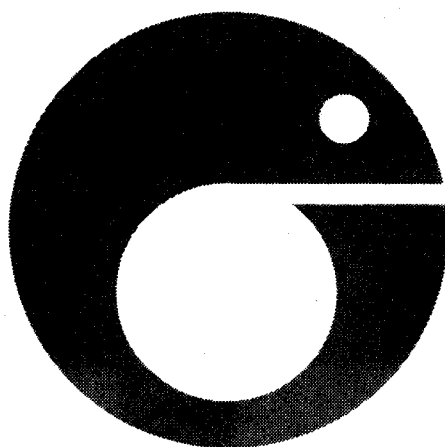


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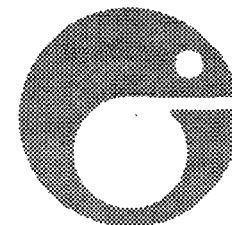
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Integrated Catch at Age Analysis

Version 1.2



K R Patterson¹ and G D Melvin²

Section A. User's Guide

1.0 Overview and Purpose

This users' manual is a guide to the practical aspects of installing and running the "Integrated Catch at Age Analysis" programmes. Theoretical and statistical aspects are not covered here, and the prospective users are strongly urged to familiarise themselves with the formal background of the analytic model, which is described in the Technical Reference, and with the literature quoted therein.

The software package named "Integrated Catch-Age Analysis" (ICA) has been written to provide an analytical stock assessment tool which allows a variety of model choices to be implemented conveniently. A full implementation of the model would be extremely difficult to use on account of the flexibility of the method, and hence of the many user choices that would need to be made in running the programme. Consequently an implementation has been written that makes usable the desired features in a convenient fashion, while restricting alternative choices that are not relevant to the pelagic fisheries problem. The main features allowed are:

- a) Tuning using either or both age-structured and spawning biomass (non-age structured) indices.
- b) Choice of catchability model: identity, linear or power.
- c) Inclusion of separable constraint.

- d) Choice of series reweighting: equal, inverse-variance or fixed.
- e) Inclusion of a Beverton and Holt stock-recruit relationship.
- f) Calculation of a "shrunk" VPA based on the model fit.

The programme allows a statistical analysis of an age-structured data set to be completed simply and relatively quickly, so that the uncertainties inherent in a stock assessment can be assessed and the consistency of an assessment evaluated. It allows estimates to be calculated of the standard deviation of the estimated fishing mortalities, and of other parameters of management interest. A post-processing programme displays a series of graphs of the parameter estimates: fishing mortality, recruitment, etc, with error bars where appropriate. Residual plots are also drawn. These allow a visual assessment of the consistency of a model fit to be made simply and quickly. A post-processing projection programme allows calculation of stock projections, with associated estimates of error and risk.

A number of diagnostic plots are provided in order that the user may check that the data conform reasonably to the assumptions. Test statistics for goodness of fit, skewness and kurtosis are also provided.

The purpose of this Users' Manual is to provide a description for the installation, testing and data file configuration of the Integrated Catch-Age Analysis software. Although the manual is geared towards the practical aspects of getting the software up-and-running, an explanation of the various

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input parameters, output files, interpretation of results and common errors has also been included. Details of the analytical methodologies and programme source code are described in the Technical Reference and Programmer's Reference manuals.

To assist the user, the manual is divided into several sections which describe the hardware and software requirements, detail the installation and testing, describe data file formats, and includes step-by-step description of the input parameters for running the software.

2.0 Hardware Requirements

Both the analysis and the display programmes of ICA have been written and compiled for use on an IBM-PC compatible microcomputer, running MS DOS (Ver 5.0 or greater). The minimum configuration is a 80386 microprocessor with 640 K of conventional memory; however a 80486 microprocessor will greatly decrease the run time. A math co-processor, although not essential, will reduce computational time considerably. Currently the ICA package contains printer drivers for Hewlett-Packard LaserjetII and EPSON compatible printers. Only systems supporting one of these printer protocols can print from the display programmes.

The software contains two separate sets of PC executable routines, one for MS-DOS and the other for Windows. For smaller data sets it is recommended that the DOS version be utilized to improve the run speed. The Windows version is primarily for larger data sets and run speed penalties are incurred due to the system's memory manipulation. The North Sea herring data set, which is used as an example data set, does not require the Windows application. Windows users are cautioned that an error may occur when trying to run either of the DOS programmes from within Windows. This is due to an error in the Microsoft compiler; it is preferable to run only the Windows versions if Windows is running on the machine.

Regardless of the application, the programme is slow to run because of the extensive

computational demands of the method. It is, however, possible to adapt the programme to faster machines such as a UNIX workstation. The programme is written in Microsoft FORTRAN and can be recompiled for most computers as long as an NAG workstation library is available. The graphics display programme is written in object-oriented Turbo PASCAL 6.0 and its application is restricted to IBM PCs for the foreseeable future.

3.0 ICA Software Presentation

The ICA software, Users' Manual and example data files are contained on a single 3.5 high density diskette. Examination of the ICA diskette will reveal the following three files and two sub-directories;

- ICA1_2.ZIP - File contains all the software programmes in a compressed form and is non-executable.
- PKUNZIP.EXE - This programme is used to unpack the ICA1_2.ZIP file into executable programmes during the installation process (Section 4.0). Note that this is a shareware product.
- ICAUSER.MAN - This file contains the Users' Manual in WordPerfect 5.1 format.
- Subdirectory: HERR_VPA - Contains a complete set of data files for testing and learning to use the software.
- SOURCE.ZIP - Contains the source code for the programmes in a compressed form. These files are not required to run the software. PKUNZIP will unpack the files if you wish to examine them.

4.0 Installation of Programmes and Test Data

4.1 DOS installation

The following provides step by step instruction for installation of the ICA Programmes and the Test Data set. For ease of understanding we have chosen to **BOLDFACE** commands which are required inputs. This convention will be used throughout this manual.

- a) Create a directory c:\ICA on your hard disk (**md c:\ica**).
- b) Insert the ICA diskette in the disk drive (assumed = a:).
- c) From C:> Type **"a:pkunzip a:ica1_2.zip c:\ica"** followed by **"cd ica"** from DOS. This will uncompress all ICA files and put you in the subdirectory c:\ica.
- d) If you do not wish to use the Windows versions then type **"del ???WIN.EXE"**. You may wish to retain this version for future use unless disc space is a problem.
- e) You must now select the printer type output. If you have an Epson-type printer then type **rename *.eps *.exe**
If you have a printer with Hewlett-Packard LaserjetII compatibility then type **rename *.hp3 *.exe**
- f) If you have neither printer, then use either one of the above, but you will not be able to print any graphs.

Upon completion of the above procedure your C:\ICA directory should contain the following files:

ICA1DOS EXE	212412 01-04-95	1:20p
ICA1WIN EXE	240888 01-04-95	1:18p
ICA2DOS EXE	327816 01-04-95	1:29p
ICA2WIN EXE	406674 11-16-94	2:04
ICAVIEW EXE	111168 10-26-93	12:56p
ICPROJ EXE	342696 10-17-94	7:39p
VIEWPRO EXE	83968 12-16-93	6:44p
IEWSRR EXE	81056 11-02-93	5:59p
VIEWPRO HP3	83968 12-16-93	6:44p
IEWSRR HP3	81056 11-02-93	5:59p
ICAVIEW HP3	111168 10-26-93	12:56p
VIEWPRO EPS	84032 12-23-93	2:39p
IEWSRR EPS	81056 12-23-93	2:40p

- g) To remove unneeded files type: **del c:\ica*.hp or del c:\ica*.eps**

The ICA software is now ready to run from your hard disk. If you wish to test the installation or familiarize yourself with the package using the test data set continue with the installation instructions.

- h) To copy a test data set on North Sea herring, create a directory **md c:\herr_vpa** on your hard disk, and copy the data from the diskette : **copy a:\herr_vpa*. * c:\herr_vpa*. *** . Please note that you can put the test data in any directory or sub-directory you like (eg C:\ica\data), but you must ensure that when entering the filenames you type the complete address.
- i) To copy a test projection file, **copy a:\fmult.dat c:\ica'**.

4.2 WINDOWS installation

Proceed as above, then start Windows in the usual manner if you have not already done so. Then, from File Manager, make the choices : **File / New / Program Group / OK**; Then in the "Description" Box enter **ICA** and click on **OK**. Leave the Group File box empty. A new window will appear entitled ICA. Then make the choices **File / New / Program Item / OK**. A program item properties box will appear. Make the following entries:

Description: **ICA1WIN**
 Command Line: **C:\ICA\ICA1WIN.EXE**
 Working Directory: **C:\HERR_VPA** (or wherever you have the data you are working on)
 Shortcut Key: **None**
 Run Minimised: **Leave blank**

and choose **OK**. Repeat the process for ICA2WIN, ICAVIEW and VIEWSRR. The ICA installation for Windows will then be complete and you will be able to run the programmes by clicking on the icons. You may wish to change the icons from the small icon library in the Program Manager. Each time you want to change the working directory to change to a new data set, select the icon, press Alt-Enter, and retype the working directory name.

5.0 Programme Limits

Memory size constraints currently limit the programme to accepting three indices of SSB and five age-structured indices, for 20 years of data, 13 age classes and 1,000 observations. No more than 75 parameters may be estimated (parameters are: selection

at age, fishing mortality at reference age, cohort strengths in the separable model; catchabilities at age; SSB catchabilities, recruitment in year after last year of catch at age data, a and b in the stock-recruit model). The complexity of the model that can be fitted also depends on the available memory at run-time. As this cannot be known in advance, the programme will check at run-time if sufficient memory is available. If there is insufficient memory available the user will be warned and the programme will stop. Releasing more conventional memory, such as by disconnecting from a network or disabling TSRs, may solve the problem. Otherwise it will be necessary to use the WINDOWS version. If the problem persists it may be necessary to install more memory in the machine.

File names and paths are limited to 40 characters.

6.0 Datafile Preparation

Careful preparation of data input files is critical to the successful operation of the ICA Software. Even a single mistyped or omitted character can cause the programme to crash. Many frustrating hours have been spent trying to locate a misplaced character or value. It is therefore recommended that users pay particular attention to data file formats.

The ICA datafile structure is a slightly restricted form of the well-known "Lowestoft VPA" format, which itself requires strict adherence to format. The following file description is a modified version of information presented in the Lowestoft VPA Manual. To further assist the user we have included a complete set of data files in Appendix 1 for the North Sea Herring (ie the test data).

To create a new data set the user will need to prepare the input data files using an external editor with ASCII output, such as MS-DOS EDIT or the Windows NOTEPAD. Three basic data file types are required for the ICA Software; a stock index file, stock data files, and one or more tuning files. Each of these will be discussed in detail in the upcoming sections.

6.1 Stock index file

The index or stock index file is the driving function of the software. Contained within this file is the stock title, sex option and a list of the data filenames which the ICA software will use to assess a given stock. To standardize labelling the filename extension ".ndx" (eg NSHERR.ndx) is recommended for this file. The following format is required for the stock index file:

Record No*	Content	Index No
1	Stock title (80 characters maximum)	
2	Sex option (value 1 only)	
3	File name for "Landings (tonnes)" data	1
4	File name for "Catch-at-age (numbers)" data	2
5	File name for "Catch weight-at-age (kg)" data	3
6	File name for "Stock weight-at-age (kg)" data	4
7	File name for "Natural Mortality" data	5
8	File name for "Proportion mature-at-age" data	6
9	File name for "Proportion of F before spawning" data	7
10	File name for "Proportion of M before spawning" data	8

*Record numbers and index numbers are not contained within the field. The file contains only a title, the figure 1 and a list of file names, content and index number in free format.

Notes:

- Filename order is important. Misplaced or misordered file names can cause the programme to stop.
- Data filenames must include the full address of a file, *drive\path\filename*. For example "C:\ica\nsherr.ndx"
- No provision has been made for dealing with discard data separately. If this information is available it should be included by summing landed catch and discards.
- File names and paths must not exceed 40 characters.

6.2 Stock datafiles

The stock data files are the files which contain information about the stock being assessed; such as catch, weight-at age, mortality estimates, etc. All stock data files have a common base format, but some differences occur in the layout of the actual data, where the structure is defined by the data format identifier (DFI) record. Three data structures are accepted by the ICA software:

DFI code	Data structure	Example files
1	Two dimensional array	NSHERRSW.DAT
3	Scalar value	NSHERRPF.DAT
5	Column array	NSHERRLA.DAT

The base format for each stock data file is:

Content	Record No
Title (80 characters maximum)	
Sex (1 only)	Index No 1
First Year	Last Year 2
First Age	Last Age 3
DFI (1,2,3 or 5)	4
(1st year) Data ... (by age)	5
-	6
-	.
-	.
-	.
(last year)	n

For ease in identifying data files it is recommended that the convention suggested below be used to label data files; remembering that DOS filenames cannot exceed eight characters. The standard extension is ".dat". Data filenames should contain a 2-3 letter identifier for the stock, 2-4 letters for the species and two letters for the file content. Thus, for the test data filename NSHERRLA.DAT, NS refers to the North Sea, HERR to herring and LA for landings. Recommended file content characters are:

Characters	Description	Example
LA	- landings (tonnes)	14.2
CN	- catch-at-age (thousands)	14.3
CW	- catch weight-at-age (kg)	14.4
SW	- stock weight-at-age (kg)	14.5
NM	- natural mortality	14.6
MO	- maturity-at-age ogive	14.7
PF	- proportion of F before spawning	14.8
PM	- proportion of M before spawning	14.9

An example of each data file for the North Sea herring is provided in Appendix 1.

The ICA programmes calculate projected populations for one year ahead of the catch-at-age matrix. For example, if there are data on catches up to 1992, the programmes will calculate populations up to 1 January 1993; if there are observations of indices of abundance during 1993 then the programmes will also need to calculate the populations at the times of the survey indices. This can be done on the assumption that F in 1993 = F in 1994, or else by specifying missing catch-at-age observations in 1993. However, it becomes necessary to have some estimates of maturity ogives, stock weights and natural mortality for this additional year. If desired, the MO, NM and SW files can be extended by an additional year in order to input these data, in which case the file headers must be modified accordingly. Otherwise, the programmes will use the data in the last year of the catch-at-age observations as estimates for the following year. A message to this effect is displayed to the user when this is done.

Data files which contain insufficient data will cause ICA to stop. For example, if the year range indicates 12 years of data and only 11 are included in the file the programme will terminate. However, the converse case of excess data will not cause the programme to stop as the additional data is ignored. It is thus important to ensure the file header matches the data.

6.3 Indices of abundance

The "tuning files" contain indices of stock abundance that are independent of the catch-

at-age data set. They are also referred to as abundance indices, and for ICA fall into two categories; age-structured and SSB index files (non-age structured), either or both of which can be used in any analysis. There may be up to three SSB indices and five age-structured indices. In the case of age structured tuning data the following format is required. Again data structure is critical to the successful operation of ICA (see Section 14.10). Up to five age-structured indices ("fleets" in demersal parlance) may be included.

6.3.1 Age-structured datafile format

Record No*	Description
1	File title (maximum 80 characters)
2	Number of fleets (+100)
3	Fleet name (maximum 20 characters)
4	First year Last year
5	Sex code Effort code Alpha Beta
6	First age Last age
7	(1st year) Effort value** Catch numbers (by age) ...→
.	-
.	-
n	- (Last year) ↓

*Record numbers are not included in the file.

**Effort values will usually all be = 1 for survey data

Records 3 to 7+ are repeated for each age-structured index. Note a run-time error may occur if software limitations are exceeded (see Section 5.0). Use Windows Version when memory constraints are expected.

General description of records:

File Title	- contains a description of fishery being assessed.
Number of indices	- 100 + number of indices in the file.
Index Name	- Name of Index (eg acoustic, Bottom Trawl, etc)
First Year	- first year of data in index

Last Year	- Last year of data in index
Sex Code	- Must be 1 to retain compatibility with old data
Effort Code	- Must be 1 to retain compatibility with old data
Alpha & Beta	- Start and end of the survey period for the index in decimal parts of a year
First Age	- First age in the index
Last Age	- Last age in the index

6.3.2 SSB datafile format

Age-aggregated indices of spawning stock biomass (SSB), such as larval surveys are also accepted by the ICA software. Details of how the programme incorporates these data are provided in Section B (Technical reference). The file structure is however different from the age-structured tuning file in that it follows the Lowestoft RCT3 format (see example file NSHERR.RCT, Section 14.11), the structure of which is described below. The first data column holds the year of the observation, the second column is a stock size estimate from a historical VPA and each of the other columns an SSB index. A maximum of three indices is permitted. The second column is ignored by ICA.

SSB data file format	Record
1	Data file title
2	<Number of Indices> <Number of Years> 2
3	Index or indices labels (maximum of 8 characters each)
4	Year VPA Data SSB Index 1 SSB Index 2 ...→
.	-
.	-
n	- (by year) ↓

*Record number is not contained within the file.

The records in the SSB datafile are:

- Record 1 - Title of data file (less than 40 characters)
- Record 2 - Number of indices
- Number of years
- 2 , for RCT3 this holds the column number for VPA
- Record 3 - Contains the indices labels, one maximum eight character name for each. Again this is for RCT3 compatibility. ICA does not use them.

Notes:

- Because this file uses the RCT3 format a number of input parameters are not utilized by the ICA Software. Record 2 contains the number of indices, the number of years and the column position for VPA data of the RCT3 programme. Since ICA ignores the VPA data any number in column 2 of Record 4 or greater is not used. It is important however that some value be put in column 2, otherwise the ICA model will confuse it with survey data. Record 3 although required in the file is also ignored by ICA.
- Year must be written out, eg 1995.
- Any negative value is considered a missing value.

6.4 Stock-recruitment datafile format

The ICA programmes can be used to fit a stock-recruit relationship with up to the 20 years of allowed catch at age data. However, when attempting to fit such a relationship it is highly desirable to include data from as long a time-series as possible. The programmes allow the inclusion of up to a further 20-*lag* "observations" of stock and recruit if these are available from external estimates such as a historical VPA. The *lag* is the number of years between spawning and the first age in the catch-at-age matrix. If users wish to include such estimates in the fitted relationship they must prepare a data file with the following format (Example Section 14.2):

Record No*	Description
1	Year in which data begin
2	(1 st year) <Stock Size> <Number Recruits>
.	-
.	-
n	(Last year) ↓

*Record number is not contained within the file.

Note: the data contained in this file are only for years which are not covered by the ICA input data. The programmes will seek to read stock and recruit "observations" from the year stated in the first line, up to the first year at which there are catch-at-age observations in the main data set.

6.5 Zeroes and missing values

Catch at age matrices can be highly variable at the youngest and the oldest ages, with gaps in some years when no fish of certain ages were found in the samples. This causes difficulties as in neither the conventional VPA nor in the separable VPA is it allowable to have a zero observation. In the former case, a zero catch implies a zero F in which case the VPA will not work, and in the latter case it is assumed that catches at age have a log-normal error distribution, which implies that the observation will never be zero.

The usual way of dealing with this problem in conventional VPA is to replace the gap in the table with a low value, which might be an arbitrary figure or might be the lowest of the remaining non-zero observations. If the ICA programmes encounter a zero (defined as values between 0.0 and 0.1) then the following procedure is used:

- If the zero value is not the terminal value, the lowest observed value in the catches-at-age is inserted in the data matrix and the conventional VPA calculation will be made, so estimating a very small fishing mortality.
- If there is a zero value at the last age, the programme will trace back up the cohort until a non-missing catch at age

observation is found. A terminal population will be estimated using the terminal fishing mortality estimated for the oldest age in the year of the observation, corrected for the estimated selection at the actual age. The cohort will then be filled-in forwards using the estimated terminal mortalities for the relevant years, as corrected for the estimated selection at the relevant ages. This allows the fitting of index values even where the catch-at-age observation is zero.

It is the users' responsibility to make sure that input data are scaled so that few of the observations lie between 0 and 0.1, otherwise much of the data will be overwritten.

An alternative way of dealing with such gaps is available, provided that the gap lies in the range of years and ages over which the separable model is to be fitted. The gap can be treated as a "missing value" in the statistical sense when the model is fitted. In such cases,

- The observation is ignored when the separable model is fitted.
- No residual is calculated for the observation, but an arbitrary value of -1 is printed in the residuals table in the output file.
- Output from the ICA1 programme should be ignored

In order to specify a value as missing, a negative number should be entered in the catch at age data file. The value of this number should be the best available estimate of the catch at age, as the quantity will be used when calculating the starting point for finding the solution. It is possible to specify an entire years' data as missing, but in such cases the variance of the estimated fishing mortality will (not unreasonably) be extremely large.

In summary: if a value in the catch at age matrix is between 0 and 0.1 it will be reset to the lowest non-zero observation. If it is given as a negative value it will be used for

initialisation but thereafter treated as a missing value. The latter option may only be used for the range of years over which the separable model is fitted.

6.6 Units and scaling

It is recommended that the user enter catch numbers in thousands and weights in the catch and stock in Kg. If other options are chosen the output table headings will be incorrect. All mortality rates are assumed to be annual rates.

7.0 Running ICA

This section describes an illustrative ICA run using the example data set. Following this example should enable the new user to duplicate the output tables and graphs presented in Appendix 2.

Once all the data files have been prepared and checked for accuracy you are ready to undertake an assessment calculation. The ICA software is comprised of two main executable routines; **ICA1DOS.exe** and **ICA2DOS.exe** (Windows equivalents are ICA1WIN and ICA2WIN), and two graphical display programmes; **ICAVIEW.exe** and **VIEWSR.R.exe**. Appropriate parameter selection is made within the former two programmes. The specific input parameters will be discussed after a general statement of what each programme does.

The **ICA1DOS.exe** programme is the initialisation routine which performs the functions preparatory to the least-squares analysis. Datafiles are read, appropriate parameter choices are requested from the user on the screen, and an initial estimate of the minimum is found. Over a range of terminal fishing mortalities specified by the user, the sum of squared residuals for each index series are calculated. The programme then produces an output file called ICA.TMP. This is a temporary data file used to pass values on to another programme, in this case to the ICA2DOS programme. A summary of the ICA1DOS routine is provided in Part 2 of Section B (Programmer's Reference Manual).

The **ICA2DOS.exe** programme performs the

multidimensional minimisation, reweighting and output functions. This programme initially accepts a choice from the user about whether reweighting is to be used. The user must also specify a stopping criterion for the reweighting iterations. A note of caution is appropriate at this point. Users may find that due to memory limitations this routine stops with an insufficient memory error. If this occurs you can run the Windows version of ICA2 from Windows. The problem is also often encountered when running the DOS version with Windows still active. Alternatively, you can re-boot your PC for DOS only.

