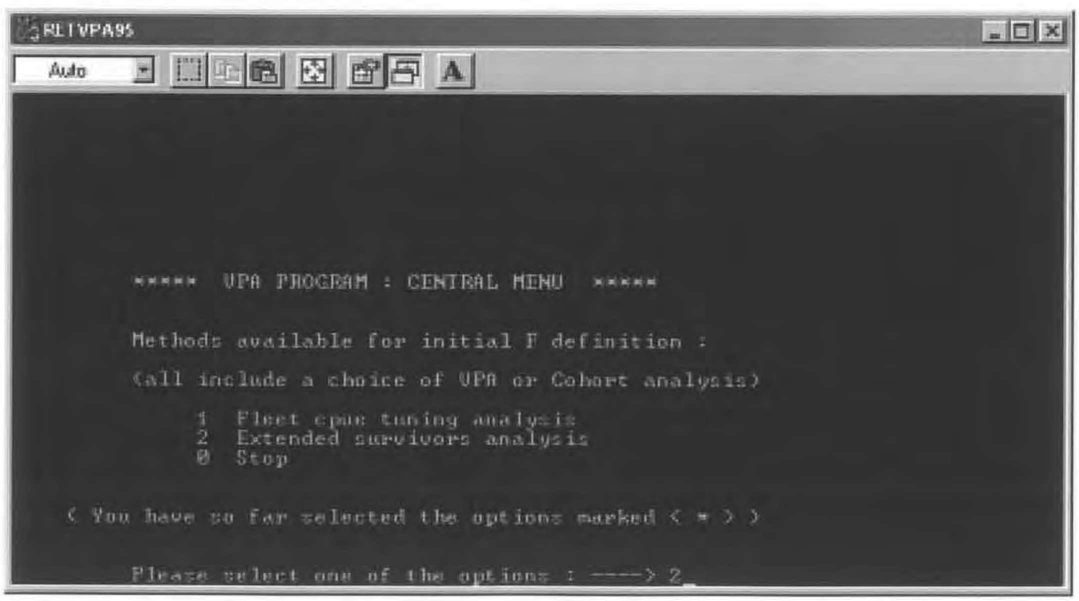
When carrying out retrospective analyses the selection of tuning fleets to be used in the assessments is important. Fleets with short time series should be avoided. As the program steps back through the data range they may drop out when there are insufficient years of fleet data for the specified analysis. In addition, short series with artificially low standard errors may erroneously dominate the assessment. The use of short time series can introduce sudden changes in the retrospective patterns and should be avoided. If required, the short series can be reintroduced for restricted retrospective analyses after the full runs.

Retrospective Extended Survivors Analysis

In the following text **action to be taken by the user** is highlighted in bold. The symbol ↵ is used to represent the Return or Enter key on the keyboard.

Open the VPA suite program and read in the index file C:\VPAS\DATA\BLACKFIN.IND. Take the default year, age and summary mean settings until the main menu is reached.

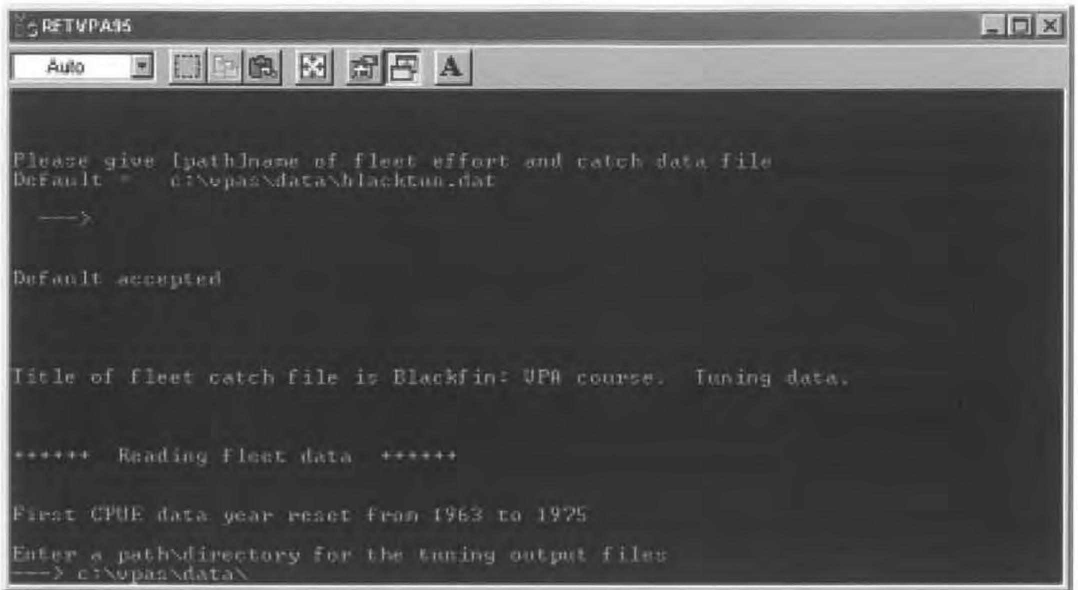
Note that we only have two options for the assessment model that we can run.



Type 2 ↵ to select the XSA model.
Type ↵ to select the default tuning data file, Blacktun.dat

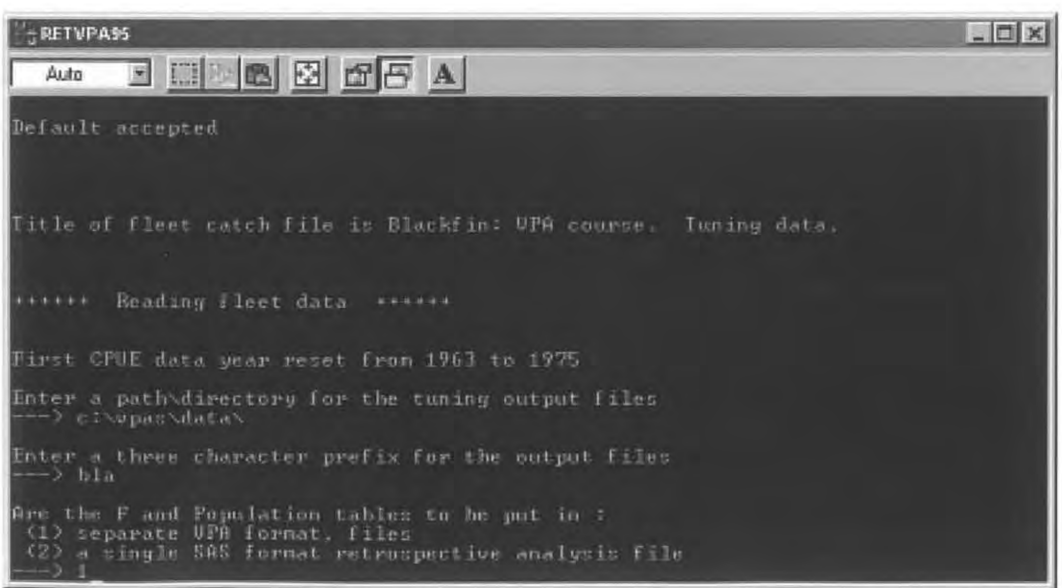
The retrospective program steps back in time fitting assessment models which finish in successively earlier years. It produces tuning diagnostic and population summary files. The user can specify where the files are to be placed.

Enter a directory path for the output files.



The program asks for a three letter code to prefix the output files for later identification. The program will create each tuning file by adding RT<yr>.CSV to the end of the prefix, <yr> represents the terminal year for the assessment being performed.

Enter a three letter code for the data files.



In addition to the tuning diagnostics files, the program generates output tables with one of two user-selected formats. They are:

1) F and population numbers-at-age tables for each assessment in the retrospective series and the stock time series summary (Tables 8, 10 and 16 from the main menu of the output from the main suite). The program will create each output file by adding RO<yr>.CSV to the end of the user-defined prefix.

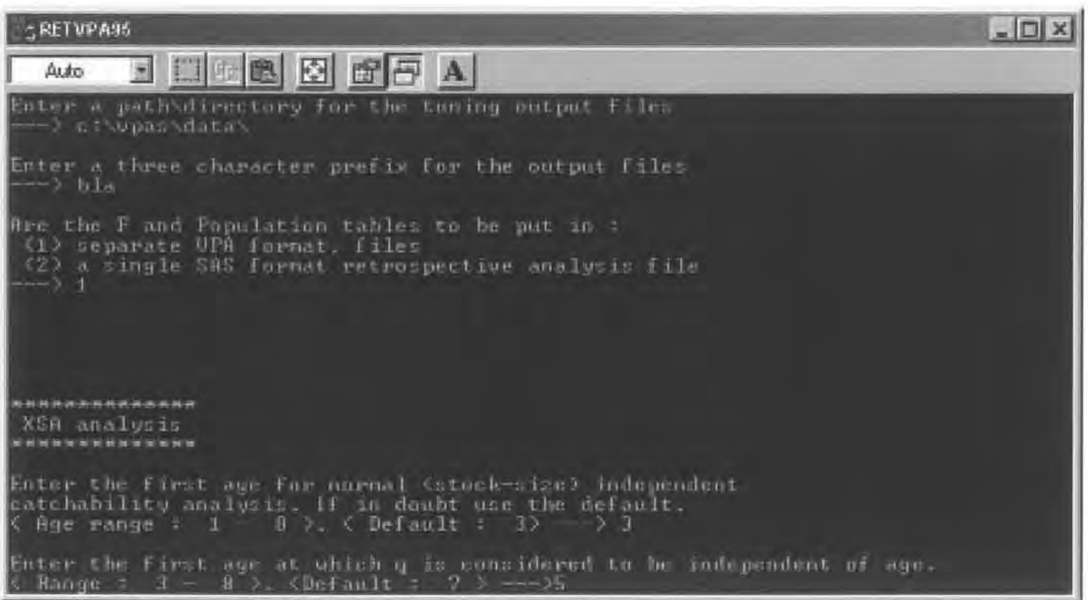
2) A single file containing the F and population numbers tables from each run in the format defined for the SAS program used to generate the figures and summary tables presented in ICES (MS 1991) and ICES (MS 1993).

Type 1 to output separate files.

We now set up the XSA analysis model that we wish to use retrospectively. The options are taken from Tutorial 4 that describes the fitting of the XSA model to the Blackfin data set.

Type 3 ↵ as the first age for the constant catchability model, that is, age 2 has a power model.

Type 5 ↵ so that catchability at ages older than 5 is set at that estimated at age 5.



Type Y ↵ in order to change the default XSA settings.

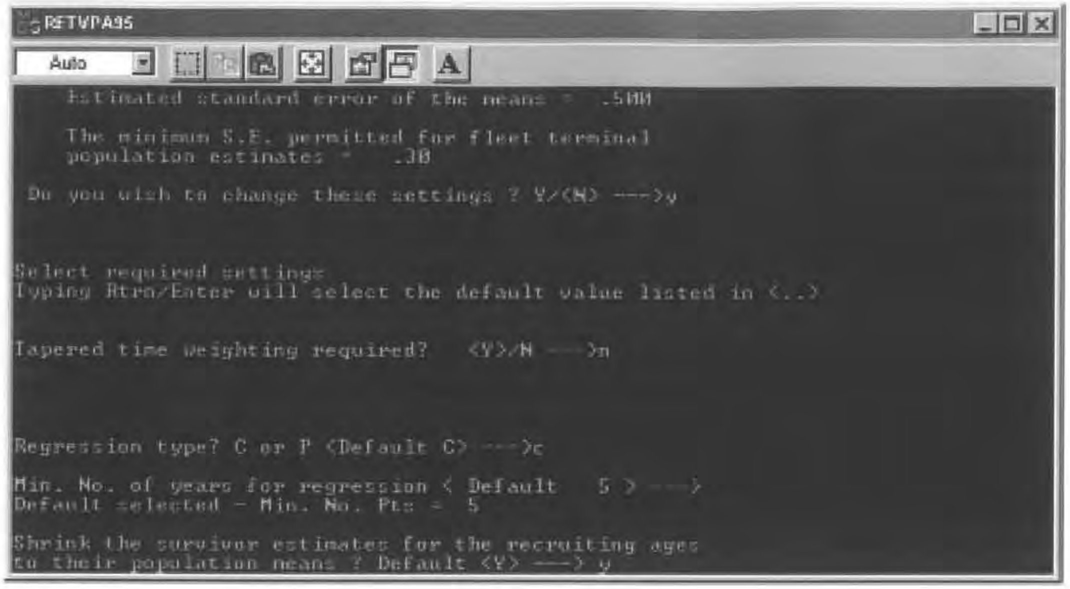
Type N ↵ to use all data in the time series with equal weight.

Type ↵ to apply the default calibration regression model

Type ↵ to take the default of a minimum of 5 data points for the fitting of a regression model.

Type ↵ to use the default option of shrinkage to the population mean with the calibration regression.

Type ↵ to take the default of using shrinkage to the mean fishing mortality.



Type ↵ to use 5 years in the fishing mortality shrinkage mean across years.

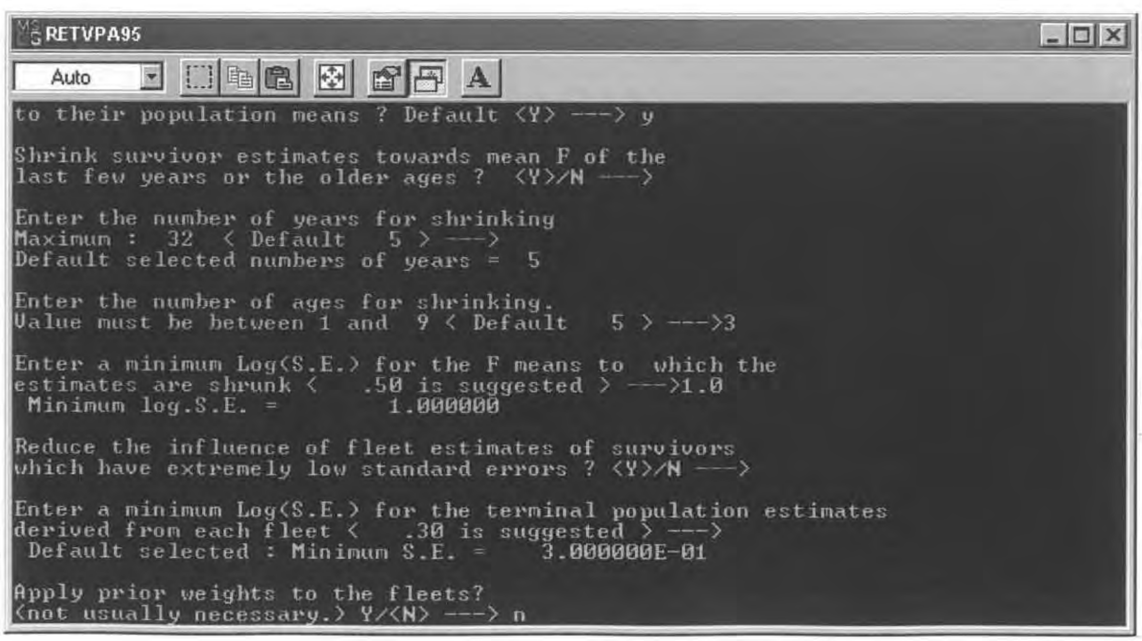
Type 3 ↵ to use 3 ages in the fishing mortality shrinkage mean across ages.

Type 1.0 ↵ for the weight (c.v) to be used for the fishing mortality shrinkage means.

Type ↵ to use a minimum value for the standard error.

Type ↵ to set the minimum to 0.3.

Type ↵ to take the default option of no individual fleet weighting.



After selection of the assessment method and model fitting options, the program asks an additional series of questions in order to define the characteristics of the retrospective run:

The first question refers to the use of the tuning data time series. The user can select between:

(1) a tuning range window, e.g. 10 years of fleet data, which is moved backwards with the terminal year for each new assessment, or
(2) the full data range in the tuning file and the removal of the most recent years data as the program steps back for each new terminal year.

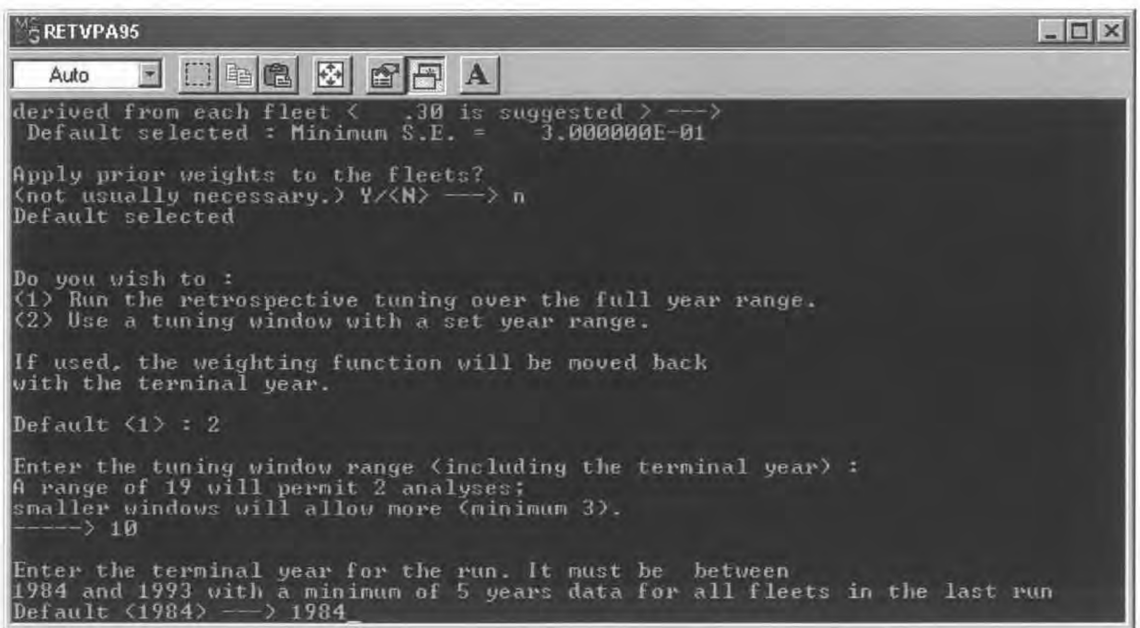
Time series weights, if used, are moved back with the assessment terminal year.

Type 2 to use a tuning window that will be moved back in time for each assessment.

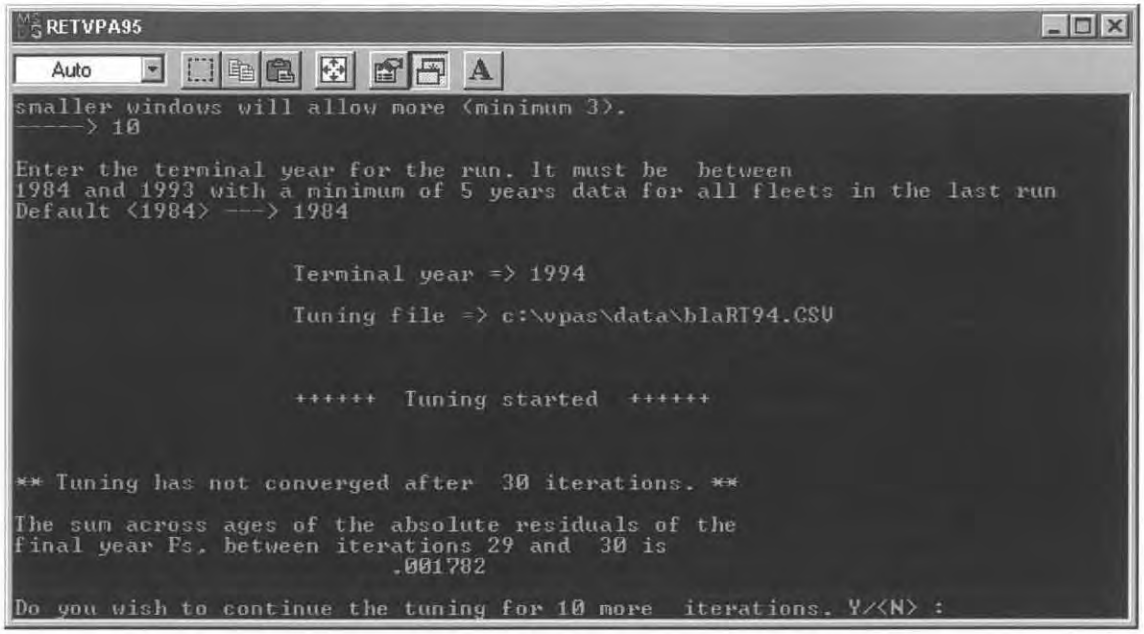
Type 10 for the number of years to use for the tuning range

The next question defines the number of years for which the retrospective analysis is to be run. Enter the finishing year for the run: the earliest terminal year. Acceptable values lie between the penultimate year in the data file and the earliest year in the complete tuning range that allows 5 years of data for each fleet. Short fleet tuning series should be removed if a retrospective series with sufficient comparison years for an acceptable analysis is to be achieved (8 years of tuning data will give 4 assessments in the retrospective series).

Type 1984 **for the final assessment year.**

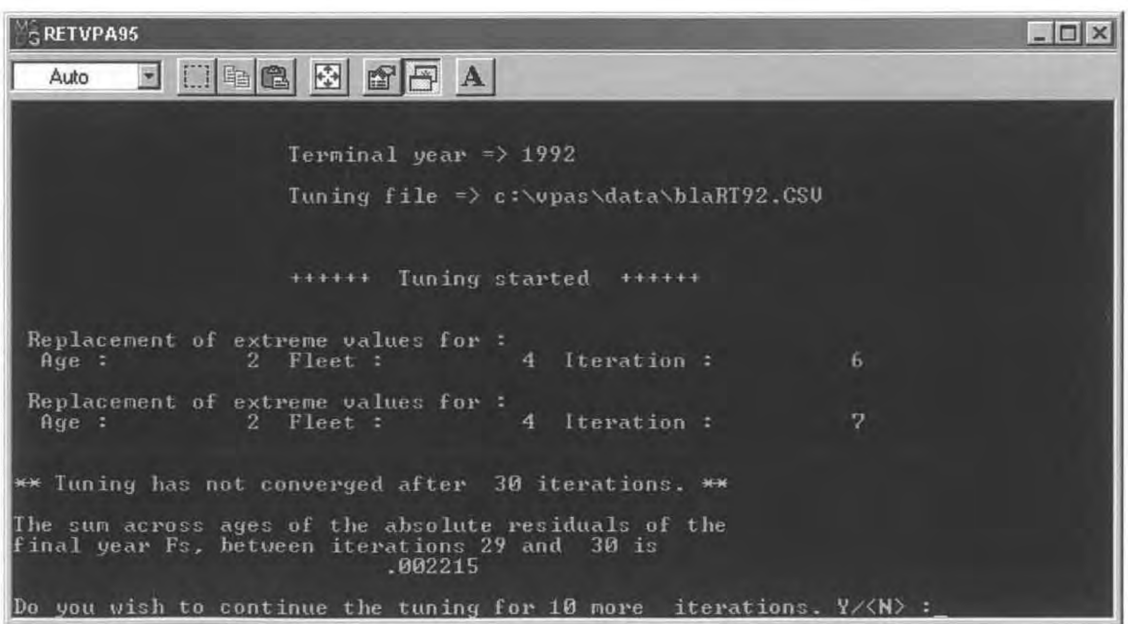


The program then begins the retrospective analysis of the data sets, printing the terminal year for the current assessment to the screen.

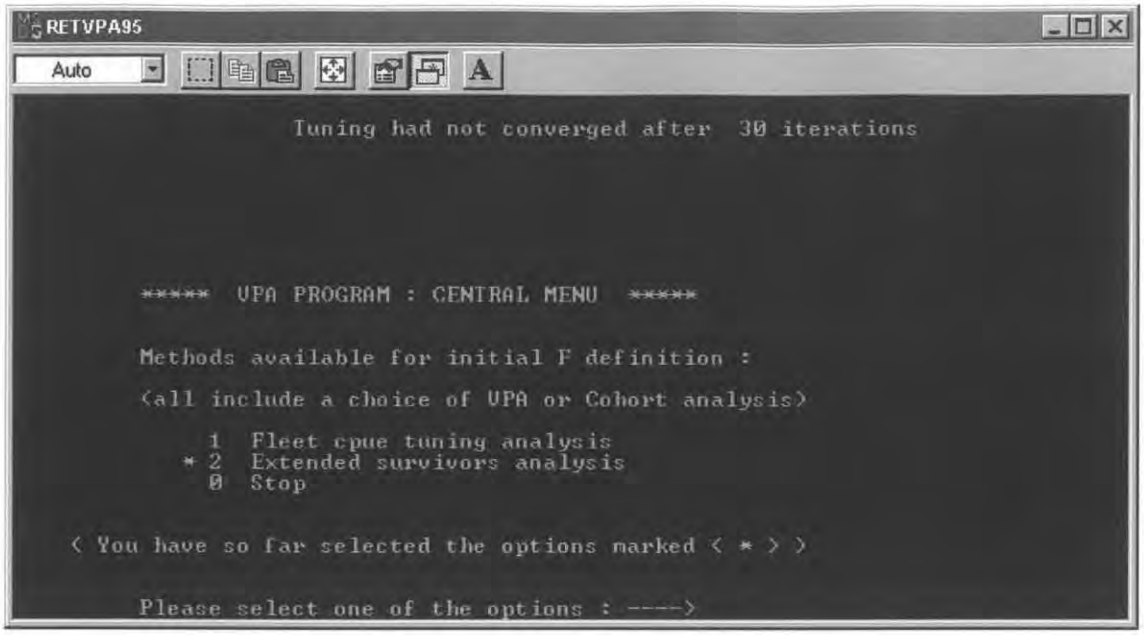


If the assessment has not converged after the required numbers of iterations (described earlier for each of the methods) the program will request clearance for further iterations.

When converged or the current assessment is terminated by the user, the program will write the output data to the file defined earlier. It will then proceed with the next assessment in the series.



After fitting an assessment to each of the user defined year ranges, the program returns to the central menu.



Results

In the directory specified for the retrospective analysis output files the program will write a tuning analysis and output summary file (Table 16) from each model fit. They are identified by the three character prefix followed by _ _ _RT<yr>.CSV, for the tuning file name and _ _ _RO<yr>.CSV for the summary files; <yr> represents the terminal year of the fitted assessment.

The analysis procedure involves the creation of retrospective time series plots for particular assessment estimates. Fig. 1–3 present the retrospective plots for the Blackfin assessment model. Fig. 1 is a plot of the time series of average fishing mortality estimates from each fit of the XSA model, Fig. 2 the estimates of recruitment and Fig. 3, spawning stock biomass.

The objective of the analysis is to compare the variation between the 'truth', the final assessment in the series, and the values estimated in each terminal year by earlier assessments. Note that this assumes that the most recent assessment, which uses all of the available data is the most unbiased.

For the majority of the time series of assessments, XSA estimates of the Blackfin stock fishing mortality are consistent from year to year (Fig. 1). The first two model fits overestimated fishing mortality; and in the most recent assessment runs there is a systematic under-estimation of average F with this XSA model structure. The model has consistently picked up the trends and the change points in fishing mortality.

The XSA estimates of Blackfin recruitment have been relatively consistent from year to year (Fig. 2). Historically there are three years in which the level of recruitment was underestimated and in recent years there is a systematic over-estimation of recruitment when using the specified XSA model structure. When fitting the XSA model we have used the power model at age 2.

The retrospective pattern for spawning stock biomass is of greater concern. Overall the assessments show an increase in the stock size during the 1960s and 1970s with a decline since the early 1980s. However, the rate at which that decline took place and when it began is uncertain (Fig. 3a). The most recent assessments with terminal years from 1990 to 1994 indicate that with the addition of more years of data the estimation of SSB is more consistent from year to year. There is no retrospective pattern that would cause concern (Fig. 3b).

Retrospective series should now be used to investigate the influence of particular assessment parameters (e.g. shrinkage to the mean F) on the accuracy and bias of the terminal year estimates. Changes to the assessment model structure are evaluated not only in terms of their influence on the model diagnostics, but also their ability to remove bias in the retrospective patterns of key model estimates. For SSB the changes to the model structure may not be required. For this stock we would be trying to improve the consistency of the estimates of fishing mortality and recruitment in the most recent years. For example a repeat of the retrospective run with a proportional catchability model at age 2 could be used to test the improvement in the predictions for recruitment.

Retrospective runs should be performed with a range of values for the selected parameter (all other parameter values are held constant), and the model structure producing the 'best' retrospective pattern chosen as the optimum value for the assessment of the particular stock. In order to simplify the analysis, it is assumed that there are no interactions in the effects on the assessment predictions.

Discussion

Sinclair *et al.* (MS 1990) and ICES (MS 1991) have shown that the biases in F and N estimates appear to be stock specific, and data induced. They are not attributable to a particular tuning methodology. Sinclair *et al.*, (MS 1990) concluded that the retrospective patterns found in the estimates for the stocks of the Northwest Atlantic could result from patterns of misreporting, trends in catchability, or mis-specification of natural mortality. Each will affect the data in a particular way and therefore influence the outcome of the tuning procedures.

ICES (MS 1991) established that the degree of bias could usually be reduced by the introduction of shrinkage to the mean F to the assessment packages. Subsequent work by the Methods Working Group has examined the influence of the degree of shrinkage imposed on the assessment (ICES, MS 1993). It recommended that retrospective analyses be used regularly to screen stock assessments.

The retrospective problem has been recognized as widespread and serious. The reasons why this problem appears are not fully known. There is a general understanding that trends in catchability, when used in models that assume constancy can cause this effect. However, it has been clearly demonstrated that the problem is more complex and that for example trends or shifts in natural mortality, discards and misreporting, mis-specification of selection and catchability at age can contribute to the problem, sometimes in a quite complex way (ICES, MS 1997).

Warning

There may be cases where the present estimate of the stock trajectory is biased, whilst those in the past may have been "right" (ICES, MS 1997). This is illustrated by the early retrospective series of the Blackfin retrospective sequence. The retrospective assessments carried out with the terminal years between 1984 and 1988 (Fig. 3c) show that the SSB was apparently consistently under-estimated during those years. In each successive year the level of SSB is increased and the latest assessment in the sequence estimates that there was a high stable stock between 1973–84.

Taking the final assessment estimates, with terminal year 1988, as the "truth", the assessment model structure would usually be altered to make the earlier assessment as consistent as possible with it. However if we examine the most recent assessments with the early series (Fig. 3c) is seen that the retrospective pattern noted in the early years was caused by the assessment estimates having a successively greater bias from the "truth" – the most recent (1994) perception of the stock trends. The estimated SSB series terminating in 1988 was actually the most distant (biased) from the most recent perception of the stock dynamics. This is a warning case where alteration of the assessment model structure to correct the retrospective pattern would have induced bias to the assessment results. Simply changing the assessment model structure to correct a retrospective pattern would have been incorrect in this instance.

References

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ICES. MS 1991 Report of the Working Group on Methods of Fish Stock Assessment. *ICES C.M. Doc.*, No. /Assess: 25, 147 p.

1993 Report of the Working Group on Methods of Fish Stock Assessment. *ICES C.M. Doc.*, No. /Assess:12, 86 p.

1997 Report of the Working Group on Methods of Fish Stock Assessment. *ICES C.M. Doc.*, No. /Assess:12, 86 p.

SINCLAIR, A., D. GASCON, R. O'BOYLE, D. RIVARD and S. GAVARIS, MS 1990. Consistency of some Northwest Atlantic groundfish stock assessments. *NAFO SCR Doc.*, No. 96, Serial No. N1831, 26 p.

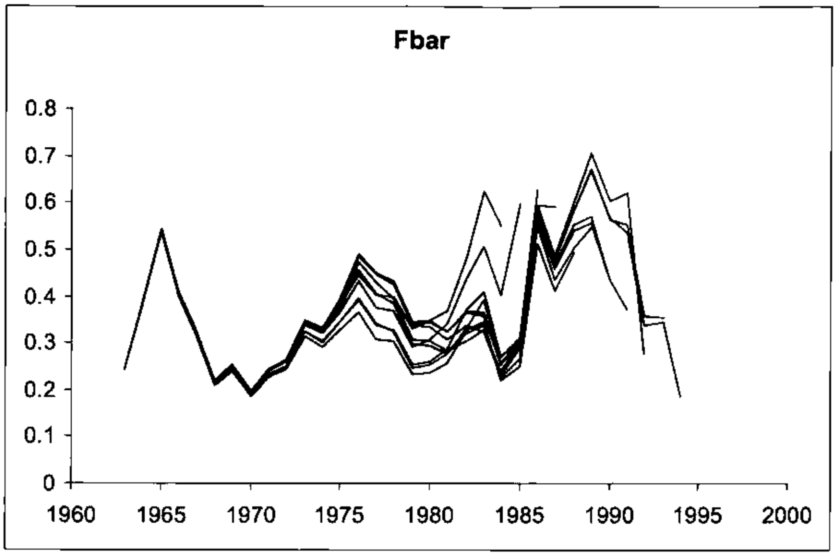

Fig. 1. The retrospective time series of XSA estimates of Blackfin average fishing mortality.

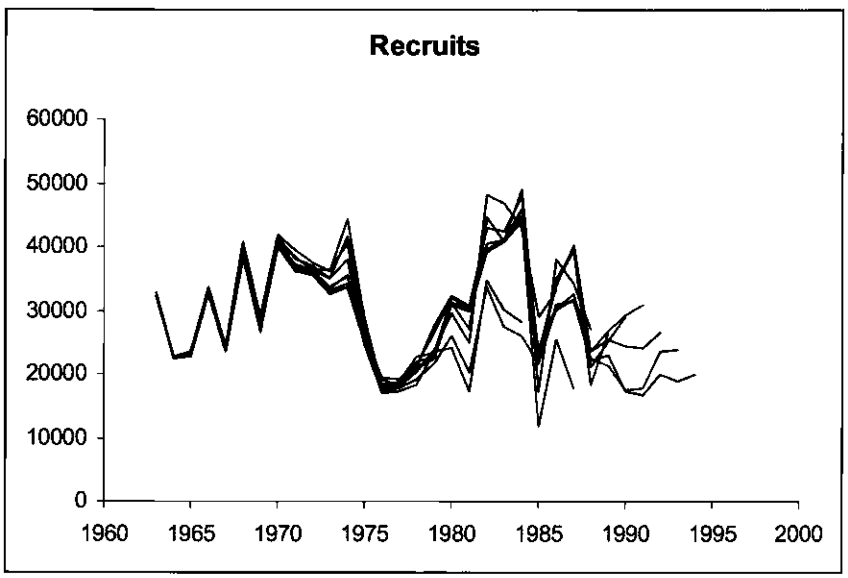

Fig. 2. The retrospective time series of XSA estimates of recruitment-at-age 1 to the Blackfin stock

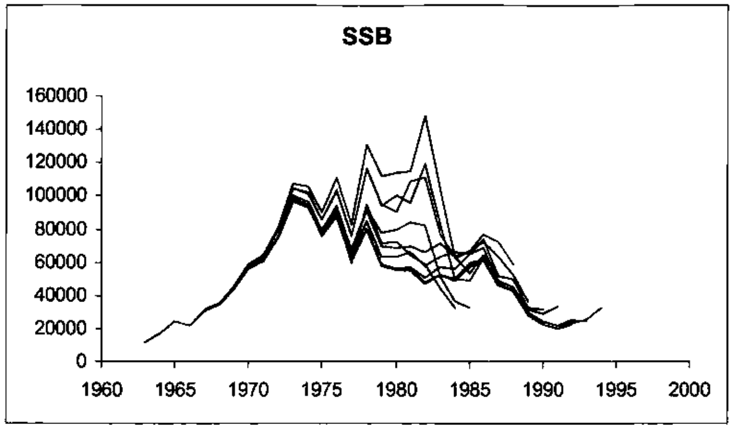

Fig. 3a. The retrospective time series of XSA estimates of spawning stock bioass of the Blackfin stock for the assessments ending in the years 1984–94.

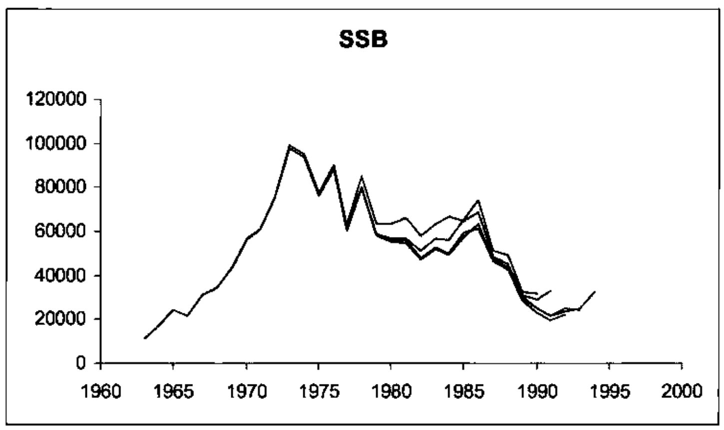

Fig. 3b. The retrospective time series of XSA estimates of spawning stock bioass of the Blackfin stock for the assessments ending in the years 1990–94.

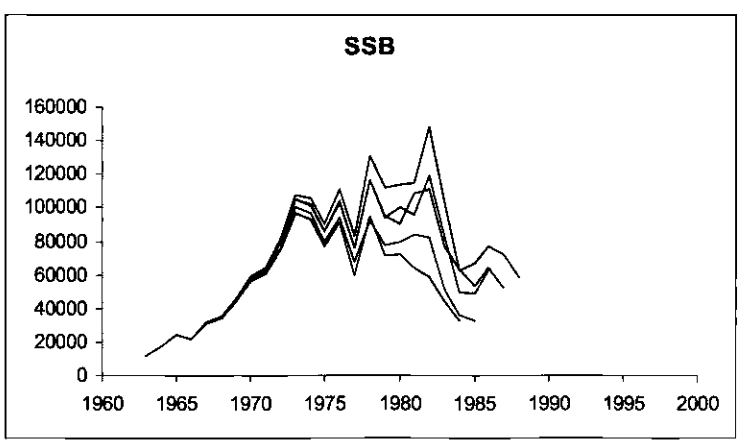

Fig. 3c. The retrospective time series of XSA estimates of spawning stock bioass of the Blackfin stock for the assessments ending in the years 1984 – 1988.

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Appendix 1: Lowestoft Stock Assessment Suite

Tutorial 6

The Multi-Fleet Deterministic Projection Program (MFDP)

by

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Abstract

This document is number six in a series of tutorials designed to assist users of the Lowestoft VPA Suite assessment software and prediction programs which use the results. The tutorial takes the user through the options required for running the multi-fleet deterministic projection program MFDP developed for ICES at CEFAS.

Introduction

This document is part of a series of tutorials that provide an introduction to the Lowestoft VPA Suite assessment software and programs which make use of the results from it. The tutorial takes the user through the options required for running multi-fleet deterministic projection program MFDP1a.exe. The tutorial assumes that the required Blackfin data files have been placed in a directory c:\vpas\data\prediction, and that the prediction index files (Blpred_standard.ind, Blpred_discards.ind) contain path names that point to the appropriate files.

In the following text **action to be taken by the user** is highlighted in bold. The symbol ↵ is used to represent the Return or Enter key on the keyboard.

Installation of the Program

Copy the directory C:\VPAS\PROGRAMS\MFDP\ to a directory on your computer. Using Explorer go to the directory C:\VPAS\PROGRAMS\MFDP\Disk1. Start the program Setup.exe and follow the on screen instructions

Data Files

The program will carry out predictions using historic data sets from age structured assessments. The user selects the targets for fishing mortality or TAC constraints for each fleet from within the user dialogs. In addition the program will allow the user to set up future selection pattern and catch weight files that can be used to examine potential changes in selection etc. Here we only consider runs from historic data.

The program uses an index file that is similar to (but not the same as) the Lowestoft format index file used for inputting data to the Lowestoft VPA Suite stock assessment program (Darby and Flatman 1994). The index file for historic data is given below, the differences in the index files are that the first, ninth, tenth and eleventh files from the VPA suite list have been omitted in MFDP. The missing files are the total landings and the optional fishing mortality on the oldest age, fishing mortality in the final year and fleet tuning files.

Several files have been added to the list required for MFDP, these are:

for single fleet or category disaggregated predictions

1) the fishing mortality at age for each of the historic assessment years;

2) population numbers at age for the historic assessment years **and one extra year** the survivors at the start of the year after the final assessment year;

in addition **for multifleet predictions**

3) a file for each fleet with total and category disaggregated catch numbers at age
4) a file for each fleet with total and category disaggregated catch weights at age

The complete index file list for a run using historic data is given below:

Index file contents	Index file number
Title	
Historic data flag (1 = Historic, 0 = Future)	
Total catch numbers at age numbers file name and path	2
Weight at age in the catch file name and path	3
Weight at age in the stock file name and path	4
Natural mortality file name and path	5
Proportion mature file name and path	6
Proportion of F before spawning file name and path	7
Proportion of M before spawning file name and path	8
Fishing mortality file name and path	12
Population numbers file name and path	13

If the prediction is not fleet or category disaggregated then this is sufficient, however if fleet or category disaggregation is required then the following lines are required.

Index file contents	Index number
Number of fleets	
Fleet 1 catch numbers at age file name and path	2
...	2
Fleet n catch numbers at age file name and path	2
Fleet 1 weight at age in the catch file name and path	3
...	3
Fleet n weight at age in the catch file name and path	3
An optional control file, if specified it must always be the last file.	

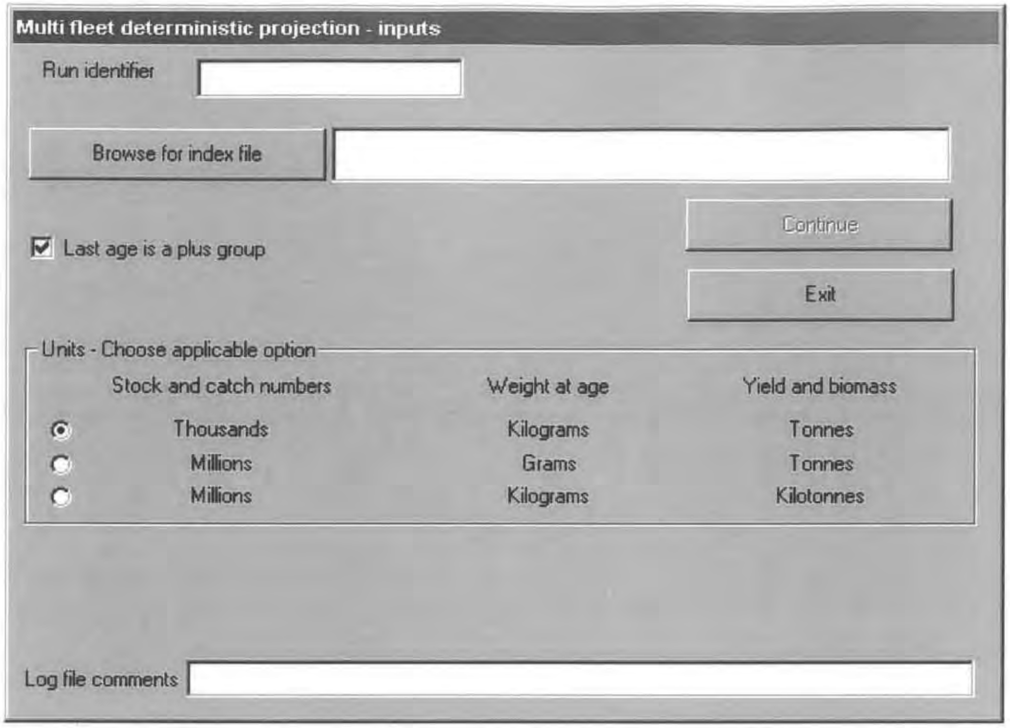
Note: If the population and fishing mortality files from the final assessment have a different age range to that of the initial VPA suite input data files, the program will make the adjusment to the new range for the user.

Running the Program for a Single Fleet Prediction

Open program MFDP1a.EXE from within Windows Explorer or using the Start button

Press the F1 key, this is the undocumented way to see the help file and documentation. The help files are installed in the C:\windows\help directory during setup.

Initially, the program presents the inputs dialog screen. The run identifier should be entered, the plus group specified and the index file located using the browse button. If errors are encountered in the input data then control will return to the inputs dialog and an error message is displayed in red type. The user can makes changes to the files, within a text editor, without closing the program and press browse again to continue. If no errors are encountered a message is displayed detailing the directory in which output files will be saved.



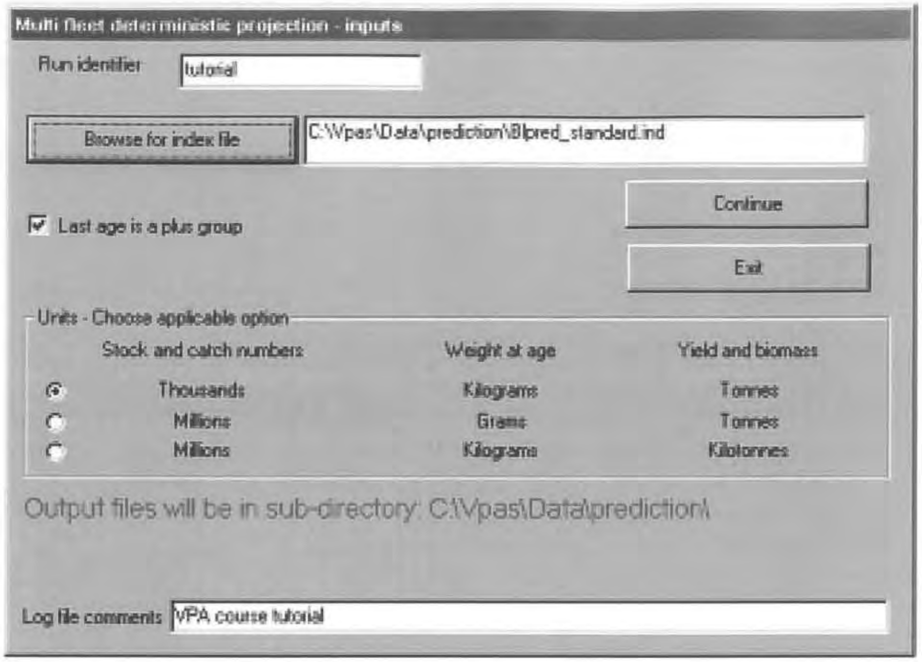
Enter run identifier.

Enter any log file comments required.

Check if the last age is age plus group for this projection run and set the option box.

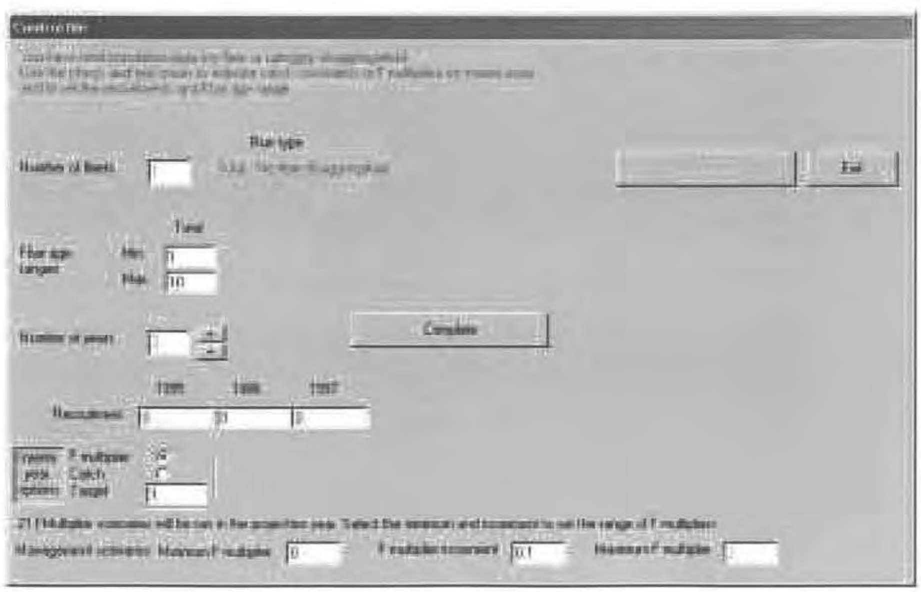
Check the units for the run

Browse for the projection run index file C:\VPAS\DATA\PREDICTION\Blpred_standard.ind.



Note that on return from the browsing the data file, the program has parsed the data files and should report any errors as red text printed above the log file comments box. If there are no errors the program will inform the user that the output files will be put in the same directory as the index file.

Press the continue button.



The text at the top of the control file box should describe the run type that you are trying to achieve. In this example we are running a single fleet projection with no disaggregation into discards or multiple use of the landed catch.

Set the minimum and maximum age for the Fbar age range.

Set the number of projection years to the required time series.

The "normal" catch forecast table has three years: the intermediate year of the assessment, the TAC year and the SSB forecast year. The defaults settings are for this form of forecast table.

Set the recruitment values for the initial age to the values required for the projection years.

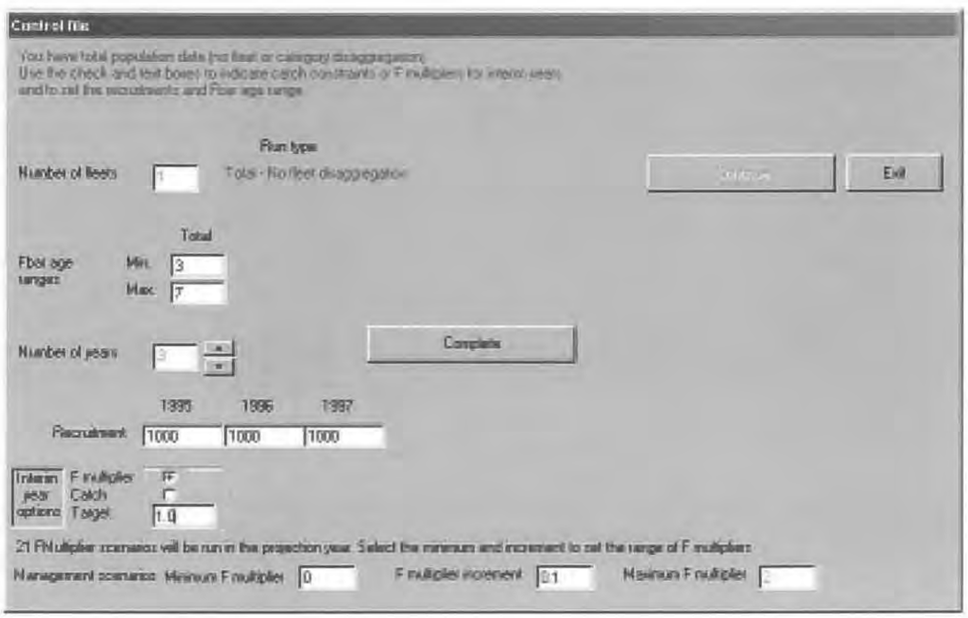
Set the intermediate year forecast option to either an F constraint or a catch constraint.

These options allow the user to specify whether a catch or F multiplier is to be used in each intermediate year. If the number of years is altered then the F multiplier and catch option buttons will be added to, or removed from the dialog. If the run is a multi target type run then these controls are not visible and are presented by fleet on a subsequent dialog.

Enter the F multiplier or catch target for the intermediate year.

In this example we shall use a status quo fishing mortality constraint in the intermediate year; an F multiplier of 1.

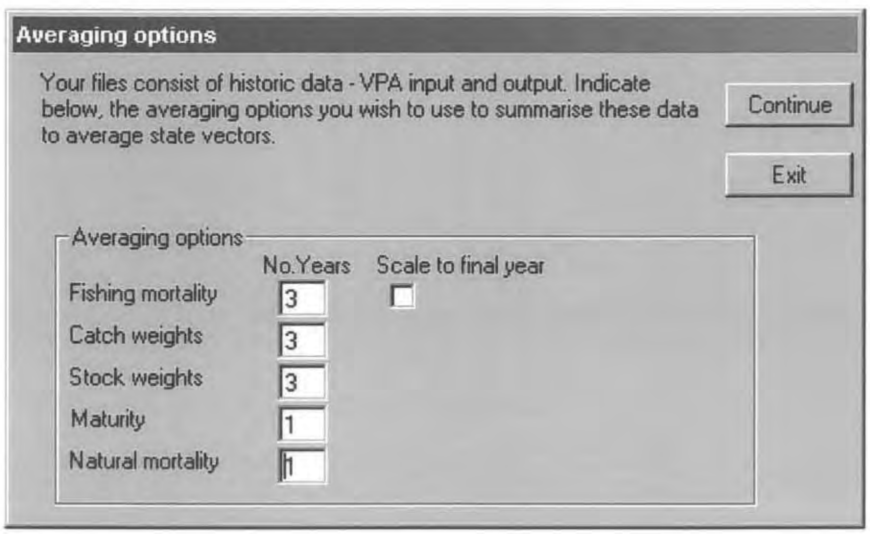
The management option table minimum, maximum and increment can usually be left unchanged. The default setting will give the standard management option table.



Press the complete button.

The button vanishes and the Continue button is enabled if the settings conform to the required input. The red information text changes and the program creates a control file for future usage.

Press the Continue Button. The program now requires us to set up the vectors used for the predictions. Initially this is carried out using the usual averaging process but the individual year vectors can be modified subsequently if required.



Set the required time periods to be used in calculating the average vectors.

Set the scale to the final year box if required.

Press the continue button.

If we require user input of specific values of population numbers, weights or fishing mortalities etc. we can check any of the required boxes and edit the vectors to be used in the forecast. The vectors should always be reviewed for outliers.

Each of the input data vectors is presented in turn in the format shown below.

After reviewing each input data set the program runs to completion

New Input Data Files

The program creates up to a series of 12 new input data files in the same directory as the index file. The files are prefixed by the run identifier entered by the user and contain the vectors of fishing mortalities, maturity at age etc. for the years over which the projection was made. They allow repeat runs using the same prediction vectors, without having to go through the set up process again. The file names are:

File contents	Filename
Index	RunCode + "ind.txt"
Natural mortality	RunCode + "M.txt"
Total catch weight	RunCode + "CWt.txt"
Stock weight	RunCode + "SWt.txt"
Maturity	RunCode + "Mat.txt"
Proportion of F before spawning	RunCode + "PF.txt"
Proportion of M before spawning	RunCode + "PM.txt"
Population numbers	RunCode + "N.txt"
Total fishing mortality	RunCode + "F.txt"
Control file	RunCode + "Ctrl.txt"

If the data are fleet disaggegated then fleet disaggegated files will be produced giving the fleet selection patterns and catch weights and the total fishing mortality and total catch weight files will not be created.

File contents	Filename
Disaggregated selection pattern	RunCode + "FleetF" + fleet number + ".txt"
Disaggregated catch weights	RunCode + "FleetCWt" + fleet number + ".txt"

Output Files

The following 5 files of output are produced:

Results in a comma delimited file with a format based on that specified by the ICES Workshop on Standard Assessment Tools for Working Groups (MS 1999), but with minor modifications (see Modifications to Workshop on Standard Assessment Tools for Working Groups output format, below). This file is named with a filename of the run index and the file extension .pro. If no run index has been specified then results will be appended to a file named MFDP.pro (Table 1).

Results in a comma delimited file with a structure similar to that of the prediction with management options table currently used by ICES. This file is named with a filename of the run index and the file extension .prm. If no run index has been specified then results will be appended to a file named MFDP.prm (Table 2).

Results in a comma delimited file with a structure similar to the single option prediction: detailed tables currently used by ICES. This file is named with a filename of the run index and the file extension .prs. If no run index has been specified then results will be appended to a file named MFDP.prs (Table 3).

A comma delimited file containing the steady state vectors used for the projection, in a form similar to the prediction with management: input data table used by ICES. This file is named with a filename of the run index and the file extension .prd. If no run index has been specified then results will be appended to a file named MFDP.prd (Table 4).

A log file in comma delimited format containing the files used for the run, the raw data, the options chosen, truncated data when appropriate, the steady state vectors, and a summary of the results. The log file is named with the run code and the file extension .prl. If no run code has been specified then this file is named MFDP.prl (Table 5).

NOTE: **If repeat runs are made with the same run identifier, the results for each run are appended to the existing files along with the run name, program name and version, stock name, time and date.**

Plotting and Tablulating Results

Open the spreadsheet TEMPLATE1.XLS

Open the output file from the MFDP run TUTORIAL.PRM in EXCEL. The file is comma separated.

Copy the sheet from TUTORIAL.PRM and paste it into the prm sheet of TEMPLATE1.XLS.

On the sheet labeled Chart (Fig. 1), the right hand graph is the standard ICES short-term forecast plot which shows the forecast catch at different levels of fishing mortality two years beyond the assessment series and for SSB three years ahead. The data is automatically plotted when the prm sheet is updated.

Running the Program for a Multi fleet or Single fleet with Discards Prediction

Open program MFDP.EXE from within Windows Explorer or using the Start button

Enter run identifier.

Enter any log file comments required.

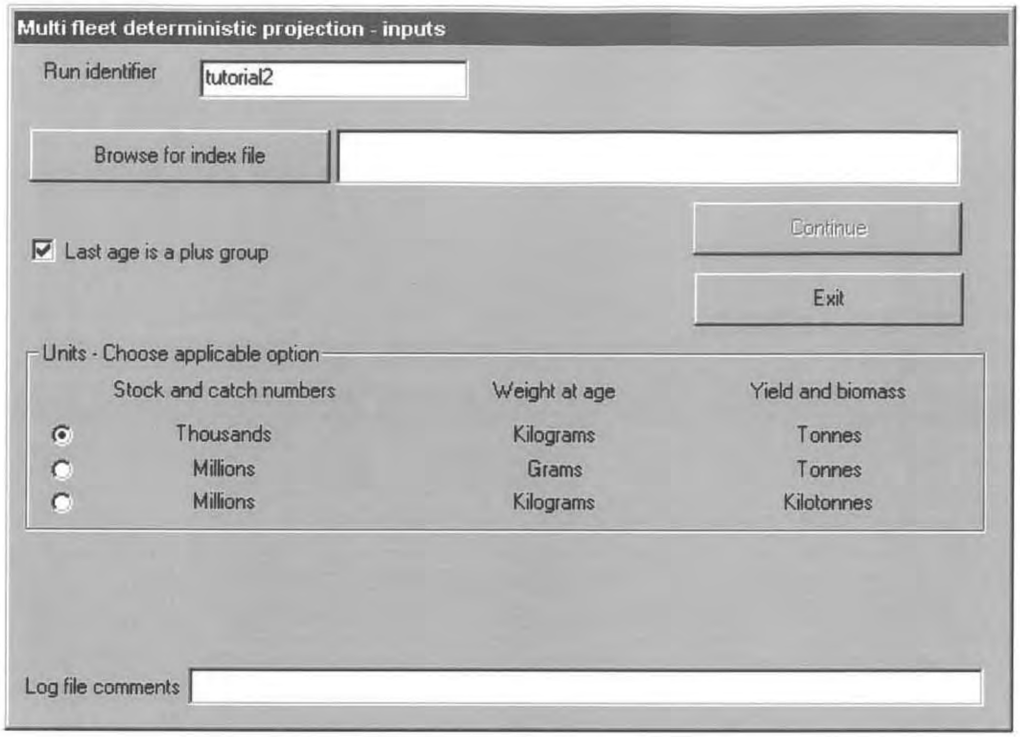
Check if the last age is age plus group for this projection run and set the option box.

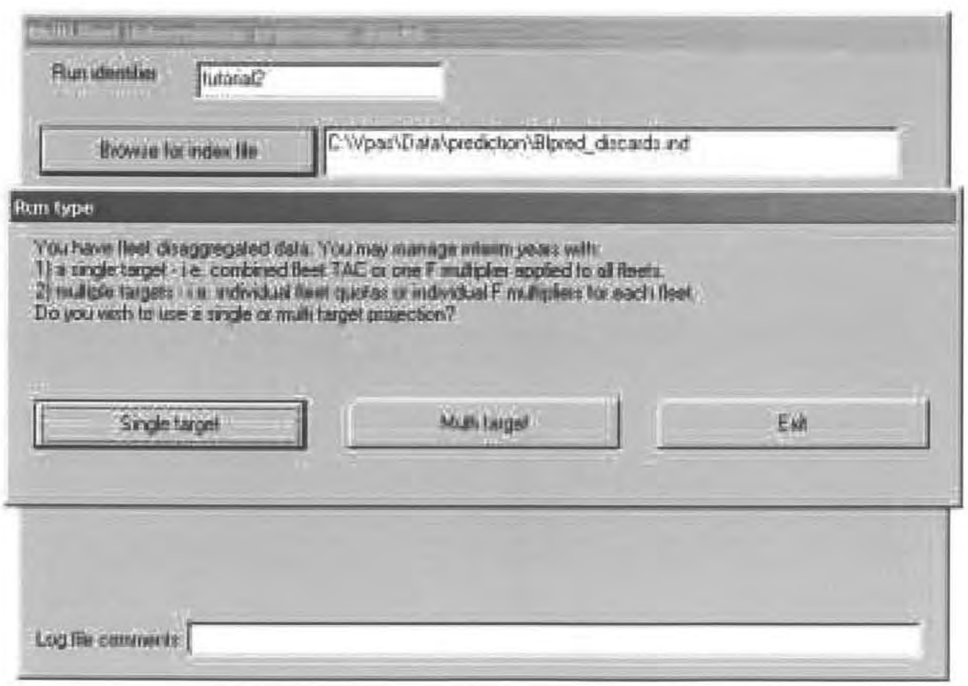
Check the units for the run

Browse for the projection run index file C:\VPAS\DATA\PREDICTION\Blpred_standard.ind.

If errors are encountered in the input data then control will return to the inputs dialog and an error message is displayed in red type. The user can makes changes to the files, within a text editor, without closing the program and press browse again to continue. If no errors are encountered a message is displayed detailing the directory in which output files will be saved.

The index file for a multi fleet (or a single fleet disaggregated by category) contains more information than the single fleet index file. The user must supply catch numbers at age files with total catch at age in each year and also the values for each fleet (see the help F1) and disaggregated catch weight at age files.



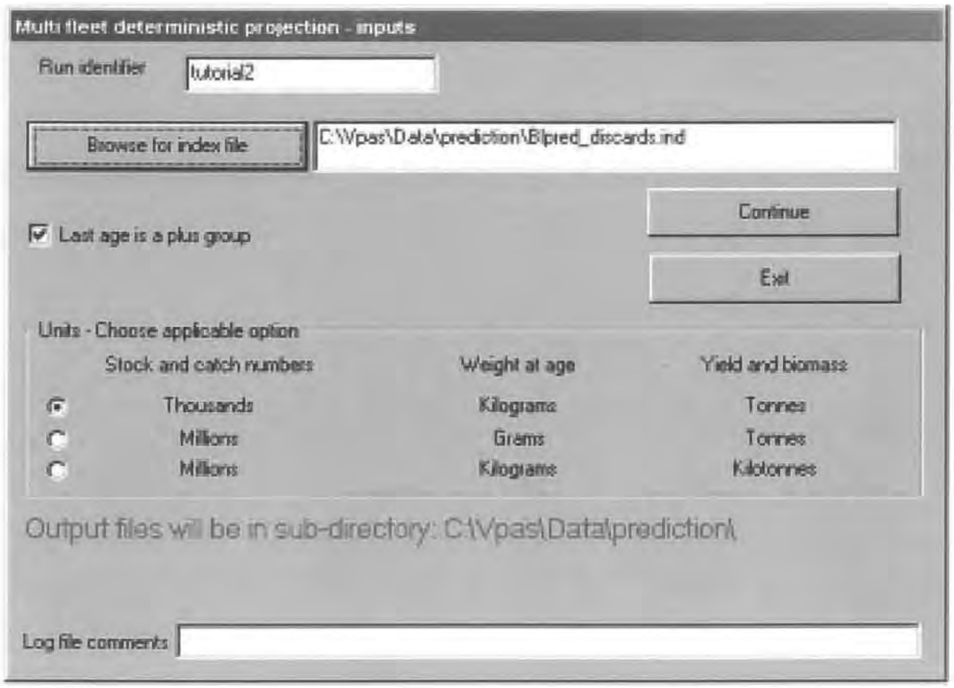


The program reads the information in the index file and notes that this will be a two category (human consumption and discards) prediction.

Select a single target such as a combined fleet TAC or F multiplier or a multi target run.

On return from the browsing the data file, the program has parsed the data files and should report any errors as red text printed above the log file comments box. If there are no errors the program will inform the user that the output files will be put in the same directory as the index file.

Press the continue button.



The multi fleet program has similar input settings to those of the single fleet run.

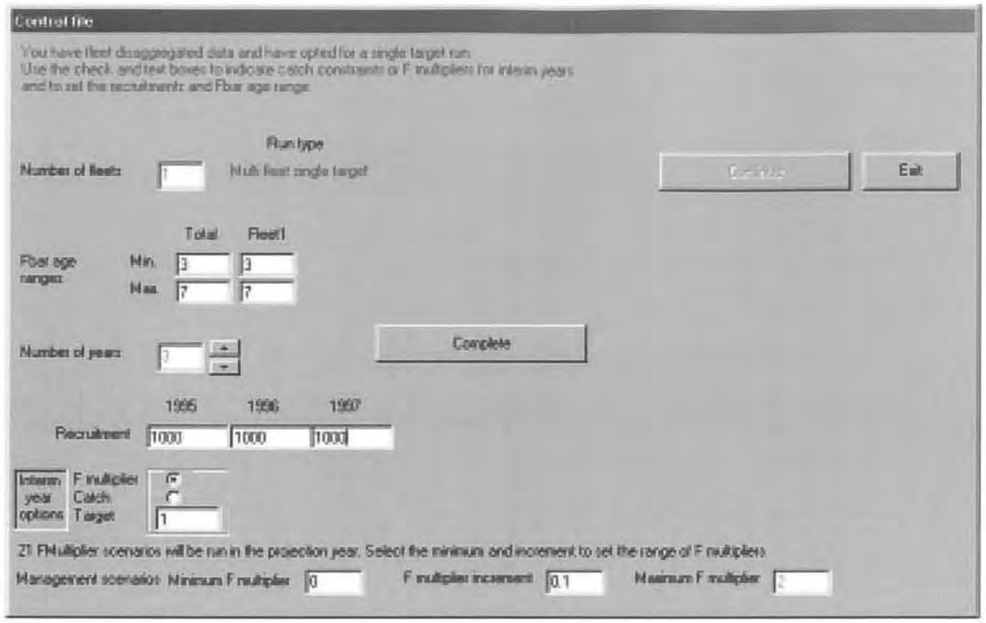
Enter the reference ages for fishing mortality of each fleet.

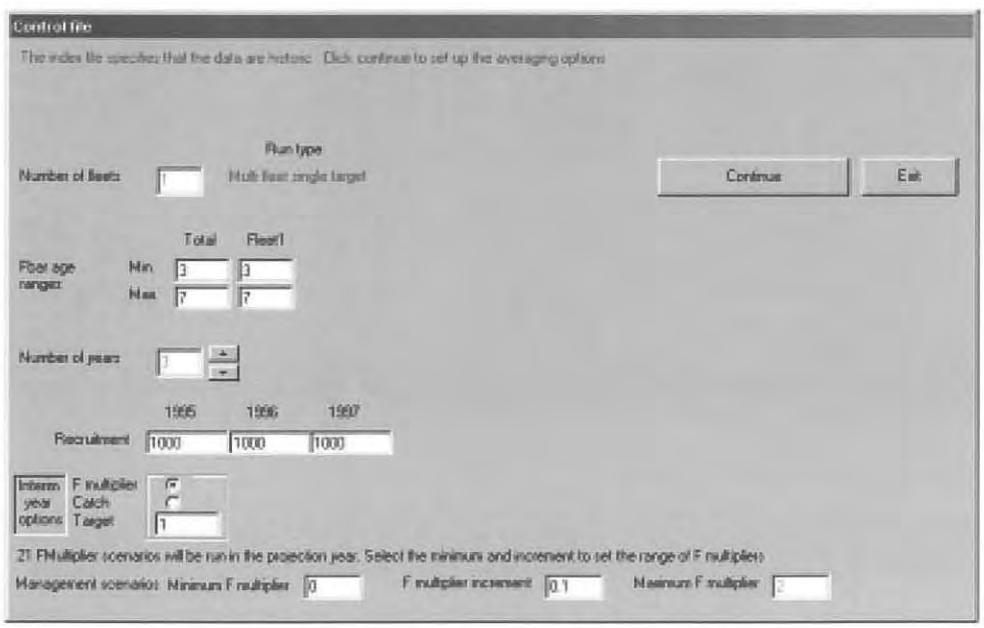
Select the number of years for the forecast and enter the recruitment at the first age for each year.

Enter the fishing mortality multiplier, in this case 1.0 for a status quo projection.

Do not adjust the range of F's or increment it is not usually necessary.

Press complete, to indicate that the inputs are complete. The program notes that the data are historic and sets up a control file. Press continue.

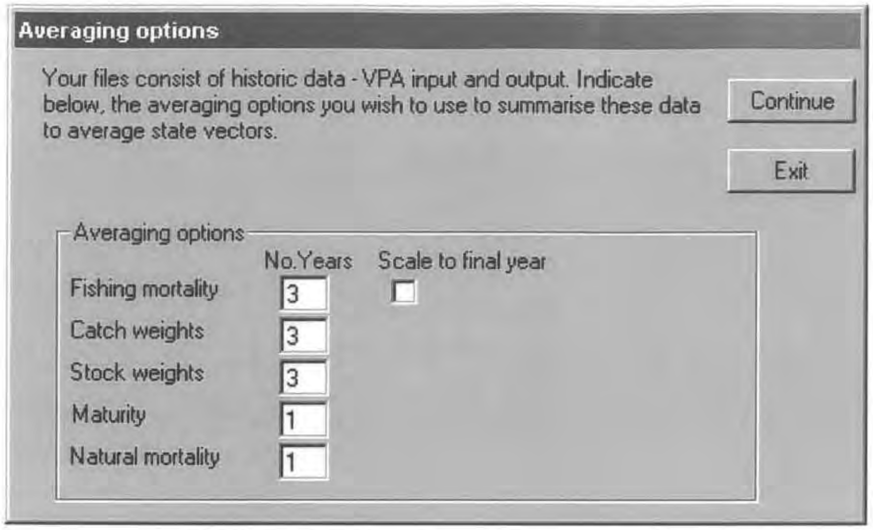




As before the program requires us to set up the vectors used for the predictions. Initially this is carried out using the usual averaging process but the individual year vectors can be modified subsequently if required.

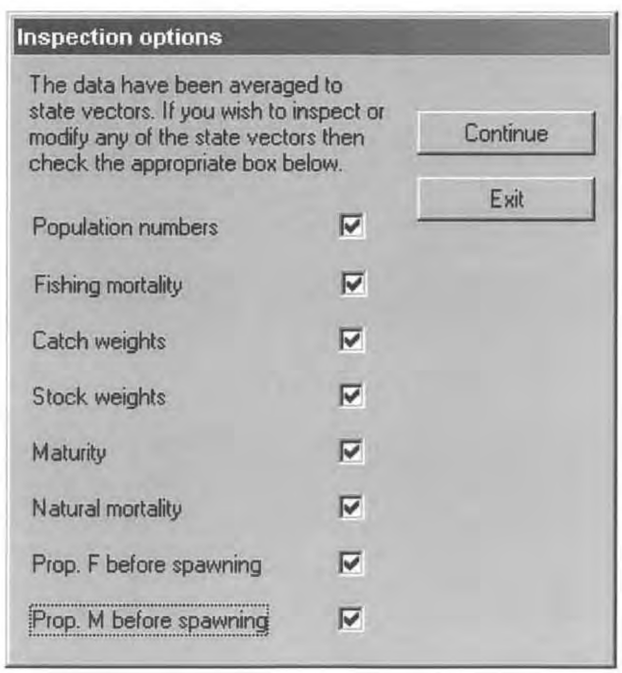
Set the required time periods to be used in calculating the average vectors.

Set the scale to the final year box if required.



Press the continue button.

If we require user input of specific values of population numbers, weights or fishing mortalities etc. we can check any of the required boxes and edit the vectors to be used in the forecast. The vectors should always be reviewed for outliers.



Each of the input data vectors is presented in turn in the format shown below.

After reviewing each input data set the program runs to completion

Output Files

The output files of are the same 5 file types produced for by the single fleet run.

NOTE if repeat runs are made with the same run identifier, the results for each run are appended to the existing files along with the run name, program name and version, stock name, time and date.

Plotting and Tabulating Results

Open the spreadsheet TEMPLATE2.XLS

Open the output file from the MFDP run TUTORIAL2.PRM in EXCEL. The file is comma separated.

Copy the sheet from TUTORIAL2.PRM and paste it into the prm sheet of TEMPLATE2.XLS.

On the sheet labeled Chart, the right hand graph is the short-term forecast plot which shows the forecast catch at different levels of fishing mortality two years beyond the assessment series and for SSB three years ahead. The data is automatically plotted when the prm sheet is updated.

