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FiSAT II

COMPUTERIZED INFORMATION SERIES
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8

FAO-ICLARM
stock assessment tools II
Revised version

User's guide

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Preparation of this document

FAO-ICLARM[*] Stock Assessment Tools (FiSAT) is the software that resulted from the merging of LFSA (Length-based Fish Stock Assessment) developed by FAO and the ELEFAN (Electronic Length Frequency Analysis) package developed at ICLARM* (International Center for Living Aquatic Resources Management), and the addition of some routines found useful for the analysis of length frequencies.

The MS DOS version of FiSAT was converted to a Windows compatible version, hereafter referred to as FiSAT II. This work was carried out between 2000 and 2002 through the European Union support project, Fisheries Information and Analysis System (FIAS).

Development of the FISAT II software was carried out by Felimon Gayanilo. The new software was thoroughly tested during an FAO working group meeting at Cidade da Praia, Cape Verde, in August 2003, under the leadership of Ana Maria Caramelo and Merete Tandstad, from the FAO Fisheries Department, producing a detailed report of the major errors then detected in the software.

The errors and bugs in the software detected during the workshop, as well as those that were discovered during the later testing phase were corrected by Pedro de Barros, Professor at the University of Algarve.

This User's Guide is an update of the previous version (Gayanilo, Sparre and Pauly, 1996). In addition to the printed document, a compact disk is provided with the software.

Acknowledgements

Thanks are due to all scientists around the world and to Ana Maria Caramelo, Denis Berthier and Merete Tandstad from FAO for their technical inputs in the development and testing of the various modules of FiSAT II; to Marie-Thérèse Magnan, Stephen Cofield and Françoise Schatto-Terribile, for editing the last version of this manual; to Ms Maria Concesa Gayanilo for her free services in painstakingly encoding the revisions made to this document.

Special thanks to Prof. Pedro de Barros, for correcting errors found by the users in the software.

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[*] ICLARM is now called WorldFish Center.

ABSTRACT

FiSAT II is a program package consisting of methodologies for use with computers, enabling users to formulate some management options for fisheries, especially in data-sparse, tropical contexts.

The FiSAT II was developed for computers running on Microsoft Windows operating systems. The new version utilizes the standard Windows graphic user interface.

FiSAT II was developed mainly for the analysis of length-frequency data, but also enables related analyses, of size-at-age, catch-at-age, selection and others.

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Chapter 1. Getting started

What you will learn from this chapter

In this chapter, you will be introduced to terminologies used in this guide, shown how to install the package, and understand the objects used in the graphic user interfaces of FiSAT II. At the end of the chapter, you will be introduced to the revised menus of FiSAT.

About the package

FiSAT (FAO-ICLARM Stock Assessment Tools) is the product that resulted from merging the LFSA (Length-based Fish Stock Assessment) developed at FAO (Sparre, 1987) with the Compleat ELEFAN (Electronic Length Frequency Analysis) package developed at ICLARM* (International Center for Living Aquatic Resources Management) (Gayanilo, Soriano and Pauly,1989). All routines in the earlier packages are included in FiSAT II.

Descriptions of many models used in this package may also be found in Pauly (1984a), Sparre and Venema (1992) and the FiSAT reference manual (Gayanilo and Pauly, 1998).

System requirements

FiSAT II, which is distributed on a compact disk, can be installed and made executable on many computer platforms or computing environments that run on the Microsoft Windows NT/2000/98/95 operating system. The minimum system requirements are as those identified when installing Microsoft Windows operating systems:

* WorldFish Center.

- Microsoft Windows 95/98/2000,
- 64MB of RAM,
- 1 024 x 768 high-resolution monitor, and
- at least 5 MB free disk space in the Windows directory and another 6 megabytes of free disk space for the destination address.

Installing and starting FiSAT II

The CD-ROM that comes with the package contains the setup.exe. Run the SETUP.EXE found in the root directory of the CD-ROM. The installation wizard will require user responses to prompts (Fig. 1.1).

DO NOT use other methods for installing the package to a hard disk. The SETUP program does not only transfer the files from the source to the destination disk but also initializes other files to be used by FiSAT II.

The installation routine will also install sample data files that can be used and an item (icon and title) in the Windows Programs menu. Selecting the item activates FiSAT II.

Fig. 1.1. A graphic user interface of SETUP.EXE when installing the FiSAT II package, the directory should be: \Program Files\FiSAT II.

It is important to note that the first display screen (hereafter referred to "Splash Screen"; Fig. 1.2) contains the version installed. This number (also available in the **About…** form), is used in reporting programming defects or in accessing technical support from the authors.

Fig. 1.2. FiSAT II splash screen showing the version number of the software installed.

The graphic user interface

FiSAT II utilizes standard icons and objects found in most commercial software packages that run in the Microsoft Windows environment to make it as user-friendly as possible (please refer to Microsoft Windows documentation for details).

The main user interface

The main features of the FiSAT II main user interface (Fig. 1.3) that may differ from other commercially available software packages are:

1. **Windows Caption**: The content of the caption also displays the version number and in addition, the caption of other windows loaded into memory if windows is maximized to occupy the whole working area.

2. **Menu Bar**: This bar contains the various menus available to the user in accessing commands (see further below).

3. **Tool Bar**: This bar contains command buttons to commonly used functions. Double-clicking the Tool Bar will open a Window that will allow the user to customize the contents of the Tool Bar.

4. **Status Bar**: This bar contains immediate help messages in the left panel (see also Help Messages below), the system date and time in the right panels used in printing of reports and time stamping of files.
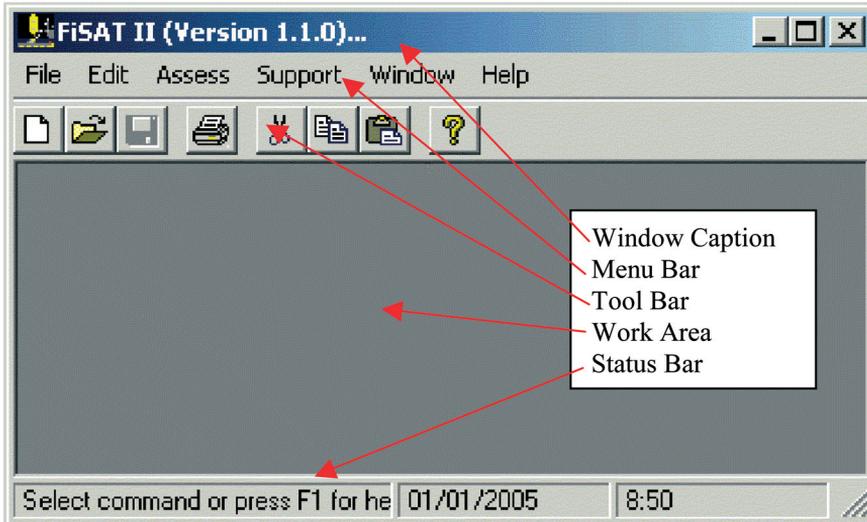
Fig. 1.3. The main window of FiSAT II. Please refer to Microsoft Windows documentation for detailed explanation of other standard objects found in a window.

User inputs to FiSAT II

To facilitate the encoding of data, input boxes (Fig. 1.4) are color-coded. Input boxes with

- Yellow background are required fields,
- White background indicates fields that are optional, although it is advisable to encode data whenever available to prevent data losses, and
- Gray background indicates fields that cannot be edited by the user.

