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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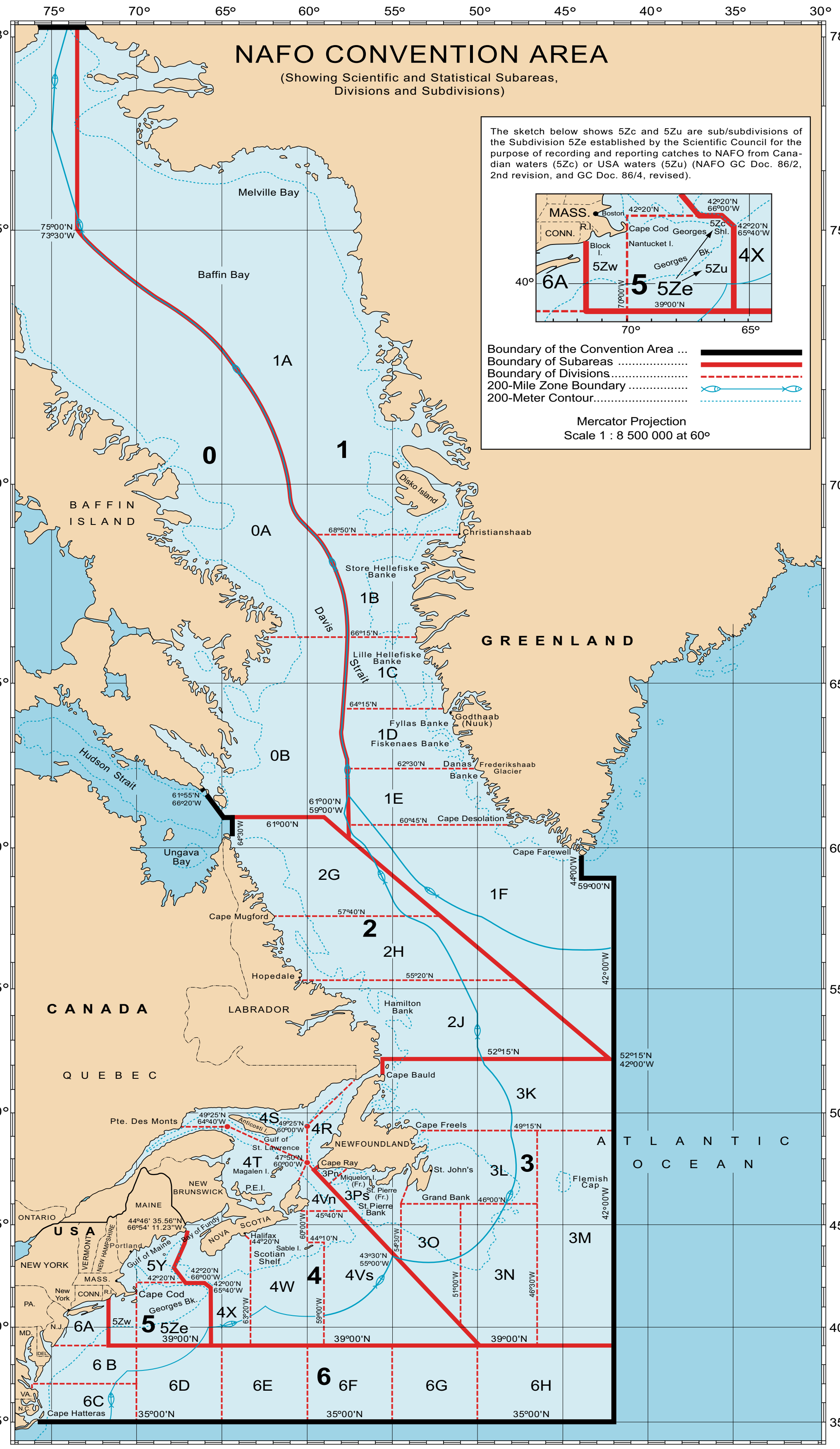

NAFO CONVENTION AREA
(Showing Scientific and Statistical Subareas, Divisions and Subdivisions)
The sketch below shows 5Zc and 5Zu are sub/subdivisions of the Subdivision 5Ze established by the Scientific Council for the purpose of recording and reporting catches to NAFO from Canadian waters (5Zc) or USA waters (5Zu) (NAFO GC Doc. 86/2, 2nd revision, and GC Doc. 86/4, revised).
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Boston
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Georges Bk.
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Boundary of Divisions
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GREENLAND
Disko Island
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Lille Hellefiske Banke
Davis Strait
Godthaab (Nuuk)
Fyllas Banke
Fiskenaes Banke
Danas Banke
Frederikshaab Glacier
Cape Desolation
Cape Farewell
Hudson Strait
Ungava Bay
Cape Mugford
Hopedale
Hamilton Bank
LABRADOR
CANADA
QUEBEC
Cape Bauld
Cape Freels
NEWFOUNDLAND
Cape Ray
St. John's
Flemish Cap
Grand Bank
St. Pierre Bank
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St. Pierre (Fr.)
Pte. Des Monts
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Gulf of St. Lawrence
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Sable I.
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Bay of Fundy
Gulf of Maine
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NAFO Sci. Coun. Studies, 36: 1–18

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	