References

DARBY, C. D. and S. FLATMAN. 1994. Virtual Population Analysis: Version 3.1 (Windows/DOS) user guide. *Info. Tech. Ser.*, MAFF Direct. Fish. Res., Lowestoft, **1**: 85 p.

ICES, MS 1999. Report of the Workshop on Standard Assessment Tools for Working Groups, Aberdeen, United Kingdom, 3–5 March 1999. *ICES C.M. Doc.*, No. 1999/ACFM:25.

TABLE 1. The MFDP short-term forecast results in the ICES SGFADS file format (*.pro)

Short term	MFDP vers	Blackfin: A	Run:tutoria		01:55	03/02/02		
1								
3								
21								
1995								
Total								
3	7							
-99	1	0.601933		0	12060.11		0	9363.821
1996								
Total								
1	0	0		0	0		0	9575.09
2	0.1	6.02E-02		0	1288.179		0	9575.09
3	0.2	0.120387		0	2493.309		0	9575.09
4	0.3	0.18058		0	3621.171		0	9575.09
5	0.4	0.240773		0	4677.126		0	9575.09
6	0.5	0.300967		0	5666.144		0	9575.09
7	0.6	0.36116		0	6592.838		0	9575.09
8	0.7	0.421353		0	7461.483		0	9575.09
9	0.8	0.481547		0	8276.05		0	9575.09
10	0.9	0.54174		0	9040.221		0	9575.09
11	1	0.601933		0	9757.415		0	9575.09
12	1.1	0.662127		0	10430.81		0	9575.09
13	1.2	0.72232		0	11063.34		0	9575.09
14	1.3	0.782513		0	11657.76		0	9575.09
15	1.4	0.842707		0	12216.6		0	9575.09
16	1.5	0.9029		0	12742.23		0	9575.09
17	1.6	0.963093		0	13236.84		0	9575.09
18	1.7	1.023287		0	13702.47		0	9575.09
19	1.8	1.08348		0	14141.03		0	9575.09
20	1.9	1.143673		0	14554.27		0	9575.09
21	2	1.203867		0	14943.84		0	9575.09
1997								
1	20127.82							
2	18739.4							
3	17450.9							
4	16254.92							
5	15144.62							
6	14113.67							
7	13156.23							
8	12266.88							
9	11440.63							
10	10672.85							
11	9959.259							
12	9295.893							
13	8679.091							
14	8105.463							
15	7571.872							
16	7075.415							
17	6613.403							
18	6183.349							
19	5782.951							
20	5410.074							
21	5062.745							

Input units are thousands and kg - output in tonnes

TABLE 2. The Blackfin MFDP single category short-term forecast management options table output (*.prm).

MFDP version 1a
Run: tutorial
Blackfin: Assessment course. Combined sex; plusgroup.
Time and date: 01:55 03/02/02
Fbar age range: 3-7

1995				
Biomass	SSB	FMult	FBar	Landings
34816	9364	1	0.6019	12060

1996					1997	
Biomass	SSB	FMult	FBar	Landings	Biomass	SSB
23924	9575	0	0	0	27071	20128
.	9575	0.1	0.0602	1288	25476	18739
.	9575	0.2	0.1204	2493	23988	17451
.	9575	0.3	0.1806	3621	22601	16255
.	9575	0.4	0.2408	4677	21306	15145
.	9575	0.5	0.301	5666	20098	14114
.	9575	0.6	0.3612	6593	18970	13156
.	9575	0.7	0.4214	7461	17917	12267
.	9575	0.8	0.4815	8276	16933	11441
.	9575	0.9	0.5417	9040	16014	10673
.	9575	1	0.6019	9757	15154	9959
.	9575	1.1	0.6621	10431	14350	9296
.	9575	1.2	0.7223	11063	13598	8679
.	9575	1.3	0.7825	11658	12894	8105
.	9575	1.4	0.8427	12217	12236	7572
.	9575	1.5	0.9029	12742	11619	7075
.	9575	1.6	0.9631	13237	11041	6613
.	9575	1.7	1.0233	13702	10499	6183
.	9575	1.8	1.0835	14141	9991	5783
.	9575	1.9	1.1437	14554	9515	5410
.	9575	2	1.2039	14944	9068	5063

Input units are thousands and kg - output in tonnes

TABLE 3. Blackfin MFDP single category short-term forecast detailed status quo forecast table output (*.prs).

MFDP version 1a
Run: tutorial
Time and date: 01:55 03/02/02
Fbar age range: 3-7

Year:		1995	F multiplier		1	Fbar:	0.6019				
Age		F	CatchNos	Yield		StockNos	Biomass	SSNos(Jar	SSB(Jan)	SSNos(ST	SSB(ST)
	1	0.001	1		1	1000	590	0	0	0	0
	2	0.178	884		761	5963	5132	0	0	0	0
	3	0.4037	3197		3616	10549	11931	0	0	0	0
	4	0.8263	2756		4029	5334	7798	0	0	0	0
	5	0.7633	651		1374	1328	2805	1328	2805	1328	2805
	6	0.592	239		685	584	1676	584	1676	584	1676
	7	0.4243	111		460	352	1458	352	1458	352	1458
	8	0.3877	46		236	157	804	157	804	157	804
	9	0.4707	31		201	91	585	91	585	91	585
	10	0.4707	77		698	225	2036	225	2036	225	2036
Total			7992		12060	25583	34816	2737	9364	2737	9364

Year:		1996	F multiplier		1	Fbar:	0.6019				
Age		F	CatchNos	Yield		StockNos	Biomass	SSNos(Jar	SSB(Jan)	SSNos(ST	SSB(ST)
	1	0.001	1		1	1000	590	0	0	0	0
	2	0.178	121		104	818	704	0	0	0	0
	3	0.4037	1238		1400	4086	4621	0	0	0	0
	4	0.8263	2980		4357	5768	8433	0	0	0	0
	5	0.7633	937		1978	1911	4037	1911	4037	1911	4037
	6	0.592	207		595	507	1454	507	1454	507	1454
	7	0.4243	83		346	265	1096	265	1096	265	1096
	8	0.3877	55		283	189	965	189	965	189	965
	9	0.4707	30		192	87	561	87	561	87	561
	10	0.4707	55		502	162	1463	162	1463	162	1463
Total			5708		9757	14792	23924	3120	9575	3120	9575

Year:		1997	F multiplier		1	Fbar:	0.6019				
Age		F	CatchNos	Yield		StockNos	Biomass	SSNos(Jar	SSB(Jan)	SSNos(ST	SSB(ST)
	1	0.001	1		1	1000	590	0	0	0	0
	2	0.178	121		104	818	704	0	0	0	0
	3	0.4037	170		192	560	634	0	0	0	0
	4	0.8263	1154		1688	2234	3266	0	0	0	0
	5	0.7633	1013		2139	2067	4365	2067	4365	2067	4365
	6	0.592	298		856	729	2093	729	2093	729	2093
	7	0.4243	72		300	230	951	230	951	230	951
	8	0.3877	42		213	142	725	142	725	142	725
	9	0.4707	36		231	105	673	105	673	105	673
	10	0.4707	44		395	127	1152	127	1152	127	1152
Total			2951		6118	8012	15154	3399	9959	3399	9959

Input units are thousands and kg - output in tonnes

TABLE 4. The Blackfin MFDP single category short-term forecast input data file (*.prd).

MFDP version 1a
Run: tutorial
Time and date: 01:55 03/02/02
Fbar age range: 3-7

1995

Age	N	M	Mat	PF	PM	SWt	Sel	CWt
1	1000	0.2	0	0	0	0.590	0.001	0.590
2	5963	0.2	0	0	0	0.861	0.178	0.861
3	10549	0.2	0	0	0	1.131	0.404	1.131
4	5334	0.2	0	0	0	1.462	0.826	1.462
5	1328	0.2	1	0	0	2.112	0.763	2.112
6	584	0.2	1	0	0	2.869	0.592	2.869
7	352	0.2	1	0	0	4.143	0.424	4.143
8	157	0.2	1	0	0	5.120	0.388	5.120
9	91	0.2	1	0	0	6.426	0.471	6.426
10	225	0.2	1	0	0	9.051	0.471	9.051

1996

Age	N	M	Mat	PF	PM	SWt	Sel	CWt
1	1000	0.2	0	0	0	0.590	0.001	0.590
2	.	0.2	0	0	0	0.861	0.178	0.861
3	.	0.2	0	0	0	1.131	0.404	1.131
4	.	0.2	0	0	0	1.462	0.826	1.462
5	.	0.2	1	0	0	2.112	0.763	2.112
6	.	0.2	1	0	0	2.869	0.592	2.869
7	.	0.2	1	0	0	4.143	0.424	4.143
8	.	0.2	1	0	0	5.120	0.388	5.120
9	.	0.2	1	0	0	6.426	0.471	6.426
10	.	0.2	1	0	0	9.051	0.471	9.051

1997

Age	N	M	Mat	PF	PM	SWt	Sel	CWt
1	1000	0.2	0	0	0	0.590	0.001	0.590
2	.	0.2	0	0	0	0.861	0.178	0.861
3	.	0.2	0	0	0	1.131	0.404	1.131
4	.	0.2	0	0	0	1.462	0.826	1.462
5	.	0.2	1	0	0	2.112	0.763	2.112
6	.	0.2	1	0	0	2.869	0.592	2.869
7	.	0.2	1	0	0	4.143	0.424	4.143
8	.	0.2	1	0	0	5.120	0.388	5.120
9	.	0.2	1	0	0	6.426	0.471	6.426
10	.	0.2	1	0	0	9.051	0.471	9.051

Input units are thousands and kg - output in tonnes

TABLE 5. The first few lines of the Blackfin MFDP single category short-term forecast log file (*.prl).

MFDP version 1a
Run: tutorial
Blackfin: Assessment course. Combined sex; plusgroup.
Time and date: 01:55 03/02/02
IndexFile C:\Vpas\Data\prediction\Blpred_standard.ind

Comments
VPA course tutorial

***** Data files *****
c:\vpas\data\prediction\blackCN.DAT
c:\vpas\data\prediction\blackCW.DAT
c:\vpas\data\prediction\blackSW.DAT
c:\vpas\data\prediction\blackNM.DAT
c:\vpas\data\prediction\blackMO.DAT
c:\vpas\data\prediction\blackPF.DAT
c:\vpas\data\prediction\blackPM.DAT
c:\vpas\data\prediction\f.txt
c:\vpas\data\prediction\n.txt

Input units are thousands and kg - output in tonnes

Last age is a plus group
***** Averaging options *****

Variable	Average Y(	ScaleToFinalYr
Selection	3	0
Natural mortality	1	0
Catch weight	3	0
Stock weight	3	0
Maturity	1	0

***** Projection type *****
Single fleet

Historic data

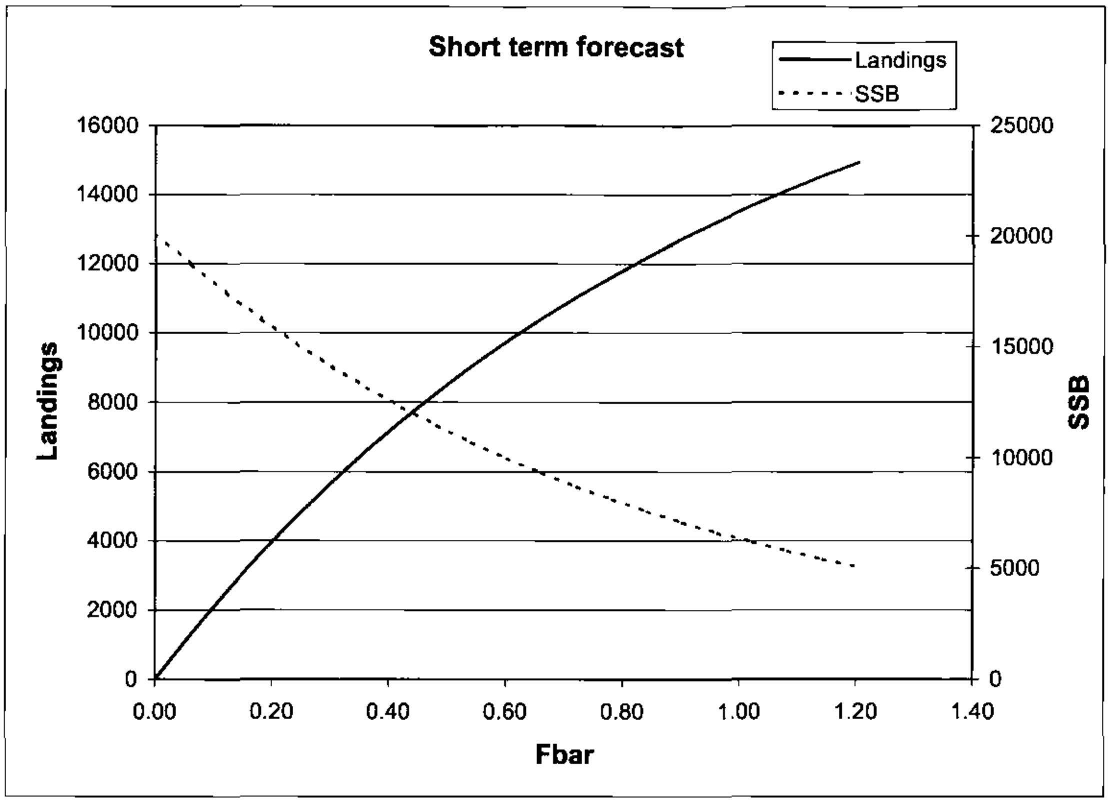
***** Control File *****

Number of years	3		
Number of fleets	1	Fleet disag #FALSE#	
Population Fbar age	3	7	
Future recruitment	1000	1000	1000

Target is catch constraint flag
#FALSE#
Targets
1

***** Raw Data *****

Population numbers	1963	1995	1	10					
32418	13434	12035	3513	1690	804	378	379	172	165
22360	26541	10858	8511	2254	1087	464	244	175	328
22893	18306	21625	6957	4851	1212	583	236	162	315
32785	18743	14779	14694	2928	2382	528	232	110	199
23609	26842	15284	9532	7589	1293	1323	310	155	259
38405	19330	21629	10656	5193	4464	816	672	171	341



MFDP version 1
Run: tutorial
Blackfin: NAFO course 2000. Combined sex; plusgroup.
Time and date: 01:55 03/02/02
Fbar age range: 3-7

Input units are thousands and kg - output in tonnes

Fig. 1. The short-term projection options figure for the Blackfin stock, showing the forecast catch at different levels of fishing mortality two years beyond the assessment series and for SSB three years ahead.

NAFO Sci. Coun. Studies, 36: 135–146

Appendix 1: Lowestoft Stock Assessment Suite

Tutorial 7

The Multi-Fleet Yield-per-Recruit Program

by

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Abstract

This document is number seven in a series of tutorials designed to assist users of the Lowestoft VPA Suite assessment software and prediction programs that use the results. The tutorial takes the user through the options required for running the multi-fleet deterministic yield per recruit program MFYPR developed for ICES at CEFAS.

Introduction

This tutorial takes the user through the options required for running multi-fleet deterministic projection program MFYPR2a.exe. The tutorial assumes that the required Blackfin data files are placed in a directory c:\vpas\data\prediction, and that the prediction index files (Blpred_standard.ind, Blpred_discards.ind) contain path names that point to the appropriate files.

In the following text action **to be taken by the user** is highlighted in bold. The symbol ↲ is used to represent the Return or Enter key on the keyboard.

Installation of the Program

Copy the MFYPR Disk1 and Disk2 files to a directory on your computer here it is assumed that we are using C:\VPAS\PROGRAMS\MFYPR. Using Explorer go to the directory C:\VPAS\PROGRAMS \MFYPR\Disk1. Start the program Setup.exe and follow the on screen instructions

Data Files

The program will carry out yield per recruit using historic data sets from age structured assessments. The analysis is per recruit, hence no units of numbers are required. The user is prompted on the inputs dialog to indicate the units of weight being used. This unit will be indicated in the output. No checks on the units are carried out and it is the responsibility of the user to ensure they are consistent.

The program uses an index file that is similar to (but not the same as) the Lowestoft format index file used for inputting data to the Lowestoft VPA Suite stock assessment program (Darby and Flatman 1994). The index file for the yield per recruit data is given below, the differences in the index files are that the first, ninth, tenth and eleventh files from the VPA suite list have been omitted in MFYPR. The missing files are the total landings and the optional fishing mortality, fishing mortality in the final year and fleet tuning files.

Several files have been added to the list required for MFYPR, these are, **for single fleet analyses:**

1) the fishing mortality at age for each of the historic assessment years;
2) population numbers at age for the historic assessment years **and one extra year** the survivors at the start of the year after the final assessment year; although the program runs a yield per recruit the stock numbers file is kept here for consistency with the program MFDP.

For multifleet predictions

3) a file with total and fleet disaggregated catch numbers at age
4) a file with total and fleet disaggregated catch weights at age

The complete index file list for a run using historic data is given below:

Index file contents	Index file number
Title	
Historic data flag (1 = Historic, 0 = Future)	
Total catch numbers at age numbers file name and path	2
Weight at age in the catch file name and path	3
Weight at age in the stock file name and path	4
Natural mortality file name and path	5
Proportion mature file name and path	6
Proportion of F before spawning file name and path	7
Proportion of M before spawning file name and path	8
Fishing mortality file name and path	12
Population numbers file name and path	13

The population numbers file is not needed for a yield per recruit run. It can be replaced by four stars (****). However, if it is placed in the index file the index file can be used for both yield per recruit and short term prediction.

If the prediction is not fleet or category disaggregated then this is sufficient, however if fleet or category disaggregation is required then the following lines are required.

Index file contents	Index number
Number of fleets	
Fleet 1 catch numbers at age file name and path	2
...	2
Fleet n catch numbers at age file name and path	2
Fleet 1 weight at age in the catch file name and path	3
...	3
Fleet n weight at age in the catch file name and path	3
An optional control file, if specified it must always be the last file.	

Note: If the population and fishing mortality files from the final assessment have a different age range to that of the initial VPA suite input data files, the program will make the adjusment to the new range for the user.

Running the Program

Open program MFYPR2a.EXE from within Windows Explorer or using the Start button

Press the F1 key, this is the undocumented way to see the help file and documentation. The help files are installed in the C:\windows\help directory during setup.

Initially, the program presents the inputs dialog screen. The run identifier should be entered, the plus group specified and the index file located using the browse button. If errors are encountered in the input data then control will return to the inputs dialog and an error message is displayed in red type. The user can makes changes to the files, within a text editor, without closing the program and press browse again to continue. If no errors are encountered a message is displayed detailing the directory in which output files will be saved.

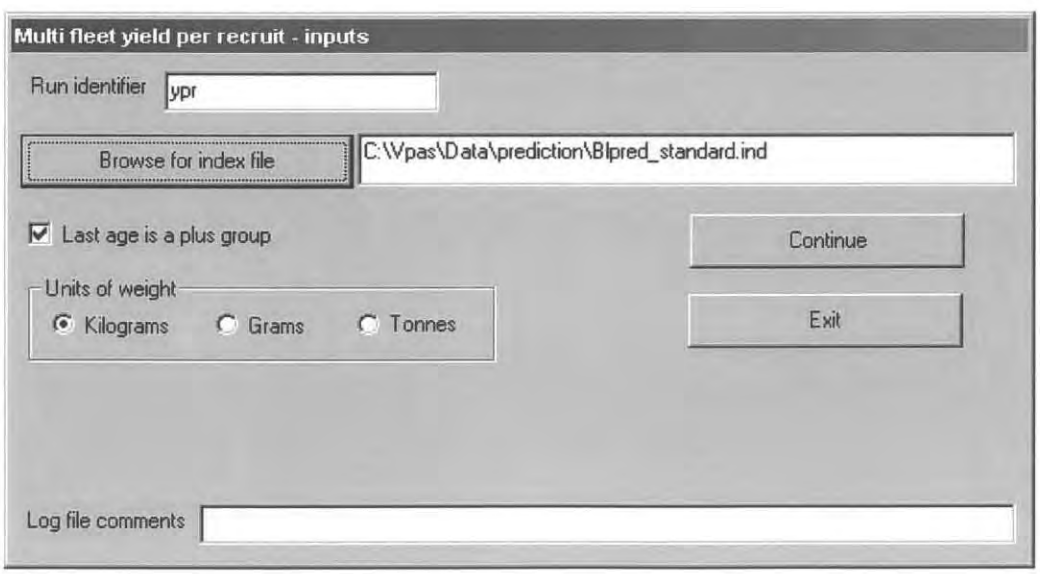
Enter run identifier.

Enter any log file comments required.

Check if the last age is age plus group for this projection run and set the option box.

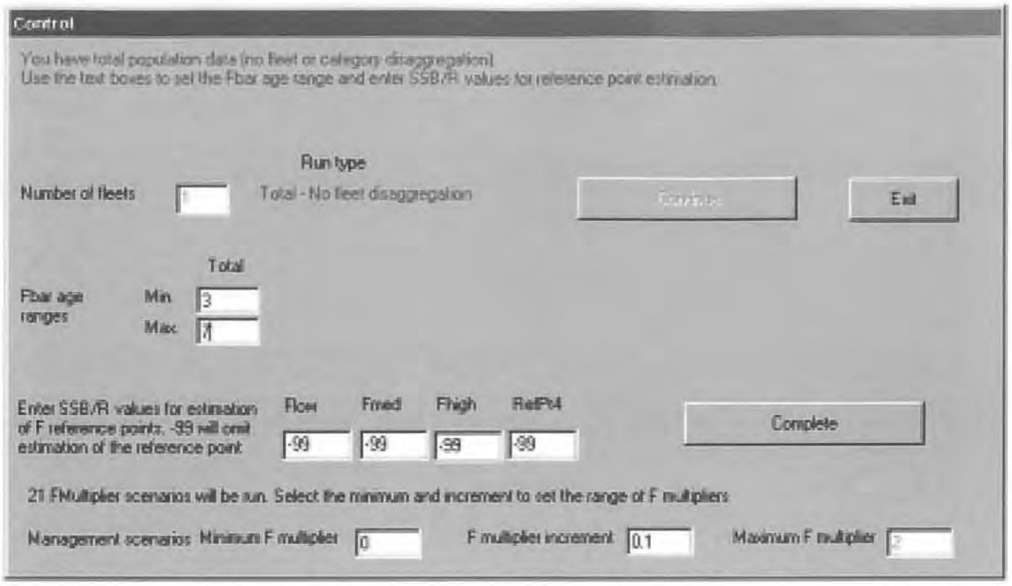
Check the units for the run

Browse for the projection run index file C:\VPAS\DATA\PREDICTION\Blpred_standard.ind.



Note that on return from the browsing the data file, the program has parsed the data files and should report any errors as red text printed above the log file comments box. If there are no errors the program will inform the user that the output files will be put in the same directory as the index file.

Press the continue button.



The text at the top of the control file box should describe the run type that you are trying to achieve. In this example we are running a single fleet yield per recruit with no disaggregation into discards or multiple use of the landed catch.

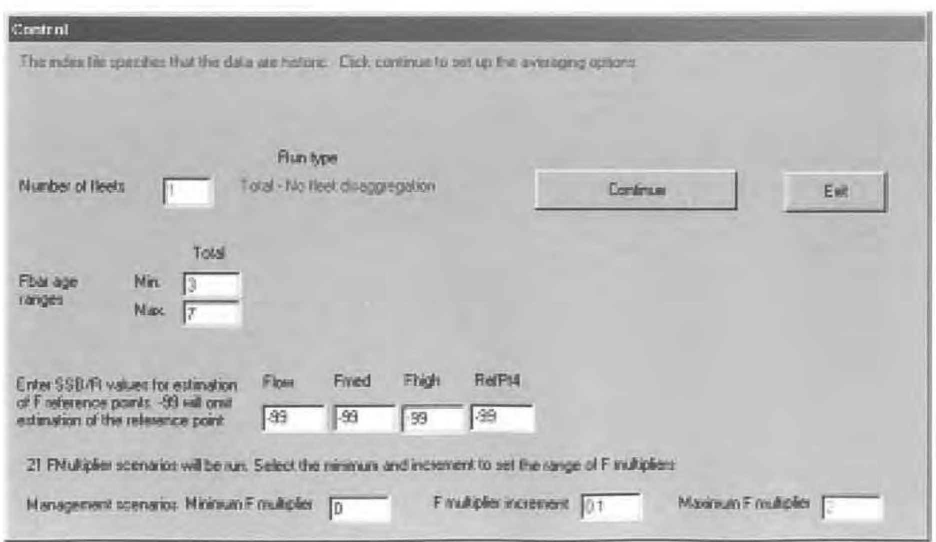
Set the minimum and maximum age for the Fbar age range.

If required set the SSB/B values for the reference points in this example leave them unchanged.

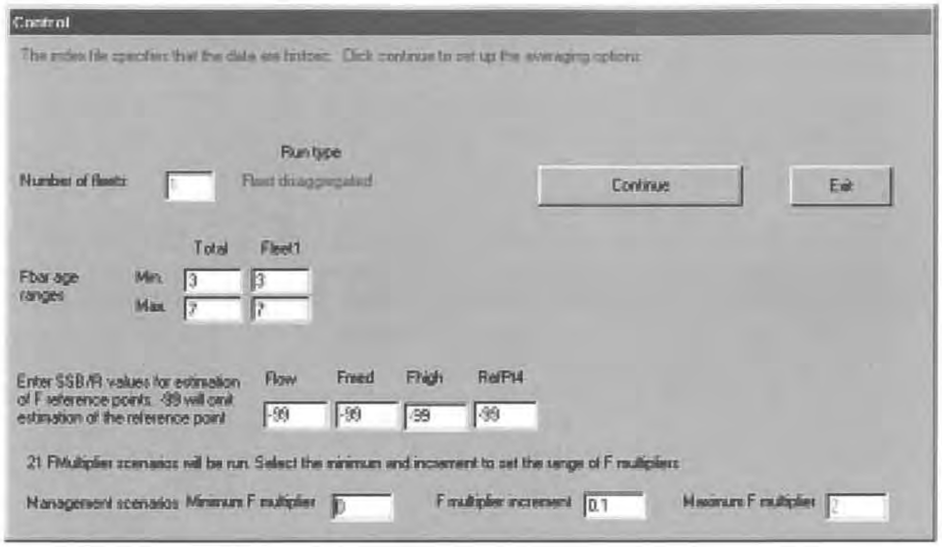
The management option table minimum, maximum and increment can usually be left unchanged. The default setting will give the standard management option table.

Press the complete button.

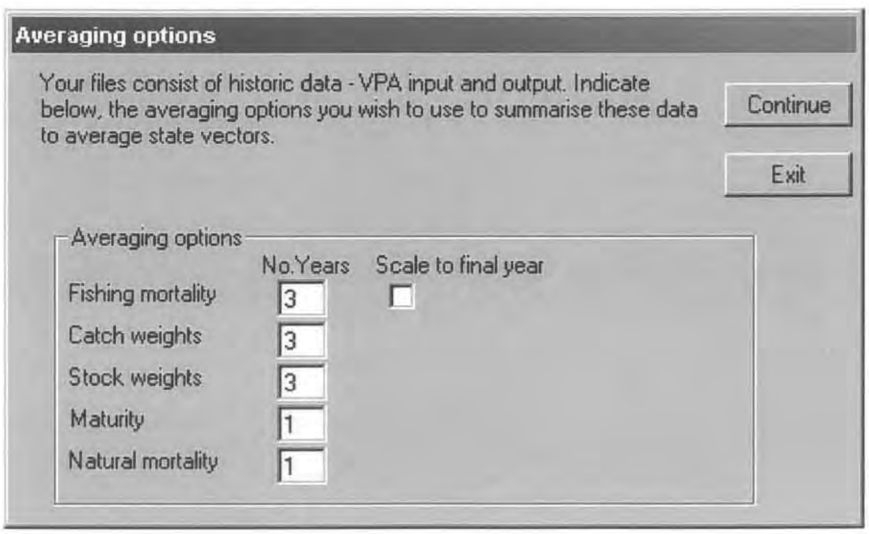
The button vanishes and the Continue button is enabled if the settings conform to the required input. The red information text changes and the program creates a control file for future usage.



If a fleet disaggregated data set has been input to the program the only difference in the option box is that there are two fishing mortality mean ranges to define.



Press the Continue Button. The program now requires us to set up the vectors used for the predictions. Initially this is carried out using the usual averaging process but the individual year vectors can be modified subsequently if required.

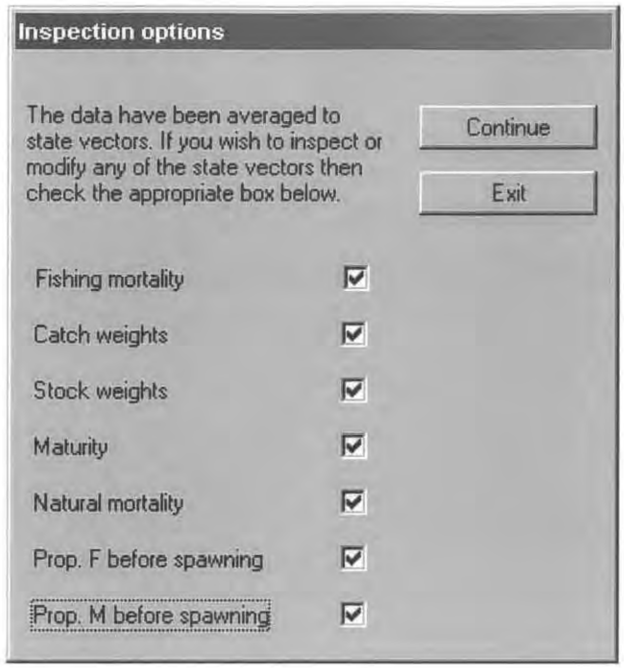


Set the required time periods to be used in calculating the average vectors.

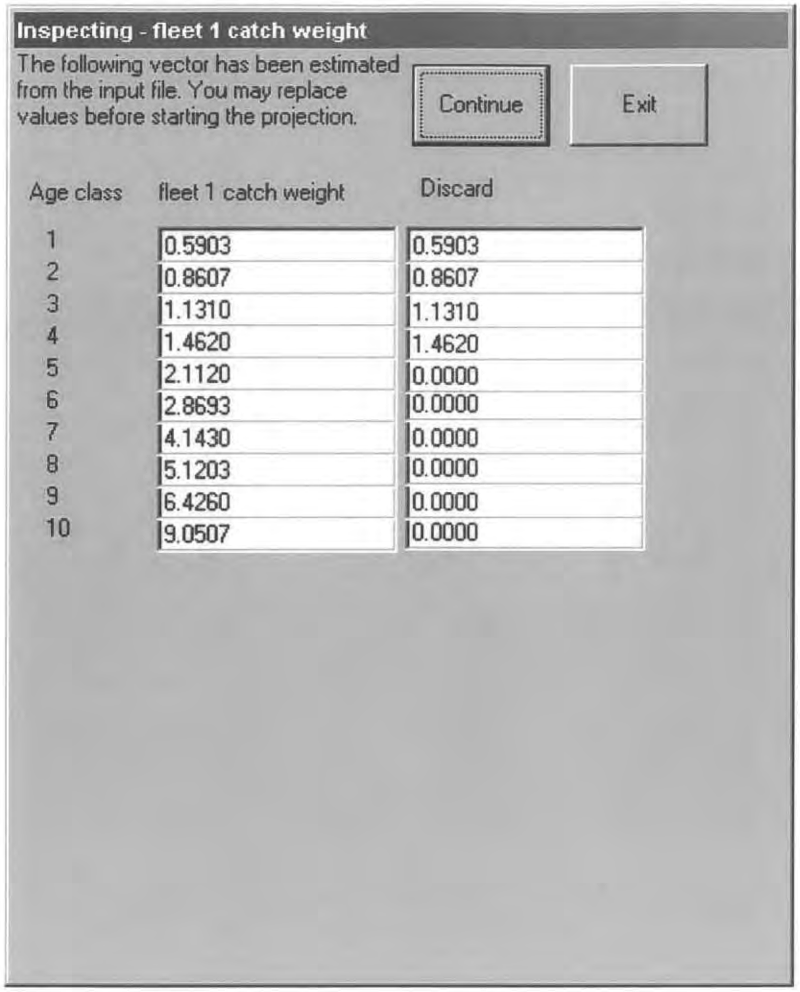
Set the scale to the final year box if required.

Press the continue button.

If we require user input of specific values of population numbers, weights or fishing mortalities etc. we can check any of the required boxes and edit the vectors to be used in the forecast. The vectors should always be reviewed for outliers.



Each of the input data vectors is presented in turn in the format shown below where the two fleet inspection box is illustrated.



After reviewing each input data set the program runs to completion

New Input File Set

The program creates up to a series of 12 new input data files in the same directory as the index file. The files are prefixed by the run identifier entered by the user and contain the vectors of fishing mortalities, maturity at age etc. for the years over which the projection was made. They allow repeat runs using the same prediction vectors, without having to go through the set up process again. The file names are:

File contents	Filename
Index	RunCode + "ind.txt"
Total catch weight	RunCode + "CWt.txt"
Stock weight	RunCode + "SWt.txt"
Maturity	RunCode + "Mat.txt"
Proportion of F before spawning	RunCode + "PF.txt"
Proportion of M before spawning	RunCode + "PM.txt"
Total fishing mortality	RunCode + "F.txt"
Control file	RunCode + "Ctrl.txt"

If the data are fleet disaggregated then no file for total F and catch weight will be produced, but files will be produced for each fleet giving the fleet partial Fs and fleet catch weights.

File contents	Filename
Disaggregated selection pattern	RunCode + "FleetF" + fleet number + ".txt"
Disaggregated catch weights	RunCode + "FleetCWt" + fleet number + ".txt"

Producing the modified file set allows subsequent runs to be undertaken without editing the data on each occasion.

Output Files

The following 4 files of output are produced. They are listed in Tables 1–4.

1) Output (Table 1)

Results in a comma delimited file with the format specified by the ICES Workshop on Standard Assessment Tools for Working Groups (1999), see the Yield per recruit results section. This file is named with a filename of the run index and the file extension .yro. If no run index has been specified then results will be appended to a file named MFYPR.yro. The results for each run are appended to the file along with the run name, program name and version, stock name, time and date.

2) Summary (Table 2)

Results in a comma delimited file with a structure similar to that of the yield per recruit summary table currently used by ICES. This file is named with a filename of the run index and the file extension .yrs. If no run index has been specified then results will be appended to a file named MFYPR.yrs. The results for each run are appended to the file along with the run name, program name and version, stock name, time and date.

3) Data (Table 3)

A comma delimited file containing the steady state vectors used for the yield per recruit analysis. This file is named with a filename of the run index and the file extension .yrd. If no run index has been specified then results will be appended to a file named MFYPR.yrd. The data for each run are appended to the file along with the run name, program name and version, stock name, time and date.

4) Log (Table 4)

A log file in comma delimited format containing the files used for the run, the raw data, the options chosen, truncated data when appropriate, the steady state vectors, and a summary of the results. The log file is named with the run code and the file extension .yrl. If no run code has been specified then this file is named MFYPR.yrl.

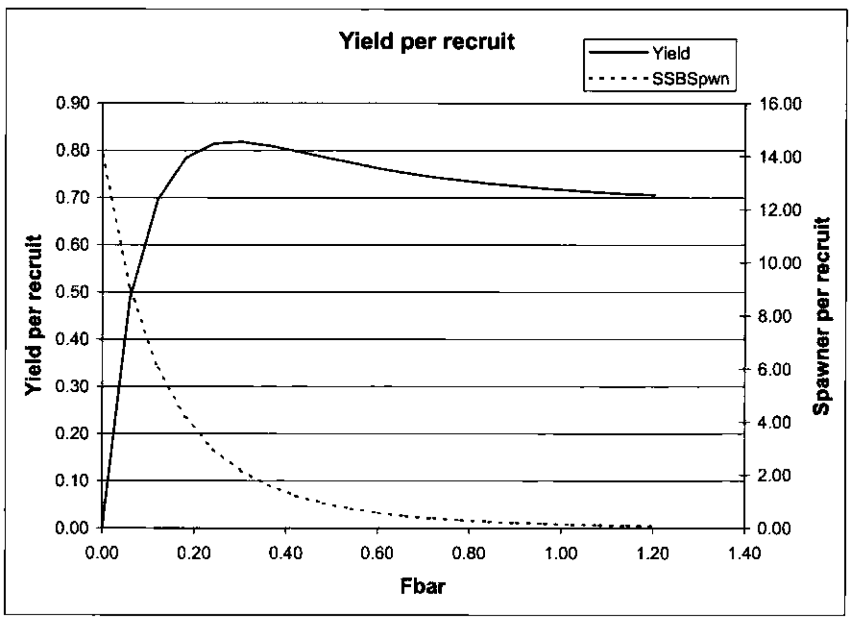
Plotting and Tabulating Results

Open the spreadsheet TEMPLATE1.XLS

Open the output file from the MFYPR run YPR.YRS in EXCEL. The file is comma separated.

Copy the sheet from YPR.YRS and paste it into the .yrs sheet of TEMPLATE1.XLS.

On the sheet labeled Chart, the left hand graph is the standard ICES yield per recruit plot which shows the yield in kilograms at different levels of fishing mortality. The data is automatically plotted when the .yrs sheet is updated.



MFYPR version 2a
Run: blackfin SAC
Time and date: 17:51 04/03/03

Reference point	F multiplier	Absolute F
Fbar(3-7)	1.0000	0.6019
FMax	0.4720	0.2841
F0.1	0.2661	0.1602
F35%SPR	0.2545	0.1532

Weights in kilograms

Fig. 1. The Blackfin single category yield per recruit plot and fishing mortality reference points.

References

DARBY, C. D. and S. FLATMAN. 1994. Virtual Population Analysis: version 3.1 (Windows/DOS) user guide. *Info. Tech. Ser.*, MAFF Direct. Fish. Res., Lowestoft, 1: 85 p.

ICES. MS 1999. Report of the Workshop on Standard Assessment Tools for Working Groups, Aberdeen, United Kingdom, 3–5 March 1999. *ICES C.M. Doc.*, No. 1999/ACFM:25.

TABLE 1. The MFYPR yield per recruit results in the ICES SGFADS format.

Blackfin: as	Yield per re	MFYPR ve	Run:ypr	23:08	06/02/02
1					
1					
21					
Total					
0.601933	0	3	7		
1	0	0	0	14.06572	16.9212
2	0.1	0.487108	0	9.004979	11.80153
3	0.2	0.697293	0	6.03255	8.772971
4	0.3	0.784026	0	4.182221	6.869175
5	0.4	0.813972	0	2.98003	5.616035
6	0.5	0.817871	0	2.172361	4.759802
7	0.6	0.810366	0	1.614692	4.155827
8	0.7	0.798509	0	1.220628	3.717597
9	0.8	0.785654	0	0.936535	3.391363
10	0.9	0.773323	0	0.728067	3.142674
11	1	0.762133	0	0.572655	2.948862
12	1.1	0.752258	0	0.455133	2.794664
13	1.2	0.743665	0	0.365107	2.669597
14	1.3	0.736235	0	0.295328	2.566328
15	1.4	0.729822	0	0.240662	2.47964
16	1.5	0.724278	0	0.197415	2.405766
17	1.6	0.719471	0	0.162896	2.341944
18	1.7	0.715284	0	0.135122	2.286121
19	1.8	0.711619	0	0.11261	2.236752
20	1.9	0.708393	0	0.094242	2.192656
21	2	0.705537	0	7.92E-02	2.152925

Weights in kilograms

TABLE 2. Blackfin MFYPR yield-per-recruit table output.

MFYPR version 2a
Run: ypr
Time and date: 23:08 06/02/02
Yield per results

FMult	Fbar	CatchNos	Yield	StockNos	Biomass	SpwnNosJ.	SSBJan	SpwnNosS	SSBSpwn
0	0	0	0	5.5167	16.9212	2.4788	14.0657	2.4788	14.0657
0.1	0.0602	0.1572	0.4871	4.7338	11.8015	1.739	9.005	1.739	9.005
0.2	0.1204	0.2603	0.6973	4.2221	8.773	1.2683	6.0326	1.2683	6.0326
0.3	0.1806	0.3322	0.784	3.8657	6.8692	0.9512	4.1822	0.9512	4.1822
0.4	0.2408	0.3849	0.814	3.6058	5.616	0.7287	2.98	0.7287	2.98
0.5	0.301	0.4249	0.8179	3.409	4.7598	0.5677	2.1724	0.5677	2.1724
0.6	0.3612	0.4563	0.8104	3.2555	4.1558	0.4483	1.6147	0.4483	1.6147
0.7	0.4214	0.4814	0.7985	3.1327	3.7176	0.3581	1.2206	0.3581	1.2206
0.8	0.4815	0.5021	0.7857	3.0322	3.3914	0.2889	0.9365	0.2889	0.9365
0.9	0.5417	0.5194	0.7733	2.9483	3.1427	0.2349	0.7281	0.2349	0.7281
1	0.6019	0.5342	0.7621	2.8773	2.9489	0.1924	0.5727	0.1924	0.5727
1.1	0.6621	0.5469	0.7523	2.8161	2.7947	0.1586	0.4551	0.1586	0.4551
1.2	0.7223	0.5581	0.7437	2.7627	2.6696	0.1314	0.3651	0.1314	0.3651
1.3	0.7825	0.568	0.7362	2.7156	2.5663	0.1095	0.2953	0.1095	0.2953
1.4	0.8427	0.5768	0.7298	2.6736	2.4796	0.0915	0.2407	0.0915	0.2407
1.5	0.9029	0.5847	0.7243	2.6358	2.4058	0.0768	0.1974	0.0768	0.1974
1.6	0.9631	0.592	0.7195	2.6016	2.3419	0.0647	0.1629	0.0647	0.1629
1.7	1.0233	0.5986	0.7153	2.5703	2.2861	0.0547	0.1351	0.0547	0.1351
1.8	1.0835	0.6047	0.7116	2.5415	2.2368	0.0463	0.1126	0.0463	0.1126
1.9	1.1437	0.6104	0.7084	2.515	2.1927	0.0393	0.0942	0.0393	0.0942
2	1.2039	0.6156	0.7055	2.4903	2.1529	0.0335	0.0792	0.0335	0.0792

Reference	F multiplier	Absolute F
Fbar(3-7)	1	0.6019
FMax	0.472	0.2841
F0.1	0.2661	0.1602
F35%SPR	0.2545	0.1532

Weights in kilograms

TABLE 3. Blackfin MFYPR yield-per-recruit input data table.

MFYPR version 2a
Run: ypr
Blackfin: assessment course. Combined sex; plusgroup.
Time and date: 23:08 06/02/02
Fbar age range: 3-7

Age	M	Mat	PF	PM	SWt	Sel	CWt
1	0.2	0	0	0	0.590333	0.001	0.590333
2	0.2	0	0	0	0.860667	0.178	0.860667
3	0.2	0	0	0	1.131	0.403667	1.131
4	0.2	0	0	0	1.462	0.826333	1.462
5	0.2	1	0	0	2.112	0.763333	2.112
6	0.2	1	0	0	2.869333	0.592	2.869333
7	0.2	1	0	0	4.143	0.424333	4.143
8	0.2	1	0	0	5.120333	0.387667	5.120333
9	0.2	1	0	0	6.426	0.470667	6.426
10	0.2	1	0	0	9.050667	0.470667	9.050667

Weights in kilograms

TABLE 4. The first few lines of the Blackfin MFYPR yield-per-recruit log file describing the analysis settings

MFYPR version 2a
Run: ypr
Time and date: 23:08 06/02/02
Blackfin: assessment course. Combined sex; plusgroup.

Comments

Weights in kilograms

IndexFile C:\Vpas\Data\prediction\Blpred_standard.ind
Data files
c:\vpas\data\prediction\blackCN.DAT
c:\vpas\data\prediction\blackCW.DAT
c:\vpas\data\prediction\blackSW.DAT
c:\vpas\data\prediction\blackNM.DAT
c:\vpas\data\prediction\blackMO.DAT
c:\vpas\data\prediction\blackPF.DAT
c:\vpas\data\prediction\blackPM.DAT
c:\vpas\data\prediction\f.txt
c:\vpas\data\prediction\n.txt

Averaging options

Variable	Average Y€	ScaleToFinalYr
Selection	3	0
Natural mo	1	
Catch weig	3	
Stock weig	3	
Maturity	1	
Fleet details		
Number of	1	Fleet disag #FALSE#
Population	3	7

Reference points - SPR values

-99	-99	-99	-99

Raw Data
Historic data

Fishing mo	1963	1994	1	10				
0	0.013	0.146	0.244	0.241	0.351	0.24	0.571	0.39	0.39
0	0.005	0.245	0.362	0.421	0.423	0.475	0.211	0.372	0.372
0	0.014	0.186	0.666	0.511	0.63	0.722	0.562	0.644	0.644
0	0.004	0.239	0.461	0.617	0.388	0.333	0.204	0.31	0.31
0	0.016	0.161	0.407	0.331	0.261	0.477	0.393	0.379	0.379
0	0.003	0.133	0.271	0.294	0.167	0.224	0.231	0.208	0.208
0	0.012	0.15	0.399	0.286	0.195	0.227	0.247	0.224	0.224
0	0.002	0.133	0.264	0.267	0.176	0.133	0.113	0.141	0.141
0	0.013	0.088	0.314	0.355	0.254	0.202	0.303	0.254	0.254

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Appendix 1: Lowestoft Stock Assessment Suite

Tutorial 8

Running the PA Software Excel Add-in (PASoft)

by

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Abstract

This document is number eight in a series of tutorials designed to assist users of the Lowestoft VPA Suite assessment software and the prediction programs that use the results. The tutorial takes the user through the options required for running the PA software EXCEL add-in used to estimate reference points and developed for ICES at CEFAS.

Introduction

This tutorial takes the user through the options required for running the PA software EXCEL add-in. The tutorial assumes that the user has followed the previous XSA tutorials and can run the VPA suite package to produce the required files or has constructed the sen and sum output files resulting from the Aberdeen medium term suite of programs.

In the following text **action to be taken by the user** is highlighted in bold. The symbol ↵ is used to represent the Return or Enter key on the keyboard.

Installing the PA Software

The software is intended to be used with Microsoft Excel Version 7 upwards. The software is an Excel add-in and results are output as Excel workbooks.

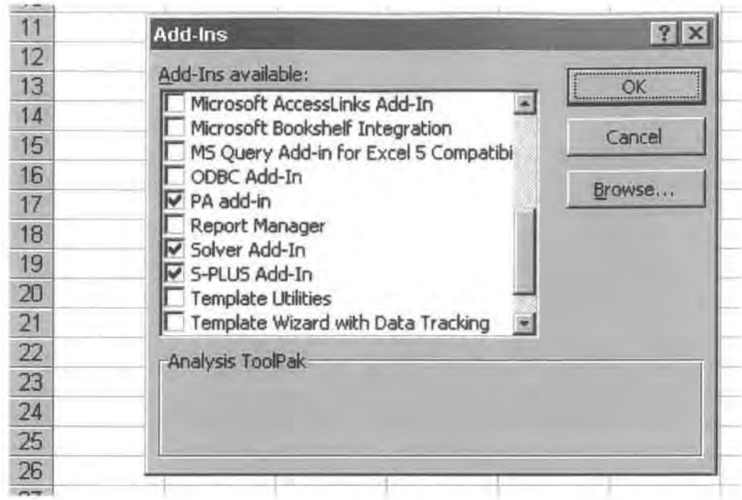
Copy the PA soft directory to your hard drive. Enter the directory disk 1 and run the setup.exe. Follow the instructions to install the pa add in.

Open EXCEL

From the menu bar **Select "Tools", "Add-ins"**

Browse for the file PAXLA.XLA which will have been placed in the installation directory.

Select PAXLA.XLA and press OK



Note that the PA add-in box has been entered and checked.

Select OK

Notice that the PASummary drop down menu has been added to the menu at the top of Excel.

Note: If you do not want to keep loading the PA add-in every time Excel is opened select "Tools", "Add-ins" and uncheck the PA add-in box. The add in box can be re-checked each time the program is required.

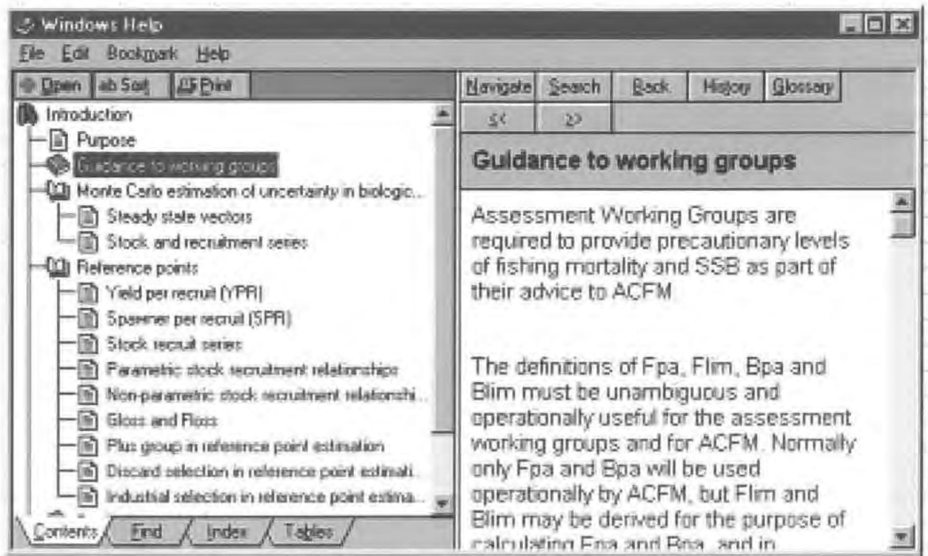
Run the program VPA95.exe for the stock for which you wish to estimate the PA reference points. Select the options for the age range, reference means etc selected in previous tutorials. When the assessment model has been fitted select option 8 from the main menu. This option will print a file that contains all of the VPA suite output in a form that can be read by the PA software.

Return to EXCEL

The PA Software Help File

At the menu bar select the "PASummary" drop down menu.
Select the Help menu option

During installation a help file is added to the Windows\system\ directory for reference when using the program. The methods used in the calculation of the reference points are detailed in the help system.

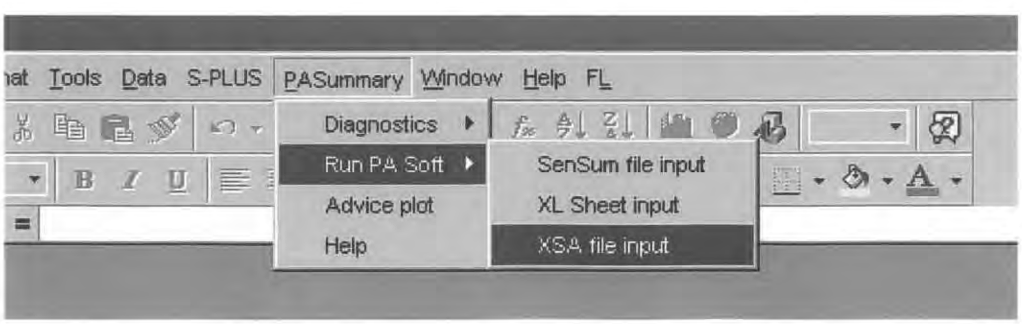


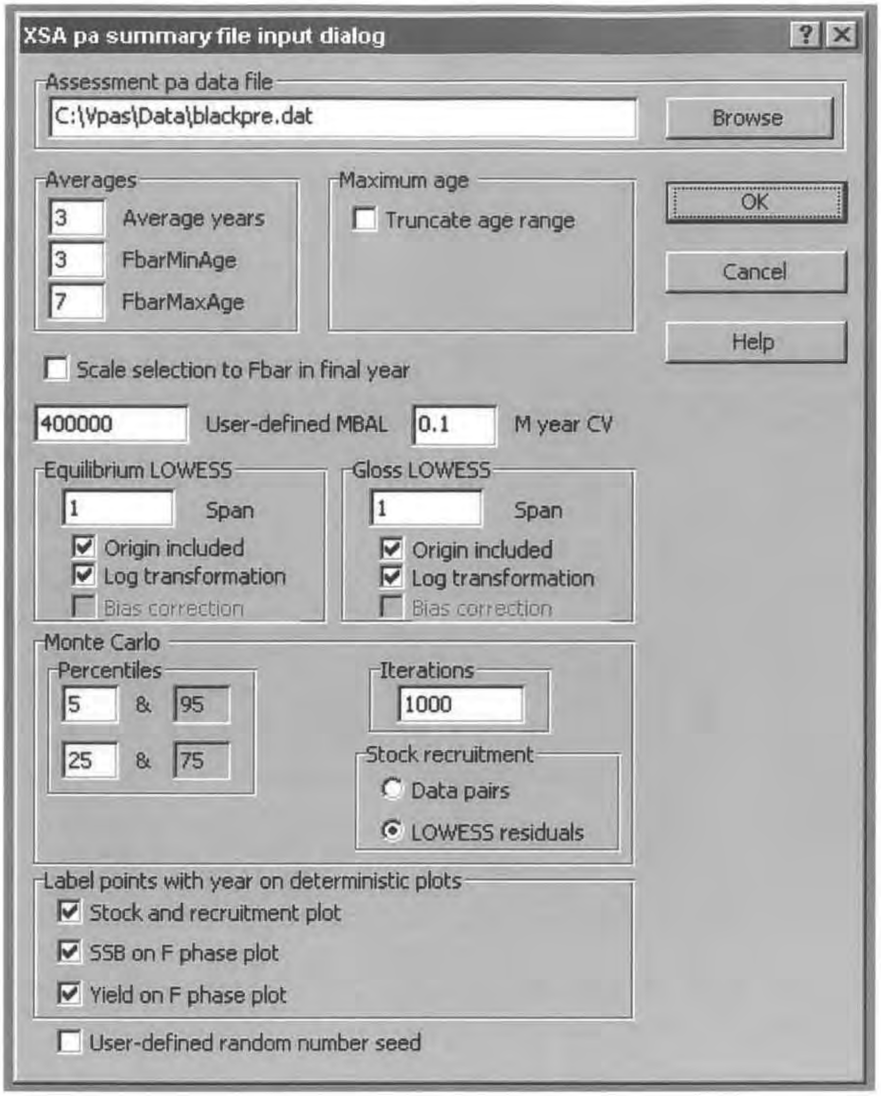
Calculation of the PA Reference Points

In this section we shall run the PA software to calculate fishing mortality and biomass reference points. This will allow us to examine the approach and the results of the methodology. In the following section we shall run a diagnostic routine to examine the selection of settings used for the smoothers used to estimate particular reference points.

At the menu bar select the "PASummary" drop down menu.

Select "Run PA Soft" and "XSA file input" Note that two other input file formats are permitted, spreadsheet entry and the .sen and .sum files created by the Aberdeen suite program INSENS.



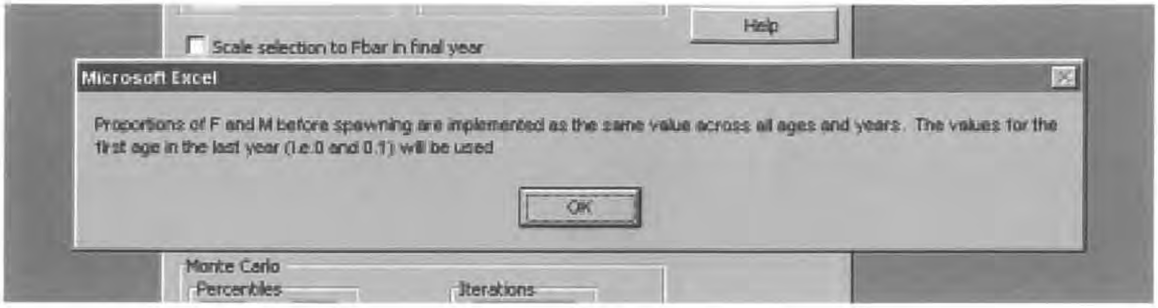


Browse for the PA software XSA input file created during the XSA run.

The range of ages for calculating average fishing mortality should correspond to those used in the XSA assessment. Default options for the setting of two LOWESS models are presented. These should be chosen after reference to the diagnostic output presented below. Other options for the percentile used in the summary plots and the number of iterations to use in the Monte Carlo simulations can be user defined. The user guide for the program details selection criteria.

The default number of iterations for the PA Software is 100 as with this number the output can be obtained fairly quickly. This is however a relatively small number for a Monte Carlo and for a final run a larger number such as 1000 is likely to give more stable estimates of the percentiles.

After completion of the selections press the OK button.



The program informs us that, as the proportions of F and M are equal for all ages and years it will use the values for the final year.

Select the OK button.

The PA soft program runs the Monte Carlo iterations sampling from the distributions of the input data and then creates five EXCEL sheets containing data and results.

Sheet Intro (Table 1)

This sheet provides a brief introduction to the results.

Sheet RefPts (Fig. 1 and Table 2)

This sheet summarizes the estimated reference points. Box and whisker plots showing the 5th, 25th, 50th, 75th and 95th percentiles of the F reference points are plotted. A table showing the deterministic value of the reference point together with the median and 2 user-specified pairs of percentiles is produced for stock and fishing mortality reference points. If the user has specified 5th, 25th, 75th and 95th percentiles then the 75th and 95th percentiles would be displayed for the stock reference points, while the 5th and 25th would be displayed for the F reference points.

The RefPts sheet also provides a record of the run specification, these include:

Spans used by the LOWESS smoothers and data transformations.
Stock name.
Averaging details for Fbar and the steady state vectors (the latter will be zero when these vectors are the input, i.e. Sen_Sum input and XLSheet input).
Number of iterations.
The type of Monte Carlo for the stock recruitment data.
The data source.
Details of the FishLab DLL used for reference point estimations.
The PASoft version.
The date and time of the run.

Sometimes certain combinations of data may cause some reference points (particularly F_{max}, F_{high} and F_{loss}) to give unreliable results, for example F_{max} may tend to infinity. The percentiles are based on the full distribution of the reference points estimations and will include these points. The output sheet "PDist" contains the estimates of all the reference points by iteration number and can be checked for outlying values. "PDist" acts as the input for the box and whisker plots hence if different percentiles are required on these plots the user can alter the percentile function calls at the foot of the data in "PDist".

Sheet Plots (Fig. 3)

This sheet provides graphical output of deterministic results. 4 plots are presented:

Recruitment against SSB
Spawner per recruit and yield per recruit curves against Fbar
Equilibrium SSB against Fbar
Equilibrium yield against Fbar

In plots 1, 3 and 4 the points are linked in chronological order by a dashed line and a colored solid line represents expected values estimated from the LOWESS smoothed stock recruitment relationship. The user also has the option to label each point with the year when the program is run.

In plots 1 and 2 a number of fishing mortality reference points are indicated as labeled points on the right axis of the stock recruit plot and at the top of the SPR and YPR chart.

Plot 1, the stock recruit plot, gives details of the LOWESS span and data transformations used for the smoother in the top left corner. This smoother is used to estimate the expected values (the solid line) in plots 3 and 4. The data used to plot the charts are held on the Plots sheets in columns U to AP.

Sometimes a large value for a reference point may cause the stock recruitment plot to be squashed at the bottom of the chart. This is because Excel has scaled the chart automatically to the largest value of R. By selecting the outlying point (which lies under the label) and deleting it the chart will re-scale more appropriately. This has been carried out for the Floss point in the Blackfin example.

Sheet Pdist (Table 3)

This sheet provides the estimates of each reference point by iteration number. These data form the input for the box and whisker plots on the "RefPts" sheet. The complete distributions of the reference point estimation allow the user to check for erroneous values or to further investigate the empirical distributions.

Sheet SV (Table 4)

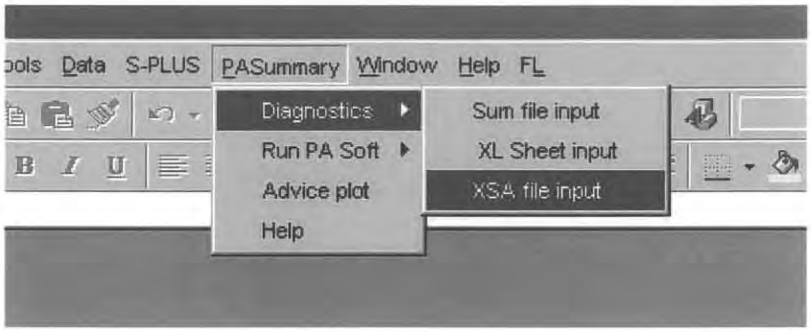
The SV sheet provides the user with the steady state vectors used during the PA run. For Sen_Sum file input or XLSheet input these should be the same as the input data. For the other input formats they will be derived from the data and as such provide a useful record of the steady state vectors.

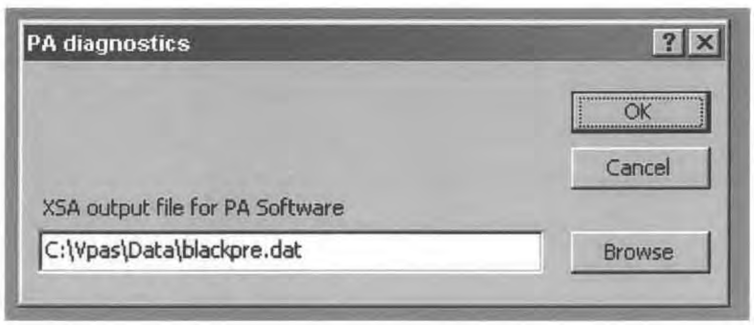
The sheet is presented in a suitable format to be used as input for further PA runs using the XLSheet dialog and can therefore be used as the basis for more investigative work. For example the effects of mortality, weight and maturity at age schedules could be explored, or the effects of different CVs investigated. This may be of particular interest where the variables or CVs are assumptions.

Diagnostic Calculation for the Lowess Smoother

At the menu bar select the "PASummary" drop down menu.

Select "Diagnostics" and "XSA file input" Note that two other input file formats are permitted, spreadsheet entry and the .sen and .sum files created by the "Aberdeen suite program INSENS".





Browse for the PA software XSA input file created during the XSA run.

The program informs us that, as the proportions of F and M are equal for all ages and years it will use the values for the final year.

Select the OK button.

The diagnostics program runs and creates four EXCEL graphs in a new sheet they present diagnostic plots used for determining the settings of the models used for the precautionary approach reference point calculations.

PASoft Diagnostic Output Graphs

Fig. 3 presents the diagnostic plots produced by PASoft within Excel.

The top left-hand chart shows recruitment (Recruits) plotted against spawning stock biomass (SSB); together with the LOWESS fits corresponding to the two spans of 0.5 (Rhat0.5) and 1.0 (Rhat1.0). The relative difference in G_{loss} between the two spans can be judged by the discrepancy in fitted values corresponding to the lowest observed SSB; i.e. the extreme left-hand points of each LOWESS fit. This graph will assist in the qualitative assessment of the effect that span has on expected recruitment.

The top right-hand chart shows the time series of recruitment with recruitment estimates obtained from the LOWESS fits corresponding to spans of 0.5 (Rhat0.5) and 1.0 (Rhat1.0). This graph, in conjunction with the one described in the previous paragraph, will assist in a qualitative assessment of time trends in the level of recruitment.

The bottom left-hand chart shows the log-normal residuals obtained from the two LOWESS fits with spans of 0.5 (LnRes0.5) and 1.0 (LnRes1.0) plotted against SSB. In addition, the residuals obtained from the LOWESS fit with a span of 1.0 are connected through time with a dashed line. This graph will aid in the detection of heteroscedasticity; i.e. non-constant variance, and the detection of patterns and trends with SSB/time that might violate modelling assumptions.

The bottom right-hand chart shows an improved Akaike information criterion (Hurvich *et al.*, 1998) for a range of LOWESS fits obtained with spans in the interval (0.5, 1], generally thought appropriate for stocks within the current ICES areas (O'Brien, 1999). A span is selected to minimise the bias-corrected Akaike information criterion (AIC) but it is important to remember that any smoothing parameter selection should be viewed as only a guideline (or benchmark), and can be adjusted based upon other factors. Such factors might include: prior knowledge about the shape of the stock-recruitment (S–R) relationship; suitability of the S–R relationship for deriving equilibrium plots; and sensitivity of the estimates of G_{loss} to outliers in the S–R data. To give an indication of the stability of the reference point G_{loss}, numerical estimates are shown (denoted by Gloss) at each span calculated. In general, a LOWESS fit with a high span near to 1.0 is appropriate for the S–R relationship if the production of equilibrium plots is required, whereas a low span will *track* the data and give inappropriate equilibrium values. Furthermore, a LOWESS fit with a high span near to 1.0 is likely to produce more robust estimates of G_{loss} and this is especially true if the data are *noisy*.

All the LOWESS fits have been achieved by inclusion of the origin as a pseudo-data point; i.e. zero recruitment from a non-existent SSB, and with the assumption that recruitment variation may be considered to follow a log-normal distribution.

For the Blackfin data set the plots show that the most appropriate span for the smoother, based on the Akaike information criterion is 1.0. However there is no significant trend in Gloss across all values of the smoother range.

The time series plot of the estimated recruitment with the observed values shows time series correlations in the residual patterns which are also obvious in the residual plots against expected value. The diagnostics illustrate that the model is a poor estimator of recruitment in the most recent time period and would not be appropriate for the estimation of recent recruitment and the value of Gloss. The fit of the smoother and therefore the estimate of Gloss appears to be highly dependent on the recruitment at the two lowest SSB values, which are the first years in the assessment time series. A sensitivity analysis exploring the influence of these point on the estimated reference points would therefore be appropriate.

References

O'BRIEN, C. M. 1999. A note on the distribution of G_{loss}. *ICES Journal of Marine Science*, **56**: 180–183.

HURVICH, C. M., J. S. SIMONOFF, and C. L. TSAI. 1998. Smoothing parameter selection in nonparametric regression using an improved Akaike information criterion. *Journal of the Royal Statistical Society*, **B60**: 271–293.

TABLE 1. The Introduction sheet from the Blackfin PaSoft Excel output file.

Introduction to PA Add-in outputs

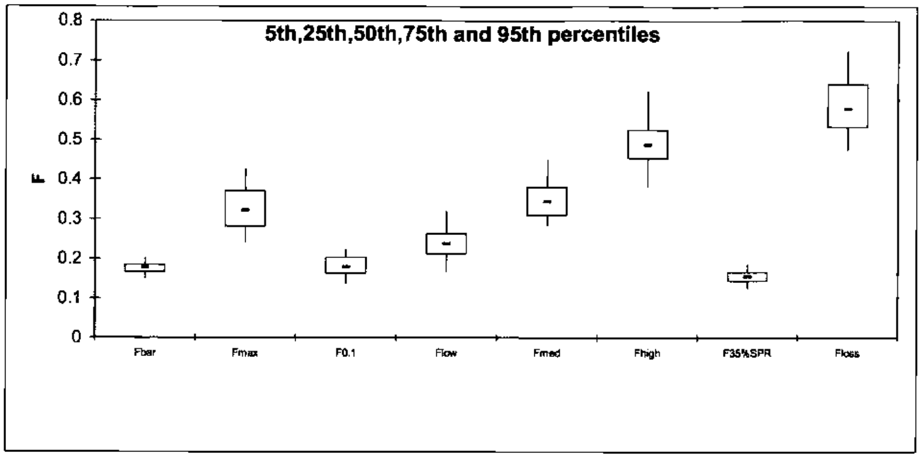
Four sheets of results are included in this workbook:

RefPts - provides stochastic output in the form of a table of reference points and a chart summarising the distributions of some referen(

Plots - provides 4 plots:
A stock recruitment plot with a LOWESS smoother as a possible stock recruitment relationship. Some reference points are also indica
A plot of YPR and SPR curves with some reference points indicated.
A plot of historical SSB against Fbar with an equilibrium curve based on the LOWESS stock recruitment relationship.
A plot of historical yield against Fbar with an equilibrium curve based on the LOWESS stock recruitment relationship.

PD - gives the value of the reference points during each iteration of the simulation and the percentiles plotted on the chart on RefPts.

SV - contains the steady state vectors and stock recruitment series used. These can be used as the basis for further runs.



Reference point	Deterministic	Median	75th percentile	95th percentile	Hist SSB < ref pt %
MedianRecruits	26149	26149	29338	31387	
MBAL	0				0.00
Bloss	11711				
SSB90%R90%Surv	31674	30240	33223	37964	31.25
SPR%ofVirgin	30.31	30.47	33.53	38.20	
VirginSPR	14.07	14.16	15.81	21.70	
SPRloss	0.56	0.50	0.55	0.60	

	Deterministic	Median	25th percentile	5th percentile	Hist F > ref pt %
FBar	0.18	0.18	0.16	0.15	96.88
Fmax	0.31	0.32	0.28	0.24	65.63
F0.1	0.18	0.18	0.16	0.14	96.88
Flow	0.21	0.24	0.21	0.17	96.88
Fmed	0.34	0.34	0.31	0.28	62.50
Fhigh	0.48	0.49	0.45	0.38	21.88
F35%SPR	0.15	0.16	0.14	0.12	100.00
Floss	0.56	0.58	0.53	0.47	18.75

For estimation of Gloss and Floss:
A LOWESS smoother with a span of 1 was used.
Stock recruit data were log-transformed
A point representing the origin was included in the stock recruit data.
For estimation of the stock recruitment relationship used in equilibrium calculations:
A LOWESS smoother with a span of 1 was used.
Stock recruit data were log-transformed
A point representing the origin was included in the stock recruit data.

Blackfin: VPA course. Combined sex; plusgroup.

Steady state selection averaged over 3 years.
FBar averaged from age 4 to 7

Number of iterations = 100
Random number seed = -99
Stock recruitment data Monte Carloed using residuals from the equilibrium LOWESS fit

Data source:
C:\vpas\data\xsapadata.csv

FishLab DLL used
FLVB32.DLL built on Jun 14 1999 at 11:53:37
PASoft 4 October 1999

14/02/03 13:18:25

Fig. 1 and Table 2. The PA Reference Point estimates estimated for the Blackfin stock and listed in the RefPts sheet from the PaSoft Excel output file.

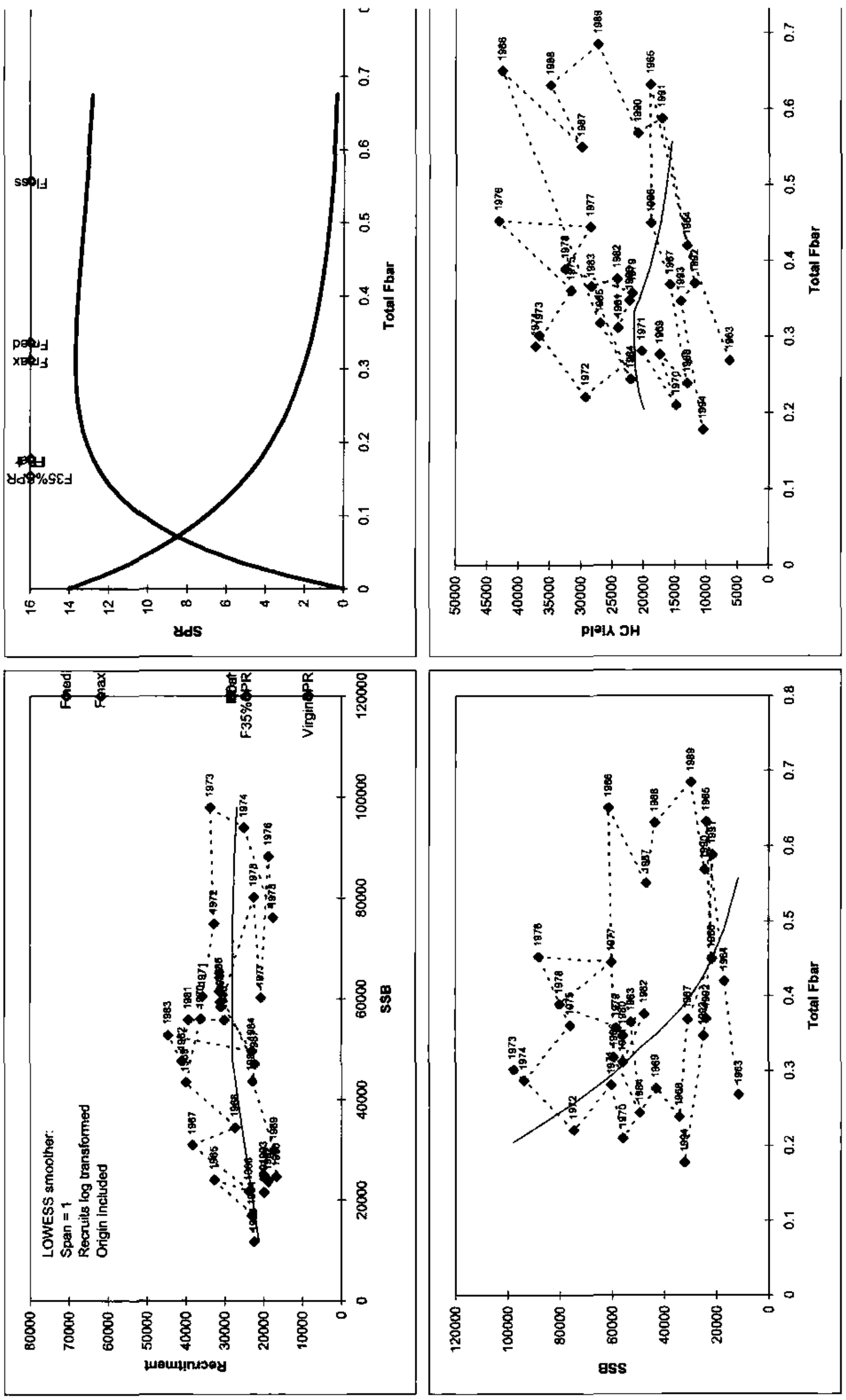


Fig. 2. The PA Reference Point plots for the Blackfin stock, presented in the Plots sheet from the PaSoft Excel output file. Top left – Recruitment against SSB; Top right – Spawner per recruit and yield per recruit curves against Fbar; Bottom left – Equilibrium SSB against Fbar; Bottom right – Equilibrium yield against Fbar.