FiSAT II uses standard fonts for the user interfaces. However, FiSAT II automatically converts font colors to red if the value was computed by the software. Also, grayed labels on command buttons of filed names indicates that the object is presently not available to the user. These are enabled only if the pre-requisites for the function to be available are met satisfactorily.
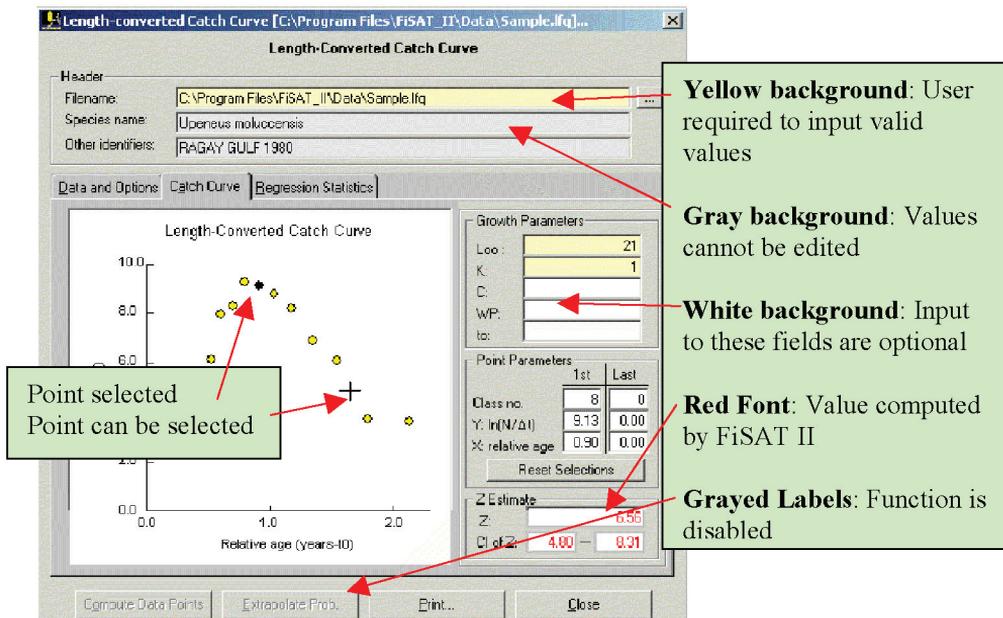
Fig. 1.4. Typical user interface showing fields with yellow, white and gray backgrounds. Also, note the use of the red font to indicate fields computed by FiSAT II. Also, note that in some cases, command are presently not available to the user. Selecting points directly from a graph are available.

There are a number of routines in FiSAT II requiring the user to select a point in the graph. Move the mouse pointer to a point to select. The standard cursor icon will change to a cross (Fig. 1.4) if a point can be selected. Clicking the mouse will select the point. If a point is selected, the yellow circle will be shaded with black.

Using the menu bar

The Menu Bar of FiSAT II contains the six other menus. Clicking on the menu will dropdown options. For example, cliking on the "File" option will drop the commands available to the user (Fig. 1.5). Note that some of the selections are disabled (colored grayed) indicating that the function(s) are currently not available. If submenus are available, an arrow head is displayed in the right corner of the menu item. Clicking the items with submenus will dropdown the contents of the submenu.
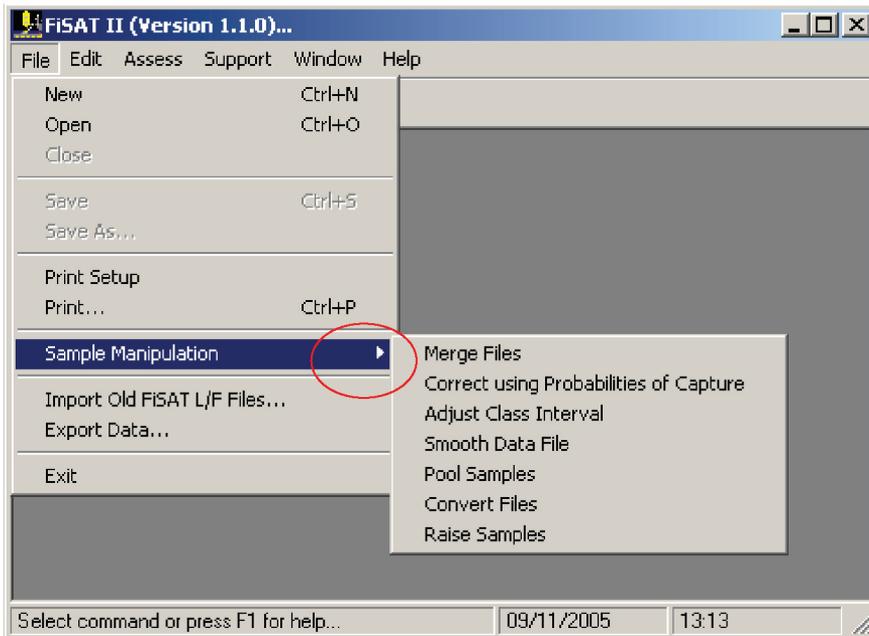
Fig. 1.5. Menu system of FiSAT II. Note that some functions are disabled if it does not apply for the given situation (in this case, no file is loaded). Also, note the presence of the arrowhead (in red circle) if a submenu is available.

Alternatively, pressing the <ALT> key together with the underlined character of the menu item access the command. For example, pressing <ALT> + <P> will open the Print dialog box. Another option is using the shortcut keys (not available to all commands). In Fig. 1.5, pressing <CTRL>+<P> will also open the Print dialog box.

Chapter 2. HELP facilities

What you will learn from this chapter

In this short chapter, you will be introduced to the types of help messages incorporated in FiSAT II, to assist you in using its various routines. However, these help messages are not intended to replace this User's Guide.

Types of HELP messages

FiSAT II has three types of help messages, classified as either immediate, warning or descriptive messages.

• **Immediate help messages** : These automatically appear in the Status Bar (i.e. at the bottom of the screen), when certain actions are to be performed. They consist of one line of information (less than 66 characters), generally to remind users of the limits for the current entry field or what options are available.

• **Warning messages** : These are messages that appear at the bottom of the screen to warn users about the value entered in the current field. In most cases, FiSAT II may require the user to provide another value before a function is performed.

• **Descriptive help messages** : These describe the routines under each item of a given menu, or provide a list of keys in a given routine that can be used but which are not shown on the display screen.

Accessing HELP

The Help Menu of FISAT II provides three ways of getting help as the need arises.

On-line help messages

Accessing the "Contents" menu item in the Help menu or pressing <F1> will open the on-line user guide (Fig. 2.1). The contents of this manual were electronically converted to facilitate the access of descriptive help messages.
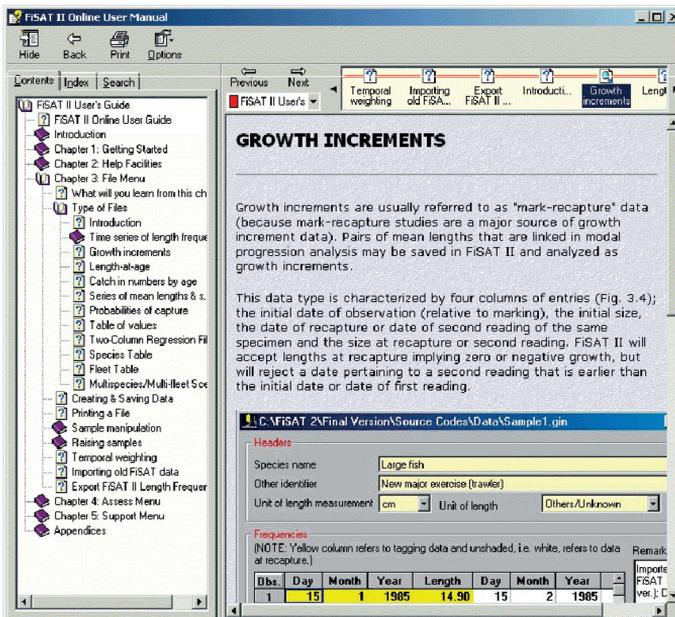
Fig. 2.1. FiSAT II on-line help messages. This is the electronic version of this document.

This standard Microsoft Windows type interface provides facilities to view the pages through the Contents list (as in Fig. 2.1) or specific topics can be located via an index field or free text searches. Please refer to Microsoft Windows references for details on how to use this interface.