The **ICAVIEW.exe** programme displays a number of summary and diagnostic graphs on the screen, which can be written to a printer if necessary. Simply type ICAVIEW from DOS and the programme will read the files "ICADIAG.OUT", "ICA.VIE" and "ICA.RES" and display the appropriate graphs.

The **VIEWSR.R.exe** is another simple utility which reads a file called "ica.srr" which is generated by ICA1 or ICA2 when a stock-recruit relation is fitted. Graphs of recruitment on SSB; residual on expected recruitment, and residual on time are displayed.

7.1 *The ICA1 routine: initialisation*

The following provides step-by-step instructions for running the ICA1 routine. For each step a brief description of what is required is provided. If an input parameter has several options or a limited range these are also explained. For the sake of consistency we have chosen to highlight executable programmes in **BOLDFACE CAPITAL** letters. The example data set input filenames and their associated addresses will be used for illustration. These will appear in **small letter boldfaced** print.

7.1.1 *Specifying input datafiles*

The ICA programme is started by typing ICA1DOS from the C:\ica> prompt.

C:\ica>**ICA1DOS**

or from Windows by double-clicking on the icon.

You will then be prompted on screen for a series of input files. The first file requested is the stock index file (See Section 6.1); Note you must specify the complete address of the file.

Enter the name of the index file —>
C:\herr_vpa\hsherr.ndx

This is followed by an on-screen listing of the data file names contained within the index file.

The next request is for the age-structured index filename (Section 6.3.1). If you do not have this type of tuning data or if you do not wish to include it in the analysis press ENTER.

Name of age-structured index
file (Enter if none) —>
C:\herr_vpa\hsherrfl.dat

The final request for file input is for the SSB index file (Section 6.3.2). Again if you do not have this type of data available or you do not wish to include it in the analysis press ENTER. You must however input either an age-structured or SSB index file or the programme will not run.

Name of the SSB index File (Enter if
none) —> **C:\herr_vpa\hsherr.rct**

Once all the data files have been read by the programme you will be prompted to make a series of selections. To aid you in responding a brief description of the input variable and their range limitations have been included.

7.1.2 *Resetting the last year*

The last year of the catch-at-age from the input data is displayed, together with an option to change it.

Last year of catch data set is 1994

Press <Enter> to Accept or else a new
last year —>**1994**

This option is presented in order to allow retrospective testing without changing the input data files. If the last year is reset by (say) two years, all the data series will be

shortened by two years. This allows the timing of the last years of the indices with respect to the last year of the catch-at-age data to be maintained consistently in the retrospectives, as is required when using a recruitment index in the model.

7.1.3 *Parameters of the separable constraint*

You will now be prompted for three parameters to constrain the exploitation pattern. These work in exactly the same way as in the Lowestoft VPA, and are:

- a) The number of years for the separable constraint. The Lowestoft programme suggests six years as a suitable choice for this parameter. Choosing less than three years will cause an error as there will be insufficient data to estimate the exploitation pattern from so few data. Choosing a large number of years is likely to use up too much memory in the minimisation. Sensible choices for this parameter would seem to lie in the range 3 to 10 years.

No years for separable constraint ? —> **3**

- b) The reference age for separable constraint. This should be your estimate of the first fully-recruited age group. Error-trapping in the programme will reject values that are within one year of the first age or within two years of the last age. Age 4 is normally used for herring.

Reference age for separable constraint? —> **4**

- c) The selection to be fixed on the last age group. As for conventional separable VPA, this should be a number of the order of 1.0, depending on prior prejudice about the exploitation pattern. Error-trapping in the programme limits this choice to the range 0.4 to 1.7.

S to be fixed on last age ? —> **1.0**

- d) The first and last age for calculation of the reference F is requested next. The

“reference F” is simply an arithmetic mean F over a defined age-range that is used for administrative purposes. It is calculated within the programmes for convenience but the choices made here do not affect the model fit. Any convenient age-range can be selected as desired, eg

First age for calculation of reference F
—> **3**

Last age for calculation of Reference F
—> **6**

7.1.4 *Specification of weights on the catches at age*

Default weighting can be chosen, in which case all ages will be weighted equally (ie = 1.0) for the separable constraint;

Default weighting (Y/N) ? —> **N**

Otherwise, you will be prompted for a relative weight at each age, relative weights by year and specific weights for year and age which can be entered by hand:

Enter relative weights at age:

Weight for age 0 —> **0.01**

Weight for age 1 —> **0.5**

.

Weight for age 9 —> **1.0**

Enter relative weights by year

Weight for year 1992 —> **1.0**

Weight for year 1993 —> **1.0**

Weight for year 1994 —> **1.0**

A weighting matrix by year and age will be formed as the product of the weights on the years and the ages. It may occasionally be desirable to downweight one or more outlying observations, or perhaps to downweight an entire cohort which may be atypical. The next option allows you to overwrite any of the values in the weighting matrix.

Specify weights for year and age:

Enter year, age, new weight

or -1, -1, -1 to finish

-1, -1, -1

In most cases it will be unnecessary to make use of this facility and typing -1 three times will allow you to proceed to the next section.

Relative weights at age are the ratio of the inverse log variances of the catch-at-age observations compared to the survey indices and to each other. You would normally choose to set all equal to one, except at those ages which are highly variable in the catches, such as perhaps the first and oldest ages. Ideally you should calculate these variances from the catch sampling procedure.

7.1.5 Plus-group specification

After entering the constraints for exploitation pattern the programme will request additional information on the catch at age indices. The last age of the catch at age data is assumed to be a plus-group. Since this is not the case for the age structured indices, the user must specify at run-time which of the indices has a plus-group as its last age. Note that the choice is most important in the case of a recruitment index: a mistake here will lead to the entire stock size being tuned by the recruitment index! It is recommended that the user record the order in which the indices are contained in the data file to avoid such an error. The request for input refers to the order in which the indices are read.

Is the last age of index 1 a plus group ?
(Y/N) → Y

Is the last age of index 2 a plus group ?
(Y/N) → N

Is the last age of index 3 a plus group ?
(Y/N) → Y

Is the last age of index 4 a plus group ?
(Y/N) → N

7.1.6 Choice of model

For each index you will be prompted for a choice of catchability relationship. Allowable options are A, L, or P for Absolute, Linear or Power. The term "catchability" is used to indicate a quantity referring to the relationship between the stock size and the abundance index in order to maintain the same terminology for both the pelagic and demersal cases. The catchability models in ICA include (1) a direct identity relationship, in the case of

some acoustic survey estimates that have been treated as estimates of absolute stock size; (2) power relationships, as in the case of larval surveys where it is thought that larval production may well be a power function of spawning biomass, and also in the case of demersal trawl surveys where it is thought that catch rates may be a power function of stock size on account of concentration effects; (3) Linear relationships have also been used where acoustic survey indices have been treated as proportionate indices of abundance. Note that the "absolute" option should only be used if the index of stock size is expressed in metric tonnes (assuming that the catch numbers are entered in thousands and the weights-at-age are in kilograms. Formally these relationships are:

- (1) Index = Stock Size.e
- (2) Index = Q.Stock Size^K.e
- (3) Index = Q.Stock Size.e

where Q and K are parameters to be estimated, and e is a lognormally distributed error term.

Model choices are made in the programme by simply responding to the questions:

Model for SSB index 1 is to be (A/L/P)
? → L

Model for aged index 1 is to be (A/L/P)
? → L

Model for aged index 2 is to be (A/L/P)
? → L

Model for aged index 3 is to be (A/L/P)
? → L

Model for aged index 4 is to be (A/L/P)
? → L

7.1.7 Fitting a stock-recruit model

If you respond yes to the request for a stock-recruit relationship;

Do you want to fit a stock-recruit relationship ? → Y

the programme will request a lag time in years and a data filename (specify the complete path), if any, for the estimates of stock and recruitment prior to the first year of

age-structured data. The specification of this time lag will depend on criteria used to age the fish. In other words, it is necessary to specify the real age of the “recruits” so that they can be matched to the appropriate spawning. The format for this datafile is described in Section 6.4. It is necessary to fit a generate a stock-recruit relationship if projections are to be run with the ICPROJ programme.

Enter the time lag in entire years between spawning and the stock size of fish aged 0 on 1 January → 1

If there are any estimates of stock and recruitment prior to the first year of age-structured data, enter the name of the file where they are held, or else press return → **c:\herr_vpa\srr.dat**

If you respond “no” to the offer of a stock-recruit relationship, these prompts will not appear.

7.1.8 Initial analysis

On completing the basic input procedures a summary table of the input data is shown. You must next specify a range of feasible fishing mortalities for the stock. It is prudent to choose a rather wide range for these: for herring in 1992, a range of 0.05 to 1.0 seems appropriate. The range of F is restricted between 0.04 and 3.0. Values outside the range will cause an error and a request for re-entry of the F values.

No of years for separable analysis:	6	
Age range in the analysis:	0	9
Year range in analysis:	1974	1992
Number of indices of SSB:	1	
Number of age-structured indices:	4	
Stock-Recruit relationship to be fitted		
Parameters to estimate:	34	

Enter lowest feasible F → **0.05**

Enter highest feasible F → **1.0**

The machine will now complete the initial analysis using the input values provided.

The implemented fitting procedure works in three stages. The first of these is a simple procedure designed to indicate whether the indices (with their specified catchability models) are consistent in their estimates of stock size. Initially 20 separable VPAs are run with equal intervals of F over the specified feasible range. For each separable VPA, a “best fit” of the tuning indices using the appropriate catchability model is calculated. The results of these analyses are written to a file named ICADIAG.OUT, the contents of which are displayed as the first graph in ICAVIEW. Interpretation of this graph is described in Section 8.1.

The programme then undertakes a simple searching procedure to find an approximate minimum, from which the formal minimisation procedure can begin. If a stock-recruit model fit has been requested, parameters are calculated by a linear regression approximation. If no reasonable estimates can be obtained, the programme will terminate with an error message. Details of these calculations are given in the Technical Reference Manual. The ICA1 programme finishes here.

7.2 ICA1 output

Once ICA1 has been run successfully the user will find several new files in the ICA directory which contain a summary results file and a number of intermediate files for internal use. The output filenames are displayed in boldface followed by a brief description of their contents for reference below.

- a) **ICA.OUT** is the principal results output file. It contains in flat ASCII format the input data set including the tuning indices used, the matrices of F and of population numbers, and the spawning stock biomass estimated from the least-squares fits to the data. Lastly, each of the fitted parameter estimates is listed together with its estimated upper and lower standard deviation bounds. Residuals of the fitted catches and fitted indices are given, as well as tables of summary statistics for each index (Section 15.1).

- b) **ICA.VIE** holds some of the quantities to be displayed by ICAVIEW, including observed data and their predicted values from the calculated parameter estimates. Data in this file are used for the residual plots. The file may also be useful for reading into a spreadsheet and plotting additional graphs. Recruitment, stock biomass, SSB and landings are summarised here (Example Section 15.2).
- c) **ICA.RES** holds a list of the observed and fitted values calculated for the model fit. This file also is read by ICAVIEW and its contents displayed graphically.
- d) **ICA.AV** holds the analysis of variance table.
- e) **ICADIAG.OUT** holds the estimates of the error about the tuning indices when fitting them to a range of separable VPAs fitted with reference fishing mortalities ranging from 0.1 to 2.0.
- f) **ICA.TMP** is a temporary file used to pass values from ICA1 to ICA2 and from ICA2 to ICPROJ.
- g) **ICA.SRR** holds estimates of stock size and observed and expected recruitment by year. It is generated by either ICA1 or ICA2 when a stock-recruit relation is fitted.
- h) **ICA.VC** holds the variance-covariance matrix and the parameter correlation matrix.

You may run the ICAVIEW programme to obtain a "quick and dirty" look at the fit (Type ICAVIEW from DOS), but most importantly an approximate view of the reference fishing mortality dimension of the least-squares surface over which the minimisation is to be run can be seen before entering the full minimisation routine. Checks that the model fit appears consistent and that there are no multiple minima exist on the F-surface should be made at this stage. No estimates of the standard deviations of the parameter estimates are available here.

7.3 *The ICA2 routine: minimisation and reweighting*

The ICA2 programme can be run from DOS by typing:

C:\ICA> **ICA2DOS**

or from WINDOWS by either double-clicking on the icon or from File Manager.

Note: If insufficient memory is available in DOS to estimate all the required parameters, the programme will terminate with a warning message. Therefore, it is preferable to free as much DOS memory as possible (eg removing network connections), but if this does not solve the problem, then the windows version of ICA2 can be run. This entails a speed disadvantage as the programme will take around 1.8 times longer to run.

The ICA2 programme works using a modified Gauss-Newton algorithm implemented in the NAG FORTRAN library (Routine E04FDF). Subsequently an auxiliary routine is called which calculates estimates of the variance-covariance matrix for the estimated parameters. These can be used to estimate parameter correlations, and to provide estimates of the standard deviations of the parameter estimates. These are printed to the output files and may be viewed as text in the ICA.OUT file or using the ICAVIEW programme.

The programme will present two options for assigning weights to the abundance indices relative to the catch-at-age data. These are:

- 1 - Recalculate all weights iteratively
 - 2 - Enter new weights by hand
- a) Full reweighting: all the index weights are recalculated according to an inverse-variance regimen. If there are few, noisy data this procedure will be unstable and may lead to wholly erroneous results.
 - b) Manual reweighting allows new weights to be entered by hand. This should be used in cases where independent

estimates of the relative variances of the indices and the catch-at-age data are available or are to be fixed at determined values. If these values are unknown it may be appropriate to specify equal weights for all the surveys. Choose this option to proceed with the example.

Enter your choice —> 2

- c) The programme will request a weight for each biomass index and a weight for each aged index. To continue with the example, enter "1" for all the weights:

Enter weight for biomass index 1 —> 1.0

Enter weight for aged index 1 at age 2 —> 1.0

Enter weight for aged index 1 at age 3 —> 1.0

" " " " " " "

-

-

These weights should ideally be the best available estimate of the ratio of the variance of the logarithms of the catch-at-age observations to the variance of the logarithms of the survey observations at each age.

A further quantity needs to be specified by the user for each age-structured index series: this figure represents the extent to which it is expected that errors in an age-structured index are correlated across ages. Consider the example of an age-structured index of stock size which is obtained by first estimating a measure of total stock size I_{tot} , which is then apportioned across a number of age-groups to yield an age structured index I_{age} . If the principal source of error in the index lies in the measurement of total stock size I_{tot} , then the errors in the I_{age} values calculated will be highly correlated. If however the main source of error lies in the repartition of I_{tot} amongst ages, then the errors will be much less strongly correlated. The weighting structure of the model needs to be slightly

different according to which of these conditions is most likely to pertain, and the programme will request from the user a value from 0 to 1 which should reflect the user's perception of the interdependence of the errors in each age-structured index.

The screen output and request for input varies depending on the option selected. For Option 1 the following request for information will be displayed on the screen:

You should enter estimates of the extent to which errors in each age of the age structured indices are correlated. These may range from zero (independence) to 1 (correlated errors).

Enter value for aged index 1 —> 1

Enter value for aged index 2 —> 1

Enter value for aged index 3 —> 1

Enter value for aged index 4 —> 1

Do you want to shrink the final populations ? (Y/N) —> N

If the shrinkage option is chosen the model will calculate a conventional VPA in which the terminal fishing mortalities are calculated from an inverse-variance weighted mean between (1) the average historical F over a time-period that is specified from the screen, and (2) the terminal F estimated from the model fit. The calculations are carried out separately for each age, and the variance of the F from the model fit is calculated from a linear approximation from the variance of F at reference age in the terminal year, and the variance of the estimate of selection at each age. The matter is described in detail on page 7 of the Technical Reference. Note that choosing the shrinkage option does not affect the model fit written to ICA.OUT and ICA.VIE; the shrunk VPA is written to a file named ICA.SHR.

If the iterative reweighting option is chosen, then after an initial analysis run using all weights assumed = 1, further analyses calculated using weights derived from the variances about the previous model fit are calculated. This process is iterated until the

fishing mortality at the reference age changes by less than a specified amount. This quantity must be specified after the reweighting menu. A suggested suitable value is 0.005, which means that the iterative reweighting will stop if the fishing mortality at the reference age changes by less than 0.5% between iterations.

The analysis will be repeated with recalculated weights until reference F changes by a proportion less than a specified tolerance.

Enter your choice for this tolerance —>
0.005

Execution time varies considerably with the size of the data set, the complexity of the model and the PC's speed. The results given in Appendix 2 (Sections 15.1 and 15.2) were obtained after some 10 mins. processing time using a 33 MHz 80486DX processor. The model will often find a stable solution in about three iterations. A summary of index weights, SSQ, and F is written to the screen after each iteration.

A note of caution: There is a cost attached to the use of the reweighting procedure. The method estimates a set of variances at age for each survey, thus increasing substantially the number of parameters estimated by the programme. It is not possible to estimate these variances well if there are few data, and attempting to do so may lead to unstable results.

Once the input requirements have been entered the programme will complete its computational procedures. If these have been completed successfully a diagnostic value of "E04FDF IFAIL = 0" or "E04FDF IFAIL =5" will be displayed. If the minimisation procedure fails to converge satisfactorily, a message to this effect will be displayed on the screen. Note however that all the usual output files will still be generated; it is the users' responsibility to check that the minimisation has worked successfully and that the resulting solution is acceptable.

8.0 Interpretation of Results

The input data set and the estimated population sizes are held in a file named "ICA.OUT", which is the principal output file for the system (Section 15.1). This holds:

- The catches at age
- The survey data
- The estimated population sizes
- The estimated fishing mortalities
- Summaries of recruitment, stock size and fishing mortality by year
- The parameter estimates and standard deviations
- Tables of residuals
- Statistical diagnostics

At the foot of the ICA.OUT file a small table of statistics is printed for the separable model fitting and for each index. The skewness and kurtosis test statistics are approximately normally distributed with zero mean and unit variance. Large positive or negative values of the skewness statistic indicate that the distribution of residuals is skewed to the right or left respectively; large positive values of the kurtosis statistic indicate that the tails of the distribution are broader than would be expected. In summary, values of either statistic further than (say) 2 from zero indicate that the assumption of lognormally distributed errors may not be justified.

Estimates of the variance-covariance matrix and of the parameter correlation matrix are held in a file named "ICA.VC". The "parameter numbers" correspond to those listed in the end of the main output file, "ICA.OUT". If any of the correlations in this matrix approach 1 or -1, this indicates that the estimates of certain parameters are strongly correlated. This can happen when both a separable constraint and an age-structured index are included in the model, as here effectively two sources of information are being used to estimate closely related parameters: catchability at age, and selection

at age: a low catchability implies a low selection.

The analysis of variance table is held in a file named "ICA.AV". This shows the sums of squared residuals that correspond to the separable constraint and to each index series. This table, which is also printed to the screen during the iterations, affords a quick and simple view of the main sources of variation in the model fit. Tables of unweighted and of weighted residuals by age are reported in this file.

8.1 Graphical diagnostics

Type **ICAVIEW** from MSDOS. The programme requires no input from the user but will show a succession of graphs on the screen. Press "P" to print any one of these, or any other key to continue to the next graph. A sample of graphical output is given in Section 16. Note that if you do not have a compatible printer (Hewlett-Packard Laser-Jet II or Epson-compatible), the print function will not work properly. The graphs shown are:

- a) An overall tuning diagnostic graph. This is a plot of the index SSQ against the F at reference age from a separable VPA. Ideally all the indices used should show U-shaped plots with minima fairly close to each other. If the minima are widely separated, this indicates that the model and the indices are inconsistent. A least-square solution, and especially an inverse-variance reweighted solution may not be meaningful in such cases. It may be worthwhile trying alternative catchability models in such cases.
- b) A stock summary. Yield, fishing mortality, recruitment and spawning stock biomass are graphed together on a single screen. Over the period for which a separable constraint was fitted (eg six years) the programme will plot reference F from the separable model \pm standard deviations; on previous years the plot is of F from the conventional VPA (initiated with the fitted model) at the reference age. Similarly, recruitment estimates for the

years of the separable VPA will be plotted \pm one standard deviation; prior recruitment plotted are recruitment estimated from conventional VPA initiated with the fitted model. If parameter estimates generated by ICA1 are being viewed no standard deviations will be plotted. The quantities graphed are described in detail in Section B (Technical Reference) but are summarised as:

- i) Yield. The yield plotted is simply the information held in the "landings" input file. The data held in that file are not used for any other purpose.
 - ii) Fishing mortality. For the years over which a separable model has been fitted, the mortality graphed is the fishing mortality at reference age, \pm the standard deviation of this parameter estimate derived from the estimated variance-covariance matrix. For earlier years, the quantity graphed is an estimate of the reference fishing mortality based on the assumption that the selection pattern in the earlier years was the same as that estimated in the separable analysis.
 - iii) Recruitment.
 - iv) The total stock biomass at 1 January and the spawning biomass at spawning time.
- c) A summary of separable model diagnostics. This shows firstly a contour plot of the residuals about the separable model. This may help identify years or ages of atypical selection, as bright or dark patches. Strong diagonal banding patterns indicate changes in selection (fishing effort is concentrated or diminished on certain cohorts). Next the selection curve is plotted together with the \pm standard deviation error bars. Note that no error bars are plotted for the reference age (assumed = 1); the last

true age (set at the terminal selection that was specified earlier); nor for the plus-group (set equal to S on the last true age). The two lower graphs show the marginal totals for the separable analysis residuals: if the model fits well to a separable constraint, these values will be close to zero. Deviations from zero indicate that the tuning indices are forcing the model fit away from a separable pattern, with respect to either ages or years.

- d) For each index series, four diagnostic plots are drawn. The first of these illustrates the consistency of the index series with the fitted populations. The stock size estimate from the fitted populations is plotted as a continuous line, and the stock size prediction calculated from each index datum, using the appropriate catchability model and estimated parameters. The error bars indicate the range of the index prediction from $(\ln(\text{index}) + \text{standard deviation})$ to $(\ln(\text{index}) - \text{standard deviation})$.