TABLE 3. The initial 30 bootstrap estimates of the PA Reference Point for the Blackfin stock, presented in the PDist sheet from the PaSoft Excel output file.

MedianRecruits	MBAL	BLOSS	SSB90%R	SPR%ofVi	VirginSPR	SPRloss	Fbar	Fmax	F0.1	Flow	Fmed	Fhigh	F35%
30500.1	0	11710.78	31987.81	32.92425	12.56292	0.492193	0.144098	0.30429	0.158286	0.148992	0.296653	0.398416	0.13
30500.1	0	11710.78	28821.32	28.06901	16.9407	0.476719	0.186422	0.287982	0.165465	0.284807	0.367829	0.542471	0.15
29092.62	0	11710.78	26384.61	31.6019	17.61149	0.391794	0.163926	0.280576	0.170775	0.249986	0.379455	0.523765	0.14
23605.62	0	11710.78	34572.25	30.42786	14.38138	0.508237	0.182946	0.31677	0.175411	0.231237	0.335241	0.505033	0.15
25037.47	0	11710.78	34084.12	34.31776	11.91618	0.476817	0.171758	0.334967	0.185622	0.253005	0.343447	0.504724	0.16
31709.35	0	11710.78	26896.93	35.2088	11.97367	0.362807	0.149738	0.311996	0.169403	0.194907	0.331645	0.499853	0.15
30074.89	0	11710.78	28951.75	28.42961	11.25885	0.518501	0.206695	0.426189	0.219188	0.229276	0.321172	0.483275	0.17
22623.305	0	11710.78	31739.28	23.36975	32.54827	0.566127	0.179196	0.176472	0.106927	0.358247	0.490666	0.6286	0.12
31370.43	0	11710.78	38922.85	36.88409	10.24911	0.619018	0.169865	0.448276	0.22273	0.196868	0.347578	0.440352	0.17
30074.89	0	11710.78	30985.35	30.80486	14.2572	0.537598	0.170803	0.337349	0.202142	0.20084	0.308771	0.445832	0.15
30074.89	0	11710.78	34732.04	28.35328	14.9713	0.505754	0.216613	0.405366	0.241789	0.290092	0.424223	0.524647	0.17
26148.7	0	11710.78	28502.84	32.4721	15.76868	0.500545	0.174331	0.316702	0.177159	0.278479	0.391798	0.588867	0.16
25432.775	0	11710.78	29729.93	24.81739	17.22952	0.463005	0.184098	0.254437	0.152597	0.238555	0.342454	0.472543	0.13
23247.35	0	11710.78	30075.01	29.89	14.12951	0.48707	0.154949	0.256911	0.137724	0.213592	0.299843	0.438707	0.13
26148.7	0	11710.78	35261.05	37.07819	12.88021	0.580616	0.14861	0.350266	0.188054	0.247337	0.338614	0.468119	0.15
27259.93	0	11710.78	29279.96	25.93441	12.51622	0.472268	0.184941	0.293628	0.163261	0.202204	0.286881	0.430571	0.14
23605.62	0	11710.78	30226.5	35.03407	15.23995	0.598271	0.150278	0.312342	0.17861	0.263362	0.327842	0.452285	0.15
24022.39	0	11710.78	23300.66	32.65281	14.29413	0.452	0.190465	0.392838	0.220128	0.249938	0.39822	0.594555	0.17
30925.31	0	11710.78	27819.15	29.81821	12.20651	0.418844	0.179038	0.333256	0.189511	0.210965	0.303154	0.445012	0.15
25037.47	0	11710.78	30253.14	27.79232	12.10182	0.51839	0.19315	0.338441	0.186312	0.258973	0.3325	0.475037	0.15
22948.195	0	11710.78	26555.73	31.11318	15.18016	0.518481	0.150074	0.242278	0.142524	0.224594	0.307531	0.46416	0.13
22889.08	0	11710.78	31653.4	28.91018	18.59249	0.462596	0.169392	0.245365	0.150577	0.274225	0.358615	0.487562	0.14
22981.845	0	11710.78	28658.1	22.99329	18.25419	0.428346	0.202298	0.261919	0.150539	0.276289	0.370082	0.498208	0.13
22922.73	0	11710.78	28646	24.74067	13.50679	0.494508	0.197191	0.322591	0.17394	0.214684	0.283565	0.460055	0.14
25432.775	0	11710.78	24092.28	28.66087	12.11946	0.49517	0.186122	0.358012	0.174597	0.230333	0.300794	0.502544	0.15
31370.43	0	11710.78	29798.36	30.14793	10.05675	0.49633	0.179867	0.358814	0.18154	0.166608	0.29823	0.447809	0.15
26148.7	0	11710.78	37572.37	34.4339	14.18645	0.613901	0.153254	0.32775	0.183061	0.240253	0.342903	0.436936	0.15
30074.89	0	11710.78	23825.86	30.98678	15.91894	0.40612	0.178543	0.30738	0.179479	0.231221	0.358914	0.545596	0.15
26148.7	0	11710.78	34895.76	31.59613	11.31906	0.50573	0.178534	0.362696	0.192132	0.215579	0.332003	0.42874	0.16
30964.5	0	11710.78	28727.33	33.31394	11.76719	0.480599	0.163386	0.312125	0.171665	0.185222	0.308376	0.472055	0.15

TABLE 4. The input data for the estimation of the PA Reference Point for the Blackfin stock, presented in the SV sheet from the PaSoft Excel output filefile.

Age	N	M	CWt	SWt	Mat	F	FPreSpwn	MPreSpwn
1	0	0.2	0.590333	0.590333	0	0.000443	0	0
2	16412.25	0.2	0.860667	0.860667	0	0.106141		
3	10517.84	0.2	1.131	1.131	0	0.165427		
4	7271.93	0.2	1.462	1.462	0	0.260107		
5	3997.49	0.2	2.112	2.112	1	0.211053		
6	2131.86	0.2	2.869333	2.869333	1	0.141556		
7	1528.56	0.2	4.143	4.143	1	0.098364		
8	617	0.2	5.120333	5.120333	1	0.085274		
9	472.54	0.2	6.426	6.426	1	0.103553		
10	992.17	0.2	9.050667	9.050667	1	0.103553		

FbarMinAge	4
FbarMaxAge	7
M year CV	0.1

NCV	MCV	CWtCV	SWtCV	MatCV	FCV
0	0.1	0.098371	0.098371	0.1	0.68172
9.75222	0.1	0.086421	0.086421	0.1	0.72884
0.26225	0.1	0.029814	0.029814	0.1	0.381266
0.19439	0.1	0.09449	0.09449	0.1	0.165987
0.18015	0.1	0.087517	0.087517	0.1	0.116818
0.1817	0.1	0.049484	0.049484	0.1	0.097805
0.18811	0.1	0.059178	0.059178	0.1	0.443046
0.2105	0.1	0.045287	0.045287	0.1	0.359722
0.22298	0.1	0.011354	0.011354	0.1	0.275606
0.22298	0.1	0.068573	0.068573	0.1	0.275606

Year	SSB	Recruitment	Yield	Fbar
1963	11710.78	32415.01	6280.488	0.268748
1964	17014.45	22357.53	13070.21	0.420165
1965	23999.6	22889.08	18876.47	0.632308
1966	21826.96	32779.56	18836.04	0.44973
1967	30964.24	23605.62	15793.87	0.368828
1968	34441.75	38390.83	13060.77	0.238885
1969	43435.16	27259.93	17454.17	0.276788
1970	56042.43	40147.54	14796.16	0.21009
1971	60518.81	36124.96	20298.13	0.281355
1972	74879.81	35679.46	29303.82	0.22157
1973	97936.71	32747.65	36686.26	0.30204
1974	93920.01	33736.42	37281.2	0.28761
1975	76136.96	25037.47	31620.7	0.36094
1976	88272.5	17554.59	43184.3	0.452655
1977	60282.17	18780.98	28509.34	0.445075
1978	80184.72	20692.79	32564.8	0.389535
1979	58436.55	22519.5	21849.07	0.35779
1980	55866.28	30925.31	22303.76	0.347528
1981	55837.82	30074.89	24071.67	0.311733
1982	47672.17	39271.43	24283.43	0.376188
1983	52781.94	40946.7	28404.82	0.365575
1984	49608.76	44469.4	22082.54	0.244073
1985	59340.07	22956.38	27004.21	0.317903
1986	61470.84	31003.69	42551.18	0.65082
1987	47081.24	31370.43	29839.76	0.550345
1988	43667.4	22295.84	34828.51	0.6314
1989	29895.96	23007.31	27311.24	0.68496
1990	24651.49	17353.34	20885.03	0.568433
1991	21559.32	16793.23	17017.17	0.587965
1992	23878.47	20007.37	11868.62	0.370095
1993	25044.56	18950.84	14055.82	0.347048
1994	32347.56	20043.07	10528.84	0.17777

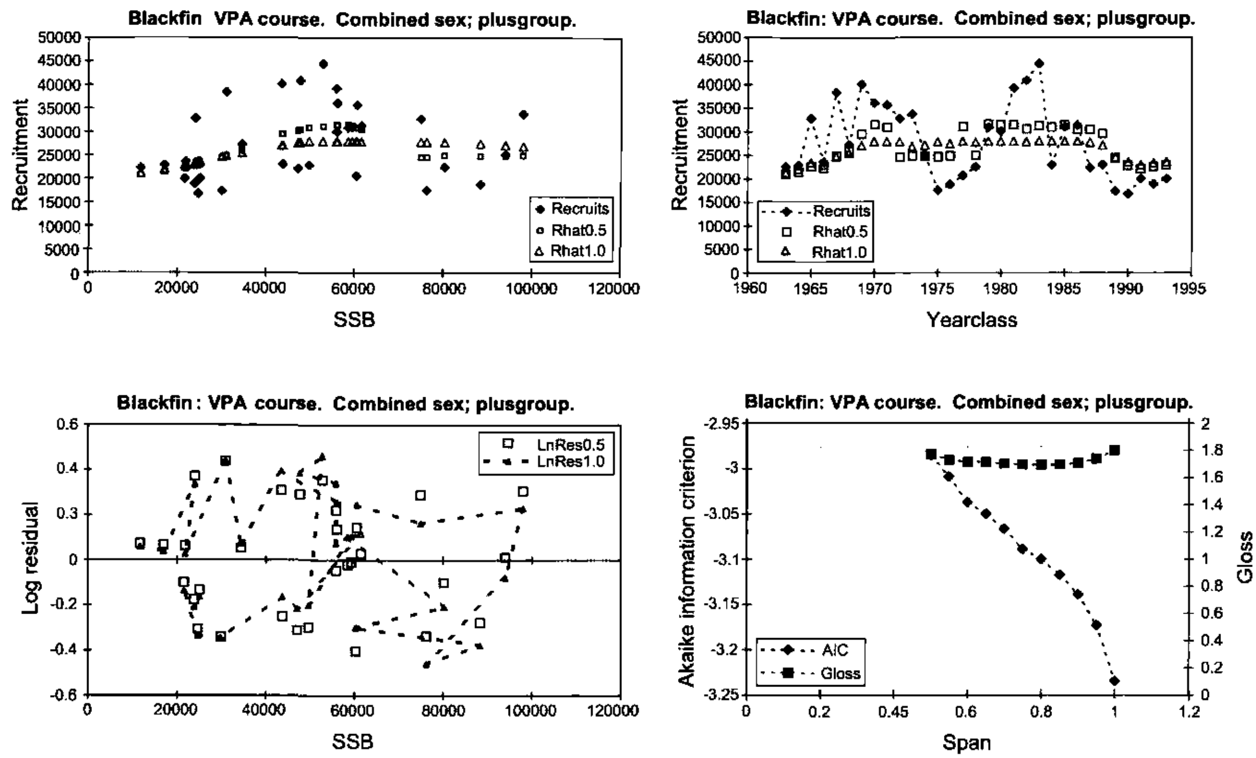


Fig. 3. The PASoft diagnostic plots for the Blackfin stock. Top left – recruitment plotted against SSB; with the LOWESS fits corresponding to the spans of 0.5 and 1.0. Top right – the time series of recruitment with recruitment estimates obtained from the two LOWESS fits. The bottom left – the log-normal residuals obtained from the two LOWESS fits.

APPENDIX 2. Woods Hole Version of ADAPT/VPA Fisheries Assessment Compilation Toolbox (FACT)

NAFO Sci. Coun. Studies, 36: 163–199

Appendix 2: Woods Hole Version of ADAPT/VPA Fisheries Assessment Compilation Toolbox (FACT)

Outlines and Data Sets

by

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Abstract

FACT is the Fishery Assessment Compilation Toolbox and the Woods Hole Assessment Toolbox's successor. Several existing assessment programs have been added to FACT making it a powerful and user-friendly tool. The assessment programs previously existed in a DOS or UNIX environment. These programs now have a user-friendly interface that makes editing of inputs and analyzing data easier, and completion of assessments more intuitive.

ADAPT is an age-structured, adaptable framework for estimating historical stock sizes of an exploited population. It is not a rigidly defined model in the mathematical sense, but rather a flexible set of modular tools designed to integrate data that may contain useful information on population size. The statistical basis of the ADAPTive approach is to minimize the discrepancy between observation of state variables and their predicted values. The observed state variables are usually (but are not limited to) age-specific indices of population size, e.g. from commercial catch-effort data, research surveys, mark-recapture experiments, etc. The predicted values are a function of a vector of estimated population size (age-specific) and catchability parameters.

This document shows how to run Adapt/VPA using a sample input file to complete a VPA. A description of the various files containing the VPA results is given. Details on the completion of a set of bootstrap analyses are also provided, and a description of the various files containing the bootstrap results is given.

Introduction

The overall purpose of FACT is to develop a set of standard tools for scientists to use for stock assessment. There is a growing need for a set of standardized and verified software for conducting stock assessments. The toolbox allows analysts to use a variety of assessment models to select options and produce diagnostics appropriate to a particular methodology. A suite of programs has been developed which includes modules for data input, formatting and error checking, and exploratory data analysis for a variety of assessment approaches.

The individual models of the toolbox were stand-alone, DOS or Unix based components, which were recompiled into dynamic link libraries and integrated with a Windows interface. At present the available models include Virtual Population Analysis (VPA) with retrospective and bootstrapping capabilities (ADAPT), Age Projection (AGEPRO), Yield per Recruit and Spawning Biomass per Recruit, and A Stock-Production model Including Covariates (ASPIC) with projection, and Precautionary Approach software. A comprehensive on-line help is also available with FACT.

In this Workshop we will use two of the modules, ADAPT and AGEPRO. This document describes the use of the ADAPT module.

ADAPT

This module is the VPA implementation using the ADAPT approach towards minimizing sums of squares in a specified objective function. In ADAPT, there is a calibration block and an estimation block.

The calibration block is the set of indices × ages which are used to 'calibrate' the VPA terminal populations. A value of q is estimated for each index in the calibration block.

The estimation block is the set of ages for which you are estimating a terminal population stock size. In ADAPT, these are considered as survivors at the end (31 December) of the terminal year of the catch at age matrix, or at the beginning (1 January) of the year following the terminal year.

Input

All of the Workshop example data files for FACT are in: **C:\Workshop\Fact**

The ADAPT module requires the following input:

Catch-at-age
Mean catch weights-at-age
Mean stock weights-at-age
Tuning indices
Natural mortality
Maturation ogive

There are also several initialization specifications to be set before the VPA can run.

All of these data are in a single example file: **gmcod2000_base.inp**

This file can be imported directly into the ADAPT module using the File dialog box.

The VPA will run using all of the data as the default. You may also wish to change the indices depending on trends in the residuals.

Diagnostics

1. In addition to the residuals, one can look for a retrospective pattern in the estimates of F, stock size-at-age, and SSB. The retrospective may be selected from the Diagnostics dialog box.

2. The final formulation of the VPA may be run through a bootstrap procedure in which a normalized residual is drawn at random from the pool, and subtracted from an observed normalized survey index. This is done for each index in the calibration block. Generally, between 500 and 1 000 bootstrap runs are performed. This may take time, so 100 is recommended for the workshop.

Output

After the VPA has run successfully, formatted output will be written by default to a file based on the name of the input file, in this case: **gmcod2000_base.2.** This file should be brought into a word processor for viewing and printing. If a Retrospective Analysis has been selected, the results will be appended to the end of this file.

An ASCII 'Flat File' may also be output as an option. This file contains VPA results and residuals selected by the user. This file should be brought into a spreadsheet for further analysis, tabulation, and plotting.

After the Bootstrap procedure has run successfully, formatted output containing a summary of all bootstrapped variables will be written to a file based on the name of the input file, in this case: **gmcod2000_base.2boot.** This file should also be brought into a word processor for viewing and printing.

The Bootstrap procedure also produces 6 'data files' in free format containing all of the bootstrap results, in this case:

gmcod2000_base.2bootF	Fully recruited F in terminal year of the VPA
gmcod2000_base.2bootN	Estimated stock sizes at age at the end of the terminal year
gmcod2000_base.2bootSSB	Spawning Stock Biomass in all years of the VPA
gmcod2000_base.2bootMB	Mean Stock Biomass in the terminal year of the VPA
gmcod2000_base.2bootJB	Beginning-year Biomass in the terminal year of the VPA
gmcod2000_base.2bootBWF	Biomass-weighted F in the terminal year of the VPA

These files may be brought into a spreadsheet for further analysis, tabulation, and plotting. The file, **gmcod2000_base.2bootN** is used as input for the forward projection program, AGEPRO. The file, **gmcod2000_base.2bootSSB,** may also be required, depending on the recruitment generation model selected in AGEPRO.

The following sections are taken from the on-line HELP available in FACT.

VPA Introduction

Virtual Population Analysis (VPA) Method

ADAPT is an age-structured, adaptable framework of estimating historical stock sizes of an exploited population. It is not a rigidly defined model in the mathematical sense, but rather a flexible set of modular tools designed to integrate data that may contain useful information on population size.

The statistical basis of the ADAPTive approach is to minimize the discrepancy between observation of state variables and their predicted values. The observed state variables are usually (but are not limited to) age-specific indices of population size, e.g. from commercial catch-effort data, research surveys, mark-recapture experiments, etc. The predicted values are a function of a vector of estimated population size (age-specific) and catchability parameters. Sequential population analysis equations (Gulland's (MS 1965) VPA) and nonlinear least squares objective functions are employed to minimize the discrepancies.

The appellation ADAPT was introduced by Gavaris (MS 1988). However, the foundation of the method was developed over the preceding decade under an umbrella of research generally referred to as VPA tuning. Although not generally recognized, Parks (1976) was the first to tune a VPA using auxiliary data and a least squares objective function. He tuned VPA back-calculated fishing mortality rates (Fs) to Fs derived independently from tagging experiments. Gray (MS 1977) suggested a least squares approach to estimate mortality rates (both F and M) using a commercial catch-per-unit-effort (CPUE) index of abundance as auxiliary data.

Doubleday (1981) used age-specific research survey indices of abundance as auxiliary data to estimate survivors in the terminal year for each cohort. This appears to have been the first attempt to utilize multiple indices of abundance in a least squares tuning procedure.

Parrack (1986) expanded upon Doubleday's work by integrating indices of abundance from widely diverse sources into the least squares objective function. His formulation allowed indices from commercial fisheries, research surveys, larval surveys, etc. Indices could be either age-specific or represent several age-classes. Indices could be expressed in either population number or biomass. Indices were related to population size either linearly or through a power function. Variance estimates were made assuming linearity at the optimal solution. He also recognized that not all indices are of equal value in measuring population abundance. Some indices will always be inherently more variable than others, and some may be biased. He introduced detailed examination of residuals and correlation statistics as an acceptance/rejection filter that each index needed to pass through in order to be used in the final tuning. The tuning procedure described by Parrack (1986) is the kernel of the method today known as ADAPT, both in terms of the objective function employed and in terms of the underlying philosophy.

The ADAPTive framework developed by Gavaris (MS 1988) generalized Parrack's procedure in several ways:

1. The adaptive aspects of the method were greatly enhanced through the use of a modular model structure and implementation in the APL programming language. This made it possible to modify the objective function significantly, as needed to rectify problems, even during the course of an assessment working group meeting.
2. A Marquardt algorithm (Bard 1974) was used for optimization of the least squares objective function. This allowed the simultaneous estimation of age-specific population sizes in the terminal year and catchabilities (Parrack estimated only the full F in the terminal year F vector). Additionally, the use of numerical derivatives in the Marquardt algorithm greatly enhanced the adaptive philosophy by making objective function modifications easy to implement.
3. The more complete statistical model allowed for improved diagnostics. In addition to residual analysis, availability of the full variance-covariance matrix (assuming linearization at the optimal solution) provided variance estimates of all parameters, correlation among parameter estimates, and in general a better sense of which parameters were estimable from the available information.

The integration of many diverse sources of information focused attention on objective procedures to account for differences in the quality of information. Collie (1988) suggested that all indices of abundance should be included in the least squares objective function rather than employing Parrack's acceptance/rejective criteria. He recommended weighting the indices by the inverse of their variances. Vaughn *et al.* (1989) used Monte Carlo simulation to investigate the effect of weighting on the Fs estimated for bluefin tuna. They found that the F estimates were unbiased only when the indices were weighted. Conser and Powers (1990) developed a more general weighting procedure that allowed for two-way effects, i.e. index and year. Gavaris and Van Eeckhaute (MS 1991) employed a similar weighting procedure using an analysis of variance approach. Gassuikov (1990) suggested an alternative approach to weighting in ADAPT using the moving check procedure of Vapnik (1982).

The approach shows how to get started using Adapt/VPA using a sample input file to demonstrate a run. The book **Getting Started with Adapt/VPA**, includes a documented input file and output file.

The *Explanation of the sample output file* provides links to explain the mathematical methods for the given results.

Input File

Output File

Demonstration with Sample program

Adapt/VPA Model Overview

ADAPT is an age-structured. adaptable framework of estimating historical stock sizes of an exploited population. It is not a rigidly defined model in the mathematical sense. but rather a flexible set of modular tools designed to integrate all available data that may contain useful information on population size.

The statistical basis of the ADAPTive approach is to minimize the discrepancy between observation of state variables and their predicted values. The observed state variables are usually (but are not limited to) age-specific indices of population size. e.g. from commercial catch-effort data, research surveys, mark-recapture experiments, etc. The predicted values are a function of a vector of estimated population size (age- specific) and catchability parameters; and standard population dynamics equations (usually Gulland's (MS 1965) VPA). Non-linear least squares objective functions are employed to minimize the discrepancies.

Model Overview

Adapt VPA model uses the application of a statistical technique, non-linear least squares, to determine the most appropriate estimate of the population matrix. Gavaris (1988) initially describes the Adapt objective function in general terms, as a minimization of the difference between observation of variables and the values of those variables predicted as functions of the population matrix (i.e. as function of the catch-at-age). That is,

$$min \sum_{k}^{K} W_k (\theta_k - \hat{\theta}_k)^2$$

where θ_k is the k_{th} observation.

$\hat{\theta} = f(\Pi, \Omega)$ (user defined)

Π is the population matrix.

Ω are the other parameters which may be required.

W_k = weight for observed variable set k.

K is the number of observations.

In this implementation of ADAPT the error in the catch at age is assumed to be negligible relative to error in the indices of abundance. This appears to be reasonable. This above objective function has been used almost exclusively in the CAFSAC and NAFO assessments that have employed ADAPT (Gavaris, pers. comm.)

Residual Sum or Squares

The objective function employed in this ADAPT Version has the following form.

$$RSS = \sum_{k=1}^{K} \sum_{j=1}^{Y+1} \left[\frac{ln\, I(k,j)}{\bar{I}(k)} - ln\, \hat{I}(k,j) \right]^2 \bullet W(k,j)$$

where k is a general pointer that specifies a particular combination of age group index type, and tuning type. For example $k = 1$ might specify the age 5 survey index from an autumn survey tuned to Jan. 1 abundance in year $T + 1$.

K is the number of indices used, as selected by the user (**Available indices** tab).

j is the year and ranges from the first year to the terminal year plus one.

I(k, j) is the observed survey index with index number k in year j .

$\hat{I}(k,j)$ is the predicted index with index number k in year j .This is calculated differently depending on the user's choice of tuning units (**Weight, Number**) and tuning date (**Jan 1** and **Mean**) in the indices tab of the user's interface. See **indices options**.

$W(k,j)$ is the weight associated with the observed indices at index number k in year j.

$\bar{I}(k)$ is the average over years for an index and is defined by the equation:

$$\bar{I}(k) = \frac{1}{Y+1} \sum_{j=1}^{Y+1} I(k,j)$$

When the index value is 0, that year is not included into the equation.

The Fitting Procedure

The fitting procedure for terminal year + 1 population numbers (N) and catchabilities (q) in ADAPT/VPA uses the Marquardt algorithm. The algorithm uses initial guesses for stock size in year, $y + 1$ and catchabilities to calculate fishing mortality (F) and population numbers using cohort equations. An iterative procedure is applied where q and N parameters are adjusted to minimize the objective function. Trial values for the parameters are adjusted at each calculation of the residual sum of squares (RSS) and compared to the previous RSS. The procedure is then repeated until the RSS is zero or effectively stops decreasing. For this ADAPT /VPA the successive RSS values are recalculated until the difference between consecutive RSS values is 0.00001 or 200 iterations have been performed. The parameters with the lowest RSS value are considered the "best fit" and are considered the most correct estimate.

One assumption in the ADAPT model is that the error in the indices is greater than the error in the catch-at-age. Since the statistical procedure does not deal with error in both variables, the model assumes error in the catch-at-age matrix, only in the survey indices. In addition, the model does not assume separability (F is represented as a fraction of catch to total stock size rather than assuming that F is a function of an age specific and year specific exploitation pattern.)

Statistical Weighting

The weights associated with each observation are not limited to the $1/\sigma^2$ type weights from research surveys, but include such weighting in addition to other weighting factors. Weighting in addition to log transformation fails to stabilize variance among the observations. Three types of weighting contribute multiplicatively to the weight assigned to each observation.

$$W(k,j) = \omega(k,j) \bullet \chi(k) \bullet \delta(j)$$

where $\omega(k,j)$ are the $1/\sigma^2$ type weights from research surveys, multiplicative models using catch-effort data, or other exogenous information. See Omega weights.

$\chi(k)$ are weights designed to stabilize the variance across the various indices of abundance. See Chi weights.

$\delta(j)$ are weights designed to stabilize the variance across years to counteract the convergence properties of VPA. This process known as down-weighting allows the user to systematically assign linear, quadratic or tricubic weights to a weighting function. See Downweighting.

The raw weights calculated by the above equation are normalized prior to use in the objective function, such that

$$\sum_k \sum_j W(k,j) = 1$$

For any given assessment, all of these weights, some subset of them, or none of them may be employed depending on the available data and the structure of the heteroscedasticity.

Omega weights – Inverse Variance Weights from Exogenous data $(\omega(k,j))$

These weights are the type suggested by Gavaris (1988). Their use is intended to discount the effect of less reliable observations on the parameter estimates and to better satisfy the usual regression assumption of homogeneity of variance among all observations. When all observed indices of abundance are based on research surveys that have been carried out in a consistent manner, these weights alone may be sufficient to stabilize variance, both across years and across indices. However, when indices of abundance are derived from different data sources (e.g. research surveys and catch-effort data), it is unlikely that variances computed from the respective data sources will stabilize the variance across indices.

Omega weights are user-defined weights where each index is individually weighted. A value of 1 has no effect on the weighting. See Statistical weighting and VPA screen.

Chi weights – Inverse Variance weights from iterative re-weighting – $X(k)$

$X(k)$ are weights designed to stabilize the variance across the various indices of abundance.
Chi weights are set to 1 during the initial VPA run and are activated by **Re-weighted VPA** of the **Run VPA** menu selection. The **Re-weighting VPA** option can only be enabled after an initial **VPA run**. The output is appended to the VPA output file.

By invoking re-weighting, the chi weights are calculated for each index and are used to re-weight the indices in the final residuals sum of squares (RSS) solution. The calculating procedure for weighting is as follows:

$$\chi(k)=\frac{\dfrac{\dfrac{1}{MSR(k)}}{\sum_{k=1}^{K}\dfrac{1}{MSR(k)}}}{\sum_{k=1}^{K}\left[\dfrac{\dfrac{1}{MSR(k)}}{\sum_{k=1}^{K}\dfrac{1}{MSR(k)}}\right]}$$

where k is the index of indices and K is the number of indices used, as selected by the user (**Available indices tab**).

MSR is the mean square residual and is defined by the following equation:

$$MSR(k)=\frac{\sum_{j}^{Y+1}Res(k,j)^2}{K_{Total}-[K+A_n]}$$

k is the index of indices, K_{Total} is the total number of non-zero indices and K is the number of catchabilities (q) estimated.
A_n is the number of ages the user enters into the **Ages to estimate** text box.
Res is the residual or the difference between the observed survey index $I(k, j)$ and the predicted index $\hat{I}(k,j)$. $\hat{I}(k)$ is the average over years for an index.

$$Res(k,j)=\frac{ln\,I(k,j)}{\hat{I}(k)}-ln\,\hat{I}(k,j)$$

See Residual Sum of Squares (RSS).

Down-weighting to counterbalance VPA convergence – $\delta(j)$

Assuming that error in the catch-at-age estimates is negligible relative to error in the indices of abundance (Gavaris 1988), the residuals from any VPA-based tuning method will tend to be smaller in the more recent years. In earlier years, where the VPA has converged, the differences between observed and predicted indices will not be affected greatly by various choices of the parameters in the terminal year. In contrast, the residuals from more recent years can be reduced appreciably by the tuning process. ADAPT/VPA has options to apply linear, quadratic or tricubic weightings to the down-weighting function.

The following expression is used to calculate the down-weighting value.

$$\delta(j) = \left(1 - \left(\frac{Y + 1 - j}{Y_{DW}} \right)^{DW} \right)^{DW}$$

for years $j=1$ to $Y+1$.

Y_{DW} is the number of years to down-weight (and DW specifies the type of down-weighting in which there are several options.

a) None or uniform = 0
b) Linear = 1
c) Biquadratic = 2
d) Tricubic = 3

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ADAPT/VPA Input Data
File: gmcod2000_base.inp

```
                              Second FACT INPUT FILE
1
GoM Cod 2000 Base Run
0.0001 0.053 0.421 1 1 1
2 3 4 5 6
3000 3000 500 500 500
1
1982
0.01*21
FLAT
1*18
1000000
0
1
0
1*19
1,7 1,6 2,6 4,6
0.1667
0.1667
4 5 6
Backward
None or Uniform
 1982
Catch at Age
 30        1380      1633      1143      633       69        230
 0.001     866       2357      1058      638       422       155
 4         446       1240      1500      437       194       136
 0.001     407       1445      991       630       128       136
 0.001     84        2164      813       250       177       95
 2         216       595       1109      277       66        79
 0.001     160       1443      953       406       43        30
 0.001     337       1583      1454      449       81        56
 0.001     205       3425      2064      430       157       99
 0.001     344       934       4161      851       143       79
 0.001     313       530       484       2018      202       84
 0.001     76        1487      641       129       457       36
 0.001     29        1016      1135      288       72        86
 0.001     218       880       1153      194       12        34
 0.001     65        584       1738      347       45        10
 0.001     53        438       435       832       68        8
 0.001     94        390       542       165       193       10
 0.001     0.001     178       192       90        27        36
Weight at Age
 0.9       1.156     1.664     2.764     4.77      6.739     11.33
 0.9       1.164     1.66      2.475     3.778     5.962     9.755
 0.9       1.159     1.67      2.721     3.677     5.898     10.176
 0.9       1.26      1.746     2.84      4.466     5.525     9.721
 0.9       1.304     1.837     2.923     4.619     6.067     10.295
 0.9       1.313     1.684     3.283     4.831     6.824     10.241
 0.9       1.268     1.881     2.426     5.166     6.767     11.233
 0.9       1.247     1.776     2.993     3.864     4.872     12.2
 0.9       1.071     1.692     2.271     4.265     7.645     13.747
 0.9       1.13      1.568     2.512     4.136     7.309     11.449
 0.9       1.533     1.922     2.714     3.061     5         10.614
 0.9       1.293     1.889     2.513     4.356     6.174     11.063
 0.9       1.45      1.943     3.151     3.444     6.132     10.018
 0.9       1.652     1.921     2.775     5.142     8.29      12.969
 0.9       1.687     2.136     2.376     3.648     7.376     11.647
 0.9       1.733     2.233     3.007     3.193     4.649     12.479
 0.9       1.277     2.089     2.979     4.191     4.211     10.262
 0.9       1.277     1.774     2.704     4.02      5.727     7.901
```

Biomass Weights

0.791	0.965	1.364	2.364	4.267	5.67	11.33
0.793	1.024	1.385	2.029	3.231	5.333	9.755
0.761	1.021	1.394	2.125	3.017	4.72	10.176
0.748	1.065	1.423	2.178	3.486	4.507	9.721
0.745	1.083	1.521	2.259	3.622	5.205	10.295
0.758	1.087	1.482	2.456	3.758	5.614	10.241
0.765	1.068	1.572	2.021	4.118	5.718	11.233
0.825	1.059	1.501	2.373	3.062	5.017	12.2
0.803	0.982	1.453	2.008	3.573	5.435	13.747
0.69	1.008	1.296	2.062	3.065	5.583	11.449
0.751	1.175	1.474	2.063	2.773	4.548	10.614
0.709	1.079	1.702	2.198	3.438	4.347	11.063
0.664	1.142	1.585	2.44	2.942	5.168	10.018
0.657	1.219	1.669	2.322	4.025	5.343	12.969
0.649	1.232	1.878	2.136	3.182	6.159	11.647
0.756	1.249	1.941	2.534	2.754	4.118	12.479
0.756	1.072	1.903	2.579	3.55	3.667	10.262
0.756	1.072	1.505	2.377	3.461	4.899	7.901
0.741	1.072	1.521	2.091	3.076	4.67	7.901

SSB Weights

0.791	0.965	1.364	2.364	4.267	5.67	11.33
0.793	1.024	1.385	2.029	3.231	5.333	9.755
0.761	1.021	1.394	2.125	3.017	4.72	10.176
0.748	1.065	1.423	2.178	3.486	4.507	9.721
0.745	1.083	1.521	2.259	3.622	5.205	10.295
0.758	1.087	1.482	2.456	3.758	5.614	10.241
0.765	1.068	1.572	2.021	4.118	5.718	11.233
0.825	1.059	1.501	2.373	3.062	5.017	12.2
0.803	0.982	1.453	2.008	3.573	5.435	13.747
0.69	1.008	1.296	2.062	3.065	5.583	11.449
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0.649	1.232	1.878	2.136	3.182	6.159	11.647
0.756	1.249	1.941	2.534	2.754	4.118	12.479
0.756	1.072	1.903	2.579	3.55	3.667	10.262
0.756	1.072	1.505	2.377	3.461	4.899	7.901
0.741	1.072	1.521	2.091	3.076	4.67	7.901

Indices

WHSpr	WHSpr	WHSpr	WHSpr	WHSpr	WHAut	WHAut	WHAut	WHAut	WHAut
2	3	4	5	6	2	3	4	5	6
1-Jan	1-Jan	1-Jan	1-Jan	1-Jan	1-Jan	1-Jan	1-Jan	1-Jan	1-Jan
number	number	number	number	number	number	number	number	number	number
1.019	0.516	0.694	0.864	0.117	0.619	0.382	0.549	0.474	0.089
0.978	0.833	0.641	0.357	0.181	0.7	3.142	2.473	1.167	0.248
1.033	1.147	0.741	0.19	0.053	1.66	0.977	0.852	0.139	0.264
0.238	0.622	0.665	0.677	0.095	0.384	0.421	0.565	0.399	0.22
0.33	0.647	0.387	0.074	0.046	0.378	0.91	0.763	0.209	0.218
0.638	0.486	0.3	0.128	0.011	0.301	0.49	0.654	0.333	0.086
1.053	0.633	0.355	0.217	0.087	0.599	1.324	0.6	0.257	0.061
0.649	0.79	0.632	0.09	0.077	1.951	2.245	0.96	0.528	0.11
0.19	1.327	0.627	0.167	0.032	0.416	2.391	1.356	0.294	0.174
0.209	0.355	1.477	0.268	0.024	0.029	0.367	1.643	0.623	0.278
0.23	0.24	0.28	1.31	0.22	0.142	0.142	0.221	0.632	0.079
0.5	0.8	0.33	0.09	0.48	0.29	0.45	0.14	0.04	0.33
0.316	0.387	0.213	0.095	0.047	0.198	0.569	0.363	0.032	0
0.18	1.12	0.37	0.15	0.03	0.21	0.88	0.83	0.09	0.05
0.02	0.59	1.33	0.4	0.06	0.07	0.28	1.23	0.33	0.08
0.132	0.399	0.264	0.876	0.242	0.12	0.38	0.19	0.54	0.06
0.224	0.33	0.517	0.142	0.421	0.297	0.086	0.16	0.182	0.149
0.344	0.713	0.344	0.315	0.134	0.097	0.32	0.115	0.192	0.039
0.725	0.438	0.457	0.107	0.101	0.431	0.363	0.59	0.243	0.132

Indices

MASpr	MASpr	MASpr	MAAut	MAAut	MAAut	CM_CPE	CM_CPE	CM_CPE	CM_CPE	CM_CPE
2	3	4	1	2	3	2	3	4	5	6
1-Jan	1-Jan	1-Jan	1-Jan	1-Jan	1-Jan	mean	mean	mean	mean	mean
number	number	number	number	number	number	number	number	number	number	number
7.06	3.418	1.147	2.018	5.652	7.29	0.07432	0.07382	0.04502	0.02168	0.00265
18.572	5.331	0.501	4.667	2.346	1.005	0.04767	0.10991	0.04215	0.02094	0.01231
5.408	2.271	0.865	1.308	0.651	0.1	0.03313	0.04478	0.04418	0.01179	0.00552
3.822	2.794	0.692	12.296	0.344	0.022	0.01372	0.04226	0.02894	0.01793	0.00361
3.222	0.887	0.426	2.832	0.419	0.018	0.00409	0.06877	0.02257	0.00661	0.00428
6.997	2.268	0.257	2.478	1.15	0.833	0.00738	0.01861	0.02599	0.00572	0.00177
11.356	2.511	1.37	389.584	2.386	0.02	0.01455	0.0492	0.02418	0.00932	0.00147
25.26	6.58	0.458	4.571	20.49	0.679	0.01698	0.0637	0.03966	0.01059	0.00231
6.89	17.77	2.64	2.971	2.7	0.35	0.01098	0.15953	0.07816	0.01219	0.0051
3.56	2.54	5.03	9.37	9.13	1.74	0.01943	0.04044	0.13551	0.0217	0.00394
6.35	3.58	0.65	4.65	4.2	0.81	0.01494	0.01733	0.0138	0.05147	0.00519
7.76	3.6	1.45	24.3	2.01	0.11	0.00267	0.04997	0.02324	0.00407	0.01395
5.67	2.46	0.52	49.92	3.32	0.61	0	0	0	0	0
1.36	3.89	1.2	33.49	14.13	6.37	0	0	0	0	0
0.97	2.11	0.81	2.56	0.64	0.54	0	0	0	0	0
1	1.34	0.2	7.59	0.15	0.02	0	0	0	0	0
1.17	0.89	1.17	2.02	0.02	0	0	0	0	0	0
3.55	3.31	1.32	2.7	1.05	0.01	0	0	0	0	0
7.34	4.03	2.3	6.63	0.84	0.14	0	0	0	0	0

Maturity Matrix

0.07	0.26	0.61	0.88	0.97	1	1
0.07	0.26	0.61	0.88	0.97	1	1
0.07	0.26	0.61	0.88	0.97	1	1
0.04	0.48	0.95	1	1	1	1
0.04	0.48	0.95	1	1	1	1
0.04	0.48	0.95	1	1	1	1
0.04	0.48	0.95	1	1	1	1
0.04	0.48	0.95	1	1	1	1
0.11	0.28	0.56	0.81	0.93	0.98	1
0.11	0.28	0.56	0.81	0.93	0.98	1
0.11	0.28	0.56	0.81	0.93	0.98	1
0.11	0.28	0.56	0.81	0.93	0.98	1
0.04	0.38	0.89	0.99	1	1	1
0.04	0.38	0.89	0.99	1	1	1
0.04	0.38	0.89	0.99	1	1	1
0.04	0.38	0.89	0.99	1	1	1
0.04	0.38	0.89	0.99	1	1	1
0.04	0.38	0.89	0.99	1	1	1

M Matrix

0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2	0.2	0.2

ADAPT/VPA Output

File: gmcod2000_base.2

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Fisheries Assessment Toolbox GoM Cod 2000 Base Run Run Number 1 8/25/20009:15:13 AM

FACT Version 1.3.6
GoM Cod 2000 Base Run  1982 - 2000
Input Parameters and Options Selected
-------------------------------------
Natural mortality is a matrix below
Oldest age (not in the plus group) is 6
For all years prior to the terminal year (18), backcalculated
stock sizes for the following ages used to estimate
total mortality (Z) for age  6 : 4 5 6
This method for estimating F on the oldest age is generally used when a
flat-topped partial recruitment curve is thought to be characteristic of the stock.
F for age 7 + is then calculated from the following
ratios of F[age 7 +] to F[age 6 ]
          1982            1
          1983            1
          1984            1
          1985            1
          1986            1
          1987            1
          1988            1
          1989            1
          1990            1
          1991            1
          1992            1
          1993            1
          1994            1
          1995            1
          1996            1
          1997            1
          1998            1
          1999            1
Stock size of the 7 + group is then calculated using
the following method:  CATCH EQUATION
 Partial recruitment estimate for 2000
 1             0.0001
 2             0.053
 3             0.421
 4             1
 5             1
 6             1
Objective function is Sum w*(LOG(OBS)-LOG(PRED))**2
 Indices normalized (by dividing by mean observed value)
before tuning to VPA stock sizes
Down-weighting is None or Uniform
Biomass estimates (other than SSB) reflect mean stock sizes.
SSB calculated as in the NEFSC projection program
(see note below SSB table for description of the algorithm).
Initial estimates of parameters for the Marquardt algorithm
and lower and upper bounds on the parameter estimates:
Par.          Initial Est   Lower Bnd     Upper Bnd
N  2          3.00E+03      0.00E+00      1.00E+06
N  3          3.00E+03      0.00E+00      1.00E+06
N  4          5.00E+02      0.00E+00      1.00E+06
N  5          5.00E+02      0.00E+00      1.00E+06
N  6          5.00E+02      0.00E+00      1.00E+06
q WHSpr2      1.00E-02      0.00E+00      1.00E+00
q WHSpr3      1.00E-02      0.00E+00      1.00E+00
q WHSpr4      1.00E-02      0.00E+00      1.00E+00
q WHSpr5      1.00E-02      0.00E+00      1.00E+00
q WHSpr6      1.00E-02      0.00E+00      1.00E+00
q WHAut2      1.00E-02      0.00E+00      1.00E+00
q WHAut3      1.00E-02      0.00E+00      1.00E+00
q WHAut4      1.00E-02      0.00E+00      1.00E+00
q WHAut5      1.00E-02      0.00E+00      1.00E+00
q WHAut6      1.00E-02      0.00E+00      1.00E+00
q MASpr2      1.00E-02      0.00E+00      1.00E+00
q MASpr3      1.00E-02      0.00E+00      1.00E+00
q MASpr4      1.00E-02      0.00E+00      1.00E+00
q MAAut1      1.00E-02      0.00E+00      1.00E+00
q MAAut2      1.00E-02      0.00E+00      1.00E+00
q MAAut3      1.00E-02      0.00E+00      1.00E+00
```

```
q CM_CPE2     1.00E-02      0.00E+00      1.00E+00
q CM_CPE3     1.00E-02      0.00E+00      1.00E+00
q CM_CPE4     1.00E-02      0.00E+00      1.00E+00
q CM_CPE5     1.00E-02      0.00E+00      1.00E+00
q CM_CPE6     1.00E-02      0.00E+00      1.00E+00
The following indices of abundance are available
 1            WHSpr2
 2            WHSpr3
 3            WHSpr4
 4            WHSpr5
 5            WHSpr6
 6            WHAut2
 7            WHAut3
 8            WHAut4
 9            WHAut5
 10           WHAut6
 11           MASpr2
 12           MASpr3
 13           MASpr4
 14           MAAut1
 15           MAAut2
 16           MAAut3
 17           CM_CPE2
 18           CM_CPE3
 19           CM_CPE4
 20           CM_CPE5
 21           CM_CPE6
 The Indices that will be used in this run are:
 1            WHSpr2
 2            WHSpr3
 3            WHSpr4
 4            WHSpr5
 5            WHSpr6
 6            WHAut2
 7            WHAut3
 8            WHAut4
 9            WHAut5
 10           WHAut6
 11           MASpr2
 12           MASpr3
 13           MASpr4
 14           MAAut1
 15           MAAut2
 16           MAAut3
 17           CM_CPE2
 18           CM_CPE3
 19           CM_CPE4
 20           CM_CPE5
 21           CM_CPE6
Obs Indices (before transformation) by index and year; with Index means
```

	1982	1983	1984	1985	1986	1987	1988
WHSpr2	1.02	0.98	1.03	0.24	0.33	0.64	1.05
WHSpr3	0.52	0.83	1.15	0.62	0.65	0.49	0.63
WHSpr4	0.69	0.64	0.74	0.67	0.39	0.30	0.36
WHSpr5	0.86	0.36	0.19	0.68	0.07	0.13	0.22
WHSpr6	0.12	0.18	0.05	0.10	0.05	0.01	0.09
WHAut2	0.62	0.70	1.66	0.38	0.38	0.30	0.60
WHAut3	0.38	3.14	0.98	0.42	0.91	0.49	1.32
WHAut4	0.55	2.47	0.85	0.57	0.76	0.65	0.60
WHAut5	0.47	1.17	0.14	0.40	0.21	0.33	0.26
WHAut6	0.09	0.25	0.26	0.22	0.22	0.09	0.06
MASpr2	7.06	18.57	5.41	3.82	3.22	7.00	11.36
MASpr3	3.42	5.33	2.27	2.79	0.89	2.27	2.51
MASpr4	1.15	0.50	0.87	0.69	0.43	0.26	1.37
MAAut1	2.02	4.67	1.31	12.30	2.83	2.48	389.58
MAAut2	5.65	2.35	0.65	0.34	0.42	1.15	2.39
MAAut3	7.29	1.01	0.10	0.02	0.02	0.83	0.02
CM_CPE2	0.07	0.05	0.03	0.01	0.00	0.01	0.01
CM_CPE3	0.07	0.11	0.04	0.04	0.07	0.02	0.05
CM_CPE4	0.05	0.04	0.04	0.03	0.02	0.03	0.02
CM_CPE5	0.02	0.02	0.01	0.02	0.01	0.01	0.01

CM_CPE6	0.00	0.01	0.01	0.00	0.00	0.00	0.00

	1989	1990	1991	1992	1993	1994	1995
WHSpr2	0.65	0.19	0.21	0.23	0.50	0.32	0.18
WHSpr3	0.79	1.33	0.36	0.24	0.80	0.39	1.12
WHSpr4	0.63	0.63	1.48	0.28	0.33	0.21	0.37
WHSpr5	0.09	0.17	0.27	1.31	0.09	0.10	0.15
WHSpr6	0.08	0.03	0.02	0.22	0.48	0.05	0.03
WHAut2	1.95	0.42	0.03	0.14	0.29	0.20	0.21
WHAut3	2.25	2.39	0.37	0.14	0.45	0.57	0.88
WHAut4	0.96	1.36	1.64	0.22	0.14	0.36	0.83
WHAut5	0.53	0.29	0.62	0.63	0.04	0.03	0.09
WHAut6	0.11	0.17	0.28	0.08	0.33	0.00	0.05
MASpr2	25.26	6.89	3.56	6.35	7.76	5.67	1.36
MASpr3	6.58	17.77	2.54	3.58	3.60	2.46	3.89
MASpr4	0.46	2.64	5.03	0.65	1.45	0.52	1.20
MAAut1	4.57	2.97	9.37	4.65	24.30	49.92	33.49
MAAut2	20.49	2.70	9.13	4.20	2.01	3.32	14.13
MAAut3	0.68	0.35	1.74	0.81	0.11	0.61	6.37
CM_CPE2	0.02	0.01	0.02	0.01	0.00	0.00	0.00
CM_CPE3	0.06	0.16	0.04	0.02	0.05	0.00	0.00
CM_CPE4	0.04	0.08	0.14	0.01	0.02	0.00	0.00
CM_CPE5	0.01	0.01	0.02	0.05	0.00	0.00	0.00
CM_CPE6	0.00	0.01	0.00	0.01	0.01	0.00	0.00

	1996	1997	1998	1999	2000	Average
WHSpr2	0.02	0.13	0.22	0.34	0.73	0.474
WHSpr3	0.59	0.40	0.33	0.71	0.44	0.651
WHSpr4	1.33	0.26	0.52	0.34	0.46	0.559
WHSpr5	0.40	0.88	0.14	0.32	0.11	0.343
WHSpr6	0.06	0.24	0.42	0.13	0.10	0.129
WHAut2	0.07	0.12	0.30	0.10	0.43	0.468
WHAut3	0.28	0.38	0.09	0.32	0.36	0.848
WHAut4	1.23	0.19	0.16	0.12	0.59	0.750
WHAut5	0.33	0.54	0.18	0.19	0.24	0.353
WHAut6	0.08	0.06	0.15	0.04	0.13	0.148
MASpr2	0.97	1.00	1.17	3.55	7.34	6.701
MASpr3	2.11	1.34	0.89	3.31	4.03	3.767
MASpr4	0.81	0.20	1.17	1.32	2.30	1.211
MAAut1	2.56	7.59	2.02	2.70	6.63	29.787
MAAut2	0.64	0.15	0.02	1.05	0.84	3.770
MAAut3	0.54	0.02	0.00	0.01	0.14	1.148
CM_CPE2	0.00	0.00	0.00	0.00	0.00	0.022
CM_CPE3	0.00	0.00	0.00	0.00	0.00	0.062
CM_CPE4	0.00	0.00	0.00	0.00	0.00	0.044
CM_CPE5	0.00	0.00	0.00	0.00	0.00	0.016
CM_CPE6	0.00	0.00	0.00	0.00	0.00	0.005

Catch at age (thousands) - D:\NAFO\SeptWS\gmcod\gmcod2000_base.2

	1982	1983	1984	1985	1986	1987	1988
1	30	00	04	00	00	02	00
2	1380	866	446	407	84	216	160
3	1633	2357	1240	1445	2164	595	1443
4	1143	1058	1500	991	813	1109	953
5	633	638	437	630	250	277	406
6	69	422	194	128	177	66	43
7	230	155	136	136	95	79	30
1+	5118	5496	3957	3737	3583	2344	3035

	1989	1990	1991	1992	1993	1994	1995
1	00	00	00	00	00	00	00
2	337	205	344	313	76	29	218
3	1583	3425	934	530	1487	1016	880
4	1454	2064	4161	484	641	1135	1153
5	449	430	851	2018	129	288	194
6	81	157	143	202	457	72	12
7	56	99	79	84	36	86	34
1+	3960	6380	6512	3631	2826	2626	2491

	1996	1997	1998	1999
1	00	00	00	00
2	65	53	94	00
3	584	438	390	178
4	1738	435	542	192
5	347	832	165	90
6	45	68	193	27
7	10	08	10	36
1+	2789	1834	1394	523

CAA Summary for ages 4 - 7

1982	1983	1984	1985	1986	1987	1988
2075	2273	2267	1885	1335	1531	1432

1989	1990	1991	1992	1993	1994	1995
2040	2750	5234	2788	1263	1581	1393

1996	1997	1998	1999
2140	1343	910	345

Weight at age (mid year) in kg - D:\NAFO\SeptWS\gmcod\gmcod2000_base.2

	1982	1983	1984	1985	1986	1987	1988
1	0.900	0.900	0.900	0.900	0.900	0.900	0.900
2	1.156	1.164	1.159	1.260	1.304	1.313	1.268
3	1.664	1.660	1.670	1.746	1.837	1.684	1.881
4	2.764	2.475	2.721	2.840	2.923	3.283	2.426
5	4.770	3.778	3.677	4.466	4.619	4.831	5.166
6	6.739	5.962	5.898	5.525	6.067	6.824	6.767
7	11.330	9.755	10.176	9.721	10.295	10.241	11.233

	1989	1990	1991	1992	1993	1994	1995
1	0.900	0.900	0.900	0.900	0.900	0.900	0.900
2	1.247	1.071	1.130	1.533	1.293	1.450	1.652
3	1.776	1.692	1.568	1.922	1.889	1.943	1.921
4	2.993	2.271	2.512	2.714	2.513	3.151	2.775
5	3.864	4.265	4.136	3.061	4.356	3.444	5.142
6	4.872	7.645	7.309	5.000	6.174	6.132	8.290
7	12.200	13.747	11.449	10.614	11.063	10.018	12.969

	1996	1997	1998	1999
1	0.900	0.900	0.900	0.900
2	1.687	1.733	1.277	1.277
3	2.136	2.233	2.089	1.774
4	2.376	3.007	2.979	2.704
5	3.648	3.193	4.191	4.020
6	7.376	4.649	4.211	5.727
7	11.647	12.479	10.262	7.901

January 1 Biomass Weights - D:\NAFO\SeptWS\gmcod\gmcod2000_base.2

	1982	1983	1984	1985	1986	1987	1988
1	0.791	0.793	0.761	0.748	0.745	0.758	0.765
2	0.965	1.024	1.021	1.065	1.083	1.087	1.068
3	1.364	1.385	1.394	1.423	1.521	1.482	1.572
4	2.364	2.029	2.125	2.178	2.259	2.456	2.021
5	4.267	3.231	3.017	3.486	3.622	3.758	4.118
6	5.670	5.333	4.720	4.507	5.205	5.614	5.718
7	11.330	9.755	10.176	9.721	10.295	10.241	11.233

	1989	1990	1991	1992	1993	1994	1995
1	0.825	0.803	0.690	0.751	0.709	0.664	0.657
2	1.059	0.982	1.008	1.175	1.079	1.142	1.219
3	1.501	1.453	1.296	1.474	1.702	1.585	1.669
4	2.373	2.008	2.062	2.063	2.198	2.440	2.322
5	3.062	3.573	3.065	2.773	3.438	2.942	4.025
6	5.017	5.435	5.583	4.548	4.347	5.168	5.343
7	12.200	13.747	11.449	10.614	11.063	10.018	12.969

	1996	1997	1998	1999
1	0.649	0.756	0.756	0.756
2	1.232	1.249	1.072	1.072
3	1.878	1.941	1.903	1.505
4	2.136	2.534	2.579	2.377
5	3.182	2.754	3.550	3.461
6	6.159	4.118	3.667	4.899
7	11.647	12.479	10.262	7.901

SSB Weights - D:\NAFO\SeptWS\gmcod\gmcod2000_base.2

	1982	1983	1984	1985	1986	1987	1988
1	0.791	0.793	0.761	0.748	0.745	0.758	0.765
2	0.965	1.024	1.021	1.065	1.083	1.087	1.068
3	1.364	1.385	1.394	1.423	1.521	1.482	1.572
4	2.364	2.029	2.125	2.178	2.259	2.456	2.021
5	4.267	3.231	3.017	3.486	3.622	3.758	4.118
6	5.670	5.333	4.720	4.507	5.205	5.614	5.718
7	11.330	9.755	10.176	9.721	10.295	10.241	11.233

	1989	1990	1991	1992	1993	1994	1995
1	0.825	0.803	0.690	0.751	0.709	0.664	0.657
2	1.059	0.982	1.008	1.175	1.079	1.142	1.219
3	1.501	1.453	1.296	1.474	1.702	1.585	1.669
4	2.373	2.008	2.062	2.063	2.198	2.440	2.322
5	3.062	3.573	3.065	2.773	3.438	2.942	4.025
6	5.017	5.435	5.583	4.548	4.347	5.168	5.343
7	12.200	13.747	11.449	10.614	11.063	10.018	12.969

	1996	1997	1998	1999
1	0.649	0.756	0.756	0.756
2	1.232	1.249	1.072	1.072
3	1.878	1.941	1.903	1.505
4	2.136	2.534	2.579	2.377
5	3.182	2.754	3.550	3.461
6	6.159	4.118	3.667	4.899
7	11.647	12.479	10.262	7.901

Computed (Rivard)from midyear weights: Jan 1 Weights - D:\NAFO\SeptWS\gmcod\gmcod2000_base.2

	1982	1983	1984	1985	1986	1987	1988
1	0.791	0.793	0.761	0.748	0.745	0.758	0.765
2	0.965	1.024	1.021	1.065	1.083	1.087	1.068
3	1.364	1.385	1.394	1.423	1.521	1.482	1.572
4	2.364	2.029	2.125	2.178	2.259	2.456	2.021
5	4.267	3.231	3.017	3.486	3.622	3.758	4.118
6	5.670	5.333	4.720	4.507	5.205	5.614	5.718
7	11.330	9.755	10.176	9.721	10.295	10.241	11.233

	1989	1990	1991	1992	1993	1994	1995
1	0.825	0.803	0.690	0.751	0.709	0.664	0.657
2	1.059	0.982	1.008	1.175	1.079	1.142	1.219
3	1.501	1.453	1.296	1.474	1.702	1.585	1.669
4	2.373	2.008	2.062	2.063	2.198	2.440	2.322
5	3.062	3.573	3.065	2.773	3.438	2.942	4.025
6	5.017	5.435	5.583	4.548	4.347	5.168	5.343
7	12.200	13.747	11.449	10.614	11.063	10.018	12.969

	1996	1997	1998	1999	2000
1	0.649	0.756	0.756	0.756	0.741
2	1.232	1.249	1.072	1.072	1.072
3	1.878	1.941	1.903	1.505	1.521
4	2.136	2.534	2.579	2.377	2.091
5	3.182	2.754	3.550	3.461	3.076
6	6.159	4.118	3.667	4.899	4.670
7	11.647	12.479	10.262	7.901	7.901

Percent Mature (females)- D:\NAFO\SeptWS\gmcod\gmcod2000_base.2

	1982	1983	1984	1985	1986	1987	1988
1	07	07	07	04	04	04	04
2	26	26	26	48	48	48	48
3	61	61	61	95	95	95	95
4	88	88	88	100	100	100	100
5	97	97	97	100	100	100	100
6	100	100	100	100	100	100	100
7	100	100	100	100	100	100	100

	1989	1990	1991	1992	1993	1994	1995
1	04	11	11	11	11	04	04
2	48	28	28	28	28	38	38
3	95	56	56	56	56	89	89
4	100	81	81	81	81	99	99
5	100	93	93	93	93	100	100
6	100	98	98	98	98	100	100
7	100	100	100	100	100	100	100

	1996	1997	1998	1999
1	04	04	04	04
2	38	38	38	38
3	89	89	89	89
4	99	99	99	99
5	100	100	100	100
6	100	100	100	100
7	100	100	100	100

Natural Mortality D:\NAFO\SeptWS\gmcod\gmcod2000_base.2

	1982	1983	1984	1985	1986	1987	1988
1	.200	.200	.200	.200	.200	.200	.200
2	.200	.200	.200	.200	.200	.200	.200
3	.200	.200	.200	.200	.200	.200	.200
4	.200	.200	.200	.200	.200	.200	.200
5	.200	.200	.200	.200	.200	.200	.200
6	.200	.200	.200	.200	.200	.200	.200
7	.200	.200	.200	.200	.200	.200	.200

	1989	1990	1991	1992	1993	1994	1995
1	.200	.200	.200	.200	.200	.200	.200
2	.200	.200	.200	.200	.200	.200	.200
3	.200	.200	.200	.200	.200	.200	.200
4	.200	.200	.200	.200	.200	.200	.200
5	.200	.200	.200	.200	.200	.200	.200
6	.200	.200	.200	.200	.200	.200	.200
7	.200	.200	.200	.200	.200	.200	.200

	1996	1997	1998	1999
1	.200	.200	.200	.200
2	.200	.200	.200	.200
3	.200	.200	.200	.200
4	.200	.200	.200	.200
5	.200	.200	.200	.200
6	.200	.200	.200	.200
7	.200	.200	.200	.200

Sex Ratio (Percent Female) - D:\NAFO\SeptWS\gmcod\gmcod2000_base.2

	1982	1983	1984	1985	1986	1987	1988
1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2	0.5	0.5	0.5	0.5	0.5	0.5	0.5
3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
4	0.5	0.5	0.5	0.5	0.5	0.5	0.5
5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
7	0.5	0.5	0.5	0.5	0.5	0.5	0.5

	1989	1990	1991	1992	1993	1994	1995
1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2	0.5	0.5	0.5	0.5	0.5	0.5	0.5
3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
4	0.5	0.5	0.5	0.5	0.5	0.5	0.5
5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
7	0.5	0.5	0.5	0.5	0.5	0.5	0.5

	1996	1997	1998	1999
1	0.5	0.5	0.5	0.5
2	0.5	0.5	0.5	0.5
3	0.5	0.5	0.5	0.5
4	0.5	0.5	0.5	0.5
5	0.5	0.5	0.5	0.5
6	0.5	0.5	0.5	0.5
7	0.5	0.5	0.5	0.5

pF is 0.1667
pM is 0.1667

```
Residual Sum of Squares from Marquardt Algorithm
Number 1
RSS             4757.4636160016
Lambda         1.00E-02

Number 2
RSS             3659.71341037588
Lambda         1.00E-03

Number 3
RSS             2871.24006283006
Lambda         1.00E-01

Number 4
RSS             2338.80230082771
Lambda         1.00E-02

Number 5
RSS             2110.59689632427
Lambda         1.00E+00

Number 6
RSS             1700.06987407547
Lambda         1.00E-01

Number 7
RSS             1546.94190193848
Lambda         1.00E+01

Number 8
RSS             1278.82209227215
Lambda         1.00E+00

Number 9
RSS             1173.18264217126
Lambda         1.00E+02

Number 10
RSS             992.137735859582
Lambda         1.00E+01

Number 11
RSS             917.73038579856
Lambda         1.00E+00

Number 12
RSS             792.489781270954
Lambda         1.00E+02

Number 13
RSS             286.055030653559
Lambda         1.00E+01

Number 14
RSS             246.596438368479
Lambda         1.00E+00

Number 15
RSS             242.849135995446
Lambda         1.00E+02

Number 16
RSS             242.798374032756
Lambda         1.00E+01

Number 17
RSS             242.798341477608
Lambda         1.00E+00

Number 18
RSS             242.798341241649
Lambda         1.00E+02
```

RESULTS

Approximate Statistics Assuming Linearity Near Solution
Sum of Squares: 242.798341241649
Mean Square Residuals: 0.72261

	PAR. EST.	STD. ERR.	T-STATISTIC	C.V.
N 2	4.39E+03	1.73E+03	2.54E+00	0.39
N 3	2.24E+03	6.58E+02	3.41E+00	0.29
N 4	1.16E+03	3.31E+02	3.51E+00	0.28
N 5	4.55E+02	1.65E+02	2.75E+00	0.36
N 6	3.03E+02	1.23E+02	2.46E+00	0.41
q WHSpr2	1.67E-04	3.31E-05	5.03E+00	0.20
q WHSpr3	2.71E-04	5.36E-05	5.06E+00	0.20
q WHSpr4	4.66E-04	9.21E-05	5.06E+00	0.20
q WHSpr5	9.92E-04	1.97E-04	5.03E+00	0.20
q WHSpr6	3.36E-03	6.72E-04	5.00E+00	0.20
q WHAut2	1.45E-04	2.89E-05	5.03E+00	0.20
q WHAut3	1.99E-04	3.93E-05	5.06E+00	0.20
q WHAut4	3.90E-04	7.71E-05	5.06E+00	0.20
q WHAut5	1.06E-03	2.11E-04	5.03E+00	0.20
q WHAut6	4.12E-03	8.49E-04	4.86E+00	0.21
q MASpr2	1.61E-04	3.19E-05	5.03E+00	0.20
q MASpr3	2.32E-04	4.58E-05	5.06E+00	0.20
q MASpr4	3.94E-04	7.79E-05	5.06E+00	0.20
q MAAut1	4.53E-05	9.25E-06	4.89E+00	0.20
q MAAut2	8.89E-05	1.77E-05	5.03E+00	0.20
q MAAut3	6.08E-05	1.23E-05	4.93E+00	0.20
q CM_CPE2	1.42E-04	3.51E-05	4.05E+00	0.25
q CM_CPE3	2.75E-04	6.78E-05	4.05E+00	0.25
q CM_CPE4	6.16E-04	1.52E-04	4.05E+00	0.25
q CM_CPE5	1.64E-03	4.04E-04	4.05E+00	0.25
q CM_CPE6	5.21E-03	1.28E-03	4.05E+00	0.25

Catchability Estimates in Original Units

	Estimate	Std.Err.	C.V.
q WHSpr2	7.89E-05	1.57E-05	0.20
q WHSpr3	1.77E-04	3.49E-05	0.20
q WHSpr4	2.61E-04	5.15E-05	0.20
q WHSpr5	3.40E-04	6.77E-05	0.20
q WHSpr6	4.34E-04	8.69E-05	0.20
q WHAut2	6.80E-05	1.35E-05	0.20
q WHAut3	1.69E-04	3.34E-05	0.20
q WHAut4	2.93E-04	5.78E-05	0.20
q WHAut5	3.75E-04	7.46E-05	0.20
q WHAut6	6.11E-04	1.26E-04	0.21
q MASpr2	1.08E-03	2.14E-04	0.20
q MASpr3	8.74E-04	1.73E-04	0.20
q MASpr4	4.77E-04	9.43E-05	0.20
q MAAut1	1.35E-03	2.76E-04	0.20
q MAAut2	3.35E-04	6.67E-05	0.20
q MAAut3	6.98E-05	1.41E-05	0.20
q CM_CPE2	3.08E-06	7.60E-07	0.25
q CM_CPE3	1.69E-05	4.17E-06	0.25
q CM_CPE4	2.69E-05	6.63E-06	0.25
q CM_CPE5	2.65E-05	6.53E-06	0.25
q CM_CPE6	2.69E-05	6.64E-06	0.25

CORRELATION BETWEEN PARAMETERS ESTIMATED

1	0.05	0.04	0.03	0.02	-0.11	-0.01	-0.01	-0.01	-0.01	-0.11	-0.01	-0.01	-0.01	-0.01	-0.11	-0.01	-0.01	-0.12	-0.11	-0.01	0	0	0	0	0
0.05	1	0.05	0.04	0.03	-0.09	-0.09	-0.01	-0.01	-0.01	-0.09	-0.09	-0.01	-0.01	-0.01	-0.09	-0.09	-0.01	-0.09	-0.09	-0.09	0	0	0	0	0
0.04	0.05	1	0.05	0.04	-0.08	-0.07	-0.08	-0.01	-0.01	-0.08	-0.07	-0.08	-0.01	-0.01	-0.08	-0.07	-0.08	-0.08	-0.08	-0.07	0	0	0	0	0
0.03	0.04	0.05	1	0	-0.06	-0.06	-0.08	-0.12	-0.05	-0.06	-0.06	-0.08	-0.12	-0.05	-0.06	-0.06	-0.08	-0.06	-0.06	-0.01	0	0	0	0	0
0.02	0.03	0.04	0	1	-0.05	-0.05	-0.06	-0.12	-0.2	-0.05	-0.05	-0.06	-0.12	-0.2	-0.05	-0.05	-0.06	-0.05	-0.05	-0.05	0	0	0	0	0
-0.11	-0.09	-0.08	-0.06	-0.05	1	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.03	0.03	0.01	0	0	0	0	0
-0.01	-0.09	-0.07	-0.06	-0.05	0.02	1	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0	0	0	0	0
-0.01	-0.01	-0.08	-0.08	-0.06	0.01	0.01	1	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0	0	0	0	0
-0.01	-0.01	-0.01	-0.12	-0.12	0.01	0.01	0.02	1	0.03	0.01	0.01	0.02	0.03	0.03	0.01	0.01	0.02	0.01	0.01	0.01	0	0	0	0	0
-0.01	-0.01	-0.01	-0.05	-0.2	0.01	0.01	0.02	0.03	1	0.01	0.01	0.02	0.03	0.04	0.01	0.01	0.02	0.01	0.01	0.01	0	0	0	0	0
-0.11	-0.09	-0.08	-0.06	-0.05	0.03	0.02	0.01	0.01	0.01	1	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.03	0.03	0.01	0	0	0	0	0
-0.01	-0.09	-0.07	-0.06	-0.05	0.02	0.02	0.01	0.01	0.01	0.02	1	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0	0	0	0	0
-0.01	-0.01	-0.08	-0.08	-0.06	0.01	0.01	0.02	0.02	0.02	0.01	0.01	1	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0	0	0	0	0
-0.01	-0.01	-0.01	-0.12	-0.12	0.01	0.01	0.02	0.03	0.03	0.01	0.01	0.02	1	0.03	0.01	0.01	0.02	0.01	0.01	0.01	0	0	0	0	0
-0.01	-0.01	-0.01	-0.05	-0.2	0.01	0.01	0.02	0.03	0.04	0.01	0.01	0.02	0.03	1	0.01	0.01	0.02	0.01	0.01	0.01	0	0	0	0	0
-0.11	-0.09	-0.08	-0.06	-0.05	0.03	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.01	1	0.02	0.01	0.03	0.03	0.01	0	0	0	0	0
-0.01	-0.09	-0.07	-0.06	-0.05	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.02	1	0.01	0.02	0.02	0.01	0	0	0	0	0
-0.01	-0.01	-0.08	-0.08	-0.06	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.01	0.01	1	0.01	0.01	0.01	0	0	0	0	0
-0.12	-0.09	-0.08	-0.06	-0.05	0.03	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.01	0.03	0.02	0.01	1	0.03	0.02	0	0	0	0	0
-0.11	-0.09	-0.08	-0.06	-0.05	0.03	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.03	1	0.01	0	0	0	0	0
-0.01	-0.09	-0.07	-0.01	-0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

```
CORRELATION BETWEEN PARAMETERS ESTIMATED (SYMBOLIC FORM)
N 2      * . . . . . . . . . . . . . . . . . . . . . .
N 3      . * . . . . . . . . . . . . . . . . . . . . .
N 4      . . * . . . . . . . . . . . . . . . . . . . .
N 5      . . . * . . . . . . . . . . . . . . . . . . .
N 6      . . . . * . . . . . . . . . . . . . . . . . .
WHSpr    . . . . . * . . . . . . . . . . . . . . . . .
WHSpr    . . . . . . * . . . . . . . . . . . . . . . .
WHSpr    . . . . . . . * . . . . . . . . . . . . . . .
WHSpr    . . . . . . . . * . . . . . . . . . . . . . .
WHSpr    . . . . . . . . . * . . . . . . . . . . . . .
WHAut    . . . . . . . . . . * . . . . . . . . . . . .
WHAut    . . . . . . . . . . . * . . . . . . . . . . .
WHAut    . . . . . . . . . . . . * . . . . . . . . . .
WHAut    . . . . . . . . . . . . . * . . . . . . . . .
WHAut    . . . . . . . . . . . . . . * . . . . . . . .
MASpr    . . . . . . . . . . . . . . . * . . . . . . .
MASpr    . . . . . . . . . . . . . . . . * . . . . . .
MASpr    . . . . . . . . . . . . . . . . . * . . . . .
MAAut    . . . . . . . . . . . . . . . . . . * . . . .
MAAut    . . . . . . . . . . . . . . . . . . . * . . .
MAAut    . . . . . . . . . . . . . . . . . . . . * . .
CM_CPE   . . . . . . . . . . . . . . . . . . . . . * .
CM_CPE   . . . . . . . . . . . . . . . . . . . . . . *
CM_CPE   . . . . . . . . . . . . . . . . . . . . . . .
CM_CPE   . . . . . . . . . . . . . . . . . . . . . . .
CM_CPE   . . . . . . . . . . . . . . . . . . . . . . .