FiSAT II on the web

A FiSAT II website is maintained by FAO to provide a venue for distributing updates to the software and other announcements related to the application of the software (Fig. 2.2).
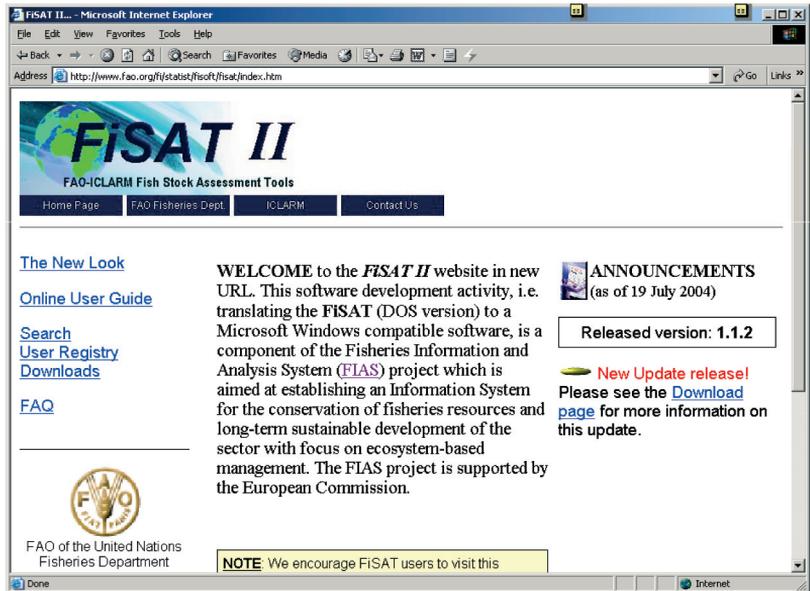
Fig. 2.2. FiSAT II home page. The content of the pages varies as the need arises. The current URL is http://www.fao.org/fi/statist/fisoft/fisat/index.html.

The content of the pages changes as the need arises. This website will contain pages to (i) allow users to quickly assess the new package, (ii) online user guide with the same content as the online help messages accessed through the Help Menu, (iii) user registration to allow FAO to update users on new developments, (iv) pages to download new updates as they become available, and pages to answer frequently asked questions (FAQ).

Users are encouraged to register their names and to regularly visit the website to keep phase with the developments of the software.

Technical support

In cases where the online help messages and the FiSAT II website are not sufficient to answer a specific query, or in reporting programming defects, FiSAT II users may forward their queries to FAO. To facilitate the services, always include the following:

1. The FiSAT II version installed;
2. The Microsoft Windows operating system; and
3. Step-by-step procedures to repeat the problem (if applicable).

In rare cases, FAO may request users to access and e-mail system information. These files may be accessed from the "About FiSAT II" form accessible through the Help Menu (Fig. 2.3).

The FAO technical staff will provide a step-by-step procedure on what needs to be retrieved and mailed to resolve a technical problem. Please refer to Microsoft Windows reference manuals for details on the use of the interface that displays system information.
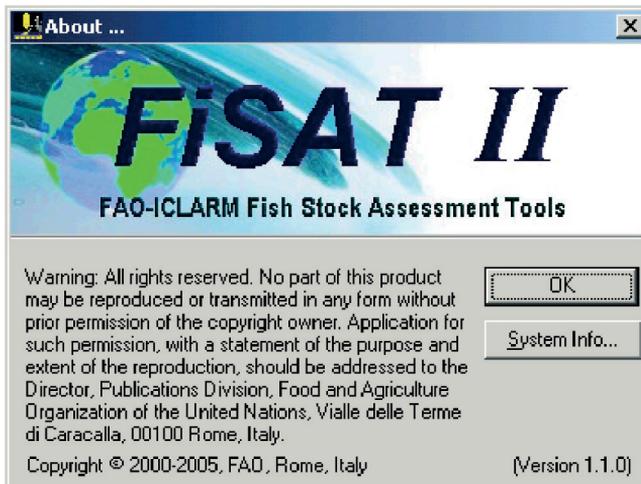
Fig. 2.3. The "About FiSAT II" form. The system information may also be accessed from this form.

Chapter 3. FILE menu

What you will learn from this chapter

In this chapter, you will be introduced to the different types of data that can be created and used in FiSAT II, how these data are encoded, edited, imported, exported and options available for manipulating data files.

Types of files

FiSAT II supports several types of data differentiated largely by their filename. Table 3.1. is a summary of the different file-types that can be created in FiSAT II.

Table 3.1. Summary of file-types supported in FiSAT II and their corresponding file extensions (see details of each file type below).

File –Type	File Extension
Grouped length frequencies	*.lfq
Ungrouped length frequencies	*.ulf
Variable grouping of length frequencies	*.vlf
Length-at-age	*.laa
Growth increments	*.gin
Catch-at-age	*.caa
Mean and s.d.	*.msd
Probabilities	*.prb
Value by size	*.val
XY regression file	*.xyf
Species table	*.spc
Fleet table	*.flt
Multispecies/multifleet scenario	*.sce

Note that, although FiSAT supports a number of data types, most of the routines available in FiSAT either require length-frequency data or data derived from length-frequencies. The different data files that can be created and stored using FiSAT are:

Time series of length frequencies

Data files of this form can either be grouped by constant class size (i.e. class interval), grouped by variable class sizes (common for data from commercial sampling of shrimp) or "ungrouped frequencies", i.e. individual measurements requiring subsequent grouping.

Length frequencies grouped by constant class size

Length frequencies of this type are characterized by lower and upper class limits, and a "mid-length", the mean of the limits (Fig. 3.1). FiSAT II does not require inputs for the upper and lower class limits but rather uses the class size (or intervals) and the smallest mid-length, which enables the mid-lengths of the subsequent classes to be computed.

Unlike other data types, this data requires inputs to sample sub-headers (Table 3.2) that include, amongst other things, the sampling date in the format (dd/mm/yyyy). The data file will not be properly saved if the sampling date is not encoded properly. Samples with invalid or missing sampling dates will be automatically deleted. A command button is available in the user interface (Fig. 3.1) to open the sample sub-header. Alternatively, double-clicking on the column or clicking on the column header opens the sample sub-header.

Fig. 3.1. User interface for recording grouped length frequencies. Note the command button to edit the sample sub-header. Alternatively, double-clicking on the column opens the form to encode the parameters for the sub-header.

The required inputs are:

- Date of sampling (DD/MM/YYYY)
- Smallest class mid-length (from 0.25 to 500)
- Class size (from 0.25 to 500)
- Type of measurement
- Frequencies (0 to 999,999) for each class.

WARNING! Although it is possible to copy contents from other Microsoft Windows software through the Microsoft clipboard (i.e. Copy->Paste procedure), such as Microsoft Excel, care should be taken to check for the input to sampling dates.

Table 3.2. Sub-header for size (length or weight) frequency data grouped by constant class interval.

Field	Type[†]	Remarks
Sample No.	N	The values for this field are automatically provided by FiSAT and cannot be edited.
Day of sampling	N	The upper limit is dependent on the month and year. A default DAY (equal to 15) is provided for convenience.
Month of sampling	N	The default value is the previous month + 1.
Year of sampling	N	Year of sampling, from 1900 to 2100; the default for this field is the year of the previous sample.
Sex*	C	Valid entries to this field are: female, male or undefined/both. Only the first letter of the choice needs to be entered; FiSAT will complete the entry when <ENTER> is pressed.
Depth (m)	C	This field should indicate the (mean) depth at which the sample was obtained.
Area	C	This indicates the area from which a sample originates.
Latitude	C	The input to this field, indicating the location of the sample will not be validated. However, it is recommended that a standard format be used, e.g., XDD:MM:SS, where X refers either to N (north) or S (south), DD refers to degrees of latitude, MM to minutes and SS to seconds (example: *S35:30:00*)
Longitude	C	As above. Thus, YDDD:MM:SS, where Y is either E (east) or W (west), DDD refers to degrees of longitude, MM to minutes and SS to seconds (example: *W12:10:30*)
Gear type	C	This field identifies the gear type used for sampling (example: *Trawl*).
Gear characteristics	C	This field should describe specific characteristics of the gear used (example: *2.5 cm mesh*)
Vessel	C	This field should contain the vessel name or type.