The second plot is a scattergram of biomass estimated from the model fit against the index datum, together with a line indicating the relationship between the two that has been fitted in the model. The two lower graphs are conventional plots of residuals against expected value and of residual against time. Both these plots should show an even, random scatter of points with no discernable pattern. Any marked trends in the plots indicate that the starting assumption that errors are random and not correlated with time have not been satisfied. Curvature in the residual-expected value plot suggests that the catchability model for the index may be wrong; similarly a fan-shaped pattern of points indicates that the index error model (which here is assumed to be a lognormal distribution) may be inappropriate. Any trend in the residual-time plot indicates that the relationship between the index and the stock size is not consistent between years; among other effects this could be due to an erroneous catchability model in a situation where there is a trend in stock size, or to a

failure to maintain consistent sampling between years.

These four graphs are plotted for each biomass index and for each age of each age-structured index. A full description of the quantities plotted is given in the Technical Reference Section.

8.2 Caveats

Appropriate use of these programmes depends on a careful attention to a suitable model specification. If wholly inappropriate models are specified for the dataset in use the resultant model fits may be grossly misleading. It is necessary to examine critically the diagnostics and distributions of residuals to ensure that the model fit is consistent with the starting assumptions (see Section 1.3). It is an inescapable feature of a programme of this type which is intended to allow the experienced user to explore a wide range of model structures that the possibility that an inexperienced user may generate a wholly inappropriate model fit is correspondingly greater than is the case for a more restricted programme. In many cases it will be helpful to examine the sensitivity of the stock assessments to different model formulations.

The following is quoted from Fournier and Archibald (1982):

"It is simply an inescapable fact that the age structure and effort data do not contain enough information to determine the relative accuracy of the aging data, the total catch data, the regularity of fishing mortality or the closeness of the relationship between effort and average fishing mortality. These procedures do however give the user a precise quantitative method of exploring the results of various assumptions about the relative error sizes involved."

9.0 Stock Projections with Variance Estimates

9.1 Background

The Methods Working Group (Anon., 1993a) indicated a need for a method which would allow medium-term calculations of likely stock

trajectories, including a consideration of uncertainty and risk. Projections of this type have heretofore been calculated using simulation methods (Anon., 1993b). An alternative approach is to make the simplifying assumption that the stock projection is a deterministic process which is conditioned upon a number of fixed parameters (Specified F-multipliers, weights at age by fleet, natural mortalities, etc) and a set of parameters which are estimated with observation error and for which a variance-covariance matrix is available (Selection at age, numbers at age, fishing mortality, stock-recruit parameters). Such an approach may have advantages of simple and rapid calculation of different F - multiplier options once a stock assessment model has been fitted. A programme to allow the testing and evaluation of this method has been included as a post-processing option. Use of this option presupposes that the Beverton and Holt stock-recruitment function fitted in the ICA method is realistic approximation to the observed history of stock and recruits. At least for North Sea herring, this appears to hold true, although there is obviously strong interannual variability about the stock-recruit relationship.

The programme documented below has only recently been implemented. It is provided for testing and evaluation purposes only.

9.2 Implementation

The ICPROJ programme has been provided here as one of a number of possible approaches to the problem. Here stock sizes in succeeding years are calculated in a deterministic way from the terminal populations of the stock assessment, and the specified fishing mortality multipliers and fleet catch ratios at age. Estimates of the variance-covariance matrix are then used to assess the uncertainty about the deterministic path by the delta-method (Section 6.3). The programme is simple to run:

- a) Type "ICPROJ" from DOS.

C:\ica\icproj

- b) The programme will then prompt for the name of the projection file (in this the example file is FMULT.DAT). The format of this file is discussed in the next section.

Enter the name of the projection file
—>**C:\ica\fmult.dat.**

- c) Natural mortalities, maturity ogives and weights at age in the stock to be used in the projections are calculated by taking over a mean of the ultimate years of the original data set. The user must specify the number of years over which these means are to be taken.

Population parameters for projections are set by taking the mean over a number of the last years of the data set.

Specify the years for taking these means.

Use mean natural mortality from 1992 back to —>**1990**

Use mean maturity ogive from 1992 back to —>**1990**

Use mean weight at age in the stock from 1992 back to —>**1990**

- d) The user must also specify the MBAL in metric tonnes.

Enter the minimum acceptable spawning stock size —>**800000**

9.3 Projection file format

An example of the projection file format is given in Appendix 1 (Section 14.13) as FMULT.DAT. Much of this data file is self explanatory. However, since the projection is based on terminal F estimated with uncertainty, it is not feasible to treat fleet partial F as an input parameter. Thus, the ratios of the catches in number by fleet to the total catches must be specified. In other words the ratios sum to 1 across each age group. These are then used internally to calculate partial Fs in the usual way.

The F Multiplier by year is the ratio of the fishing mortality exerted by each fleet in each year to the last year in which catch at age

data are available. For example, if a fleet exerts a partial fishing mortality of 0.4 in the last year of catch data and if all the "F-multipliers" are set to equal 1 in subsequent years, it is assumed for projections that this fleet will continue to exert a fishing mortality of 0.4 in future years. If for any year the "F-multiplier" is set to 2, then this implies that the fishing mortality for that fleet will rise twofold to 0.8 in that year. In the example projection scenario given, the effect of reducing the fishing mortality exerted by the second fleet (Fleet B) by 25% is calculated.

9.4 Projection output

Three files are created by the programme. Estimates of the populations in the projections are written to "PROJECT.POP"; The projected stock sizes and catches, together with their variance estimates and estimates of the probability of stock size falling below MBAL, are written to "ICA.PRO". The first part of the ICA.PRO output file holds four columns: (1) Year; (2) Spawning stock size at spawning time; (3) Variance of the spawning stock size; (4) Probability that the spawning stock size will be below MBAL. In the following section the projected catches and their estimated variances by fleet are given.

Lastly for diagnostic purposes, the vectors of derivatives of dX/dC and dX/dS for each year of the projections are written to a file named "DERIVS.TST" (where X: parameter estimates; C: catch by fleet; S: Spawning stock size). Estimates of risk are calculated on the assumption of normal distribution of the estimated stock size and catches. This assumption is more conservative than the assumption of lognormality made in Anon. (1993b).

Graphical results can be obtained by running "VIEWPRO" from DOS. This programme reads the ICA.PRO file and draws appropriate graphs. Example output from VIEWPRO is given in Section 17.

10.0 Common Errors

a) Run-Time error (File not found). The most common source for this type of

error is the incorrect spelling of a filename or its full directory address.

Solution: Using a standard editor, edit the index file so that it contains the correct locations (ie sub-directory) of the example data files.

b) Insufficient memory available to programme. This error generally occurs when running ICA2DOS with larger data sets from DOS. It is also more likely to occur if the other software (such as Windows or netware) is running in the background.

Solution: Remembering there is a time compromise between the DOS and Windows version of ICA, the user can either; (a) reboot the system for DOS only, thereby making more memory available, or (b) use the Windows version of ICA.

c) Another common runtime error occurs when one or more of the data file formats are incorrect or incomplete. For example, early versions of the test age-structured tuning data file did not contain a "Alpha" and a "Beta" value. Omission of the beta value caused a fatal run-time error which was difficult to detect.

Solution: Ensure that all data files contain the information described in this manual.

d) When running a "shrunk" model fit, remember that the shrunk VPA is written to the file "ICA.SHR" and the model parameters written to "ICA.OUT" and displayed by "ICAVIEW" are not changed.

e) Do not have any missing values in the catch-at-age matrix if you are calculating a shrunk VPA.

f) If the ICA1 programme crashes after writing the message F SSQ, then check the following:

- The year range of all the survey data should lie within the year range of the catch at age data plus one year.

- There should be no zeroes in the survey data.
- If an “absolute” catchability model is chosen for any index, then check the units are consistent. If catch numbers are in thousands of fish and catch weights are in kg, then an “absolute” SSB index should be in tonnes.

11.0 Summary

This manual was prepared as a general guide to running the Integrated Catch-Age Analysis software. Technical details of the programmes can be found in the Programmers and Technical Reference Manuals. Unfortunately, like most software manuals there are bound to be a few inherent errors or limitations which individual will encounter or identify. We encourage you to notify the authors of any problems you encounter so future versions may be improved.

12.0 Acknowledgements

Dr Robin Cook suggested the use of this type of analytical method for pelagic fish and supported the development of these programmes. I am grateful to Dr R. Fryer for his statistical advice, and to Dr M.R. Bravington for the use of his “XYplotW” and “ContourW” object libraries, used in the ICAVIEW, VIEWSRR and VIEWPRO programmes. Dr Per Sparre made a very helpful revision of an early draft of this document.

13.0 References

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Anonymous. 1993b. Report on the working group on the assessment of demersal stocks in the North Sea and Skagerrak. ICES CM 1993/Assess:6.

Fournier, D. and Archibald, C.P. 1982. A general theory for analysing catch at age data. *Canadian Journal of Fisheries and Aquatic Sciences*, **39**, 1195—1207.

14.0 Appendix 1: Data File Examples

The example data are taken from the 1995 assessment of North Sea herring. Comments have been added in italic type for improved clarity; they need not be included in the data files.

14.1 Example of the stock index file

Filename: **NSHERR.NDX**

North Sea Herring	<i>Run title</i>
1	<i>Sex code, always = 1</i>
c:\herr_vpa\NSHERRLA.DAT	
c:\herr_vpa\NSHERRCN.DAT	
c:\herr_vpa\NSHERRCW.DAT	
c:\herr_vpa\NSHERRSW.DAT	
c:\herr_vpa\NSHERRNM.DAT	
c:\herr_vpa\NSHERRMO.DAT	
c:\herr_vpa\NSHERRPF.DAT	
c:\herr_vpa\NSHERRPM.DAT	

14.2 Example of a commercial landing data file

Filename: **NSHERRLA.DAT**

NORTH SEA HERRING - LANDINGS (t)		
1	1	<i>Sex code, data type (1=landings)</i>
1975	1994	<i>First year, last year of catch-at-age data</i>
0	9	<i>First age, last age</i>
5		<i>Data format identifier (5=column)</i>
		<i>Catches by year ...</i>

312800
174800
46000
11000
25100
70764
174879
275079
387202
409489
609108
660553
773411
875923
768886
619963
635929
694206
647435
600000

14.3 Example of a catch-at-age data file

Filename: **NSHERRCN.DAT**

NORTH SEA HERRING. CATCH NUMBERS AT AGE

1	2	<i>Sex code, data type (2= catch numbers)</i>							
1975	1994	<i>First year, last year</i>							
0	9	<i>First age, last age</i>							
1	<i>Format identifier (1 = matrix)</i>								
263800	2460500	541700	259600	140500	57200	16100	9100	3400	1400
238200	126600	901500	117300	52000	34500	6100	4400	1000	400
256800	144300	44700	186400	10800	7000	4100	1500	700	100
130000	168600	4900	5700	5000	300	200	200	200	300
542000	159200	34100	10000	10100	2100	200	800	600	100
1262700	245100	134000	91800	32200	21700	2300	1400	400	100
9519700	872000	284300	56900	39500	28500	22700	18700	5500	1100
11956700	1116400	299400	230100	33700	14400	6800	7800	3600	1100
13296900	2448600	573800	216400	105100	26200	22800	12800	11000	12100
6661900	1737200	1095000	421700	192500	77500	21600	24100	10600	17800
4178900	3228200	1316200	1173400	365700	123600	43300	20000	13000	16000
3664000	4723200	1246100	827100	458300	127700	61100	20200	13400	14600
8035500	6675400	2086900	652200	456100	240000	72900	23200	7800	8000
3122900	7762800	2202900	1076200	378600	252400	126400	37500	15100	8400
2984000	3070000	1555200	1330900	789800	206700	120700	59500	19000	8500
1251800	2901700	864100	748600	827300	372300	77100	52300	27700	11400
2306500	2067100	1094800	538000	530500	484400	198400	38000	24700	12600
10005700	2230500	1244400	428700	350100	349100	363800	147600	38000	22600
9892400	3687700	1133600	586900	294400	207800	217800	181200	84100	40200
4259500	1690200	1688300	463100	329100	103200	86900	72300	66300	44100

14.4 Example of a catch weight-at-age (kg) data file

Filename: **NSHERRCW.DAT**

NORTH SEA HERRING - MEAN WEIGHT IN CATCHES

1	3	<i>Sex code, data type (3 = catch weight)</i>							
1975	1994	<i>First year, last year</i>							
0	9	<i>First age, last age</i>							
1	<i>Format identifier (1 = matrix)</i>								
.015	.05	.126	.176	.211	.243	.251	.267	.271	.271
.015	.05	.126	.176	.211	.243	.251	.267	.271	.271
.015	.05	.126	.176	.211	.243	.251	.267	.271	.271
.015	.05	.126	.176	.211	.243	.251	.267	.271	.271
.015	.05	.126	.176	.211	.243	.251	.267	.271	.271
.015	.05	.126	.176	.211	.243	.251	.267	.271	.271
.007	.049	.118	.142	.189	.211	.222	.267	.271	.271
.01	.059	.118	.149	.179	.217	.238	.265	.274	.275
.01	.059	.118	.149	.179	.217	.238	.265	.274	.275
.01	.059	.118	.149	.179	.217	.238	.265	.274	.275
.009	.036	.128	.164	.194	.211	.22	.258	.27	.292
.006	.067	.121	.153	.182	.207	.221	.238	.252	.262
.011	.035	.099	.149	.18	.211	.234	.258	.278	.295
.011	.055	.111	.145	.174	.197	.216	.237	.253	.263
.017	.043	.115	.153	.173	.208	.231	.247	.265	.259
.019	.055	.114	.149	.177	.193	.229	.236	.25	.287
.017	.058	.13	.166	.184	.203	.217	.235	.259	.271
.0099	.0526	.103	.175	.189	.207	.223	.237	.249	.287
.001	.033	.115	.145	.189	.204	.228	.244	.256	.310
.006	.056	.130	.159	.181	.214	.240	.255	.273	.281

14.5 Example of a stock weight-at-age (kg) data file

Filename: **NSHERRSW.DAT**

NORTH SEA HERRING. STOCK WEIGHTS.

1	4	Sex code, data type (4= stock weights)							
1975	1994	First year, last year							
0	9	First age, last age							
1		Format identifier (1 = matrix)							
.015	.05	.155	.187	.223	.239	.276	.299	.306	.312
.015	.05	.155	.187	.223	.239	.276	.299	.306	.312
.015	.05	.155	.187	.223	.239	.276	.299	.306	.312
.015	.05	.155	.187	.223	.239	.276	.299	.306	.312
.015	.05	.155	.187	.223	.239	.276	.299	.306	.312
.015	.05	.155	.187	.223	.239	.276	.299	.306	.312
.015	.05	.155	.187	.223	.239	.276	.299	.306	.312
.015	.05	.155	.187	.223	.239	.276	.299	.306	.312
.015	.05	.155	.187	.223	.239	.276	.299	.306	.312
.015	.05	.155	.187	.223	.239	.276	.299	.306	.312
.009	.064	.141	.193	.228	.248	.258	.3	.318	.316
.006	.078	.146	.19	.224	.248	.281	.287	.328	.364
.006	.049	.133	.183	.22	.247	.263	.285	.31	.342
.007	.043	.122	.163	.215	.239	.27	.277	.297	.31
.012	.051	.14	.178	.211	.254	.283	.288	.316	.362
.016	.064	.145	.186	.208	.232	.257	.282	.278	.318
.017	.065	.158	.198	.224	.236	.26	.275	.298	.317
.008	.078	.142	.209	.219	.243	.255	.272	.312	.311
.01	.069	.115	.147	.202	.225	.277	.286	.305	.340
.01	.060	.138	.209	.220	.251	.289	.315	.323	.346

14.6 Example of a natural mortality data file

Filename: **NSHERRNM.DAT**

NORTH SEA HERRING - NATURAL MORTALITY

[illegible]

14.7 Example of a maturity-at-age ogive data file

Filename: **NSHERRMO.DAT**

NORTH SEA HERRING - MATURITY OGIVE

1	6	<i>Sex code, data type (6 = maturity ogive)</i>							
1975	1994	<i>First year, last year</i>							
0	9	<i>First age, last age</i>							
1		<i>Format identifier (1 = matrix)</i>							

0	0	.82	1	1	1	1	1	1	1
0	0	.82	1	1	1	1	1	1	1
0	0	.82	1	1	1	1	1	1	1
0	0	.82	1	1	1	1	1	1	1
0	0	.82	1	1	1	1	1	1	1
0	0	.82	1	1	1	1	1	1	1
0	0	.82	1	1	1	1	1	1	1
0	0	.82	1	1	1	1	1	1	1
0	0	.82	1	1	1	1	1	1	1
0	0	.82	1	1	1	1	1	1	1
0	0	.7	1	1	1	1	1	1	1
0	0	.75	1	1	1	1	1	1	1
0	0	.63	1	1	1	1	1	1	1
0	0	.66	.9	1	1	1	1	1	1
0	0	.79	.94	1	1	1	1	1	1
0	0	.73	.97	1	1	1	1	1	1
0	0	.64	.98	1	1	1	1	1	1
0	0	.513	1	1	1	1	1	1	1
0	0	.416	.629	1	1	1	1	1	1
0	0	.721	.858	1	1	1	1	1	1

14.8 Example of a proportion of F before spawning data file

Filename: **NSHERRPF.DAT**

NORTH SEA HERRING - PROP. F BEFORE SPAWNING

1	7	<i>Sex code, data type (7 = propn of F before spawning)</i>							
1975	1994	<i>First year, last year</i>							
0	9	<i>First age, last age</i>							
3		<i>Format identifier (3 = scalar)</i>							

		.67							
--	--	-----	--	--	--	--	--	--	--

14.9 Example of a proportion of M before spawning data file

Filename: **NSHERRPM.DAT**

NORTH SEA HERRING - PROP. M BEFORE SPAWNING (ASSUMED, NOT WG)

1	8	<i>Sex code, data type (8 = propn of M before spawning)</i>							
1975	1994	<i>First year, last year</i>							
0	9	<i>First age, last age</i>							
3		<i>Format identifier (3 = scalar)</i>							

		.75							
--	--	-----	--	--	--	--	--	--	--

14.10 Example of an age-structured tuning data file

Filename: **NSHERRFL.DAT**

NORTH SEA HERRING. TUNING DATA

104

IYFS Survey Data at ages 2 - 5+

1983 1995
1 1 0.12 0.14
2 5

1	.109e3	.418e2	.141e2	.337e2
1	.161e3	.747e2	.318e2	.690e1
1	.716e3	.256e3	.262e2	.364e2
1	.661e3	.235e3	.565e2	.172e2
1	.838e3	.117e3	.555e2	.436e2
1	.410e4	.783e3	.554e2	.260e2
1	.775e3	.411e3	.864e2	.100e2
1	.580e3	.322e3	.271e3	.703e2
1	.794e3	.283e3	.250e3	.170e3
1	.377e3	.181e3	.630e2	.102e3
1	.762e3	.236e3	.445e2	.637e2
1	.109e4	.199e3	.636e2	.400e2
1	.128e4	.153e3	.462e2	.930e1

Number of surveys + 100

First survey begins here ...

First and last years for this survey

Sex code, effort code, start and end of survey (as fractions of year)

First and last ages for this survey

Effort value (=1), Data ...

IYFS Survey Data at age 1

The above data structure is repeated for each survey

1979 1995
1 1 0.12 0.14
1 1

1	.172e3
1	.312e3
1	.431e3
1	.772e3
1	.126e4
1	.144e4
1	.208e4
1	.254e4
1	.368e4
1	.453e4
1	.231e4
1	.102e4
1	.116e4
1	.116e4
1	.294e4
1	.1667e4
1	.1188e4

Acoustic Survey Data

1989	1994							
1	1	0.54	0.56					
2	9							
1	.373e7	.375e7	.161e7	.488e6	.281e6	.120e6	.440e5	.220e5
1	.297e7	.353e7	.337e7	.135e7	.395e6	.211e6	.134e6	.430e5
1	.283e7	.150e7	.210e7	.198e7	.748e6	.262e6	.112e6	.560e5
1	.418e7	.163e7	.140e7	.151e7	.131e7	.474e6	.155e6	.163e6
1	.371e7	.189e7	.909e6	.795e6	.788e6	.546e6	.178e6	.116e6
1	.328e7	.957e6	.429e6	.363e6	.321e6	.328e6	.220e6	.132e6

MIK Recruitment Index

1978 1995
1 1 0.24 0.26
0 0

1	13.1
1	52.1
1	101.1
1	76.7
1	133.9
1	91.8
1	115.0
1	181.3
1	177.4
1	270.9
1	168.9
1	71.4
1	25.9
1	69.9
1	200.7
1	190.1
1	101.7
1	.127e3

14.11 Example of an SSB tuning data file

Filename: NSHERR.RCT

'HERRING IN NORTH SEA'

1	10	2	
YEAR'	'VPA'	'LPE'	Number of surveys, Number of years, dummy value always=2
1983	428	635	The column labelled 'VPA' is not used by ICA but is retained for compatibility with RCT3
1984	726	871	
1985	764	1022	
1986	818	1244	
1987	935	699	
1988	1123	1249	
1989	-11	1328	
1990	-11	1547	
1991	-11	889	
1992	-11	860	

14.12 Example of a stock and recruit data file

Filename: SRR.DAT

1958		Starting year
1397309	34940780	Spawning stock at spawning time (t), Recruits.
2601470	44713732	
2133604	12115316	
1830966	108894912	
1239819	46320808	
2329719	47660696	
2138496	62821148	
1527896	34899436	
1319586	27854342	
929250	40260220	
418661	38701164	
427025	21577270	
377244	41067172	
272770	32293970	
288985	20877350	
233148	10010326	
161853	21747382	
80204	2694527	
76911	2647761	

14.13 Example of a projection data file

Filename: FMULT.DAT

Fishing Mortality Multipliers for Forwards Projections

Number of fleets			Number of Years		
5			10		
Catch Ratio for each fleet at age in 1994					
Age	Fleet A	Fleet B	Fleet D	Fleet E	Fleet F
0	0	0.729	0	0.0904	0.181
1	0.112	0.612	0.046	0.0919	0.115
2	0.577	0.106	0.160	0.0077	0.149
3	0.995	0.005	0	0	0
4	0.992	0.008	0	0	0
5	0.971	0.008	0	0	0
6	0.992	0.006	0	0	0
7	0.994	0.006	0	0	0
8	0.994	0.006	0	0	0
9	0.994	0.006	0	0	0

F Multipliers by year

1995	1.0	1.0	1	1	1
1996	1.0	0.75	1	1	1
1997	1.0	0.75	1	1	1
1998	1.0	0.75	1	1	1
1999	1.0	0.75	1	1	1
2000	1.0	0.75	1	1	1
2001	1.0	0.75	1	1	1
2002	1.0	0.75	1	1	1
2003	1.0	0.75	1	1	1
2004	1.0	0.75	1	1	1

Mean weight at age in the catches of each fleet

0	0.007	0.006	0.0276	0.0209	0.0142
1	0.084	0.040	0.086	0.0174	0.0327
2	0.130	0.098	0.0925	0.0501	0.0716
3	0.160	0.116	0.1	1	1
4	0.181	0.161	0.1	1	1
5	0.215	0.196	0.1	1	1
6	0.240	0.239	0.1	1	1
7	0.256	0.191	0.2	1	1
8	0.276	0.240	0.2	1	1
9	0.276	0.240	0.2	1	1

15.0 Appendix 2. Example ICA Output Files

15.1 Example of main output file: ICA.OUT

CATCH NUMBERS AT AGE (Millions)

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0	264.	238.	257.	130.	542.	1263.	9520.	11957.	13297.	6662.	4179.	3664.	8036.	3123.	2984.	1252.	2307.	10006.	9892.	4260.
1	2461.	127.	144.	169.	159.	245.	872.	1116.	2449.	1737.	3228.	4723.	6675.	7763.	3070.	2902.	2067.	2231.	3688.	1690.
2	542.	902.	45.	5.	34.	134.	284.	299.	574.	1095.	1316.	1246.	2087.	2203.	1555.	864.	1095.	1244.	1134.	1688.
3	260.	117.	186.	6.	10.	92.	57.	230.	216.	422.	1173.	827.	652.	1076.	1331.	749.	538.	429.	587.	463.
4	141.	52.	11.	5.	10.	32.	40.	34.	105.	193.	366.	458.	456.	379.	790.	827.	531.	350.	294.	329.
5	57.	35.	7.	0.	2.	22.	29.	14.	26.	78.	124.	128.	240.	252.	207.	372.	484.	349.	208.	103.
6	16.	6.	4.	0.	0.	2.	23.	7.	23.	22.	43.	61.	73.	126.	121.	77.	198.	364.	218.	87.
7	9.	4.	2.	0.	1.	1.	19.	8.	13.	24.	20.	20.	23.	38.	60.	52.	38.	148.	181.	72.
8	3.	1.	1.	0.	1.	0.	6.	4.	11.	11.	13.	13.	8.	15.	19.	28.	25.	38.	84.	66.
9	1.	0.	0.	0.	0.	0.	1.	1.	12.	18.	16.	15.	8.	8.	9.	11.	13.	23.	40.	44.