SYMBOLS:  = LARGE NEGATIVE CORRELATION    whenever -1 <= R <  -L
          - MODERATE NEGATIVE CORRELATION whenever -L <= R <  -M
          . SMALL CORRELATION             whenever -M <= R <= +M
          + MODERATE POSITIVE CORRELATION whenever +M <  R <= +L
          * LARGE POSITIVE CORRELATION    whenever +L <  R <= +1
```

Where R is the estimated correlation, M is, 0.25 and L is 0.5

Partial variance (and proportion of total) by index

Index	Partial Variance	Proportion
WHSpr 2	0.571	0.04
WHSpr 3	0.182	0.013
WHSpr 4	0.15	0.01
WHSpr 5	0.27	0.019
WHSpr 6	0.929	0.065
WHAut 2	0.633	0.044
WHAut 3	0.261	0.018
WHAut 4	0.295	0.02
WHAut 5	0.355	0.025
WHAut 6	0.312	0.022
MASpr 2	0.321	0.022
MASpr 3	0.293	0.02
MASpr 4	0.602	0.042
MAAut 1	1.827	0.127
MAAut 2	2.165	0.15
MAAut 3	4.004	0.278
CM_CPE 2	0.981	0.068
CM_CPE 3	0.163	0.011
CM_CPE 4	0.041	0.003
CM_CPE 5	0.028	0.002
CM_CPE 6	0.01	0.001

Standardized residuals by index and year; with row/column/grand means

	1982	1983	1984	1985	1986	1987	1988
WHSpr2	0.410	1.063	1.248	-0.874	0.045	0.337	0.580
WHSpr3	-0.462	-0.323	0.788	0.075	-0.323	-0.184	-0.336
WHSpr4	-0.002	0.204	-0.044	0.548	0.070	-0.644	-0.508
WHSpr5	0.499	-0.107	-0.322	0.743	-0.756	-0.101	0.023
WHSpr6	0.569	-0.748	-1.282	0.072	-1.209	-1.750	1.011
WHAut2	-0.001	0.845	1.981	-0.136	0.380	-0.371	0.092
WHAut3	-0.763	1.292	0.652	-0.331	0.131	-0.121	0.585
WHAut4	-0.414	1.657	-0.016	0.221	0.732	0.137	-0.026
WHAut5	-0.322	1.172	-0.804	0.006	0.352	0.910	0.108
WHAut6	-0.155	-0.779	0.205	0.659	0.219	0.267	0.192
MASpr2	-0.386	1.453	0.122	-0.681	-0.347	0.082	0.305
MASpr3	-0.119	-0.020	-0.290	-0.039	-1.833	-0.253	-0.596
MASpr4	-0.122	-0.796	-0.573	-0.115	-0.528	-1.537	0.370
MAAut1	-1.665	-0.552	-2.444	0.728	-1.483	-1.987	3.049
MAAut2	0.724	0.391	-0.997	-2.142	-1.375	-0.671	-0.159
MAAut3	3.745	0.990	-0.990	-2.764	-3.444	1.542	-3.308
CM_CPE2	1.364	1.558	1.197	-0.258	-1.175	-0.955	-0.514
CM_CPE3	0.417	0.464	0.135	0.140	0.281	-1.020	-0.244
CM_CPE4	-0.086	0.232	-0.136	0.242	0.049	-0.233	-0.506
CM_CPE5	-0.419	0.175	0.082	0.146	0.093	0.055	0.083
CM_CPE6	-0.170	-0.053	-0.089	0.208	-0.059	0.031	0.031
Col Avg	0.126	0.387	-0.075	-0.169	-0.485	-0.308	0.011

	1989	1990	1991	1992	1993	1994	1995
WHSpr2	-0.904	-0.163	-0.056	-0.591	0.449	-0.599	-0.036
WHSpr3	-0.444	-0.749	-0.038	-0.432	0.252	-0.541	0.183
WHSpr4	-0.083	-0.572	-0.482	0.268	0.137	-0.826	-0.358
WHSpr5	-1.379	-0.595	-0.621	0.210	0.009	-0.240	0.366
WHSpr6	0.241	-1.622	-1.897	0.532	0.366	0.116	1.480
WHAut2	0.567	0.935	-2.204	-0.982	-0.017	-0.974	0.321
WHAut3	0.837	-0.003	0.054	-0.996	-0.372	-0.035	-0.048
WHAut4	0.273	0.199	-0.493	-0.147	-1.008	-0.335	0.456
WHAut5	0.588	-0.044	0.258	-0.762	-1.059	-1.634	-0.349
WHAut6	0.259	-0.032	0.583	-1.075	-0.477	0.000	1.680
MASpr2	0.331	0.989	0.207	0.240	0.602	-0.276	-0.729
MASpr3	0.168	0.422	0.396	0.867	0.140	-0.247	-0.233
MASpr4	-1.172	0.408	0.249	0.548	1.168	-0.487	0.315
MAAut1	0.005	-0.507	0.197	-0.502	0.936	3.008	2.508
MAAut2	1.456	1.258	2.686	1.125	0.384	0.466	3.396
MAAut3	0.470	-1.224	2.924	2.092	-0.990	1.086	3.320

CM_CPE2	-1.246	0.463	1.164	0.167	-1.764	0.000	0.000
CM_CPE3	-0.359	-0.195	0.648	-0.453	0.186	0.000	0.000
CM_CPE4	-0.049	0.228	-0.092	0.027	0.321	0.000	0.000
CM_CPE5	-0.317	-0.092	0.165	0.127	-0.097	0.000	0.000
CM_CPE6	0.005	0.075	-0.191	0.113	0.098	0.000	0.000
Col Avg	-0.036	-0.039	0.165	0.018	-0.035	-0.101	0.767

	1996	1997	1998	1999	2000
WHSpr2	-2.651	-0.040	0.368	0.546	0.868
WHSpr3	0.777	0.194	0.367	1.078	0.119
WHSpr4	0.394	0.158	0.618	0.637	0.485
WHSpr5	0.933	0.704	0.271	0.798	-0.434
WHSpr6	0.519	1.794	1.027	1.093	-0.312
WHAut2	-1.002	0.023	0.875	-0.767	0.432
WHAut3	-0.047	0.189	-1.163	0.189	-0.049
WHAut4	0.166	-0.365	-0.898	-0.788	0.649
WHAut5	0.593	0.021	0.449	0.101	0.416
WHAut6	0.456	-0.248	-0.596	-0.761	-0.398
MASpr2	-1.158	-0.731	-0.761	0.219	0.519
MASpr3	0.395	-0.262	-0.347	1.003	0.849
MASpr4	-0.900	-0.879	0.868	1.508	1.675
MAAut1	-0.126	0.938	-0.945	-1.159	0.000
MAAut2	-0.275	-1.591	-4.176	0.158	-0.660
MAAut3	1.765	-2.235	0.000	-2.849	-0.130
CM_CPE2	0.000	0.000	0.000	0.000	0.000
CM_CPE3	0.000	0.000	0.000	0.000	0.000
CM_CPE4	0.000	0.000	0.000	0.000	0.000
CM_CPE5	0.000	0.000	0.000	0.000	0.000
CM_CPE6	0.000	0.000	0.000	0.000	0.000
Col Avg	-0.010	-0.146	-0.270	0.063	0.252

Percent of total sum of squares by index and year; with row/column sums

	1982	1983	1984	1985	1986	1987	1988
WHSpr2	0.050	0.336	0.463	0.227	0.001	0.034	0.100
WHSpr3	0.064	0.031	0.185	0.002	0.031	0.010	0.034
WHSpr4	0.000	0.012	0.001	0.090	0.001	0.123	0.077
WHSpr5	0.074	0.003	0.031	0.164	0.170	0.003	0.000
WHSpr6	0.096	0.166	0.489	0.002	0.435	0.912	0.304
WHAut2	0.000	0.213	1.168	0.005	0.043	0.041	0.003
WHAut3	0.173	0.497	0.127	0.033	0.005	0.004	0.102
WHAut4	0.051	0.817	0.000	0.014	0.159	0.006	0.000
WHAut5	0.031	0.409	0.193	0.000	0.037	0.246	0.003
WHAut6	0.007	0.181	0.012	0.129	0.014	0.021	0.011
MASpr2	0.044	0.629	0.004	0.138	0.036	0.002	0.028
MASpr3	0.004	0.000	0.025	0.000	1.000	0.019	0.106
MASpr4	0.004	0.189	0.098	0.004	0.083	0.703	0.041
MAAut1	0.825	0.091	1.778	0.158	0.654	1.175	2.766
MAAut2	0.156	0.046	0.296	1.366	0.563	0.134	0.008
MAAut3	4.175	0.292	0.292	2.274	3.531	0.708	3.257
CM_CPE2	0.554	0.723	0.427	0.020	0.411	0.271	0.079
CM_CPE3	0.052	0.064	0.005	0.006	0.024	0.310	0.018
CM_CPE4	0.002	0.016	0.005	0.017	0.001	0.016	0.076
CM_CPE5	0.052	0.009	0.002	0.006	0.003	0.001	0.002
CM_CPE6	0.009	0.001	0.002	0.013	0.001	0.000	0.000
++	6.424	4.723	5.603	4.668	7.203	4.740	7.013

	1989	1990	1991	1992	1993	1994	1995
WHSpr2	0.243	0.008	0.001	0.104	0.060	0.107	0.000
WHSpr3	0.059	0.167	0.000	0.055	0.019	0.087	0.010
WHSpr4	0.002	0.097	0.069	0.021	0.006	0.203	0.038
WHSpr5	0.566	0.105	0.115	0.013	0.000	0.017	0.040
WHSpr6	0.017	0.783	1.071	0.084	0.040	0.004	0.652
WHAut2	0.096	0.260	1.445	0.287	0.000	0.282	0.031
WHAut3	0.209	0.000	0.001	0.295	0.041	0.000	0.001
WHAut4	0.022	0.012	0.072	0.006	0.302	0.033	0.062
WHAut5	0.103	0.001	0.020	0.173	0.334	0.795	0.036
WHAut6	0.020	0.000	0.101	0.344	0.068	0.000	0.840

MASpr2	0.033	0.291	0.013	0.017	0.108	0.023	0.158
MASpr3	0.008	0.053	0.047	0.223	0.006	0.018	0.016
MASpr4	0.409	0.050	0.018	0.089	0.406	0.071	0.030
MAAut1	0.000	0.076	0.012	0.075	0.260	2.693	1.872
MAAut2	0.631	0.471	2.147	0.377	0.044	0.065	3.432
MAAut3	0.066	0.446	2.544	1.302	0.292	0.351	3.281
CM_CPE2	0.462	0.064	0.403	0.008	0.927	0.000	0.000
CM_CPE3	0.038	0.011	0.125	0.061	0.010	0.000	0.000
CM_CPE4	0.001	0.015	0.002	0.000	0.031	0.000	0.000
CM_CPE5	0.030	0.003	0.008	0.005	0.003	0.000	0.000
CM_CPE6	0.000	0.002	0.011	0.004	0.003	0.000	0.000
++	3.015	2.916	8.226	3.545	2.958	4.750	10.499

	1996	1997	1998	1999	2000	++
WHSpr2	2.092	0.000	0.040	0.089	0.224	4.181
WHSpr3	0.179	0.011	0.040	0.346	0.004	1.334
WHSpr4	0.046	0.007	0.114	0.121	0.070	1.099
WHSpr5	0.259	0.148	0.022	0.189	0.056	1.976
WHSpr6	0.080	0.958	0.314	0.355	0.029	6.793
WHAut2	0.299	0.000	0.228	0.175	0.056	4.632
WHAut3	0.001	0.011	0.402	0.011	0.001	1.912
WHAut4	0.008	0.040	0.240	0.185	0.125	2.156
WHAut5	0.105	0.000	0.060	0.003	0.052	2.599
WHAut6	0.062	0.018	0.106	0.172	0.047	2.154
MASpr2	0.399	0.159	0.172	0.014	0.080	2.348
MASpr3	0.046	0.020	0.036	0.300	0.214	2.143
MASpr4	0.241	0.230	0.224	0.677	0.835	4.401
MAAut1	0.005	0.262	0.266	0.400	0.000	13.367
MAAut2	0.023	0.753	5.189	0.007	0.130	15.837
MAAut3	0.927	1.487	0.000	2.415	0.005	27.645
CM_CPE2	0.000	0.000	0.000	0.000	0.000	4.348
CM_CPE3	0.000	0.000	0.000	0.000	0.000	0.724
CM_CPE4	0.000	0.000	0.000	0.000	0.000	0.184
CM_CPE5	0.000	0.000	0.000	0.000	0.000	0.124
CM_CPE6	0.000	0.000	0.000	0.000	0.000	0.045
++	4.772	4.105	7.453	5.460	1.928	100.000

STOCK NUMBERS (Jan 1) in thousands - D:\NAFO\SeptWS\gmcod\gmcod2000_base.2

	1982	1983	1984	1985	1986	1987	1988
1	6162	5534	7746	4914	7410	9954	21647
2	9108	5018	4530	6339	4023	6067	8148
3	4328	6208	3325	3306	4821	3218	4772
4	2666	2066	2950	1600	1399	1989	2096
5	1661	1149	734	1058	413	410	625
6	166	787	363	206	296	112	85
7	547	284	250	214	156	132	58
1+	24639	21046	19900	17636	18519	21882	37431

	1989	1990	1991	1992	1993	1994	1995
1	3375	3391	5879	5283	8137	2870	2947
2	17723	2763	2776	4813	4325	6662	2350
3	6526	14206	2077	1962	3657	3472	5428
4	2601	3911	8531	855	1126	1649	1924
5	854	814	1334	3220	262	342	323
6	145	293	277	322	810	98	20
7	98	182	151	131	63	114	55
1+	31322	25559	21025	16587	18382	15208	13046

	1996	1997	1998	1999	2000
1	2113	2536	3345	5363	00
2	2413	1730	2076	2738	4391
3	1727	1917	1369	1615	2242
4	3648	885	1173	768	1161
5	532	1414	331	470	455
6	89	121	405	122	303
7	19	14	21	162	175
1+	10541	8617	8719	11236	8727

FISHING MORTALITY - D:\NAFO\SeptWS\gmcod\gmcod2000_base.2

	1982	1983	1984	1985	1986	1987	1988
1	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2	0.18	0.21	0.12	0.07	0.02	0.04	0.02
3	0.54	0.54	0.53	0.66	0.69	0.23	0.41
4	0.64	0.83	0.83	1.15	1.03	0.96	0.70
5	0.55	0.95	1.07	1.07	1.10	1.37	1.26
6	0.61	0.90	0.89	1.16	1.08	1.05	0.82
7	0.61	0.90	0.89	1.16	1.08	1.05	0.82

	1989	1990	1991	1992	1993	1994	1995
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.02	0.09	0.15	0.07	0.02	0.00	0.11
3	0.31	0.31	0.69	0.35	0.60	0.39	0.20
4	0.96	0.88	0.77	0.98	0.99	1.43	1.09
5	0.87	0.88	1.22	1.18	0.78	2.66	1.09
6	0.97	0.90	0.84	1.18	0.98	1.67	1.13
7	0.97	0.90	0.84	1.18	0.98	1.67	1.13

	1996	1997	1998	1999
1	0.00	0.00	0.00	0.00
2	0.03	0.03	0.05	0.00
3	0.47	0.29	0.38	0.13
4	0.75	0.78	0.71	0.32
5	1.28	1.05	0.80	0.24
6	0.82	0.97	0.75	0.28
7	0.82	0.97	0.75	0.28

1,7
1,6
2,6
4,6
Average F for 1,7 1,6 2,6 4,6

	1982	1983	1984	1985	1986	1987	1988
1,7	0.45	0.62	0.62	0.76	0.71	0.67	0.58
1,6	0.42	0.57	0.57	0.69	0.65	0.61	0.54
2,6	0.51	0.69	0.69	0.82	0.78	0.73	0.64
4,6	0.60	0.89	0.93	1.13	1.07	1.13	0.93

	1989	1990	1991	1992	1993	1994	1995
1,7	0.59	0.56	0.65	0.71	0.62	1.12	0.68
1,6	0.52	0.51	0.61	0.63	0.56	1.03	0.60
2,6	0.63	0.61	0.73	0.75	0.67	1.23	0.72
4,6	0.93	0.88	0.95	1.11	0.92	1.92	1.10

	1996	1997	1998	1999
1,7	0.59	0.58	0.49	0.18
1,6	0.56	0.52	0.45	0.16
2,6	0.67	0.63	0.54	0.19
4,6	0.95	0.93	0.75	0.28

Average F weighted by N for 1,7 1,6 2,6 4,6

	1982	1983	1984	1985	1986	1987	1988
1,7	0.29	0.39	0.30	0.35	0.31	0.17	0.12
1,6	0.28	0.38	0.30	0.34	0.31	0.16	0.12
2,6	0.38	0.52	0.49	0.47	0.51	0.30	0.28
4,6	0.61	0.88	0.88	1.12	1.05	1.03	0.83

	1989	1990	1991	1992	1993	1994	1995
1,7	0.19	0.36	0.50	0.38	0.24	0.33	0.30
1,6	0.19	0.36	0.49	0.37	0.24	0.32	0.29
2,6	0.21	0.41	0.69	0.54	0.43	0.39	0.38
4,6	0.94	0.88	0.83	1.14	0.96	1.64	1.09

	1996	1997	1998	1999
1,7	0.42	0.34	0.23	0.06
1,6	0.41	0.34	0.23	0.05
2,6	0.52	0.48	0.38	0.11
4,6	0.82	0.95	0.74	0.29

Average F for weighted by Catch for 1,7 1,6 2,6 4,6

	1982	1983	1984	1985	1986	1987	1988
1,7	0.47	0.63	0.69	0.83	0.81	0.74	0.60
1,6	0.46	0.62	0.68	0.82	0.80	0.73	0.60
2,6	0.46	0.62	0.68	0.82	0.80	0.73	0.60
4,6	0.61	0.88	0.88	1.13	1.05	1.04	0.87

	1989	1990	1991	1992	1993	1994	1995
1,7	0.61	0.55	0.79	0.94	0.75	1.16	0.69
1,6	0.61	0.54	0.79	0.93	0.74	1.14	0.68
2,6	0.61	0.54	0.79	0.93	0.74	1.14	0.68
4,6	0.94	0.88	0.85	1.14	0.96	1.68	1.09

	1996	1997	1998	1999
1,7	0.74	0.77	0.59	0.24
1,6	0.74	0.77	0.59	0.23
2,6	0.74	0.77	0.59	0.23
4,6	0.84	0.96	0.74	0.29

Biomass Weighted F

1982	1983	1984	1985	1986	1987	1988
0.40	0.53	0.45	0.50	0.45	0.30	0.20

1989	1990	1991	1992	1993	1994	1995
0.27	0.44	0.63	0.50	0.38	0.40	0.37

1996	1997	1998	1999
0.48	0.43	0.36	0.11

BACKCALCULATED PARTIAL RECRUITMENT

	1982	1983	1984	1985	1986	1987	1988
1	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2	0.29	0.22	0.11	0.06	0.02	0.03	0.02
3	0.84	0.57	0.50	0.57	0.62	0.17	0.32
4	1.00	0.88	0.77	0.99	0.93	0.70	0.55
5	0.85	1.00	1.00	0.92	1.00	1.00	1.00
6	0.96	0.94	0.83	1.00	0.98	0.76	0.65
7	0.96	0.94	0.83	1.00	0.98	0.76	0.65

	1989	1990	1991	1992	1993	1994	1995
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.02	0.10	0.12	0.06	0.02	0.00	0.10
3	0.32	0.34	0.56	0.30	0.60	0.15	0.18
4	1.00	0.97	0.63	0.83	1.00	0.54	0.96
5	0.90	0.98	1.00	1.00	0.79	1.00	0.97
6	1.00	1.00	0.69	1.00	0.98	0.63	1.00
7	1.00	1.00	0.69	1.00	0.98	0.63	1.00

	1996	1997	1998	1999
1	0.00	0.00	0.00	0.00
2	0.02	0.03	0.06	0.00
3	0.37	0.28	0.47	0.40
4	0.59	0.75	0.89	1.00
5	1.00	1.00	1.00	0.74
6	0.64	0.92	0.94	0.87
7	0.64	0.92	0.94	0.87

MEAN BIOMASS (using catch mean weights at age)

	1982	1983	1984	1985	1986	1987	1988
1	5013	4514	6317	4008	6044	8119	17658
2	8746	4788	4504	6987	4701	7081	9266
3	5090	7269	3938	3872	5877	4407	6729
4	4981	3186	5021	2490	2355	3869	3355
5	5582	2577	1528	2672	1067	997	1696
6	766	2849	1303	621	1014	437	360
7	4243	1685	1551	1137	905	770	410
1+	34422	26868	24161	21786	21963	25680	39473

	1989	1990	1991	1992	1993	1994	1995
1	2753	2766	4795	4309	6638	2341	2404
2	19827	2575	2650	6452	5021	8735	3341
3	9071	18829	2159	2894	4762	5095	8605
4	4604	5442	13693	1362	1654	2563	3004
5	2025	2125	2947	5346	728	389	933
6	416	1358	1258	875	2941	273	90
7	708	1515	1072	757	408	517	392
1+	39403	34609	28574	21994	22152	19912	18768

	1996	1997	1998	1999	
1	1724	2068	2728	4374	
2	3636	2673	2344	3169	
3	2690	3382	2171	2440	
4	5601	1695	2289	1616	
5	1013	2577	878	1529	
6	411	333	1102	554	
7	142	103	137	1013	
1+	15217	12831	11650	14696	00

Summaries for ages 1,7 1,6 2,6 4,6

	1982	1983	1984	1985	1986	1987	1988
1,7	34422	26868	24161	21786	21963	25680	39473
1,6	30179	25183	22610	20650	21057	24910	39063
2,6	25166	20670	16293	16642	15013	16791	21405
4,6	11330	8613	7851	5783	4435	5303	5411

	1989	1990	1991	1992	1993	1994	1995
1,7	39403	34609	28574	21994	22152	19912	18768
1,6	38695	33094	27502	21238	21744	19395	18377
2,6	35942	30329	22707	16929	15106	17054	15973
4,6	7045	8925	17898	7583	5323	3224	4027

	1996	1997	1998	1999
1,7	15217	12831	11649	14696
1,6	15075	12728	11512	13683
2,6	13351	10659	8784	9309
4,6	7025	4605	4269	3700

Catch BIOMASS (using catch mean weights)

	1982	1983	1984	1985	1986	1987	1988
1	27	00	04	00	00	02	00
2	1603	1013	519	514	110	284	203
3	2746	3955	2093	2555	4027	1008	2737
4	3198	2659	4144	2872	2421	3704	2343
5	3052	2452	1638	2868	1178	1370	2144
6	471	2557	1163	722	1095	459	295
7	2606	1512	1384	1322	978	809	337
1+	13703	14149	10944	10853	9808	7636	8060

	1989	1990	1991	1992	1993	1994	1995
1	00	00	00	00	00	00	00
2	421	220	390	481	99	42	361
3	2831	5835	1484	1026	2842	1990	1699
4	4428	4763	10604	1337	1640	3665	3262
5	1763	1864	3596	6307	570	1033	1017
6	402	1220	1062	1031	2872	454	102
7	683	1361	905	892	398	862	441
1+	10527	15263	18040	11074	8420	8047	6882

	1996	1997	1998	1999
1	00	00	00	00
2	110	92	120	00
3	1259	984	821	317
4	4188	1327	1637	523
5	1294	2707	702	364
6	337	322	824	156
7	117	100	103	284
1+	7305	5532	4207	1644

Summaries for ages 1,7 1,6 2,6 4,6

	1982	1983	1984	1985	1986	1987	1988
1,7	13703	14149	10944	10853	9808	7636	8060
1,6	11097	12637	9560	9531	8830	6827	7723
2,6	11070	12637	9556	9531	8830	6825	7723
4,6	6721	7669	6945	6462	4693	5534	4782

	1989	1990	1991	1992	1993	1994	1995
1,7	10527	15262	18040	11074	8420	8047	6882
1,6	9844	13902	17135	10183	8022	7185	6441
2,6	9844	13902	17135	10183	8022	7185	6441
4,6	6592	7847	15261	8675	5082	5153	4381

	1996	1997	1998	1999
1,7	7304	5532	4207	1644
1,6	7188	5432	4104	1359
2,6	7188	5432	4104	1359
4,6	5819	4356	3162	1042

Jan 1 BIOMASS (using Jan 1 mean weights)

	1982	1983	1984	1985	1986	1987	1988
1	4874	4388	5895	3675	5520	7545	16560
2	8789	5138	4626	6751	4357	6595	8702
3	5904	8598	4635	4704	7333	4769	7501
4	6303	4192	6269	3485	3160	4886	4236
5	7088	3711	2215	3688	1497	1540	2575
6	942	4198	1714	927	1542	630	485
7	6202	2775	2549	2082	1605	1350	655
1+	40102	33001	27903	25313	25015	27313	40714

	1989	1990	1991	1992	1993	1994	1995
1	2785	2723	4056	3967	5769	1906	1936
2	18769	2714	2798	5655	4667	7608	2865
3	9796	20641	2692	2891	6225	5504	9060
4	6172	7853	17592	1765	2476	4023	4467
5	2614	2908	4090	8929	902	1007	1300
6	725	1591	1548	1467	3522	507	105
7	1198	2496	1727	1394	694	1142	707
1+	42059	40925	34502	26068	24255	21697	20439

	1996	1997	1998	1999
1	1372	1917	2529	4054
2	2972	2161	2225	2936
3	3243	3720	2605	2430
4	7792	2244	3025	1825
5	1692	3895	1176	1626
6	547	500	1485	597
7	227	175	212	1276
1+	17845	14611	13257	14744

Summaries for ages 1,7 1,6 2,6 4,6

	1982	1983	1984	1985	1986	1987	1988
1,7	40102	33001	27903	25313	25015	27313	40714
1,6	33900	30226	25354	23230	23409	25964	40059
2,6	29026	25838	19459	19555	17889	18418	23499
4,6	14333	12102	10198	8100	6199	7055	7296

	1989	1990	1991	1992	1993	1994	1995
1,7	42059	40925	34502	26068	24255	21697	20439
1,6	40861	38429	32776	24674	23561	20555	19732
2,6	38076	35706	28720	20707	17792	18649	17796
4,6	9511	12352	23230	12160	6900	5537	5872

	1996	1997	1998	1999
1,7	17845	14611	13257	14744
1,6	17618	14436	13044	13468
2,6	16247	12519	10516	9413
4,6	10031	6638	5686	4048

SSB AT THE START OF THE SPAWNING SEASON -MALES AND FEMALES (MT) (using SSB mean weights)

	1982	1983	1984	1985	1986	1987	1988
1	330	297	399	142	214	292	641
2	2144	1247	1141	3096	2015	3041	4025
3	3184	4633	2503	3872	6011	4218	6440
4	4820	3105	4650	2781	2575	4029	3647
5	6071	2971	1738	2983	1205	1184	2017
6	823	3496	1429	739	1245	511	409
7	5415	2311	2125	1659	1297	1096	552
1+	22786	18061	13984	15272	14561	14370	17732

	1989	1990	1991	1992	1993	1994	1995
1	108	290	432	422	614	74	75
2	8683	725	739	1513	1260	2794	1034
3	8545	10617	1300	1476	3052	4439	7546
4	5085	5317	12113	1174	1644	3035	3569
5	2187	2260	3002	6598	712	625	1048
6	597	1298	1275	1142	2837	371	84
7	987	2078	1451	1108	570	836	567
1+	26191	22585	20311	13432	10690	12175	13924

	1996	1997	1998	1999
1	53	74	98	157
2	1087	790	811	1079
3	2582	3051	2105	2047
4	6587	1885	2571	1655
5	1322	3162	995	1511
6	462	411	1268	551
7	191	144	181	1178
1+	12285	9517	8029	8179

ADAPT/VPA Bootstrap Output

File: gmcod2000_base.2boot

The number of bootstraps: 100

Bootstrap Output Variable: N hat

	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
N 2	4391	4457	1592	0.36
N 3	2242	2357	635	0.28
N 4	1161	1242	341	0.29
N 5	455	464	157	0.35
N 6	303	330	124	0.41

	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V. FOR CORRECTED ESTIMATE	LOWER 80%CI	UPPER 80%CI
N 2	67	159	1.52	4324	0.368318	2564	6190
N 3	115	63	5.11	2127	0.298377	1308	2919
N 4	82	34	7.03	1079	0.315954	684	1553
N 5	09	16	2.01	446	0.353130	325	792
N 6	27	12	8.76	277	0.449921	164	492

Bootstrap Output Variable: Q_unscaled

	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
q WHSpr2	0.0000789	0.0000813	0.0000154	0.19
q WHSpr3	0.0001766	0.0001758	0.0000355	0.20
q WHSpr4	0.0002607	0.0002616	0.0000476	0.18
q WHSpr5	0.0003404	0.0003363	0.0000643	0.19
q WHSpr6	0.0004341	0.0004445	0.0000898	0.21
q WHAut2	0.0000680	0.0000686	0.0000138	0.20
q WHAut3	0.0001688	0.0001705	0.0000328	0.19
q WHAut4	0.0002927	0.0003097	0.0000618	0.21
q WHAut5	0.0003750	0.0003840	0.0000754	0.20
q WHAut6	0.0006108	0.0006193	0.0001095	0.18
q MASpr2	0.0010758	0.0011056	0.0001972	0.18
q MASpr3	0.0008737	0.0008904	0.0001683	0.19
q MASpr4	0.0004771	0.0004840	0.0001001	0.21
q MAAut1	0.0013482	0.0013375	0.0002738	0.20
q MAAut2	0.0003353	0.0003417	0.0000617	0.18
q MAAut3	0.0000698	0.0000697	0.0000123	0.18
q CM_CPE2	0.0000031	0.0000030	0.0000006	0.21
q CM_CPE3	0.0000169	0.0000173	0.0000038	0.23
q CM_CPE4	0.0000269	0.0000277	0.0000065	0.24
q CM_CPE5	0.0000265	0.0000270	0.0000059	0.22
q CM_CPE6	0.0000269	0.0000274	0.0000067	0.25

	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V. FOR CORRECTED ESTIMATE	LOWER 80%CI	UPPER 80%CI
q WHSpr2	0.00000232	0.000001536	2.941	0.000076626	0.20	0.0000579	0.0000968
q WHSpr3	-0.00000080	0.000003546	-0.456	0.000177375	0.20	0.0001354	0.0002199
q WHSpr4	0.00000083	0.000004762	0.318	0.000259914	0.18	0.0002074	0.0003273
q WHSpr5	-0.00000408	0.000006428	-1.199	0.000344453	0.19	0.0002739	0.0004425
q WHSpr6	0.00001038	0.000008975	2.392	0.000423735	0.21	0.0003295	0.0005553
q WHAut2	0.00000057	0.000001382	0.832	0.000067432	0.20	0.0000521	0.0000924
q WHAut3	0.00000172	0.000003282	1.019	0.000167090	0.20	0.0001354	0.0002222
q WHAut4	0.00001702	0.000006180	5.815	0.000275701	0.22	0.0002214	0.0003767
q WHAut5	0.00000900	0.000007539	2.401	0.000366042	0.21	0.0003135	0.0005427
q WHAut6	0.00000857	0.000010947	1.403	0.000602192	0.18	0.0004777	0.0007961
q MASpr2	0.00002980	0.000019721	2.770	0.001046014	0.19	0.0007848	0.0013173
q MASpr3	0.00001664	0.000016827	1.904	0.000857091	0.20	0.0006550	0.0010604
q MASpr4	0.00000690	0.000010014	1.447	0.000470175	0.21	0.0004004	0.0006712
q MAAut1	-0.00001065	0.000027381	-0.790	0.001358838	0.20	0.0011042	0.0018513
q MAAut2	0.00000648	0.000006168	1.933	0.000328775	0.19	0.0002602	0.0004070
q MAAut3	-0.00000012	0.000001227	-0.166	0.000069885	0.18	0.0000572	0.0000895
q CM_CPE2	-0.00000010	0.000000065	-3.180	0.000003179	0.20	0.0000027	0.0000050
q CM_CPE3	0.00000038	0.000000382	2.253	0.000016543	0.23	0.0000112	0.0000207
q CM_CPE4	0.00000086	0.000000646	3.218	0.000026007	0.25	0.0000189	0.0000378
q CM_CPE5	0.00000054	0.000000594	2.029	0.000025924	0.23	0.0000196	0.0000331
q CM_CPE6	0.00000043	0.000000666	1.614	0.000026502	0.25	0.0000205	0.0000347

Bootstrap Output Variable: N t1

	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
Age 1	5068.4	5076.3	156.2	0.0308
Age 2	4390.5	4457.5	1592.5	0.3627
Age 3	2242.0	2356.6	634.8	0.2831
Age 4	1160.9	1242.4	341.0	0.2937
Age 5	454.8	463.9	157.4	0.3460
Age 6	303.2	329.8	124.5	0.4105
Age 7	175.3	175.0	44.9	0.2562

	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V. FOR CORRECTED ESTIMATE	LOWER 80%CI	UPPER 80%CI
Age 1	7.84	15.62	0.155	5060.58	0.03	4814.2	5218.5
Age 2	66.90	159.25	1.524	4323.64	0.37	2564.2	6190.5
Age 3	114.62	63.48	5.112	2127.37	0.30	1308.0	2919.5
Age 4	81.59	34.10	7.028	1079.27	0.32	683.8	1552.6
Age 5	9.13	15.74	2.008	445.63	0.35	325.4	791.5
Age 6	26.57	12.45	8.763	276.63	0.45	164.4	492.4
Age 7	-0.28	4.49	-0.158	175.53	0.26	138.6	254.4

Bootstrap Output Variable: F t

	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
Age 1	0.0000	0.0000	0.0000	0.40
Age 2	0.0000	0.0000	0.0000	0.28
Age 3	0.1299	0.1308	0.0379	0.29
Age 4	0.3235	0.3427	0.0903	0.28
Age 5	0.2379	0.2473	0.0870	0.37
Age 6	0.2807	0.2950	0.0649	0.23
Age 7	0.2807	0.2950	0.0649	0.23

	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V. FOR CORRECTED ESTIMATE	LOWER 80%CI	UPPER 80%CI
Age 1	0.0000000	0.0000000	11.102	0.0000002	0.45	0.0000	0.0000
Age 2	0.0000000	0.0000000	2.061	0.0000004	0.28	0.0000	0.0000
Age 3	0.0009154	0.0037909	0.705	0.1290096	0.29	0.0971	0.1965
Age 4	0.0191060	0.0090312	5.905	0.3044409	0.30	0.1845	0.4237
Age 5	0.0093784	0.0086969	3.942	0.2285263	0.38	0.1513	0.3723
Age 6	0.0142422	0.0064933	5.073	0.2664836	0.24	0.1895	0.3396
Age 7	0.0142422	0.0064933	5.073	0.2664836	0.24	0.1895	0.3396

Bootstrap Output Variable: F full t

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
0.2807	0.2950	0.0649	0.23

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V. FOR CORRECTED ESTIMATE	LOWER 80%CI	UPPER 80%CI
0.01424	0.00649	5.07	0.26648	0.24	0.1895	0.3396

Bootstrap Output Variable: PR t

	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
Age 1	0.0000	0.0000	0.0000	0.48
Age 2	0.0000	0.0000	0.0000	0.34
Age 3	0.4016	0.3855	0.1484	0.37
Age 4	1.0000	0.9549	0.1022	0.10
Age 5	0.7353	0.7079	0.2237	0.30
Age 6	0.8677	0.8314	0.0943	0.11
Age 7	0.8677	0.8314	0.0943	0.11

	ESTIMATE	STD ERROR	BIAS	FOR BIAS	STIMATE	80%CI	UPPER 80%CI
Age 1	0.00000	0.000000	6.73	0.00000059	0.52	0.0000	0.0000
Age 2	0.00000	0.000000	-3.27	0.00000129	0.33	0.0000	0.0000
Age 3	-0.01611	0.014837	-4.01	0.41767448	0.36	0.3019	0.8742
Age 4	-0.04505	0.010215	-4.51	1.04505144	0.10	0.5386	1.0000
Age 5	-0.02739	0.022370	-3.73	0.76269571	0.29	0.5098	1.0000
Age 6	-0.03622	0.009426	-4.17	0.90387357	0.10	0.7693	0.9848
Age 7	-0.03622	0.009426	-4.17	0.90387357	0.10	0.7693	0.9848

Bootstrap Output Variable: PR mean

	NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
Age 1	0.0000	0.0000	0.0000	0.23
Age 2	0.0014	0.0013	0.0002	0.16
Age 3	0.3748	0.3612	0.0410	0.11
Age 4	0.8735	0.8494	0.0338	0.04
Age 5	0.9026	0.8759	0.0934	0.10
Age 6	0.9071	0.8834	0.0587	0.06
Age 7	0.9071	0.8834	0.0587	0.06

	BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V. FOR CORRECTED ESTIMATE	LOWER 80%CI	UPPER 80%CI
Age 1	0.00000	0.0000000	-0.50	0.0000005	0.23	0.0000	0.0000
Age 2	-0.00004	0.0000218	-2.99	0.0014208	0.15	0.0012	0.0019
Age 3	-0.01356	0.0041020	-3.62	0.3883452	0.11	0.3506	0.4868
Age 4	-0.02408	0.0033759	-2.76	0.8975813	0.04	0.8604	0.8902
Age 5	-0.02667	0.0093355	-2.95	0.9292533	0.10	0.7988	0.9885
Age 6	-0.02367	0.0058667	-2.61	0.9307563	0.06	0.8411	0.9614
Age 7	-0.02367	0.0058667	-2.61	0.9307563	0.06	0.8411	0.9614

Bootstrap Output Variable: Mean Biomass

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
14696.3238	15227.0049	2167.2455	0.15

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V. FOR CORRECTED ESTIMATE	LOWER 80%CI	UPPER 80%CI
530.6811	216.7246	3.61	14165.6427	0.15	10937.6621	16395.9087

Bootstrap Output Variable: SSB f mean

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
3605.2593	4297.8627	670.4795	0.19

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V. FOR CORRECTED ESTIMATE	LOWER 80%CI	UPPER 80%CI
692.603	67.048	19.21	2912.656	0.23	2947.5296	3711.4627

Bootstrap Output Variable: SSB spawn t

NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
8178.8261	8495.8262	1257.3919	0.15

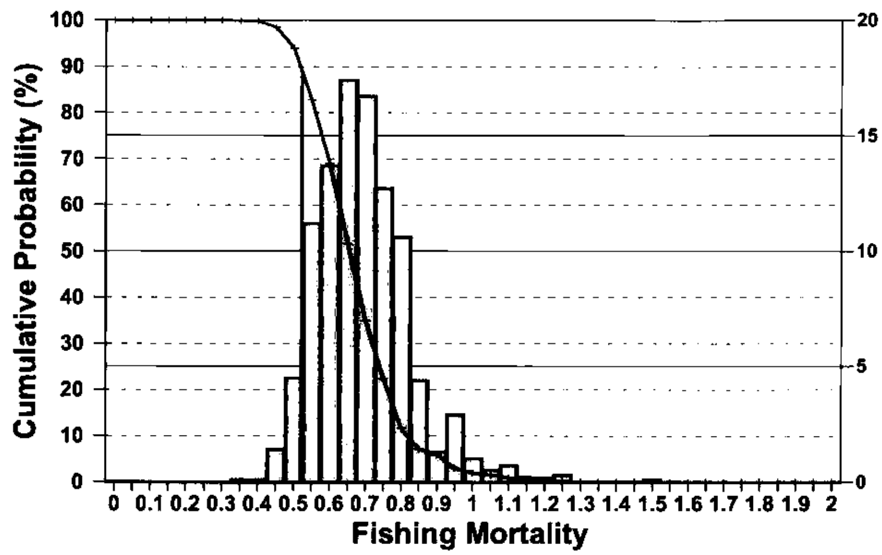
BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V. FOR CORRECTED ESTIMATE	LOWER 80%CI	UPPER 80%CI
317.00	125.74	3.88	7861.83	0.16	6032.3126	9442.0787

Bootstrap Output Variable: Jan 1 biomass

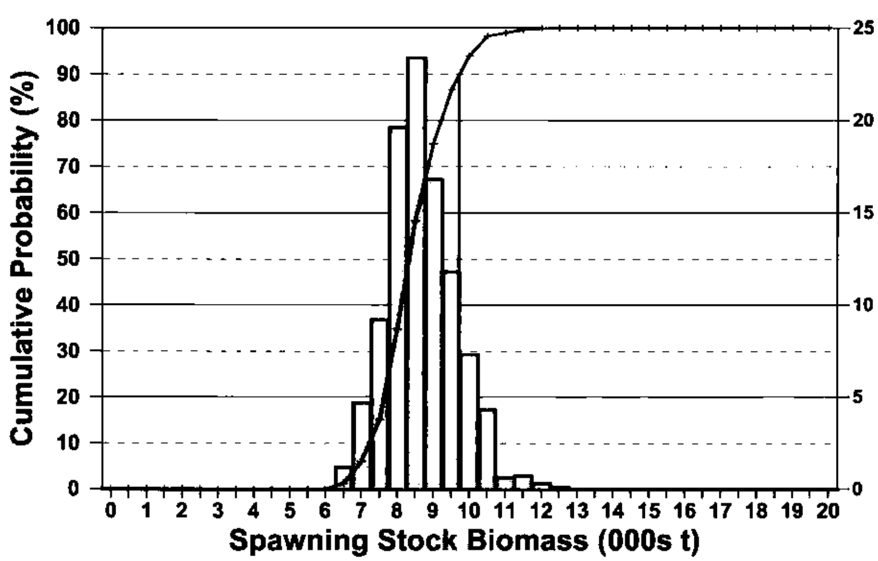
NLLS ESTIMATE	BOOTSTRAP MEAN	BOOTSTRAP StdError	C.V. FOR NLLS SOLN
14743.7195	15242.0697	2036.2864	0.14

BIAS ESTIMATE	BIAS STD ERROR	PERCENT BIAS	NLLS EST CORRECTED FOR BIAS	C.V. FOR CORRECTED ESTIMATE	LOWER 80%CI	UPPER 80%CI
498.35	203.63	3.38	14245.37	0.14	11483.96	16397.45

Gulf of Maine Cod
Precision of 1998 F Estimate



Precision of 1998 SSB Estimate



APPENDIX 3. St. Andrews (S. Gavaris) Version of ADAPT

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Appendix 3: St. Andrews (S. Gavaris) Version of ADAPT

Estimation of Population Abundance

by

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Abstract

This document is intended as a tutorial to assist the first users of the ADAPT software. The ADAPTive Framework uses a non-linear least squares fit to calibrate a virtual population analysis against independent indices of abundance. The tutorial is based on a data set mimicking a gadoid stock having four indices of abundance exhibiting various anomalies (trends in catchability, year effects, conflicting trends in indices). The tutorial outlines working procedures that would permit a user to analyze the results using the various diagnostics available and to explore the impact of various formulations of the estimation problem. It aims not only at showing how the software works but also at establishing good working practices to analyze the results.

An adaptive framework – its origin

The ADAPTive framework, commonly called "ADAPT", was developed in the mid-1980s to allow the exploration of various formulations for the calibration of virtual population analysis (VPA) against indices of stock abundance. Earlier methods of calibration for VPA were sensitive to the value of the index for the most recent years. ADAPT, like survivor analyses, was designed to reduce the sensitivity of the estimates of stock abundance upon the most recent year of data. This is particularly important in situations where there is only one, or a few, indices of abundance available. Another objective was to bring the estimation process within a statistical framework that would allow for the estimation of the uncertainty (variance, bias) attached with the estimates of stock abundance. For the estimation of unknown parameters and their associated uncertainty, an approach based on non-linear least-squares was adopted.

Typically, in an ADAPT formulation, the unknown parameters are:

- the catchability coefficients at age for each index;
- the estimates of survivors at the end of the period covered by the catch data.

It is also possible to estimate the survivors after the oldest age covered by the catch data. However, most often, the population abundance for the oldest age is calculated by relating the fishing mortality on the last age group to the fishing mortality on younger ages. The recent version of ADAPT (Version 2.1) also allows the estimation of natural mortality for specified blocks of ages and years.

A detailed illustration of an application of the population dynamics model behind ADAPT is provided in Gavaris and Van Eeckhaute (1998), together with a description of the estimation procedure. The approaches used to measure uncertainty are discussed in Gavaris (1991, 1993, 1999a) and Smith and Gavaris (1993). For convenience, a description of the computational algorithms used by ADAPT are included as Annex 1. For this tutorial we will be using Version 2.1 of the ADAPT software (Gavaris 1999b).

Data set for tutorial

We will use the "blackfin" data, corresponding to data for a gadoid (saithe) stock with trends in the tuning data for two of four fleets (C. Darby, CEFAS, Lowestoft, U.K., pers. comm.). This data set includes a number of difficulties (e.g. conflicting trends in indices of abundance, poor consistency between consecutive estimates of the cohorts, poor convergence of the VPA, sensitivity of results to model assumptions). The tutorial outlines working procedures that would permit a user to analyze the results using the various diagnostics available and to explore the impact of various formulations of the estimation problem. It aims not only at showing how the software works but also at establishing good working practices to analyze the results.

Preparing your data using the spreadsheet template (ADAPT Template.xls)

There are two approaches to data input: 1) data could be copied from any Windows (Microsoft Corporation, WA, USA) application, e.g. a spreadsheet, through the Windows Clipboard or they could be loaded from TAB-delimited text files. In this tutorial, we will use the Clipboard to transfer your data from a spreadsheet to ADAPT.

To assist in the preparation of your own data for using ADAPT, a template is provided in the spreadsheet "ADAPT Template.xls". Essentially, the template provides placeholders for your input data. The template also provides a means to display your data in a graphical form. In the template, placeholders for your data are colored in light yellow. The template can also be used to transfer the results of ADAPT back to your spreadsheet for displaying graphically or for further analysis. You do not have to use the template to prepare data for input to ADAPT (any of your own spreadsheets will do). However, the template includes some data validation and formatting, thereby reducing the possibility of erroneous entries. The template has been formatted to allow easy copying between the spreadsheet and ADAPT.

If you use your own spreadsheet (instead of the template provided) to copy data to ADAPT, please note the following:

Warning for matrices or arrays with blank entries:

In ADAPT, TABs are necessary to mark empty cells in matrices. When copying data to the clipboard from an Excel spreadsheet (Microsoft Corporation, WA, USA), there are situations where TABs are not generated and transferred via the clipboard. To ensure that the TABS are created and transferred, format (e.g. to 2 decimals) the cells containing your data before selecting and copying to the clipboard. Also, do not format the numbers in the cells so that they could include separators, such as "," (e.g. to delimit thousands). Note that in some computers installed with international keyboards, the default format may include such separators or may use a comma to identify decimals. In such cases, you should overwrite that default.

Alternatively, if you input data via text files, you should verify that your text editor generates the necessary TABs.

Data are to be input in individual sheets acting as placeholders for the following:

Sheet	Data description	Comments
LA	landings	
Cn	Catch-at-age, in numbers	
Cw	catch weight-at-age	
Sw	stock weight-at-age	Beginning of year weight-at-age for calculating biomass
MO	maturity ogives	For calculation of stock spawning biomass
NM	natural mortality	
TunX	index X: effort and catch-at-age	One sheet per index

[*Note: sheet names have been selected to be consistent with input files for the Lowestoft Tuning Package*]

For this tutorial, data have been pre-assembled in the spreadsheet "ADAPT Tutorial – Estimation.xls". Load this spreadsheet now and inspect its content to gain some familiarity with its design. Only the sheets Cn, catch-at-age in numbers, and TunX, index X, are required for input to ADAPT. The other sheets can be used to generate summaries of assessment results. [Note: to assist you in completing the tutorial, the "completed" spreadsheet is given in the file "ADAPT Template – Example.xls".]

Landings (sheet LA):

This data sheet can be used to tabulate the landings (landed quantities in weight). Input your landing data in this sheet as follows:

Cell	Input
B1	Title for your project
B3	First year covered by your landing data
B7-B56	Landings in tons

The "landings" sheet is provided for your convenience as ADAPT does not typically require that input.

Catch-at-age, in numbers (sheet Cn):

This data sheet can be used to tabulate the catch-at-age information. Catches should be provided in numbers (i.e. number of fish caught). Take note of the scaling factor used when entering your data (e.g. 1000 for thousands). Input your catch-at-age data in this sheet as follows:

Cell	Input
B3	First year covered in your catch-at-age data
B4	First age-group covered in your catch-at-age data
B10-P59	Catch-at-age data (in number of fish)
F8	Scale multiplier for your catch-at-age data

The catch-at-age may include a plus group for the oldest age-group. Also, the time intervals for the VPA are specified through the time intervals used when specifying the catch-at-age. In this tutorial, the time intervals are taken as one year (as is often the case) but they do not have to be one year or constant when using ADAPT 2.1.

Weight at age from commercial sampling (sheet Cw):

This data sheet can be used to tabulate the weight information corresponding to the catch-at-age. This information generally comes from the sampling of commercial fisheries. Weights should be provided in kilograms (kg). Input your weight-at-age data in this sheet as follows:

Cell	Input
B10-P59	Weight-at-age data from sampling of commercial fisheries

Stock weight at age (sheet Sw):

This data sheet serves to tabulate the weight-at-age (at the beginning of year) to be applied to population numbers. The beginning of year weights can be interpolated from the catch weight-at-age or can come from survey information. Weights are provided in kilograms (kg). Input your weight-at-age data in this sheet as follows:

Cell	Input
B10-P59	Weight-at-age corresponding to the beginning of the year, to be applied to the population numbers.

Maturity ogives (sheet MO):

This data sheet serves as a placeholder for maturity data to be used in the calculation of the stock spawning numbers and biomass. This data takes the form of maturity ogives given as the percent mature at each age. Input your maturity at age data in this sheet as follows:

Cell	Input
B10-P59	Maturity-at-age

Natural Mortality (sheet NM):

This data sheet serves as a placeholder for natural mortality data to be used in the virtual population analysis. This data takes the form of a matrix providing the natural mortality rate at a given age in a given year. If a constant is used for all ages or a vector for all years, copy these values to the relevant cells to simplify data entry. Input your natural mortality data in this sheet as follows:

Cell	Input
B10-P59	Natural mortality-at-age

Tuning indices (sheets TunX):

You will need to create one data sheet per index. Four template sheets are provided in the template but you can add sheets by copying one of the four empty templates. Each data sheet can be used to tabulate the effort and catch-at-age information for a given index; when such data are provided, catch-rate-at-age (your index of abundance) is calculated from the input. Alternatively, someone can input the index directly, generally in the form of catch rate at age or relative abundance estimates-at-age, directly into the sheet. Input your data for each index in these sheets as follows:

Cell	Input
B3	Name of index (e.g. Trawl survey)
B4	First year of index data
B5	First age-group in index
B6	Month of survey
B12-B61	Effort data (optional)
E12-S61	Catch-at-age data, in number of fish. (optional)
E67-S116	Index at age: catch rate or relative abundance estimate. Note that this index will be used to calibrate population numbers; consequently, its units should be numbers or counts of individual fish. [Note: if you are entering the index directly, overwrite the formula in the cells]
D67-D116	Time of survey. Note that a default value has been calculated from year and month of the survey. Adjust entries as necessary to account for missing years, multiple surveys per year or seasonal changes in the timing of the surveys.
G65	Scalar for the Index-at-age
K65	Unit for your index
E121-S170	Weight at age corresponding to your index. Required if the index is meant as an index of biomass.
E181-S230	Maturity at age corresponding to this index. Required if the index is meant as an index of spawning biomass.

The entry cells for effort and catch-at-age are hidden in the template as the index-at-age data have typically been input directly in ADAPT. The effort and catch-at-age fields are provided for convenience (and consistency with other packages such as the Lowestoft Tuning Package) and, if you need to use these fields, expand them by selecting the "+ button" appearing in the left margin.

Note that indices of biomass or spawning stock biomass (SSB) can also be specified in ADAPT. We will not use this option in this tutorial and the template (spreadsheet) does not provide placeholders for these. When an index of biomass or SSB is specified in ADAPT, the corresponding weight-at-age and maturity data must also be provided.

Data visualization

Graphical representations of your data are given in the "In-G" sheet. The initial scale for each graph is determined from your input and from the full range of years and ages permitted in the template. It may be necessary to adjust the scale of certain graphs (the bubble graphs in particular), to zoom on the years and ages of interest. Adjust the scales as necessary.

The first printable page of this sheet (Fig. 1) gives the time trajectory for the landings and the numbers taken in the catch. It also provides time trajectories for the weight-at-age data (from the commercial fishery data and for the stock) and for maturity data. Use these to get an appreciation of temporal changes or shifts in these entities.

The second printable page of this sheet (Fig. 2) gives the time trajectory for the indices (all ages aggregated). It also provides bubble plots of the indices-at-age. For these, each age has been normalized by its mean to remove the age-effect. Use these graphs to get insight about year trends or year effects, or about cohort effects.

Blackfin Example:

These graphs serve to illustrate some of the difficulties in the indices for this particular example. Conflicting trends are obvious between the aggregated catch rates for the seine fleet and the light trawl. The prawn trawl shows a peak in the earlier years, a peak that is not reflected in other indices. There is a "year effect" apparent in the otter trawl catch rates at age in 1990 (see bubble chart). There is poor consistency between consecutive estimates of year classes (try to follow cohorts in the bubble graphs). This could be due to the absence of a strong signal in the year class strength over the time period covered by these surveys but could also be an indication that these stock indices are not tracking year class strength consistently.

Loading ADAPT

The following assumes that you have already installed the runtime version of ADAPT V2.1. Activate ADAPT V2.1 from the Windows Start/Program Menu or as indicated in the installation guide. In a typical installation, the ADAPT program can be activated from the Start/Program Menu or by typing the following in the Start/Run Box:

C:/aplwr20/aplwr.exe C:/adapt2_1/ADAPT.W3 6000000

The value 6000000 specifies the workspace size. While this is sufficient for this tutorial, you may wish to increase that value for large data sets. The directories leading to the files *aplwr.exe* and *ADAPT.W3* should match those of your installation.

Data Input

You can input the catch matrix and the four indices prepared in the Tutorial spreadsheet as follows:

Input the catch at age data:

1. Go to Excel.
2. Go to the "Cn" sheet.
3. Highlight the cells A9-K42, which contain the data.
   [**Note:** *Row 42 contains the "year" label followed by "blank" entries for each age. It is important to include these "blank" entries as part of your selection so that the population matrix can be dimensioned properly. Essentially, that additional year is a placeholder for ADAPT to put its estimates of survivors. Accordingly, if you estimate survivors for the last age-group in each year, you will need to include in your catch matrix an extra age-column with 0 values for the catches.*]
4. Copy to the Clipboard.
5. Go to ADAPT.
6. Select Insert.
7. Select "From Clipboard".
8. Select "Catch".
   A message will appear reminding you to copy your data to the clipboard before selecting OK. If your data has already been copied to the clipboard, select OK. If not, do steps 1–5 and select OK when you return to this message.
9. Message: "Is the last age-group a plus group?" For this first run, select "No" and then select OK.
10. Your catch at age data will appear in the Session-log (which is displayed on the screen).

Input the indices at age:

11. **Go to Excel.**
12. **Go to the "Tun1" sheet, which contains data for the first index.**
13. **Highlight the cells D66-I86 which contain the data.**
14. **Copy to the Clipboard.**
15. **Go to ADAPT.**
16. **Select Insert.**
17. **Select "From Clipboard".**
18. **Select "Index".**
19. **Select "Pop. Numbers".**
    A message will appear, reminding you to copy your data to the clipboard before selecting OK.
    If your data has already been copied to the clipboard, select OK. If not, do steps 11–15 and select OK when you return to this message.
20. **Data for this index will appear in the Session-log (which is displayed on the screen)**

The same process is followed to input an index of the population biomass or spawning biomass, with the exception that at step "19", you select the relevant entry. Also, you will be asked to provide data on weight-at-age and maturity-at-age, as appropriate. The year-range and age-range specified on the weight-at-age and maturity-at-age data must match those for the indices.

To add new indices to ADAPT, repeat steps 11–20 for each index, with the exception that, at step 13, adjust the selection so as to include the cells containing your data. Using the Blackfin example, proceed to input data the for three other indices of abundance, i.e. data for the "Seine" index, for the "Light trawl" index and for the "prawn trawl" index.

At this point, you have provided ADAPT with your data on catches and indices of stock size (abundance, biomass or spawning biomass). The next step consists of setting up the estimation model.

Setting up the estimation

In this step, you specify which parameters are to be estimated using the non-linear estimation procedure.

21. **In ADAPT:**
22. **Select Setup.**
23. **Select "VPA".**
24. **The template of the "Population" tab will appear. Using this template, you have to specify one, and only one, calculation process per cohort. In this particular case, you are allowed either a) to estimate the abundance corresponding to the cell(s) identified, b) to assign a fix value to the abundance corresponding to these cells, or c) to base the calculation of abundance on the fishing mortality-at-age.**
25. **Click the boxes corresponding to 1995, ages 1 and 2. This indicates to ADAPT that you wish to specify one of the calculation processes for these two cohorts. REMINDER: Click one or more boxes first to identify cohorts, then select a procedure for the calculation of these cohorts.**
26. **Select "Assign N" from the top bar. You will be prompt to enter a value for these cells. Enter 15000. These boxes will be marked in red and the corresponding boxes along these entire cohorts will be grayed.**
27. **Click the box corresponding to 1995, age 3. Then, select "Estimate N" from the top bar. You will be prompt to enter a value for that cell, the initial guess to start the non-linear estimation process. Enter 25000. This box will be marked in green and the corresponding entries along that cohort will be grayed.**

28. **Repeat step 27 for each age (4 to 10) in 1995. In doing so, specify 25000 for age 4, 20000 for 5, 15000 for 6, 10000 for 7, 5000 for 8, 5000 for 9, and 5000 for 10. You have now specified initial guesses for each of these age groups.**
29. **Click the boxes corresponding to 1994, age 10, followed by 1993, age 10, and so on... until all boxes along age 10 have been selected (the last one will be age 10 in 1963). In doing so, you are going up the template. Use the scroll bar of that window to display hidden boxes.**
30. **Then, select from the top bar "Calculate F". You will be prompt to enter F Ratios for specific ages. In each of the cells corresponding to ages 4, 5 and 6, enter the value of 1 (unity). Select OK.**
31. **You will be prompted to select the method to average these fishing mortality values (unweighted or weighted by population numbers). Select "Unweighted" and then OK. Through steps 29 to 31, you have specified that the average (unweighted) fishing mortality values for these ages will be applied to age 10.**
32. **Select the "Natural Mortality" tab. You will be presented with a template similar to the preceding one. Each box has to be specified to identify the process by which natural mortality will be calculated: the choices being "estimated" or "fixed". To simplify your task, you can select blocks of cells at once by selecting the upper left corner first and then selecting the lower right corner while holding down the Shift key. Click on the first box (1963 age 1); then go to the bottom right corner of the template and "Shift-click" the box corresponding to 1994, age 10). Check marks will fill the boxes selected.**
33. **Select "Assign M" from the top bar. You will be presented with a prompt to enter a value. Enter 0.2. Then click OK. The template will appear (the selected boxes will now appear in red).**
34. **When finished, select the "Done" button.**
35. **The model specified by your entries will be described in the Session-log.**

Steps 25 to 33 are important as they allow you to specify the parameters to be estimated through the non-linear estimation procedure. After completion of these steps, you have specified initial "guess" values for each of the parameters. You have also specified some of the fishing mortality constraints to be applied in the form of functional relationships linking the F for the oldest age group and F values for younger age groups.

In step 26, you have assigned fixed values for ages 1 and 2 in 1995. If this is your final formulation, the fixed values are typically replaced by the geometric mean of population-size estimates for each of these ages for the most recent time period (e.g. for the last decade covered by your data). You can do these adjustments in sheet "N" of the spreadsheet template, but it may be useful to adjust the final ADAPT estimation as these numbers will appear in any subsequent projection results.

Note that if you have a plus-group, two other options, pertinent only to plus groups, are available for setting up the estimation on the Population tab.

You may find that the process of setting up your model is not always successful. While the interface provides flexibility for specifying the estimation model, the drawback of such flexibility is that some of the formulations may not be feasible. As you gain experience with the program, setting up ADAPT for estimating abundance should get easier. Many of the issues related to formulation of the estimation model can be related to one of the warnings given below. Read them carefully, especially those that are underlined.

Defining the catchability model

You can specify various functional relationships to link the indices of stock size to the stock size calculated through the VPA. Three options are available: 1) indices are proportionally related to population abundance; 2) they are related to population abundance through a power function; and 3) they are related to population abundance through a time trend model.

Warnings:

It is recommended that you assign fixed cohorts first, then the cohorts to be estimated, and last the cohorts having to be calculated from fishing mortality values.

For the lower left corner, it is necessary to "Assign N" (i.e. to fix these values) if these cohorts are not represented in any of the indices. It is not possible to estimate survivors for cohorts not represented in the indices [you have no data to estimate them].

You can "Estimate N" for the oldest age only if that cohort is represented in one of the indices. It is not possible to estimate population size for cohorts that are not represented in the indices. These cohorts have to be assigned a fixed value or should be determined by relating the fishing mortality for the oldest age to previous ages.

When you assign a fixed value or an initial guess for a population value, **ensure that it is greater than the catch number** or you will get a computation error.

If you select multiple boxes and then chose to estimate population abundance, the selected cohorts will have a common abundance for the time periods that are checked. If you wish population abundance to be estimated independently for each cohort, they must be selected individually.

36. In ADAPT:
37. Select Setup.
38. Select "Catchability model".
39. Select "Pop. numbers".
40. You will be presented with a menu allowing you to select the catchability models available. For this example, we will use the default ("Proportional"). Select OK. [Note that you can select a specific catchability model for one or some of the indices by selecting the relevant entries from the list.]
41. A description of the catchability model will appear in the Session-log

Estimating parameters

Once the VPA formulation and the catchability model have been specified, you are ready to start the non-linear least-squares estimation process.

42. In ADAPT:
43. Select "Compute".
44. Select "NLLS fit" (i.e. use Non-Linear Least-Squares to fit the data).
45. The output scrolls off the top of the active window and the top bar will likely blink, indicating that the program is operating. This is normal behavior.

46. **When the estimation is completed, the output appears in the Session-log. You should inspect the results by using the scrolling bar. In particular, you should verify that the estimation completed normally (i.e. no error messages).**

If the iterative process completed normally, you can then compute the statistics of the estimates.

47. **In ADAPT:**
48. **Select "Compute".**
49. **Select "Analytical"** (i.e. **compute the bias and variance of parameter estimates analytically).**
50. **Select "Statistics".**
51. **This generally takes a few seconds. The arrow cursor changes to an hourglass to indicate that ADAPT is computing. Wait for the results to appear in the session-log.**

The results take the form of tables showing the parameter estimates, their standard error, the relative error, the bias and relative bias. These results are given both in the log-scale and arithmetic-scale.

The next step is to inspect the results. Special attention should be given to the relative error of the parameter estimates and to their bias estimates. Large values for the relative error (say greater than 50%) indicate poor precision.

> In the Blackfin example, the relative error of parameter estimates is of the order of 40% or more, and the bias generally less than 10%. The relative error of the survey catchabilities is of the order of 25%, and their relative bias of the order of 3–4%.

The estimates of population and of fishing mortality can be adjusted for bias as follows:

52. **In ADAPT:**
53. **Select "Compute".**
54. **Select "Analytical"** (i.e. **compute from the bias and variance estimated analytically).**
55. **Select "VPA bias adjusted".**
56. **The results, namely the bias-adjusted estimates of the population and of the fishing mortality-at-age, appear in the session-log.**

Output

Other diagnostics are available to assist you in evaluating the performance of your model or the "goodness" of fit. We explore them in this section.

Residuals

57. **In ADAPT:**
58. **Select "Output".**
59. **Select "To Session log".**
60. **Select "Residuals".**
61. **Select "Diagnostics".**
62. **The results appear in the Session-log.**

It is a good practice to check that the average Mean Square Residuals (MSR) for each of the indices are in the same ballpark (assumption of homogeneity). If they differ substantially, this indicates that weighting should be used, an option which is not available in the current version of ADAPT. It is generally easier to inspect the residuals for patterns, e.g. "year-effects" or "age-effects", with graphs. Copying the residuals to the "Clipboard", instead of the "Session log", and transferring them to your spreadsheet allows graphical representation of the residuals or further analyses on them. Placeholders are provided in the ADAPT-template, in the "TunX" tabs, to put the residuals in a matrix form. However, because of the format for the residuals, you will need first to copy the residuals to a worksheet and select the relevant columns. The columns are 1) time, 2) ln of the observed index, 3) ln of the predicted index, 4) residuals and 5) ln of the population numbers. These columns are repeated for each index, age by age.

63. **In ADAPT:**
64. **Select "Output".**
65. **Select "To Clipboard".**
66. **Select "Residuals". A menu will appear allowing you to select the residuals to be copied. Select all ages for the first index (Otter trawl). Click OK.**
67. **A message will appear in the Session log indicating that the data were copied to the clipbooard.**
68. **In Excel:**
69. **Go to the "WS-Res" sheet (Working Sheet – Residuals). Copy the content of the clipboard to cell A3. In the next steps, we will reconstruct the matrix of residuals and paste it in the index sheets ("TunX").**
70. **Go to D3. Do "Ctrl-Shift-Down Arrow", followed by "Shift-F8".**
71. **Go to I3. Do "Ctrl-Shift-Down Arrow", followed by "Shift-F8".**
72. **Go to N3. Do "Ctrl-Shift-Down Arrow", followed by "Shift-F8".**
73. **Go to S3. Do "Ctrl-Shift-Down Arrow", followed by "Shift-F8".**
74. **Go to X3. Do "Ctrl-Shift-Down Arrow".**
75. **Copy to Clipboard.**
76. **Go to the "Tun1" sheet. Go to cell X67. Paste the content of the clipboard using "Paste Special [Value]".**

Once you have completed this process, "bubble" plots, which are a convenient way to identify year-effects or age-effects, will be generated automatically. Go to the "Res-G" Sheet. Re-scale the graphs so that the bubbles are spread over the entire area of the graph (Fig. 3).

Copy the residuals of the other indices in a similar way and adjust the scale of the corresponding graphs accordingly. Prior to copying the information for the otter indices, make sure to delete previous entries in the "WS-Res" sheet. Note that all graphs use the same maximum size for the bubbles, as determined from the maximum observed in all variables. This allows you to make comparisons between graphs.

In the catchability model selected ("proportional"), the catchability coefficients at age are assumed to be constant over time. When this assumption is violated for a given index, the residuals aggregated for all ages in any given year will usually show trends or patterns over time. These (i.e. the residuals aggregated for all ages in any given year) are presented in the "Res-G" sheet (see Fig. 4).

> In the Blackfin example, the Prawn trawl index shows runs in residuals (consecutive years with predominantly positive or negative values) indicating a lack of fit. A similar effect is apparent for the seine index, to a lesser degree. Also noticeable is a "year" effect in 1990 for the Otter trawl index, as indicated by large positive residuals for most ages in that year.

Also, look at the time trend in the residuals aggregated by year for the prawn trawl index. This, together with the corresponding bubble plot, indicates a significant trend in the catchability of this index. This suggests that using a power model or a trend model for the catchability of some fleets may be more appropriate.

In our initial inspection of the data, we had already noted the value of the otter trawl index for 1990 was anomalous. Many of these anomalies are more obvious here and someone would take the observations made using the diagnostics to make adjustments to the ADAPT formulation (e.g. drop an index series, drop age groups that have little information content and are poorly estimated, change the catchability model for some indices, etc.).

Correlation matrix of parameter estimates

77. **In ADAPT:**
78. **Select "Output".**
79. **Select "To Session log".**
80. **Select "Correlation (parameter)".**
81. **The correlation of parameter estimates appears in the session-log.**

The absolute values that are off the diagonal in the correlation matrix should be lower than 0.3, indicating a relative independence of parameter estimates. Absolute values higher than 0.7 indicate a serious over-specification (too many parameters in relation to the information contained in the data) and the number of parameter should be reduced. Values between 0.3 and 0.7 are in a "gray" zone and, if they are too numerous, the "absolute value" of population estimates should be interpreted with caution. In particular, if carried forward into stochastic projections, the correlation between parameter estimates should be taken into account.

In the Blackfin Example, as most values are below 0.15, the formulation used did not result in over-specifying number of parameters to be estimated.

Abundance and fishing mortality estimates

If you are satisfied with these results, you should copy the population estimates and fishing mortality estimates obtained with ADAPT to the spreadsheet:

82. **In ADAPT:**
83. **Select "Output".**
84. **Select "To Clipboard".**
85. **Select "Population numbers".**
86. **Select "Adjusted for bias (Anal.)" .**
87. **The estimates of population numbers, adjusted for bias, are copied to the clipboard.**
88. **In Excel:**
89. **Go to the "N" sheet.**
90. **Paste the content of the clipboard to cell A9.**

To complete the data transfer, also copy the bias-adjusted estimates of fishing mortality to the "F" sheet of the template.

When the data transfer has been completed, the biomass and stock spawning biomass are calculated. The time trajectory of these entities are given in the "Out-G" Sheet (Fig. 5). Inspect these for consistency with other sources of information you may have.

In the Blackfin Example, the trends in population numbers are inconsistent with some indices. In essence, the aggregated results confirm the observations made in the inspection of residuals. Typically, someone would evaluate the "value" of each index as a possible indicator of stock abundance and decide which indices are to be kept in a subsequent ADAPT-formulation. Some indices may be affected by changes in survey gear, changes in commercial practices, etc. These aspects are key considerations in evaluating the potential of an index as an indicator of stock abundance.

Printing the Session-log

At this point, you should save your work for future reference.

91. **In ADAPT:**
92. **Select "File".**
93. **Select "Save".**
94. **You will be asked to provide a name for your file. When finished, select OK.**
95. **The ADAPT work file has been saved. The work file contains all data and results to date. You can open this file later and start working where you left off. To assist in managing your files, it is advisable to adopt a convention for the ADAPT work file extension that includes the version number, e.g. fileX.aw2.**

You can also copy the Session-log via the Clipboard directly into a word processor. This is a convenient way to prepare technical annexes of your ADAPT analyses for your assessment documents. However, there are a few steps to take to ensure that the file will print properly.

96. **In ADAPT:**
97. **Select "Output".**
98. **Select "To Clipboard".**
99. **Select "Session log".**
100. **The Session log will be copied to the clipboard. Go to your word processor and paste the content of the clipboard in the first row of a new document.**

The Session log reads better with a fixed-pitch font and, accordingly, you should change the font of your work processor to a fixed pitch font such as Courier. To do so, select the entire document and change the font to "Courier".

The Session log could still include some non-ASCII characters. In particular, the "high minus" appears as "*y*" in this file. To change this character to a "minus" sign or "–", do a global replace for that character. The easiest way to generate that character is to locate its first occurrence in the file, copy it to the clipboard and paste it in the "Replace [Find what]?" field. The Session log for this tutorial appears in Annex 2.

Sensitivity to assumptions

When using ADAPT, or any other VPA-calibration technique, it is important to verify the sensitivity of the results to various assumptions.

Blackfin Example:

The next steps in the formulation of this estimation problem would be to:

1. Try estimating the oldest age-groups. The Session log for this formulation appears in Annex 3. The correlation matrix of parameter estimates gives very high values for all entries in the matrix, indicating that the estimation problem is over-specified. Also, the relative errors of parameter estimates are much higher than the preceding formulation.
2. Formulate a model that accounts for the trend in catchability for the "Spawn trawl" index.
3. Verify the sensitivity to the assumptions used for defining the fishing mortality for the last age. Is the time trajectory for the stock sensitive to the way the fishing mortality for the oldest age is determined?
4. Determine what influence data points associated with year effects in residuals have on the population estimates.
5. Carry out a retrospective analysis to evaluate if the assessment procedure has a tendency to over- or under-estimate population abundance. Retrospective analyses are typically done by repeating the estimation with the same formulation but by dropping the most recent years from the time series; the results are then compared to the results obtained for the corresponding years with the full series. A retrospective pattern emerges when the processes governing the data are widely different than those assumed in the model (e.g. immigration/emigration, changes in catch reporting practices, changing in discarding practices, changes in natural mortality, etc.).

This completes the tutorial for estimation of population abundance with ADAPT. The ADAPT software also provides ways to carry out projections and risk analyses from the results. These functions are explored in a separate tutorial (Rivard and Gavaris, 2000).

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Annex 1 – Algorithms used in ADAPT

Population Dynamics Model

Consider an age-structured model. Mortality is partitioned into two components, fishing mortality, F, associated with the fishery harvest and natural mortality, M, associated with all other causes of death. Denoting population abundance in numbers by N and time by t, the mortality dynamics are described by the system of differential equations

$$\frac{dN}{dt} = -(F + M)N$$

$$\frac{dC}{dt} = FN$$

Solving the differential equations using year as the unit of time yields the familiar exponential decay and catch equation used for Virtual Population Analysis (VPA).

$$N_{a+\Delta t,t+\Delta t} = N_{a,t}e^{-(F_{a,t}+M_{a,t})\Delta t}$$

$$C_{a,t} = \frac{F_{a,t}\Delta t N_{a,t}\left(1 - e^{-(F_{a,t}+M_{a,t})\Delta t}\right)}{\left(F_{a,t} + M_{a,t}\right)\Delta t}$$

With year as the unit of time, ages are expressed in years and mortality rates are annual instantaneous rates. The catch, designated $C_{a,t}$, represents the number caught during the time interval Δt but are indexed by the age and time at the beginning of the interval.

It is not possible to estimate a complete array of age and time varying natural mortality. Often a single common value, or at most, a few values common over large blocks, is prescribed. Although it is desirable to estimate natural mortality, the data may not support any estimation at all. In many applications natural mortality is assumed known.

Though estimation of a complete array of age and time varying fishing mortality is technically possible, results tend to be unreliable and such practice is not common. One prevalent technique for reducing the number of parameters required to be estimated is to assume that the errors in the catch at age are negligible. This is the conventional "VPA" assumption, i.e. the catch equation may be applied deterministically. This form of population dynamics model only requires the estimation of one parameter for each year-class, typically the survivors at the oldest age or in the last time period.

Frequently, the stability of the solution and the reliability of the results may be enhanced by making the further assumption that the fishing mortality rate for the oldest age may be calculated from the fishing mortality rate for younger ages. The number of parameters required to be estimated are reduced further through such practice. This feature is implemented as follows (for simplicity, age group and time period subscripts are not shown and are the same for all quantities):

$$N_c = C(F_c + M)/F_c(1 - e^{-(F_c+M)\Delta t})$$

F_c is the calculated fishing mortality rate obtained from

$$F_c = \sum_i R_i F_i \Big/ n \qquad \text{for unweighted}$$

$$F_c = \sum_i N_i R_i F_i \Big/ \sum_i N_i \qquad \text{for population weighted}$$

R_i is the assumed ratio of the fishing mortality rate for the cohort being calculated relative to the fishing mortality rate for cohort i.

Some analyses involve a plus group. Two methods for handling a plus group have been implemented. Plus group ages are denoted by a'. Let A represent the oldest non-plus group age e.g. A is 9 then $(A+1)'$ is 10+ and A' is 9+. Also, let T represent the terminal time in the VPA.

For the FIRST method, all cohorts must be specified. In addition, the population abundance of the plus group in the first time of the VPA must be specified. Therefore we have $N_{A,1}$ and $N_{(A+1)',1}$. We can compute

$$N_{(A+1)',2} = N_{A,1} e^{-(F_{A,1}+M_{A,1})\Delta t_1} + N_{(A+1)',1} e^{-(F_{(A+1)',1}+M_{(A+1)',1})\Delta t_1}$$

and

$$N_{A,2} = N_{A-1,1} e^{-(F_{A-1,1}+M_{A-1,1})\Delta t_1}.$$

These calculations are repeated for all times moving forwards.

For the FRATIO method all the cohorts in the terminal time must be specified. In addition, the population abundance for the plus group in the terminal time must be specified. Solve for $F_{A',T-1}$ using $C_{A',T-1}$ and $N_{(A+1)',T}$ in the catch equation. Then

$$F_{A,T-1} = F_{A',T-1}\left(C_{(A+1)',T-1} + R_{t'} C_{A,T-1}\right) / R_{t'} C_{A',T-1}$$

where $R_{t'}$ is an F ratio which may be assigned or estimated. The ratio may be specified for each time period but typically a common ratio is specified for blocks of time periods. Now

$$N_{A,T-1} = C_{A,T-1}\left(F_{A,T-1} + M_{A,T-1}\right) / F_{A,T-1}\left(1 - e^{-(F_{A,T-1}+M_{A,T-1})\Delta t_t}\right)$$

Also $F_{(A+1)',T-1} = R_{t'} F_{A,T-1}$ therefore $N_{(A+1)',T-1}$ can be calculated in a similar manner. These calculations are repeated for all times moving backwards.

Catchability Model

It is well known that stock status is not reliably determined from information on catch at age alone. Most methods of fishery stock assessment also use information on relative abundance trends provided by indices. The model relationships that link the indices to the population must be defined. Indices of abundance may be compared to population numbers, population biomass or spawning biomass, either age by age or age aggregated. Typically, measures are taken to obtain indices that are proportional to the population.

$$I_{a',t} = q_{a'} P_{a',t}$$

where a' is a single age or an aggregate of ages, $I_{a',t}$ is the index for age(s) a' at time t and $P_{a',t}$ is the population (numbers, biomass or spawning biomass) for age(s) a' at time t. In addition to the more common proportional model, two other models are implemented, a power model

$$I_{a',t} = q_{a'} P^{\alpha}_{a',t}$$

and a time trend model

$$I_{a',t} = \left(q_{a'} \beta^{t-t_1}\right) P_{a',t}$$

Error Model

As noted earlier, the error in the catch at age is assumed to be negligible. The errors for the observed indices about the model fit are assumed to be independent and identically distributed on the logarithmic scale. It is not necessary to make any assumptions about the form of the parametric distribution.

Estimation

Model parameters are transformed to the logarithmic scale.

$v_{a',t'} = lnN_{a',t'}$ for survivors being estimated

$\kappa_{s,a'} = lnq_{s,a'}$ for each age specific or age aggregated index, s

$\mu_{a',t'} = lnM_{a',t'}$ for designated age/time blocks if M is estimated

$\rho_{t'} = lnR_{t'}$ for designated time blocks if F ratios on plus group is estimated

Solve for the parameters by minimizing the objective function

$$\Psi\left(\hat{\theta}\right) = \sum_{s,a,t}\left(\psi_{s,a,t}\left(\hat{\theta}\right)\right)^2 = \sum_{s,a,t}\left(lnI_{s,a,t} - \left(\hat{\kappa}_{s,a} + lnN_{a,t}\right)\right)^2$$

where θ represents the parameter vector of all estimated parameters. The objective function requires the calculation of population numbers from a VPA. The VPA population numbers are functions the estimated parameters log survivors, log M and log F ratio, $N_{a,t}(\hat{v}, \hat{\mu}, \hat{\rho})$, but for convenience, it is abbreviated by $N_{a,t}$. At time t', the population abundance is obtained directly from the parameter estimates, $N_{a',t'} = e^{\hat{v}_{a',t'}}$. For all other times, the population abundance is computed using the virtual population analysis algorithm. This involves solving for F in the catch equation using an iterative Newton-Raphson algorithm and then using the derived F in the exponential decay equation to calculate $N_{a,t}$. A Levenberg-Marquardt nonlinear minimization is used to obtain the least squares estimates of parameters.

Statistics for model parameters and for interest parameters, e.g. fully recruited exploitation rate or spawning stock biomass, derived from the model parameters may be obtained from analytical approximations or from bootstrap.

Analytical

The covariance matrix of the model parameters, θ, is estimated using the common linear approximation (Kennedy and Gentle, 1980, p. 476)

$$\mathrm{cov}\left(\hat{\theta}\right) = \hat{\sigma}^2\left[J^T\left(\hat{\theta}\right)J\left(\hat{\theta}\right)\right]^{-1}$$

where $\hat{\sigma}^2$ is the mean square residual and $J\left(\hat{\theta}\right)$ is the Jacobian matrix of the vector of residuals. The variance of an interest parameter, $\hat{\eta} = g\left(\hat{\theta}\right)$ where g is the transformation function, is estimated using the Delta approximation (Ratkowsky 1983).

$$Var(\hat{\eta}) = tr\left[GG^T \operatorname{cov}(\hat{\theta})\right]$$

where G is the vector of first derivatives of g with respect to parameters.

Due to non-linearity, estimation bias is expected. The bias of the model parameters is estimated using Box's (1971) approximation, which assumes that the errors are normally distributed:

$$Bias(\hat{\theta}) = \frac{-\hat{\sigma}^2}{2}\left(\sum_{i'} J_{i'}(\hat{\theta})J_{i'}^T(\hat{\theta})\right)^{-1}\left(\sum_{i} J_i(\hat{\theta})\right) tr\left[\left(\sum_{i'} J_{i'}(\hat{\theta})J_{i'}^T(\hat{\theta})\right)^{-1} H_i(\hat{\theta})\right]$$

where $J_i(\hat{\theta}) = J_{i'}(\hat{\theta})$ are vectors of the first derivatives for each residual and $H_i(\hat{\theta})$ are the Hessian matrices of second derivatives for each residual. The bias of interest parameters is then derived using the method described in Ratkowsky (1983).

$$Bias(\hat{\eta}) = G^T Bias(\hat{\theta}) + tr\left[W \operatorname{cov}(\hat{\theta})\right]/2$$

where W is the matrix of second derivatives of g with respect to parameters.

Bootstrap

Statistical properties of model parameters or derived interest parameters can be obtained from a bootstrap simulation Efron (1979). Again letting η represent any interest parameter, (with estimate $\hat{\eta}$ corresponding to the least-squares solution), its statistical properties are derived from the bootstrap replicate estimates $\hat{\eta}^b$. The replicates are computed by applying the estimation formulae to bootstrap samples. Non-parametric bootstrap replications are obtained when bootstrap samples are generated by random sampling with replacement from the observed data. Here, model-conditioned bootstrap replications are obtained from bootstrap samples generated by sampling with replacement from all the observed abundance index residuals (non-parametric) and adding these to the model predicted values for the abundance indices. The bootstrap estimates of variance and bias are:

$$Var(\hat{\eta}) = \sum_{b=1}^{B} \left(\hat{\eta}^b - \overline{\eta}\right)^2 \Big/ B - 1$$

$$Bias(\hat{\eta}) = \overline{\eta} - \hat{\eta}$$

where

$$\overline{\eta} = \sum_{b=1}^{B} \hat{\eta}^b \Big/ B .$$

Annex 2. ADAPT Session Log

ANNEX 2. - ADAPT Session Log

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SATURDAY, JULY 29, 2000  9:55:59.900 AM
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APL  Ver. 2.0.00
ADAPT_W  Ver. 2.1
Workspace size = 6000000
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Cn

	1	2	3	4	5	6	7	8	9	10
1963.00	0	155	1483	688	327	215	73	149	50	49
1964.00	0	117	2136	2340	700	339	159	42	49	93
1965.00	0	231	3327	3060	1757	512	271	92	69	137
1966.00	0	68	2838	4909	1220	693	135	39	27	48
1967.00	0	385	2053	2885	1934	268	454	91	44	75
1968.00	2	49	2435	2287	1197	621	148	126	29	58
1969.00	0	335	1983	4618	1498	507	568	106	79	71
1970.00	0	33	2857	2335	1805	599	240	196	41	122
1971.00	0	382	1385	4444	1891	1085	465	362	300	238
1972.00	57	3973	8419	3894	2256	456	333	160	92	162
1973.00	350	7753	7665	5251	1946	883	468	336	199	472
1974.00	897	3374	6062	2417	2158	617	949	925	502	869
1975.00	25	2592	6672	2546	1328	873	1013	711	198	343
1976.00	36	2826	8274	2782	1806	1122	662	518	586	1365
1977.00	160	1257	4680	2734	1687	743	562	386	290	922
1978.00	38	4452	4278	2362	1306	701	293	244	163	1326
1979.00	10	1000	1836	1205	1181	724	372	157	191	757
1980.00	46	1023	3351	954	685	638	471	194	91	817
1981.00	154	2490	3932	1981	588	410	341	223	154	673
1982.00	43	1403	4633	1687	1250	574	388	247	136	461
1983.00	35	3519	4761	2574	834	764	509	158	105	506
1984.00	157	3026	5590	2407	880	685	302	140	57	160
1985.00	6	2288	5122	3051	1459	1230	610	187	105	225
1986.00	232	773	7101	8441	3787	1399	1056	470	186	347
1987.00	1	1698	2194	6967	1928	1359	779	454	261	210
1988.00	21	3591	5702	3518	2627	1051	892	698	330	329
1989.00	22	759	7291	5703	2255	1400	376	258	157	184
1990.00	58	1485	5595	3729	1194	786	525	245	132	157
1991.00	153	1243	3594	2946	1175	607	424	235	96	223
1992.00	28	861	1773	3093	968	354	107	61	54	93
1993.00	15	2511	2668	2827	1185	270	112	56	43	83
1994.00	3	2408	2029	1080	492	280	109	65	50	110
1995.00										

Otter trawl

	2	3	4	5	6
1975.50	132.69	70.39	14.56	11.60	12.41
1976.50	88.95	168.20	25.83	5.87	7.63
1977.50	36.01	36.30	19.17	4.94	2.90
1978.50	55.08	39.29	10.66	7.90	6.52
1979.50	70.07	52.70	13.47	10.78	18.27
1980.50	33.51	58.90	7.11	3.55	4.57
1981.50	86.12	126.47	15.52	0.00	1.55
1982.50	164.86	81.02	78.20	2.11	0.70
1983.50	337.87	55.52	10.84	9.98	1.73
1984.50	232.29	125.12	4.98	5.98	15.45
1985.50	253.26	28.37	4.20	1.05	3.15
1986.50	202.26	150.21	13.38	4.46	4.46
1987.50	25.89	19.80	35.02	3.81	6.09
1988.50	95.54	141.34	39.26	28.79	5.23
1989.50	16.93	213.98	47.38	14.30	16.34
1990.50	11.65	287.13	244.91	115.78	64.29
1991.50	139.62	158.19	57.36	31.66	10.25
1992.50	39.05	82.23	30.41	11.66	6.20
1993.50	61.01	61.13	6.45	3.31	2.32
1994.50	31.89	76.09	27.87	17.16	7.71

Seine

	2	3	4	5
1975.50	6.20	31.90	15.07	2.13
1976.50	2.71	12.01	9.68	1.94
1977.50	1.60	11.76	1.60	1.07
1978.50	15.22	8.39	1.24	0.93
1979.50	0.75	0.50	1.01	3.02
1980.50	3.83	1.49	0.85	0.43
1981.50	8.21	5.16	1.88	0.23
1982.50	14.99	18.53	1.09	0.82
1983.50	16.02	5.25	3.15	2.89
1984.50	60.89	10.15	0.34	1.01
1985.50	5.31	14.79	9.48	0.76
1986.50	7.01	28.56	27.56	12.53
1987.50	47.64	4.57	3.05	0.38
1988.50	14.50	13.56	4.68	4.21
1989.50	5.13	15.78	5.30	0.63
1990.50	6.30	13.68	4.82	1.50
1991.50	39.63	35.11	8.24	1.82
1992.50	74.88	34.46	44.54	7.15
1993.50	147.70	44.69	8.35	3.45
1994.50	111.82	89.67	34.04	11.29

Light trawl

	2	3	4	5	6	7
1975.50	31.51	86.21	28.11	5.36	5.36	0.60
1976.50	31.52	68.64	39.30	7.24	3.04	1.40
1977.50	22.65	66.61	29.83	10.07	4.51	2.15
1978.50	181.68	78.48	9.58	4.75	0.91	0.82
1979.50	13.52	4.40	6.70	24.62	12.42	3.08
1980.50	20.67	19.71	15.00	9.16	7.93	3.14
1981.50	51.82	53.99	12.62	1.75	0.36	0.42
1982.50	22.92	49.75	13.38	3.99	2.66	1.63
1983.50	41.84	16.29	8.99	1.87	2.40	0.36
1984.50	22.54	74.73	3.10	2.87	1.74	0.91
1985.50	18.42	49.15	25.84	2.10	3.08	0.56
1986.50	4.58	44.18	26.16	10.19	1.58	1.26
1987.50	51.20	12.99	6.53	1.90	1.14	0.91
1988.50	25.73	17.64	4.74	5.75	0.63	0.25
1989.50	5.35	29.52	7.52	1.80	1.67	0.48
1990.50	16.45	32.19	17.61	2.84	1.12	1.25
1991.50	17.39	16.76	11.02	4.95	1.37	0.84
1992.50	11.49	12.26	8.97	1.75	0.72	0.37
1993.50	25.70	13.72	3.95	0.88	1.02	0.75
1994.50	11.68	18.65	7.42	3.35	2.23	0.61

Prawn trawl

	2	3	4
1975.50	23.64	91.85	17.24
1976.50	24.57	26.28	8.72
1977.50	2.35	51.37	10.51
1978.50	2.16	4.84	2.01
1979.50	4.92	0.74	1.23
1980.50	7.80	2.79	0.76
1981.50	15.71	3.08	0.85
1982.50	2.25	2.11	0.42
1983.50	11.86	1.70	0.68
1984.50	8.79	5.94	0.16
1985.50	4.97	5.39	0.83
1986.50	2.03	14.50	0.49
1987.50	3.87	1.04	0.28
1988.50	4.40	0.18	0.03
1989.50	0.36	2.55	0.18
1990.50	1.62	0.25	0.37
1991.50	0.67	0.25	0.12
1992.50	0.78	0.13	0.13
1993.50	0.51	0.11	0.09
1994.50	0.16	0.24	0.06

VPA setup

Plus Group : No plus group

Population

	1	2	3	4	5	6	7	8	9	10
1995.00	(15000)	(15000)	25000	25000	20000	15000	10000	5000	5000	5000

F ratios

	1	2	3	4	5	6	7	8	9	10
1963.00				1.00	1.00	1.00				(1.00)
1964.00				1.00	1.00	1.00				(1.00)
1965.00				1.00	1.00	1.00				(1.00)
1966.00				1.00	1.00	1.00				(1.00)
1967.00				1.00	1.00	1.00				(1.00)
1968.00				1.00	1.00	1.00				(1.00)
1969.00				1.00	1.00	1.00				(1.00)
1970.00				1.00	1.00	1.00				(1.00)
1971.00				1.00	1.00	1.00				(1.00)
1972.00				1.00	1.00	1.00				(1.00)
1973.00				1.00	1.00	1.00				(1.00)
1974.00				1.00	1.00	1.00				(1.00)
1975.00				1.00	1.00	1.00				(1.00)
1976.00				1.00	1.00	1.00				(1.00)
1977.00				1.00	1.00	1.00				(1.00)
1978.00				1.00	1.00	1.00				(1.00)
1979.00				1.00	1.00	1.00				(1.00)
1980.00				1.00	1.00	1.00				(1.00)
1981.00				1.00	1.00	1.00				(1.00)
1982.00				1.00	1.00	1.00				(1.00)
1983.00				1.00	1.00	1.00				(1.00)
1984.00				1.00	1.00	1.00				(1.00)
1985.00				1.00	1.00	1.00				(1.00)
1986.00				1.00	1.00	1.00				(1.00)
1987.00				1.00	1.00	1.00				(1.00)
1988.00				1.00	1.00	1.00				(1.00)
1989.00				1.00	1.00	1.00				(1.00)
1990.00				1.00	1.00	1.00				(1.00)
1991.00				1.00	1.00	1.00				(1.00)
1992.00				1.00	1.00	1.00				(1.00)
1993.00				1.00	1.00	1.00				(1.00)
1994.00				1.00	1.00	1.00				(1.00)

Natural Mortality

	1	2	3	4	5	6	7	8	9	10
1963.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)

1964.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1965.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1966.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1967.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1968.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1969.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1970.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1971.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1972.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1973.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1974.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1975.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1976.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1977.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1978.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1979.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1980.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1981.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1982.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1983.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1984.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1985.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1986.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1987.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1988.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1989.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1990.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1991.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1992.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1993.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1994.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)

Virtual Population Analysis using initial values

Population Numbers

	1	2	3	4	5	6	7	8	9	10
1963.00	42717	26978	19837	5948	3948	2244	809	1356	833	499
1964.00	50006	34974	21948	14904	4250	2937	1644	596	976	637
1965.00	93765	40942	28528	16044	10095	2849	2099	1202	450	755
1966.00	55080	76768	33312	20358	10382	6683	1872	1474	901	306
1967.00	96039	45096	62791	24714	12256	7401	4847	1411	1172	714
1968.00	78709	78630	36573	49555	17634	8293	5817	3559	1073	920
1969.00	82593	64440	64333	27747	38508	13357	6230	4629	2800	852
1970.00	72744	67621	52456	50881	18560	30176	10478	4588	3694	2221
1971.00	73816	59558	55334	40369	39550	13568	24165	8362	3580	2988

1972.00	64021	60435	48417	44053	29046	30674	10130	19365	6520	2660
1973.00	47749	52364	45896	32062	32556	21746	24702	7993	15710	5255
1974.00	50400	38778	35889	30676	21523	24899	17007	19802	6241	12683
1975.00	31653	40454	28706	23926	22935	15676	19828	13068	15378	4657
1976.00	24718	25893	30782	17505	17294	17579	12046	15320	10057	12411
1977.00	23922	20205	18652	17771	11827	12531	13380	9265	12075	7706
1978.00	23908	19441	15409	11066	12088	8163	9589	10448	7237	9624
1979.00	29891	19539	11915	8774	6936	8719	6051	7586	8333	5778
1980.00	34821	24464	15095	8102	6098	4615	6486	4619	6069	6650
1981.00	37532	28468	19106	9346	5773	4375	3204	4885	3606	4887
1982.00	50960	30590	21062	12106	5870	4197	3213	2316	3798	2814
1983.00	46626	41684	23778	13078	8392	3682	2919	2281	1673	2987
1984.00	49621	38143	30954	15185	8392	6119	2327	1932	1725	1275
1985.00	43642	40484	28499	20312	10265	6077	4392	1633	1455	1361
1986.00	59223	35725	31081	18723	13882	7090	3869	3046	1169	1097
1987.00	53654	48278	28551	19063	7789	7965	4546	2220	2071	789
1988.00	39972	43927	37994	21397	9367	4645	5298	3021	1409	1460
1989.00	51076	32707	32726	25972	14351	5310	2858	3534	1846	857
1990.00	52307	41797	26093	20238	16136	9719	3090	2001	2661	1370
1991.00	52394	42773	32880	16332	13214	12134	7248	2057	1417	2060
1992.00	52300	42758	33897	23680	10720	9759	9386	5552	1473	1074
1993.00	40553	42794	34230	26153	16601	7904	7670	7588	4490	1157
1994.00	18324	33188	32771	25619	18864	12523	6227	6179	6162	3638
1995.00	15000	15000	25000	25000	20000	15000	10000	5000	5000	5000

Fishing Mortality

	1	2	3	4	5	6	7	8	9	10
1963.00	0.000	0.006	0.086	0.136	0.096	0.111	0.105	0.129	0.068	0.114
1964.00	0.000	0.004	0.113	0.190	0.200	0.136	0.113	0.081	0.057	0.175
1965.00	0.000	0.006	0.137	0.235	0.212	0.220	0.153	0.088	0.185	0.223
1966.00	0.000	0.001	0.099	0.307	0.139	0.121	0.083	0.030	0.034	0.189
1967.00	0.000	0.009	0.037	0.138	0.191	0.041	0.109	0.074	0.042	0.123
1968.00	0.000	0.001	0.076	0.052	0.078	0.086	0.028	0.040	0.030	0.072
1969.00	0.000	0.006	0.035	0.202	0.044	0.043	0.106	0.026	0.032	0.096
1970.00	0.000	0.001	0.062	0.052	0.113	0.022	0.026	0.048	0.012	0.062
1971.00	0.000	0.007	0.028	0.129	0.054	0.092	0.021	0.049	0.097	0.092
1972.00	0.001	0.075	0.212	0.102	0.089	0.017	0.037	0.009	0.016	0.069
1973.00	0.008	0.178	0.203	0.199	0.068	0.046	0.021	0.047	0.014	0.104
1974.00	0.020	0.101	0.205	0.091	0.117	0.028	0.063	0.053	0.093	0.079
1975.00	0.001	0.073	0.295	0.125	0.066	0.063	0.058	0.062	0.014	0.085
1976.00	0.002	0.128	0.349	0.192	0.122	0.073	0.062	0.038	0.066	0.129
1977.00	0.007	0.071	0.322	0.185	0.171	0.068	0.047	0.047	0.027	0.141
1978.00	0.002	0.290	0.363	0.267	0.127	0.099	0.034	0.026	0.025	0.164
1979.00	0.000	0.058	0.186	0.164	0.207	0.096	0.070	0.023	0.026	0.156
1980.00	0.001	0.047	0.279	0.139	0.132	0.165	0.083	0.047	0.017	0.145

1981.00	0.005	0.101	0.256	0.265	0.119	0.109	0.125	0.052	0.048	0.164
1982.00	0.001	0.052	0.277	0.166	0.266	0.163	0.143	0.125	0.040	0.199
1983.00	0.001	0.098	0.248	0.244	0.116	0.259	0.213	0.079	0.072	0.206
1984.00	0.003	0.091	0.221	0.192	0.123	0.132	0.154	0.083	0.037	0.149
1985.00	0.000	0.064	0.220	0.181	0.170	0.252	0.166	0.135	0.083	0.201
1986.00	0.004	0.024	0.289	0.677	0.356	0.244	0.356	0.186	0.192	0.426
1987.00	0.000	0.040	0.088	0.511	0.317	0.208	0.209	0.255	0.149	0.345
1988.00	0.001	0.094	0.180	0.199	0.368	0.286	0.205	0.293	0.297	0.284
1989.00	0.000	0.026	0.281	0.276	0.190	0.341	0.156	0.084	0.098	0.269
1990.00	0.001	0.040	0.269	0.226	0.085	0.093	0.207	0.145	0.056	0.135
1991.00	0.003	0.033	0.128	0.221	0.103	0.057	0.067	0.134	0.078	0.127
1992.00	0.001	0.022	0.059	0.155	0.105	0.041	0.013	0.012	0.041	0.100
1993.00	0.000	0.067	0.090	0.127	0.082	0.038	0.016	0.008	0.011	0.082
1994.00	0.000	0.083	0.071	0.048	0.029	0.025	0.019	0.012	0.009	0.034