[†]C - character field; N - numeric field; Ch - limited choice field
*The fields from Sex to Remarks are optional fields

Table 3.2 (Cont). Sub-header for size (length or weight) frequency data grouped by constant class interval.

Field	Type[†]	Remarks
Time of day	C	This field refers, on a 24h basis, to the time the collection started or ended in hours and minutes. (example: *14:30*).
Bottom type	C	This field indicates the bottom structure at the sampling site (example: *sandy*).
Type of catch	C	This field may be used to describe the data at hand, e.g., commercial or research data.
Effort	N	This field should contain a measure of the effort expended to obtain the sample in question (e.g., no. of hauls, no. of hours, no. of boats, etc.). This field will be used when the data are to be re-expressed as catch per unit of effort (C/f); thus it is important that the unit used is standardized.
Wt. of the sample	N	This field should indicate the weight of the sample, as taken out of the total catch. This implies that the unit used in measuring weight should be consistent for all samples.
Total wt. of species	N	This field should indicate the weight of the species as a subset of the sample collected. It is important to note that the value provided should be less than the WT. OF THE SAMPLE and that the unit used in measuring weights should be the same throughout.
Total wt. of catch	N	This field is for a value representing the total multi-species catch. As in the two previous fields, the unit used in measuring weight should be the same.
a	N	The coefficient "a" of the length-weight relationship ($W = aL^b$). The default value is the one used in the previous sample.
b	N	The coefficient "b" of the length-weight relationship complementing the previous field. The default value is the one used in the previous sample.
Remarks	C	Other information not included in any of the above fields.

Ungrouped length frequencies

This form of length frequencies is characterized by only one column of inputs (Fig. 3.2), the length of individual specimens. As with the previous data form, data of this form cannot be used for analysis in FiSAT II unless regrouped with constant class size. This is provided as an option in FiSAT II when saving this type of file.

Fig. 3.2. User interface in encoding ungrouped length frequencies. This data type may also be saved as grouped length frequencies.

The required inputs are:

- Date of sampling (DD/MM/YYYY);
- Measured lengths (0.25 to 999)

When saving to a form with a constant class size, the required inputs are:

- Class interval to use (0.25 to 500);
- Smallest class mid-length to use (0.25 to 500);
- Filename to store the new file (if the filename already exists, the data will be appended to the existing file).

Data grouped by variable class sizes

This form of length frequency data is characterized by explicit lower and upper limits for each class (Fig. 3.3). The mid-length cannot be used in this case. Files in this form can be stored, but they cannot be used within FiSAT II unless regrouped with constant class size.

Fig. 3.3. User interface to encode length frequencies with variable length classes.

The required inputs are:

- Date of sampling (DD/MM/YYYY);
- All lower and upper class limits (0.25 to 999);
- Frequencies (0 to 999,999) for each class.

When saving to a form with a constant class size, the required inputs are:

- Class size (0.25 to 500);
- Smallest mid-length to use (0.25 to 500);
- Filename to store the new file (if the filename already exists, the data will be appended to the existing file).

Growth increments

Growth increments are usually referred to as "mark-recapture" data (because mark-recapture studies are a major source of growth increment data). Pairs of mean lengths that are linked in modal progression analysis may be saved in FiSAT II and analysed as growth increments.

This data type is characterized by four columns of entries (Fig. 3.4); the initial date of observation (relative to marking), the initial size, the date of recapture or date of second reading of the same specimen and the size at recapture or second reading. FiSAT II will accept lengths at recapture implying zero or negative growth, but will reject a date pertaining to a second reading that is earlier than the initial date or date of first reading.

Fig. 3.4. User interface in encoding growth increments. The columns with a dark yellow background refer to tagging data and those with a white background are recaptured data.

The required inputs are:

- Initial date or date of first reading (DD/MM/YYYY);
- Corresponding length (0.25 to 999);
- Final date or date of second reading (DD/MM/YYYY);
- Corresponding length (0.25 to 999).

Length-at-age

The age of a fish may be obtained by directly reading otoliths, scales or other hard parts. Pairs of observations, (age, length) collected for individual fish, form length-at-age data. Series of mean lengths, as identified by modal class progression analysis, can also be treated as length-at-age data, although they actually represent lengths at *relative* age (precluding the direct estimation of t_o).

This type of data is characterized by two column entries; the ages (or relative ages if derived from modal progression analysis) and the corresponding length measurements (Fig. 3.5). The ages can either be in days, months or years and may be any values from 0 to 999. The length values can only be from 0.25 to 999, and the units must either be in cm, mm or inches. FiSAT II provides a third column entry for a weighting factor (WF) for each observation. These weighting factors (default of 1.0; acceptable range 0.01-100) can be used to emphasize or de-emphasize observations during data analysis.

Fig. 3.5. User interface in encoding length-at-age data in FiSAT II.

The required inputs are:

- Ages (0.01 to 999);
- Lengths (0.25 to 999);
- Weighting factors (default is 1.0; 0.01 to 100)

Catch in numbers by age

This data type (also referred to as catch-at-age, Fig. 3.6) can be used only for one routine, i.e. age-structured VPA. The required inputs are similar to length-at-age data. The required input consists of two columns: (i) the ages

(starting with the youngest group) and (ii) the catches in numbers.

Fig. 3.6. User interface to encode catch-at-age data in FiSAT II.

> The required inputs are:
>
> - Age (0.01 to 999);
> - Catches, in numbers (1 to 999,999).

Series of mean lengths and standard deviations

In most cases, the data in this file type will be products of the decomposition of normal distributions using, e.g., Bhattacharya's method or Hasselblad's NORMSEP as implemented in FiSAT II, which automatically generate such files (see next chapter). However, creation of such

files from external sources for subsequent analysis by FiSAT II is possible.

The file is characterized by three columns of entries; (i) the date of sampling, (ii) the mean length, and (iii) the standard deviation (Fig. 3.7).

Fig. 3.7. User interface in encoding means and standard deviation file.

The required inputs are:

- Date of observation (DD/MM/YYYY);
- Mean length (0.25 to 999);
- Standard deviation.

Probabilities of capture

One common cause of bias in length-frequency data is the selectivity of the gear(s) used to obtain the samples. This bias can be in part overcome by correcting size frequency samples with the probabilities of capture stored in a "probabilities of capture file", and generated either through

a selection experiment, or a length-converted catch curve (see next chapter).

This type of data file (Fig. 3.8) is characterized by two columns of entries; (i) the class mid-length (0.25 to 999) and (ii) the probability of capture which may range from 0 to a maximum of 1. Entries less than 0.001 will be registered as 0. Note that a file in which all values are equal to 0 or 1 will not be stored.

Fig. 3.8. User interface in encoding probabilities in FiSAT II.

The required inputs are:

- Smallest class mid-length (0.25 to 500);
- Class size (0.25 to 500);
- Probability of capture (default is 1.0; 0 to 1.0)

Table of values

The commercial (e.g., market price) or biological value (e.g., in terms of fecundity) of fish often varies with size. This can be accommodated, for various assessments by using size-specific values as multipliers. In FISAT II, the values are used as a multiplier in the Thompson and Bell Yield-Stock Prediction routine.

This data type (Fig. 3.9) is characterized by two columns of data: (i) Class midlength, and (ii) value for each group.

Fig. 3.9. User interface for encoding table of values.

The required inputs are:

- Date of sampling (DD/MM/YYYY);
- Lower and upper class limits (0.25 to 999);
- Value (0 to 999) for each class.

Two-column regression files

Linear regression analysis is an important statistical tool for fish stock assessment. One common application is to derive the relationship between the (log-transformed) lengths and weights of fish.