INDICES OF SPAWNING STOCK BIOMASS

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	.635E+03	.871E+03	.102E+04	.124E+04	.699E+03	.125E+04	.133E+04	.155E+04	.889E+03	.860E+03	-.110E+02

AGE - STRUCTURED INDICES

INDEX : from 1983 to 1995

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
2	.109E+03	.161E+03	.716E+03	.661E+03	.838E+03	.410E+04	.775E+03	.580E+03	.794E+03	.377E+03	.762E+03	.109E+04	.128E+04
3	.418E+02	.747E+02	.256E+03	.235E+03	.117E+03	.783E+03	.411E+03	.322E+03	.283E+03	.181E+03	.236E+03	.199E+03	.153E+03
4	.141E+02	.318E+02	.262E+02	.565E+02	.555E+02	.554E+02	.864E+02	.271E+03	.250E+03	.630E+02	.445E+02	.636E+02	.462E+02
5	.337E+02	.690E+01	.364E+02	.172E+02	.436E+02	.260E+02	.100E+02	.703E+02	.170E+03	.102E+03	.637E+02	.400E+02	.930E+01

INDEX : 2 from 1979 to 1995

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
1	.172E+03	.312E+03	.431E+03	.772E+03	.126E+04	.144E+04	.208E+04	.254E+04	.368E+04	.453E+04	.231E+04	.102E+04	.116E+04	.116E+04	.294E+04	.167E+04	.119E+04

INDEX : 3 from 1989 to 1994

	1989	1990	1991	1992	1993	1994
2	.373E+07	.297E+07	.283E+07	.418E+07	.371E+07	.328E+07
3	.375E+07	.353E+07	.150E+07	.163E+07	.189E+07	.957E+06
4	.161E+07	.337E+07	.210E+07	.140E+07	.909E+06	.429E+06
5	.488E+06	.135E+07	.198E+07	.151E+07	.795E+06	.363E+06
6	.281E+06	.395E+06	.748E+06	.131E+07	.788E+06	.321E+06
7	.120E+06	.211E+06	.262E+06	.474E+06	.546E+06	.328E+06
8	.440E+05	.134E+06	.112E+06	.155E+06	.178E+06	.220E+06
9	.220E+05	.430E+05	.560E+05	.163E+06	.116E+06	.132E+06

INDEX : 4 from 1978 to 1995

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
0	.131E+02	.521E02	.101E+03	.767E+02	.134E+03	.918E+02	.115E+03	.181E+03	.177E+03	.271E+03	.169E+03	.714E+02	.259E+02	.699E+02	.201E+03	.190E+03	.102E+03	.127E+03

15.1 Continued

FISHING MORTALITY

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0	.1510	.1437	.0966	.0450	.0838	.1263	.4853	.3377	.4047	.2188	.0859	.0619	.1616	.1247	.1294	.0557	.1041	.1134	.1346	.1060
1	.6854	.2372	.2896	.1978	.1647	.1134	.2869	.2273	.2551	.1986	.3827	.3156	.3692	.5892	.4251	.4402	.2907	.2556	.3035	.2391
2	1.2902	1.3249	.2116	.0235	.0934	.3583	.3249	.2623	.3061	.3037	.4052	.4542	.4023	.3557	.4034	.3627	.5520	.4729	.5616	.4423
3	1.4984	1.3497	1.3557	.0396	.0644	.4121	.2698	.5103	.3275	.4138	.6685	.5184	.4916	.4001	.4046	.3696	.4322	.4771	.5665	.4463
4	1.3450	1.7039	.3735	.0962	.0870	.2861	.2962	.2406	.4392	.5131	.7289	.5709	.5753	.5626	.5462	.4490	.4612	.6198	.7360	.5797
5	1.8072	1.4677	1.1140	.0140	.0481	.2426	.3912	.1498	.2662	.5958	.6449	.5356	.5896	.6451	.6079	.4761	.4568	.5711	.6782	.5342
6	1.2514	.9271	.5827	.0674	.0105	.0614	.3814	.1352	.3316	.3254	.6981	.6827	.5920	.6300	.6518	.4236	.4451	.6631	.7875	.6203
7	1.9640	1.3977	.5384	.0438	.3674	.0849	.8339	.1943	.3577	.6131	.4992	.7350	.5301	.6145	.6100	.5804	.3390	.6180	.7339	.5781
8	1.6778	1.3757	.7725	.1115	.1604	.2817	.4836	.3260	.4060	.4994	.7013	.6516	.6230	.6975	.6446	.5666	.5289	.6198	.7360	.5797
9	1.6778	1.3757	.7725	.1115	.1604	.2817	.4836	.3260	.4060	.4994	.7013	.6516	.6230	.6975	.6446	.5666	.5289	.6198	.7360	.5797

NUMBERS AT AGE (Millions)

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
0	2941.	2783.	4378.	4653.	10590.	16666.	37665.	64208.	61160.	52681.	79714.	96020.	84052.	41722.	38486.	36388.	36608.	63617.	52930.	35514.	50397.
1	7427.	930.	887.	1462.	1636.	3583.	5404.	8529.	16851.	15010.	15572.	26910.	33202.	26306.	13550.	12440.	12661.	12136.	20895.	17019.	11750.
2	839.	1377.	270.	244.	441.	511.	1177.	1492.	2500.	4803.	4527.	3907.	7220.	8444.	5369.	3258.	2947.	3483.	3458.	5675.	4930.
3	360.	171.	271.	162.	177.	298.	264.	630.	850.	1364.	2626.	2237.	1838.	3577.	4383.	2657.	1680.	1257.	1608.	1461.	2701.
4	198.	66.	36.	57.	127.	136.	162.	165.	310.	502.	738.	1102.	1090.	920.	1963.	2394.	1503.	893.	639.	747.	766.
5	71.	47.	11.	23.	47.	106.	92.	109.	118.	181.	272.	322.	563.	555.	474.	1029.	1383.	858.	435.	277.	379.
6	23.	11.	10.	3.	20.	41.	75.	56.	85.	81.	90.	129.	171.	283.	263.	234.	578.	792.	438.	200.	147.
7	11.	6.	4.	5.	3.	18.	35.	46.	45.	55.	53.	41.	59.	85.	136.	124.	138.	335.	369.	180.	97.
8	4.	1.	1.	2.	4.	2.	15.	14.	35.	28.	27.	29.	18.	31.	42.	67.	63.	89.	164.	160.	92.
9	2.	1.	1.	1.	2.	5.	5.	11.	16.	30.	32.	27.	26.	21.	24.	31.	50.	60.	73.	102.	133.

STOCK SUMMARY

Year	Recruits x10 ⁶	Total B tonnes	Spawn B tonnes	Landings tonnes	Yld/SSB	Ref.F Fbar 2- 6
1975	2941.	685359.	83755.	312800.	3.7347	1.4384
1976	2783.	364905.	80910.	174800.	2.1604	1.3547
1977	4378.	217632.	52031.	46000.	.8841	.7275
1978	4653.	232404.	69830.	11000.	.1575	.0482
1979	10590.	390159.	113469.	25100.	.2212	.0607
1980	16666.	638138.	138565.	70764.	.5107	.2721
1981	37665.	1162068.	202534.	174879.	.8635	.3327
1982	64208.	1838441.	284967.	275079.	.9653	.2596
1983	61160.	2455780.	431834.	387202.	.8966	.3341
1984	52681.	2752338.	716933.	409489.	.5712	.4304
1985	79714.	3152893.	734605.	609108.	.8292	.6291
1986	96020.	4064385.	770129.	660553.	.8577	.5524
1987	84052.	3883050.	877928.	773411.	.8810	.5302
1988	41722.	3482922.	1067503.	875923.	.8205	.5187
1989	38486.	3354994.	1286067.	768886.	.5979	.5228
1990	36388.	3205324.	1138273.	619963.	.5447	.4162
1991	36608.	3129630.	993154.	635929.	.6403	.4695
1992	63617.	2956592.	778008.	694206.	.8923	.5608
1993	52930.	3133569.	483626.	647435.	1.3387	.6659
1994	35514.	2900346.	789956.	600000.	.7595	.5246

15.1 Continued

PARAMETER ESTIMATES \pm SD

Separable Model: Reference F by year

1	1992	.6198	.4917	.7811
2	1993	.7360	.5779	.9372
3	1994	.5797	.4317	.7785

Separable Model: Selection (S) by age

4	0	.1829	.0357	.9367
5	1	.4124	.2806	.6063
6	2	.7630	.5621	1.0359
7	3	.7698	.5678	1.0436
	4	1.0000	Fixed : Reference age	
8	5	.9215	.6871	1.2360
9	6	1.0700	.8055	1.4213
10	7	.9971	.7497	1.3262
	8	1.0000	Fixed : last true age	

Separable Model: Populations in year 1994

11	0	35513644.	27882302.	45233673.
12	1	17019329.	13408238.	21602954.
13	2	5674515.	4537867.	7095872.
14	3	1460872.	1135453.	1879554.
15	4	747089.	572700.	974579.
16	5	276814.	208042.	368321.
17	6	199562.	146413.	272004.
18	7	180473.	128955.	252572.
19	8	160459.	113830.	226188.

Separable Model: Populations at age 8

20	1992	89270.9947	60503.9247	131715.5958
21	1993	163519.5606	118482.4423	225676.0258

Recruitment in Year 1995

22	0	50396609.4946	33594387.6858	75602456.9432
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SSB Index catchabilities

23	1	Linear Model : Q	.11784E-02	.10411E-02	.13338E-02
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Age-structured index catchabilities

Age-Structured Index 1

Linear model fitted. Slopes at age:

24	2 Q	.16381E-03	.13133E-03	.20432E-03
25	3 Q	.11045E-03	.88452E-04	.13792E-03
26	4 Q	.70355E-04	.56288E-04	.87937E-04
27	5 Q	.40580E-04	.32428E-04	.50782E-04

Age-Structured Index 2

Linear model fitted. Slopes at age:

28	1 Q	.12311E-03	.11141E-03	.13605E-03
----	-----	------------	------------	------------

Age-Structured Index 3

Linear model fitted. Slopes at age:

29	2 Q	.13348E+01	.84486E+00	.21088E+01
30	3 Q	.14320E+01	.90512E+00	.22655E+01
31	4 Q	.16265E+01	.10272E+01	.25754E+01
32	5 Q	.20318E+01	.12809E+01	.32230E+01
33	6 Q	.21925E+01	.13794E+01	.34850E+01
34	7 Q	.21527E+01	.13500E+01	.34326E+01
35	8 Q	.21582E+01	.13447E+01	.34639E+01
36	9 Q	.20784E+01	.12984E+01	.33271E+01

Age-Structured Index 4

Linear model fitted. Slopes at age:

37	0 Q	.33227E-05	.30135E-05	.36636E-05
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Parameters of the B.-H. stock-recruit relationship

38	a	.6638340E+08	.5682490E+08	.7754973E+08
39	b	.5137349E+06	.3860412E+06	.6836669E+06

RESIDUALS ABOUT THE MODEL FIT

Separable Model Residuals (log(Observed Catch)-log(Expected Catch)) and weights (W) used in the analysis.

Age	1992	1993	1994	
0	.83304E+00	.84239E+00	.62579E+00	.10000E-01
1	.23309E+00	.39700E-01	-.32222E+00	.50000E+00
2	.81350E-01	-.13813E+00	-.48282E-01	.10000E+01
3	-.16048E-01	-.80730E-01	-.36192E-01	.10000E+01
4	-.11907E+00	-.78770E-01	.46072E-01	.10000E+01
5	-.21820E-01	.14528E-01	-.59337E-01	.10000E+01
6	-.10247E-01	-.49425E-01	-.15184E-01	.10000E+01
7	-.15325E-02	-.14744E-01	-.46739E-01	.10000E+01
8	-.37293E-01	.30673E-01	-.17958E-01	.10000E+01
Wts	.10000E+01	.10000E+01	.10000E+01	

15.1 Continued

Biomass Index Residuals: $\log(\text{Observed Index}) - \log(\text{Expected Index})$

Idx	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	.22141E+00	.30491E-01	.16602E+00	.31536E+00	-.39208E+00	-.71479E-02	-.13208E+00	.14264E+00	-.27496E+00	-.63973E-01	-.10000E+01

Aged Index Residuals: $\log(\text{Observed Index}) - \log(\text{Expected Index})$

Aged Index

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
2	-.12447E+01	-.15081E+01	.56535E-01	.13028E+00	-.25331E+00	.11718E+01	-.34973E-01	.16925E+00	.60847E+00	-.31384E+00	.40864E+00	.25574E+00	.55715E+00
3	-.74105E+00	-.62137E+00	-.12112E-01	.43485E-01	-.46113E+00	.76195E+00	-.85133E-01	.16686E+00	.50454E+00	.35331E+00	.38395E+00	.29371E+00	-.58376E+00
4	-.36472E+00	-.24864E-01	-.57625E+00	-.22920E+00	-.23587E+00	-.69870E-01	-.38510E+00	.54682E+00	.93328E+00	.96809E-01	.99058E-01	.27900E+00	-.64986E-01
5	.10821E+01	-.71170E+00	.73417E+00	-.16551E+00	.33921E+00	-.32437E+00	-.12445E+01	.22989E+00	.70975E+00	.25632E+00	.16809E+00	.15690E+00	-.12210E+01

Aged Index 2

Age	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1	-.65971E-02	-.20144E+00	-.26682E+00	-.14799E+00	-.33544E+00	-.93612E-01	.26132E+00	-.94651E-01	.72956E-01	.54219E+00	.51082E+00	-.21920E+00
	1991	1992	1993	1994	1995							
	-.12767E+00	-.89894E-01	.30302E+00	-.67579E-01	-.35867E-01							

Aged Index 3

Age	1989	1990	1991	1992	1993	1994
2	-.26605E+00	-.16938E-01	.13946E+00	.31879E+00	.25553E+00	-.42861E+00
3	-.18251E+00	.23835E+00	-.12442E+00	.27328E+00	.22415E+00	-.42661E+00
4	-.32935E+00	.15729E+00	.15654E+00	.35954E+00	.32636E+00	-.66733E+00
5	-.29153E+00	-.12032E+00	-.43703E-01	.22586E+00	.32308E+00	-.89059E-01
6	-.30705E+00	.27478E-01	-.22785E+00	.13743E+00	.28951E+00	.86434E-01
7	-.50306E+00	.13726E+00	.11238E+00	-.25533E-01	.82632E-01	.20366E+00
8	-.30850E+00	.29087E+00	.15341E+00	.17833E+00	-.22465E+00	-.79845E-01
9	-.39870E+00	-.42063E-01	-.27981E+00	.65704E+00	.19308E+00	-.10449E+00

Aged Index 4

Age	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
0	.95650E-01	.66343E+00	.88351E+00	-.11827E+00	-.13137E+00	-.44346E+00	-.11540E+00	-.10758E+00	-.32143E+00	.25995E+00	.47868E+00	-.30041E+00
	1990	1991	1992	1993	1994	1995						
	-.12768E+01	-.27796E+00	.22651E+00	.36147E+00	.12785E+00	.65748E-10						

PARAMETERS OF THE DISTRIBUTION OF \ln CATCHES AT AGE

Separable model fitted from 1992 to 1994

Variance	:	.3211
Skewness test statistic	:	5.3333
Kurtosis test statistic	:	4.8654
Partial chi-square	:	.1350
Probability of chi-square	:	1.0000
Degrees of freedom	:	6

15.1 Continued

PARAMETERS OF THE DISTRIBUTION OF THE SSB INDICES

DISTRIBUTION STATISTICS FOR ln SSB INDEX 1

Linear catchability relationship assumed.

Last age is a plus-group.

Variance	:	.0498
Skewness test statistic	:	-.4612
Kurtosis test statistic	:	-.5505
Partial chi-square	:	.0653
Probability of chi-square	:	1.0000
Number of observations	:	10
Degrees of freedom	:	9
Weight in the analysis	:	1.0000

PARAMETERS OF THE DISTRIBUTION OF THE AGE-STRUCTURED INDICES

DISTRIBUTION STATISTICS FOR ln AGED INDEX 1

Linear catchability relationship assumed.

Age	:	2	3	4	5
Variance	:	.5269	.2266	.1665	.5149
Skewness test stat	:	-1.1037	-.2875	1.2723	-.7084
Kurtosis test stat	:	.1231	-.8373	.2124	-.4971
Partial chi-square	:	.9758	.5289	.4631	1.9575
Prob. of chi-square	:	1.0000	1.0000	1.0000	.9995
Number of data	:	13	13	13	13
Degrees of freedom	:	12	12	12	12
Weight in analysis	:	.2500	.2500	.2500	.2500

DISTRIBUTION STATISTICS FOR ln AGED INDEX 2

Linear catchability relationship assumed.

Age	:	1
Variance	:	.0664
Skewness test stat.	:	1.6171
Kurtosis test stat.	:	-.1133
Partial chi-square	:	.1448
Prob. of chi-square	:	1.0000
Number of data	:	17
Degrees of freedom	:	16
Weight in analysis	:	1.0000

DISTRIBUTION STATISTICS FOR ln AGED INDEX 3

Linear catchability relationship assumed.

Age	:	2	3	4	5	6	7	8	9
Variance	:	.0882	.0825	.1678	.0529	.0514	.0667	.0584	.1438
Skewness test stat.	:	-.3827	-.3738	-.7778	.3226	-.2489	-1.4538	-.1136	.8211
Kurtosis test stat.	:	-.6718	-.6926	-.4795	-.6010	-.6368	.2890	-.7831	-.2272
Partial chi-square	:	.0290	.0288	.0608	.0196	.0194	.0272	.0254	.0647
Prob. of chi-square	:	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	.9999
Number of data	:	6	6	6	6	6	6	6	6
Degrees of freedom	:	5	5	5	5	5	5	5	5
Weight in analysis	:	.1250	.1250	.1250	.1250	.1250	.1250	.1250	.1250

DISTRIBUTION STATISTICS FOR ln AGED INDEX 4

Linear catchability relationship assumed.

Age	:	0
Variance	:	.2282
Skewness test stat.	:	-1.0453
Kurtosis test stat.	:	1.1344
Partial chi-square	:	.9156
Prob. of chi-square	:	1.0000
Number of data	:	18
Degrees of freedom	:	17
Weight in analysis	:	1.0000

15.2 Example of graphics data transfer file: ICA.VIE

DATA TRANSFER FILE FOR ICAVIEW

1975	1994	0	9	3	1	4	<— Firstyear, lastyear, firststage, lastage, No of years to fit selection pattern, No of SSB surveys, No of aged surveys
LANDINGS BY YEAR							
1975	312800.0000						
1976	174800.0000						
1977	46000.0000						
1978	11000.0000						
1979	25100.0000						
1980	70764.0000						
1981	174879.0000						
1982	275079.0000						
1983	387202.0000						
1984	409489.0000						
1985	609108.0000						
1986	660553.0000						
1987	773411.0000						
1988	875923.0000						
1989	768886.0000						
1990	619963.0000						
1991	635929.0000						
1992	694206.0000						
1993	647435.0000						
1994	600000.0000						

FISHING MORTALITY +/- STANDARD DEVIATION

1975	1.4984	-1.0000	-1.0000	-1 indicates the s.d. is not available
1976	1.3497	-1.0000	-1.0000	
1977	1.3557	-1.0000	-1.0000	
1978	.0396	-1.0000	-1.0000	
1979	.0644	-1.0000	-1.0000	
1980	.4121	-1.0000	-1.0000	
1981	.2698	-1.0000	-1.0000	
1982	.5103	-1.0000	-1.0000	
1983	.3275	-1.0000	-1.0000	
1984	.4138	-1.0000	-1.0000	
1985	.6685	-1.0000	-1.0000	
1986	.5184	-1.0000	-1.0000	
1987	.4916	-1.0000	-1.0000	
1988	.4001	-1.0000	-1.0000	
1989	.4046	-1.0000	-1.0000	
1990	.3696	-1.0000	-1.0000	
1991	.4322	-1.0000	-1.0000	
1992	.6198	.4917	.7811	
1993	.7360	.5779	.9372	
1994	.5797	.4317	.7785	

RECRUITMENT

1975	2940656.	-1.	-1.
1976	2783076.	-1.	-1.
1977	4378307.	-1.	-1.
1978	4652713.	-1.	-1.
1979	10590152.	-1.	-1.
1980	16666463.	-1.	-1.
1981	37664605.	-1.	-1.
1982	64208280.	-1.	-1.
1983	61159651.	-1.	-1.
1984	52681042.	-1.	-1.
1985	79714046.	-1.	-1.
1986	96019556.	-1.	-1.
1987	84052500.	-1.	-1.
1988	41721944.	-1.	-1.
1989	38485673.	-1.	-1.
1990	36387941.	-1.	-1.
1991	36607978.	-1.	-1.
1992	63616569.	-1.	-1.
1993	52929546.	-1.	-1.
1994	35513645.	-1.	-1.