```
Models selected
Otter trawl 2 Proportional
Otter trawl 3 Proportional
Otter trawl 4 Proportional
Otter trawl 5 Proportional
Otter trawl 6 Proportional
Seine       2 Proportional
Seine       3 Proportional
Seine       4 Proportional
Seine       5 Proportional
Light trawl 2 Proportional
Light trawl 3 Proportional
Light trawl 4 Proportional
Light trawl 5 Proportional
Light trawl 6 Proportional
Light trawl 7 Proportional
Prawn trawl 2 Proportional
Prawn trawl 3 Proportional
Prawn trawl 4 Proportional

LAMBDA       1.00000E-2
RSS          4.51364E2
NPHI         4.51364E2

Parameters
   1.01266E1     1.01266E1     9.90349E0     9.61581E0     9.21034E0     8.51719E0
   8.51719E0     8.51719E0

LAMBDA       1.00000E-3
RSS          4.15005E2
NPHI         4.15005E2
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Parameters
   9.21491E0      9.45684E0      8.66336E0      8.59416E0      8.10329E0      7.66734E0
   7.94553E0      7.44161E0

LAMBDA       1.00000E-4
RSS          4.14815E2
NPHI         4.14815E2

Parameters
   9.26865E0      9.51054E0      8.70897E0      8.58918E0      8.10566E0      7.73432E0
   8.09045E0      7.46342E0

LAMBDA       1.00000E-5
RSS          4.14814E2
NPHI         4.14814E2

Parameters
   9.26792E0      9.51026E0      8.70557E0      8.58697E0      8.10223E0      7.72350E0
   8.09144E0      7.45383E0

RELATIVE CHANGE IN RESIDUAL SUM OF SQUARES LESS THAN 0.00001

LAMBDA       1.00000E-2
RSS          4.14814E2
NPHI         4.14814E2

Parameters
   9.26792E0      9.51026E0      8.70557E0      8.58697E0      8.10223E0      7.72350E0
   8.09144E0      7.45383E0     -5.71299E0     -5.26109E0     -6.19060E0     -6.71967E0
  -6.68427E0     -7.49187E0     -7.17500E0     -7.73313E0     -8.30475E0     -6.90287E0
  -6.28343E0     -6.77241E0     -7.45870E0     -7.80999E0     -8.32394E0     -8.93198E0
  -8.99187E0     -9.85030E0

LAMBDA       1.00000E-3
RSS          4.14814E2
NPHI         4.14814E2

Parameters
   9.26804E0      9.51039E0      8.70603E0      8.58709E0      8.10261E0      7.72498E0
   8.09215E0      7.45432E0     -5.71310E0     -5.26121E0     -6.19076E0     -6.71986E0
  -6.68448E0     -7.49197E0     -7.17512E0     -7.73328E0     -8.30494E0     -6.90297E0
  -6.28355E0     -6.77257E0     -7.45889E0     -7.81020E0     -8.32417E0     -8.93208E0
  -8.99199E0     -9.85046E0

RELATIVE CHANGE IN RESIDUAL SUM OF SQUARES LESS THAN 0.00001
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Estimated VPA (biased)

Population Numbers

	1	2	3	4	5	6	7	8	9	10
1963.00	42088	26443	19502	5857	3864	2202	796	1331	818	490
1964.00	48688	34459	21510	14629	4175	2868	1609	586	956	625
1965.00	89916	39862	28107	15685	9871	2788	2043	1174	442	738
1966.00	53681	73617	32428	20014	10089	6500	1822	1428	878	300
1967.00	92450	43951	60211	23990	11974	7161	4697	1370	1134	695
1968.00	76315	75692	35636	47444	17042	8062	5621	3436	1039	889
1969.00	79452	62479	61927	26979	36779	12873	6041	4468	2700	825
1970.00	70426	65050	50851	48911	17932	28760	10082	4434	3563	2139
1971.00	70880	57660	53229	39055	37938	13054	23006	8037	3453	2880
1972.00	62159	58032	46863	42329	27970	29354	9709	18416	6254	2557
1973.00	46419	50840	43928	30791	31145	20865	23621	7649	14933	5037
1974.00	48780	37688	34642	29066	20482	23744	16286	18917	5959	12046
1975.00	30693	39128	27814	22906	21617	14824	18883	12478	14653	4426
1976.00	23610	25107	29696	16776	16459	16500	11349	14546	9574	11818
1977.00	23031	19298	18008	16884	11230	11848	12497	8695	11441	7310
1978.00	23117	18711	14666	10540	11362	7675	9030	9725	6770	9105
1979.00	27583	18893	11318	8167	6506	8125	5652	7128	7742	5396
1980.00	32850	22574	14566	7613	5602	4264	6000	4292	5694	6166
1981.00	34094	26854	17559	8913	5374	3969	2916	4487	3339	4580
1982.00	45814	27775	19741	10841	5516	3870	2880	2080	3473	2594
1983.00	43407	37471	21474	11998	7356	3392	2651	2008	1480	2720
1984.00	45578	35507	27505	13301	7508	5271	2090	1713	1502	1117
1985.00	29231	37174	26342	17491	8723	5354	3698	1440	1276	1178
1986.00	39349	23927	28371	16959	11574	5829	3278	2479	1010	950
1987.00	45051	32007	18892	16848	6357	6080	3515	1737	1607	660
1988.00	28838	36883	24673	13490	7563	3474	3756	2177	1014	1080
1989.00	28801	23591	26960	15075	7884	3837	1902	2274	1156	534
1990.00	26086	23560	18630	15525	7236	4431	1888	1219	1629	805
1991.00	21308	21305	17950	10232	9359	4849	2920	1074	777	1215
1992.00	31338	17307	16321	11463	5733	6604	3423	2009	668	550
1993.00	19056	25632	13393	11765	6607	3822	5087	2706	1590	498
1994.00	18324	15588	18722	8565	7091	4343	2886	4064	2165	1263
1995.00	15000	15000	10594	13499	6039	5362	3303	2264	3269	1727

Fishing Mortality

	1	2	3	4	5	6	7	8	9	10
1963.00	0.000	0.006	0.087	0.138	0.098	0.114	0.106	0.132	0.070	0.117
1964.00	0.000	0.004	0.116	0.193	0.204	0.139	0.115	0.082	0.058	0.179
1965.00	0.000	0.006	0.140	0.241	0.218	0.225	0.158	0.090	0.188	0.228
1966.00	0.000	0.001	0.101	0.314	0.143	0.125	0.085	0.031	0.034	0.194
1967.00	0.000	0.010	0.038	0.142	0.196	0.042	0.113	0.076	0.044	0.127

1968.00	0.000	0.001	0.078	0.055	0.081	0.089	0.029	0.041	0.031	0.075
1969.00	0.000	0.006	0.036	0.209	0.046	0.044	0.109	0.027	0.033	0.100
1970.00	0.000	0.001	0.064	0.054	0.117	0.023	0.027	0.050	0.013	0.065
1971.00	0.000	0.007	0.029	0.134	0.057	0.096	0.023	0.051	0.101	0.095
1972.00	0.001	0.078	0.220	0.107	0.093	0.017	0.039	0.010	0.016	0.072
1973.00	0.008	0.184	0.213	0.208	0.071	0.048	0.022	0.050	0.015	0.109
1974.00	0.020	0.104	0.214	0.096	0.123	0.029	0.066	0.055	0.097	0.083
1975.00	0.001	0.076	0.306	0.131	0.070	0.067	0.061	0.065	0.015	0.089
1976.00	0.002	0.132	0.365	0.201	0.129	0.078	0.066	0.040	0.070	0.136
1977.00	0.008	0.074	0.336	0.196	0.181	0.072	0.051	0.050	0.028	0.149
1978.00	0.002	0.303	0.385	0.282	0.135	0.106	0.036	0.028	0.027	0.175
1979.00	0.000	0.060	0.196	0.177	0.223	0.103	0.075	0.025	0.028	0.168
1980.00	0.002	0.051	0.291	0.148	0.145	0.180	0.090	0.051	0.018	0.158
1981.00	0.005	0.108	0.282	0.280	0.128	0.121	0.138	0.056	0.052	0.176
1982.00	0.001	0.057	0.298	0.188	0.286	0.178	0.160	0.140	0.044	0.217
1983.00	0.001	0.109	0.279	0.269	0.133	0.284	0.237	0.091	0.081	0.229
1984.00	0.004	0.099	0.253	0.222	0.138	0.154	0.173	0.094	0.043	0.171
1985.00	0.000	0.070	0.240	0.213	0.203	0.291	0.200	0.154	0.095	0.236
1986.00	0.007	0.036	0.321	0.781	0.444	0.306	0.435	0.234	0.226	0.510
1987.00	0.000	0.060	0.137	0.601	0.404	0.282	0.279	0.338	0.197	0.429
1988.00	0.001	0.113	0.293	0.337	0.478	0.403	0.302	0.433	0.441	0.406
1989.00	0.001	0.036	0.352	0.534	0.376	0.509	0.245	0.133	0.162	0.473
1990.00	0.002	0.072	0.399	0.306	0.200	0.217	0.364	0.250	0.094	0.241
1991.00	0.008	0.066	0.248	0.379	0.149	0.148	0.174	0.275	0.146	0.225
1992.00	0.001	0.056	0.127	0.351	0.205	0.061	0.035	0.034	0.093	0.206
1993.00	0.001	0.114	0.247	0.306	0.220	0.081	0.025	0.023	0.030	0.202
1994.00	0.000	0.186	0.127	0.149	0.080	0.074	0.043	0.018	0.026	0.101

APPROXIMATE STATISTICS ASSUMING LINEARITY NEAR SOLUTION

ORTHOGONALITY OFFSET......... 0.001027
MEAN SQUARE RESIDUALS 1.245688

Estimates for parameters

PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS
9.27E0	6.28E-1	0.068	-1.09E-2	-0.001
9.51E0	4.59E-1	0.048	-7.43E-3	-0.001
8.71E0	4.09E-1	0.047	-5.32E-3	-0.001
8.59E0	4.02E-1	0.047	-1.24E-2	-0.001
8.10E0	4.42E-1	0.055	-2.24E-2	-0.003
7.72E0	4.42E-1	0.057	-2.61E-2	-0.003
8.09E0	4.15E-1	0.051	-2.18E-2	-0.003
7.45E0	4.96E-1	0.067	-3.92E-2	-0.005
-5.71E0	2.55E-1	-0.045	-3.75E-3	0.001
-5.26E0	2.55E-1	-0.048	-2.37E-3	0.000
-6.19E0	2.56E-1	-0.041	1.85E-4	0.000
-6.72E0	2.66E-1	-0.040	4.10E-3	-0.001
-6.68E0	2.60E-1	-0.039	6.96E-3	-0.001
-7.49E0	2.55E-1	-0.034	-3.75E-3	0.001
-7.18E0	2.55E-1	-0.035	-2.37E-3	0.000
-7.73E0	2.56E-1	-0.033	1.85E-4	0.000
-8.30E0	2.59E-1	-0.031	3.95E-3	0.000
-6.90E0	2.55E-1	-0.037	-3.75E-3	0.001
-6.28E0	2.55E-1	-0.041	-2.37E-3	0.000
-6.77E0	2.56E-1	-0.038	1.85E-4	0.000
-7.46E0	2.59E-1	-0.035	3.95E-3	-0.001
-7.81E0	2.60E-1	-0.033	6.96E-3	-0.001
-8.32E0	2.60E-1	-0.031	8.64E-3	-0.001
-8.93E0	2.55E-1	-0.029	-3.75E-3	0.000
-8.99E0	2.55E-1	-0.028	-2.37E-3	0.000
-9.85E0	2.56E-1	-0.026	1.85E-4	0.000

[NOTE: The labels appearing below to identify the parameters were added with the word processor.]

Parameters in linear scale

	PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS
N(1995, 3)	1.06E4	6.65E3	0.628	1.97E3	0.186
N(1995, 4)	1.35E4	6.19E3	0.459	1.32E3	0.098
N(1995, 5)	6.04E3	2.47E3	0.409	4.72E2	0.078
N(1995, 6)	5.36E3	2.16E3	0.402	3.67E2	0.068
N(1995, 7)	3.30E3	1.46E3	0.442	2.49E2	0.075
N(1995, 8)	2.26E3	1.00E3	0.442	1.62E2	0.072
N(1995, 9)	3.27E3	1.36E3	0.415	2.10E2	0.064
N(1995,10)	1.73E3	8.57E2	0.496	1.45E2	0.084
Otter trawl 2	3.30E-3	8.43E-4	0.255	9.52E-5	0.029
Otter trawl 3	5.19E-3	1.32E-3	0.255	1.56E-4	0.030
Otter trawl 4	2.05E-3	5.25E-4	0.256	6.77E-5	0.033
Otter trawl 5	1.21E-3	3.21E-4	0.266	4.76E-5	0.039
Otter trawl 6	1.25E-3	3.25E-4	0.260	5.10E-5	0.041
Seine 2	5.58E-4	1.42E-4	0.255	1.61E-5	0.029
Seine 3	7.65E-4	1.95E-4	0.255	2.30E-5	0.030
Seine 4	4.38E-4	1.12E-4	0.256	1.45E-5	0.033
Seine 5	2.47E-4	6.40E-5	0.259	9.26E-6	0.037
Light trawl 2	1.00E-3	2.57E-4	0.255	2.90E-5	0.029
Light trawl 3	1.87E-3	4.75E-4	0.255	5.61E-5	0.030
Light trawl 4	1.14E-3	2.94E-4	0.256	3.79E-5	0.033
Light trawl 5	5.76E-4	1.49E-4	0.259	2.16E-5	0.037
Light trawl 6	4.06E-4	1.06E-4	0.260	1.66E-5	0.041
Light trawl 7	2.43E-4	6.31E-5	0.260	1.03E-5	0.042
Prawn trawl 2	1.32E-4	3.37E-5	0.255	3.81E-6	0.029
Prawn trawl 3	1.24E-4	3.17E-5	0.255	3.74E-6	0.030
Prawn trawl 4	5.27E-5	1.35E-5	0.256	1.74E-6	0.033

VPA using analytical bias adjusted parameters (linear scale)

Population Numbers

	1	2	3	4	5	6	7	8	9	10
1963.00	42057	26415	19484	5852	3859	2200	796	1330	817	489
1964.00	48620	34433	21487	14615	4171	2865	1607	585	954	624
1965.00	89711	39807	28086	15666	9858	2785	2040	1172	441	737
1966.00	53604	73449	32382	19996	10073	6490	1819	1426	877	299
1967.00	92257	43888	60074	23953	11960	7148	4689	1368	1132	694
1968.00	76195	75534	35584	47331	17011	8051	5610	3430	1038	887
1969.00	79295	62381	61798	26937	36687	12848	6031	4460	2694	823
1970.00	70305	64921	50771	48805	17897	28685	10061	4426	3556	2134
1971.00	70718	57561	53123	38990	37851	13026	22944	8021	3447	2874
1972.00	62055	57899	46782	42243	27917	29283	9686	18365	6240	2551
1973.00	46351	50755	43819	30724	31074	20821	23563	7630	14892	5026
1974.00	48704	37633	34572	28977	20428	23686	16250	18869	5943	12013
1975.00	30643	39066	27769	22849	21544	14780	18835	12448	14614	4413
1976.00	23547	25066	29646	16739	16412	16441	11313	14507	9550	11786
1977.00	22978	19246	17975	16843	11200	11809	12448	8665	11410	7290
1978.00	23076	18668	14624	10513	11328	7650	8998	9685	6746	9080
1979.00	27484	18858	11283	8133	6484	8098	5631	7103	7709	5376
1980.00	32766	22493	14538	7584	5573	4245	5977	4275	5673	6139
1981.00	33880	26785	17492	8890	5350	3946	2901	4469	3325	4563
1982.00	45472	27599	19685	10786	5497	3850	2861	2068	3457	2583
1983.00	43249	37190	21330	11952	7312	3377	2635	1993	1471	2708
1984.00	45414	35378	27276	13183	7471	5235	2078	1700	1489	1109
1985.00	28713	37040	26236	17303	8627	5323	3669	1429	1265	1168
1986.00	38465	23503	28262	16872	11420	5750	3253	2455	1002	941
1987.00	44006	31283	18545	16758	6286	5955	3450	1716	1587	653
1988.00	28176	36028	24080	13206	7490	3417	3654	2124	997	1064
1989.00	27972	23049	26260	14590	7652	3778	1855	2190	1113	521
1990.00	25086	22881	18186	14953	6841	4241	1839	1180	1560	770
1991.00	20256	20487	17394	9870	8892	4526	2755	1035	746	1158
1992.00	28934	16446	15651	11008	5437	6221	3159	1882	636	524
1993.00	16115	23664	12688	11216	6236	3580	4774	2490	1486	472
1994.00	18324	13181	17111	7988	6643	4039	2688	3808	1988	1178
1995.00	15000	15000	8624	12180	5567	4995	3054	2102	3059	1582

Fishing Mortality

	1	2	3	4	5	6	7	8	9	10
1963.00	0.000	0.006	0.088	0.139	0.098	0.114	0.107	0.132	0.070	0.117
1964.00	0.000	0.004	0.116	0.194	0.204	0.140	0.115	0.082	0.058	0.179
1965.00	0.000	0.006	0.140	0.242	0.218	0.226	0.158	0.090	0.189	0.228
1966.00	0.000	0.001	0.102	0.314	0.143	0.125	0.085	0.031	0.035	0.194
1967.00	0.000	0.010	0.038	0.142	0.196	0.042	0.113	0.076	0.044	0.127
1968.00	0.000	0.001	0.078	0.055	0.081	0.089	0.030	0.041	0.031	0.075

1969.00	0.000	0.006	0.036	0.209	0.046	0.044	0.109	0.027	0.033	0.100
1970.00	0.000	0.001	0.064	0.054	0.118	0.023	0.027	0.050	0.013	0.065
1971.00	0.000	0.007	0.029	0.134	0.057	0.096	0.023	0.051	0.101	0.096
1972.00	0.001	0.079	0.220	0.107	0.093	0.017	0.039	0.010	0.016	0.073
1973.00	0.008	0.184	0.214	0.208	0.072	0.048	0.022	0.050	0.015	0.109
1974.00	0.021	0.104	0.214	0.096	0.124	0.029	0.067	0.056	0.098	0.083
1975.00	0.001	0.076	0.306	0.131	0.070	0.067	0.061	0.065	0.015	0.090
1976.00	0.002	0.133	0.365	0.202	0.129	0.078	0.067	0.040	0.070	0.136
1977.00	0.008	0.075	0.336	0.197	0.181	0.072	0.051	0.050	0.028	0.150
1978.00	0.002	0.304	0.387	0.283	0.136	0.106	0.037	0.028	0.027	0.175
1979.00	0.000	0.060	0.197	0.178	0.223	0.104	0.076	0.025	0.028	0.168
1980.00	0.002	0.051	0.292	0.149	0.145	0.181	0.091	0.051	0.018	0.158
1981.00	0.005	0.108	0.283	0.281	0.129	0.122	0.139	0.057	0.052	0.177
1982.00	0.001	0.058	0.299	0.189	0.287	0.179	0.162	0.141	0.044	0.218
1983.00	0.001	0.110	0.281	0.270	0.134	0.286	0.239	0.091	0.082	0.230
1984.00	0.004	0.099	0.255	0.224	0.139	0.155	0.174	0.095	0.043	0.173
1985.00	0.000	0.071	0.241	0.215	0.206	0.293	0.202	0.155	0.096	0.238
1986.00	0.007	0.037	0.323	0.787	0.451	0.311	0.439	0.236	0.228	0.516
1987.00	0.000	0.062	0.140	0.605	0.410	0.288	0.285	0.343	0.200	0.434
1988.00	0.001	0.116	0.301	0.346	0.484	0.411	0.312	0.446	0.450	0.414
1989.00	0.001	0.037	0.363	0.557	0.390	0.520	0.252	0.139	0.169	0.489
1990.00	0.003	0.074	0.411	0.320	0.213	0.228	0.375	0.259	0.098	0.254
1991.00	0.008	0.069	0.257	0.396	0.157	0.160	0.185	0.287	0.153	0.238
1992.00	0.001	0.059	0.133	0.368	0.218	0.065	0.038	0.036	0.098	0.217
1993.00	0.001	0.124	0.263	0.324	0.234	0.087	0.026	0.025	0.032	0.215
1994.00	0.000	0.224	0.140	0.161	0.085	0.079	0.046	0.019	0.028	0.109

[Residuals]

Otter trawl
Age : 2
Ln calibration constant : -5.71310

Year	Observed	Predicted	Residual	Ln Pop.
1975.50	4.88802	4.72359	0.16443	10.43668
1976.50	4.48807	4.25164	0.23643	9.96474
1977.50	3.58380	4.01740	-0.43360	9.73050
1978.50	4.00879	3.87242	0.13637	9.58552
1979.50	4.24949	4.00337	0.24612	9.71647
1980.50	3.51184	4.18583	-0.67399	9.89893
1981.50	4.45574	4.33121	0.12454	10.04430
1982.50	5.10510	4.39015	0.71495	10.10324
1983.50	5.82266	4.66362	1.15904	10.37672
1984.50	5.44799	4.61511	0.83287	10.32821
1985.50	5.53442	4.67516	0.85926	10.38826
1986.50	5.30955	4.25151	1.05804	9.96461
1987.50	3.25386	4.53044	-1.27659	10.24354
1988.50	4.55955	4.64571	-0.08617	10.35881
1989.50	2.82909	4.23748	-1.40839	9.95058
1990.50	2.45531	4.21823	-1.76292	9.93132
1991.50	4.93892	4.12036	0.81856	9.83346
1992.50	3.66484	3.91758	-0.25274	9.63068
1993.50	4.11104	4.28143	-0.17039	9.99453
1994.50	3.46229	3.74805	-0.28576	9.46115

Average squared residual : 0.63995

Otter trawl
Age : 3
Ln calibration constant : -5.26121

Year	Observed	Predicted	Residual	Ln Pop.
1975.50	4.25405	4.71928	-0.46523	9.98049
1976.50	5.12515	4.75525	0.36990	10.01646
1977.50	3.59182	4.26955	-0.67773	9.53076
1978.50	3.67097	4.03937	-0.36840	9.30057
1979.50	3.96462	3.87470	0.08992	9.13590
1980.50	4.07584	4.07962	-0.00378	9.34083
1981.50	4.84001	4.27097	0.56903	9.53218
1982.50	4.39470	4.38026	0.01444	9.64147
1983.50	4.01674	4.47387	-0.45713	9.73508
1984.50	4.82927	4.73458	0.09470	9.99578

...... {there is one table for each index-age combination }

```
[ Correlation matrix for paramterer estimates - As this matrix is symmetric around its diagnonal, only the bottom p
art is shown to improve readability ]

 1.00
 0.04  1.00
 0.04  0.06  1.00
 0.04  0.06  0.05  1.00
 0.04  0.05  0.06  0.09  1.00
 0.03  0.05  0.10  0.11  0.13  1.00
 0.03  0.05  0.09  0.11  0.13  0.12  1.00
 0.03  0.05  0.09  0.11  0.14  0.12  0.12  1.00
-0.13 -0.09 -0.09 -0.08 -0.08 -0.07 -0.07 -0.07  1.00
-0.02 -0.10 -0.10 -0.09 -0.09 -0.09 -0.09 -0.08  0.04  1.00
-0.02 -0.02 -0.12 -0.11 -0.12 -0.12 -0.11 -0.11  0.04  0.04  1.00
-0.02 -0.03 -0.06 -0.14 -0.15 -0.15 -0.14 -0.14  0.04  0.05  0.06  1.00
-0.02 -0.03 -0.07 -0.08 -0.18 -0.17 -0.15 -0.16  0.04  0.05  0.06  0.07  1.00
-0.13 -0.09 -0.09 -0.08 -0.08 -0.07 -0.07 -0.07  0.04  0.04  0.04  0.04  0.04  1.00
-0.02 -0.10 -0.10 -0.09 -0.09 -0.09 -0.09 -0.08  0.04  0.04  0.04  0.05  0.05  0.04  1.00
-0.02 -0.02 -0.12 -0.11 -0.12 -0.12 -0.11 -0.11  0.04  0.04  0.05  0.06  0.06  0.04  0.04  1.00
-0.02 -0.03 -0.06 -0.14 -0.15 -0.14 -0.14 -0.14  0.04  0.04  0.06  0.07  0.07  0.04  0.04  0.06  1.00
-0.13 -0.09 -0.09 -0.08 -0.08 -0.07 -0.07 -0.07  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.04  1.00
-0.02 -0.10 -0.10 -0.09 -0.09 -0.09 -0.09 -0.08  0.04  0.04  0.04  0.05  0.05  0.04  0.04  0.04  0.04  0.04  1.00
-0.02 -0.02 -0.12 -0.11 -0.12 -0.12 -0.11 -0.11  0.04  0.04  0.05  0.06  0.06  0.04  0.04  0.05  0.06  0.04  0.04  1.00
-0.02 -0.03 -0.06 -0.14 -0.15 -0.14 -0.14 -0.14  0.04  0.04  0.06  0.07  0.07  0.04  0.04  0.06  0.07  0.04  0.04  0.06  1.00
-0.02 -0.03 -0.07 -0.08 -0.18 -0.17 -0.15 -0.16  0.04  0.05  0.06  0.07  0.08  0.04  0.05  0.06  0.07  0.04  0.05  0.06  0.07  1.
00
-0.02 -0.03 -0.08 -0.09 -0.12 -0.18 -0.16 -0.17  0.04  0.05  0.06  0.07  0.08  0.04  0.05  0.06  0.07  0.04  0.05  0.06  0.07  0.
08  1.00
-0.13 -0.09 -0.09 -0.08 -0.08 -0.07 -0.07 -0.07  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.
04  0.04
-0.02 -0.10 -0.10 -0.09 -0.09 -0.09 -0.09 -0.08  0.04  0.04  0.04  0.05  0.05  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.04  0.
05  0.05 -0.02 -0.02 -0.12 -0.11 -0.12 -0.12 -0.11 -0.11  0.04  0.04  0.05  0.06  0.06  0.04  0.04  0.05  0.06  0.04  0.04  0.05
 0.06  0.06  0.06

...                                                                                                         1.00
...                                                                                                         0.04  1.0
...
      0.04  .04  1.0
```

Annex 3. ADAPT Session Log for a Formulation Whereby all Cohorts are Estimated (Including Bottow Row)

MONDAY, JULY 31, 2000 11:27:24.980 AM
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APL Ver. 2.0.00
ADAPT_W Ver. 2.1
Workspace size = 6000000

[Data entry was the same as that for Annex 2 for Catch at age and the four indices of abundance, except for the Line trawl for which only the ages 2-6 were taken.]

VPA setup
Plus Group : No plus group

Population

	1	2	3	4	5	6	7	8	9	10
1979.00										5000
1980.00										5000
1981.00										5000
1982.00										5000
1983.00										5000
1984.00										5000
1985.00										5000
1986.00										5000
1987.00										5000
1988.00										5000
1989.00										5000
1990.00										5000
1991.00										5000
1992.00										5000
1993.00										5000
1994.00										5000
1995.00	(15000)	(15000)	(15000)	5000	5000	5000	5000	5000	5000	5000

F ratios

	1	2	3	4	5	6	7	8	9	10
1963.00				1.00	1.00	1.00				(1.00)
1964.00				1.00	1.00	1.00				(1.00)
1965.00				1.00	1.00	1.00				(1.00)
1966.00				1.00	1.00	1.00				(1.00)
1967.00				1.00	1.00	1.00				(1.00)
1968.00				1.00	1.00	1.00				(1.00)
1969.00				1.00	1.00	1.00				(1.00)

1970.00				1.00	1.00	1.00				(1.00)
1971.00				1.00	1.00	1.00				(1.00)
1972.00				1.00	1.00	1.00				(1.00)
1973.00				1.00	1.00	1.00				(1.00)
1974.00				1.00	1.00	1.00				(1.00)
1975.00				1.00	1.00	1.00				(1.00)
1976.00				1.00	1.00	1.00				(1.00)
1977.00				1.00	1.00	1.00				(1.00)
1978.00				1.00	1.00	1.00				(1.00)

Natural Mortality

	1	2	3	4	5	6	7	8	9	10
1963.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1964.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1965.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1966.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1967.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1968.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1969.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1970.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1971.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1972.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1973.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1974.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1975.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1976.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1977.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1978.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1979.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1980.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1981.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1982.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1983.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1984.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1985.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1986.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1987.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1988.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1989.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1990.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1991.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1992.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1993.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
1994.00	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)

Virtual Population Analysis using initial values

Population Numbers

	1	2	3	4	5	6	7	8	9	10
1963.00	48889	28299	19641	5841	4174	2461	866	1362	835	518
1964.00	51847	40027	23029	14743	4162	3122	1821	643	981	639
1965.00	87176	42449	32666	16928	9964	2777	2251	1348	489	759
1966.00	52849	71374	34545	23745	11106	6576	1813	1598	1020	338
1967.00	104674	43269	58374	25724	15025	7993	4759	1363	1273	811
1968.00	95080	85700	35078	45940	18460	10559	6302	3487	1034	1003
1969.00	129216	77843	70121	26523	35548	14034	8085	5026	2741	820
1970.00	68027	105793	63430	55620	17558	27752	11032	6107	4019	2173
1971.00	63818	55696	86586	49354	43430	12748	22181	8816	4823	3254
1972.00	64705	52249	45255	69640	36400	33851	9459	17740	6891	3678
1973.00	61004	52924	39194	29475	53503	27766	27303	7444	14380	5559
1974.00	62606	49630	36348	25193	19406	42048	21936	21931	5791	11594
1975.00	54235	50447	37590	24301	18447	13943	33868	17103	17121	4289
1976.00	46770	44381	38964	24770	17601	13905	10628	26815	13361	13838
1977.00	47571	38260	33787	24460	17773	12782	10373	8104	21486	10410
1978.00	49430	38803	30190	23446	17561	13030	9795	7985	6287	17329
1979.00	51338	40435	27757	20864	17067	13200	10035	7755	6318	5000
1980.00	59959	42023	32203	21069	15994	12908	10154	7881	6207	5000
1981.00	59548	49048	33482	23344	16389	12477	9992	7888	6277	5000
1982.00	68803	48614	37910	23869	17326	12887	9845	7873	6257	5000
1983.00	70514	56293	38535	26863	18020	13058	10033	7710	6223	5000
1984.00	72989	57700	42913	27260	19673	14001	10001	7755	6170	5000
1985.00	51895	59617	44510	30098	20148	15313	10845	7916	6223	5000
1986.00	59223	42482	46745	31826	21891	15179	11427	8329	6312	5000
1987.00	53654	48278	34083	31876	18475	14514	11166	8404	6395	5000
1988.00	39972	43927	37994	25926	19833	13388	10658	8440	6471	5000
1989.00	34452	32707	32726	25972	18057	13871	10013	7921	6280	5000
1990.00	25100	28187	26093	20238	16136	12752	10095	7859	6253	5000
1991.00	18991	20498	21738	16332	13214	12134	9731	7791	6213	5000
1992.00	15834	15410	15660	14561	10720	9759	9386	7584	6167	5000
1993.00	25632	12939	11840	11224	9140	7904	7670	7588	6154	5000
1994.00	18324	20972	8334	7295	6649	6416	6227	6179	6162	5000
1995.00	15000	15000	15000	5000	5000	5000	5000	5000	5000	5000

Fishing Mortality

	1	2	3	4	5	6	7	8	9	10
1963.00	0.000	0.006	0.087	0.139	0.090	0.101	0.097	0.128	0.068	0.110

1964.00	0.000	0.003	0.108	0.192	0.205	0.127	0.101	0.075	0.057	0.175
1965.00	0.000	0.006	0.119	0.222	0.216	0.226	0.142	0.078	0.169	0.221
1966.00	0.000	0.001	0.095	0.258	0.129	0.123	0.086	0.027	0.030	0.170
1967.00	0.000	0.010	0.040	0.132	0.153	0.038	0.111	0.076	0.039	0.107
1968.00	0.000	0.001	0.080	0.056	0.074	0.067	0.026	0.041	0.031	0.066
1969.00	0.000	0.005	0.032	0.212	0.048	0.041	0.081	0.024	0.032	0.100
1970.00	0.000	0.000	0.051	0.047	0.120	0.024	0.024	0.036	0.011	0.064
1971.00	0.000	0.008	0.018	0.104	0.049	0.098	0.023	0.046	0.071	0.084
1972.00	0.001	0.087	0.229	0.064	0.071	0.015	0.040	0.010	0.015	0.050
1973.00	0.006	0.176	0.242	0.218	0.041	0.036	0.019	0.051	0.015	0.098
1974.00	0.016	0.078	0.203	0.112	0.131	0.016	0.049	0.048	0.100	0.086
1975.00	0.001	0.058	0.217	0.123	0.083	0.071	0.034	0.047	0.013	0.092
1976.00	0.001	0.073	0.266	0.132	0.120	0.093	0.071	0.022	0.050	0.115
1977.00	0.004	0.037	0.165	0.131	0.110	0.066	0.062	0.054	0.015	0.103
1978.00	0.001	0.135	0.169	0.118	0.085	0.061	0.034	0.034	0.029	0.088
1979.00	0.000	0.028	0.076	0.066	0.079	0.062	0.042	0.023	0.034	0.182
1980.00	0.001	0.027	0.122	0.051	0.048	0.056	0.052	0.028	0.016	0.198
1981.00	0.003	0.058	0.138	0.098	0.040	0.037	0.038	0.032	0.027	0.160
1982.00	0.001	0.032	0.144	0.081	0.083	0.050	0.044	0.035	0.024	0.107
1983.00	0.001	0.071	0.146	0.112	0.052	0.067	0.058	0.023	0.019	0.118
1984.00	0.002	0.060	0.155	0.102	0.051	0.055	0.034	0.020	0.010	0.036
1985.00	0.000	0.043	0.135	0.118	0.083	0.093	0.064	0.026	0.019	0.051
1986.00	0.004	0.020	0.183	0.344	0.211	0.107	0.107	0.064	0.033	0.080
1987.00	0.000	0.040	0.074	0.275	0.122	0.109	0.080	0.061	0.046	0.047
1988.00	0.001	0.094	0.180	0.162	0.158	0.090	0.097	0.096	0.058	0.075
1989.00	0.001	0.026	0.281	0.276	0.148	0.118	0.042	0.037	0.028	0.041
1990.00	0.003	0.060	0.269	0.226	0.085	0.070	0.059	0.035	0.024	0.035
1991.00	0.009	0.069	0.201	0.221	0.103	0.057	0.049	0.034	0.017	0.050
1992.00	0.002	0.064	0.133	0.266	0.105	0.041	0.013	0.009	0.010	0.021
1993.00	0.001	0.240	0.284	0.324	0.154	0.038	0.016	0.008	0.008	0.018
1994.00	0.000	0.135	0.311	0.178	0.085	0.049	0.019	0.012	0.009	0.025

[Non-linear Estimation: iterations]

```
LAMBDA       1.00000E-2
RSS          4.51893E2
NPHI         4.51893E2

Parameters
   8.51719E0      8.51719E0      8.51719E0      8.51719E0      8.51719E0      8.51719E0
   8.51719E0      8.51719E0      8.51719E0      8.51719E0      8.51719E0      8.51719E0
   8.51719E0      8.51719E0      8.51719E0      8.51719E0      8.51719E0      8.51719E0
   8.51719E0      8.51719E0      8.51719E0      8.51719E0      8.51719E0
LAMBDA       1.00000E-3
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```
RSS          3.68220E2
NPHI         3.68220E2

Parameters
   1.00605E1     9.37805E0     9.73547E0     9.86258E0     9.87178E0     9.54798E0
   8.38474E0     8.05192E0     8.25053E0     8.95524E0     8.81634E0     7.62892E0
   9.42465E0     8.75410E0     9.38143E0     8.35641E0     1.05535E1     9.91090E0
   9.78857E0     9.42812E0     9.03886E0     9.63226E0     9.05529E0
LAMBDA       1.00000E-4
RSS          3.67339E2
NPHI         3.67339E2

Parameters
   9.77755E0     9.16618E0     9.53861E0     9.66578E0     9.59638E0     9.33441E0
   8.25261E0     7.87276E0     8.10121E0     8.80086E0     8.66910E0     7.17401E0
   9.21215E0     8.61864E0     9.13816E0     8.22161E0     1.02720E1     9.68501E0
   9.52070E0     9.19955E0     8.85165E0     9.42020E0     8.87787E0
LAMBDA       1.00000E-5
RSS          3.67327E2
NPHI         3.67327E2

Parameters
   9.90668E0     9.29921E0     9.65752E0     9.77813E0     9.71115E0     9.45262E0
   8.38597E0     8.01429E0     8.25768E0     8.93548E0     8.81524E0     7.42346E0
   9.34079E0     8.76039E0     9.27749E0     8.39093E0     1.03625E1     9.78865E0
   9.63701E0     9.33012E0     8.99299E0     9.53869E0     9.01442E0
LAMBDA       1.00000E-5
RSS          3.67320E2
NPHI         3.67320E2

Parameters
   9.80402E0     9.19380E0     9.56341E0     9.68853E0     9.61913E0     9.35949E0
   8.28270E0     7.90276E0     8.13500E0     8.83006E0     8.70211E0     7.19349E0
   9.23743E0     8.65341E0     9.16644E0     8.25328E0     1.02914E1     9.70788E0
   9.54644E0     9.22821E0     8.88227E0     9.44525E0     8.90730E0
LAMBDA       1.00000E-5
RSS          3.67317E2
NPHI         3.67317E2
```

```
Parameters
   9.88787E0     9.27978E0     9.64053E0     9.76207E0     9.69454E0     9.43574E0
   8.36695E0     7.99348E0     8.23422E0     8.91589E0     8.79400E0     7.37765E0
   9.32179E0     8.74113E0     9.25680E0     8.36456E0     1.03501E1     9.77433E0
   9.62059E0     9.31129E0     8.97222E0     9.52178E0     8.99447E0

RELATIVE CHANGE IN RESIDUAL SUM OF SQUARES LESS THAN 0.00001

LAMBDA        1.00000E-2
RSS           3.67317E2
NPHI          3.67317E2

Parameters
   9.88787E0     9.27978E0     9.64053E0     9.76207E0     9.69454E0     9.43574E0
   8.36695E0     7.99348E0     8.23422E0     8.91589E0     8.79400E0     7.37765E0
   9.32179E0     8.74113E0     9.25680E0     8.36456E0     1.03501E1     9.77433E0
   9.62059E0     9.31129E0     8.97222E0     9.52178E0     8.99447E0    -6.41006E0
  -6.09725E0    -7.20270E0    -7.89043E0    -7.97847E0    -8.18894E0    -8.01116E0
  -8.74523E0    -9.45376E0    -7.59994E0    -7.11959E0    -7.78451E0    -8.60771E0
  -9.10419E0    -9.62905E0    -9.82803E0    -1.08624E1

LAMBDA        1.00000E-3
RSS           3.67313E2
NPHI          3.67313E2

Parameters
   9.83117E0     9.22156E0     9.58876E0     9.71297E0     9.64371E0     9.38425E0
   8.31015E0     7.93237E0     8.16630E0     8.85756E0     8.73193E0     7.24659E0
   9.26500E0     8.68307E0     9.19522E0     8.28665E0     1.03109E1     9.72967E0
   9.57036E0     9.25463E0     8.91026E0     9.47017E0     8.93487E0    -6.37460E0
  -6.05660E0    -7.15670E0    -7.83952E0    -7.92427E0    -8.15347E0    -7.97051E0
  -8.69922E0    -9.40306E0    -7.56447E0    -7.07894E0    -7.73850E0    -8.55701E0
  -9.04999E0    -9.59358E0    -9.78738E0    -1.08164E1

LAMBDA        1.00000E-4
RSS           3.67312E2
NPHI          3.67312E2

Parameters
   9.86726E0     9.25858E0     9.62178E0     9.74431E0     9.67620E0     9.41716E0
   8.34622E0     7.97092E0     8.20927E0     8.89467E0     8.77110E0     7.32572E0
   9.30102E0     8.71969E0     9.23437E0     8.33640E0     1.03362E1     9.75839E0
   9.60259E0     9.29089E0     8.95001E0     9.50316E0     8.97295E0    -6.39703E0
  -6.08233E0    -7.18582E0    -7.87176E0    -7.95857E0    -8.17590E0    -7.99624E0
  -8.72835E0    -9.43516E0    -7.58691E0    -7.10467E0    -7.76763E0    -8.58911E0
  -9.08429E0    -9.61602E0    -9.81311E0    -1.08455E1
```

RELATIVE CHANGE IN RESIDUAL SUM OF SQUARES LESS THAN 0.00001

Estimated VPA (biased)

Population Numbers

	1	2	3	4	5	6	7	8	9	10
1963.00	76536	46046	28287	8194	7178	4215	1310	2059	1255	812
1964.00	104924	62663	37559	21821	6088	5582	3257	1007	1551	983
1965.00	175153	85905	51198	28823	15756	4354	4264	2523	786	1226
1966.00	87311	143403	70124	38916	20840	11316	3103	3247	1983	581
1967.00	217631	71484	117347	54851	27438	15961	8640	2419	2623	1599
1968.00	200118	178181	58178	94222	42305	20720	12826	6664	1898	2108
1969.00	277605	163841	145838	45435	75077	33555	16403	10367	5342	1528
1970.00	154536	227284	133839	117611	33035	60115	27015	12917	8392	4303
1971.00	97088	126523	186055	106998	94184	25418	48677	21901	10399	6834
1972.00	125793	79489	103243	151078	83591	75403	19831	39434	17604	8243
1973.00	133986	102939	61495	76935	120176	66402	61323	15936	32141	14330
1974.00	128801	109382	77286	43441	58252	96635	53568	49784	12744	26135
1975.00	98404	104643	86508	57809	33385	45745	78560	43001	39925	9981
1976.00	42013	80544	83334	64809	45032	26135	36664	63405	34564	32509
1977.00	34829	34365	63393	60768	50550	35239	20385	29420	51444	27769
1978.00	41406	28371	27001	47680	47285	39864	28180	16182	23739	41857
1979.00	65217	33866	19219	18254	36905	37535	32005	22807	13028	19288
1980.00	68710	53386	26825	14080	13858	29149	30077	25867	18531	10494
1981.00	38440	56213	42785	18942	10667	10728	23289	24200	21003	15090
1982.00	104831	31333	43776	31484	13723	8203	8413	18760	19612	17057
1983.00	77320	85790	24387	31664	24255	10108	6198	6538	15136	15934
1984.00	104758	63273	67062	15683	23603	19105	7587	4615	5210	12298
1985.00	46886	85627	49072	49864	10672	18530	15024	5939	3652	4214
1986.00	76713	38381	68040	35559	38073	7423	14062	11750	4694	2896
1987.00	95319	62597	30726	49305	21527	27757	4819	10560	9196	3675
1988.00	50971	78040	49717	23177	34091	15886	21499	3244	8236	7293
1989.00	53863	41713	60653	35566	15808	25542	12058	16797	2028	6445
1990.00	51771	44079	33466	43087	23984	10911	19649	9533	13519	1519
1991.00	46381	42334	34748	22363	31914	18559	8224	15613	7584	10949
1992.00	62923	37835	33538	25210	15655	25068	14647	6351	12571	6122
1993.00	25632	51492	30199	25859	17853	11944	20205	11895	5144	10243
1994.00	18324	20972	39892	22319	18623	13547	9535	16441	9688	4173
1995.00	15000	15000	15000	30829	17299	14803	10839	7708	13402	7887

Fishing Mortality

	1	2	3	4	5	6	7	8	9	10
1963.00	0.000	0.004	0.060	0.097	0.052	0.058	0.063	0.083	0.045	0.069
1964.00	0.000	0.002	0.065	0.126	0.135	0.069	0.055	0.047	0.035	0.110
1965.00	0.000	0.003	0.074	0.124	0.131	0.139	0.073	0.041	0.102	0.131
1966.00	0.000	0.001	0.046	0.149	0.067	0.070	0.049	0.013	0.015	0.095
1967.00	0.000	0.006	0.019	0.060	0.081	0.019	0.060	0.042	0.019	0.053
1968.00	0.000	0.000	0.047	0.027	0.032	0.034	0.013	0.021	0.017	0.031
1969.00	0.000	0.002	0.015	0.119	0.022	0.017	0.039	0.011	0.016	0.053
1970.00	0.000	0.000	0.024	0.022	0.062	0.011	0.010	0.017	0.005	0.032
1971.00	0.000	0.003	0.008	0.047	0.022	0.048	0.011	0.018	0.032	0.039
1972.00	0.001	0.057	0.094	0.029	0.030	0.007	0.019	0.004	0.006	0.022
1973.00	0.003	0.087	0.148	0.078	0.018	0.015	0.008	0.024	0.007	0.037
1974.00	0.008	0.035	0.090	0.063	0.042	0.007	0.020	0.021	0.044	0.037
1975.00	0.000	0.028	0.089	0.050	0.045	0.021	0.014	0.018	0.005	0.039
1976.00	0.001	0.039	0.116	0.048	0.045	0.048	0.020	0.009	0.019	0.047
1977.00	0.005	0.041	0.085	0.051	0.037	0.024	0.031	0.015	0.006	0.037
1978.00	0.001	0.189	0.191	0.056	0.031	0.020	0.012	0.017	0.008	0.036
1979.00	0.000	0.033	0.111	0.076	0.036	0.022	0.013	0.008	0.016	0.044
1980.00	0.001	0.021	0.148	0.078	0.056	0.024	0.017	0.008	0.005	0.090
1981.00	0.004	0.050	0.107	0.122	0.063	0.043	0.016	0.010	0.008	0.050
1982.00	0.000	0.051	0.124	0.061	0.106	0.080	0.052	0.015	0.008	0.030
1983.00	0.000	0.046	0.241	0.094	0.039	0.087	0.095	0.027	0.008	0.036
1984.00	0.002	0.054	0.096	0.185	0.042	0.040	0.045	0.034	0.012	0.014
1985.00	0.000	0.030	0.122	0.070	0.163	0.076	0.046	0.035	0.032	0.061
1986.00	0.003	0.022	0.122	0.302	0.116	0.232	0.086	0.045	0.045	0.141
1987.00	0.000	0.030	0.082	0.169	0.104	0.055	0.196	0.049	0.032	0.065
1988.00	0.000	0.052	0.135	0.183	0.089	0.076	0.047	0.270	0.045	0.051
1989.00	0.000	0.020	0.142	0.194	0.171	0.062	0.035	0.017	0.069	0.032
1990.00	0.001	0.038	0.203	0.100	0.056	0.083	0.030	0.029	0.011	0.121
1991.00	0.004	0.033	0.121	0.157	0.041	0.037	0.059	0.017	0.014	0.023
1992.00	0.000	0.025	0.060	0.145	0.071	0.016	0.008	0.011	0.005	0.017
1993.00	0.001	0.055	0.102	0.128	0.076	0.025	0.006	0.005	0.009	0.009
1994.00	0.000	0.135	0.058	0.055	0.030	0.023	0.013	0.004	0.006	0.030