This data type (Fig. 3.10) is characterized by two columns of entries, the X-values and the Y-values, both of which may range from 0 to 999. In FiSAT II, only the regression analysis routine can use this type of data. It is also the only routine whose headers are used only for labelling graphs.
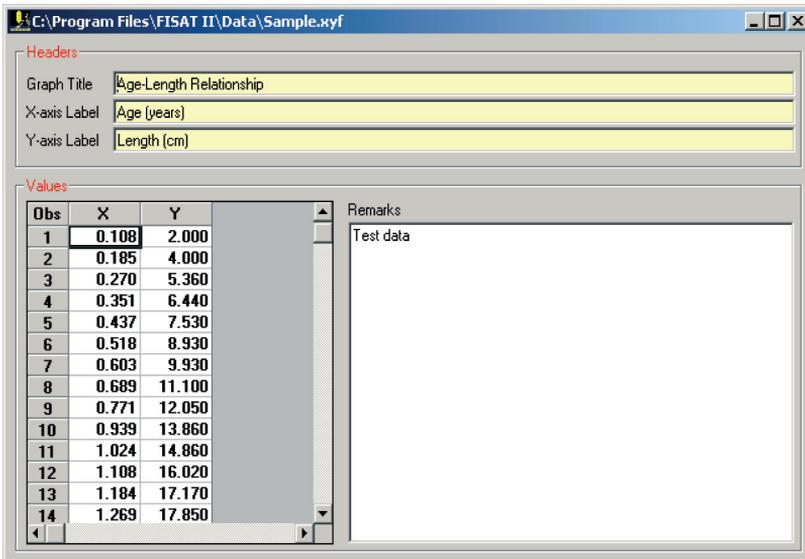
Fig. 3.10. User interface for encoding two-column data for regression analysis.

The required inputs are:
- X-axis and Y-axis labels;
- X-values (0 to 999);
- Y-values (0 to 999).

Species table

The Thompson and Bell Yield-Stock Prediction routine requires population parameters and importantly, an array of fishing mortality (F). In FiSAT II, these data are results when executing length-structured VPA. To simplify the procedures in creating a scenario for the Thompson and Bell Yield-Stock Prediction routine, these results are saved as a Species Table (Fig. 3.11 and Fig. 3.12). Note, however, that these data may also be manually encoded and/or edited by the user.

Fig. 3.11. User interface for encoding population parameters when creating/editing Species Tables.

Fig. 3.12. Portion of the user interface (second tab as shown in Fig. 3.11) to record F-array and table of values.

> The required inputs are:
>
> - Population parameters (class details, F_t, M, L_∞, K, number of recruits, and coefficients of the length-weight relationship [8a, b]);
> - F-array;
> - Table of values.

Fleet table

In simulating a multi-fleet scenario when executing the Thompson and Bell Yield Stock routine, a fleet indicator file is required to differentiate the catches recorded by various fleets. In FiSAT II, a Fleet Table can be created for the purpose (Fig. 3.13).
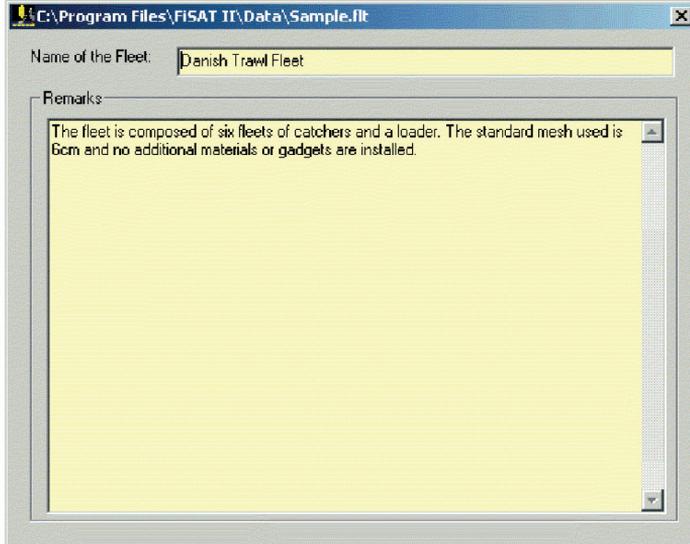
Fig. 3.13. User interface to encode the descriptive parameters defining a fleet.

The required inputs are:

- Fleet name;
- Fleet description.

Multispecies/multifleet scenario

The file that sets the relationship between the exploited species and fishing fleet is the scenario file (Fig. 3.14 and Fig. 3.15). To compute the contribution of each fleet to the species' F-array, catches by fleet are required. To allow the simulation on the change of mesh sizes, selection parameters of each fleet to a specific species also have to be encoded.

Fig. 3.14. Header records of the Multi-species/multi-fleet scenario file identifying the list of species and fleets to be included in the simulation.

Fig. 3.15. Tab to encode the catches and selection parameters for a species by fleet.

Creating a file

The "New" command in the File Menu provides the option to create any of the file types enumerated above. Depending on the type of file to be created, the data entry user interfaces will be automatically loaded. The "Open" command in the File Menu allows the loading of any of the file types and users have the option to load the same file as many times as desired, depending on the capacity of the computing environment. Loaded data can be edited and saved. Care should be taken when the same file is loaded more than once not to overwrite previously edited records.

All inputs in the memory of the computer can be uniquely catalogued on the designated storage medium by providing a filename. In the Microsoft Windows environment, the number of characters making up a filename is not limited to only eight characters, as in the case of IBM DOS files, and users are encouraged to use more descriptive filenames to facilitate file identification and retrieval.

Though the choice of filenames is left to the user, a coherent system for naming files is still advisable. One practical approach for naming files (now commonly applied) is through a fixed format, e.g., **GSSSAR**. **G** stands for the first letter of the fish's family name, **SSS** for a combination of the first letter of the genus and the first two letters of the species name, and **AR** for the area or stock from which this file was taken. Using this format for a data set on *Upeneus moluccensis*, the file may be named **MUMORG** where **M** refers to the family name (Mullidae), **U** from *Upeneus*, **MO** from *moluccensis* and **RG** for Ragay Gulf, Philippines.

This format can be further expanded to allow for further identification. For example, if the length-frequency data in MUMORG, a file originally with 1 cm class intervals, were regrouped to 2 cm, it would be appropriate to keep the original file and to use another filename for the new file.

The new filename may contain the original name MUMORG plus a suffix, say 2, referring to the larger class interval. Thus, the new filename would be MUMORG2.

WARNING!

New data entered or edited are not automatically saved on disk. The "Save" and "Save As…" option under the FILE menu of FiSAT II must be used to save data that have been entered. It is good practice to save a file right after it has been created or edited to avoid losses, e.g., due to power failures.

The DATA subdirectory of FiSAT is the default address when saving and retrieving files. However, FiSAT II provides the option to save data to a different address. However, as with filenames, it is advisable to also label data folders properly for efficient retrieval of records.

WARNING!

Edited data are not automatically saved to disk. THEREFORE, IT IS ADVISABLE TO FIRST SAVE THE DATA AFTER EDITING BEFORE ANY ANALYSIS IS PERFORMED.

Printing a file

The "Print..." option of the File Menu allows the user to print the loaded file to a printer or to a file. The "Print…" command is only applicable to data files and not to results of data analysis. A separate "Print" command button is available to users if the results are to be printed or graphs saved to disks.

The output device can be reconfigured from the "Print Setup" command of the File Menu. The printer re-configuration option can also be accessed from the Printer

Control Panel of Microsoft Windows or from a command button in the "Print" dialog box.

Sample manipulation

As defined in earlier sections, file manipulation pertains to file operations which alter the original content of the file. The changes which result from these manipulations are not automatically stored to disk. It is therefore necessary to save the altered file if the new data need to be accessed for later use.

WARNING!

If the manipulation of the data generates values greater than the upper limit or smaller than the lower limit set for a field, FiSAT II will display a warning message. Also, the high value(s) will be replaced by the upper limit (and conversely for low values).