1995	.50397E+08	.33594E+08	.75602E+08
TOTAL AND SPAWNING BIOMASS			
1975	685359.	83755.	
1976	364905.	80910.	
1977	217632.	52031.	
1978	232404.	69830.	
1979	390159.	113469.	
1980	638138.	138565.	
1981	1162068.	202534.	
1982	1838441.	284967.	
1983	2455780.	431834.	
1984	2752338.	716933.	
1985	3152893.	734605.	
1986	4064385.	770129.	
1987	3883050.	877928.	
1988	3482922.	1067503.	
1989	3354994.	1286067.	
1990	3205324.	1138273.	
1991	3129630.	993154.	
1992	2956592.	778008.	
1993	3133569.	483626.	
1994	2900346.	789956.	
1995	2865938.	874959.	

15.2 Continued

SELECTION PATTERN +/- STANDARD DEVIATION

0	.18290450	.03571664	.93665168
1	.41242510	.28055369	.60628133
2	.76303409	.56205150	1.03588552
3	.76977544	.56782045	1.04355915
4	1.	-1.	-1.
5	.92152809	.68707723	1.23598045
6	1.06998850	.80554104	1.42125023
7	.99714120	.74972201	1.32621231
8	.10000E+01	-.10000E+01	-.10000E+01
9	.10000E+01	-.10000E+01	-.10000E+01

NUMBERS AT AGE AND YEAR

2940656.	7427038.	838635.	360154.	197506.	70893.	23460.	10954.	4335.	1590.
2783076.	930163.	1376734.	170980.	65903.	46560.	10527.	6073.	1391.	1001.
4378307.	886827.	269919.	271111.	36299.	10851.	9709.	3769.	1358.	547.
4652713.	1462413.	244220.	161833.	57213.	22608.	3223.	4906.	1991.	796.
10590152.	1636259.	441440.	176723.	127352.	47018.	20171.	2726.	4249.	2256.
16666463.	3582623.	510533.	297855.	135665.	105636.	40548.	18062.	1708.	5013.
37664605.	5403929.	1176647.	264326.	161501.	92211.	74992.	34504.	15013.	4589.
64208280.	8528602.	1492209.	629859.	165242.	108667.	56425.	46340.	13561.	10935.
61159651.	16850533.	2499695.	850394.	309576.	117539.	84651.	44597.	34526.	15999.
52681042.	15010363.	4803216.	1363524.	501823.	180546.	81497.	54976.	28218.	30462.
79714046.	15571707.	4527235.	2626423.	738028.	271809.	90038.	53259.	26945.	32224.
96019556.	26910172.	3907130.	2236524.	1101978.	322159.	129045.	40535.	29252.	26552.
84052500.	33202041.	7220467.	1837921.	1090345.	563397.	170617.	58995.	17587.	26318.
41721944.	26306006.	8443961.	3577341.	920383.	554970.	282693.	85404.	31418.	21307.
38485673.	13549610.	5368624.	4383097.	1963140.	474484.	263443.	136230.	41801.	23751.
36387941.	12439730.	3258359.	2656895.	2394370.	1028743.	233779.	124223.	66976.	31134.
36607978.	12661171.	2946650.	1679541.	1503180.	1382816.	578245.	138480.	62912.	50373.
63616569.	12136365.	3482873.	1256885.	892568.	857642.	792382.	335267.	89272.	60399.
52929546.	20895133.	3457690.	1607947.	638623.	434563.	438368.	369409.	163521.	72870.
35513645.	17019330.	5674516.	1460873.	747090.	276815.	199563.	180474.	160460.	102465.
50396609.	11750355.	4929606.	2701049.	765505.	378595.	146808.	97109.	91608.	133240.

FISHING MORTALITY AT AGE AND YEAR

.1510283	.6854134	1.2902265	1.4983511	1.3450258	1.8071835	1.2514211	1.9639511	1.6777908	1.6777908
.1436628	.2372370	1.3249402	1.3497478	1.7039207	1.4676525	.9270626	1.3976821	1.3756739	1.3756739
.0965743	.2895807	.2115594	1.3557429	.3735035	1.1140428	.5826876	.5383824	.7725036	.7725036
.0450380	.1978007	.0234837	.0396096	.0962479	.0140407	.0673991	.0437695	.1114579	.1114579
.0838292	.1647135	.0934370	.0643954	.0869521	.0480512	.0104729	.3673804	.1604003	.1604003
.1262721	.1134262	.3582694	.4120917	.2861123	.2426181	.0614242	.0848996	.2816904	.2816904
.4852953	.2868685	.3249286	.2697708	.2962259	.3911666	.3813771	.8338652	.4836059	.4836059
.3377499	.2272567	.2623131	.5102937	.2406473	.1497509	.1352446	.1943028	.3260170	.3260170
.4047468	.2550966	.3060966	.3274532	.4392142	.2662057	.3316392	.3576898	.4059743	.4059743
.2188000	.1986296	.3036627	.4138459	.5131470	.5957584	.3254013	.6130936	.4994001	.4994001
.0859414	.3826524	.4051882	.6685166	.7289366	.6449422	.6980653	.4992035	.7013031	.7013031
.0619405	.3155847	.4541681	.5184289	.5708762	.5356210	.6827072	.7350206	.6515954	.6515954
.1616443	.3691599	.4023000	.4916000	.5753361	.5896223	.5920317	.5300675	.6230023	.6230023
.1246695	.5892255	.3556959	.4000742	.5625621	.6450780	.6300152	.6144692	.6974535	.6974535
.1293907	.4251341	.4034137	.4046353	.5462074	.6078514	.6517545	.6100067	.6445512	.6445512
.0556975	.4402265	.3627028	.3695748	.4489985	.4760959	.4236499	.5803514	.5666349	.5666349
.1040599	.2906824	.5520325	.4321739	.4611513	.4568340	.4450688	.3390391	.5289373	.5289373
.1133577	.2556056	.4728994	.4770774	.6197610	.5711278	.6631378	.6179899	.6197610	.6197610
.1346120	.3035310	.5615668	.5665282	.7359646	.6782128	.7874744	.7338613	.7359646	.7359646
.1060336	.2390907	.4423450	.4462530	.5797177	.5342267	.6202919	.5780610	.5797177	.5797177
.1060336	.2390907	.4423450	.4462530	.5797177	.5342267	.6202919	.5780610	.5797177	.5797177

[illegible]

Unweighted Residuals About the Model fit

Partition of the weighted residuals

[illegible]

16.0 Appendix 3. Example Graphical Output

16.1 Example output from ICAVIEW

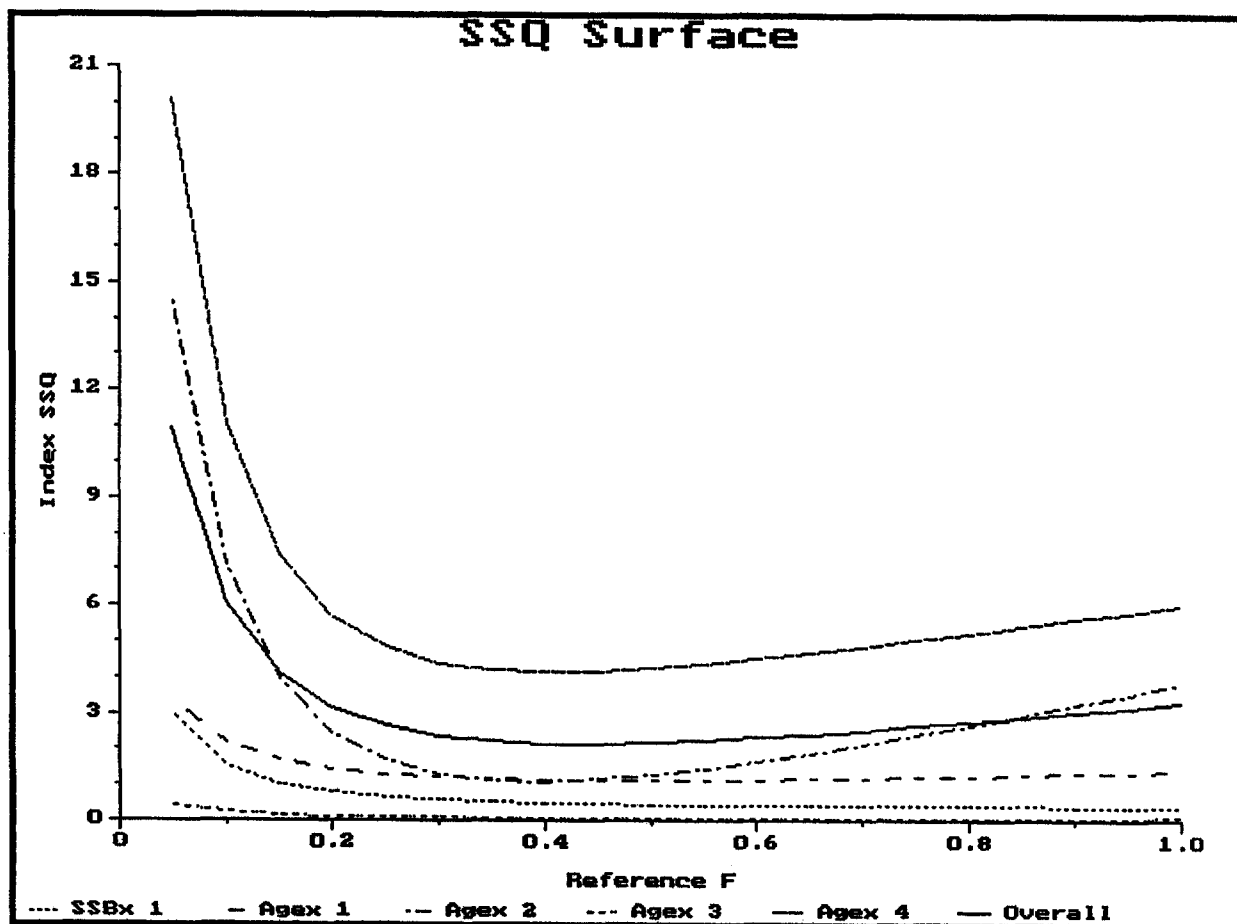


Figure 16.1.1. Graph generated by ICAVIEW. Unweighted sums of squared residuals for each index are plotted against the fishing mortality at reference age for 20 separable VPA fits over a user-specified range of fishing mortalities. This diagnostic graph can be used to detect differences in the fishing mortality predictions from different index series. In this example, the SSB index (labelled SSBx 1) indicates a fishing mortality around 0.7 whereas the third aged index (labelled Agex 3) indicates a fishing mortality around 0.3.

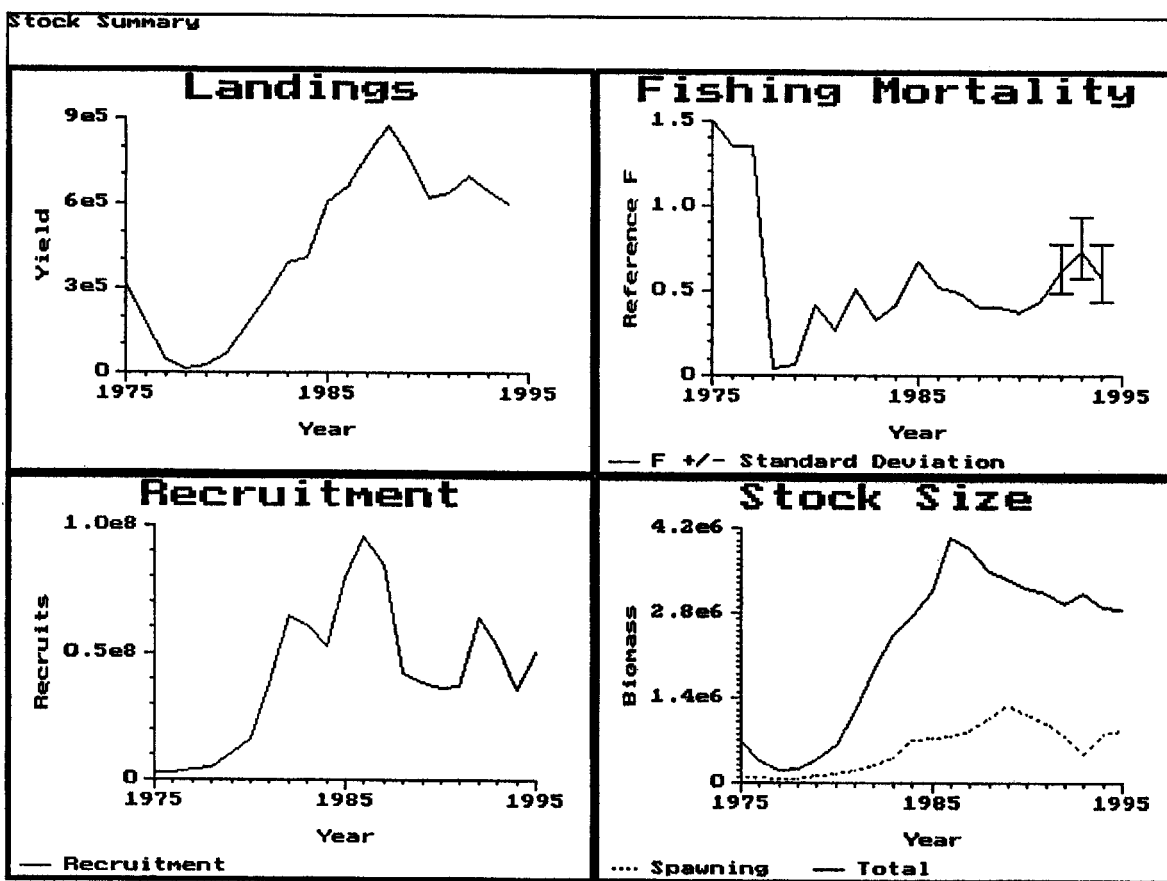


Figure 16.1.2. Graph generated by ICAVIEW. Summary of the stock assessment. Clockwise from top left: 1) Landings by year in tonnes; 2) Fishing mortality at reference age \pm standard deviation; 3) Total and spawning stock biomasses; 4) Recruitment.

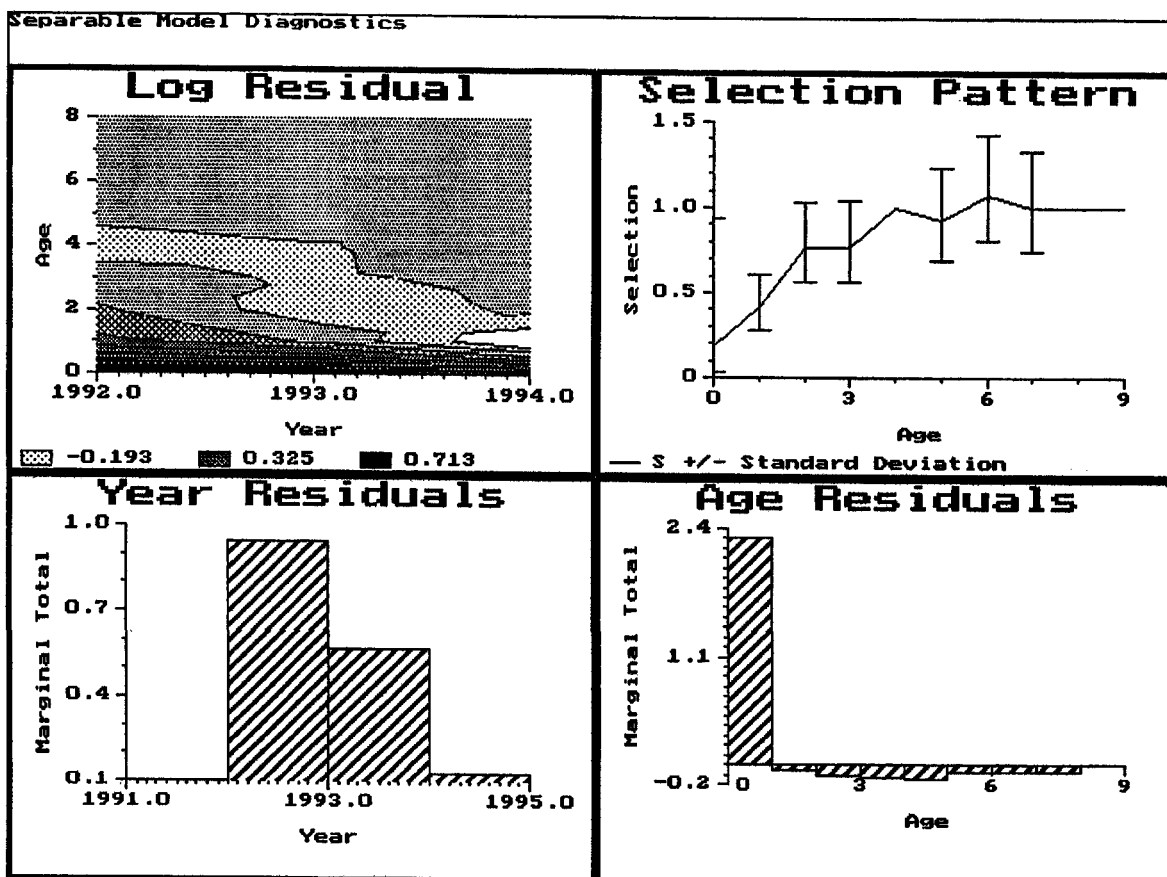


Figure 16.1.3. Graph generated by ICAVIEW. Separable model diagnostics: 1) Contour plot of catch residuals against the separable model by year and age; 2) Selection at age \pm standard deviation; 3) and 4) Year and age marginal totals respectively.

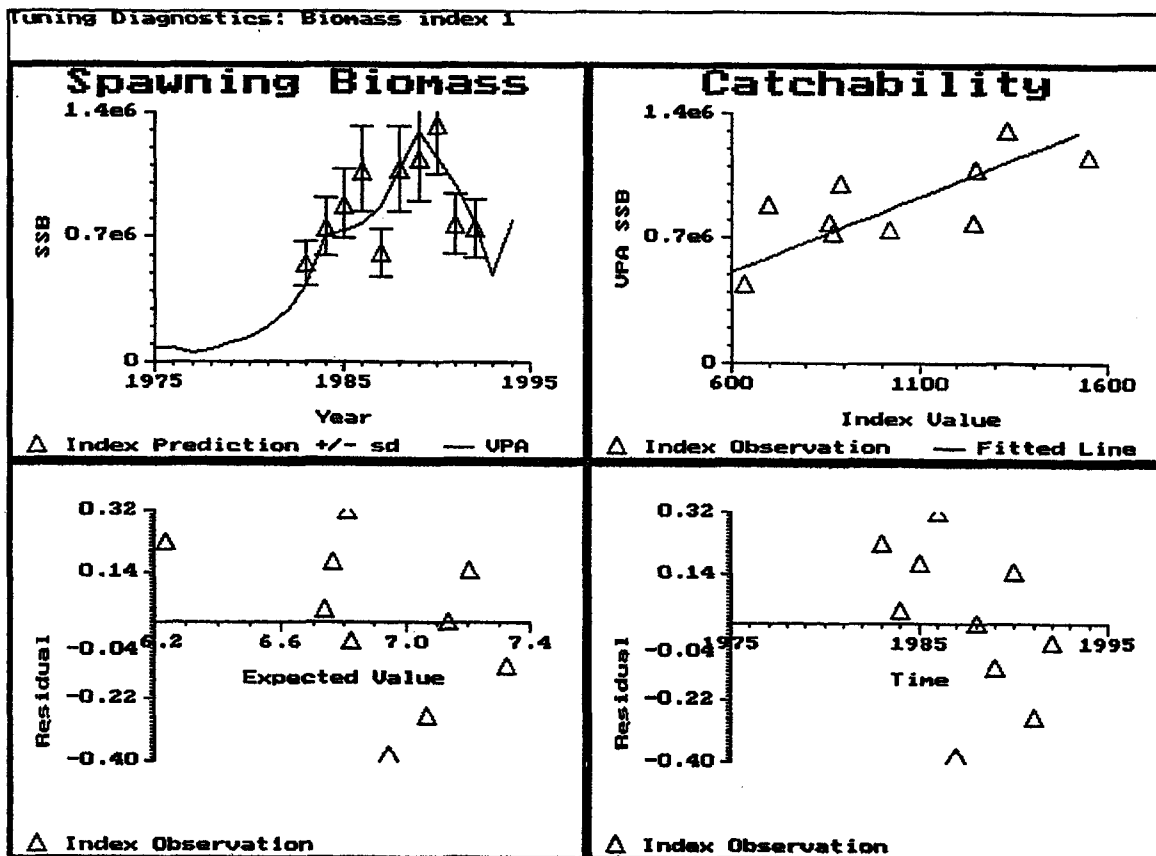


Figure 16.1.4. Graph generated by ICAVIEW. Fitting diagnostics for the index of spawning biomass, which in this example is the "Larval Production Estimate" for North Sea herring. A linear catchability model is fitted. Clockwise from top left: 1) Stock size and index prediction; 2) Estimated SSB, observed index values and the relation fitted; 3) Log residual and log expected values for the catchability model fit; 4) Log residual plotted on time.