APPROXIMATE STATISTICS ASSUMING LINEARITY NEAR SOLUTION
ORTHOGONALITY OFFSET......... 0.012596
MEAN SQUARE RESIDUALS 1.228467

Estimates for parameters

PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS
9.87E0	1.15E0	0.116	-6.44E-2	-0.007
9.26E0	9.77E-1	0.105	-6.90E-2	-0.007
9.62E0	8.36E-1	0.087	-2.89E-2	-0.003
9.74E0	7.89E-1	0.081	-1.96E-2	-0.002
9.68E0	7.65E-1	0.079	-1.72E-2	-0.002
9.42E0	7.69E-1	0.082	-1.89E-2	-0.002
8.35E0	8.71E-1	0.104	-6.23E-2	-0.007
7.97E0	9.68E-1	0.121	-1.14E-1	-0.014
8.21E0	9.81E-1	0.120	-1.22E-1	-0.015
8.89E0	8.57E-1	0.096	-5.82E-2	-0.007
8.77E0	9.63E-1	0.110	-1.15E-1	-0.013
7.33E0	1.85E0	0.253	-9.98E-1	-0.136
9.30E0	8.80E-1	0.095	-6.81E-2	-0.007
8.72E0	9.91E-1	0.114	-1.18E-1	-0.014
9.23E0	8.94E-1	0.097	-7.17E-2	-0.008
8.34E0	9.84E-1	0.118	-1.19E-1	-0.014
1.03E1	6.90E-1	0.067	3.24E-2	0.003
9.76E0	7.07E-1	0.072	1.50E-2	0.002
9.60E0	7.43E-1	0.077	-3.74E-3	0.000
9.29E0	8.04E-1	0.087	-2.99E-2	-0.003
8.95E0	8.32E-1	0.093	-3.98E-2	-0.004
9.50E0	7.75E-1	0.082	-1.93E-2	-0.002
8.97E0	8.39E-1	0.094	-4.40E-2	-0.005
-6.40E0	5.37E-1	-0.084	-4.70E-2	0.007
-6.08E0	6.03E-1	-0.099	-3.81E-2	0.006
-7.19E0	6.70E-1	-0.093	-1.68E-2	0.002
-7.87E0	7.33E-1	-0.093	6.65E-3	-0.001
-7.96E0	7.77E-1	-0.098	2.89E-2	-0.004
-8.18E0	5.37E-1	-0.066	-4.70E-2	0.006
-8.00E0	6.03E-1	-0.075	-3.81E-2	0.005
-8.73E0	6.70E-1	-0.077	-1.68E-2	0.002
-9.44E0	7.30E-1	-0.077	6.43E-3	-0.001
-7.59E0	5.37E-1	-0.071	-4.70E-2	0.006
-7.10E0	6.03E-1	-0.085	-3.81E-2	0.005
-7.77E0	6.70E-1	-0.086	-1.68E-2	0.002
-8.59E0	7.30E-1	-0.085	6.43E-3	-0.001
-9.08E0	7.77E-1	-0.086	2.89E-2	-0.003
-9.62E0	5.37E-1	-0.056	-4.70E-2	0.005
-9.81E0	6.03E-1	-0.061	-3.81E-2	0.004
-1.08E1	6.70E-1	-0.062	-1.68E-2	0.002

Parameters in linear scale

	PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS
N(1995, 4)	1.93E4	2.22E4	1.149	1.15E4	0.595
N(1995, 5)	1.05E4	1.03E4	0.977	4.28E3	0.408
N(1995, 6)	1.51E4	1.26E4	0.836	4.84E3	0.321
N(1995, 7)	1.71E4	1.35E4	0.789	4.97E3	0.292
N(1995, 8)	1.59E4	1.22E4	0.765	4.39E3	0.276
N(1995, 9)	1.23E4	9.45E3	0.769	3.40E3	0.276
N(1995, 10)	4.21E3	3.67E3	0.871	1.34E3	0.317
N(1994, 10)	2.90E3	2.80E3	0.968	1.03E3	0.354
N(1993, 10)	3.67E3	3.61E3	0.982	1.32E3	0.360
N(1992, 10)	7.29E3	6.25E3	0.857	2.25E3	0.309
N(1991, 10)	6.45E3	6.21E3	0.963	2.25E3	0.349
N(1990, 10)	1.52E3	2.81E3	1.852	1.09E3	0.717
N(1989, 10)	1.09E4	9.64E3	0.880	3.50E3	0.319
N(1988, 10)	6.12E3	6.07E3	0.992	2.29E3	0.374
N(1987, 10)	1.02E4	9.16E3	0.894	3.36E3	0.328
N(1986, 10)	4.17E3	4.11E3	0.984	1.52E3	0.365
N(1985, 10)	3.08E4	2.13E4	0.690	8.33E3	0.270
N(1984, 10)	1.73E4	1.22E4	0.707	4.59E3	0.265
N(1983, 10)	1.48E4	1.10E4	0.743	4.03E3	0.272
N(1982, 10)	1.08E4	8.72E3	0.804	3.18E3	0.293
N(1981, 10)	7.71E3	6.41E3	0.832	2.36E3	0.306
N(1980, 10)	1.34E4	1.04E4	0.775	3.77E3	0.281
N(1979, 10)	7.89E3	6.62E3	0.839	2.43E3	0.308
Otter trawl 2	1.67E-3	8.96E-4	0.537	1.62E-4	0.097
Otter trawl 3	2.28E-3	1.38E-3	0.603	3.27E-4	0.143
Otter trawl 4	7.57E-4	5.07E-4	0.670	1.57E-4	0.208
Otter trawl 5	3.81E-4	2.80E-4	0.733	1.05E-4	0.275
Otter trawl 6	3.50E-4	2.72E-4	0.777	1.16E-4	0.331
Seine 2	2.81E-4	1.51E-4	0.537	2.74E-5	0.097
Seine 3	3.37E-4	2.03E-4	0.603	4.83E-5	0.143
Seine 4	1.62E-4	1.09E-4	0.670	3.36E-5	0.208
Seine 5	7.99E-5	5.83E-5	0.730	2.18E-5	0.273
Light trawl 2	5.07E-4	2.73E-4	0.537	4.94E-5	0.097
Light trawl 3	8.21E-4	4.95E-4	0.603	1.18E-4	0.143
Light trawl 4	4.23E-4	2.84E-4	0.670	8.79E-5	0.208
Light trawl 5	1.86E-4	1.36E-4	0.730	5.08E-5	0.273
Light trawl 6	1.13E-4	8.81E-5	0.777	3.75E-5	0.331
Prawn trawl 2	6.67E-5	3.58E-5	0.537	6.49E-6	0.097
Prawn trawl 3	5.47E-5	3.30E-5	0.603	7.85E-6	0.143
Prawn trawl 4	1.95E-5	1.31E-5	0.670	4.05E-6	0.208

[Correlation matrix of parameter estimates]

1.00																	
0.56	1.00																
0.60	0.72	1.00															
0.61	0.74	0.79	1.00														
0.62	0.74	0.80	0.82	1.00													
0.62	0.74	0.80	0.82	0.83	1.00												
0.62	0.74	0.80	0.82	0.83	0.83	1.00											
0.62	0.74	0.79	0.82	0.83	0.83	0.83	1.00										
0.62	0.75	0.80	0.82	0.83	0.83	0.83	0.83	1.00									
0.62	0.74	0.80	0.82	0.83	0.83	0.83	0.83	0.83	1.00								
0.62	0.74	0.80	0.82	0.83	0.83	0.83	0.83	0.83	0.83	1.00							
0.62	0.75	0.80	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.83	1.00						
0.62	0.74	0.80	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	1.00					
0.62	0.75	0.80	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	1.00				
0.62	0.75	0.80	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	1.00			
0.62	0.75	0.80	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	1.00		
0.53	0.64	0.68	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	1.00	
0.58	0.70	0.75	0.78	0.79	0.79	0.79	0.78	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.69	1.00
0.60	0.73	0.78	0.81	0.82	0.82	0.82	0.81	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.71	0.78
0.62	0.75	0.80	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.72	0.79
0.62	0.75	0.80	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.72	0.79
0.62	0.74	0.80	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.72	0.79
0.62	0.75	0.80	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.72	0.79
-0.60	-0.72	-0.77	-0.79	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.72	-0.78
-0.61	-0.74	-0.79	-0.83	-0.84	-0.84	-0.84	-0.83	-0.84	-0.84	-0.84	-0.83	-0.84	-0.84	-0.84	-0.84	-0.74	-0.80
-0.63	-0.75	-0.82	-0.84	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.73	-0.81
-0.63	-0.78	-0.83	-0.85	-0.86	-0.86	-0.86	-0.85	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.74	-0.80
-0.68	-0.79	-0.84	-0.86	-0.87	-0.87	-0.87	-0.86	-0.87	-0.87	-0.87	-0.87	-0.87	-0.87	-0.87	-0.87	-0.74	-0.81
-0.60	-0.72	-0.77	-0.79	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.72	-0.78
-0.61	-0.74	-0.79	-0.83	-0.84	-0.84	-0.84	-0.83	-0.84	-0.84	-0.84	-0.83	-0.84	-0.84	-0.84	-0.84	-0.74	-0.80
-0.63	-0.75	-0.82	-0.84	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.73	-0.81
-0.63	-0.78	-0.83	-0.85	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.74	-0.81
-0.60	-0.72	-0.77	-0.79	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.72	-0.78
-0.61	-0.74	-0.79	-0.83	-0.84	-0.84	-0.84	-0.83	-0.84	-0.84	-0.84	-0.83	-0.84	-0.84	-0.84	-0.84	-0.74	-0.80
-0.63	-0.75	-0.82	-0.84	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.73	-0.81
-0.63	-0.78	-0.83	-0.85	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.86	-0.74	-0.81
-0.68	-0.79	-0.84	-0.86	-0.87	-0.87	-0.87	-0.86	-0.87	-0.87	-0.87	-0.87	-0.87	-0.87	-0.87	-0.87	-0.74	-0.81
-0.60	-0.72	-0.77	-0.79	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.81	-0.72	-0.78
-0.61	-0.74	-0.79	-0.83	-0.84	-0.84	-0.84	-0.83	-0.84	-0.84	-0.84	-0.83	-0.84	-0.84	-0.84	-0.84	-0.74	-0.80
-0.63	-0.75	-0.82	-0.84	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.85	-0.73	-0.81

[Correlation matrix - continued]

1.00																	
0.82	1.00																
0.82	0.83	1.00															
0.82	0.83	0.83	1.00														
0.82	0.83	0.83	0.83	1.00													
-0.80	-0.81	-0.81	-0.81	-0.81	1.00												
-0.82	-0.84	-0.84	-0.84	-0.84	0.81	1.00											
-0.84	-0.85	-0.85	-0.85	-0.85	0.82	0.85	1.00										
-0.85	-0.86	-0.86	-0.86	-0.86	0.83	0.85	0.87	1.00									
-0.84	-0.87	-0.87	-0.87	-0.87	0.84	0.86	0.88	0.89	1.00								
-0.80	-0.81	-0.81	-0.81	-0.81	0.79	0.81	0.82	0.83	0.84	1.00							
-0.82	-0.84	-0.84	-0.84	-0.84	0.81	0.83	0.85	0.85	0.86	0.81	1.00						
-0.84	-0.85	-0.85	-0.85	-0.85	0.82	0.85	0.86	0.87	0.88	0.82	0.85	1.00					
-0.85	-0.86	-0.86	-0.86	-0.86	0.83	0.86	0.87	0.88	0.89	0.83	0.86	0.87	1.00				
-0.80	-0.81	-0.81	-0.81	-0.81	0.79	0.81	0.82	0.83	0.84	0.79	0.81	0.82	0.83	1.00			
-0.82	-0.84	-0.84	-0.84	-0.84	0.81	0.83	0.85	0.85	0.86	0.81	0.83	0.85	0.86	0.81	1.00		
-0.84	-0.85	-0.85	-0.85	-0.85	0.82	0.85	0.86	0.87	0.88	0.82	0.85	0.86	0.87	0.82	0.85	1.00	
-0.85	-0.86	-0.86	-0.86	-0.86	0.83	0.86	0.87	0.88	0.89	0.83	0.86	0.87	0.88	0.83	0.86	0.87	1.00
-0.84	-0.87	-0.87	-0.87	-0.87	0.84	0.86	0.88	0.89	0.90	0.84	0.86	0.88	0.89	0.84	0.86	0.88	0.89
-0.80	-0.81	-0.81	-0.81	-0.81	0.79	0.81	0.82	0.83	0.84	0.79	0.81	0.82	0.83	0.79	0.81	0.82	0.83
-0.82	-0.84	-0.84	-0.84	-0.84	0.81	0.83	0.85	0.85	0.86	0.81	0.83	0.85	0.86	0.81	0.83	0.85	0.86
-0.84	-0.85	-0.85	-0.85	-0.85	0.82	0.85	0.86	0.87	0.88	0.82	0.85	0.86	0.87	0.82	0.85	0.86	0.87

[Correlation matrix - continued]

1.00			
0.84	1.00		
0.86	0.81	1.00	
0.88	0.82	0.85	1.00

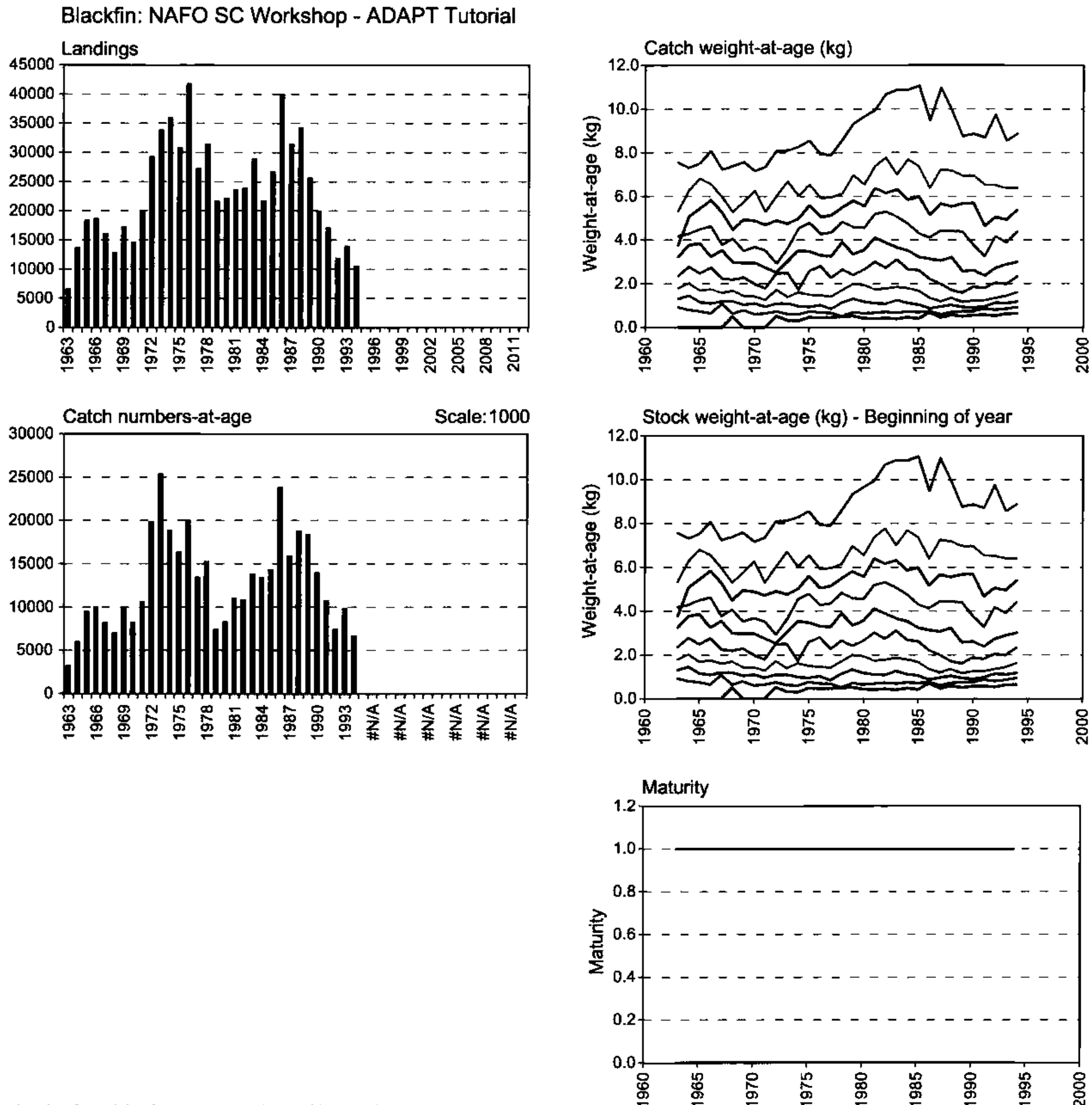

Fig. 1. Graphical representation of input data.

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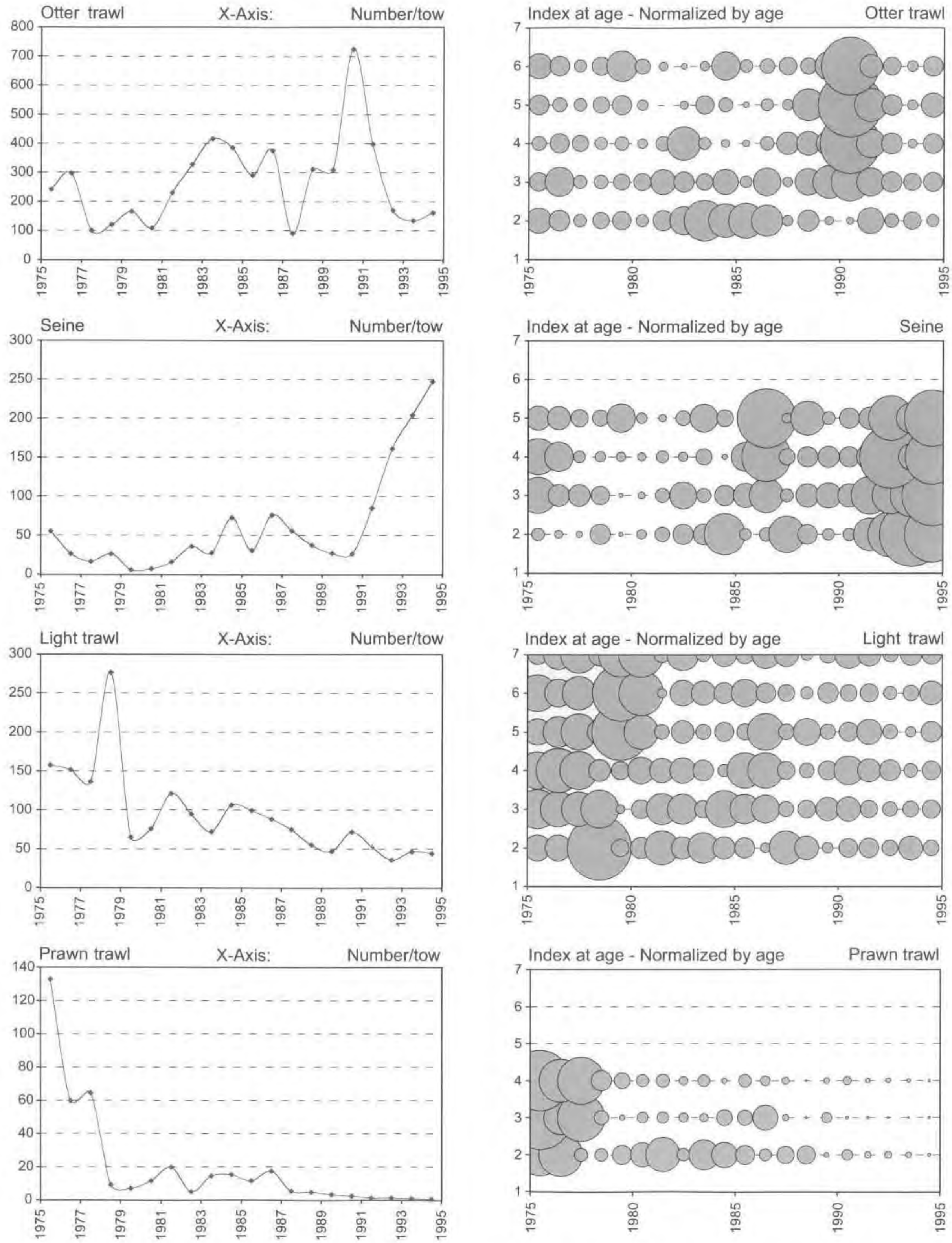

Fig. 2. Time trends of population abundance indices and bubble plots representing the catch-rate-at-age for each index. In the bubble plots, the age effect has been removed by dividing the index by the mean value for each age.

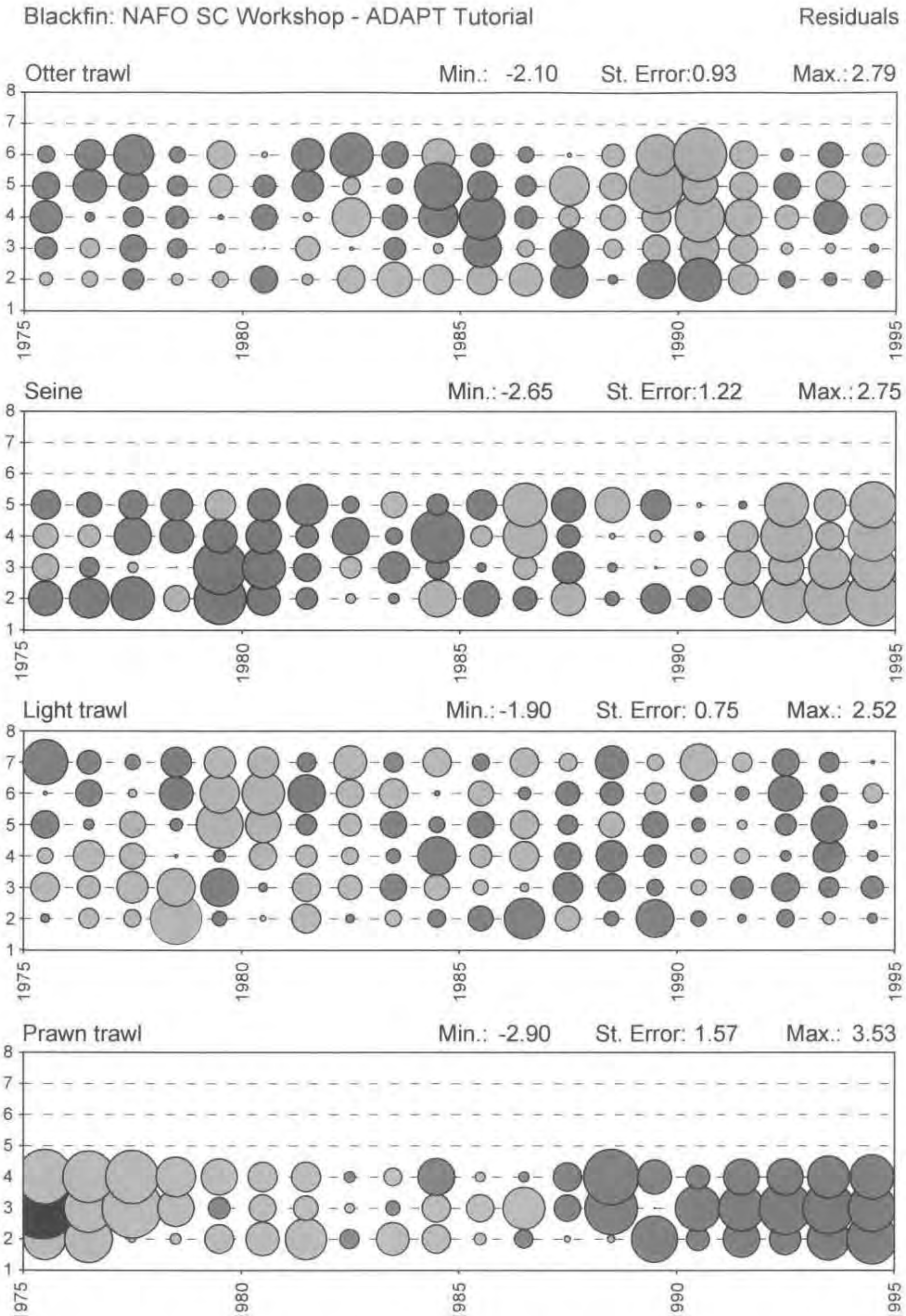

Fig. 3. Graphical representation of residuals. Note that all graphs are normalized to the same maximum bubble size to facilitate the comparison between indices.

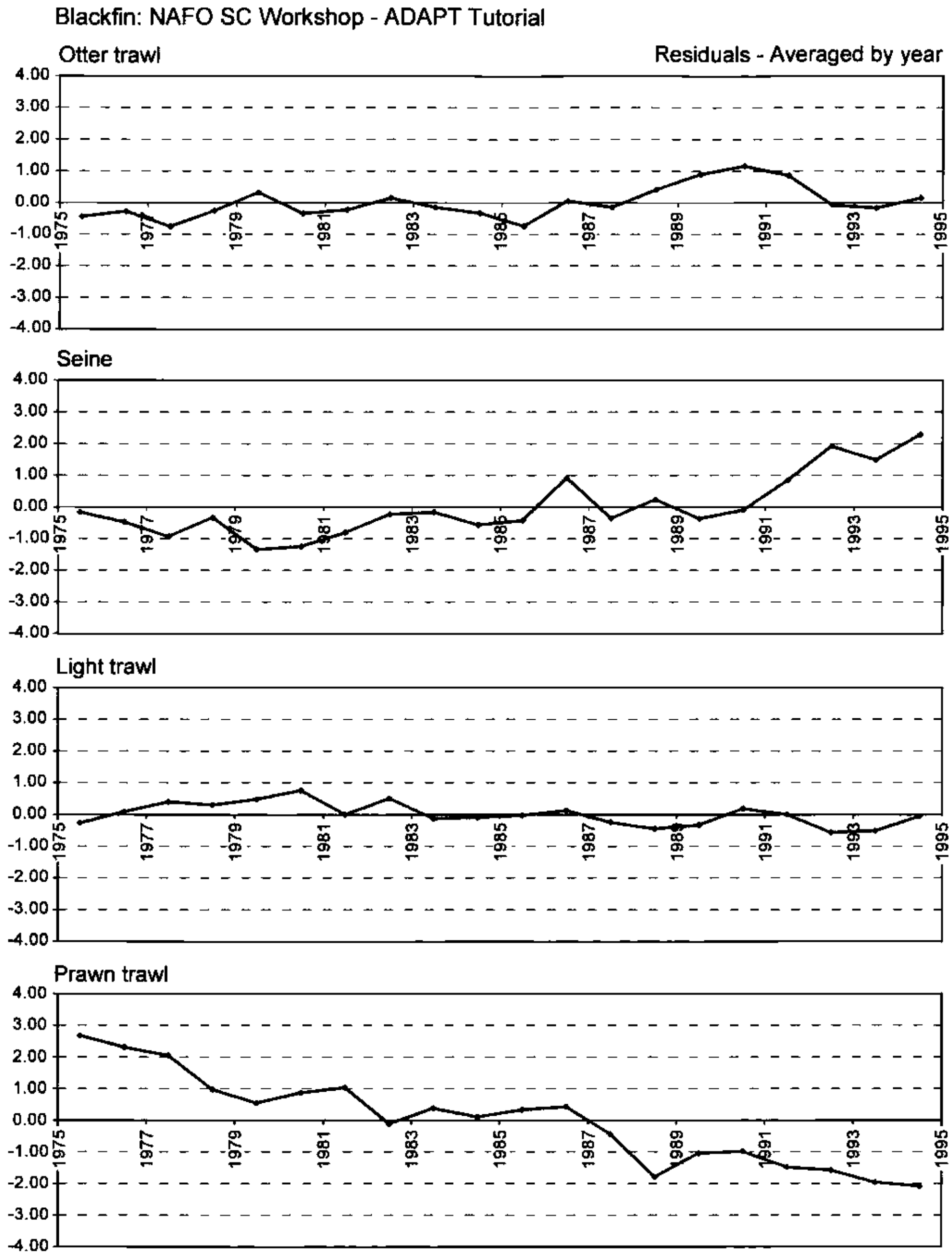

Fig. 4. Graphical representation of mean residuals for each year by index. Time trends in these graphs indicate that other functions relationships should be investigated for catchability of the surveys. Year effects in catchability would appear as significant deviations to the zero line in comparison to other years.

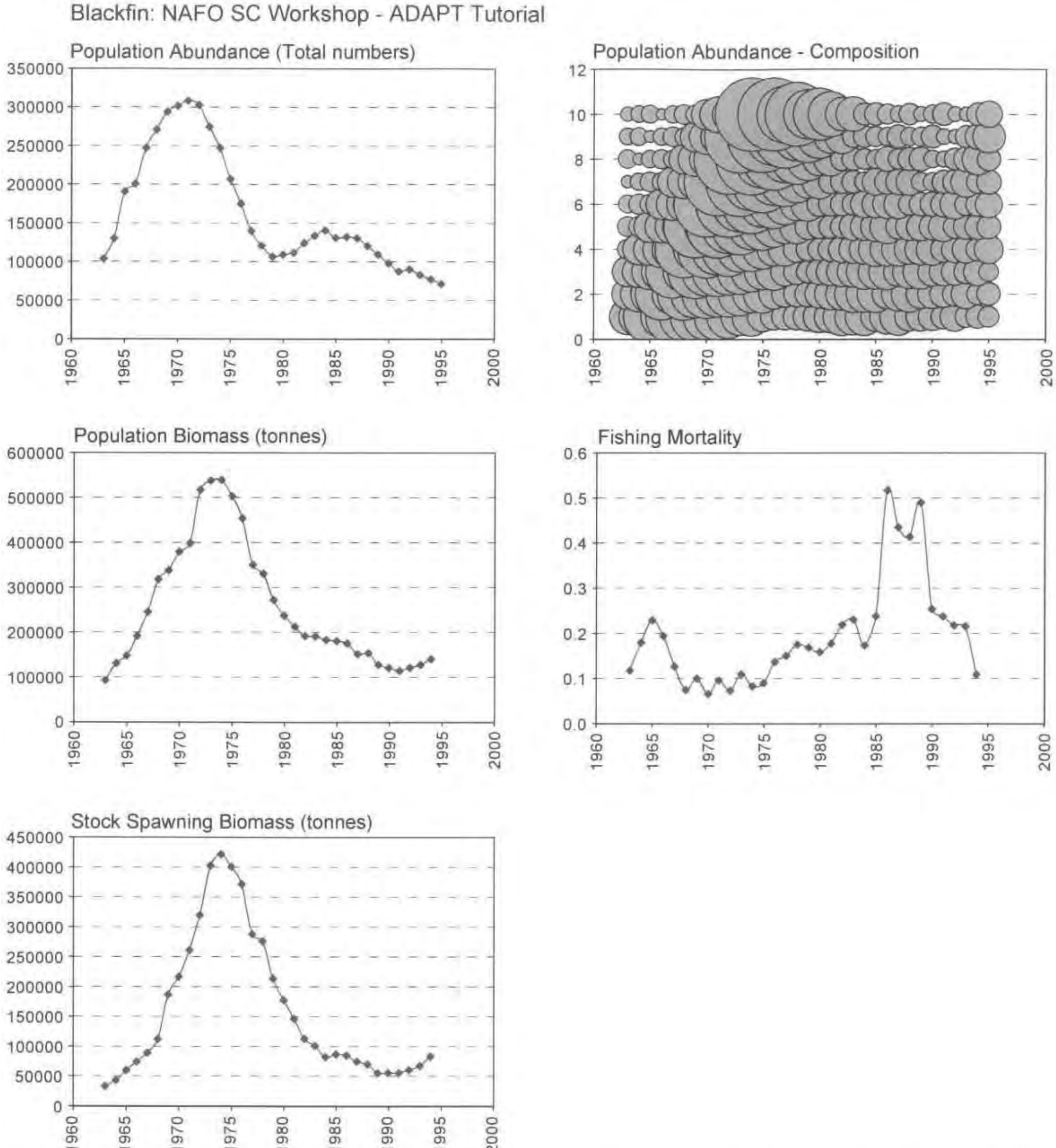

Fig. 5. Graphical representation of output data as time series, together with bubble graph representing the age composition of the stock. In the latter, the age effect has been removed (by dividing the abundance by the mean value for each age) to allow easier identification of strong or weak cohorts and/or time trends in stock abundance.

APPENDIX 4. Projections and Risk Analysis with ADAPT

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Appendix 4: Projections and Risk Analysis with ADAPT

by

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Abstract

This document is intended as a tutorial to assist the first users of the ADAPT software. The ADAPTive Framework uses a non-linear least-squares fit to calibrate a virtual population analysis against independent indices of abundance. The tutorial explores the functions available to carry out stock forecasts and analyses of the risks associated with various scenarios. Risk analyses can be based on variance estimates from analytical approximations or bootstrap. The risks are expressed in relation to three fisheries management parameters: 1) a relative change in spawning stock biomass, 2) an absolute spawning stock biomass level (e.g. a limit biomass reference points) or 3) a given exploitation level.

Introduction

This document is intended as a tutorial for the use of the ADAPTive Framework (ADAPT) software and, in particular, for the functions related to catch projections and risk analysis. As such, this document complements the ADAPT User's Guide (Gavaris, 1999).

The tutorial for the estimation of population abundance (Rivard and Gavaris, 2000; see also Rivard and Gavaris in this publication) should be done first to develop an understanding of the procedures available for obtaining abundance estimates and their statistical properties. From these, the ADAPT software allows deterministic projections and evaluation of risks associated with alternative catch quota options.

Deterministic projections make forecasts of stock characteristics from the point estimates of stock abundance for fishery scenarios that you specify. Risk evaluations make forecasts using the point estimates as well as accounting for their uncertainty. The statistical properties can either be obtained analytically, or through a bootstrap procedure. References on approaches used to measure uncertainty were provided in Rivard and Gavaris (2000).

The uncertainty in the estimation of model parameters is translated into risk of alternative management actions as described in Gavaris and Sinclair (1998). These uncertainties are conditioned on the set of assumptions used in the analyses. Though these assumptions might be deemed most suitable, there may be other plausible assumptions. These calculations do not include uncertainty due to variations in weight at age, partial recruitment to the fishery and natural mortality, or systematic errors in data reporting and model mismatch. The fact that uncertainty associated with making a choice among competing assumptions and models is not incorporated must be considered when making management decisions. Use of relative measures, such as change in biomass, rather than absolute quantities such as biomass should be more reliable. Accordingly, these risk evaluations are suited for short-term projections where the assumed model may be adequate and the largest source of uncertainty is associated with the point estimates of population abundance. A brief description of the projection model and algorithms used in risk analyses is provided in Annex 1.

Preparing your data using the spreadsheet template (ADAPT Template.xls)

The spreadsheet "ADAPT Template.xls" provides placeholders for your entries for catch projection and risk analysis. The template also provides a means to display your results in a graphical form. It includes some data validation and has been formatted to allow easy copying between Excel (Microsoft Corporation, WA, USA) and ADAPT.

For this tutorial, data have been pre-assembled in the spreadsheet "ADAPT Tutorial – Forecast.xls". Load this spreadsheet now and inspect its content to gain some familiarity with its design. This data corresponds to the gadoid (saithe) stock used in the tutorial on estimation of population abundance (Rivard and Gavaris, 2000).

Loading ADAPT

Activate ADAPT V2.1 from the Windows (Microsoft Corporation, WA, USA) Start/Program Menu or as indicated in the installation guide. In a typical installation, the ADAPT program can be activated from the Start/Program Menu or by typing the following in the Start/Run Box:

C:/aplwr20/aplwr.exe C:/adapt2_1/ADAPT.W3 6000000

The directories leading to the files *aplwr.exe* and *ADAPT.W3* should match those of your installation.

Data Input (ADAPT Tutorial – Forecast.aw2)

For the purpose of this tutorial, data input, model specification and estimation has already been done and the ADAPT work file saved as "ADAPT Tutorial – Forecast.aw2". Open this file now and inspect its content. You will see that the information on catch at age and on the four tuning indices has already been provided, and that the VPA formulation has been specified and that the estimation has already been carried out. You are thus ready to proceed with the projections.

Deterministic projections

Deterministic projections use the point estimates of population abundance as a starting point for stock forecasts. The fishery scenarios can be specified either by providing a quota or a fishing mortality level for each year of the projection horizon. The sheet "Forecast" in the Excel-Template can be used to prepare your scenarios (see table 1). The sheet uses the input information for ADAPT, as well as the estimates of stock abundance and fishing mortality to suggest "defaults" for your scenarios. The defaults are based on long-term averages; adjust the entries as necessary.

1. **In ADAPT**
2. **Select "Compute".**
3. **Select "Analytical".**
4. **Select "Project bias adjusted". Note that this option is active only when statistics and bias corrections have been computed. You will be provided with a menu to describe the scenario for your forecast.**
5. **In the box labeled "Enter subsequent years for projection", enter "1996 1997" (without the quotes).**
6. **In the box labeled "Enter abundance at age 1 for 1996 1997", enter 25000 25000.**
7. **In the box labeled "Enter quota (biomass) or fishing mortality for 1995 1996", enter "0.2 0.2" (without the quotes). The values "0.2" indicate that you want to make projections using a fishing mortality of 0.2 in each year. NOTE than an entry larger than 2 is interpreted as a quota, while an entry less than 2 is interpreted as a fishing mortality.**
8. **The next entries for your projection scenario have to come from Excel, using the PASTE-buttons provided in the menu. In essence, you have to provide the natural mortality, partial recruitment, stock weight-at-age and catch weight at age for the projection horizon. Note that when selecting entries to Paste into ADAPT, always include the cells containing the "age" and "year" labels.**

9. In Excel
10. Select the "Forecast" sheet.
11. Enter 25000 in cells D6 and E6.
12. Enter 0.2 in cells C7 and D7 (defaults are provided; change only if necessary).
13. Go to the A9 cell, which marks the beginning of the natural mortality matrix. Defaults have been calculated for you here. Adjust as necessary.
14. Highlight the relevant data and copy to the clipboard.
15. In ADAPT [returning to the "Project Menu"]
16. Click the PASTE-button against the "Copy M..." option.
17. In Excel
18. Select the "Forecast" sheet (if not already selected).
19. Go to the A22 cell, which marks the beginning of the PR (partial recruitment) matrix. Defaults have been calculated for you here. Adjust as necessary.
20. Highlight the relevant data and copy to the clipboard.
21. In ADAPT [returning to the "Project Menu"]
22. Click the PASTE-button against the "Copy PR..." option.
23. In Excel
24. Select the "Forecast" sheet (if not already selected).
25. Go to the A34 cell, which marks the beginning of the stock weight-at-age matrix. Defaults have been calculated for you here. Adjust as necessary.
26. Highlight the relevant data and copy to the clipboard.
27. In ADAPT [returning to the "Project Menu"]
28. Click the PASTE-button against the "Copy beginning of year population weight-at-age..." option.
29. In Excel
30. Select the "Forecast" sheet (if not already selected).
31. Go to the A47 cell, which marks the beginning of the catch weight-at-age matrix. Defaults have been calculated for you here. Adjust as necessary.
32. Highlight the relevant data and copy to the clipboard.
33. In ADAPT [returning to the "Project Menu"]
34. Click the PASTE-button against the "Copy average catch weight-at-age ... " option.
35. Click the OK-button of the "Project Menu".
36. The results of this projection scenario appear in the Session-log.

Results (see Annex 2):

The results show that a fishing mortality of 0.2 would generate a catch of 13139 t in 1995 and 12890 t in 1996. These catch levels would lead to a reduction of the total biomass, from 131 355 t at the beginning of 1995 to 122 375 t at the beginning of 1997.

Computation of risk

Risk analyses use not only the point estimates of population abundance as a starting point for stock forecasts but use also a measure of their reliability to make inferences on the likelihood of various outcomes. The risks are expressed in relation to three specific outcomes: 1) the attainment of a given exploitation level, 2) a relative change in spawning stock biomass, or 3) the realization of an absolute spawning stock biomass level (e.g. a limit biomass reference point). The risk evaluation is for the final year in the projection time horizon.

37. In ADAPT
38. Select "Compute".
39. Select "Analytical".
40. Select "Risk". Note that this option is active only when statistics and bias corrections have been computed. You will be provided with a menu to describe the scenario for your forecast.
41. In the box labeled "Enter subsequent years for projection", enter "1996 1997" (without the quotes).
42. In the box labeled "Enter abundance at age 1 for 1996 1997", enter 25000 25000.
43. In the box labeled "Enter quota (biomass) or fishing mortality for 1995", enter "20000" (without the quotes). This value indicates that you want to make projections using a quota of 20000 t for the first year of the projection. NOTE than an entry larger than 2 is interpreted as a quota, while an entry less than 2 is interpreted as a fishing mortality. Also, when there is no intervening year, the label for this box will not show a year, indicating that no input is required.
44. In the box labeled "Enter starting quota, increment, # steps separated by spaces for 1995", enter "1000 2000 30" (without the quotes). **Warning**: The starting quota has to be larger than zero. If you enter zero as the starting quota, ADAPT will start the calculation but will quit at one point without showing the results.
45. The next entries for your projection scenario have to come from Excel, using the PASTE-buttons provided in the menu. In essence, you have to provide the natural mortality, partial recruitment, stock weight-at-age and catch weight at age for the projection horizon. When selecting entries to Paste into ADAPT, always include the cells containing the labels, which identify the ages and years.
46. In Excel
47. Select the "Forecast" sheet.
48. Enter 25000 in cells D6 and E6.
49. Enter 20000 in cell C7 and 0.2 in cell D7 (defaults are provided; adjust only if necessary).
50. Go to the A9 cell, which marks the beginning of the natural mortality matrix. Defaults have been calculated for you here. Adjust as necessary.
51. Highlight the relevant data and copy to the clipboard.
52. In ADAPT [returning to the "Project Menu"]
53. Click the PASTE-button against the "Copy M..." option.
54. In Excel
55. Select the "Forecast" sheet (if not already selected).
56. Go to the A22 cell, which marks the beginning of the PR (partial recruitment) matrix. Defaults have been calculated for you here. Adjust as necessary.
57. Highlight the relevant data and copy to the clipboard.
58. In ADAPT [returning to the "Project Menu"]
59. Click the PASTE-button against the "Copy PR..." option.
60. In Excel
61. Select the "Forecast" sheet (if not already selected).
62. Go to the A34 cell, which marks the beginning of the stock weight-at-age matrix. Defaults have been calculated for you here. Adjust as necessary.
63. Highlight the relevant data and copy to the clipboard.
64. In ADAPT [returning to the "Project Menu"]
65. Click the PASTE-button against the "Copy beginning of year population weight-at-age..." option.
66. In Excel
67. Select the "Forecast" sheet (if not already selected).
68. Go to the A47 cell, which marks the beginning of the catch weight at age matrix. Defaults have been calculated for you here. Adjust as necessary.
69. Highlight the relevant data and copy to the clipboard.
70. In ADAPT [returning to the "Project Menu"].
71. Click the PASTE-button against the "Copy average catch weight at age ... " option.
72. In Excel

73. Select the "Forecast" sheet (if not already selected).
74. Go to the A59 cell, which marks the beginning of the maturity-at-age matrix. Defaults have been calculated for you here from initial input. Adjust as necessary.
75. Highlight the relevant data and copy to the clipboard.
76. In ADAPT [returning to the "Project Menu"]
77. Click the PASTE-button against the "Copy maturity-at-age for ..." option.
78. In the box labeled "Inverse exploration", enter "5".
79. In the box labeled "%Biomass change", enter "0". Note that this % change refers to a change in the Stock Spawning Biomass (SSB).
80. In the box labeled "Absolute biomass", enter "50000". Note that this value refers to the Stock Spawning Biomass (SSB).
81. Your entries must look like the Menu illustrated in Fig.1.
    Click the OK-button of the "Risk Menu".
82. These calculations can take a few minutes. The results of this projection scenario appear in the Session-log.

Inspect the session log to explore the results. You can copy these results to the clipboard for transfer to the Excel-template.

HINT: If the correct M, partial recruitment and weights have previously been entered for a deterministic projection and if you are doing the risk analysis for the same timeframe, you need only Paste the maturity for the calculation of the SSB. The other values will be taken from the variables previously defined.

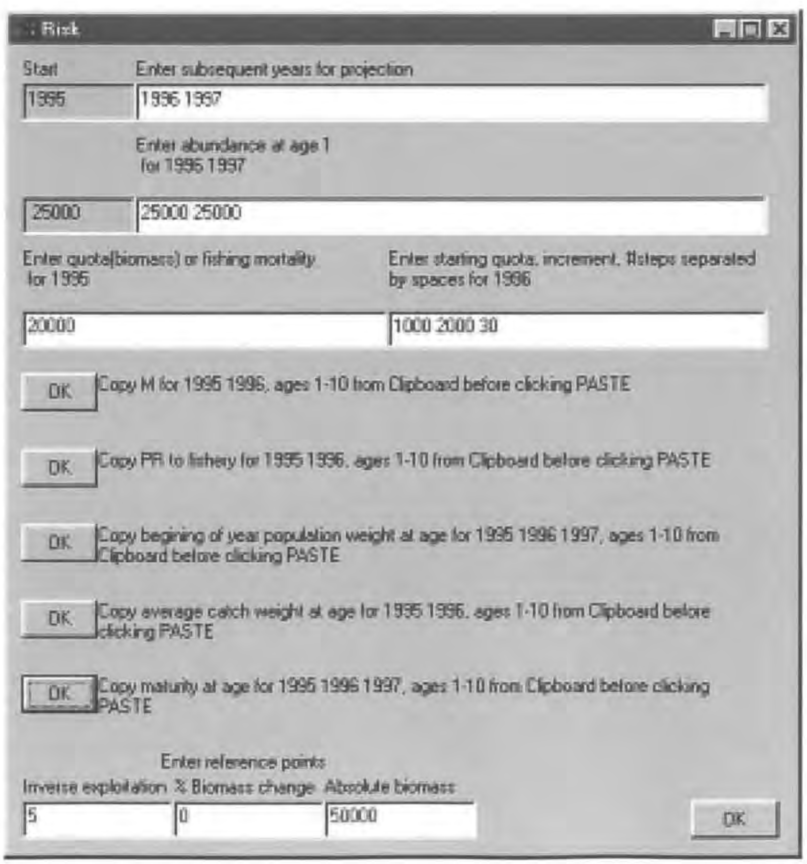

Fig. 1. Risk Menu.

To display the risk curves, you can copy these results to the "WS-For" sheet of the Excel Template. This is a working sheet for the forecasts.

83. In ADAPT
84. Select "Output".
85. Select "To Clipboard".
86. Select "Risk".
87. Select "Analytical".
88. The results of this risk scenario are copied to the clipboard.
89. In Excel.
90. Go to the "WS-For" sheet.
91. Copy the content of the clipboard to cell A3.

The risk curves will be generated in the "For-G" sheet of the Excel template (Figs. 2 and 3).

Note that the risk projections (analytical or bootstrap) are **always bias-corrected**. The results of the risk projections should thus be compared with bias-corrected historical re-constructions of the population metrics (abundance, biomass, SSB).

As an exercise, repeat the risk computations but, this time, use the bootstrap approach. When asked for the number of replicates in the bootstrap, enter "100". The entries for the "risk Menu" are exactly the same as those for the risk calculations using the analytical approach (see Fig. 1). When the bootstrap is completed, copy the results in the second placeholder (cell A51) of the "WS-For" sheet. Provide labels for the plots as necessary. The risk curves for the bootstrap results will be generated in the "For-G" sheet of the Excel template.

Notes on bootstrap:

- The most common practice is to use the bootstrap procedure (as opposed to the analytical approach) for calculating risk curves from ADAPT results. While it takes longer to obtain results because of the re-sampling procedure, bootstrap is believed to give a better appreciation for the shape of the risk curve (assuming, of course, a sufficient number of replicates) (Gavaris *et al.*, 2000).
- For a typical bootstrap simulation, someone would do 500 or 600 replicates in a "well-behaved" estimation problem. Use 1000 replicates if uncertain. You may need more simulations if you need to pay a particular attention to some characteristics of the distribution of the results, e.g. if the "tail" of the risk curve are particularly important in management decisions.
- In the current version of ADAPT, the bootstrap is performed by re-sampling all residuals assuming that they are independent and identically distributed (i.i.d.). Despite efforts to make the residuals i.i.d. when calibrating VPAs, residuals often show significant departures from this assumption. Research is ongoing on possible refinements to the bootstrap procedure so as to take such factors into account.

Conclusions

All results have been transferred to the spreadsheet. You can now inspect the forecasts and interpret the results of the risk analysis.

Results:

Figs. 2 and 3 suggest that the stock spawning biomass (SSB) has a high probability of declining even with no fishing in 1996. Under no fishing in 1996, there is a probability of 10% or less that the SSB will be below 50 000 t at the beginning of 1997. That probability increases as the quota for 1996 is increased. With a catch of 60 000 t in 1996, the probability of the SSB at the beginning of 1997 to be less that 50 000 t is of the order of 75–90%.

Fig. 2 (lower panel) indicates that the SSB would be of the order of 80 000 t at the beginning of 1997 if there is no fishing in 1996. A catch of 50,000 t in 1996 would generate a fishing mortality of 0.7-0.8 in 1996 and would leave a SSB of about 40 000 t at the beginning of 1997.

This concludes the tutorial for projections and risk computations using ADAPT. You should save your work (both the ADAPT Workspace and the spreadsheet) for future reference. The ADAPT Session Log for this tutorial is printed in Annex 2 and the "completed" spreadsheet is given in file "ADAPT Template – Example".

References and Related Reading

EFRON, B. 1982. The Jacknife, the bootstrap and other resampling plans. Philadelphia: Society for Industrial and Applied Mathematics **38**: 92 p.

GAVARIS S. 1999. ADAPT (ADAPTive framework) User's Guide. Mimeographed. 25 pages. Available at http://www.mar.dfo-mpo.gc.ca/science/adapt/index.html.

GAVARIS, S. and A. SINCLAIR. 1998. From fisheries assessment uncertainty to risk analysis for immediate management actions. *In*: Fishery Stock Assessment Models. F. Funk *et al.* (eds). Alaska Sea Grant College Program Report No. AK-SG-98-01. University of Alaska, Fairbanks.

GAVARIS, S., K. R. PATTERSON, C. D. DARBY, P. LEWY, B. MESNIL, A. E. PUNT, R. M. COOK, L. T. KELL, C. M. O'BRIEN, V. R. RESTREPO, D. W. SKAGEN, and G. STEFÁNSSON. 2000. Comparison of uncertainty estimates in the short term using real data. *ICES C.M. Doc.* No. 2000/V:03, 30 p.

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TABLE 1. Example of input data for deterministic projections and risk analyses.

Years	1995	1996	1997
N at Age 1	25000	25000	25000
Quota or F	20000	0.20	

M	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1995	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1996	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

PR	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1995	0.01	0.29	0.86	1.00	0.73	0.59	0.51	0.41	0.33	0.77
1996	0.01	0.29	0.86	1.00	0.73	0.59	0.51	0.41	0.33	0.77

Wt stock	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1995	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77
1996	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77
1997	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77

Wt catch	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1995	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77
1996	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77

Maturity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1995	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
1997	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 2. This table, which is a replicate of the Excel Sheet "WS-For" (Work Sheet for Forecasts), summarizes the risk calculations done using the analytical approach.

	Inverse Exploitation:					SSB Change:					SSB Reference:				
Quota	Mean	S.E.	Bias	Adj. Mean	Prob.	Mean	S.E.	Bias	Adj. Mean	Prob.	Mean	S.E.	Bias	Adj. Mean	Prob.
1000	78.70	63.04	18.72	59.98	0.19	-4.38	14.94	3.32	-7.70	0.70	88384	24218	10606	77778	0.13
3000	26.34	21.10	6.27	20.07	0.24	-6.03	14.88	3.36	-9.40	0.74	86857	24218	10606	76251	0.14
5000	15.87	12.71	3.78	12.10	0.29	-7.68	14.83	3.41	-11.10	0.77	85331	24217	10607	74724	0.15
7000	11.38	9.12	2.71	8.68	0.34	-9.33	14.79	3.46	-12.79	0.81	83804	24216	10608	73196	0.17
9000	8.89	7.12	2.12	6.78	0.40	-10.99	14.76	3.51	-14.49	0.84	82277	24215	10609	71668	0.19
11000	7.31	5.85	1.74	5.57	0.46	-12.64	14.74	3.56	-16.19	0.86	80751	24213	10611	70140	0.20
13000	6.21	4.97	1.48	4.73	0.52	-14.29	14.73	3.61	-17.90	0.89	79225	24211	10613	68612	0.22
15000	5.41	4.33	1.29	4.12	0.58	-15.94	14.74	3.66	-19.60	0.91	77699	24208	10616	67083	0.24
17000	4.79	3.84	1.14	3.65	0.64	-17.59	14.75	3.71	-21.30	0.93	76172	24205	10619	65553	0.26
19000	4.31	3.45	1.02	3.28	0.69	-19.24	14.78	3.76	-23.00	0.94	74646	24201	10623	64023	0.28
21000	3.92	3.14	0.93	2.98	0.74	-20.89	14.82	3.81	-24.70	0.95	73120	24197	10628	62493	0.30
23000	3.59	2.88	0.85	2.74	0.78	-22.54	14.87	3.86	-26.41	0.96	71595	24192	10633	60961	0.33
25000	3.32	2.66	0.79	2.53	0.82	-24.19	14.92	3.92	-28.11	0.97	70069	24186	10640	59429	0.35
27000	3.09	2.47	0.73	2.35	0.86	-25.85	14.99	3.97	-29.82	0.98	68543	24180	10647	57896	0.37
29000	2.89	2.32	0.69	2.20	0.89	-27.50	15.07	4.03	-31.53	0.98	67018	24173	10656	56362	0.40
31000	2.72	2.18	0.65	2.07	0.91	-29.15	15.16	4.09	-33.24	0.99	65492	24165	10666	54826	0.42
33000	2.57	2.06	0.61	1.96	0.93	-30.80	15.26	4.15	-34.95	0.99	63967	24157	10677	53290	0.45
35000	2.43	1.95	0.58	1.85	0.95	-32.45	15.37	4.21	-36.66	0.99	62442	24147	10691	51752	0.47
37000	2.31	1.85	0.55	1.76	0.96	-34.10	15.49	4.28	-38.37	0.99	60917	24137	10706	50212	0.50
39000	2.21	1.77	0.52	1.68	0.97	-35.75	15.61	4.34	-40.09	0.99	59392	24126	10723	48670	0.52
41000	2.11	1.69	0.50	1.61	0.98	-37.39	15.75	4.41	-41.81	1.00	57868	24113	10742	47125	0.55
43000	2.02	1.62	0.48	1.54	0.98	-39.04	15.89	4.49	-43.53	1.00	56344	24099	10765	45579	0.57
45000	1.94	1.56	0.46	1.48	0.99	-40.69	16.04	4.56	-45.26	1.00	54819	24084	10790	44029	0.60
47000	1.87	1.50	0.45	1.43	0.99	-42.34	16.20	4.64	-46.99	1.00	53295	24068	10820	42476	0.62
49000	1.81	1.45	0.43	1.38	0.99	-43.99	16.36	4.73	-48.72	1.00	51772	24050	10853	40919	0.65
51000	1.75	1.40	0.42	1.33	1.00	-45.64	16.53	4.82	-50.46	1.00	50248	24030	10891	39357	0.67
53000	1.69	1.35	0.40	1.29	1.00	-47.29	16.71	4.92	-52.20	1.00	48725	24008	10935	37790	0.69
55000	1.64	1.31	0.39	1.25	1.00	-48.93	16.89	5.02	-53.96	1.00	47203	23985	10985	36217	0.72
57000	1.59	1.27	0.38	1.21	1.00	-50.58	17.08	5.14	-55.72	1.00	45680	23959	11043	34637	0.74
59000	1.55	1.24	0.37	1.18	1.00	-52.23	17.27	5.26	-57.49	1.00	44158	23930	11110	33049	0.76
61000	1.51	1.21	0.36	1.15	1.00	-53.87	17.46	5.39	-59.27	1.00	42637	23899	11187	31451	0.78

TABLE 3. This table, which is a replicate of the Excel Sheet ":WS-For" (Work Sheet for Forecasts), summarizes the risk calculations done using the bootstrap approach.

	Inverse Exploitation:					SSB Change:					SSB Reference:				
Quota	Mean	S.E.	Bias	Adj. Mean	Prob.	Mean	S.E.	Bias	Adj. Mean	Prob.	Mean	S.E.	Bias	Adj. Mean	Prob.
1000	78.70	20.49	8.07	70.63	0.00	-4.38	14.22	2.47	-6.85	0.77	88384	28359	11155	77228	0.04
3000	26.34	6.83	2.69	23.65	0.00	-6.03	14.05	2.51	-8.54	0.79	86857	28221	11124	75733	0.08
5000	15.87	4.09	1.61	14.26	0.00	-7.68	13.89	2.55	-10.23	0.85	85331	28084	11092	74238	0.08
7000	11.38	2.92	1.15	10.23	0.00	-9.33	13.74	2.59	-11.93	0.88	83804	27947	11061	72743	0.11
9000	8.89	2.27	0.90	8.00	0.00	-10.99	13.60	2.63	-13.62	0.91	82277	27812	11029	71248	0.11
11000	7.31	1.85	0.73	6.57	0.14	-12.64	13.47	2.67	-15.31	0.91	80751	27678	10997	69754	0.13
13000	6.21	1.57	0.62	5.59	0.30	-14.29	13.35	2.72	-17.01	0.92	79225	27545	10966	68259	0.13
15000	5.41	1.36	0.54	4.87	0.53	-15.94	13.24	2.76	-18.70	0.93	77699	27413	10934	66764	0.20
17000	4.79	1.20	0.47	4.32	0.73	-17.59	13.14	2.80	-20.39	0.94	76172	27283	10903	65270	0.20
19000	4.31	1.07	0.42	3.88	0.91	-19.24	13.05	2.84	-22.08	0.96	74646	27153	10871	63775	0.20
21000	3.92	0.97	0.38	3.53	0.95	-20.89	12.97	2.88	-23.77	0.96	73120	27024	10839	62281	0.20
23000	3.59	0.88	0.35	3.24	0.97	-22.54	12.90	2.92	-25.47	0.97	71595	26897	10808	60787	0.22
25000	3.32	0.81	0.32	3.00	0.99	-24.19	12.85	2.96	-27.16	0.98	70069	26771	10776	59293	0.28
27000	3.09	0.75	0.30	2.79	0.99	-25.85	12.80	3.01	-28.85	0.98	68543	26646	10744	57799	0.32
29000	2.89	0.69	0.28	2.61	0.99	-27.50	12.77	3.05	-30.54	0.98	67018	26522	10713	56305	0.34
31000	2.72	0.65	0.26	2.46	0.99	-29.15	12.75	3.09	-32.23	0.98	65492	26399	10681	54811	0.36
33000	2.57	0.61	0.24	2.32	0.99	-30.80	12.74	3.13	-33.93	0.98	63967	26277	10649	53318	0.37
35000	2.43	0.57	0.23	2.20	0.99	-32.45	12.74	3.17	-35.62	0.98	62442	26156	10618	51824	0.41
37000	2.31	0.54	0.22	2.10	1.00	-34.10	12.75	3.21	-37.31	0.99	60917	26037	10586	50331	0.44
39000	2.21	0.51	0.20	2.00	1.00	-35.75	12.78	3.25	-39.00	0.99	59392	25918	10555	48838	0.49
41000	2.11	0.48	0.19	1.92	1.00	-37.39	12.81	3.30	-40.69	0.98	57868	25801	10523	47345	0.55
43000	2.02	0.46	0.19	1.84	1.00	-39.04	12.86	3.34	-42.38	0.99	56344	25684	10492	45852	0.59
45000	1.94	0.44	0.18	1.77	1.00	-40.69	12.92	3.38	-44.07	0.99	54819	25569	10460	44359	0.62
47000	1.87	0.42	0.17	1.70	1.00	-42.34	12.99	3.42	-45.76	0.99	53295	25455	10429	42866	0.64
49000	1.81	0.40	0.16	1.64	1.00	-43.99	13.07	3.46	-47.45	0.99	51772	25342	10398	41374	0.66
51000	1.75	0.38	0.16	1.59	1.00	-45.64	13.16	3.51	-49.14	0.99	50248	25229	10367	39882	0.68
53000	1.69	0.37	0.15	1.54	1.00	-47.29	13.26	3.55	-50.83	0.99	48725	25118	10336	38390	0.71
55000	1.64	0.35	0.14	1.50	1.00	-48.93	13.36	3.59	-52.52	0.99	47203	25008	10305	36898	0.80
57000	1.59	0.34	0.14	1.45	1.00	-50.58	13.48	3.63	-54.21	0.99	45680	24898	10274	35406	0.84
59000	1.55	0.32	0.13	1.41	1.00	-52.23	13.61	3.68	-55.90	0.99	44158	24789	10244	33915	0.86
61000	1.51	0.31	0.13	1.38	1.00	-53.87	13.74	3.72	-57.59	0.99	42637	24680	10214	32423	0.88

ANNEX 1. Algorithm Used in ADAPT for Forecasts

Projection Model

Forecast projections may be computed by specifying future fishing mortality rate or by specifying future catch quota. In either case, the partial recruitment to the fishery by age and time period, $PR_{a,t}$, must be provided.

To project with a specified fishing mortality rate for ages fully recruited to the fishery, $F_{full,t}$, first compute age specific fishing mortality rates as $F_{a,t} = F_{full,t} PR_{a,t}$ and then apply the fundamental exponential decay model

$$N_{a+\Delta t,t+\Delta t} = N_{a,t} e^{-(F_{a,t}+M_{a,t})\Delta t}$$

starting with the bias adjusted population abundance estimates in the terminal year.

To project with a specified catch quota, Q_t, first solve for the fishing mortality rate in the fundamental catch equation using the iterative algorithm

$$\text{initialize } F^0_{a,t} = PR_{a,t} \ ,$$

compute catch $$C^j_{a,t} = \frac{F^j_{a,t} \Delta t N_{a,t}\left(1 - e^{-(F^j_{a,t}+M_{a,t})\Delta t}\right)}{\left(F^j_{a,t} + M_{a,t}\right)\Delta t}$$

if $$0.01 \le \left| Q_t - \sum_a C^j_{a,t} W'_{a,t} \right| \text{ update } F^{j+1}_{a,t} = \frac{F^j_{a,t} Q_t}{\sum_a C^j_{a,t} W'_{a,t}} \text{ and re-compute catch.}$$

$W'_{a,t}$ is the average weight-at-age of fish caught in the fishery.

Almost invariably, natural mortality is considered a stationary process and forecast natural mortality for projections is drawn from the same estimated or assumed distribution used for recent years. Similarly, partial recruitment to the fishery and growth are typically deemed to be stationary over the recent past. Accordingly, both $W'_{a,t}$ and $PR_{a,t}$ are derived from observed values in previous years and are assumed to have negligible error.

Risk analysis

Risk analyses is used to determine the consequences of alternative quota tactics. The consequences are measured against reference points for fisheries management interest parameters. Three fisheries management interest parameters are considered, inverse exploitation rate on fish fully recruited to the fishery, relative change in spawning stock biomass and absolute spawning stock biomass. Inverse exploitation rate rather than exploitation rate is used for computational reasons involved with the analytical approach. These interest parameters are evaluated against their respective prescribed reference points for a specified range of potential alternative catch quotas. The requisite information can be summarized as

$$\Pr\left\{ 1/u_{full,t} > 1/u_{ref} \mid Q_t \right\}$$

$$\Pr\left\{ \Delta B_{t+1} < \Delta B_{ref} \mid Q_t \right\}$$

$$\Pr\left\{ B_{t+1} < B_{ref} \mid Q_t \right\}$$

where u is exploitation rate

$$u_{full.y_t+1} = F_{full.y_t+1}\left(1-e^{-\left(F_{full.y_t+1}+M_{full.y_t+1}\right)}\right)/\left(F_{full.y_t+1}+M_{full.y_t+1}\right)$$

and ΔB is relative change in spawning stock biomass and B is the spawning stock biomass

$$B_t = \sum_a N_{a,t} W_{a,t} m_{a,t}\,.$$

where $W_{a,t}$ is the average weight at age of fish in the population and $m_{a,t}$ is the maturity-at-age.

Risk analyses can be based on the statistics from analytical approximation or bootstrap.

Analytical

The analytical method uses the approximate estimates of variance and bias for the interest parameters and couples that with an assumption about the parametric form of their sampling distribution to derive confidence distributions. A bias adjusted Delta confidence distribution is constructed by shifting results to account for the magnitude of the estimated bias and ignoring any increase in variance associated with the variance of the bias estimate. Assuming a Gaussian distribution, confidence distributions of the interest parameters are approximated as

$$N \sim \left(\hat{\eta} - Bias(\hat{\eta}), \sqrt{Var(\hat{\eta})}\right).$$

Bootstrap

The percentile method confidence distribution of the interest parameter is defined as the proportion of bootstrap replicates, $\hat{\eta}^b$, less than or equal to that value,

$$\hat{\Omega}(x) = \text{Prob}\{\hat{\eta} \le x\} = \frac{\#\{\hat{\eta}^b \le x\}}{B}$$

where B is the total number of bootstrap replicates.

The bias-corrected percentile method of Efron (1982) that is reported in ADAPT results, improves on the percentile method by adjusting for differences between the median of the bootstrap percentile density function and the estimate obtained with the original data sample. The confidence distribution of the interest parameter is obtained with the bias-corrected percentile method by constructing the paired values $\left(\hat{\eta}^b_{BC}, \alpha\right)$. The α are the respective probability levels equal to $1/B, 2/B, 3/B, \cdots, B-1/B$. For each α, calculate the bias adjusted quantity,

$$\hat{\eta}^b_{BC} = \hat{\Omega}^{-1}\left(\Phi(2z_0 + z_\alpha)\right).$$

Here, Φ is the cumulative distribution function of a standard normal variate, $z_\alpha = \Phi^{-1}(\alpha)$ and $z_0 = \Phi^{-1}\left(\hat{\Omega}(\hat{\eta})\right)$. The term z_0 achieves the bias adjustment. The notation $\hat{\Omega}^{-1}(\;)$ or $\Phi^{-1}(\;)$ is used to represent the inverse distribution function, i.e. the critical value corresponding to the specified probability level. Note that computations are not carried out for $\alpha = B/B$ because $z_\alpha = \Phi^{-1}(\alpha = 1)$ is not defined.