A number of routines are presented below, with information arranged as follows:

Required file	*Defining the type of file required;*
Input parameters	*Listing the parameters required from the user;*
Function(s)	*Defining the mathematical model or function used by the routine and identifying its variables;*
User interface	*Providing notes on how to use the routine.*
Remarks	*Providing some comments and remarks to better describe the routine;*
Readings	*Providing a few suggested readings on the principles behind the routine (arranged in alphabetical order) other than the required readings, Gayanilo, Sparre and Pauly (1996), Gayanilo and Pauly (1998) and Sparre and Venema (1992).*

Merging two files

Similar files may be merged, resulting in consolidated files. FiSAT II will not prevent users from merging several files with different labels. In such cases, however, the user should operate with care (as in any other file manipulating routines).

Required file	Length-frequency or weight-frequency data file with constant class size.
Input parameter	Source files to merge (file already loaded into memory as default input) and destination file.

Function   None

User interface   This routine (Fig. 3.16) will require
                    only the identification of two length
                    frequency files with the same class sizes
                    and filename where the merged file will
                    be saved. The file loaded is by default,
                    one of the two files to merge. However,
                    the inputs for the source files can be
                    altered.
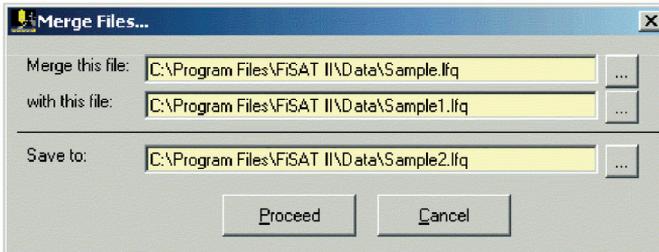
Fig. 3.16. User interface in merging two length frequency files.

Remarks   The same file may be merged to itself.

Correcting using probabilities of capture

Length or weight frequencies biased by gear selection can
be (partly) corrected using this routine, which divides
frequencies by their corresponding probabilities of capture.

FiSAT II provides two options (Fig. 3.17), (1) using a
probability file or (2) using selection parameters (L_{50}, L_{75},
R_{50}, and R_{75}).

Required file   Length- or weight-frequency data file
                    with constant class size

Input parameters   **Option 1**: Filename of the probability of capture file

Option 2: L_{50}, L_{75}, R_{50}, and R_{75}

In both cases, the destination filename will be required.
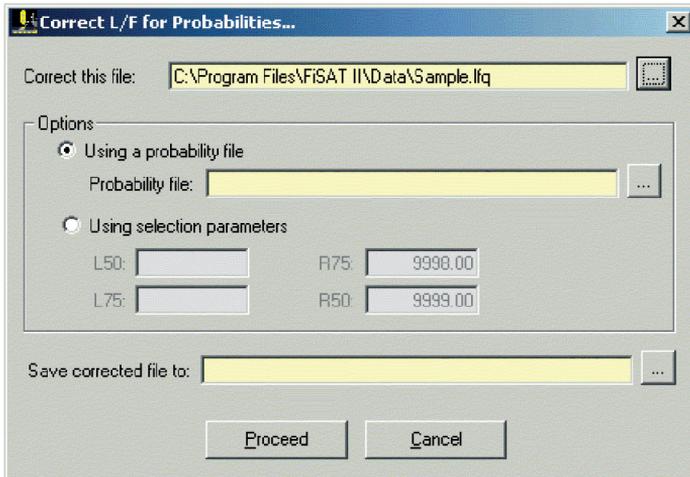
Fig. 3.17. User interface for correcting length frequencies for probability of capture.

Functions   The new frequency (N_{new}) for the class group L, is computed from

$$N_{new} = N_{old} / P_L$$

where P_L is the probability of capture. If P_L is to be computed (i.e. **Option 2**), this is done using:

$$P_L = 1 / (1 + \exp (S_1 - S_2 \cdot L)) \cdot \ldots$$
$$(1 + \exp (S_3 - S_4 \cdot L))$$

where

$$S_1 = ((L_{50} \cdot \ln(3))/(L_{75} - L_{50})),$$
$$S_2 = S_1 / L_{50},$$

$$S_3 = ((L_{50} \cdot \ln(3))/(R_{75}-R_{50})),$$
$$S_4 = S_3/R_{50}$$

User interface   The option to use in correcting the selected length frequency file for errors associated with probability of capture is presented in radio buttons. To select an option, click the button to enable the other input fields. Note that the default values for R_{50} and R_{75} are huge values indicating there is no deselection. However, these values can be altered.

If **Option 1** is used and the class size of the file which contains the selection data does not coincide with the length- or weight-frequency data file loaded onto memory, FiSAT II will cancel the operation and prompt for another filename.

Remarks   Setting the right-hand selection (or "deselection") to very high values would have the effect of ignoring deselection completely for **Option 2**.

Adjusting class intervals

The routine to adjust class sizes can be used to (i) allow two files with different class sizes to be merged, (ii) reduce the number of classes to fit into the limits set by FiSAT II or (iii) smooth out irregularities, and hence improve the interpretability of a data set. In FiSAT II, this routine regroups the frequencies by "slicing" the original file.

Required file   Length- or weight-frequency data file with constant class size

Input parameter   New class size

Functions   The frequencies of the new classes have the value:

$$N_{new} = N_1 + N_2$$

where

$$N_1 = N_i \cdot \left(\frac{X_{i+1} - Y_i}{X_{i+1} - X_i} \right)$$

$$N_2 = N_{i+1} \cdot \left(\frac{Y_{i+1} - X_{i+1}}{X_{i+2} - X_{i+1}} \right)$$

where

N_i - frequency of the first class,
N_{i+1} - frequency of the following class,
X_i - lower limit of the first class,
X_{i+1} - upper limit of the first class and lower limit of the following class, i+1,
X_{i+2} - upper limit of class i+1,
Y_i - lower limit of the new class, and
Y_{i+1} - upper limit of the new class.

User interface   As a default, the active length frequency file will be the default source file. A new class size and the destination file will be required by the routine.
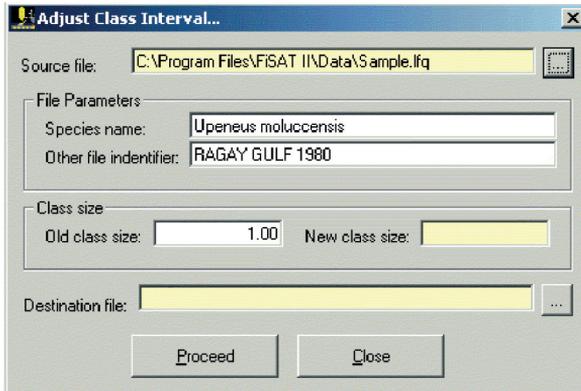
Fig. 3.18. User interface for adjusting the constant class size of a length frequency file in FiSAT II.

Remarks Adjusting class sizes is another approach for smoothing the data files. It is advisable to always use the original file when adjusting class intervals and not to use files previously manipulated.

Smoothing data files

This routine is meant to smooth out irregularities (Fig. 3.19). Smoothing can be done by: (1) a running average over 3 classes or (2) a running average over 5 classes.

Required file Length- or weight-frequency data file with constant class size

Input parameter None

Functions **Option 1:**
$$N_{i,new} = (N_{i-1} + N_{i,old} + N_{i+1})/3$$

Option 2:
$$N_{i,new} = (N_{i-2} + N_{i-1} + N_{i,old} + N_{i+1} + N_{i+2})/5$$
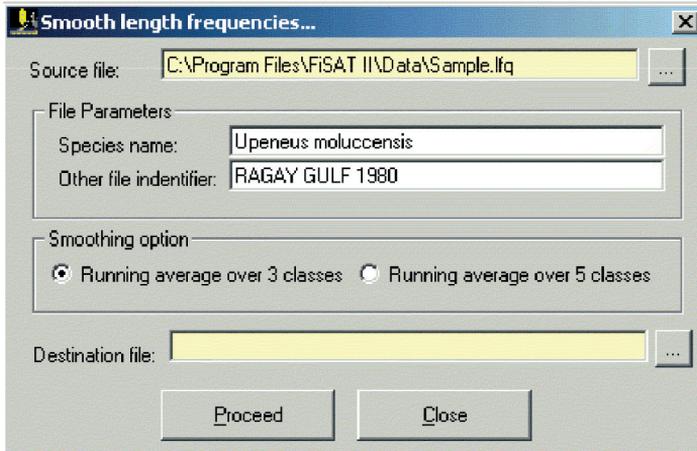
Fig. 3.19. User interface in smoothing length frequencies using running averages.