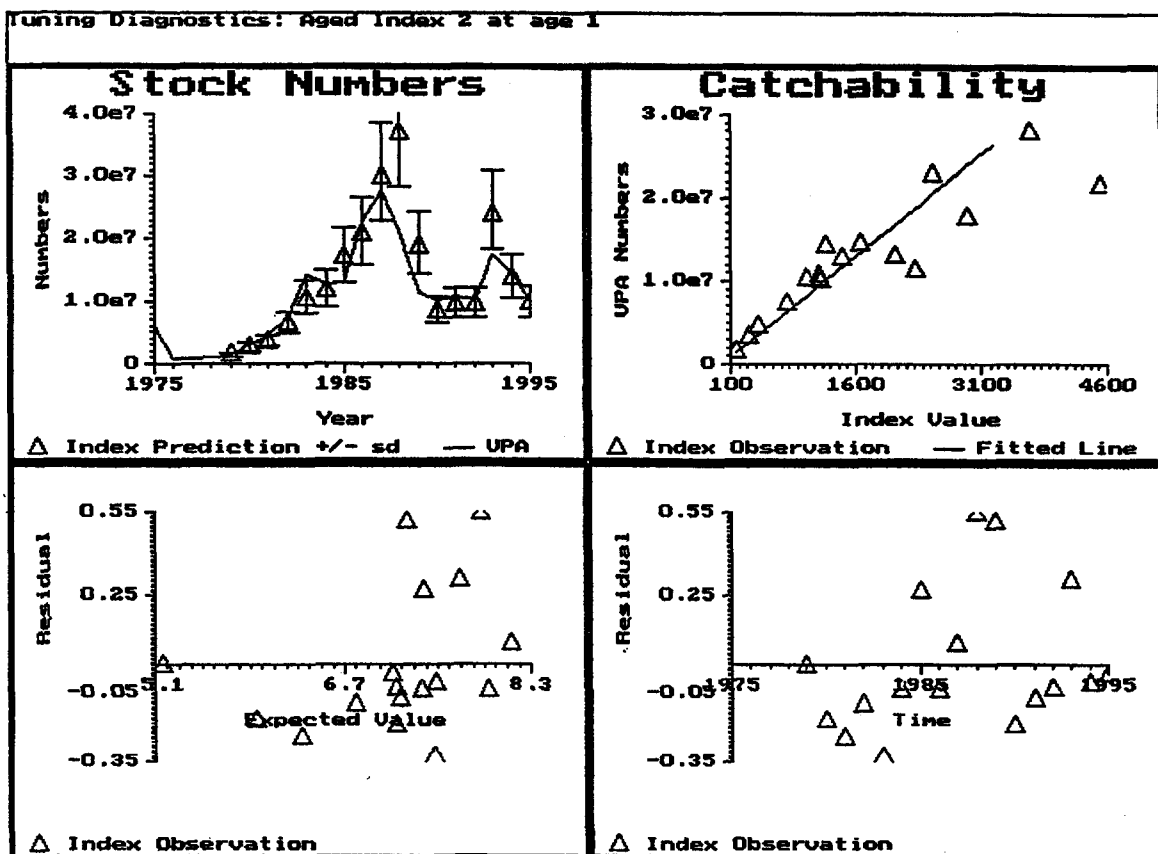


Figure 16.1.5. Graph generated by ICAVIEW. Example fitting diagnostics for one age of an age-structured index (here, the IBTS estimate of the relative abundance of 1-ring herring). One of these graphs is drawn for each age of each age-structured index. A linear catchability model is fitted. Clockwise from top left: 1) Stock size and index prediction; 2) Estimated stock size of one-ringers, observed index values and the relation fitted; 3) Log residual and log expected values for the catchability model fit; 4) Log residual plotted on time.

16.2 Example output from VIEWSRR

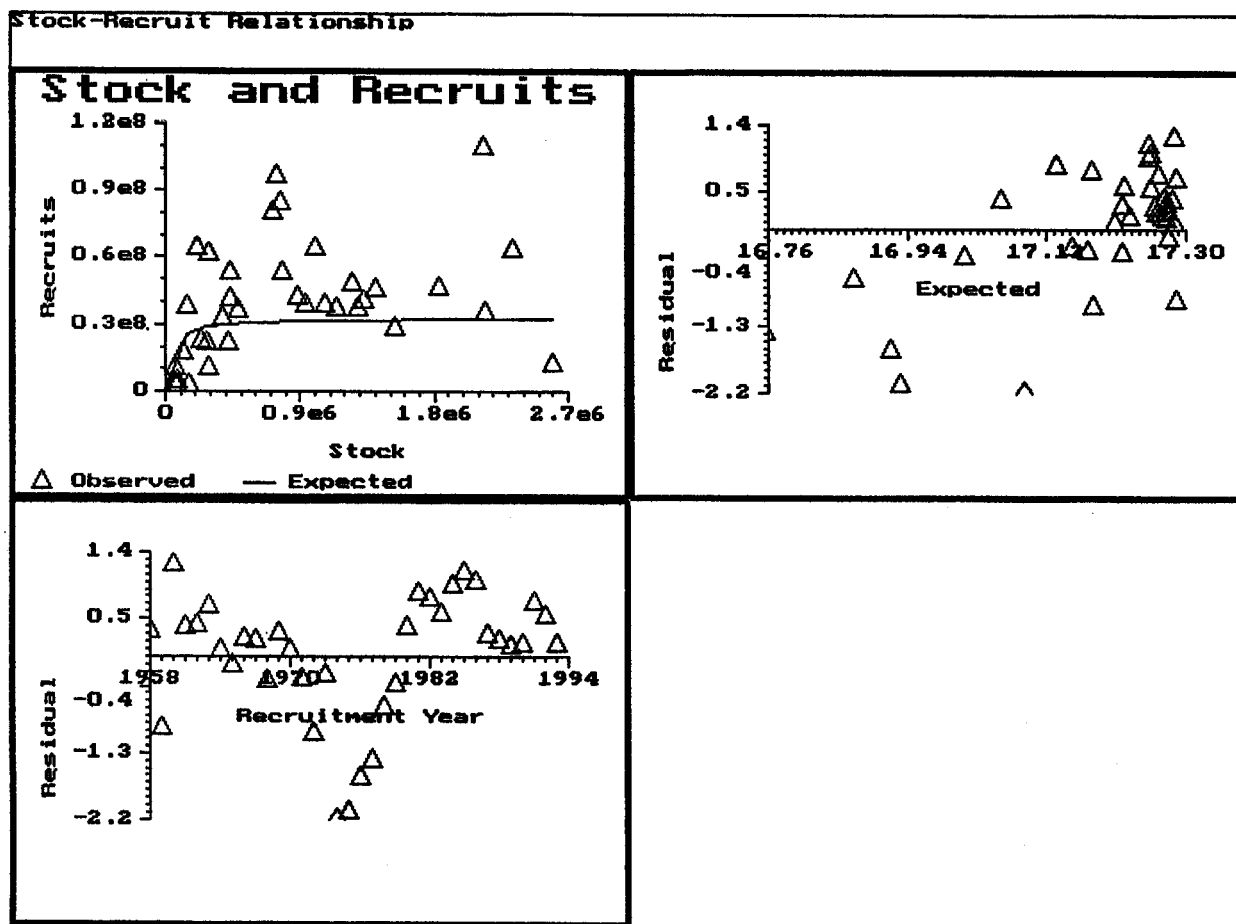


Figure 16.2.1. Graph generated by VIEWSRR. Graphs show 1) the fitted line and estimates of spawning stock and corresponding recruitment; 2) plot of residual on expected value; 3) a plot of residuals on time.

16.3 Example output from VIEWPRO

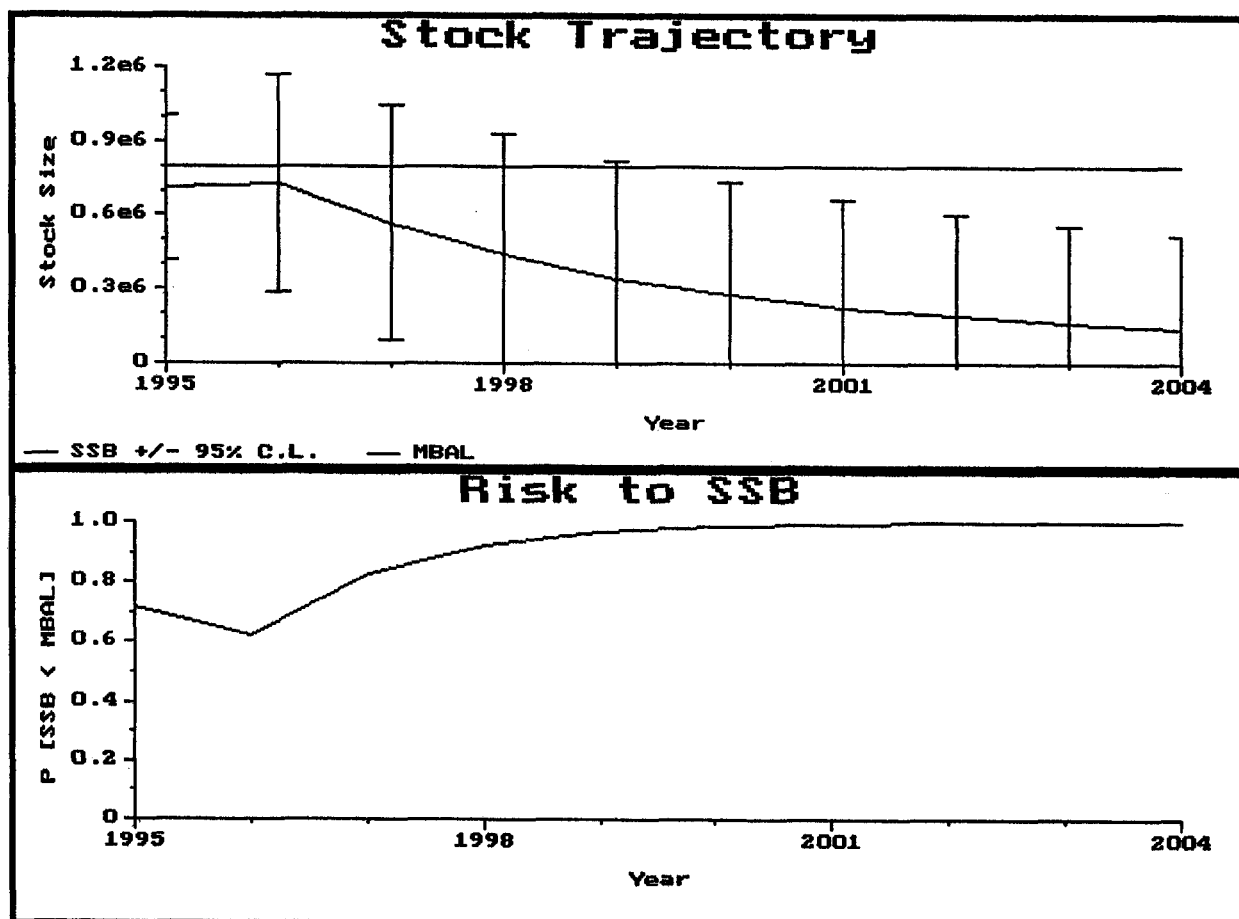


Figure 16.3.1. Graph generated by VIEWPRO. Example projection based on North Sea herring, using the fleet F multipliers given in Table 14.10. Upper: spawning stock size \pm 95% confidence limits, and the minimum biological acceptable stock size (MBAL). Lower: risk of projection option, as the estimated probability that the stock size will fall below MBAL in any given year.

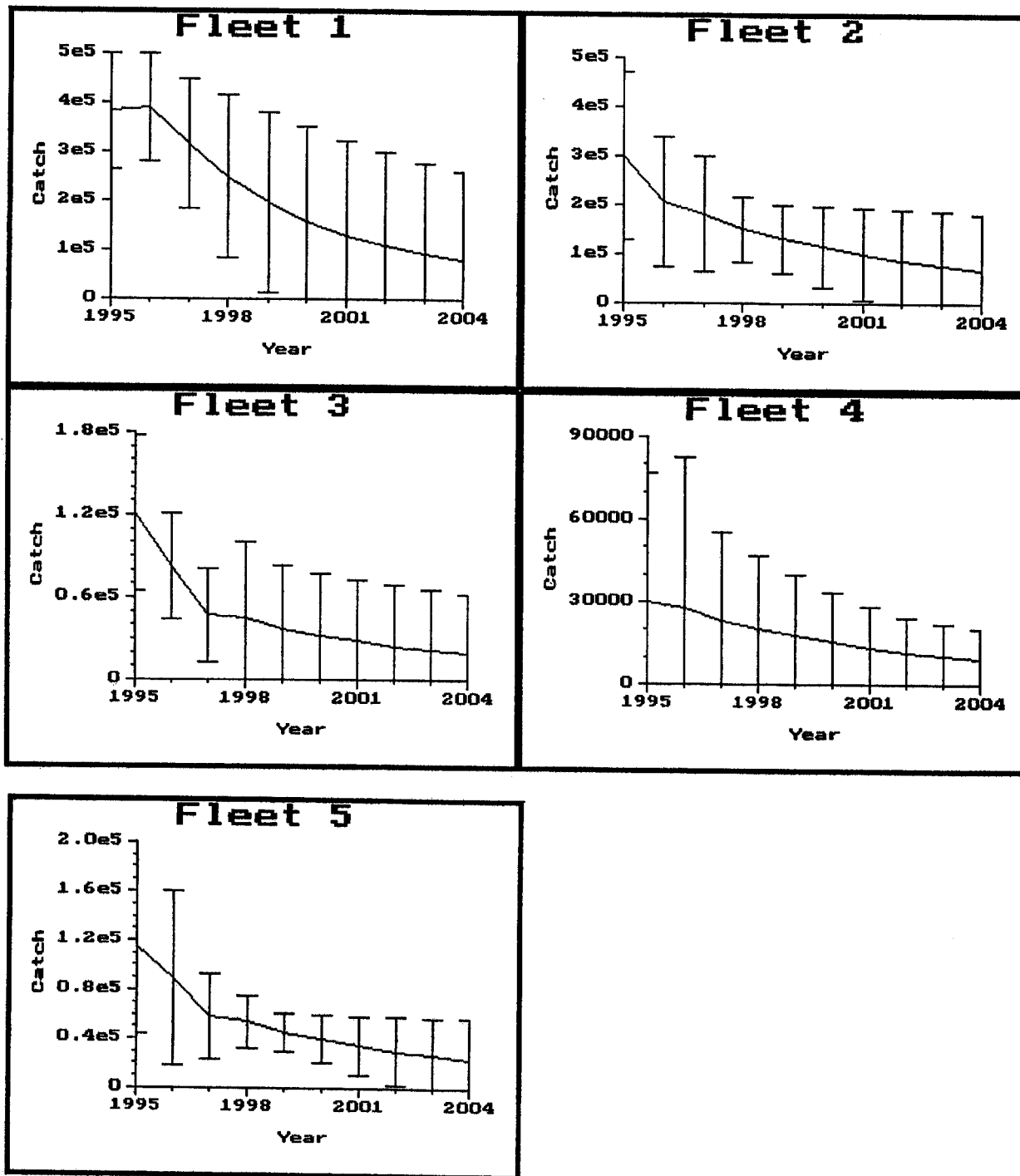


Figure 16.3.2. Graph generated by VIEWPRO. Example projection based on North Sea herring, using the F-multipliers given in Table 14.10. Estimated catches by fleet, \pm 95% confidence limits.

Section B. Technical Reference

1.0 General

1.1 Introduction

The ICA programmes are intended to provide a method for analysing time-series of catch-at-age and research vessel survey information. They provide a convenient implementation of a method which has been described by Deriso *et al.* (1985). Some of the properties of the model have been discussed by Kimura (1986) and Gudmundsson (1986). The user should refer to these documents for a detailed account of the method. The distinguishing features of this implementation are:

- a) Survey data may be either as age-structured indices or as indices of spawning biomass.
- b) The relationship between survey index and stock abundance may be either :
 - identity, where an absolute measure of stock size is estimated;
 - proportionate, where the index is assumed to bear a linear relationship to stock abundance;
 - power, where the index is assumed to bear a power-law relation to stock abundance.
- c) Separability in the catches at age is assumed.
- d) Assignment of statistical weights to the various data types may be either by the user, if these are known from internal sources or if they are to be assigned arbitrary values, or they may be assigned using an iterated inverse-variance reweighting scheme.

An advantage of this type of model is that approximate estimates of the variance of many of the estimated parameters of interest can be calculated. As a well-defined model is fitted to the data, a number of conventional statistics such as measures of goodness-of-fit can be calculated, and an assessment can be made of the extent to which the data conform to the assumptions of the model.

1.2 The Deriso-Gudmundsson-Kimura Model

The model is a simplified derivative of the general model described by Fournier and Archibald (1982) in which the model is fitted by simple nonlinear least squares. Variables are defined on page 52.

In its simplest form the model may be thought of as a minimisation of:

$$\sum \lambda_c (C - \hat{C})^2 + \sum \lambda_i (I - \hat{I})^2 \quad (1)$$

where C are the catch at age observations; \hat{C} are the catches at age that are predicted by the model; I are the index observations and \hat{I} are the index observations that are predicted by the model. Internally the catches at age are assumed to be linked by the usual catch equations; the index series and the stock sizes are linked by one of three catchability models.

The various parameters of interest such as cohort strengths and fishing mortalities are estimated by minimising the term in equation (1). Actual observations of catch and abundance index are compared directly with the predictions of the entire model so that the parameters that best explain the observed data will be found.

The first term in the model represents a separable constraint. Fitting a separable VPA with no tuning series is equivalent to minimising the first term in Eqn 1.2.1. The second term in the model represents the tuning of the separable VPA to the index series. The indices may represent numbers at age or spawning stock size.

Additional terms may be included in the model to allow estimation of stock-recruit relations etc.

1.3 Prior assumptions

The following principal prior basic assumptions are made in the model:

- (1) Indices of abundance are related to stock size according to the specified catchability model.
- (2) Indices are unbiased and errors are

uncorrelated. Catchability is assumed constant with time.

- (3) The usual VPA assumptions about stock unity, migration and mortality rates apply.
- (4) Selection pattern is assumed constant ie $F_{a,y} = S_a F S_y$.
- (5) Errors are lognormally - distributed; variance is constant with time.
- (6) Optionally, that recruitment depends on spawning stock size according to the relation described by Beverton and Holt (1957).

Appropriate use of the model depends on these assumptions not being violated.

1.4 Treatment of errors in the catches at age

Catches at age are assumed to be measured with an error that has an independent lognormal distribution. The estimates of the population sizes that are calculated in fitting the model are the least-squares estimates appropriate to the specified model structure. In contrast, in a conventional VPA (As in XSA and ADAPT) it is assumed that the catches at age are measured without error, and the population sizes are then reconstructed along a cohort. The two assumptions about errors in the catches at age lead to different estimates of mortalities and cohort strengths. Estimates of population sizes made using the two methods are not necessarily reconcilable: terminal population sizes estimated using the least-squares method may not be consistent with a "conventional" VPA. For example, consider the case where catches at age are measured with substantial error, particularly at the oldest ages. A least-squares method will yield estimates of population size that are most consistent with the estimated catches and with the index data over the entire cohort; it can happen that the resulting estimate of final population size may be lower than the estimated catch at the oldest age. In such a case, an attempt to recalculate a conventional VPA from the terminal populations estimated using the model will cause a numerical error. This problem is also discussed by Shepherd

(1992), who refers to it as a "negative survivors" problem.

Various authors have dealt with this problem in different ways. Shepherd's (op cit.) answer has been to treat the catches as precise throughout; but he recognises that this simplification is not always desirable. Gudmundsson (1986) used a weighted mean between the fitted population and the "conventional" VPA, but the weighting factor used was arbitrarily chosen. The choice taken here has been to use the fitted populations as the best available estimates of population size and age in the period for which the separable model is fitted. In earlier years, a "conventional" VPA initiated with the populations in the first year for which the separable model is fitted has been used. This makes the model internally consistent over the period of fitting the separable constraint. Earlier years are treated in a simplistic fashion on account of their lesser importance for management purposes, and in order to decrease the number of parameters that need to be estimated.

It remains somewhat unrealistic to assume that the errors in the catches at age are uncorrelated. Fournier and Archibald (1982) described a model with a more realistic error structure in which the errors in estimating total catch are considered independently from the errors in estimating the ageing errors. This approach is appealing, but does not seem to have yet gained general acceptance. In future implementations of this type, one might wish to move towards either an approach of the Fournier and Archibald type, or else to abandon the assumption of uncorrelated errors in the catch at age data and instead to attempt to estimate the matrix of variances and covariances for the catches at age.

1.5 Shrinkage

Use of shrinkage in stock assessments has been found helpful in some circumstances (Anon., 1993). An option has been included in the programmes to generate a "shrunk" VPA based on the model fit. Although conceptually similar, the implementation is quite different to

that used by Anon. (1993), so that their advice on appropriate levels of “minimum s.e. of the mean” are not applicable here.

2.0 Implementation

2.1 Overview and purpose

The software package named “Integrated Catch-Age analysis” (ICA) has been written to provide a tool which allows a variety of model choices described in section 1 to be implemented conveniently.

The programme allows a statistical analysis of an age-structured data set to be completed simply and relatively quickly, so that the uncertainties inherent in a stock assessment can be assessed and the consistency of an assessment can be evaluated. It allows estimates to be calculated of the standard deviation of the estimated fishing mortalities, and of other parameters of management interest. A post-processing programme displays a series of graphs of the parameter estimates: fishing mortality, recruitment, etc, with error bars where appropriate. Residual plots are also drawn. These allow a visual assessment of the consistency of a model fit to be made simply and quickly. A post-processing projection programme allows calculation of stock projections, with associated estimates of error and risk.

A number of diagnostic plots are provided in order that the user may check that the data conform reasonably to the assumptions in Section 1.3. Test statistics for goodness of fit, skewness and kurtosis are provided.

2.2 The programmes

2.2.1 ICA1.EXE: Initialisation

This programme performs the functions preparatory to the least-squares analysis proper. The data files are read, appropriate parameter choices are requested from the user on the screen, and an initial estimate of the minimum is found. Over a range of terminal fishing mortalities specified by the user, the sum of squared residuals for each index series is calculated. A simple one-dimensional minimisation method is then

used to find the terminal F corresponding to the lowest sum of squared residuals in the separable VPA.