ANNEX 2. ADAPT Session Log – Tutorial for Projections and Risk Analysis with ADAPT

```
THURSDAY, OCTOBER 12, 2000  9:38:19.230 AM

Portions of this program are copyrighted works of APL2000, Inc.
Copyright 1996 APL2000, Inc.
APL  Ver. 2.0.00
ADAPT_W  Ver. 2.1
Workspace size = 6000000

Note:  Log file truncated to show only the material relevant to the forecast. See Rivard
       and Gavaris (2000) for description of log file relevant to the estimation.


Projection results using analytical bias adjusted point estimates

Projected Population Numbers
              1       2       3       4       5       6       7       8       9      10
 1995.00  15000   15000    8624   12180    5567    4995    3054    2102    3059    1582
 1996.00  25000   12256   11589    5945    8165    3939    3634    2258    1585    2344
 1997.00  25000   20427    9469    7989    3985    5777    2866    2687    1703    1215

Fishing Mortality
              1       2       3       4       5       6       7       8       9      10
 1995.00  0.002   0.058   0.172   0.200   0.146   0.118   0.102   0.082   0.066   0.154
 1996.00  0.002   0.058   0.172   0.200   0.146   0.118   0.102   0.082   0.066   0.154

M
              1       2       3       4       5       6       7       8       9      10
 1995.00   0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20
 1996.00   0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20    0.20

PR
              1       2       3       4       5       6       7       8       9      10
 1995.00   0.01    0.29    0.86    1.00    0.73    0.59    0.51    0.41    0.33    0.77
 1996.00   0.01    0.29    0.86    1.00    0.73    0.59    0.51    0.41    0.33    0.77

Wgtstock
              1       2       3       4       5       6       7       8       9      10
 1995.00   0.36    0.72    1.08    1.56    2.32    3.22    4.24    5.31    6.49    8.77
 1996.00   0.36    0.72    1.08    1.56    2.32    3.22    4.24    5.31    6.49    8.77
 1997.00   0.36    0.72    1.08    1.56    2.32    3.22    4.24    5.31    6.49    8.77
```

Projected Population Biomass

	1	2	3	4	5	6	7	8	9	10	1+	2+	3+	4+
1995.00	5400	10800	9314	19002	12916	16084	12951	11161	19851	13876	131355	125955	115155	105841
1996.00	9000	8825	12516	9274	18942	12683	15410	11991	10290	20559	129491	120491	111666	99150
1997.00	9000	14708	10227	12463	9246	18601	12152	14268	11055	10657	122375	113375	98668	88441

Projected Catch Numbers

	1	2	3	4	5	6	7	8	9	10
1995.00	27	767	1239	2008	687	505	269	150	177	205
1996.00	45	627	1665	980	1008	398	320	161	92	304
1997.00										

Wgt catch

	1	2	3	4	5	6	7	8	9	10
1995.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77
1996.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77

Projected Catch Biomass

	1	2	3	4	5	6	7	8	9	10	1+	2+	3+	4+
1995.00	10	552	1338	3132	1594	1626	1140	798	1150	1800	13139	13130	12578	11240
1996.00	16	451	1798	1529	2338	1282	1357	857	596	2666	12890	12874	12423	10625
1997.00														

Input for Analytical risk analysis of projection results

M

	1	2	3	4	5	6	7	8	9	10
1995.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
1996.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

PR

	1	2	3	4	5	6	7	8	9	10
1995.00	0.01	0.29	0.86	1.00	0.73	0.59	0.51	0.41	0.33	0.77
1996.00	0.01	0.29	0.86	1.00	0.73	0.59	0.51	0.41	0.33	0.77

Wgtstock

	1	2	3	4	5	6	7	8	9	10
1995.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77
1996.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77
1997.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77

Wgt catch

	1	2	3	4	5	6	7	8	9	10
1995.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77
1996.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77

Maturity

	1	2	3	4	5	6	7	8	9	10
1995.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
1996.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
1997.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00

Inverse Exploitation Rate (Reference = 5)

Quota	Mean	Std. Err.	Bias	Adj. Mean	Prob
1000	78.701	63.041	18.723	59.978	0.192
3000	26.342	21.100	6.267	20.075	0.237
5000	15.871	12.713	3.776	12.095	0.288
7000	11.384	9.119	2.708	8.676	0.343
9000	8.892	7.123	2.115	6.777	0.402
11000	7.307	5.853	1.738	5.569	0.461
13000	6.210	4.974	1.477	4.733	0.521
15000	5.406	4.330	1.286	4.120	0.581
17000	4.792	3.838	1.140	3.652	0.637
19000	4.307	3.450	1.025	3.282	0.691
21000	3.915	3.136	0.931	2.984	0.740
23000	3.592	2.877	0.854	2.737	0.784
25000	3.320	2.659	0.790	2.530	0.823
27000	3.089	2.475	0.735	2.354	0.858
29000	2.890	2.315	0.688	2.203	0.887
31000	2.718	2.177	0.647	2.071	0.911
33000	2.566	2.055	0.610	1.956	0.931
35000	2.432	1.948	0.579	1.853	0.947
37000	2.313	1.853	0.550	1.763	0.960
39000	2.206	1.767	0.525	1.681	0.970
41000	2.110	1.690	0.502	1.608	0.978
43000	2.023	1.620	0.481	1.542	0.984
45000	1.944	1.557	0.462	1.482	0.988
47000	1.872	1.500	0.445	1.427	0.991
49000	1.806	1.447	0.430	1.377	0.994
51000	1.746	1.398	0.415	1.331	0.996
53000	1.690	1.354	0.402	1.288	0.997
55000	1.639	1.313	0.390	1.249	0.998
57000	1.592	1.275	0.379	1.213	0.999
59000	1.548	1.240	0.368	1.179	0.999
61000	1.507	1.207	0.358	1.148	0.999

% Biomass Change (Reference = 0)

Quota	Mean	Std. Err.	Bias	Adj. Mean	Prob
1000	-4	15	3	-8	0.697
3000	-6	15	3	-9	0.736
5000	-8	15	3	-11	0.773
7000	-9	15	3	-13	0.807
9000	-11	15	4	-14	0.837
11000	-13	15	4	-16	0.864
13000	-14	15	4	-18	0.888
15000	-16	15	4	-20	0.908
17000	-18	15	4	-21	0.926
19000	-19	15	4	-23	0.940
21000	-21	15	4	-25	0.952
23000	-23	15	4	-26	0.962
25000	-24	15	4	-28	0.970
27000	-26	15	4	-30	0.977
29000	-27	15	4	-32	0.982
31000	-29	15	4	-33	0.986
33000	-31	15	4	-35	0.989
35000	-32	15	4	-37	0.991
37000	-34	15	4	-38	0.993
39000	-36	16	4	-40	0.995
41000	-37	16	4	-42	0.996
43000	-39	16	4	-44	0.997
45000	-41	16	5	-45	0.998
47000	-42	16	5	-47	0.998
49000	-44	16	5	-49	0.999
51000	-46	17	5	-50	0.999
53000	-47	17	5	-52	0.999
55000	-49	17	5	-54	0.999
57000	-51	17	5	-56	0.999
59000	-52	17	5	-57	1.000
61000	-54	17	5	-59	1.000

Biomass (Reference = 50000)

Quota	Mean	Std. Err.	Bias	Adj. Mean	Prob
1000	88384	24218	10606	77778	0.126
3000	86857	24218	10606	76251	0.139
5000	85331	24217	10607	74724	0.154
7000	83804	24216	10608	73196	0.169
9000	82277	24215	10609	71668	0.185
11000	80751	24213	10611	70140	0.203
13000	79225	24211	10613	68612	0.221
15000	77699	24208	10616	67083	0.240
17000	76172	24205	10619	65553	0.260
19000	74646	24201	10623	64023	0.281
21000	73120	24197	10628	62493	0.303
23000	71595	24192	10633	60961	0.325
25000	70069	24186	10640	59429	0.348
27000	68543	24180	10647	57896	0.372
29000	67018	24173	10656	56362	0.396
31000	65492	24165	10666	54826	0.421
33000	63967	24157	10677	53290	0.446
35000	62442	24147	10691	51752	0.471
37000	60917	24137	10706	50212	0.497
39000	59392	24126	10723	48670	0.522
41000	57868	24113	10742	47125	0.547
43000	56344	24099	10765	45579	0.573
45000	54819	24084	10790	44029	0.598
47000	53295	24068	10820	42476	0.623
49000	51772	24050	10853	40919	0.647
51000	50248	24030	10891	39357	0.671
53000	48725	24008	10935	37790	0.694
55000	47203	23985	10985	36217	0.717
57000	45680	23959	11043	34637	0.739
59000	44158	23930	11110	33049	0.761
61000	42637	23899	11187	31451	0.781

Analytical risk results copied to ClipBoard

BOOTSTRAP STATISTICS

Estimates for parameters

PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS
9.27E0	6.35E-1	0.069	-9.87E-3	-0.001
9.51E0	4.32E-1	0.045	2.96E-3	0.000
8.71E0	4.14E-1	0.048	-1.66E-2	-0.002
8.59E0	4.46E-1	0.052	-3.14E-3	0.000
8.10E0	4.28E-1	0.053	-3.61E-2	-0.004
7.72E0	4.40E-1	0.057	-1.47E-2	-0.002
8.09E0	4.02E-1	0.050	-1.07E-2	-0.001
7.45E0	6.30E-1	0.085	-1.61E-1	-0.022
-5.71E0	2.24E-1	-0.039	-1.46E-2	0.003
-5.26E0	2.46E-1	-0.047	-2.07E-2	0.004
-6.19E0	2.53E-1	-0.041	2.65E-2	-0.004
-6.72E0	2.26E-1	-0.034	-3.34E-2	0.005
-6.68E0	2.32E-1	-0.035	-3.36E-2	0.005
-7.49E0	2.28E-1	-0.030	2.82E-2	-0.004
-7.18E0	2.27E-1	-0.032	-4.01E-2	0.006
-7.73E0	2.52E-1	-0.033	-2.92E-3	0.000
-8.30E0	2.39E-1	-0.029	-4.72E-2	0.006
-6.90E0	2.43E-1	-0.035	4.28E-2	-0.006
-6.28E0	2.30E-1	-0.037	5.32E-2	-0.008
-6.77E0	2.62E-1	-0.039	-7.32E-3	0.001
-7.46E0	2.60E-1	-0.035	6.28E-3	-0.001
-7.81E0	2.50E-1	-0.032	1.73E-2	-0.002
-8.32E0	2.69E-1	-0.032	-5.49E-3	0.001
-8.93E0	2.34E-1	-0.026	-1.36E-2	0.002
-8.99E0	2.61E-1	-0.029	1.09E-2	-0.001
-9.85E0	2.32E-1	-0.024	1.87E-3	0.000

Parameters in linear scale

PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS
1.06E4	9.07E3	0.856	2.19E3	0.207
1.35E4	7.26E3	0.538	1.42E3	0.105
6.04E3	2.56E3	0.424	4.08E2	0.068
5.36E3	2.64E3	0.492	5.31E2	0.099
3.30E3	1.49E3	0.451	1.82E2	0.055
2.26E3	1.21E3	0.534	2.03E2	0.090
3.27E3	1.41E3	0.430	2.31E2	0.071
1.73E3	9.26E2	0.536	1.20E1	0.007
3.30E-3	7.25E-4	0.219	3.24E-5	0.010
5.19E-3	1.30E-3	0.250	4.88E-5	0.009
2.05E-3	5.51E-4	0.269	1.23E-4	0.060
1.21E-3	2.66E-4	0.221	-9.94E-6	-0.008
1.25E-3	2.87E-4	0.229	-8.62E-6	-0.007
5.58E-4	1.43E-4	0.256	3.16E-5	0.057
7.65E-4	1.81E-4	0.237	-1.03E-5	-0.014
4.38E-4	1.14E-4	0.260	1.27E-5	0.029
2.47E-4	6.03E-5	0.244	-4.43E-6	-0.018
1.00E-3	2.55E-4	0.254	7.44E-5	0.074
1.87E-3	4.86E-4	0.260	1.56E-4	0.084
1.14E-3	3.06E-4	0.267	3.06E-5	0.027
5.76E-4	1.57E-4	0.272	2.35E-5	0.041
4.06E-4	1.13E-4	0.279	2.06E-5	0.051
2.43E-4	6.57E-5	0.271	7.29E-6	0.030
1.32E-4	3.21E-5	0.243	1.85E-6	0.014
1.24E-4	3.30E-5	0.265	5.60E-6	0.045
5.27E-5	1.21E-5	0.230	1.49E-6	0.028

Input for Bootstrap risk analysis of projection results

M

	1	2	3	4	5	6	7	8	9	10
1995.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
1996.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

PR

	1	2	3	4	5	6	7	8	9	10
1995.00	0.01	0.29	0.86	1.00	0.73	0.59	0.51	0.41	0.33	0.77
1996.00	0.01	0.29	0.86	1.00	0.73	0.59	0.51	0.41	0.33	0.77

Wgtstock

	1	2	3	4	5	6	7	8	9	10
1995.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77
1996.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77
1997.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77

Wgt catch

	1	2	3	4	5	6	7	8	9	10
1995.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77
1996.00	0.36	0.72	1.08	1.56	2.32	3.22	4.24	5.31	6.49	8.77

Maturity

	1	2	3	4	5	6	7	8	9	10
1995.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
1996.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
1997.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00

Inverse Exploitation Rate (Reference = 5)

Quota	Mean	Std. Err.	Bias Adj.	Mean	Prob
1000	78.701	20.490	8.073	70.629	0.000
3000	26.342	6.825	2.690	23.651	0.000
5000	15.871	4.092	1.614	14.257	0.000
7000	11.384	2.920	1.152	10.232	0.000
9000	8.892	2.269	0.896	7.996	0.000
11000	7.307	1.855	0.733	6.574	0.140
13000	6.210	1.568	0.620	5.591	0.300
15000	5.406	1.357	0.537	4.869	0.530
17000	4.792	1.196	0.473	4.318	0.730
19000	4.307	1.069	0.423	3.884	0.910
21000	3.915	0.965	0.383	3.532	0.950
23000	3.592	0.880	0.349	3.242	0.970
25000	3.320	0.808	0.321	2.999	0.990
27000	3.089	0.747	0.297	2.792	0.990
29000	2.890	0.694	0.276	2.614	0.990
31000	2.718	0.648	0.258	2.459	0.990
33000	2.566	0.608	0.242	2.324	0.990
35000	2.432	0.571	0.228	2.204	0.990
37000	2.313	0.539	0.216	2.097	1.000
39000	2.206	0.510	0.204	2.002	1.000
41000	2.110	0.484	0.194	1.916	1.000
43000	2.023	0.460	0.185	1.838	1.000
45000	1.944	0.438	0.177	1.767	1.000
47000	1.872	0.418	0.169	1.703	1.000
49000	1.806	0.399	0.162	1.645	1.000
51000	1.746	0.382	0.155	1.591	1.000
53000	1.690	0.366	0.149	1.541	1.000
55000	1.639	0.351	0.144	1.495	1.000
57000	1.592	0.337	0.138	1.453	1.000
59000	1.548	0.324	0.133	1.414	1.000
61000	1.507	0.311	0.129	1.378	1.000

% Biomass Change (Reference = 0)

Quota	Mean	Std. Err.	Bias Adj.	Mean	Prob
1000	-4	14	2	-7	0.770
3000	-6	14	3	-9	0.790
5000	-8	14	3	-10	0.850
7000	-9	14	3	-12	0.880
9000	-11	14	3	-14	0.910
11000	-13	13	3	-15	0.910
13000	-14	13	3	-17	0.920
15000	-16	13	3	-19	0.930
17000	-18	13	3	-20	0.940
19000	-19	13	3	-22	0.960
21000	-21	13	3	-24	0.960
23000	-23	13	3	-25	0.970
25000	-24	13	3	-27	0.980
27000	-26	13	3	-29	0.980
29000	-27	13	3	-31	0.980
31000	-29	13	3	-32	0.980
33000	-31	13	3	-34	0.980
35000	-32	13	3	-36	0.980
37000	-34	13	3	-37	0.990
39000	-36	13	3	-39	0.990
41000	-37	13	3	-41	0.980
43000	-39	13	3	-42	0.990
45000	-41	13	3	-44	0.990
47000	-42	13	3	-46	0.990
49000	-44	13	3	-47	0.990
51000	-46	13	4	-49	0.990
53000	-47	13	4	-51	0.990
55000	-49	13	4	-53	0.990
57000	-51	13	4	-54	0.990
59000	-52	14	4	-56	0.990
61000	-54	14	4	-58	0.990

Biomass (Reference = 50000)

Quota	Mean	Std. Err.	Bias Adj.	Mean	Prob
1000	88384	28359	11155	77228	0.040
3000	86857	28221	11124	75733	0.080
5000	85331	28084	11092	74238	0.080
7000	83804	27947	11061	72743	0.110
9000	82277	27812	11029	71248	0.110
11000	80751	27678	10997	69754	0.130
13000	79225	27545	10966	68259	0.130
15000	77699	27413	10934	66764	0.200
17000	76172	27283	10903	65270	0.200
19000	74646	27153	10871	63775	0.200
21000	73120	27024	10839	62281	0.200
23000	71595	26897	10808	60787	0.220
25000	70069	26771	10776	59293	0.280
27000	68543	26646	10744	57799	0.320
29000	67018	26522	10713	56305	0.340
31000	65492	26399	10681	54811	0.360
33000	63967	26277	10649	53318	0.370
35000	62442	26156	10618	51824	0.410
37000	60917	26037	10586	50331	0.440
39000	59392	25918	10555	48838	0.490
41000	57868	25801	10523	47345	0.550
43000	56344	25684	10492	45852	0.590
45000	54819	25569	10460	44359	0.620
47000	53295	25455	10429	42866	0.640
49000	51772	25342	10398	41374	0.660
51000	50248	25229	10367	39882	0.680
53000	48725	25118	10336	38390	0.710
55000	47203	25008	10305	36898	0.800
57000	45680	24898	10274	35406	0.840
59000	44158	24789	10244	33915	0.860
61000	42637	24680	10214	32423	0.880

```
Bootstrap risk results copied to ClipBoard

THURSDAY, OCTOBER 12, 2000  4:11:03.750 PM
APL  Ver. 2.0.00

ADAPT_W  Ver. 2.1

Workspace size = 6000000
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Blackfin: NAFO SC Workshop – ADAPT Tutorial
Bias adjusted

Impact of 1996 quota, assuming quota of 20000 t taken in 1995.

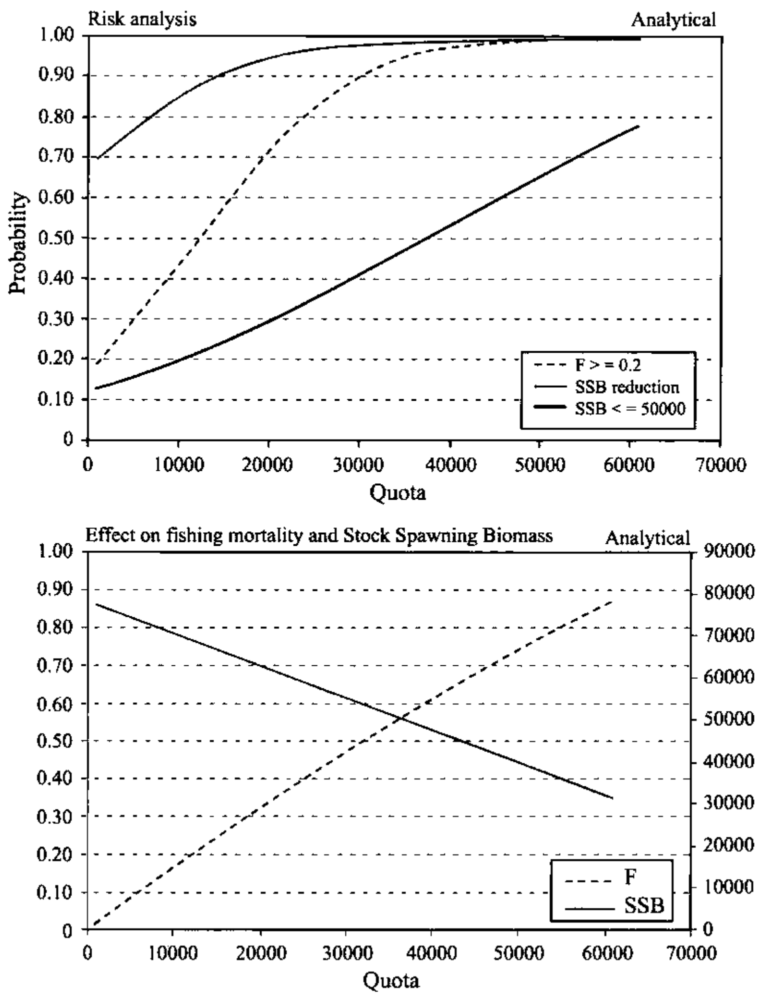
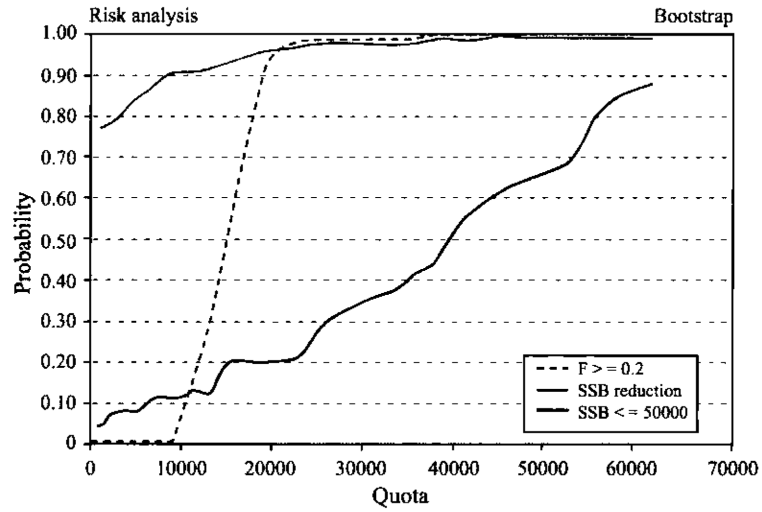


Fig. 2. Graphical representation of catch projections and risk calculations using the analytical approach.

Blackfin: NAFO SC Workshop – ADAPT Tutorial
Bias adjusted

Impact of 1996 quota, assuming quota of 20000 t taken in 1995.



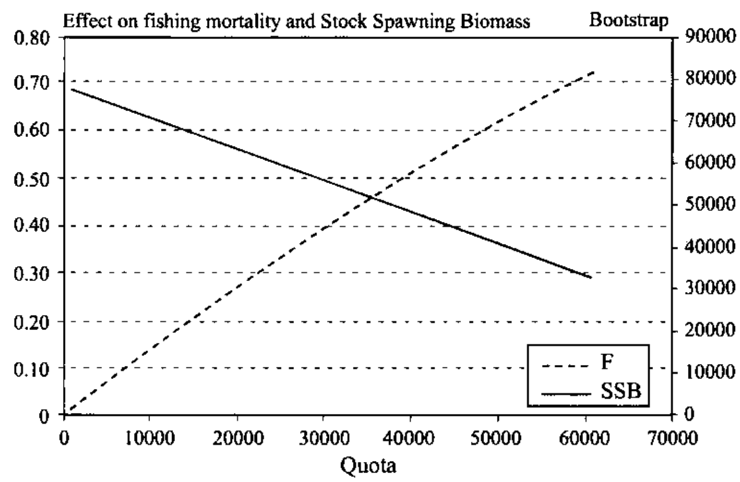


Fig. 3. Graphical representation of catch projections and risk calculations using the bootstrap approach.

APPENDIX 5. Stochastic Projections in the Context of the Precautionary Approach

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Appendix 5: Stochastic Projections in the Context of the Precautionary Approach

by

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Abstract

This document is intended as a tutorial to explore risk analyses using spreadsheets. The tutorial uses @Risk, an Add-in to the Excel spreadsheet software to add risk analysis capabilities to your models. The Add-in provides a framework to handle probability distributions for any variable or input parameter to a model. It also provides tools to analyze the distribution of the results, i.e. any calculated field (or cell) dependent upon your input. The concepts are applied to a fisheries model allowing long-term projections in the context of the Precautionary Approach.

Introduction

This document is intended as a tutorial for the use of @Risk (Anon. 2000), an Add-in to Excel (Microsoft Corp., WA, USA), in the context of fishery models. This add-in allows a user to specify probability distributions for any variable or parameter of a model specified in an Excel spreadsheet. It also provides the tools necessary to analyze the distribution of the results, i.e. of any calculated field (or cell) dependent upon input quantity (or cell).

In this tutorial, we will 1) learn how to use @risk functions, 2) explore @Risk menus for setting up a simulation, 3) develop a simple model and run a simulation, 4) explore results using @Risk interface, 5) apply what we have learned to a model allowing long term projections in the context of Precautionary Approach (PA) frameworks.

Simple Model for Tutorial

A simple model will first be constructed to explore the use of @Risk functions for simulating probability distributions. Load the spreadsheet "LogNormal Study.xls". Type the following equations in the designated cells:

Cell	Equation
B9	=RiskNormal(B5,C5)
C9	=RiskStdDev(B9)
D9	=RiskOutput() + EXP(B9)
E9	=RiskStdDev(D9)
F9	=RiskMean(D9)
G9	=RiskPercentile(D9, 0.5)
H9	=RiskMean(B9)

You have entered three types of @Risk functions. The first type, such as RiskNormal(mean, standard deviation) describes a probability distribution of an input to your model (parameter or variable). The second type, such as RiskStdDev(B9), allows you to monitor the characteristics of a distribution for a cell (here Excel cell B9). The third type, such as RiskOutput(), tells @Risk that this is an entry that you want to monitor with @Risk; @Risk will monitor the distribution of the values of this output cell when the input cells are sampled during simulations.

At this point, load @Risk. The @Risk software is generally loaded from the Windows Start Menu, under "Programs - Palisade Decision Tools / @Risk 4.0 for Excel".

1. **In Excel sheet "LogNormal Study.xls":**
2. **Select the "Simulation Settings" Menu.**
3. **Select "Iterations" tab.**
4. **Enter 1000 in the "# iterations" box.**
5. **Ensure that the "Update display" selection is marked.**
6. **Select the "Sampling" tab.**
7. **Ensure that the "Latin Hypercube" selection is marked.**
8. **Click OK.**
9. **Select the "Start Simulation" Menu. The simulation will start. When the simulation is completed, the Risk Result display will appear. The "Summary Statistics" sheet in Tab 1 summarizes the statistics (minimum, mean, maximum, etc.) for each of the output and input cells.**
10. **In the @Risk Explorer window, select the Output marked "D9-Normal(lnN,lnSD / N" entry.**
11. **Select "Insert / Detailed Statistics". The detailed statistics sheet will appear.**
12. **Because we have used the @Risk functions to return the results to our spreadsheet, the results of interest also appear in the proper cells in the Excel spreadsheet. Return to the Excel sheet by selecting the Excel Icon. See the results displayed in F9 and G9: these cells provide the mean and median of D9, respectively. While the @Risk Output functions are useful to return results quickly to your spreadsheet, you can always go back to the @Risk menus to get more details on the statistics of your input or results.**

As an exercise, we will now use the log-normal functions of @Risk to generate log-normal data directly. @Risk provides two ways to generate log-normal data. We will use the LogNormal2 function to generate log-normal data directly from the parent normal distribution.

Type the following equations in the designated cells:

Cell	Equation
D10	=RiskLogNorm2(B5,C5)
B10	=RiskOutput() + LN(D10)
C10	=RiskStdDev(B10)

Note that you can display the distribution of an input cell by selecting the Define distribution icon on the @Risk Toolbar.

Select cells E9-H9 and paste starting at the E10 cell. The following entries will be created.

Cell	Equation
E10	=RiskStdDev(D10)
F10	=RiskMean(D10)
G10	=RiskPercentile(D10, 0.5)
H10	=RiskMean(B10)

Repeat steps 9–12 above to run a new simulation. You should **note that the value displayed in an Excel cell does not necessarily correspond to the mean of the inherent distribution**. Inspect the results of D9 and F9, for example. What is displayed in D9 is EXP(value displayed in B9), not the mean of the distribution in D9. If a cell contains an @Risk distribution, @Risk provides options to display in this cell either the last value sampled or the expected value of the underlying distribution. When working with distributions and @Risk functions, it is important to make a distinction between what is displayed at the end of a simulation and the characteristics (mean, median, etc.) of the distribution underlying a given cell/entry.

@Risk Functions

There are more than 30 distribution functions available in @Risk. You can invoke the functions like you would do for any Excel-function, either by typing them directly into any cell, or by using the menu.

13. **In Excel sheet "LogNormal Study.xls":**
14. **Select the cell D12.**
15. **Select the "Insert/Function" Menu.**
16. **In the "Function Category:" box, select @Risk Distribution.**
17. **In the "Function Category:" box, scan the list to get an appreciation of the distributions available. Select RiskLogNormal.**
18. **You will see a menu allowing you to specify the Mean and Standard deviation for the function. Enter D6 for the Mean and E5 for the standard deviation. Click OK.**
19. **The function will be inserted in cell D12.**

Graphical Output of Results in Spreadsheet

You can produce a graph of the distribution of any "input" or "output" cell directly in the Excel spreadsheet by using the RiskResultsGraph() function.

Cell	Equation
A15	=RiskResultsGraph(D9,B15:F30,0,TRUE,5,95)
A32	=RiskResultsGraph(D10,B32:F47,0,TRUE,5,95)
A49	=RiskResultsGraph(D12,B49:F64,0,TRUE,5,95)

Repeat steps 9–12 above to generate the Graph.

Discussion:

This part of the tutorial was intended to set up the stage for a discussion on the input to be used in long-term projections. What should be the distribution of the abundance estimates for the starting year, for instance? Note how different the distributions could be, depending on what distribution is used to generate the input.

For estimates coming from an ADAPT model (see Rivard and Gavaris, 2000), the common practice has been to use the log-normal distribution with a mean corresponding to the bias-corrected estimate on the arithmetic scale and with a standard deviation corresponding to the standard error of the estimate. Bias-correction is suggested because ADAPT uses a non-linear estimation procedure to get its estimates. Simulations attempting to simulate the assessment procedure suggest that the bias-corrected results give estimates that are consistent with the "true" value. Note that this aspect is still under active investigation by a number of experts.

The point here is that for your projections to be representative of the real world, care should be taken to model distributions that are consistent with your observations and with the dynamics of your stock (e.g. no negative values possible, etc.). Insights on the error structure of the inputs for @Risk models require thorough investigation of available data.

You can also generate graphs from the @Risk – Results sheet.

20. In the @Risk Explorer window, select the Output marked "D9-Normal(lnN,lnSD / N" entry.
21. Select "Insert / Graph / Histogram". The histogram will appear in a separate sheet. You can change the format of this graph by using one of the "Format Active Graph" Icons.

Adding and Removing the Output Function from Selected Cells

To monitor the distribution of a given variable (or cell), you need to add the Output function to that cell. You can do this by entering the RiskOutput() function directly in the cell, as was done in cell B10 above, or by clicking the "Add to Output" Icon in the @Risk menu. For example, cell B12 has been defined as follows:

Cell	Equation
B12	=LN(D12)

22. In Excel sheet "LogNormal Study.xls":
23. Select the cell B12.
24. Select the "Add Output" icon. That cell will be added to the output list. You will see that the function RiskOutput() has been added to the B12 cell, i.e. added to its original content.
25. You can also check that B12 is indeed in the Ouput list by selecting the "Display List of Outputs and Inputs" icon. Do it now. The @Risk-Model panel will appear.

To remove a variable or cell from the Output list, do the following:

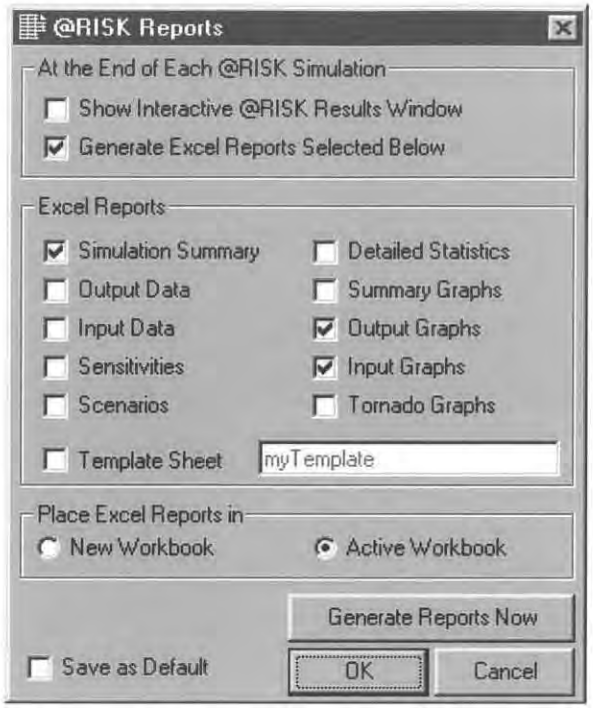
26. In Excel sheet "LogNormal Study.xls":
27. Select the "Display List of Outputs and Inputs" icon.
28. Select the cells for which you wish to delete from the Output list in the @Risk explorer's window.
29. Select from the menu "Model / Delete Ouputs". You will be asked "Are you sure you want to delete this ouptut?". Select Yes. The RiskOutput() function will be deleted from the cells selected. Note that the original formula in this cell remains intact. Only the RiskOuput() function has been removed, so that the cell will not be monitored anymore by @Risk.

Reports

Simulations results may be displayed in the @Risk Results Window or sent directly to the Excel spreadsheet.

30. In Excel sheet "LogNormal Study.xls":
31. Select the "Report Settings" icon on the @Risk tooolbar.
32. In the "At the End of Each @Risk Simulation" section, select only "Generate Excel Reports Selected Below".
33. In the "Excel Reports" section: Select "Simulation Summary", "Ouput Graphs" and "Input Graphs".
34. In the "Place Excel reports in" section: select "Active Workbook".
35. Select the OK button to activate these options.

At the end of step 34, the @Risk Report template should look like this:



Run a simulation now to see how these reports are generated. The reports selected will be put automatically your excel spreadsheet at the end of each simulation. Note that if you have many Input and Output cells in your model, the number of graphs could be large. In such a case, you should probably focus on key cells and generate the graphs of interests directly in Excel using the procedures explained in the "Graphical Output of Results in Spreadsheet" section (see above).

Identification of Entries in @Risk Interactive Windows

Go to the @Risk-Results Window to see how @Risk identifies Input and Output cells in its interactive windows. For instance, one of the inputs is identified as "D9 – Normal(lnN, lnSD / N". The cell for this input is D9. @Risk also adds labels by scanning your spreadsheet for the nearest label to the left of the cell of interest, as well as the nearest label above the cell of interest. In the case at hand, the nearest label to the left is "Normal(lnN, lnSD)" and the nearest label above D9 is "N".

Entering descriptive labels in strategic locations makes it easier to analyze your results in the @Risk Interactive Windows. Note that values corresponding to "years" and "ages" generated through Excel formulas are not "seen" as labels. You must create labels from these formulas (i.e. where numbers are defined as "text") to allow @Risk to generate proper entries.

Long-term Projections

We will explore further the use of @Risk in a fish population dynamics model developed to evaluate the outcome of harvest control rules (HRCs) in the context of the Precautionary Approach. In particular, the spreadsheet can be used to mimic HCRs under the ICES and NAFO PA frameworks, or simply to evaluate constant F-scenarios. It also permits to account for fishing mortality resulting from by-catch in periods of moratorium.

A description of the model algorithm is given in Annex 1. Additional examples using this model are provided in Rivard *et al.* (1999a and 1999b).

The model is contained in the Excel spreadsheet "PA-HRCs.xls". The use of @Risk in combination with this model allows someone to specify uncertainty in initial conditions of the state variables and in certain population dynamic parameters (we focus here on the definition of the stock-recruit relationship). The resulting model provides a framework to calculate the probability of achieving limits or targets in the simulation years, to calculate the time it takes to reach these targets and to evaluate other elements of interest to managers (e.g. number of closures after re-opening, recovery time).

Using this model, we will illustrate the use of @Risk to simulate the effect of various harvest control rules. In doing so, we will take the following steps:

1. Select and define the Precautionary Approach framework.
2. Input abundance estimates and define their distributions.
3. Input historical data on the stock (to relate the past to the future).
4. Select/define the stock-recruit relationship.
5. Run simulations/scenarios.

The @Risk distributions commonly used in such a model would be

- LogNorm (mean, standard deviation)
- LogNorm2 (mean of corresponding normal dist., standard deviation of normal)
- Duniform ({X_1, X_2, ..., X_n }), i.e. discrete uniform distribution with n possible outcomes having equal probability of occurring.
- SIMTABLE ({X_1, X_2, ..., X_n }), where the X_i are a list of values to be used in each of a series of simulations.

If you have not already done so, load the "PA-HRCs.xls" Excel spreadsheet now.

1. **Select and define the Precautionary Approach framework**

The model simulates the response of the stock to fixed levels of fishing mortality or to specify harvest control rules in relation to a PA framework. Three PA frameworks are already programmed: the ICES PA Framework, the NAFO PA Framework and a general framework allowing more flexibility in specifying harvest control rules in relation to PA reference points (Fig.1). These frameworks are pre-defined in cells E10-H19. To enable one option, copy the relevant cells to cells C10-C19. For example, to enable the constant F option,

36. **In the Excel file "PA-HRCs.xls":**
37. **Select the "Input" tab.**
38. **Copy cells G10-G19 to C10-C19.**
39. **See how the PA framework graph changes to reflect the selection.**

The constant F option uses a special @Risk function, SIMTABLE(), allowing someone to specify a list inputs to be used sequentially in a series of simulations, i.e. simulations at various fishing mortality levels in our case. See the formula in cell C10.

40. **If not already loaded, load @Risk Version 4.0.**
41. **Select the "Simulation Settings: icon on the @Risk Toolbar.**
42. **In the "# iterations" box, enter 40.**
43. **In the "# simulations" box, enter 10.**
44. **In the "Each Iteration" section, select "Update display".**
45. **Select the OK button.**
46. **Select the "Calc" tab.**
47. **Select the cell AS329 (corresponding to the yield in the last year of the projection.**
48. **Select "Add Output" on the @Risk Toolbar.**
49. **Select the "Monitor" tab.**
50. **Select the "Start Simulation" icon on the @Risk Toolbar.**

You will see in the @Risk-Results Screen that 10 simulation have been run, each with a different value for fishing mortality, as listed in cell C10 of the "Input" sheet.

Discussion:

If someone assumes that "equilibrium" has been reached in that year, the results of this simulation essentially give an approximation of the underlying production curve, with its confidence intervals. By declaring the biomass, fishing mortality and yield as Ouput to @Risk, you can generate the Yield/F graphs and Yield/biomass graphs typical of production analyses.

2. **Input abundance estimates and define their distributions**

For simulating the error in the estimation of the initial stock size, the initial population size will be sampled with @Risk from a log-normal distribution. Other distribution could be used, depending of the origin of the estimates of the initial stock size. Input values for the projections are given in Table 1.

NOTE: *To be consistent with projections made in ADAPT, the log-normal distribution should have a mean equivalent to the bias-corrected estimate (on the linear scale). The standard deviation of the log-normal distribution is to be taken as the standard error of the stock size estimate on the linear scale.*

51. **In the Excel file "PA-HRCs.xls" (re-load this sheet to ensure that you have it in its original form):**
52. **Select the "Input" tab.**
53. **Cells E45-E65 contain the initial estimates of stock size.**
54. **Cells F45-F65 contain the corresponding C.V.**
55. **Cells H45-H65 contain the weight-at-age, mid-year.**
56. **Cells I45-I65 contain the weight-at-age, start of year.**
57. **Cells J45-J65 contain the partial recruitment to be applied to the fishing mortality.**
58. **Cells K45-65 contain the maturity at age.**
59. **Cells L45-65 contain 0 or 1 to indicate which ages are to be used in calculating the mean F (to generate the values needed for certain scenarios).**

3. **Input historical data on the stock**

60. **In the Excel file "PA-HRCs.xls".**
61. **Select the "Input" tab.**
62. **Cells C75-C115 contain the fishing mortality for the years specified.**
63. **Cells D75-D115 contain the Stock Spawning Biomass (SSB).**
64. **Cells E75-E115 contain the Stock Spawning Numbers (SSN).**
65. **Cells F75-F115 contain the recruits.**
66. **Cells G75-G115 contain the population size (total numbers).**
67. **Cells H75-H115 contain the biomass (total weight).**
68. **Cells I75-I115 contain the total yield.**
69. **Cells J75-J115 contain the total catch, in numbers.**

Historical data are listed in Table 2. These are needed for graphical display and, under certain scenarios, could be needed for setting up the re-sampling of the historical SSB-recruit observations.

Discussion:

These entries should be consistent with the estimates of initial stock size, e.g. use bias-corrected estimates if the initial stock size estimates have been bias-corrected. Also, typically, the historical SSB-recruit pairs are expected to be correlated with estimates of initial stock size. For more realistic simulations, taking such correlation into account may be necessary. This could be done in various ways (e.g. correlation calculated from bootstrap results or direct re-sampling of bootstrap results) but this could become quite complex and such exploration is beyond the scope of this tutorial.

4. **Select/define the stock-recruit relationship**

Long-term simulations must make assumptions on the dynamics linking recruitment to the stock spawning biomass. Long-term simulations are very sensitive to the characteristics of the spawner-recruit description. Often, recruitment and spawning stock size are only weakly related.

Many authors have suggested various ways to capture both the dynamics and the uncertainties of the recruitment process by re-sampling the recruit-SSB scatter points. In this spreadsheet, one option available is to split the observed range of SSB into quartiles and to resample the observed recruitment within these quartiles. Since this approach is based on re-sampling observations, it does not require making assumptions about the recruitment probability density function (pdf). Depensation at lower levels of SSB, varying degrees of compensation and the variability of the response of recruitment to SSB levels typically observed make it particularly difficult to derive functional relationships that are convincing. The benefit of non-parametric descriptions of stock-recruitment relationships is that they are able to capture the dynamics of the recruitment process without requiring explicit assumptions about the shape of the relationship. One requirement, however, is that the dynamics has been captured in the range of observations previously observed.

Other options for the stock recruit relationship are 1) "stationary" recruitment, i.e. recruitment assumed to be coming from a log-normal distribution with a given mean and standard deviation and 2) recruitment assumed to be coming from a Beverton-Holt relationship with an error term.

To select the desired option for the stock-recruit relationship.

70. **In the Excel file "PA-HRCs.xls":**
71. **Select the "Input SR" tab.**
72. **Adjust the parameters for the model to be used and select the desired model by clicking on the appropriate "Select this S/R Model" button. In our case, we will use the default (re-sampling the observations), so there is no need to activate any of the buttons at this stage.**
73. **Select the "Calc" tab.**
74. **Go to cells I19-AS19 to ensure that the proper formulas have been transferred to these cells.**

    NOTE that you may have to adjust these formulas so that the SSR and recruitment are lagged properly.

If the "re-sampling the data points" option has been selected, you will need to make additional adjustments to ensure that the quartiles for re-sampling recruitment are defined properly. A working area (cells A459-S526) is provided at the bottom of the "Calc" sheet to define these quartiles. Follow the instructions in this area. Note that the re-sampling of the observations is done through the @Risk function RiskDuniform() [see the formula in cell I19].

5. **Run simulations/scenarios**

To illustrate the use of such a model, we will run a simulation using the NAFO PA framework. Our interest will be the impact of this scenario on the Stock Spawning Biomass and Yield.

75. Load the original Excel file "PA-HRCs.xls" to ensure that default values are defined properly for this tutorial.
76. Select the "Input" tab.
77. Select the NAFO PA framework by copying cells G10-G19 to C10-C19.
78. See how the PA framework graph changes to reflect the selection.
79. If not already loaded, load @Risk Version 4.0.
80. Select the "Simulation Settings: icon on the @Risk Toolbar.
81. In the "# iterations" box, enter 100.
82. In the "# simulations" box, enter 1.
83. In the "Each iteration" section, select the "Update display" option.
84. Select the OK button.
85. Select the "Calc" tab.
86. Select the SSB for 1999 to 2036 by selecting the cells H-281-AS281.
87. Select "Add Output" on the @Risk Toolbar.
88. You will be prompt to "Enter a name for this output range:": Enter "SSB".
89. Select the Yield for 1999 to 2036 by selecting the cells H-329-AS329.
90. Select "Add Output" on the @Risk Toolbar.
91. You will be prompt to "Enter a name for this output range:": Enter "Yield".
92. Select the "Monitor" tab (the Monitoring Windows are also illustrated in Fig. 2).
93. Select the "Start Simulation" icon on the @Risk Toolbar.

The simulation will start and the results reported in the @Risk Results window.

94. In the @Risk Results Widow:
95. Select the Stock Spawning Biomass for 2010 in the left hand-side explorer.
96. Select "Insert / Graph / Histogram" from the Menu. A histogram representing the distribution of the biomass for 2010. See how individual simulation results stand in relation to the biomass limit value of 60 000 t.
97. To see a graph of the distribution of SSB for all years in the simulation, select the "Range Summary" tab above the graph. A graph will appear showing the spread of SSB for each year of the simulation.

How simulation results stand in relation to "Target values" can be investigated further with @Risk. The probability of achieving a specific target or outcome can be calculated using the

98. In the @Risk Results Widow:
99. Select the "Summary Statistics" Window.
100. In the "x1" column, enter "60000" in the SSB/2010 row.
101. See how the corresponding probability adjusts to your entry.
102. When a range of output has been specified, someone can get time trends in the probability of meeting the target. For instance, in the "x1" column, enter "60000" in the SSB/1999 row.
103. While your are still pointing at this cell, extend your selection so as to include the entire range of SSBs. Use the "Fill Down" command to copy your entry (i.e. "60000") to all rows corresponding to the SSB range.
104. See how the corresponding probability adjusts to these entries. In essence, you now have the probability of simulation results being below the biomass limit for each year of the simulation.

As an exercise, repeat the preceding steps to calculate the probability of returning to an historical yield of 25000 t.

Harvest Control Rules

Harvest control rules are, in essence, rules that dictate the application of a fishing mortality in a given projection year. What triggers the application of a given fishing mortality level is where the current fishing mortality and Stock Spawning Biomass stand in relation to reference points.

You can define your own rules and test their impact using a spreadsheet such as the one provided here. In the "Calc" sheet, rows 332–340 act as placeholders for the rules that you wish to investigate. The rules pre-programmed here have been designed for the purpose of this tutorial to illustrate various ways of programming harvest control rules under the General PA Framework. If you use this spreadsheet as a template for your own simulations, you will have to put in these rows the HRCs that you wish to test. To illustrate the process that you have to follow, we describe below a decision rule to control harvest, which is based on six rules that can be triggered when SSB_t and F_t values are within predefined ranges delimited by reference points.

The reference points used as triggers for various actions are as follows:

Symbol	Definition
F_{lim}	Fishing mortality limit
B_{lim}	Spawning Biomass limit
B_{buf}	Buffer for Spawning Stock Biomass (SSB); also the B_{pa} in the Ices Framework.
F_{buf}	Buffer for fishing mortality, also the F_{pa} in the Ices Framework.
F_{closed}	Fishing mortality when $SSB<B_{lim}$; typically, this would correspond to the fishing mortality resulting from a bycatch in other fisheries.
B_{tr}	Spawning Stock Biomass target
F_{atBbuf}	Maximum fishing mortality allowed at B_{buf}
F_{tr}	Target fishing mortality

For each year of the projection, six levels of fishing mortalities are calculated as potential candidates for selection. These six possible levels are as follows [note that the equations given follow the notation for specifying arguments in an Excel IF() function]:

Rule 1:

$$F_1 = \text{If}\,(F_{tr}<F_{closed}\,,\, F_{tr},\, F_{closed})$$

Rule 2:

$$F_2 = \text{If}\,((F_{tr}<(F_{closed}+((F_{atBbuf}-F_{closed})*(1-((B_{buf}-SSB_t)/(B_{buf}-B_{lim})))))),\ F_{tr},\ (F_{closed}+((F_{atBbuf}-F_{closed})*(1-((B_{buf}-SSB_t)/(B_{buf}-B_{lim}))))))$$

Rule 3:

$$F_3 = \text{If}\,((F_{tr}<(F_{atBbuf}+((F_{buf}-F_{atBbuf})*(1-((B_{tr}-SSB_t)/(B_{tr}-B_{buf})))))),\ F_{tr},\ (F_{atBbuf}+((F_{buf}-F_{atBbuf})*(1-((B_{tr}-SSB_t)/(B_{tr}-B_{buf}))))))$$

Rule 4 (progressive reduction in F desired when $SSB_t>B_{tr}$):

$$F_4 = \text{If}\,(F_{t-1}>F_{lim},\ (F_{t-1}-((F_{t-1}-F_{lim})*\text{PercentRule})),\ \text{If}\,(F_{t-1}>F_{buf}\,,\, F_{buf}\,,\ F_{buf}))$$

Note that Rule 4 is used to allow a progressive reduction of the fishing mortality estimated for the previous year towards F_{lim}. The estimate of fishing mortality for the previous year, say F_{t-1}, is assumed to be subject to an estimation error and, as such, is taken from a log-normal distribution with mean F_{t-1} (the F applied to year t-1) and standard deviation calculated from the coefficient of variation provided in the "input" sheet. The coefficient "PercentRule" is a decimal value between 0 and 1 representing the proportion of the difference between F_{t-1} and F_{lim} to be applied to the current fishing mortality to reduce it towards F_{lim}.

Rule 5 (applied when PrecentRule = 0, $F_{tr} > F_{buf}$ and $SSB_t > B_{tr}$):

$$F_5 = F_{tr}$$

Rule 6 (applied when PrecentRule = 0, $F_{tr} <= F_{buf}$ and $SSB_t > B_{tr}$):

$$F_6 = \text{If}\,(F_{t-1} > F_{lim}\,,\, F_{lim}\,,\, \text{If}\,(\,F_{t-1} > F_{buf}\,,\, F_{buf}\,,\, F_{tr}\,)\,)$$

Which "rule" is applied in any given year t depends upon the following decision rule:

$$F_t = \text{If}\,(SSB_t < B_{lim}\,,\, F_1,\, \text{If}\,(SSB_t < B_{buf}\,,\, F_2,\, \text{If}\,(SSB_t < B_{tr}\,, F_3,\, \text{If}\,(\,\text{PercentRule} > 0\,,\, F_4,\, \text{If}\,(F_{tr} > F_{buf}\,,\, F_5,\, F_6)))))$$

Note that the decision rule implemented here is solely intended for the purpose of this tutorial. If this spreadsheet is used as a template for particular case studies, you should ensure that the functions enabled create the decision rule that is suitable for your situation. Most applications will require adjustments/modifications to the harvest control rules presented here.

Time trajectories for fishing mortality, recruitment, stock abundance and biomass, and yield are plotted in the "Time Graphs" sheet (see also Fig. 3). In a typical simulation, thousands of trajectories are obtained through Monte-Carlo re-sampling. The @Risk interface provides the functionality required to monitor the probability profiles for any variable of interest over the projection horizon. When combined with the functionality provided by the Excel statistical functions, it also provides the means to monitor the probability profiles for derivatives of the results (e.g. to measure the variability of the projections over a given time horizon, the mean level of a variable over a given timeframe, etc).

Discussion:

The current model accounts for uncertainty in implementation of the harvest control rules (i.e. fishing mortality actually realized) only when the SSB_t is $>B_{tr}$. How would you change this model to account for uncertainty in the estimation of SSB_t, which is also used to trigger harvest control rules? How would you change the model to take into account uncertainty in implementing the decision rule itself?

You may also wish to take into account of uncertainty in other population parameters, such as those controlling growth. For instance, how would you model stochastic process for growth?

How would you model regime shifts, i.e. shifts in key population dynamics parameters? Are there other ways to account for assessment and implementation uncertainty? How would you change this model to account for correlated error between certain variables?

Limitations of Long-term Projections

Long-term projections make a number of assumptions on the "realization" of key population parameters in future years. While projection models can be made to account for some of the uncertainties, they rarely capture all possible outcomes. Nevertheless, a well-designed model could be useful for evaluating the response of a stock to various exploitation patterns or regimes. As all sources of uncertainty are rarely captured, actual trajectories may deviate substantially from the model results, even when these are expressed in terms of probabilities. For this reason, when long-term projections are used to investigate the impact of various approaches, the results should be interpreted in relative terms (i.e. in relation to other approaches or scenarios) rather than in absolute terms.

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TABLE 1. Stochastic projections require as input the initial estimate of stock abundance and its standard error. as well as data on weights-at-age, partial recruitment and maturity. In addition to these, the historical SSB-recruit pairs are required (see Table 2).

	Abundance			Weight (kg)		Partial	Maturity
Age	Estimate 1999	C.V.	Std Err.	Mid-year 1972–97	Start of year 1972–97	recruitment 1959–97	(proportion) 1975–97
3	113	0.66	74.6	0.55	0.42	0.20	0.00
4	113	0.48	54.2	0.92	0.74	0.64	0.02
5	437	0.40	174.8	1.42	1.15	0.97	0.13
6	297	0.36	106.9	2.15	1.79	1.00	0.46
7	136	0.32	43.5	3.12	2.61	1.00	0.83
8	64	0.35	22.4	4.45	3.71	1.00	0.97
9	394	0.33	130.0	6.42	5.75	1.00	1.00
10	568	0.32	181.8	8.00	7.54	1.00	1.00
11	62	0.33	20.3	8.99	8.17	1.00	1.00
12	44	0.40	17.6	10.90	11.09	1.00	1.00
13	10	0.40	4.0	10.53	10.35	1.00	1.00
14	1	0.40	0.4	10.89	10.71	1.00	1.00
15				11.28	11.08	1.00	1.00
16				11.67	11.47	1.00	1.00
17				12.08	11.87	1.00	1.00
18				12.50	12.29	1.00	1.00
19				12.94	12.72	1.00	1.00
20				13.39	13.16	1.00	1.00
21				13.86	13.62	1.00	1.00
22				14.35	14.10	1.00	1.00
23				14.85	15.11	1.00	1.00

TABLE 2. Historical data on fishing mortality, spawning abundance and biomass, total stock abundance and biomass, recruitment, and yield. The recruitment process is simulated by re-sampling the SSB-recruit pairs within SSB-quartiles.

Year	Fishing mortality	Spawning stock Abundance (#)	Spawning stock Biomass (tons)	Total stock Abundance (#)	Total stock Biomass (tons)	Recruits (#)	Yield
1959	0.428	30617	87921	207010	206497	53067	64370
1960	0.412	27764	74628	190698	191146	52090	79677
1961	0.506	30139	73170	200419	183688	81045	72724
1962	0.296	26755	70048	237003	187355	106515	34984
1963	0.555	31525	77503	257783	225337	77456	69742
1964	0.282	37335	84493	294232	253676	110562	64461
1965	0.655	46115	110168	352275	287897	160052	99187
1966	0.981	39507	104120	453470	338652	207114	108919
1967	0.829	35654	87556	492097	395438	181079	226784
1968	0.842	31775	78821	358255	320412	99509	165511
1969	0.571	25133	67143	286634	242353	126175	117705
1970	0.556	25942	69411	256537	232731	79267	111561
1971	0.603	28963	76002	249719	241423	83222	126296
1972	0.677	26818	73505	196905	198393	61009	103374
1973	0.515	19817	65822	147611	173992	34539	80429
1974	0.991	18636	62841	100666	130332	36122	73389
1975	1.617	9729	31367	65444	62800	22725	44174
1976	0.386	4208	10680	61495	43083	26976	24283
1977	0.581	3512	11278	77826	56494	44648	17604
1978	0.248	5235	14953	97205	80937	40875	14718
1979	0.326	10183	23678	88377	99809	17069	27851
1980	0.184	14968	37512	76327	101039	19361	19991
1981	0.238	24986	69035	81762	128589	27015	24344
1982	0.293	22146	82581	81045	148790	21326	31605
1983	0.219	21625	84671	92942	164147	34672	28819
1984	0.250	22913	87284	109541	173627	40710	27103
1985	0.358	21060	82186	113844	173605	31807	36899
1986	0.388	16555	77906	86423	148619	8613	50645
1987	0.352	19567	80815	60946	127221	6332	41619
1988	0.573	15521	51035	50823	86929	12464	43150
1989	0.516	14498	49712	40531	71981	12326	33215
1990	0.601	8088	36672	28076	54449	4902	28846
1991	0.936	5506	27742	16331	36585	5180	29454
1992	0.631	3107	11717	21875	23202	13646	12752
1993	0.696	2061	5222	16185	11639	5984	10646
1994	0.335	1740	2759	8207	6851	540	2702
1995	0.013	2162	3204	3552	4346	331	172
1996	0.025	2424	4544	3326	5281	568	174
1997	0.057	2159	4807	3287	5533	641	442
1998	0.068	1941	5893	2648	6479	125	150
1999		1732	6282	2061	6414	87	

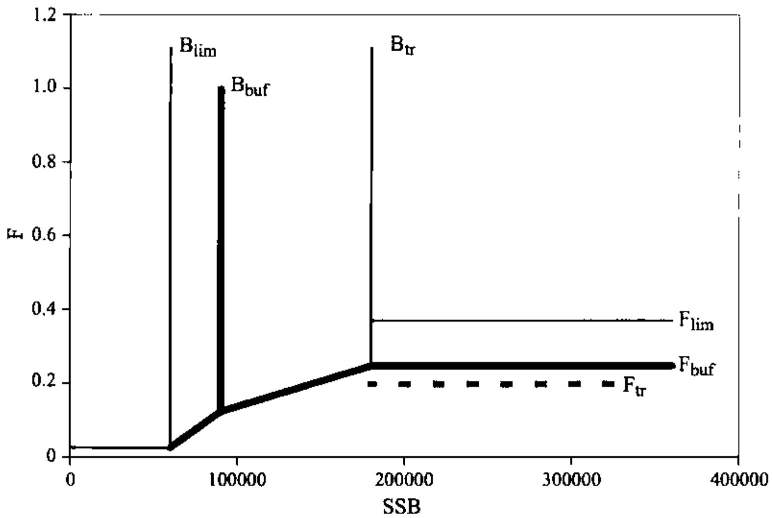

Fig. 1. Generalized framework for a precautionary approach. Controls are provided in terms of a fishing mortality limit (F_{lim}), a spawning biomass limit (B_{lim}), a buffer for fishing mortality (F_{buf}), a buffer for spawning biomass (B_{buf}) and a spawning biomass target (B_{tr}). The impact of by-catch due to fishing on other species can be evaluated by specifying a fishing mortality level below the biomass limit. Also, as separate control rules can be specified above and below B_{buf}, the generalized framework can be used to mimic the features of the ICES or the NAFO precautionary approach frameworks.

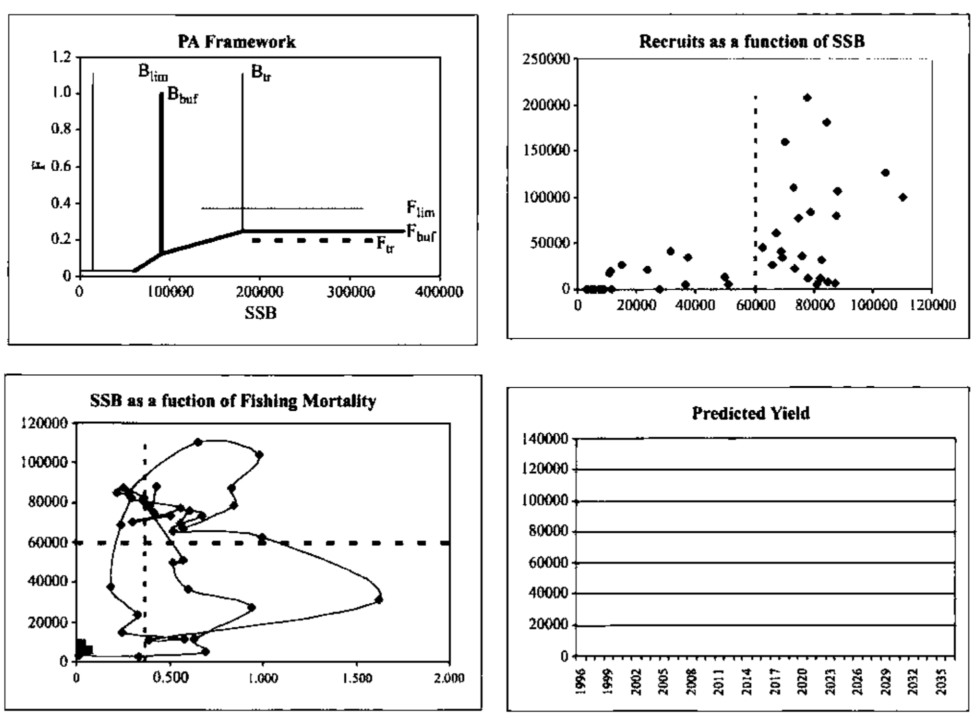

Fig. 2. "Windows" to monitor the simulations. As the simulation proceeds, the stock and fishery trajectories are displayed in these windows to monitor its progress.

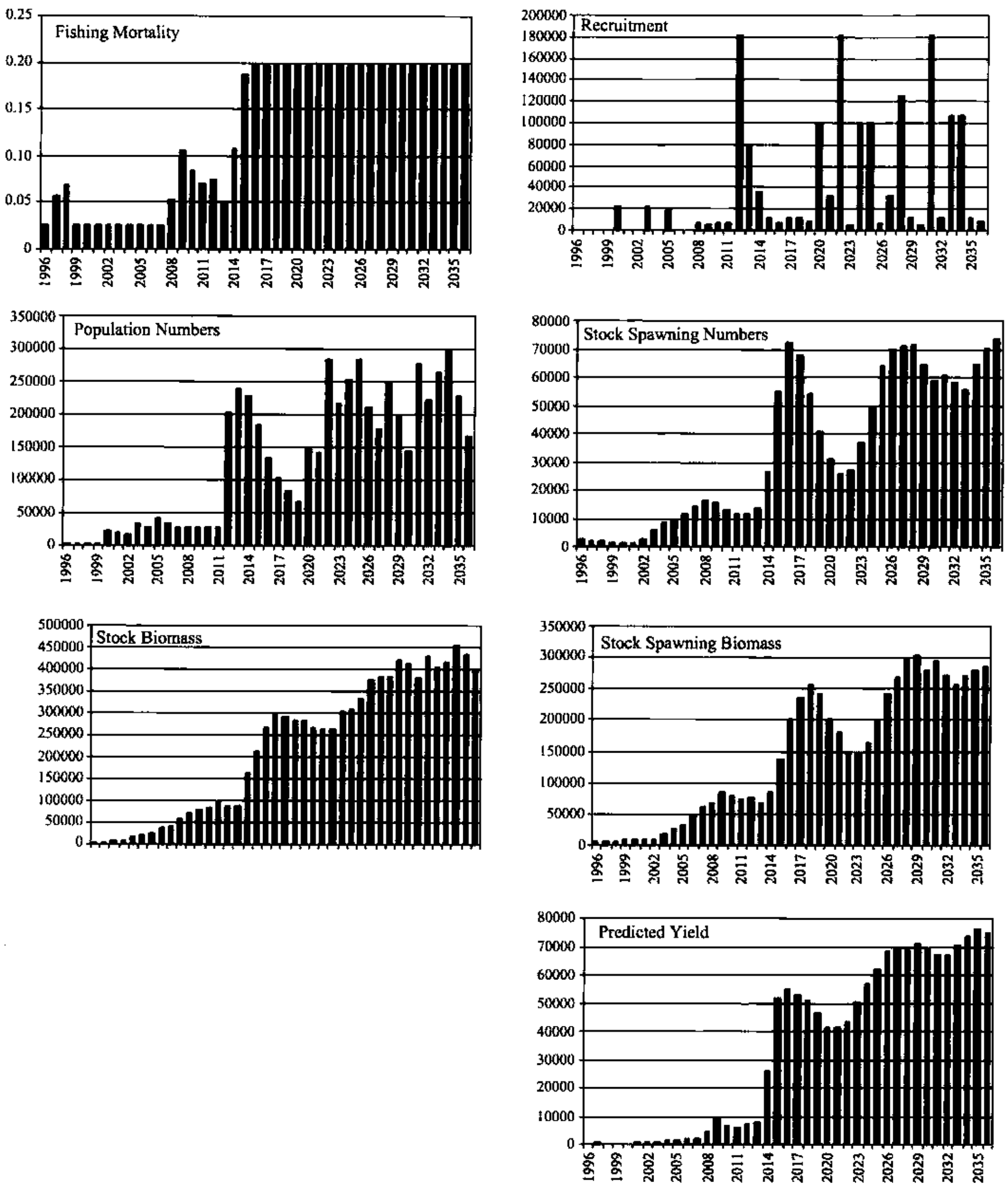

Fig. 3. Time trajectory for fishing mortality, recruitment, stock numbers and biomass (spawning and total), and yield. Represented here are the results for only one of the replicates realized during the Monte-Carlo simulation. In a typical simulation, thousands of replicates are generated.

Annex 1. Population Dynamics Algorithm

Notation. The subscripts *i* and *t* are used below to identify an entity at a specific time while the Greek letter ι identifies the interval between *i* and *i+1*, and τ, the interval between *t* and *t+1*.

The input information required for the simulation consists of:

$N_{i,t}$	Population numbers at age i, for the first year of your projection. Estimates of population numbers and their variances, are typically obtained from age-structured analyses of historical data on catch information and survey indices.
$W_{i+0.5}$	Mid-year estimates of weight-at-age, in kilograms.
W_i	Beginning-of-year estimates of weight-at-age, in kilograms.
d_i (i=3, ..., 23) :	a value, between 0 and 1, indicating the proportion of fish in age-group i which are have attained maturity.
r_ι	"Partial recruitment" coefficients. These are values, between 0 and 1, indicating the proportion of fishing mortality to be applied to age-group i,i+1.

The instantaneous rate of natural mortality, M, is assumed to be constant for all ages and all years included in the simulations.

Fishing strategies. The evaluation of harvest control laws requires the application of a target fishing mortality for each year considered in the projection, say F_τ. The calculation of the instantaneous fishing mortalities at each age in each year-period $_\tau$ are given by:

$$F_{\iota,\tau} = r_\iota F_\tau$$

where r_ι are the "partial recruitment" coefficients.

Population numbers. The number of fish at age i in year t is given by:

$$N_{i,t} = N_{i-1,t-1} \exp(-Z_{\iota-1,\tau-1})$$

where

$$Z_{\iota-1,\tau-1} = F_{\iota,\tau} + M_{\iota,\tau}$$

Fish are assumed to leave the exploited stock beyond the oldest age-group. For each year of the projection, the numbers in the first age-group considered are set equal to the recruits R_t. The recruits in each year come from a stock recruit relationship, which is to be specified by the user.

The total number of fish is given by:

$$N_{\bullet,t} = \Sigma N_{i,t}$$

where the summation is over all ages *i*. Similarly, the total number of mature fish in year t is given by $\Sigma\ d_i N_{i,t}$, where the summation is over ages.

Population biomass. The age-specific biomass at the beginning of each year is given by:

$$B_{i,t} = W_{i,t} N_{i,t}$$

The total biomass is given by:

$$B_{\bullet,t} = \Sigma\ B_{i,t}$$

where the summation is over all ages. Similarly, the total biomass of mature fish at the beginning of each year is given by $\Sigma\ d_i B_{i,t}$. The average biomass (age-specific) for each year is given by:

$$B_{i,t} = W_{i+0.5} N_{i,t}\ (1 - \exp(-Z_{i,t}))\ /\ Z_{i,t}$$

Catch in numbers. The catch at age in each year is given by:

$$C_{i,t} = F_{i,t} N_{i,t}\ (1 - \exp(-Z_{i,t}))\ /\ Z_{i,t}$$

The total number of fish in the catch in any given year is given by:

$$C_{\bullet,t} = S\ C_{i,t}$$

Yield. The age-specific yield is calculated in any given year as:

$$Y_{i,t} = W_{i+0.5}\, C_{i,t}$$

The total yield in any given year is given by:

$$Y_{\bullet,t} = S\ Y_{i,t}$$

APPENDIX 6. AGEPRO Stochastic Simulations: Woods Hole Fisheries Assessment Compilation Toolbox (FACT)

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Appendix 6: AGEPRO Stochastic Simulations: Woods Hole Fisheries Assessment Compilation Toolbox (FACT)

Outlines and Data Sets

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Abstract

FACT is the Fishery Assessment Compilation Toolbox and the Woods Hole Assessment Toolbox's successor. Several existing assessment programs have been added to FACT making it a powerful and user-friendly tool. The assessment programs previously existed in a DOS or UNIX environment. These programs now have a user-friendly interface that makes editing of inputs and analyzing data easier, and completion of assessments more intuitive.

AGEPRO was added to FACT to allow a seamless transition from VPA results to catch forecasts. The AGEPRO program performs stochastic projections of the abundance of an exploited age-structured population over a time horizon of up to 25 years. The primary purpose of the AGEPRO model is to characterize the sampling distribution of key fishery system outputs such as landings, spawning stock biomass, and recruitment under uncertainty. The acronym "AGEPRO" indicates that the program performs age-structured projections in contrast to size- or biomass-based projection models.

This document shows how to run AGEPRO using a sample input file to define the run parameters, recruitment options and biological inputs. A description of the various files containing the VPA bootstrap results that are required to initiate the catch projections is given. Sample results from the completion of a set of projections under 4 recruitment options are also provided, and a description of the output file containing the projection results is given.

Introduction

The overall purpose of FACT is to develop a set of standard tools for scientists to use for stock assessment. There is a growing need for a set of standardized and verified software for conducting stock assessments. The toolbox allows analysts to use a variety of assessment models to select options and produce diagnostics appropriate to a particular methodology. A suite of programs has been developed which includes modules for data input, formatting and error checking, and exploratory data analysis for a variety of assessment approaches.

The individual models of the toolbox were stand-alone, DOS or Unix based components, which were recompiled into dynamic link libraries and integrated with a Windows interface. At present the available models include Virtual Population Analysis (VPA) with retrospective and bootstrapping capabilities (ADAPT), Age Projection (AGEPRO), Yield per Recruit and Spawning Biomass per Recruit, and A Stock-Production model Including Covariates (ASPIC) with projection, and Precautionary Approach software. A comprehensive on-line help is also available with FACT.

In this Workshop we will use two of the modules, ADAPT and AGEPRO. This document describes the use of the AGEPRO module.

AGEPRO

This module is the implementation of age-based stochastic projection software in FACT. The stock sizes at age estimated at the end of the terminal year of the VPA are used as input for the forward projection. The stochastic aspect of the projection is based on 2 sets of input data:

1. The results of the Bootstrap procedure run in ADAPT. The example bootstrap file, **gmcod2000_base.2bootN**, contains 1 row for each bootstrap iteration performed in ADAPT. Each age is in a separate column.

2. The incoming recruitment estimated for each year in the projection time horizon.

AGEPRO is generally used to forecast catches several years ahead, based on an input set of annual fully recruited instantaneous fishing mortality rates. AGEPRO can also iteratively solve for F, given an input set of annual catches. It is also possible to specify a target SSB level, and AGEPRO will determine the probability of exceeding the target in each year of the projection time horizon.

Input

All of the Workshop example data files for FACT are in: **C:\Workshop\Fact**

The age-based forward projection starts in the year immediately following the terminal year of the VPA. In addition to the initial stock sizes-at-age and incoming recruitment, many of the same input data used in the VPA are required in AGEPRO, including:

Mean catch weights-at-age
Mean stock weights-at-age
Natural mortality
Maturation ogive
Partial recruitment-at-age

In the case of AGEPRO, however, these data are input as smoothed multi-year averages that are judged to be representative of the projection time horizon.

There are also many initialization and control flags, which may be specified. All of these data are in a several example files, depending on the recruitment model:

gmc99mod2.in Recruitment model 2 – Recruits per spawning biomass distribution
gmc99mod3.in Recruitment model 3 – Empirical recruitment distribution
gmc99mod5.in Recruitment model 5 – Beverton-Holt model with Log-normal error
gmc99mod9.in Recruitment model 9 – Time-vary empirical recruitment distribution

There are 9 recruitment models in AGEPRO, but we will use these 4 in our examples.

Output

After AGEPRO has run successfully, formatted output will be written to a file named during the run by the user. These files should be brought into a word processor for viewing and printing.

AgePro Introduction

Introduction

AgePro was added to FACT in 1999 to allow a seamless transfer of data to the VPA. A windows interface was added. In addition, the spawning stock biomass (SSB) is no longer back calculated from the population numbers and fishing mortality. Those numbers are now taken directly from a bootstrapped FACT ADAPT/VPA file (filename.BOOTN, filename.BOOTSSB).

The AgePro User's guide written by Jon K. T. Brodziak and Paul J. Rago has been adapted by Hugh Popenoe for this version with new documentation for the user interface.

The AGEPRO Program performs stochastic projections of the abundance of an exploited age-structured population over a time horizon of up to 25 years. The primary purpose of the AGEPRO model is to characterize the sampling distribution of key fishery system outputs such as landings, spawning stock biomass, and recruitment under uncertainty. The acronym "AGEPRO" indicates that the program performs age-structured projections in contrast to size- or biomass-based projection models. In this framework, the USER chooses the level of harvest that will be taken from the population by setting quotas or fishing mortality rates in each year of the time horizon.

There are three elements of uncertainty incorporated in the AGEPRO model: recruitment, initial population size, and natural mortality.

Recruitment is the primary stochastic element in the population model in AGEPRO, where recruitment is either the number of age-1 or age-2 fish in the population at the beginning of each year in the time horizon.

There are a total of nine stochastic recruitment sub models that can be used for population projection. It should be noted that it is possible to simulate the case of deterministic recruitment with AGEPRO through a suitable choice of recruitment sub model and input data.

Initial population size is a second potential source of uncertainty in AGEPRO that can be incorporated into population projection. To use this feature, the USER must have an initial distribution of population sizes that can be projected through the time horizon. Alternatively, the USER can choose to base the projections on a single estimate of initial population size.

A third potential source of uncertainty in the AGEPRO model is natural mortality. In particular, the instantaneous natural mortality rate is assumed to be equal for all age classes in the population. The USER can choose to have a constant or a stochastic natural mortality rate. In the stochastic case, the natural mortality rates are taken to be realizations from a uniform distribution specified by the USER.

The AGEPRO model was conceived as part of a study to determine optimal strategies to rebuild a depleted fish stock. The AGEPRO model was initially developed in winter 1994 to compare the effects of various harvesting scenarios on a depleted stock. Subsequently, a manuscript describing the model was presented at the May 1994 meeting of the NEFSC Methods Working Group (Brodziak and Rago, Unpublished manuscript). This software was then applied to assessment results for several stocks at the 18th SARC (NEFSC, 1994) to evaluate the potential consequences of harvest policies. The model was extended in autumn 1994 to assist the Groundfish Plan Development Team and was also revised during summer 1995 to assist in the evaluation of Amendment 7 to the Northeast Multispecies Fishery Management Plan. Throughout these developments, the AGEPRO software was considered to be research software that had no documentation, except for comments in the source code. As a result, this USER'S GUIDE was written to provide documentation for the AGEPRO model and software.

Demonstration of AgePro with Sample Program

AgePro Input File

The sample file shown below illustrates the format for input parameters for AgePro. **The line numbers and description have been added for a reference and should not be included as part of the input file.**

For a run of AgePro, a second file is also needed, which contain the bootstrapped population numbers (BOOTN) or bootstrapped spawning stock biomass (BOOTSSB). These files are created by a bootstrapped FACT ADAPT/ VPA run.

Download AgePro sample input.

If you cannot download the sample file as a file or the file opens in the browser, see Troubleshooting downloading of input sample files.

AgePro Sample ## Name of projection run

1998 ## First year of projection run

3 ## Length of planning horizon (between 1 and 25)

100 ## Number of simulations per initial population vector (between 1 and 200)

123456 ## Number of reps to initialize the random number generator

0 ## lag recruitment flag

1 ## Catch projections based on a mixture of F and Q

1 ## Discard flag (1=true, O=false)

0 ## quota based management flag

0 ## Constant harvest strategy flag (1=true, O=false)

0 ## F target flag Print (1 =true, O=false)

0 ## Index flag

1 ## threshold flag

0 ## market category flag

0 ## total mortality flag

0 ## partial recruitment flag

1 ## constant discard flag

0 ## bounded recruitment flag

1 ## constant natural mortality flag

1 ## bootstrap flag

6 1 ## number of age-classes and age of recruitment

0.2 ## constant natural mortality

0.0280.1250.2680.4090.5160.785 ## mean spawning weights-at-age

0.150.340.390.470.580.785 ## mean landed weights-at-age

0.0560.235 0.365 0.463 0.582 0.785 ## mean discard weights-at-age

1 1 1 1 1 1 ## fraction mature-at-age

0 ## fraction of total mortality that occurs before spawning

3 ## model number

13 ## number of observed recruitments

98910004712000675500021230000 770000062930009176000 73060007455000
6839000 6554000 6829000 3397000 ## observed recruitments

10 ## number of bootstraps

D:\FACThelp\Agepro\AgeProBootN.bootN ## name of bootstrap N's file

1000 ## units for bootstrap

6100000 ## thresholds

0.020.140.66 1 1 1 ## Constant partial recruitment

1 0.67 0.24 0.09 0.05 0.02 ## constant discard fraction

1 0 0 ## How to mix Quota and F

132000000 ## Q series

01.01 1.01 ## F series

Catch Projections Based on a Mixture of F and Q Flag

The seventh input is the mixture flag for harvesting. If true, catch projections are based on a mixture of F-based and quota-based management by year; otherwise, the harvest is based on one management strategy.

Discard Flag

The eighth input is the discard flag. If true, discards-at-age are included in the projection analysis; otherwise, no discards are included in the analysis.

Quota-based Management Flag

The ninth input is the quota-based management flag. If true, catch projections are based on quotas; otherwise catch projections are F-based.

Constant Harvest Strategy Flag

The tenth input is the constant harvest strategy flag. If true, the harvest strategy does not change in time, e.g. the F or the quota is fixed; otherwise the harvest strategy can vary from year to year.

F Target Flag

The eleventh input is the F-target flag. If true, then a target value of F is applied in the year after any year when the SSB threshold is achieved; otherwise no change occurs.

Index Flag

The twelfth input is the index flag. If true, a prediction of an age-specific recruitment index is made; otherwise no prediction is made.

SSB Threshold Flag

The thirteenth input is the SSB threshold flag. If true, realized SSB levels are compared to a threshold level; otherwise no comparisons are made.

Market Category Flag

The fourteenth input is the market category flag. If true, landings are summarized by market category and output to file; otherwise no market category summaries are made.

Total Mortality Flag

The fifteenth input is the total mortality flag. If true, the fraction of total mortality that occurs prior to spawning can vary from year to year; otherwise there is no annual variation.

Partial Recruitment Flag

The sixteenth input is the partial recruitment flag. If true, the partial recruitment to fishing mortality vector can vary from year to year; otherwise there is no annual variation.

Constant Discard Flag

The seventeenth input is the constant discard flag. If true, the fraction discarded at age is constant; otherwise the fraction discarded at age can vary from year to year.

Bounded Recruitment Flag

The eighteenth input is the bounded recruitment flag. If true, then realized recruitments generated with the lognormal, Beverton-Holt, Ricker, and Shepherd stock-recruitment models will be bounded based on realized R/SSB ratios; otherwise no bounds are applied.

Constant Natural Mortality Flag

The nineteenth input is the constant natural mortality flag. If true, natural mortality is constant; otherwise it is a uniformly distributed random variable.

Bootstrap Flag

The twentieth input is the bootstrap flag. If true, a file of bootstrapped initial population vectors is used in the projection analysis; otherwise a single initial population vector is used.

Natural Mortality Rates

The twenty-second input is the instantaneous natural mortality rate (M), if M is constant. If M is not constant, the twenty-second input is the interval $[L_M, U_M]$ for stochastic natural mortality. The input criteria for natural mortality rates varies depending on the **Constant natural mortality flag** (input #19) and **Recruitment lag flag** (input # 6).

For input conditions

If **constant natural mortality flag** (input #19) = true, then input: M

If **constant natural mortality flag** (input #19) = false and **Recruitment lag flag** (input #6) = false, then lower (L_M) and upper (U_M) bounds for random natural mortality.

If **constant natural mortality flag** (input #19) = false and Recruitment lag flag (input #6) = true, then input: lower (L_M) and upper (U_M) bounds for random natural mortality and on the next line input: M(O).

Mean Spawning Weights-at-age

The twenty-third input is the vector of mean weights-at-age in the stock ordered from youngest (left) to oldest (right) separated by spaces.

Input: $W_{S,1}$, $W_{S,2}$, $W_{S,3}$, ..., $W_{S,A}$

Mean Landed Weights-at-age

The twenty-fourth input is the vector of mean weights-at-age in the landings ordered from youngest (left) to oldest (right) separated by spaces.

Input: $W_{L,1}$, $W_{L,2}$, $W_{L,3}$, ... , $W_{L,A}$

Mean Discarded Weights-at-age

If discards-at-age are included in the projection, the twenty-fifth input is the vector of mean weights-at-age of discarded fish ordered from youngest (left) to oldest (right) separated by spaces.

Input: $W_{D,1}$, $W_{D,2}$,$W_{D,3}$,......., $W_{D,A}$

Input required if **Discard flag** input #8 = true, otherwise not.

Fraction Mature-at-age

The twenty-sixth input is the vector of fraction mature-at-age ordered from youngest (left) to oldest (right) separated by spaces.

Input: FM_1 , FM_2 , FM_3 ,....... , FM_A

Fraction of Total Mortality that Occurs Before Spawning

The twenty-seventh input is the fraction of total mortality that occurs prior to spawning (ZPROJ). If the **total mortality flag** (input 15) is true, then a set of values of ZPROJ must be input. In particular, if the **total mortality flag** is true and the **recruitment age is age-2** then the value of ZPROJ in the previous year is input first on one line followed by a line with the vector of values of ZPROJ ordered from the first (left) to the last (right) year of the time horizon is input. If the total mortality flag is false, then the constant value of ZPROJ is input, regardless of whether the recruitment age is age-2.

In other words,

If input **total mortality flag** (input #19) = false, then input: ZPROJ

If **total mortality flag** (input #19) = true and **recruitment lag flag** (input #6) = false, input: ZPROJ(1) , ZPROJ(2) , ... , ZPROJ(Y).

If **total mortality flag** (input #19) = true and **Recruitment lag flag** (input #6) = true, input: ZPROJ(O) and on the next line input: ZPROJ(1) , ZPROJ(2) , ..., ZPROJ(Y)

Model Number

The twenty-eighth input is the recruitment flag, which is a number from 1 to 9 that identifies the choice of stochastic stock-recruitment model to be used. These models are numbered 1 to 9 in exact correspondence with their descriptions (see Stock-recruitment Relationship).

Recruitment Model Parameters

The thirtieth input is the set of parameters needed for the chosen stock recruitment model. The set of parameters depends on the chosen model and are specified below for each of the nine stock-recruitment models.

1. Markov Matrix
2. Recruits-per-spawning Biomass Distribution
3. Empirical Recruitment Distribution
4. Two-stage Recruits-per-spawning Biomass Distribution
5. Beverton-Holt Curve with Lognormal Error
6. Ricker Curve with Lognormal Error
7. Shepherd Curve with Lognormal Error
8. Lognormal Distribution
9. Time-varying Empirical Recruitment Distribution

If input #28 = 1, Model 1 – Markov Matrix

Input the number of recruitment levels: K and on the next line input the recruitment levels: $N_{R,1}$, $N_{R,2}$, $N_{R,3}$,...., $N_{R,K}$
and on the next line input the number of spawning stock levels: J
and on the next line input the SSB cut points to define spawning stock levels: SSB_2 , SSB_3 , SSB_4 ,......, SSB_J
and on the next J lines input the probability of recruitment level (k) given SSB level (j)
$P_{1,1}$, $P_{1,2}$, $P_{1,3}$,........, $P_{1,K}$
$P_{2,1}$, $P_{2,2}$, $P_{2,3}$,........, $P_{2,K}$
$P_{J,1}$, $P_{J,2}$, $P_{J,3}$,......., $P_{J,K}$

If input #28=2, Model 2 – Recruits-per-spawning Biomass Distribution

Input the number of observed recruitment/SSB data points: T
and on the next line input the observed recruitment series: $N_R(1)$, $N_R(2)$, $N_R(3)$,......, $N_R(T)$
and on the next line input the observed SSB series: SSB(1-R) , SSB(2-R) , SSB(3-R) ,........., SSB(T-R)

If input #28=3, Model 3 – Empirical recruitment Distribution

Input the number of observed recruitments: T
and on the next line input the observed recruitment series: $N_R(1)$, $N_R(2)$, $N_R(3)$,......., $N_R(T)$;

If input #28=4, Model 4 – Two-stage Recruits-per-spawning Biomass Distribution

Input the low (1) and the high (2) SSB data points: T_{LOW}, T_{HIGH} ;
and on the next line input the cut point between the low and the high SSB states: SSB*;
and on the next line the LOW-SSB STATE RECRUITMENTS: $N_R(1)$, $N_R(2)$, $N_R(3)$,......, $N_R(T_{LOW})$
and on the next line the LOW-SSB STATE SSBs: SSB(1-R), SSB(2-R) , SSB(3-R) ,......, SSB(T_{LOW}-R)
and on the next line the HIGH-SSB STATE RECRUITMENTS: $N_R(1)$, $N_R(2)$, $N_R(3)$,......., $N_R(T_{HIGH})$
and on the next line the HIGH-SSB STATE SSBs: SSB(1-R) , SSB(2-R) , SSB(3-R) ,......, SSB(T_{HIGH}-R)

If input #28=5, Model 5 – Beverton-Holt Curve with Lognormal Error

Input: a, b , st σ_w^2 stock recruitment parameters.

and on the next line input the conversion coefficients for spawning stock biomass and recruitment: C_{SSB} , C_R

If input #28=6, Model 6 – Ricker Curve with Lognormal Error

Input: a, b, σ_w^2 stock recruitment parameters.

and on the next line input the conversion coefficients for spawning stock biomass and recruitment: C_{SSB} , C_R

If input #28=7, Model 7 – Shepherd Curve with Lognormal Error

Input: a, b, k, σ_w^2 stock recruitment parameters.

and on the next line input the conversion coefficients for spawning stock biomass and recruitment: C_{SSB} , C_R

If input #28=8, Model 8 – Lognormal Distribution

Input: $\mu_{log\,R}$ and $\sigma_{log\,R}$

and on the next line input the conversion coefficients for spawning stock biomass and recruitment: C_{SSB} , C_R

If input #28=9, Model 9 – Time-varying Empirical Recruitment Distribution

Input the number of observed recruitments for-each year in the time horizon: T
and on the next line input: $N_R(1,1)$, $N_R(1,2)$, $N_R(1,3)$,........, $N_R(1,T)$
and on the next line input: $N_R(2,1)$, $N_R(2,2)$, $N_R(2,3)$,......, $N_R(2, T)$
and on the next line input: $N_R(Y,1)$, $N_R(Y,2)$, $N_R(Y,3)$,....., $N_R(Y,T)$

Number of Bootstraps

This is the number of lines in a bootstrapped ADAPT/VPA file.

File with Bootstraps

The filename and location of the bootstrapped ADAPT/VPA file.

Bootstrap Units

This is the units used in the bootstrapped N or SSB file (i.e. 1000, 10,000 or 1,000,000).

Time-varying Partial Recruitment

The Partial recruitment vector ordered from youngest (left) to oldest (right) for all age-classes.

Time-varying Discard Fraction

The discard fraction vector ordered from youngest (left) to oldest (right) for all age-classes.

How to Mix Quota and F

This input determines how the catch projections are based on quota or fishing mortality (F) for the number of years to be projected. Catch projection can be based on both, F and quota. Use inputs 1 for F and 0 for quota for each year of projection.

Quota Series

This input contains the quota numbers for each year to be projected. In the case of when catch projection are based on a mixture of quota and fishing mortality (How to mix quota and F) , use O or -1 as a placeholder for years when catch projections are based on F.

F Series

This input contains the fishing mortality (F) numbers for each year to be projected. In the case of when catch projection are based on a mixture of quota and fishing mortality (How to mix quota and F), use O or -1 as a placeholder for years when catch projections are based on quota.

AGEPRO Model 2 Results