User interface   The default source file is the active length frequency file. Simply click the desired option, and provide the inputs for the desired destination file to complete the inputs.

Remarks   For both options, pseudo classes with frequencies of zero (0) are added below and above the extreme sizes, i.e. the smallest and largest classes before computing the new frequencies. FiSAT II will not prevent users from re-applying the smoothing function. However, this is not recommended, as repeated smoothing leads to loss of information.

Readings   Laurec and Mesnil (1987)

Pooling samples

This routine (Fig. 3.20) allows a user to pool samples from several sampling dates. The weighting options (by the square root of sample total or % of sample total) that must

be considered before actual pooling are presented further below.

Required file   Length- or weight-frequency data file with constant class size

Input parameters Identification of samples to be pooled.

Function $N_{new} = N_{sample\ 1} + N_{sample\ 2} + ...$
$$+ N_{sample\ n}$$

User interface   As with previous routines, the default source file is the active length frequency file. Using the mouse, select the samples to pool, provide the new sampling date (default is the average of the dates of the samples selected). Provide the address of the destination file and click the command button "Pool Selected Samples". Continue the process until all samples to pool has been completed. Click the command button "Save File" to save the results.
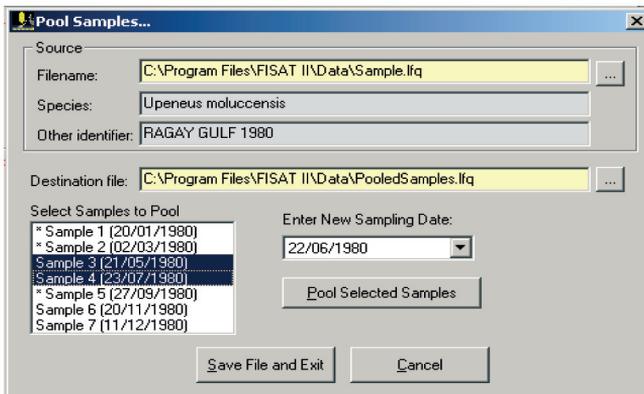
Fig. 3.20. User interface in pooling length frequency files.

Remarks   It will be recalled that for length or weight frequencies stored through FiSAT II, a header may be attached to

each sample (e.g., sex, type of gear, depth, etc.). When pooling samples, these values (or entries) will be retained if and only if they are the same. Entries for total weight of the sample, total weight of the species and total weight of the catch will be added.

Converting files

Certain data sets need converting before they can be used. FiSAT II (Fig. 3.21) provides two options using either: $L_{new} = d + e \cdot L_{old}^{f}$ (or length-to-length) or $L_{new} = d \cdot W^{e}$ (or weight-to-length) functions.
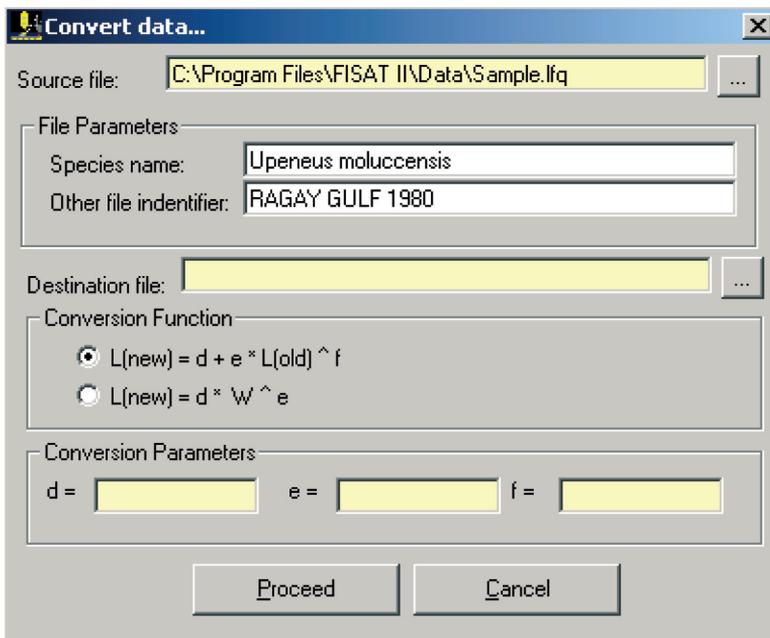
Fig. 3.21. User interface in converting grouped frequencies in FiSAT II.

Required file   Length-frequency data file with constant class size

Input parameters	Depending on the option selected the parameters for d, e and f (for Option 1 only).
Function	**Option 1:** $L_{new} = d + e \bullet L_{old}^{\ f}$ **Option 2:** $L_{new} = d \bullet W^e$
User interface	Enter the address of the destination file, select the conversion function to use using the mouse and enter the parameters before proceeding. Option 1 is used for converting one length measurement into another, e.g., total length into fork length or carapace length to total length when the variable "f" is set to 1.
Remarks	Option 1 can also be used for conversions based on a proportionality (e.g., inches to cm), by setting d = 0, and e = conversion factor. Also, a constant can be added, by setting e = 1 and d = constant. Option 2 can be used to convert weight-frequency data to length-frequency data given the parameters (a,b) of a length-weight relationship by setting d=$(1/a)^{(1/b)}$, and e=1/b.

Raising samples

For some of the fish stock assessment methodologies included in FiSAT II, length or weight frequencies may be required to represent certain quantities, for example, total catch. The following (Fig. 3.22) are options for raising frequencies:
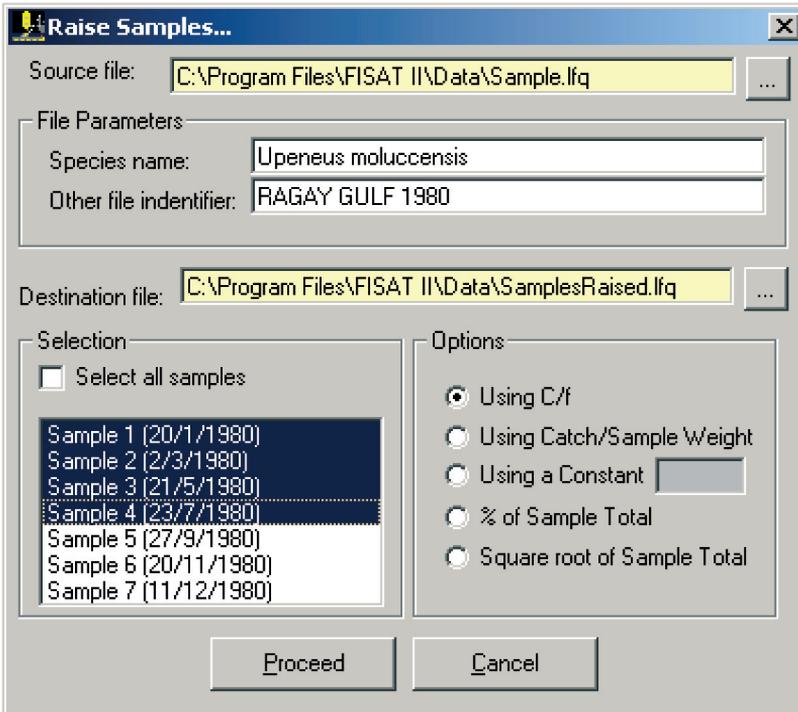
Fig. 3.22. User interface in raising length frequency files.

Using catch per unit of effort (C/f)

When the total catch and a measure of effort is available, the frequencies can be raised to represent the catch per unit of effort (C/f).

Required file   Length- or weight-frequency data file with constant class size

Input parameters   Catch per unit of effort (C/f) per sample

Function $N_{new} = N_{old} \cdot (C/f)$

User interface   Select the samples to raise and click on this option to select.