ICA1 estimates fishing mortality at reference age by performing a minimisation of

$$\sum_a \sum_y \sum_A (\ln(I_{a,y,A}) - \ln(\hat{I}_{a,y,A}))^2 + \sum_y \sum_B (\ln(I_{y,B}) - \ln(\hat{I}_{y,B}))^2 \quad (2)$$

where the \hat{I} are generated using the specified catchability models,

$$\hat{I}_{y,B} = g_B (SSB_y) \quad ; \quad \hat{I}_{a,y,A} = h_A (N_{a,y,A}, PZ_A) \quad (3)$$

SSB is estimated from the VPA populations, weights at age, and maturity ogives:

$$SSB_y = \sum_a N_{a,y} W_{a,y} O_{a,y} \exp(-(F_{a,y} PF + M_{a,y} PM)) \quad (4)$$

where $g_B(SSB)$ may take one of three forms:

$$\begin{aligned} \hat{I}_y &= SSB & [\text{Identity Model}] \\ \hat{I}_y &= Q_B \cdot SSB_y & [\text{Linear Model}] \\ \hat{I}_y &= Q_B \cdot SSB_y^{K_B} & [\text{Power Model}] \end{aligned} \quad (5)$$

similarly, $h_A(N_{a,y}, PZ_A)$ may take one of three forms:

$$\begin{aligned} \hat{I}_{a,y,A} &= N_{a,y} \cdot \exp(-(F_{a,y} + M_{a,y}) \cdot PZ_A) & [\text{Identity Model}] \\ \hat{I}_{a,y,A} &= Q_{a,A} \cdot N_{a,y} \cdot \exp(-(F_{a,y} + M_{a,y}) \cdot PZ_A) & [\text{Proportionate Model}] \\ \hat{I}_{a,y,A} &= Q_{a,A} \cdot (N_{a,y})^{K_{a,A}} \cdot \exp(-(F_{a,y} + M_{a,y}) \cdot PZ_A) & [\text{Power Model}] \end{aligned} \quad (6)$$

The catchability parameters Q and K are calculated from simple regressions (where necessary) of I against population size, against a VPA in which

$$\sum_a \sum_y (\ln(C_{a,y}) - \ln(\hat{C}_{a,y}))^2 \quad (7)$$

where

$$\hat{C}_{a,y} = FS_y \cdot S_a \cdot \bar{N}_{a,y}$$

where

$$\bar{N}_{a,y} = \frac{N_{a,y}(1 - \exp(-FS_y \cdot S_a - M_{a,y}))}{FS_y \cdot S_a + M_{a,y}} \quad (8)$$

has previously been minimised by the method of Pope and Shepherd (1982). If a Beverton and Holt stock-recruit relation is to be fitted, starting parameters a and b are found by a linear regression of:

$$\frac{\hat{SSB}_y}{R_y} = \frac{b}{a} + \frac{1}{a} \hat{SSB}_y \quad (9)$$

where b/a and $1/a$ are the intercept and slope of the regression. The method is explained by Hilborn and Walters (1992).

2.2.2 ICA2.EXE: Model fitting, reweighting and shrinkage

This programme performs the multidimensional minimisation, reweighting and output functions. The programme initially accepts the users' choice as to whether or not to recalculate weights and variances iteratively. The next parameter to be input is the estimate of internal correlation of the errors in each age-structured index (see α in Eqn 14). The user must also specify a stopping criterion for the reweighting iterations.

The programme performs a nonlinear minimisation of

$$\begin{aligned} & \sum_{a,y} \lambda_{a,y} (\ln(C_{a,y}) - \ln(\hat{C}_{a,y}))^2 + \\ & \sum_{b,y} \lambda_{b,y} (\ln(I_{y,B}) - \ln(\hat{I}_{y,B}))^2 + \\ & \sum_{a,y,A} \lambda_{a,A} (\ln(I_{a,y}) - \ln(\hat{I}_{a,y,A}))^2 \end{aligned} \quad (10)$$

where the predicted catches and index values are related to the fitted population sizes as given in Eqns 3-6 and 8.

Elements of N are assumed related as:

$$N_{a+1,y+1} = N_{a,y} \cdot \exp(-FS_y \cdot S_a - M_{a,y}) \quad (11)$$

If a stock-recruit model is to be fitted, an additional term is included in the minimisation:

$$\lambda_{sr} \sum_y (\ln(R_y) - \ln(\frac{a \hat{SSB}_y}{b + \hat{SSB}_y}))^2 \quad (12)$$

Note that this approach is not strictly correct; SSB_y and R_y are treated as data although

they are of course quantities estimated elsewhere in the model. This is unavoidable unless the problem were to be reformulated in a new and unconventional manner, which for the moment has been eschewed.

The parameters estimated by the model are:

- Population sizes N for all true ages in the last year, and for the last true age in the years for which the separable model is to be fitted.
- Population size N for the first true age (ie recruitment) in the year succeeding the last year for which there are catch-at-age observations, if there is a survey observation that allows this forthcoming recruitment to be estimated.
- Other population sizes are estimated from Eqn 11.
- Fishing mortality at reference age FS for each year in which the separable model is fitted.
- Selection S at each true age, except for the reference age and for the last true age.

Catchability parameters Q and K as specified for each index.

Parameters a and b of the Beverton and Holt stock-recruit relationship (if fitted).

Parameters assumed as fixed and measured without error are:

- Natural mortality
- Weights at age in the stock
- Maturity ogives
- Proportions of annual F , M and Z before spawning and before each age-structured survey (PF, PM, PZ).

Where the option to recalculate all weights iteratively is used, these are calculated as

$$\lambda_B = \frac{\sigma_C^2}{\sigma_B^2} \quad (13)$$

for the indices of SSB , and as

$$\lambda_{A,a} = \frac{(\alpha_A (1-k_A) + 1)}{k_A} \times \frac{\sigma_C^2}{\sigma_{A,a}^2} \quad (14)$$

for the age-structured indices. λ_{srr} is a user-specified parameter indicating the extent of the correlation of the errors in the age-structured survey index observations at different ages in the same years. Here,

$$\begin{aligned}\sigma_c^2 &= \frac{1}{df_C} \sum_{a,y} (\ln(C_{a,y}) - \ln(\hat{C}_{a,y}))^2 \\ \sigma_B^2 &= \frac{1}{df_B} \sum_y (\ln(I_{B,y}) - g_B(SSB_y))^2 \\ \sigma_{a,A}^2 &= \frac{1}{df_{a,A}} \sum_y (\ln(I_{a,y,A}) - \ln(\hat{I}_{a,y,A}))\end{aligned} \quad (15)$$

where

$$df_C = \text{Number of catch at age observations} - \text{Number of N, S, F parameters fitted for the separable model} \quad (16)$$

$$df_B = \text{Number of SSB index observations} - \text{Number of } Q_B, K_B \text{ parameters fitted} \quad (17)$$

$$df_{a,A} = \text{Number of observations of } I_{a,A} - \text{Number of } Q_{a,A}, K_{a,A} \text{ parameters fitted} \quad (18)$$

λ_{srr} are calculated in an analogous fashion.

A shrunk estimator can be considered as a weighted average of a parameter estimate obtained from a complex model and that obtained from a much simpler model. It is assumed that the complex model affords a good representation of the structure of the data and therefore returns an unbiased, though highly variable parameter estimate. The simpler model provides an estimator which is less variable but is biased. Using a shrunk estimator is an attempt at combining the useful properties of the two estimators. Let the simple estimator be a straightforward arithmetic mean (Y_{AM}), and denote the estimator from the complex model as Y_{model} . The shrunk estimator Y_{SH} is then :

$$Y_{SH} = (1 - \theta) Y_{AM} + \theta Y_{model} \quad (19)$$

A very simple approach has been used here to calculate a "shrunk VPA" as follows:

- (1) The complex model in question is that fitted by the ICA2 programme;

- (2) Catches at age are here considered precise, as is usual in VPA calculations
- (3) The shrunk parameters, Y_{SH} are the log fishing mortalities at each age in the last year used to initiate the VPA
- (4) The F from the model is calculated as:

$$F_{a,y} = FS_y \cdot S_a \quad (20)$$

- (5) An arithmetic mean of $\ln(F_a)$ and associated variance estimate are calculated separately for each age over a range of years specified by the user. The user may specify a "Minimum CV of the mean"; if the estimated CV of the mean falls below the corresponding value it will be overwritten.
- (6) The weighting factor θ is calculated as :

$$\theta_a = \frac{\text{var}(\ln(\bar{F}_a))}{\text{var}(\ln(FS_y) + \ln(S_a)) + \text{var}(\ln(\bar{F}_a))} \quad (21)$$

- (7) Variances and covariances of FS_y and S_a are available from the model fit. The variance of $FS_y \cdot S_a$ is obtained by simple linear approximation as described in section 2.2.5.

The shrunk VPA is therefore a conventional VPA generated with F in the last year at each age estimated from:

$$\ln(F_{a,y}) = (1 - \theta_a) \ln(\bar{F}_a) + \theta_a \cdot \ln(FS_y \cdot S_a) \quad (22)$$

F on the last true age in the shrunk conventional VPA are found by assuming that the selection pattern conforms to the estimated S_a from the model fit, and iterating the VPA 20 times, with the F in the last year obviously being unchanged.

2.2.3 ICAVIEW.EXE: Graphical display of results

This programme displays a number of summary and diagnostic graphs on the screen, which can be written to a printer if necessary. The quantities plotted in the graphs are described below.

- a) An overall tuning diagnostic graph. This is a plot of the index SSQ against the F at reference age from a separable VPA. The index SSQ are calculated as:
- AGED SURVEY

$$\sum_{a,y} (\ln(I_{a,y}) - \ln(\hat{I}_{a,y}))^2$$

SSB SURVEY (23)

$$\sum_y (\ln(I_y) - \ln(\hat{I}_y))^2$$

where the predicted index values are related to the population sizes as in Eqns 5 and 6.

The “total SSQ” is simply calculated as the sum of the SSQs for all the indices. Note that these are sums of squares of unweighted residuals.

- b) A stock summary screen. Yield, fishing mortality, recruitment and spawning stock biomass are graphed together on a single screen. These quantities are:

- i) Yield. Simply the information held in the “landings” input file.
- ii) Fishing mortality. For the years over which a separable model has been fitted, the mortality graphed is the fishing mortality at reference age, \pm the standard deviation of this parameter estimate (if available from ICA2). For earlier years, the quantity graphed is:

$$\frac{1}{\text{Number of ages}} \sum_a \frac{F_a}{S_a} \quad (24) \quad \text{and}$$

- iii) Recruitment. For the years over which the separable model was fitted, the recruitments plotted are the population sizes at the earliest age estimated from the analysis. For earlier years, the recruitments are the population sizes at the earliest age calculated by conventional VPA within the model.
- iv) Stock sizes. Two estimates of stock size are plotted. One is simply the total stock biomass at 1 January, as

$$\sum_a N_a W_a \quad (25)$$

The other is an estimate of spawning stock size at spawning time, as:

$$\sum_a N_{a,y} W_{a,y} O_a e^{-F_{a,y} PF - M_{a,y} PM} \quad (26)$$

- c) The quantities displayed in the separable model diagnostics screen are:

- i) Separable model residuals, as $\ln(C) - \ln(\hat{C})$, where C are the observed catches and the \hat{C} are the expected catches predicted from the separable analysis.
- ii) Estimates of selection at age, \pm standard deviations. Note that selection at the reference age is fixed (=1) and the selection on the last age is selected by the user at run-time. Selection on the plus-group is assumed equal to the selection on the last true age. These three points are not therefore parameter estimates and do not have associated estimates of standard errors.
- iii/iv) Year and age marginal totals. These quantities are respectively

$$\sum_a (\ln(C_{a,y}) - \ln(\hat{C}_{a,y})) \quad (27)$$

$$\sum_y (\ln(C_{a,y}) - \ln(\hat{C}_{a,y})) \quad (28)$$

- d) For each index series, the four diagnostic plots display:

- i) Stock size and index predictions. The continuous line in the graph in the top-left corner is a plot of either spawning stock biomass at the time of spawning (see above) in the case of an SSB index, or in the case of an age structured index the quantity plotted is the estimated population size at age at the time of the survey, as:

$$N_{a,y} \cdot \exp(-F_{a,y} - M_{a,y}) PZ_A \quad (29)$$

Using the linear catchability model for an SSB index as an example, the plotted triangles in the graph are stock sizes estimated from each index observation:

$$\frac{I_{y,B}}{\hat{Q}_B} \quad (30)$$

Age-structured indices are treated similarly, except that the population size at the time of the survey should be substituted for SSB in the foregoing. Equations corresponding to the other catchability models are used in this diagnostic plot when the other catchability models are chosen.

The two lower graphs on this screen are plots of

$\ln(I_{y,B}) - \ln(Q_B \cdot SSB_y)$ against $\ln(Q_B \cdot SSB_y)$;

and of

$\ln(I_{y,B}) - \ln(Q_B \cdot SSB_y)$

against time, for indices of spawning stock size; for age structured indices the quantities are

$\ln(I_{a,y,A}) - \ln(Q_{a,A} N_{a,y,A} \exp(-(F_{a,y} + M_{a,y}) \cdot PZ_A))$

against

$\ln(Q_{a,A} N_{a,y,A} \exp(-(F_{a,y} + M_{a,y}) \cdot PZ_A))$

and of

$\ln(I_{a,y,A}) - \ln(Q_{a,A} N_{a,y,A} \exp(-(F_{a,y} + M_{a,y}) \cdot PZ_A))$

against time.

2.2.4 VIEWSRR.EXE: Graphical display of stock-recruit model fit

The fitted line representing the stock-recruit relationship is the line

$$R = \frac{a \text{ SSB}}{b + \text{SSB}} \exp(\sigma_{\text{srr}}^2 / 2) \quad (31)$$

Residual plots as described above are also drawn.

2.2.5 ICPROJ.EXE: Stock projection with variance estimates

The ICPROJ programme has been provided here as one of a number of possible approaches to the problem of estimating the uncertainties associated with calculations of stock size in future years. Here stock sizes in succeeding years are calculated in a deterministic way from the terminal populations of the stock assessment, and the specified fishing mortality multipliers and fleet catch ratios at age. Estimates of the variance-covariance matrix are then used to assess the uncertainty about the deterministic path by the delta-method.

Stock projections are calculated in the usual way. Given a starting population size $N_{a,y+1}$ (where y = last year of data), then $F_{y+1,age}$ and the corresponding populations and catches are given by

$$\text{Fleet } F_{a,y+1,f} = F_{\text{mult}} \cdot F_{y+1} \cdot S_a \cdot CR_{a,f} \quad (32)$$

$$F_{y+1,a} = \sum_f \text{Fleet } F_{a,y+1,f}$$

In subsequent years, say for year $y+2$,

$$N_{a+1,y+2} = N_{a,y+1} \exp(-F_{a,y+1} - M_{a,y}) \quad (33)$$

$$\text{Fleet Catch}_{y,f} =$$

$$\sum_a \left(\frac{\text{Fleet } F_{a,y+1,f}}{F_{a,y+1} + M_{a,y+1}} \cdot N_{y+1,a} (1 - \exp(-F_{a,y+1} - M_{a,y+1})) W_{a,y+1} \right)$$

If an estimate of recruitment for year $y+1$ is available as a parameter from the model fit, it is used directly. If not, and in any case for subsequent years, recruitment is estimated from the Beverton and Holt stock-recruit relationship. For parameter estimates a and b and stock size SSB corresponding to year i , then mean recruitment is given by

$$R_{y+lag} = \frac{a \cdot \hat{\text{SSB}}_y}{b + \hat{\text{SSB}}_y} \exp(\sigma_{\text{srr}}^2 / 2) \quad (34)$$

SSB is calculated as in Eqn 4; a and b are parameter estimates derived by the ICA2 procedure, σ_{srr}^2 is the variance about the stock-recruit relationship.

Now consider the calculation of SSB in projections as a function $SSB_y = f(X)$, where X is vector of parameters comprising the $N_{a,y}$, estimates of S_a , a and b of the stock-recruit relation, recruits in year $y+1$ if available, and F_y . Assume the remaining parameters (Natural mortality M , spawning ogive O , catch ratios CR , mean weights W , etc.), are estimated with negligible variance. The variance-covariance matrix of X is a subset of the parameter variance-covariance matrix estimated in the ICA2 procedure. Estimates of the variances of the projected SSBs may then be calculated using the delta method,

$$\text{Var}(\hat{SSB}_y) = \sum_{i=1}^{i=j} \left(\frac{d\hat{SSB}_y}{dX_i} \right)^2 \text{Var}(X_i) + 2 \sum_{i=1}^{i=j-1} \sum_{k=i+1}^k \frac{d\hat{SSB}_y}{dX_i} \frac{d\hat{SSB}_y}{dX_k} \text{CoVar}(X_i, X_k) \quad (35)$$

Variances of the catch by fleet may be calculated in an exactly analogous manner. The $dX/dSSB$ and $dX/d(\text{Fleet Catch})$ are estimated numerically. Risk is calculated by assuming SSB is normally distributed.

2.2.6 VIEWPRO.EXE: Display results of projections

The programme displays the stock biomasses for the years over which the projections have been calculated, together with the estimated probability that in any given year the stock size will fall below the specified biologically-allowable minimum (MBAL). In addition the projected catches by fleet are plotted.

The first screen displays in its upper half the projected spawning stock with 95% confidence limits drawn as error bars, together with the specified MBAL. The lower part of this screen displays the estimated probability that the stock size would fall below MBAL in forthcoming years.

Stock size is calculated from Eqn 4 applied to population abundances N estimated in projections by the method of Eqns 32 and 33. 95% confidence limits are estimated conventionally using the variance estimates calculated from Eqn 35.

Subsequent screens display the estimated catches by fleet with 95% confidence limits drawn as error bars.

2.3 Missing values

2.3.1 Missing values in the survey indices

Missing observations in either the age-structured or the spawning biomass survey indices can be flagged by setting them to any negative value. These values will then simply be ignored in all the calculations.

2.3.2 Missing values in the catches at age

If any of the catch at age observations are zero or negative in the range of years and ages over which the separable model is to be fitted, then they will be treated as missing values and will be ignored in the separable model fit. In the conventional VPA used to generate starting values for the separable model, two treatments are possible:

- (1) If the value is zero and at the last true age, the lowest observation in the catch at age matrix is used in the VPA calculation.
- (2) If the value is zero but not at the last true age (ie it lies within the cohort), the observation is ignored and F at this year and age is approximated by calculating its expected value on the assumption that the pattern of F across ages is similar to that in other years
- (3) If the value is negative, the absolute value is used in the VPA calculations. This choice allows the user to insert guessed values to initiate a conventional VPA, but the subsequent model fit will ignore the observations. This option is useful where an entire years' catch at age observations may be missing.

3.0 References

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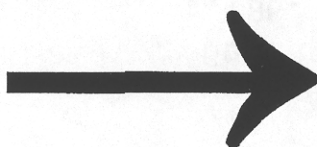
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FOLD OUT FOR VARIABLE LIST



Appendix: Index to Variables

Suffices and indexing variables

a,y suffices indicate age and year throughout.

A suffix indicates the Ath age-structured survey index

B suffix indicates the Bth survey index of spawning stock biomass

j,k suffices index parameters in the vector of parameter estimates calculated in the model fit and subsequently used to initiate the projections

f suffix indicates the fth fleet in the projections

Parameters and data

a, b = parameters of the Beverton and Holt stock-recruit relationship.

$C_{a,y}$ = catch in numbers

$\hat{C}_{a,y}$ = catch in numbers predicted from model

$CR_{a,f}$ = ratio of the catch in number at age a by fleet f to the total catch in number by all fleets, in the last year for which there are catch at age data.

df_C = degrees of freedom for the separable model

df_B = degrees of freedom for the Bth biomass index

df_A = degrees of freedom for the Ath age-structured index

$F_{a,y}$ = fishing mortality at age and year

$Fmult_{t,y}$ = proportionate change in the fishing mortality exerted by fleet f in year y, relative to the mortality exerted by that fleet in the last year for which there are catch-at-age data.

FS_y = reference fishing mortality for the separable model, by year.

$g_B()$ = catchability model for the Bth index of

spawning biomass

$h_A()$ = catchability model for the Ath index of spawning biomass

I_y = index observations

\hat{I}_y = model predictions of index observations

K_B = parameter describing deviation of the catchability relationship of the Bth SSB index from linearity

K_A = parameter describing deviation of the catchability relationship of the Ath SSB index from linearity

k_A = number of ages in the Ath age-structured index

lag = the number of calendar years between spawning and recruitment

$M_{a,y}$ = natural mortality at age and year

$N_{a,y}$ = numbers of fish alive in the sea on 1 January, at year and age.

$O_{a,y}$ = proportion of fish spawning at age and year

PF,PM = proportions of F and M that occur before spawning

PZ_A = proportion of total mortality incurred between 1 January and the time of the Ath survey

Q_B = catchability of the Bth index of spawning biomass

$Q_{a,A}$ = catchability of the Ath age-structured index at age

R_y = numbers of recruiting fish on 1 January of each year, at the first age in the catch-at-age matrix.

S_a = selection at age

$SSB \hat{I}_y$ = spawning stock biomass at year from fitted populations

$W_{a,y}$ = weight at age at spawning time at age and year

$\lambda_{a,y,C}$ = relative weight to be given to the catch at age observation at age a in year y.

λ_B = weight to be given to the Bth SSB index relative to the catches at age.

$\lambda_{a,A}$ = weight to be given to the Ath age-structured index at age a relative to the catches at age

λ_{srr} = weight to be given to the stock-recruit relationship

α = extent to which the errors in the age-structured index are correlated across the ages

Section C. Programmer's Reference

1.0 Introduction

1.1 Background

This text documents the Integrated Catch at Age programmes (Version 1.2). These programmes form an implementation of least-squares integrated statistical catch-at-age analysis. The present documentation complements the User Guide and the Technical Reference. The purpose of this document is to enable programmers to modify the source code as required, and to enable them to implement such modifications as may be necessary to install the routines on systems other than MSDOS.

The approach to the documentation taken here has been to provide an overview of the system functions, programme structures and file structures. Detailed documentation of the code has not been included here, but has rather been included as extensive comments in the source code.

Three analytic programmes are documented here:

ICA1 - Data reading, estimation of starting parameters and index divergence diagnostics;

ICA2 - Model minimisation and estimation of variance-covariance matrix;

ICPROJ - Multifleet stock projection with variance estimates and calculation of risk.

Source code for three graphics routines is also provided:

ICAVIEW - Stock summary and residual plots.

VIEWSRR - View stock-recruit relationship and residual plots

VIEWPRO - View stock projections.