```
Input File: gmc99mod2.in

Recruitment model 2 - Recruits per spawning biomass distribution

GM Cod F=Fmax SSB Target    ## Name of projection run
 2000          ## First year of projection run
 11            ## Length of planning horizon (between 1 and 25)
 1             ## Number of simulations per initial population vector (between 1 and 200)
 24680         ## Number of reps to initialize the random number generator
 0             ## lag recruitment flag
 0             ## Catch projections based on a mixture of F and Q
 0             ## Discard flag (1=true, 0=false)
 0             ## quota based management flag
 0             ## Constant harvest strategy flag (1=true, 0=false)
 0             ## F target flag Print (1=true, 0=false)
 0             ## Index flag
 1             ## threshold flag
 0             ## market category flag
 0             ## total mortality flag
 0             ## partial recruitment flag
 0             ## constant discard flag
 0             ## bounded recruitment flag
 1             ## constant natural mortality flag
 1             ## bootstrap flag
 7              1             ## number of age classes and age of recruitment
 0.2           ## constant natural mortality
 0.613  1.087  1.79  2.347  3.21  4.712  11.635 ## mean spawning weights at age
 0.9  1.563  2.024  2.764  3.957  6.524  11.635 ## mean landed weights at age
 0  0.38  0.89  0.99  1  1  1 ## fraction mature at age
 0.1667        ## fraction of total mortality that occurs before spawning
 2             ## Model number
 16            ## number of observed recruitment/SSB data points
 5534000  7746000  4914000  7410000  9954000  21648000  3376000  3391000  5883000
5309000  8260000  3090000  2912000  1983000  2204000  0 ## observed recruitment series
 22786000  18061000  13984000  15272000  14561000  14371000  17732000  26192000  22585000
20313000  13438000  10710000  12258000  14173000  12711000  0  ## the observed SSB series
 100           ## number of bootstraps
C:\Workshop\Fact\gmcod2000_base.2bootN          ## name of bootstrap N's file
 1000          ## units for bootstrap
 20000000      ## thresholds
 0.0614  0.373  0.924  1  1  1  1 ## Constant partial recruitment
 0.64  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27 ## F series
```

07 Sep 2000 at 10:47.15

PROJECTION RUN: GM Cod F=Fmax SSB Target
INPUT FILE: C:\Nafo\Workshop\gmcod\gmc99mod2.in
OUTPUT FILE: C:\Nafo\Workshop\gmcod\gmc99mod2.out
RECRUITMENT MODEL: 2
NUMBER OF SIMULATIONS: 1

Bootstrapped Population Numbers

AGE	AVG N	STD
1	5076.259	156.209
2	4457.452	1592.477
3	2356.606	634.759
4	1242.444	341.000
5	463.895	157.366
6	329.767	124.461
7	174.981	44.895

PERCENTILES OF Bootstrapped Population Numbers

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	4652.896	4819.785	4857.587	4955.638	5088.163	5179.793	5244.828	5330.930	5447.146
2	1665.745	2286.521	2548.306	3368.059	4262.300	5355.144	6045.256	7813.131	9363.643
3	1271.062	1323.649	1555.983	1977.917	2310.130	2657.227	3071.718	3433.747	4099.466
4	450.096	736.132	807.075	1015.968	1210.729	1470.548	1671.914	1821.812	2162.420
5	220.540	267.481	298.548	351.413	432.922	543.687	673.343	791.504	880.318
6	119.558	146.389	187.788	235.576	306.653	390.245	498.722	530.817	710.647
7	92.089	110.333	124.155	146.377	165.140	200.252	239.598	251.869	289.561

F-BASED PROJECTIONS
TIME-VARYING F

YEAR	F
2000	0.640
2001	0.270
2002	0.270
2003	0.270
2004	0.270
2005	0.270
2006	0.270
2007	0.270
2008	0.270
2009	0.270
2010	0.270

SPAWNING STOCK BIOMASS (THOUSAND MT)

YEAR	AVG SSB (000 MT)	STD
2000	11.927	1.738
2001	12.922	1.887
2002	15.759	2.297
2003	18.198	4.223
2004	20.898	5.162
2005	23.972	6.343
2006	26.718	8.294
2007	29.527	11.051
2008	34.354	14.617
2009	38.574	17.392
2010	43.429	21.172

PERCENTILES OF SPAWNING STOCK BIOMASS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	8.570	9.122	9.528	10.543	12.055	13.068	13.860	14.294	15.521
2001	9.361	10.082	10.452	11.432	12.685	13.899	15.144	15.938	17.875
2002	9.687	12.359	13.496	14.280	15.450	17.023	18.935	20.248	21.872
2003	4.782	13.054	14.205	16.190	17.475	20.086	22.498	24.506	32.967
2004	6.761	13.609	15.488	18.143	20.356	23.508	27.778	29.865	35.984
2005	7.449	13.616	16.422	19.756	23.547	27.395	31.269	34.551	40.968
2006	4.877	13.892	16.110	21.134	25.533	31.107	37.664	40.576	47.380
2007	7.365	9.223	16.776	23.401	27.938	35.097	42.591	48.439	54.082
2008	6.555	11.514	18.578	23.709	31.150	43.340	55.451	59.344	73.576
2009	0.000	14.762	17.100	26.656	35.865	49.890	62.309	67.943	79.789
2010	0.883	9.898	19.153	29.070	38.961	57.744	68.914	81.472	105.145

ANNUAL PROBABILITY THAT SSB EXCEEDS THRESHOLD: 20.0000000000000
THOUSAND MT

YEAR	Pr(SSB > Threshold Value)
2000	0.000
2001	0.000
2002	0.060
2003	0.270
2004	0.530
2005	0.740
2006	0.820
2007	0.820
2008	0.860
2009	0.880
2010	0.890

RECRUITMENT UNITS ARE: 1000.00000000000 FISH

BIRTH YEAR	AVG RECRUITMENT	STD
2000	3771.955	4138.616
2001	5023.582	3910.124
2002	4599.980	3522.927
2003	5704.606	6196.019
2004	6021.897	5847.902
2005	9540.633	9180.435
2006	8627.503	7717.078
2007	11317.765	10119.496
2008	8836.019	12703.966
2009	8218.734	15610.798
2010	12557.458	16867.532

PERCENTILES OF RECRUITMENT UNITS ARE: 1000.00000000000 FISH

BIRTH YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	-1.000	-1.000	1634.712	2203.101	3007.786	5563.592	7418.228	8301.357	20369.121
2001	-1.000	1584.825	2051.683	2647.278	3538.214	6353.408	11311.377	13610.217	15188.391
2002	-1.000	1767.971	2112.018	3005.495	4183.826	5776.122	8716.215	10300.094	13834.771
2003	-1.000	-1.000	1744.763	3125.165	4585.605	7784.733	14082.071	17331.565	21487.979
2004	-1.000	2201.200	2505.358	3668.626	5066.776	7412.867	11446.517	17009.771	21014.784
2005	-1.000	2902.946	3291.348	4270.108	6237.009	11291.537	23173.395	28673.886	38097.796
2006	-1.000	2408.972	3457.207	4863.953	6574.482	9680.319	17362.270	22686.375	40322.484
2007	-1.000	2459.435	3029.401	5682.541	8258.234	12833.842	21886.239	30464.816	48429.732
2008	-1.000	-1.000	2700.420	4756.274	8361.203	14006.224	21229.637	23059.846	37453.869
2009	-1.000	-1.000	-1.000	4545.936	9196.852	12660.618	18554.506	25931.298	58293.030
2010	-1.000	-1.000	2677.952	5534.992	10536.140	18627.135	29104.727	32218.910	63289.866

LANDINGS FOR F-BASED PROJECTIONS

YEAR	AVG LANDINGS (000 MT)	STD
2000	7.550	1.071
2001	3.684	0.522
2002	4.471	0.694
2003	5.148	1.191
2004	5.902	1.468
2005	6.654	1.825
2006	7.357	2.430
2007	8.233	3.146
2008	9.521	4.118
2009	10.736	4.946
2010	11.990	5.855

PERCENTILES OF LANDINGS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	5.431	5.797	6.101	6.677	7.620	8.290	8.658	9.235	9.856
2001	2.674	2.890	3.040	3.319	3.645	3.942	4.303	4.558	5.048
2002	2.512	3.286	3.752	4.036	4.342	4.793	5.395	5.662	6.470
2003	1.509	3.713	3.984	4.561	4.989	5.670	6.420	7.100	9.159
2004	1.872	3.905	4.281	5.048	5.742	6.675	7.949	8.683	10.140
2005	2.023	3.794	4.459	5.445	6.530	7.619	8.528	9.956	11.537
2006	1.269	3.188	4.402	5.719	7.003	8.531	10.614	11.591	13.788
2007	1.953	2.688	4.437	6.309	8.005	9.739	12.261	13.698	15.418
2008	1.192	3.151	4.829	6.441	8.739	12.184	15.361	16.746	20.530
2009	0.000	3.729	4.667	7.257	9.960	13.685	17.367	18.536	23.437
2010	0.025	2.506	5.218	8.053	10.574	16.099	18.870	22.276	28.999

50th PERCENTILES OF NUMBERS AT AGE

	1	2	3	4	5	6	7
2000	5088.	4262.	2310.	1211.	433.	307.	165.
2001	3008.	4005.	2749.	1047.	523.	187.	212.
2002	3538.	2422.	2965.	1753.	654.	327.	254.
2003	4184.	2849.	1793.	1892.	1096.	409.	365.
2004	4586.	3369.	2109.	1144.	1182.	685.	497.
2005	5067.	3693.	2494.	1346.	715.	739.	732.
2006	6237.	4080.	2734.	1591.	841.	447.	923.
2007	6574.	5022.	3020.	1744.	994.	526.	866.
2008	8258.	5294.	3718.	1927.	1090.	622.	951.
2009	8361.	6650.	3919.	2372.	1204.	681.	1034.
2010	9197.	6733.	4923.	2500.	1483.	753.	1101.

```
AGEPRO Model 3 Results

Input File: gmc99mod3.in

Recruitment model 3 - Empirical recruitment distribution

GM Cod F=Fmax SSB Target    ## Name of projection run
 2000          ## First year of projection run
 11            ## Length of planning horizon (between 1 and 25)
 5             ## Number of simulations per initial population vector (between 1 and 200)
 24680         ## Number of reps to initialize the random number generator
 0             ## lag recruitment flag
 0             ## Catch projections based on a mixture of F and Q
 0             ## Discard flag (1=true, 0=false)
 0             ## quota based management flag
 0             ## Constant harvest strategy flag (1=true, 0=false)
 0             ## F target flag Print (1=true, 0=false)
 0             ## Index flag
 1             ## threshold flag
 0             ## market category flag
 0             ## total mortality flag
 0             ## partial recruitment flag
 0             ## constant discard flag
 0             ## bounded recruitment flag
 1             ## constant natural mortality flag
 1             ## bootstrap flag
 7    1        2     4      ## number of age classes and age of recruitment
 0.2           ## constant natural mortality
 0.613  1.087  1.79  2.347  3.21  4.712  11.635 ## mean spawning weights at age
 0.9  1.563  2.024  2.764  3.957  6.524  11.635 ## mean landed weights at age
 0  0.38  0.89  0.99  1  1  1 ## fraction mature at age
 0.1667        ## fraction of total mortality that occurs before spawning
 3             ## Model number
 16            ## number of observed recruitments
 5534000  7746000  4914000  7410000  9954000  21648000  3376000  3391000  5883000
5309000  8260000  3090000  2912000  1983000  2204000  3490000 ## observed recruitments
 100           ## number of bootstraps
C:\Workshop\Fact\gmcod2000_base.2bootN           ## name of bootstrap N's file
 1000          ## units for bootstrap
 20000000  1    1      ## thresholds for SSB and mean Biomass and F mean Biomass.
 0.0614  0.373  0.924  1  1  1  1 ## Constant partial recruitment
 0.64  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27 ## F series
```

15 Sep 2000 at 11:52.54

PROJECTION RUN: GM Cod F=Fmax SSB Target
INPUT FILE: C:\Workshop\Fact\gmc99mod3.in
OUTPUT FILE: C:\Workshop\Fact\gmc99mod3.out
RECRUITMENT MODEL: 3
NUMBER OF SIMULATIONS: 5

Bootstrapped Population Numbers

AGE	AVG N	STD
1	5076.259	156.209
2	4457.452	1592.477
3	2356.606	634.759
4	1242.444	341.000
5	463.895	157.366
6	329.767	124.461
7	174.981	44.895

PERCENTILES OF Bootstrapped Population Numbers

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	4652.896	4819.785	4857.587	4955.638	5088.163	5179.793	5244.828	5330.930	5447.146
2	1665.745	2286.521	2548.306	3368.059	4262.300	5355.144	6045.256	7813.131	9363.643
3	1271.062	1323.649	1555.983	1977.917	2310.130	2657.227	3071.718	3433.747	4099.466
4	450.096	736.132	807.075	1015.968	1210.729	1470.548	1671.914	1821.812	2162.420
5	220.540	267.481	298.548	351.413	432.922	543.687	673.343	791.504	880.318
6	119.558	146.389	187.788	235.576	306.653	390.245	498.722	530.817	710.647
7	92.089	110.333	124.155	146.377	165.140	200.252	239.598	251.869	289.561

F-BASED PROJECTIONS
TIME-VARYING F

YEAR	F
2000	0.640
2001	0.270
2002	0.270
2003	0.270
2004	0.270
2005	0.270
2006	0.270
2007	0.270
2008	0.270
2009	0.270
2010	0.270

SPAWNING STOCK BIOMASS (THOUSAND MT)

YEAR	AVG SSB (000 MT)	STD
2000	11.927	1.731
2001	12.922	1.880
2002	16.459	2.357
2003	20.392	4.737
2004	23.947	5.988
2005	27.889	6.882
2006	30.684	7.361
2007	33.068	9.002
2008	34.412	9.311
2009	35.685	9.307
2010	36.403	9.377

PERCENTILES OF SPAWNING STOCK BIOMASS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	8.570	9.122	9.528	10.543	12.055	13.068	13.860	14.294	15.521
2001	9.361	10.082	10.452	11.432	12.685	13.899	15.144	15.938	17.875
2002	12.286	13.274	13.722	14.946	16.084	17.468	20.051	21.274	23.090
2003	14.074	15.311	16.097	17.310	19.203	21.823	25.551	32.900	36.663
2004	15.682	17.093	18.144	19.910	22.406	26.013	33.434	36.098	43.000
2005	17.214	19.740	21.013	22.821	26.069	31.060	37.993	41.113	48.773
2006	19.321	21.760	22.794	25.159	29.009	35.263	42.035	45.267	50.146
2007	20.246	22.131	23.516	26.157	30.889	38.016	45.359	49.372	58.595
2008	20.781	22.859	24.250	27.133	32.499	40.211	47.239	51.232	60.557
2009	20.167	23.693	25.419	28.569	33.880	41.205	48.704	51.594	62.197
2010	21.327	23.742	25.361	29.516	34.574	42.840	48.671	52.052	62.487

ANNUAL PROBABILITY THAT SSB EXCEEDS THRESHOLD: 20.0000000000000
THOUSAND MT

YEAR	Pr(SSB > Threshold Value)
2000	0.000
2001	0.000
2002	0.104
2003	0.420
2004	0.736
2005	0.942
2006	0.982
2007	0.996
2008	0.998
2009	0.994
2010	0.994

RECRUITMENT UNITS ARE: 1000.00000000000 FISH

BIRTH YEAR	AVG RECRUITMENT	STD
2000	5985.488	4758.484
2001	5792.318	4570.269
2002	6378.298	4869.243
2003	6210.534	4703.621
2004	6313.956	4819.665
2005	6086.008	4611.579
2006	6117.450	4542.492
2007	6550.480	5133.028
2008	5735.118	4175.204
2009	6344.790	4941.309
2010	6283.130	4861.721

PERCENTILES OF RECRUITMENT UNITS ARE: 1000.00000000000 FISH

BIRTH YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	1983.000	1983.000	2204.000	3090.000	4914.000	7410.000	9954.000	21648.000	21648.000
2001	1983.000	1983.000	2204.000	3376.000	4914.000	7410.000	9954.000	21648.000	21648.000
2002	1983.000	1983.000	2204.000	3376.000	5309.000	7746.000	9954.000	21648.000	21648.000
2003	1983.000	2204.000	2912.000	3090.000	4914.000	7746.000	9954.000	21648.000	21648.000
2004	1983.000	1983.000	2204.000	3376.000	5309.000	7746.000	9954.000	21648.000	21648.000
2005	1983.000	1983.000	2204.000	3090.000	4914.000	7746.000	9954.000	21648.000	21648.000
2006	1983.000	2204.000	2204.000	3090.000	5309.000	7746.000	9954.000	21648.000	21648.000
2007	1983.000	1983.000	2204.000	3376.000	5309.000	7746.000	9954.000	21648.000	21648.000
2008	1983.000	1983.000	2204.000	3090.000	4914.000	7410.000	9954.000	9954.000	21648.000
2009	1983.000	1983.000	2204.000	3376.000	5309.000	7746.000	9954.000	21648.000	21648.000
2010	1983.000	1983.000	2204.000	3090.000	5309.000	7746.000	9954.000	21648.000	21648.000

LANDINGS FOR F-BASED PROJECTIONS

YEAR	AVG LANDINGS (000 MT)	STD
2000	7.550	1.067
2001	3.713	0.518
2002	4.723	0.726
2003	5.793	1.342
2004	6.791	1.686
2005	7.767	1.922
2006	8.486	2.138
2007	9.043	2.456
2008	9.386	2.506
2009	9.674	2.496
2010	9.835	2.523

PERCENTILES OF LANDINGS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	5.431	5.797	6.101	6.677	7.620	8.290	8.658	9.235	9.856
2001	2.706	2.936	3.082	3.353	3.670	3.976	4.321	4.752	5.134
2002	3.505	3.748	3.948	4.248	4.587	5.017	5.826	6.286	6.855
2003	3.977	4.365	4.558	4.903	5.468	6.172	7.462	9.175	10.477
2004	4.440	4.931	5.152	5.638	6.348	7.424	9.426	10.188	12.234
2005	4.808	5.501	5.793	6.329	7.240	8.700	10.565	11.643	13.362
2006	5.241	5.890	6.124	6.841	8.021	9.800	11.611	12.752	14.268
2007	5.478	6.043	6.352	7.146	8.496	10.619	12.441	13.554	15.941
2008	5.567	6.203	6.605	7.363	8.845	10.973	12.804	13.806	16.310
2009	5.586	6.346	6.840	7.712	9.158	11.197	13.089	13.853	17.055
2010	5.770	6.400	6.819	7.964	9.326	11.547	13.088	14.146	17.158

50th PERCENTILES OF NUMBERS AT AGE

	1	2	3	4	5	6	7
2000	5088.	4262.	2310.	1211.	433.	307.	165.
2001	4914.	4005.	2749.	1047.	523.	187.	212.
2002	4914.	3957.	2965.	1753.	654.	327.	254.
2003	5309.	3957.	2929.	1892.	1096.	409.	365.
2004	4914.	4275.	2929.	1869.	1182.	685.	497.
2005	5309.	3957.	3165.	1869.	1168.	739.	732.
2006	4914.	4275.	2929.	2019.	1168.	730.	923.
2007	5309.	3957.	3165.	1869.	1262.	730.	1021.
2008	5309.	4275.	2929.	2019.	1168.	789.	1113.
2009	4914.	4275.	3165.	1869.	1262.	730.	1228.
2010	5309.	3957.	3165.	2019.	1168.	789.	1310.

```
AGEPRO Model 5 Results

Input File: gmc99mod5.in

Recruitment model 5 - Beverton-Holt model with Log-normal error

GM Cod F=Fmax SSB Target    ## Name of projection run
 2000          ## First year of projection run
 11            ## Length of planning horizon (between 1 and 25)
 1             ## Number of simulations per initial population vector (between 1 and 200)
 24680         ## Number of reps to initialize the random number generator
 0             ## lag recruitment flag
 0             ## Catch projections based on a mixture of F and Q
 0             ## Discard flag (1=true, 0=false)
 0             ## quota based management flag
 0             ## Constant harvest strategy flag (1=true, 0=false)
 0             ## F target flag Print (1=true, 0=false)
 0             ## Index flag
 1             ## threshold flag
 0             ## market category flag
 0             ## total mortality flag
 0             ## partial recruitment flag
 0             ## constant discard flag
 0             ## bounded recruitment flag
 1             ## constant natural mortality flag
 1             ## bootstrap flag
 7              1            ## number of age classes and age of recruitment
 0.2           ## constant natural mortality
 0.613  1.087  1.79  2.347  3.21  4.712  11.635 ## mean spawning weights at age
 0.9  1.563  2.024  2.764  3.957  6.524  11.635 ## mean landed weights at age
 0  0.38  0.89  0.99  1  1  1 ## fraction mature at age
 0.1667        ## fraction of total mortality that occurs before spawning
 5             ## Model number
 5894.962       6424.442      0.1          ## a b sigma stock recruitment parameters
 1000           1000         ## conversion coefficients for spawning stock biomass and
recruitment
 100           ## number of bootstraps
C:\Workshop\Fact\gmcod2000_base.2bootN          ## name of bootstrap N's file
 1000          ## units for bootstrap
 20000000      ## thresholds
 0.0614  0.373  0.924  1  1  1  1 ## Constant partial recruitment
 0.64  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27 ## F series
```

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PROJECTION RUN: GM Cod F=Fmax SSB Target
INPUT FILE: C:\Workshop\Fact\dumb.in
OUTPUT FILE: C:\Workshop\Fact\gmc99mod5.out
RECRUITMENT MODEL: 5
NUMBER OF SIMULATIONS: 1

Bootstrapped Population Numbers

AGE	AVG N	STD
1	5076.259	156.209
2	4457.452	1592.477
3	2356.606	634.759
4	1242.444	341.000
5	463.895	157.366
6	329.767	124.461
7	174.981	44.895

PERCENTILES OF Bootstrapped Population Numbers

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	4652.896	4819.785	4857.587	4955.638	5088.163	5179.793	5244.828	5330.930	5447.146
2	1665.745	2286.521	2548.306	3368.059	4262.300	5355.144	6045.256	7813.131	9363.643
3	1271.062	1323.649	1555.983	1977.917	2310.130	2657.227	3071.718	3433.747	4099.466
4	450.096	736.132	807.075	1015.968	1210.729	1470.548	1671.914	1821.812	2162.420
5	220.540	267.481	298.548	351.413	432.922	543.687	673.343	791.504	880.318
6	119.558	146.389	187.788	235.576	306.653	390.245	498.722	530.817	710.647
7	92.089	110.333	124.155	146.377	165.140	200.252	239.598	251.869	289.561

F-BASED PROJECTIONS
TIME-VARYING F

YEAR	F
2000	0.640
2001	0.270
2002	0.270
2003	0.270
2004	0.270
2005	0.270
2006	0.270
2007	0.270
2008	0.270
2009	0.270
2010	0.270

SPAWNING STOCK BIOMASS (THOUSAND MT)

YEAR	AVG SSB (000 MT)	STD
2000	11.927	1.738
2001	12.922	1.887
2002	15.864	1.808
2003	18.185	1.951
2004	20.306	2.158
2005	22.969	2.657
2006	24.682	2.490
2007	25.576	2.714
2008	26.393	2.946
2009	27.411	3.289
2010	27.981	3.544

PERCENTILES OF SPAWNING STOCK BIOMASS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	8.570	9.122	9.528	10.543	12.055	13.068	13.860	14.294	15.521
2001	9.361	10.082	10.452	11.432	12.685	13.899	15.144	15.938	17.875
2002	12.262	12.878	13.464	14.773	15.615	16.828	18.066	19.439	20.076
2003	14.454	15.304	15.880	16.797	18.043	19.380	20.978	21.471	22.889
2004	16.294	17.532	17.867	18.556	19.900	21.482	23.041	23.890	26.215
2005	17.616	19.053	19.724	20.995	22.441	24.234	26.380	27.250	31.361
2006	19.194	20.740	21.704	22.807	24.120	26.435	27.875	28.947	31.448
2007	20.570	21.065	22.163	23.429	25.225	27.563	28.980	29.773	32.399
2008	20.788	22.121	23.220	23.974	25.693	28.157	30.460	32.098	33.435
2009	21.749	22.752	23.232	24.860	27.174	29.341	31.700	33.423	37.112
2010	21.659	22.153	23.117	25.533	27.654	30.521	32.180	34.182	36.806

ANNUAL PROBABILITY THAT SSB EXCEEDS THRESHOLD: 20.0000000000000
THOUSAND MT

YEAR	Pr(SSB > Threshold Value)
2000	0.000
2001	0.000
2002	0.020
2003	0.180
2004	0.500
2005	0.900
2006	0.980
2007	1.000
2008	1.000
2009	1.000
2010	1.000

RECRUITMENT UNITS ARE: 1000.00000000000 FISH

BIRTH YEAR	AVG RECRUITMENT	STD
2000	4103.599	1404.938
2001	4058.148	1304.897
2002	4561.047	1296.447
2003	4394.321	1438.414
2004	4811.885	1543.555
2005	4820.500	1541.429
2006	5129.254	1803.778
2007	4967.304	1492.090
2008	4881.952	1738.437
2009	5032.773	1496.815
2010	5121.645	1751.055

PERCENTILES OF RECRUITMENT UNITS ARE: 1000.00000000000 FISH

BIRTH YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	1700.185	2472.493	2704.789	3119.429	3781.739	4685.789	5770.399	6854.894	9012.327
2001	1758.392	2221.928	2487.815	3132.115	3707.745	4811.243	5747.163	6473.726	7338.282
2002	1925.921	2748.382	2906.435	3664.515	4437.142	5281.422	6391.156	7103.888	7722.691
2003	1714.121	2160.646	2640.388	3408.110	4179.872	5100.604	6438.130	7199.916	8220.347
2004	2078.294	2630.813	2995.137	3734.300	4536.452	5612.008	6515.324	7560.958	9188.586
2005	2336.903	2818.776	3311.671	3746.843	4353.110	5580.017	7296.101	8120.370	9305.970
2006	2235.788	2751.628	2990.027	3885.603	4661.633	5983.139	7676.372	8834.303	9721.773
2007	2473.886	2686.532	3135.744	3745.445	4910.821	5906.224	6955.609	7374.633	8603.477
2008	2374.742	2606.254	3025.965	3591.020	4568.926	5600.915	7025.885	8216.482	10858.507
2009	2310.421	2840.148	3154.569	3924.804	4897.376	5883.553	6976.860	8020.831	8620.385
2010	2262.560	2987.435	3150.060	3763.016	4743.561	6528.069	7436.619	7874.342	9828.440

LANDINGS FOR F-BASED PROJECTIONS

YEAR	AVG LANDINGS (000 MT)	STD
2000	7.550	1.071
2001	3.688	0.514
2002	4.494	0.504
2003	5.122	0.549
2004	5.721	0.614
2005	6.334	0.693
2006	6.708	0.686
2007	6.947	0.747
2008	7.185	0.817
2009	7.433	0.905
2010	7.594	0.969

PERCENTILES OF LANDINGS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	5.431	5.797	6.101	6.677	7.620	8.290	8.658	9.235	9.856
2001	2.713	2.897	3.016	3.319	3.637	3.939	4.289	4.562	5.034
2002	3.454	3.679	3.813	4.176	4.396	4.781	5.052	5.498	5.668
2003	4.092	4.317	4.489	4.679	5.069	5.450	5.888	6.029	6.490
2004	4.577	4.923	5.039	5.229	5.651	6.064	6.480	6.731	7.488
2005	4.913	5.300	5.488	5.871	6.223	6.668	7.272	7.340	8.482
2006	5.236	5.618	5.877	6.194	6.583	7.177	7.579	7.874	8.475
2007	5.573	5.718	6.041	6.383	6.819	7.493	7.968	8.120	8.770
2008	5.666	6.027	6.279	6.561	7.020	7.674	8.332	8.685	9.197
2009	5.877	6.125	6.241	6.702	7.341	8.026	8.528	8.952	10.088
2010	5.832	6.044	6.306	6.867	7.474	8.341	8.730	9.209	10.180

50th PERCENTILES OF NUMBERS AT AGE

	1	2	3	4	5	6	7
2000	5088.	4262.	2310.	1211.	433.	307.	165.
2001	3782.	4005.	2749.	1047.	523.	187.	212.
2002	3708.	3045.	2965.	1753.	654.	327.	254.
2003	4437.	2986.	2254.	1892.	1096.	409.	365.
2004	4180.	3573.	2210.	1438.	1182.	685.	497.
2005	4536.	3366.	2645.	1410.	899.	739.	732.
2006	4353.	3653.	2492.	1687.	881.	562.	923.
2007	4662.	3505.	2704.	1590.	1055.	551.	954.
2008	4911.	3754.	2595.	1725.	994.	659.	971.
2009	4569.	3955.	2779.	1656.	1078.	621.	1001.
2010	4897.	3679.	2928.	1773.	1035.	674.	1037.

```
AGEPRO Model 9 Results

Input File: gmc99mod9.in

Time-vary empirical recruitment distribution

GM Cod: F=Fmax   SSB Target ## Name of projection run
 2000         ## First year of projection run
 11           ## Length of planning horizon (between 1 and 25)
 1            ## Number of simulations per initial population vector (between 1 and 200)
 24680        ## Number of reps to initialize the random number generator
 0            ## lag recruitment flag
 0            ## Catch projections based on a mixture of F and Q
 0            ## Discard flag (1=true, 0=false)
 0            ## quota based management flag
 0            ## Constant harvest strategy flag (1=true, 0=false)
 0            ## F target flag Print (1=true, 0=false)
 0            ## Index flag
 1            ## threshold flag
 0            ## market category flag
 0            ## total mortality flag
 0            ## partial recruitment flag
 0            ## constant discard flag
 0            ## bounded recruitment flag
 1            ## constant natural mortality flag
 1            ## bootstrap flag
 7             1          ## number of age classes and age of recruitment
 0.2          ## constant natural mortality
 0.613  1.087  1.79  2.347  3.21  4.712  11.635 ## mean spawning weights at age
 0.9  1.563  2.024  2.764  3.957  6.524  11.635 ## mean landed weights at age
 0.04  0.38  0.89  0.99  1  1  1 ## fraction mature at age
 0.1667       ## fraction of total mortality that occurs before spawning
 9            ## Model number
 16           ## number of observed recruitments for each year in the time horizon
 3090000  2912000  1983000  2204000  3490000  3090000  2912000  1983000  2204000  3490000  3090000
2912000  1983000  2204000  3490000  3900000 ## observed recruitments for each year in the time horizon
 3090000  2912000  1983000  2204000  3490000  3090000  2912000  1983000  2204000  3490000  3090000
2912000  1983000  2204000  3490000  3090000 ## observed recruitments for each year in the time horizon
 3090000  2912000  1983000  2204000  3490000  3090000  2912000  1983000  2204000  3490000  3090000
2912000  1983000  2204000  3490000  3090000 ## observed recruitments for each year in the time horizon
 3376000  3391000  5883000  5309000  8260000  3090000  2912000  1983000  2204000  3490000  3391000
5883000  5309000  8260000  3090000  2912000 ## observed recruitments for each year in the time horizon
 3376000  3391000  5883000  5309000  8260000  3090000  2912000  1983000  2204000  3490000  3391000
5883000  5309000  8260000  3090000  2912000 ## observed recruitments for each year in the time horizon
 3376000  3391000  5883000  5309000  8260000  3090000  2912000  1983000  2204000  3490000  3391000
5883000  5309000  8260000  3090000  2912000 ## observed recruitments for each year in the time horizon
 3376000  3391000  5883000  5309000  8260000  3090000  2912000  1983000  2204000  3490000  3391000
5883000  5309000  8260000  3090000  2912000 ## observed recruitments for each year in the time horizon
 5534000  7746000  4914000  7410000  9954000  21648000  3376000  3391000  5883000  5309000  8260000
3090000  2912000  1983000  2204000  3490000 ## observed recruitments for each year in the time horizon
 5534000  7746000  4914000  7410000  9954000  21648000  3376000  3391000  5883000  5309000  8260000
3090000  2912000  1983000  2204000  3490000 ## observed recruitments for each year in the time horizon
 5534000  7746000  4914000  7410000  9954000  21648000  3376000  3391000  5883000  5309000  8260000
3090000  2912000  1983000  2204000  3490000 ## observed recruitments for each year in the time horizon
 5534000  7746000  4914000  7410000  9954000  21648000  3376000  3391000  5883000  5309000  8260000
3090000  2912000  1983000  2204000  3490000 ## observed recruitments for each year in the time horizon
 100          ## number of bootstraps
C:\Workshop\Fact\gmcod2000_base.2bootN          ## name of bootstrap N's file
 1000         ## units for bootstrap
 20000000     ## thresholds
 0.0614  0.373  0.924  1  1  1  0 ## Constant partial recruitment
 0.64  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27  0.27 ## F series
```

07 Sep 2000 at 10:50.58

07 Sep 2000 at 10:50.58

PROJECTION RUN: GM Cod: F=Fmax SSB Target
INPUT FILE: C:\Nafo\Workshop\gmcod\gmc99mod9.in
OUTPUT FILE: C:\Nafo\Workshop\gmcod\gmc99mod9.out
RECRUITMENT MODEL: 9
NUMBER OF SIMULATIONS: 1

Bootstrapped Population Numbers

AGE	AVG N	STD
1	5076.259	156.209
2	4457.452	1592.477
3	2356.606	634.759
4	1242.444	341.000
5	463.895	157.366
6	329.767	124.461
7	174.981	44.895

PERCENTILES OF Bootstrapped Population Numbers

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	4652.896	4819.785	4857.587	4955.638	5088.163	5179.793	5244.828	5330.930	5447.146
2	1665.745	2286.521	2548.306	3368.059	4262.300	5355.144	6045.256	7813.131	9363.643
3	1271.062	1323.649	1555.983	1977.917	2310.130	2657.227	3071.718	3433.747	4099.466
4	450.096	736.132	807.075	1015.968	1210.729	1470.548	1671.914	1821.812	2162.420
5	220.540	267.481	298.548	351.413	432.922	543.687	673.343	791.504	880.318
6	119.558	146.389	187.788	235.576	306.653	390.245	498.722	530.817	710.647
7	92.089	110.333	124.155	146.377	165.140	200.252	239.598	251.869	289.561

F-BASED PROJECTIONS
TIME-VARYING F

YEAR	F
2000	0.640
2001	0.270
2002	0.270
2003	0.270
2004	0.270
2005	0.270
2006	0.270
2007	0.270
2008	0.270
2009	0.270
2010	0.270

SPAWNING STOCK BIOMASS (THOUSAND MT)

YEAR	AVG SSB (000 MT)	STD
2000	12.245	1.774
2001	13.857	1.983
2002	16.727	1.909
2003	18.289	1.810
2004	19.822	1.842
2005	22.497	2.338
2006	25.588	2.744
2007	27.307	3.102
2008	28.831	3.289
2009	30.403	3.438
2010	33.555	5.313

PERCENTILES OF SPAWNING STOCK BIOMASS (000 MT)

YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	8.831	9.364	9.836	10.793	12.363	13.403	14.202	14.690	15.977
2001	10.077	10.748	11.276	12.307	13.631	15.088	16.365	16.695	19.203
2002	13.088	13.785	14.125	15.292	16.574	17.741	19.098	19.795	21.780
2003	14.555	15.458	15.833	17.158	18.288	19.318	20.625	21.396	23.087
2004	15.808	16.978	17.391	18.338	19.765	20.942	22.175	22.965	24.755
2005	16.984	19.250	19.566	20.786	22.297	23.771	25.141	27.422	28.880
2006	19.963	21.808	22.405	23.755	24.928	26.957	29.266	31.093	33.505
2007	21.416	22.697	23.554	25.049	26.710	29.042	32.087	33.107	35.349
2008	21.833	23.931	24.894	26.230	28.538	30.859	32.885	35.361	37.025
2009	23.107	25.198	26.250	27.811	30.528	32.104	35.211	36.496	39.348
2010	24.137	26.371	27.475	29.829	32.756	36.647	40.582	43.891	48.487

ANNUAL PROBABILITY THAT SSB EXCEEDS THRESHOLD: 20.0000000000000
THOUSAND MT

YEAR	Pr(SSB > Threshold Value)
2000	0.000
2001	0.000
2002	0.050
2003	0.140
2004	0.470
2005	0.870
2006	0.990
2007	1.000
2008	1.000
2009	1.000
2010	1.000

RECRUITMENT UNITS ARE: 1000.00000000000 FISH

BIRTH YEAR	AVG RECRUITMENT	STD
2000	2744.380	613.426
2001	2736.230	555.447
2002	2762.290	541.816
2003	4222.780	1836.194
2004	4445.960	2009.916
2005	4656.140	2162.239
2006	4250.230	1900.424
2007	5641.680	4072.855

2008	6512.660	4981.173
2009	6688.360	4679.051
2010	6408.220	5063.186

PERCENTILES OF RECRUITMENT UNITS ARE: 1000.00000000000 FISH

BIRTH YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	1983.000	1983.000	1983.000	2204.000	2912.000	3090.000	3490.000	3490.000	3900.000
2001	1983.000	1983.000	1983.000	2204.000	2912.000	3090.000	3490.000	3490.000	3490.000
2002	1983.000	1983.000	1983.000	2204.000	2912.000	3090.000	3490.000	3490.000	3490.000
2003	1983.000	2204.000	2204.000	3090.000	3391.000	5309.000	8260.000	8260.000	8260.000
2004	1983.000	1983.000	1983.000	3090.000	3391.000	5883.000	8260.000	8260.000	8260.000
2005	1983.000	2204.000	2204.000	2912.000	3391.000	5883.000	8260.000	8260.000	8260.000
2006	1983.000	1983.000	1983.000	2912.000	3391.000	5309.000	8260.000	8260.000	8260.000
2007	1983.000	1983.000	2204.000	3090.000	4914.000	7410.000	9954.000	9954.000	21648.000
2008	1983.000	2204.000	2912.000	3376.000	5309.000	7746.000	9954.000	21648.000	21648.000
2009	1983.000	2204.000	2912.000	3391.000	5534.000	7746.000	9954.000	21648.000	21648.000
2010	1983.000	1983.000	2204.000	3090.000	5309.000	7746.000	9954.000	21648.000	21648.000

LANDINGS FOR F-BASED PROJECTIONS

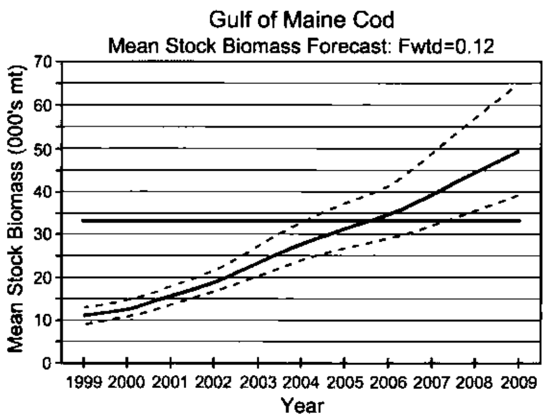
YEAR	AVG LANDINGS (000 MT)	STD
2000	6.668	0.951
2001	3.124	0.478
2002	3.672	0.467
2003	3.689	0.431
2004	3.656	0.422
2005	3.403	0.304
2006	3.326	0.544
2007	3.732	0.695
2008	4.109	0.791
2009	4.572	0.940
2010	5.005	1.329

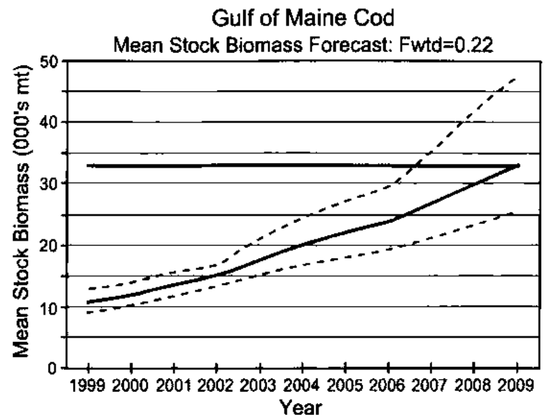
PERCENTILES OF LANDINGS (000 MT)

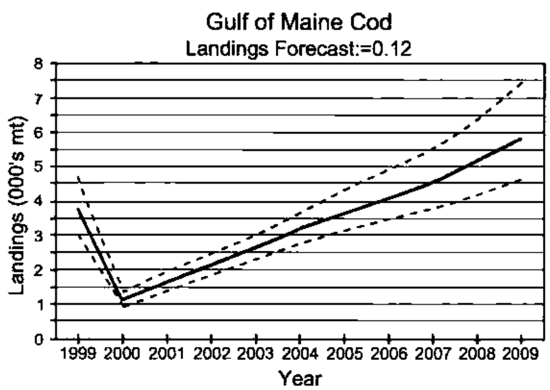
YEAR	1%	5%	10%	25%	50%	75%	90%	95%	99%
2000	4.773	5.131	5.365	5.970	6.658	7.319	7.634	8.131	8.929
2001	1.991	2.403	2.523	2.871	3.067	3.385	3.670	3.956	4.495
2002	2.583	2.974	3.042	3.423	3.651	3.848	4.192	4.432	5.070
2003	2.868	3.006	3.134	3.437	3.660	3.891	4.129	4.473	4.931
2004	2.808	3.014	3.112	3.357	3.615	3.862	4.122	4.418	4.854
2005	2.839	2.929	2.982	3.189	3.390	3.589	3.780	3.913	4.181
2006	2.351	2.608	2.736	2.928	3.224	3.614	4.162	4.307	4.677
2007	2.557	2.804	2.920	3.207	3.583	4.150	4.796	4.923	5.213
2008	2.612	2.957	3.221	3.475	3.946	4.653	5.128	5.399	5.760
2009	2.376	3.199	3.371	3.859	4.457	5.138	5.614	6.124	6.890
2010	2.615	3.288	3.599	4.113	4.738	5.562	6.804	7.026	8.770

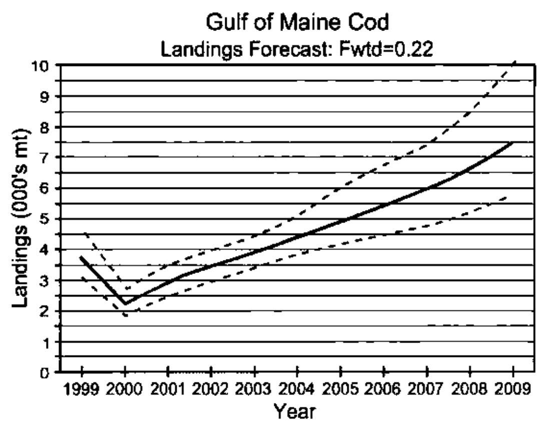
50th PERCENTILES OF NUMBERS AT AGE

	1	2	3	4	5	6	7
2000	5088.	4262.	2310.	1211.	433.	307.	165.
2001	2912.	4005.	2749.	1047.	523.	187.	276.
2002	2912.	2345.	2965.	1753.	654.	327.	351.
2003	2912.	2345.	1736.	1892.	1096.	409.	495.
2004	3391.	2345.	1736.	1107.	1182.	685.	686.
2005	3391.	2731.	1736.	1107.	692.	739.	982.
2006	3391.	2731.	2021.	1107.	692.	433.	1264.
2007	3391.	2731.	2021.	1290.	692.	433.	1300.
2008	4914.	2731.	2021.	1290.	806.	433.	1318.
2009	5309.	3957.	2021.	1290.	806.	504.	1335.
2010	5534.	4275.	2929.	1290.	806.	504.	1446.


Gulf of Maine Cod
Mean Stock Biomass Forecast: Fwtd=0.12
Mean Stock Biomass (000's mt)
Year


Gulf of Maine Cod
Mean Stock Biomass Forecast: Fwtd=0.22
Mean Stock Biomass (000's mt)
Year


Gulf of Maine Cod
Landings Forecast:=0.12
Landings (000's mt)
Year


Gulf of Maine Cod
Landings Forecast: Fwtd=0.22
Landings (000's mt)
Year

NAFO Sci. Coun. Studies, 36: 313–314

NOTICE

Workshop on Mapping and Geostatistical Methods for Fisheries Stock Assessment

Hosted by the Scientific Council of the Northwest Atlantic Fisheries Organization (NAFO)

10–12 September 2003
Holiday Inn, Dartmouth, Canada

The Scientific Council of NAFO is pleased to announce this Workshop to be held in conjunction with the NAFO Annual Meeting in Canada in September 2003. The workshop will be convened by L. Hendrikson (National Marine Fisheries Service – USA) and D. W. Kulka (Fisheries and Oceans – Canada) and organized by the NAFO Secretariat.

The purpose of the Workshop is two fold:

a) To introduce Scientific Council fisheries scientists, using practical demonstrations relevant to NAFO issues, to spatial techniques that can be applied to survey and environmental data to solve fisheries problems.

b) To provide Scientific Council members with enough background that they can interpret GIS analyses.

GIS is a broad field and the Workshop can only touch upon some of the aspects of spatial analysis. It will focus on techniques that will be most useful to the user group. The Workshop will show how:

- the raw data (set attributes) can be effectively Visualized (mapping techniques), progressing through Point to Surface Transformation (e.g. methods such as Contouring, Voronoi, Potential Mapping, Kriging that produce the continuous surfaces required to facilitate spatial modeling),
- to Overlay Modeling and Geostatistics,
- to evaluate mixed species interactions within the Precautionary Approach framework.

The Workshop will be structured to introduce NAFO Scientific Council participants to a subset of techniques and concepts relevant to their work. Examples and demonstrations will use real data from the Grand Banks and Flemish Cap. Where appropriate, underlying theory and procedures of geostatistics will be elaborated to facilitate the understanding of GIS analyses.

Scientific Council agreed that the proposed Workshop is important to the work of Scientific Council. The Council scheduled the Workshop to be held in conjunction with the 25th Annual Meeting in 2003, in Dartmouth, Nova Scotia, Canada, during 10–12 September 2003.

NAFO Sci. Coun. Studies, 36: 315–316

Information for Preparing Manuscripts for NAFO Scientific Publications

Introduction

The manuscript should be in English. The sequence of the material should be: title page, Abstract, text including Introduction, Materials and Methods, Results, Discussion and Acknowledgements and References. Number all pages, including the title page, consecutively with arabic numbers in the center of the top margin. There is usually no page limitation or page charge for accepted publications.

Content of Manuscript

Title page

This page should contain the title, followed by the name(s) and address(es) of the author(s) including professional affiliation, and any related footnotes. The title should be limited to what is documented in the manuscript and be as concise as possible. Where necessary the scientific names of species should be included.

Abstract

An informative abstract must be provided, which does not exceed one double-spaced page or about 250 words, the ultimate length being dependent on the size of the manuscript. The abstract should concisely indicate the content and emphasis of the paper. It should begin with the main conclusion from the study and be supported by statements of relevant findings. The scientific names of species where necessary should be included here. It is important that the abstract accurately reflect the contents of the paper because it is often separated from the main body of the paper by abstracting and indexing services.

Text

In general, the text should be organized into Introduction, Materials and Methods, Results, Discussion, Acknowledgments and References. Authors should be guided by the organization of papers that have been published in the NAFO Journal or Studies and by such authorities as the Council of Biological Editors Style Manual (CBE, 9650 Rockville Pike, Bethesda, MD 20814, USA).

The **Introduction** should be limited to the purpose and rationale of the study. The article should begin with a clear description of the subject (include where necessary the scientific names of species), stating the hypothesis and/or defining the problem(s) the research was designed to solve. Define the time of the study, along with literature review and other information limited to what is relevant to the problem.

The **Materials and Methods** should provide the framework for obtaining answers to the problems which concern the purpose of the study. Describe in sufficient detail the materials and methods used so as to enable other scientists to evaluate the work or replicate the work.

The **Results** should answer the questions evolving from the purpose of the study in a comprehensive manner in an orderly and coherent sequence, with illustrative tables and figures. Ensure only relevant information is presented to substantiate the findings. Avoid any confusion between facts and inferences and the restatement of table and figure captions in the text.

The **Discussion** should give the main contributions from the study, with appropriate interpretation of the results focussing on the problem or hypothesis. Compare with those of other authors. Speculation should be limited to what can be supported with reasonable evidence. In the case of short papers, it may be useful to combine Results and Discussion to avoid repetition.

The **Acknowledgements** should be limited to the names of individuals who provided significant scientific and technical support, including reviews, during the preparation of the manuscript, and the names of agencies which provided financial support.

The **References** represents the list of references cited in the text listed alphabetically. Good judgment should be used in the selection of references, which should be restricted largely to significant published literature. Unpublished data and documents, manuscripts in preparation, and manuscripts awaiting acceptance to other journals may be noted in the text as unpublished data or personal communications, with full contact addresses.

Literature references cited in the text must be by author's surname and year of publication, e.g. (Collins, 1960). The surnames of two authors may be used in a citation, but, for more than two authors the citation should be (Collins *et al.*, 1960). The citation of mimeographed manuscript reports and meeting documents should contain the abbreviation "MS", e.g. (Collins *et al.*, MS 1960). All papers referred to in the text must be cited in the References alphabetically by the first author's surname and initials, followed by the initials and surnames of other authors, year of publication, full title of the paper, name of the periodical, volume and/or number, and range of pages. Abbreviations of periodicals should, if possible, follow the "*World List of Aquatic Sciences and Fisheries Serials Titles*", published periodically by FAO (Food and Agriculture Organization of the United Nations). References to monographs should, in addition to the author(s), year and title, contain the name and place of the publisher and the number of pages in the volume. Reference to a paper in a book containing a collection of papers should also contain the page range of the paper, name(s) of editor(s), and actual title of the book. The accuracy of all references and their correspondence with text citations is the responsibility of the author.

Comments on Tables and Figures

All Tables and Figures must be mentioned or discussed in the text. Tables and Figures must be numbered consecutively in arabic numerals, which correspond with the order of presentation in the text. The required position of the Tables and Figures in the text should be indicated in the left margin of the relevant page. Place the originals of Tables and Figures after the list of references.

Tables. Note a well constructed Table can eliminate elaborate text descriptions. Each Table should be carefully constructed to be easily read and understood. Each column and row must be concisely headed, ensuring relevant units of the values are given (usually within parentheses). Each Table should have a complete but concise descriptive heading, and should be on a separate sheets.

Figures. Note any reference to geographic areas relevant to the study should be shown in a Figure (or map) form giving coordinates. These and illustrations and photographs can eliminate elaborate text descriptions.

Each Figure should be carefully constructed and labelled to be easily read and understood. Each vertical and horizontal axis (e.g. x and y axes on a graph or latitude and longitudes on a map) must have a concise header with relevant units (usually within parentheses). Each Figure would have a complete but concise descriptive heading, and should be on a separate sheet.

When preparing figures, consideration should be given to details such as shading and lettering with respect to the effects of reduction in size to a page width (e.g. lettering should not be overbearing or too small). If oversized figures are necessary, only good quality page-size photocopies should be submitted. If the paper contains photographs, ensure they have good contrast whether they are in colour or black and white.

Mathematical equations and formulae must be accurately stated, with clear definitions of the various letters and symbols. If logarithmic expressions are used, the type of function (e.g. log, ln, $\log_{10}$ or $\log_e$) must be clearly indicated.

Manuscript Submission

NOTE: The following are the two major NAFO scientific publications, while the Scientific Council Research Documents (SCR Doc.) and Summary Document (SCS Doc.) are series that are submitted for meeting considerations.

The NAFO Secretariat now prefers to receive manuscript submissions, for any of the above publications in a computer electronic form. Coloured Tables and Figures are now accepted.

The manuscript submissions may be done by e-mail (with a hard copy and diskette also forwarded by mail), or by mail (one hard copy and diskette). All texts, Tables and Figures should be formatted using Word or WordPerfect (Word is preferred), with each Table and Figure saved in a separate file (eps (preferably), tiff, pct, jpg, bmp or gif).

The Secretariat may request alternative formats as publication technologies develop.

Journal of Northwest Atlantic Fishery Science

The Journal provides a forum for the primary publication of original research papers. While it is intended to be regional in scope, papers of general applicability and methodology, irrespective of region, may be considered. Both practical and theoretical papers are eligible. Space is also provided for notes, letters to the editor and notices.

Such manuscripts are considered for publication with the understanding that the content is unpublished and is not being submitted elsewhere for publication. Each manuscript is assigned to an Associate Editor of the Journals Editorial Board, for scientific editing. Papers are normally sent by the Associate Editors to two referees for appraisal regarding its suitability as a primary article.

NAFO Scientific Council Studies

The Studies publishes papers which are of topical interest and importance to the current and future activities of the Scientific Council, but which are not considered to be sufficiently high quality to meet the standards for primary publication in the Journal. Such papers have usually been presented as research documents at Scientific Council meetings and nominated for publication by the Standing Committee on Publications. These manuscripts are not normally refereed but undergo critical scrutiny by the Studies editor and by an expert familiar with the subject matter selected from the Journal editorial board.

Manuscripts (one hard copy and one copy saved on a computer diskette) being submitted should be addressed to:

Deputy Executive Secretary
Northwest Atlantic Fisheries Organization
P. O. Box 638
Dartmouth, Nova Scotia
Canada B2Y 3Y9

Tel: +902–468–5590
Fax: +902–468–5538
E-mail: info@nafo.ca

NAFO Sci. Coun. Studies, 36: 317–320

Scientific Publications of the Northwest Atlantic Fisheries Organization

Journal of Northwest Atlantic Fishery Science

The Journal provides an international forum for the primary publication of original research papers on fisheries science in the Northwest Atlantic, with emphasis on environmental, biological, ecological and fishery aspects of the living marine resources and ecosystems. (Scientific publications during ICNAF times during 1949–79 are available at the Secretariat).

Vol. 1	–	Miscellaneous papers, (10), December 1980, 112 pp.
Vol. 2	–	Miscellaneous papers, (10), October 1981, 76 pp.
Vol. 3, No. 1, 2	–	Miscellaneous papers, (17), May and December 1982, 180 pp.
Vol. 4	–	Special issue *Guide to the Early Stages of Marine Fishes Occurring in the Western North Atlantic Ocean, Cape Hatteras to the Southern Scotian Shelf*, July 1983, 424 pp.
Vol. 5, No. 1, 2	–	Miscellaneous papers, (26), January and November 1984, 224 pp.
Vol. 6, No. 1, 2	–	Miscellaneous papers, (17), June and December 1985, 179 pp.
Vol. 7, No. 1, 2	–	Miscellaneous papers, (18), December 1986 and December 1987, 177 pp.
Vol. 8	–	Miscellaneous papers, (7), December 1988, 88 pp.
Vol. 9	–	Miscellanous papers, (13), September and December 1989, 159 pp.
Vol. 10	–	Special issue, (1), *The Delimitation of Fishing Areas in the Northwest Atlantic*, December 1990, 57 pp.
Vol. 11	–	Miscellaneous papers, (7), February 1991, 80 pp.
Vol. 12	–	Miscellaneous papers, (7), January 1992, 84 pp.
Vol. 13	–	Miscellaneous papers, (7), December 1992, 114 pp.
Vol. 14	–	Symposium papers, (12), on *Changes in Biomass, Production and Species Composition of the Fish Populations in the Northwest Atlantic over the Last 30 Years, and Their Possible Causes*, December 1992, 160 pp.
Vol. 15	–	Special issue, (1), *Decapod Crustacean Larvae from Ungava Bay*, December 1993, 170 pp.
Vol. 16	–	Miscellaneous papers, (7), July 1994, 100 pp.
Vol. 17	–	Miscellaneous papers, (6), October 1994, 78 pp.
Vol. 18	–	Miscellaneous papers, (6) (1 Note), April 1996, 115 pp.
Vol. 19	–	Symposium papers, (11), on *Gear Selectivity/Technical Interactions in Mixed Species Fisheries*, September 1996, 145 pp.
Vol. 20	–	Special issue, (1), *North Atlantic Fishery Management Systems: A Comparison of Management Methods and Resource Trends*, September 1996, 143 pp.
Vol. 21	–	Miscellaneous papers, (5), April 1997, 83 pp.
Vol. 22	–	Symposium papers, (25) (1 Note), on *The Role of Marine Mammals in the Ecosystem*, December 1997, 387 pp.
Vol. 23	–	Symposium papers, (16), *What Future for Capture Fisheries*, October 1998, 277 pp.
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Vol. 29	–	Miscellaneous papers, (5), December, 2001, 99 pp.
Vol. 30	–	Miscellaneous papers, (5), December, 2002, 91 pp.
Vol. 31	–	(in preparation).

NAFO Scientific Council Studies

This publication includes papers of topical interest and importance to the current and future activities of the Scientific Council.

No. 1	–	Miscellaneous papers, (11), March 1981, 101 pp.
No. 2	–	Manual on *Groundfish Surveys*, December 1981, 56 pp.

NAFO Scientific Council Studies (Continued)

No. 3 – Miscellaneous papers, (8), April 1982, 82 pp.
No. 4 – Special Session papers, (12), on *Remote-Sensing Applications to Fishery Science*, September 1982, 98 pp.
No. 5 – Symposium papers, (12), on *Environmental Conditions in 1970–79*, December 1982, 114 pp.
No. 6 – Miscellaneous papers, (8), December 1983, 104 pp.
No. 7 – Miscellaneous papers, (9), August 1984, 98 pp.
No. 8 – Miscellaneous papers, (12), April 1985, 96 pp.
No. 9 – Special Session papers, (17), on *Squids*, November 1985, 180 pp.
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No. 14 – Miscellaneous papers, (6), May 1990, 74 pp.
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No. 18 – Symposium papers, (18), on *Changes in Abundance and Biology of Cod Stocks and Their Possible Causes*, July 1993, 110 pp.
No. 19 – Miscellaneous papers, (8), October 1993, 98 pp.
No. 20 – Miscellaneous papers, (7), February 1994, 114 pp.
No. 21 – Collections of Papers, (10), Related to *Northern Cod and Seals in NAFO Divisions 2J and 3KL*, December 1994, 165 pp.
No. 22 – Miscellaneous papers, (6), May 1995, 95 pp.
No. 23 – Miscellaneous papers, (5), September 1995, 95 pp.
No. 24 – Symposium papers, (12), on *Impact of Anomalous Oceanographic Conditions at the Beginning of the 1990s in the Northwest Atlantic on the Distribution and Behaviour of Marine Life*, September 1994, 155 pp.
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No. 29 – Selected Papers, (11), *Selected Studies Related to Assessment of Cod in NAFO Divisions 2J+3KL*, May 1997, 125 pp.
No. 30 – Miscellaneous papers, (9), December 1997, 117 pp.
No. 31 – Miscellaneous papers, (8), December 1998, 165 pp.
No. 32 – Miscellaneous papers, (8), April 1999, 133 pp.
No. 33 – Miscellaneous papers, (7), May 2000, 135 pp.
No. 34 – Miscellaneous papers, (3), October, 2001, 91 pp.
No. 35 – Workshop on *The Canada-United States Yellowtail Flounder Age Reading*, December 2002, 68 pp.

NAFO Scientific Council Reports

This publication contains reports of Scientific Council Meetings held through each year since NAFO replaced ICNAF. (The comparable publication during ICNAF was called the *Redbook*).

1980 – Reports of seven meetings in 1979 and 1980, Published December 1980, 190 pp.
1981 – Reports of four meetings in 1981, Published December 1981, 148 pp.
1982 – Reports of two meetings in 1982, Published December 1982, 110 pp.
1983 – Reports of three meetings in 1983, Published December 1983, 152 pp.
1984 – Reports of three meetings in 1984, Published December 1984, 126 pp.
1985 – Reports of three meetings in 1985, Published December 1985, 146 pp.
1986 – Reports of three meetings in 1986, Published December 1986, 156 pp.
1987 – Reports of three meetings in 1987, Published December 1987, 138 pp.
1988 – Reports of two meetings in 1988, Published December 1988, 150 pp.
1989 – Reports of two meetings in 1989, Published December 1989, 180 pp.
1990 – Reports of two meetings in 1990, Published December 1990, 188 pp.

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1991 – Reports of two meetings in 1991, Published December 1991, 164 pp.
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1993 – Reports of three meetings in 1993, Published January 1994, 234 pp.
1994 – Reports of four meetings in 1994, Published January 1995, 234 pp.
1994 – Reports of four meetings in 1994, Published January 1995, 234 pp.
1995 – Reports of three meetings in 1995, Published January 1996, 244 pp.
1996 – Reports of three meetings in 1996, Published January 1997, 226 pp.
1997 – Reports of three meetings in 1997, Published January 1998, 274 pp.
1998 – Reports of three meetings in 1998, Published January 1999, 257 pp.
1999 – Report of four meetings in 1999, Published January 2000, 327 pp.
2000 – Report of four meetings in 2000, Published January 2001, 303 pp.
2001 – Report of three meetings in 2001, Published January 2002, 339 pp.
2002 – Report of three meetings in 2002, Published January 2003, 323 pp.

NAFO Statistical Bulletin

This publication replaced *ICNAF Statistical Bulletin* which terminated with Vol. 28 (revised). The volume numbering continues the series as the *NAFO Statistical Bulletin.*

Vol. 29 – Fishery statistics for 1979, Originally published July 1981; revised edition published November 1984, 290 pp.
Vol. 30 – Fishery statistics for 1980, Originally published August 1982; revised edition published October 1984, 280 pp.
Vol. 31 – Fishery statistics for 1981, Originally published September 1983; revised edition published March 1985, 276 pp.
Vol. 32 – Fishery statistics for 1982, Published December 1984, 284 pp.
Vol. 33 – Fishery statistics for 1983, Published December 1985, 280 pp.
Vol. 34 – Fishery statistics for 1984, Published December 1986, 304 pp.
Vol. 35 – Fishery statistics for 1985, Published December 1987, 322 pp.
Vol. 36 – Fishery statistics for 1986, Published October 1989, 304 pp.
Vol. 37 – Fishery statistics for 1987, Published April 1990, 295 pp.
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Vol. 39 – Fishery statistics for 1989, Published February 1993, 300 pp.
Vol. 40 – Fishery statistics for 1990, Published February 1994, 309 pp.
Vol. 41 – Fishery statistics for 1991, Published February 1995, 318 pp.
– Statistical Bulletin Supplementary Issue, 1960–90, (statistics) Published April 1995, 156 pp.
Vol. 42 – Fishery statistics for 1992, Published October 1995, 310 pp.
Vol. 43 – Fishery statistics for 1993, Published December 1997, 329 pp.
Vol. 44 – Fishery statistics for 1994, Published December 2000, 201 pp.
Vol. 45 – Fishery statistics for 1995, Published October 2001, 207 pp.
Vol. 46 – Fishery statistics for 1996, Published November 2001, 214 pp.
Vol. 47 – Fishery statistics for 1997, Published November 2001, 216 pp.
Vol. 48 – Fishery statistics for 1998, Published November 2001, 210 pp.
Vol. 49 – Fishery statistics for 1999, Published January 2002, 210 pp.

Inventory of Sampling Data

This publication replaced *ICNAF Inventory of Sampling Data* 1967–1978 which was completed in 1986.

Inventory of Sampling Data 1979–1984, Published April 1989, 250 pp.
Inventory of Sampling Data 1985–1989, Published March 1993, 265 pp.
Inventory of Sampling Data 1990–1994, Published October 1999, 287 pp.
Inventory of Sampling Data 1995–1999, Published November 2002, 142 pp.

NAFO Index of Meeting Documents

This publication contains lists of all documents along with a subject and author index of the NAFO Scientific Council documents issued during 5-year periods.

1979–84 – Index of Meeting Documents, Published March 1985, 146 pp.
1985–89 – Index of Meeting Documents, Published December 1990, 116 pp.
1990–94 – Index of Meeting Documents, Published November 1995, 139 pp.
1995–99 – Index of Meeting Documents, Published December 2000, 141 pp.