1.2 Language and version

The ICA1 and ICA2 programmes are written in Microsoft FORTRAN Version 5.1. They require linking to the Numerical Algorithms Group (NAG) FORTRAN workstation library

(Release 1) (Anon., 1989). Routines BRENT, GAMMQ, GSER and GCF are as given by Press *et al.* (1989)..

Language-intrinsic routines used are:

SCAN : a function to search a string variable;

ALLOCATE and DEALLOCATE to define run-time memory;

GETTIM and GETDAT : return system time and date

Some use is also made of Microsoft FORTRAN file access error codes.

The ICAVIEW, VIEWSRR and VIEWPRO programmes are written in Borland Turbo PASCAL Version 5.0. They require linking at run-time to the XYPlotW and ContourW graphics object libraries written by M.V. Bravington, Renewable Resources Assessment Group, Imperial College of Science and Technology, London.

1.3 A note on array indexing

Different parts of the data set may begin and end at different years or ages, and in addition the separable model will probably be fitted only over a restricted part of the catch-at-age data. The following convention has been used when storing and accessing these data:

- The first years' datum for the catch at age, the SSB surveys and the aged surveys is stored in the first location of each of the arrays. For example, if catch data are from 1975 to 1990 and from ages 1 to 10, and aged survey data are from 1980 to 1989 and ages 3 to 7, then CN(1,1) stores the catch at age in 1975 at age 1, and Aindex(index, 1, 1) stores the survey index in 1980 at age 3, and similarly for the other types of data.
- In most cases and except where it is obvious, do loop indexing variables run in true years, eg from 1975 to 1990, and are dereferenced to the start of the array. Hence a loop to access both catch and survey data in the above example would look like this:

do year = 1980, 1989

CN(year-firstyear+1, ...) = ...

Aindex(index, year-fyear(index)+1, ...) =

enddo

where firstyear is the first year of catch at age data and fyear(index) is the first year of the survey index. The age range is dealt with in a similar fashion. Although slightly inefficient and cumbersome this approach makes the code a little more legible.

1.4 A note on common blocks

Contrary to conventional FORTRAN usage, most of the data and parameters are stored and passed in common blocks except where there is a clear requirement to do otherwise. This avoids the use of confusingly long parameter lists when calling routines, and is more akin to object-orientated programming methods.

2.0 Function Summary

The functioning of the ICA1 programme is described below in pseudocode. The names of the main routines implementing each step are given in parentheses.

```

Read in data files (READER, READSBIX, READAGIX)
Accept run-time choices from the user (PARMSET)
Ask user for lowest and highest likely F
From lowest to highest F, in 20 intervals, do
    Calculate a separable VPA by Pope & Shepherd (1982) method (SEPVPA)
    Calculate a conventional VPA initiated from separable VPA (CONVPA, CVPA)
    Fit the catchability relationships (CONVPA)
    Calculate the sum of squared residuals (SSQ) for each index, write these to a file (ICADIAG.OUT)
    Remember at which F the total SSQ is lowest, =Flow
End do

Start from Flow
While (F is not at minimum SSQ) do (BRENT)
    Calculate a separable VPA by Pope & Shepherd (1982) method (SEPRES)
    Fit the catchability relationships (CONVPA, CVPA)
    Calculate the sum of squared residuals (SSQ) for all the tuning series
    Calculate a new F for best fit to the indices
End do

From the VPA so obtained, calculate starting estimates for all parameters (CONVPA)
Create all the output files (TABLEOUT, WRITEBLK, LSFUN1)

STOP

```

The ICA2 programme function is summarised as:

```

Read the data and parameters estimated in ICA1 (READBLOCK)
Prompt the user for reweighting options, F tolerance and age-structured index internal correlations.
REPEAT UNTIL F CONVERGENCE
CRITERION IS MET
    IF not the first run then
    REPEAT UNTIL SSQ CONVERGENCE
    CRITERION IS MET
        Fit the Separable model over the specified number of last years of the data set, and fit the indices over all years
        Recalculate the conventional VPA based on the separable model fit (NAG E04FDF) (LSFUN1)
    ITERATE
    Calculate Variance-Covariance matrix estimates (NAG E04YCF)
    ENDIF
    Write the Var-CoVar Matrix to file (WRITEVCV)
    Calculate residuals about the model fit (MAIN, UNWTDSSQ)
    Display the Analysis of Variance table (DISPLAYWTS)
    Recalculate the weights according to the user's choice
    ITERATE
    Calculate variances etc (CALCSTATS)
    Write out results (TABLEOUT)
    Write out the stock-recruit file (WRITESRRFILE)
    Calculate and write out shrunk VPA if required (SHRINKF)
    Write the data and new parameter estimates to disk (WRITEBLOCK)
STOP

```

Lastly, the ICPROJ summary:

```

Read the data and parameters estimated in ICA2 (READBLOCK)
Read the Variance-Covariance matrix (READVCV)
Read the data for the projections (READPROJFILE)
Check the given catch ratios are correct (CHKCATRATIO)
Calculate mean Wt, M, maturity for projection (SETPROJVAR)
Calculate a baseline projection (PROJECT)
Get the minimum acceptable stock size (READMBAL)
Write baseline projection to detailed output file
Calculate derivative matrix (CALCDEVS)
Calculate variances of catch and stock by delta method
Write estimates of catch and stock with associated variances & risk to file
Write the derivative matrix to file
STOP

```

3.0 Convergence Testing

As a simple test of the convergence of the algorithm using the data and model specified in Appendix 2, the ICA2 programme was restarted 20 times from a randomised starting point based on the initialising position estimated by the ICA1 method. The new starting positions were formed by:

$$X' = X * (1 + N)$$

where **N** is a random variate with uniform

distribution from -0.2 to +0.2, and X is the starting vector estimated in the ICA1 method. This trial indicated that fishing mortality on reference age converged reliably to within 0.04%. Further testing is documented in Appendix 1 to Anon. (1994).

4.0 Files Written by the Programmes

4.1 ICA.OUT

This file is the principal output file from the system. It contains:

- a) Input estimates of catches of numbers of fish at age and year.
- b) Input estimates of fish abundances from surveys of spawning stock biomass.
- c) Input estimates of fish abundances from age-structured surveys.
- d) Estimates of population abundance by year and age.
- e) Estimates of fishing mortality by year and age.
- f) A summary of stock estimates: landings, total and spawning stock sizes, arithmetic mean fishing mortality over a specified age-range, and yield per spawning stock biomass ratio.
- g) A list of parameter estimates \pm one standard deviation (on log scale).
- h) Summaries of the distributions of residuals about different parts of the model.

The file is generated by the routine TABLEOUT in unit READER.

4.2 ICA.VIE

This file contains essentially the same information as ICA.OUT, but whereas the former file is laid out in a suitable manner for inclusion in a report or working document, ICA.VIE is designed for the transfer of data from one programme to another. More particularly it is designed to pass data from ICA1 or ICA2 to ICAVIEW, although it could equally be used to pass information to spreadsheets.

The file is generated by the routine TABLEOUT in unit READER.

4.3 ICA.RES

Contains a list of the observed and expected values for each of the observations used to fit the model, in the order:

year	age	Observed Catch in Number	Expected catch in number
		(termination code -99)	
index	year	Observed SSB survey datum	Expected SSB survey datum
		(termination code -99)	
index	year	age	Observed aged survey datum
			Expected aged survey datum
			(termination code -99)

The file is written by the LSFUN1 routine when it is called with WRITEOUT set = .TRUE. It is read by ICAVIEW and also by the routine CALCSTATS (called by ICA2 and TABLEOUT).

4.4 ICA.SRR

Contains a list of pseudo-observed and expected stock and recruit values, as used for fitting the stock-recruit relation.

The file is written by WRITESRRFILE

4.5 ICADIAG.OUT

Contains estimates of the sums of squared residuals of the surveys compared with conventional VPA populations initiated with separable VPA, for 20 values of reference F over the range specified by the user.

The file is written by ICA1.

4.6 ICA.AV

Contains information about the analysis of variance about the model fit.

File written by ICA2.

4.7 ICA.VC

Contains (1) The parameter covariance matrix, and (2) the parameter correlation matrix.

File written by ICA2. It is read by READVCV

4.8 ICA.TMP

Contains all data and parameters; used to pass information between ICA1 and ICA2 and between ICA2 and IC PROJ.

File written by ICA1 and ICA2, and read by ICA2 and ICPROJ; ICA2 overwrites the file after completing a run.

4.9 PROJECT.POP

Contains details of the baseline projection: stock sizes, partial F by fleet, catch in numbers by fleet and catch in weight by fleet.

File written by ICPROJ.

4.10 ICA.PRO

Contains the SSB and catch by fleet and by year, with associated estimates of variance and the risk that the SSB will fall below MBAL.

File written by ICPROJ.

4.11 DERIVS.TST

Contains the matrix of derivatives : d(Stock size in projections)/d(ICA parameter estimate).

File written by ICPROJ.

4.12 ICA.SHR

If the user has chosen to generate a shrunk VPA it is written to this file. The model fit is left unchanged and is written to ICA.OUT as before. The file holds shrinkage diagnostics, fitted populations and a stock summary table.

The file is written by SHRINKF.

5.0 Compilation

The FORTRAN analytic programmes may be compiled for either MS-DOS or WINDOWS. Compilation under MS-DOS will result in programmes that run faster, but the ICA2 programme compiled under DOS will be limited to analysing rather small data sets. Compilation under WINDOWS incurs speed disadvantages but will allow any additional memory installed to be used. Batch files for compiling under WINDOWS and under DOS are given together with the source code.

6.0 Index of Subroutines

ROUTINE	UNIT	DESCRIPTION
APPROXSRR	SRR.FOR	Approximate estimates of Bev-Holt SRR
BRENT	ICA1.FOR	One-dimensional root finding
CALCSTATS	STATS.FOR	Calculates variances etc.

CALCDEVS	ICPROJ.FOR	Calculate matrix of derivatives for projections
CHKCATRATIO	ICPROJ.FOR	Checks catch ratios given in projection file
CONVPA	CONVPA.FOR	Runs VPA, fits surveys and calculates variances
CVPA	CVPA1.FOR	VPA calculation initiated with separable VPA
CVPA2	CVPA1.FOR	VPA calculation initiated with objective function
DISPLAYWTS	ICA2.FOR	Display weights assigned to the indices on screen
E04FDF	NAG LIBRARY	Quasi-Newton Nonlinear estimation
E04YCF	NAG LIBRARY	Estimates variance-covariance matrix
GAMMLN	STATS.FOR	Runs incomplete gamma function(*)
GAMMQ	STATS.FOR	Runs incomplete gamma function(*)
GCF	STATS.FOR	Runs incomplete gamma function (c.f.) (*)
GETSRR	SRR.FOR	Extracts stock & recruits from VPA
GSER	STATS.FOR	Runs incomplete gamma function (series) (*)
HELLO	ICA2.FOR	Displays start-up message
ICA1	ICA1.FOR	Data reading and initialisation
ICA2	ICA2.FOR	Fitting full separable model
ICPROJ	ICPROJ.FOR	Multifleet projection with variance estimates
IOCHECK	READER.FOR	Checks whether a file exists
LSFUNI	OBJECT.FOR	Objective function
PARMSET	PARMSET.FOR	Reads run-time options from user at screen
REPORT	ICA2.FOR	Display E04FDF NAG error number and message on screen
READAGIX	READER.FOR	Reads age-structured indices
READBLOCK	READER.FOR	Reads temporary file (ICA.TMP) to common blocks
READER	READER.FOR	Reads catch and catch sampling data
READMBAL	ICPROJ.FOR	Reads the MBAL from screen
READPROJFILE	ICPROJ.FOR	Reads projection file
READSBIX	READER.FOR	Reads indices of spawning biomass
READSRRDAT	SRR.FOR	Reads historic stock & recruit estimates
READVCV	ICPROJ.FOR	Reads variance-covariance matrix from ICA.VC
SEPVPA	SEPVPA.FOR	Does Pope & Shepherd separable VPA
SETPROJVAR	ICPROJ.FOR	Calculates M, ogive & wts for projections
SHRINKF	SHRINK.FOR	Generates VPA with F shrinkage based on mode lft
TABLEOUT	READER.FOR	Generates output files: (ICA.OUT and ICA.VIE)
WRITEBLOCK	WRITEBLK.FOR	Writes the common blocks to disk (ICA.TMP)
WRITESRRFILE	SRR.FOR	Writes stock and recruit estimates to file
WRITEVCV	ICA2.FOR	Write the variance-covariance matrix to file

7.0

Index of Functions

FUNCTION	UNIT	DESCRIPTION
BRENT	ICA1.FOR	One-dimensional minimisation
CALCSSB	PARMSET.FOR	Calculate spawning stock biomass from fitted Ns
CALCPROSSB	ICPROJ.FOR	Calculate SSB from populations in projections
CALCRECRUIT	ICPROJ.FOR	Calculate recruitment from SSB and SRR
COHORT	PARMSET.FOR	Pope's cohort approximation
GAMMQ	STATS.FOR	Incomplete gamma function
GAMMLN	STATS.FOR	returns ln(gamma(X))

MISSING	SEPVPA.FOR	Treatment of missing and zero values
REFINE	PARMSET.FOR	Calculates F, N to specified precision for VPA
SEPRES	ICA1.FOR	Runs Separable VPA and calculates residuals against indices

8.0 Index of Common Blocks

Indat.inc	Input data
SepModel.inc	Model parameters and options
stats.inc	Variances, number of observations, etc.
srr.inc	Data and parameters used for estimating stock-recruit relation
proj.inc	Populations and data for projections

Pope, J.G. and Shepherd, J.G. 1982. A simple method for the consistent interpretation of catch at age data. *Journal du Conseil International pour l'Exploration de la Mer*, **40**, 176—184.

Press, W.H., Flannery, B.P., Teukolsky, S.A. and Vetterling, W.T. 1989. Numerical Recipes. Cambridge University Press, 702pp.

9.0 PASCAL Programmes

Copies of the source code for the graphics viewing programmes VIEWSRR, VIEWPRO and ICAVIEW are provided. ICAVIEW reads the files ICADIAG.OUT, ICA.VIE and ICA.RES. It produces a series of “tableaux”, each containing four graphs. The first graphs display general parameters of the stock assessment and the remaining ones display residual plots for each tuning index.

VIEWSRR is a short programme which reads the fitted parameters and pseudo-observations for the stock-recruit relation, and draws three graphs from these.

VIEWPRO displays the projected stock size with error bars, and risk of the stock size declining below the specified minimum level. Next the projected catches by fleet (with error bars) are displayed.

10.0 Structure Diagrams

Structure diagrams for the ICA1, ICA2 and IC PROJ programmes are given in Figures 10.1 – 10.3.

11.0 References

Anonymous. 1989. Handbook for the NAG FORTRAN workstation library. Published by NAG Ltd, Wilkinson House, Jordan Hill Road, Oxford, United Kingdom.

Anonymous. 1994. Report of the Herring Working Group for the Area South of 62°N. ICES CM 1994/Assess:13.

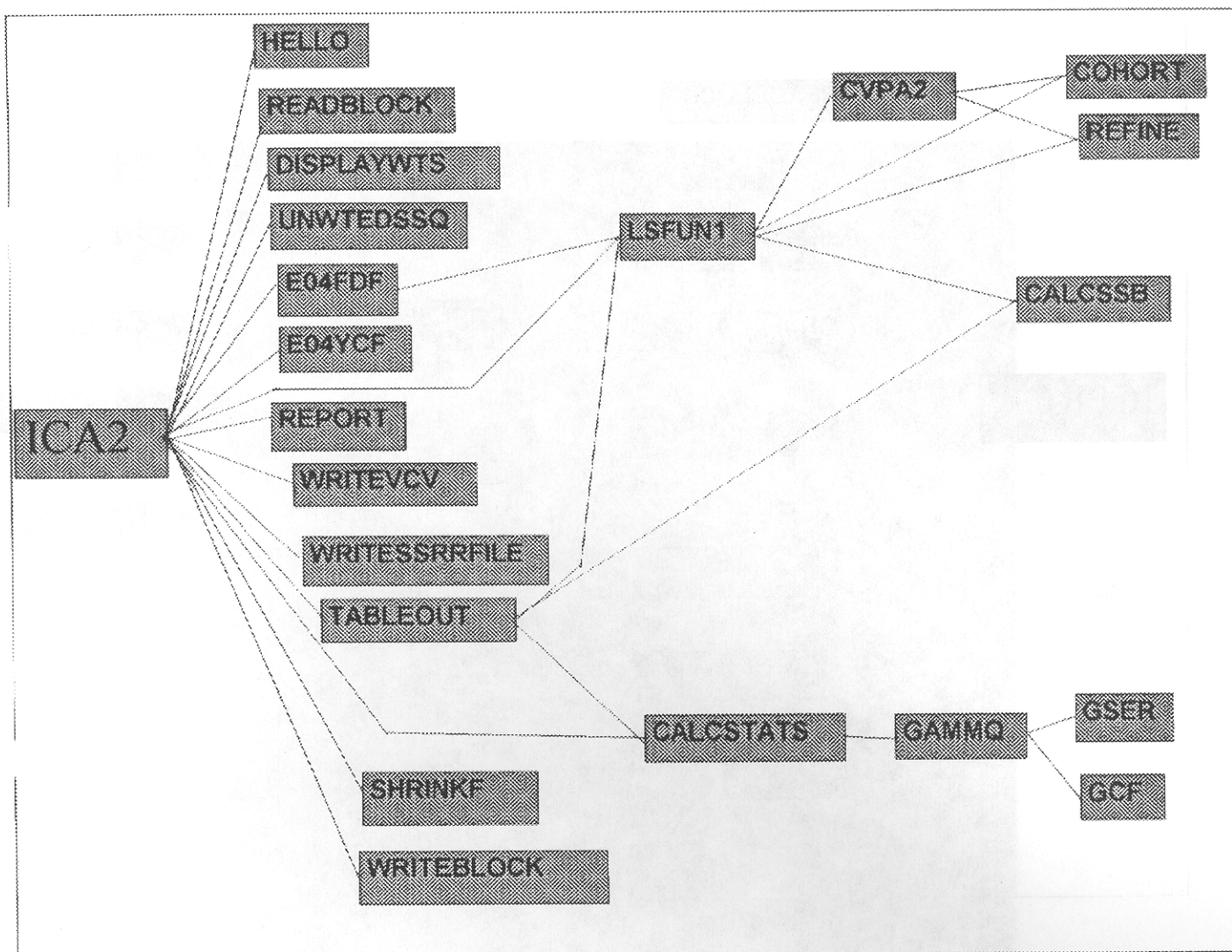


Figure 10.2 Structure diagram for the ICA2 programme

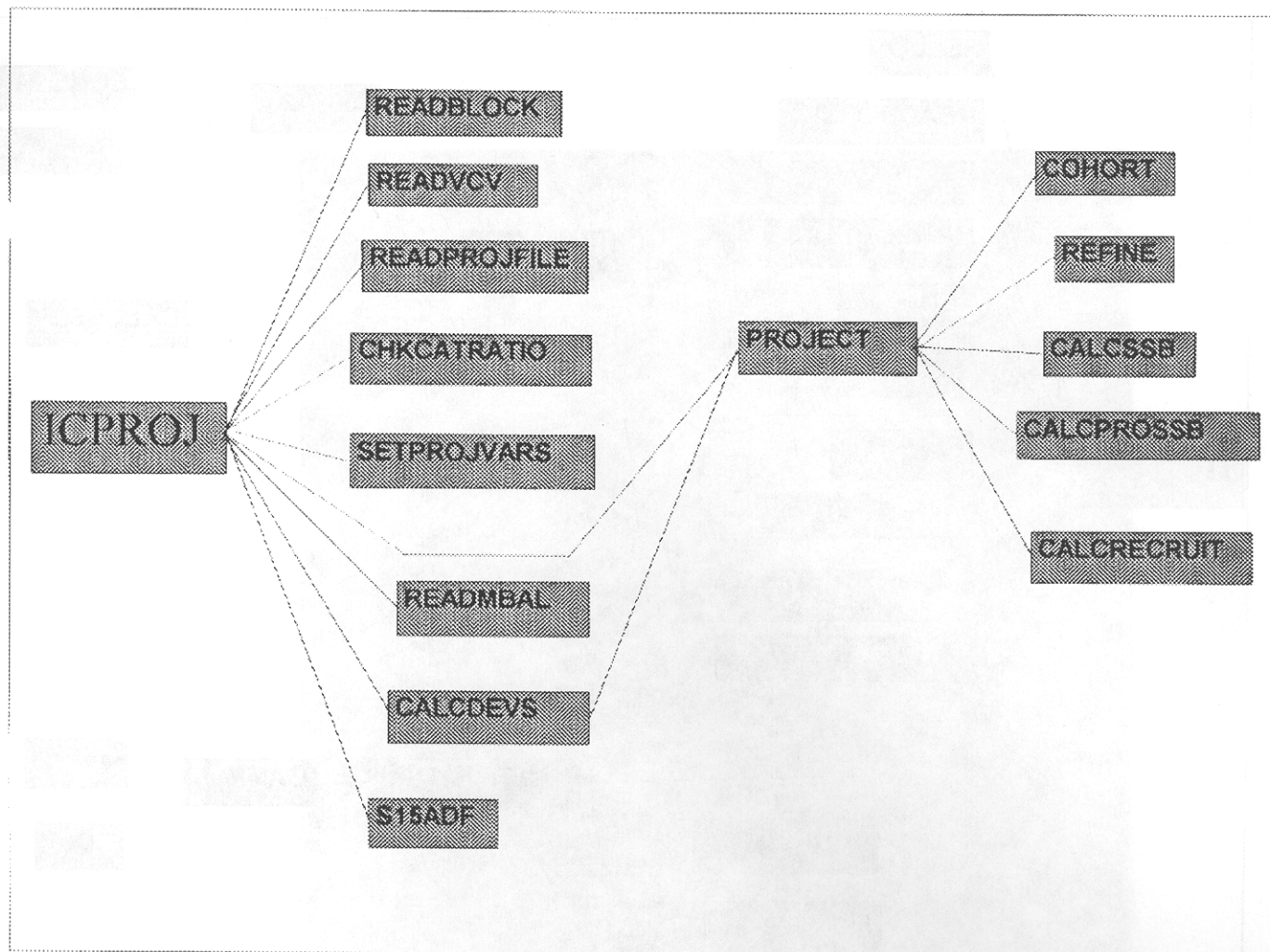


Figure 10.3 Structure diagram for the ICPROJ programme