FiSAT II will use the C/f data provided on the sample sub-header as default

values; in the absence thereof, FiSAT II will cease processing.

Remarks   In a multifleet fishery, data may need to be raised using this option to obtain a better representation of total catches.

Using catch/sample weight

When in addition to the total sample weight (WS), the weight of the total catch (WC) is available, this option will allow frequencies to be raised to better represent the total catch.

Required file   Length- or weight-frequency data file with constant class size.

Input parameters   Total weight of the catch (WC) and total weight of the sample (WS), or the 'a' and 'b' coeficient of the length-weight relationship to estimate total sample weight.

Function $N_{new} = N_{old} \cdot (WC/WS)$.

User interface   Select the samples to raise and click on this option to select.

FiSAT II will use the WC and WS data provided on the sample sub-header as default values. In the absence of required parameters, the routine will prompt an error and will discontinue processing.

Remarks   This option may be necessary to raise data to represent the total catch required for the length-structured VPA and related routines.

Using a constant

This option may be used when independent estimates of an appropriate raising factor (RF) are available, or to change units of measurements, e.g., inches to cm.

Required file Length- or weight-frequency data file with constant class size

Input parameters The factor (0 to 999,999) to raise the frequencies.

Function $N_{new} = N_{old} \cdot RF$

      where RF is a constant

User interface Select the samples to raise and click on this option to select.

      When this option is selected, FiSAT II will prompt for input of the constant. A default value of 1 (one) is provided.

Remarks   None

Percent of sample total

This option allows the frequencies of samples to be re-expressed as % frequencies; this option can be used to give equal weight to all samples of a file; preferably it should be applied to samples having similar sizes to start with.

Required file Length- or weight-frequency data file with constant class size.

Input parameters None.
Function   The new frequencies are defined by

      $N_{new} = [N_{old}/\Sigma(N_{old})] \cdot 100$

where:

N_{new} = new frequency,
N_{old} = original frequency,
$\Sigma(N_{old})$ = total frequency in the sample.

User interface Select the samples to raise and click on this option to select.

Remarks This type of data transformation is also available in some of the routines that require data to be pooled (e.g., catch curve analysis); however, these routines do not allow saving of the data thus transformed.

Square root of sample total

This option allows the frequencies of a sample to be re-expressed such that their sum becomes proportional to the square root of the total sample size; it should be considered for samples with initially very dissimilar sizes.

Required file Length- or weight-frequency data file with constant class size.

Input parameters None

Function The new frequencies are defined by

$$N_{new} = [N_{old} /\Sigma(N_{old})^{½}] \bullet 100$$

where:

N_{new} = new frequency count,
N_{old} = original frequency,
ΣN_{old} = total frequency of the 'old' (original) sample.

User interface   Select the samples to raise and click on this option to select.

Remarks   As with the previous option, this type of data transformation is also available (but without saving) on some of the routines that require pooling of samples.

Temporal weighting

Temporal weighting will raise each sample by a factor proportional to the time separating it from the nearest other sample, which gives more emphasis to samples representing longer periods and less to samples collected at close intervals.

Required file   Length- or weight-frequency data file with constant class size

Input parameters   None

Function $N_{new} = [N_{old} \bullet D^{½}]$

where:

D is the number of days separating the sample from its nearest neighbour.

User interface   (see routines with this prompt: e.g. length-converted catch curve).

Remarks   FiSAT II will not weigh samples by time if D exceeds 3 months.

Importing old FiSAT data

This routine will allow users of the old version of FiSAT to readily migrate to the updated FiSAT II version.

Required file   Length -frequency data file saved in the old version of FiSAT

Input parameters Source and destination files

Function   None

User interface   Enter the source file (i.e. old FiSAT data) and the destination file (Fig. 3.23).

Remarks   The contents of the sub-header will not be imported other than the data of sampling.
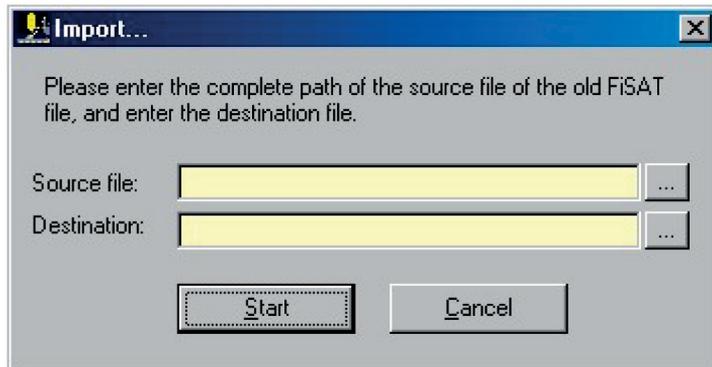
Fig. 3.23. User interface when importing old FiSAT data files to the new format.

Exporting FiSAT II length frequencies

In many cases, the FiSAT II file may have to exported to other forms for report purposes or to allow data importation to other software packages (e.g. Microsoft Excel).

Required file   Length-frequency   data   file   with constant class size.

Input parameters   None

Function   None

User interface   The routine will access the standard dialog box (Fig. 3.24) for exporting a file. A tab-delimited file will be generated that is standard to most commercially available electronic spreadsheets and word processors.
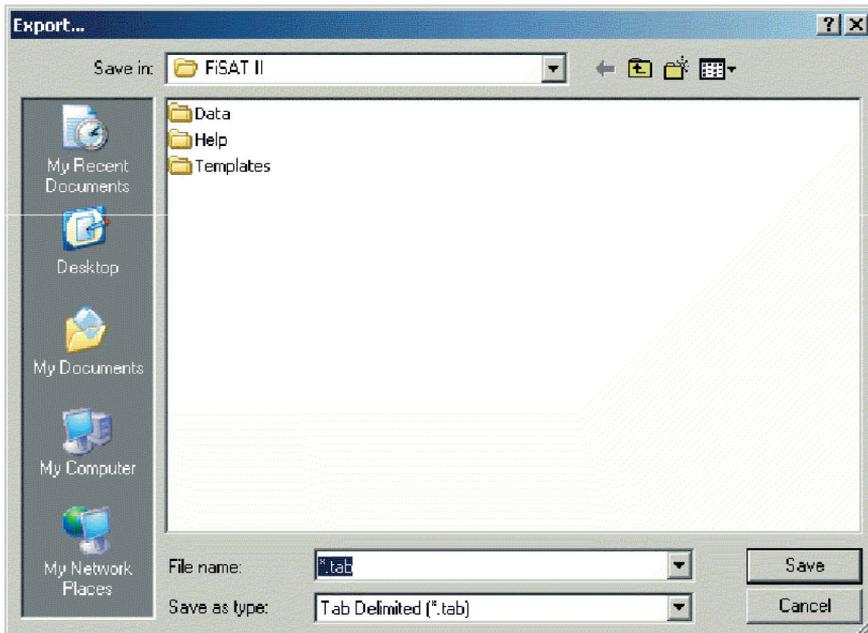
Fig. 3.24. Dialog box used when identifying the destination file of the data to be exported.

Remarks   The sub-headers will not be exported other than the date of sampling.

Chapter 4. ASSESS menu

What you will learn from this chapter

This chapter presents routines for analysis of the various types of data presented in the previous chapter. However, these are presented in a summarized form, and we remind FiSAT users to read the FiSAT reference manual (Gayanilo and Pauly, 1998), and other documents explaining the background of these routines.

The format in module description

The Assess menu is divided into two parts, (i) the routines to estimate parameters (e.g., L_∞, K, C, M, Z, etc.) and (ii) the routines to predict yield or stock-related attributes given certain fishing scenarios. In the following, the modules are presented as given in Chapter 3, with one description added:

Output(s) *This section defines the output of the model or methodology being described. Examples will be provided when necessary.*

Parameter estimation

The step that should immediately follow data entry and manipulation is the estimation of population parameters. These are required inputs to the second set of analytical routines that deals with predictions.

Direct fit of length-frequency data

The set of routines classified under this heading are those which estimate growth parameters directly from the length composition of the stock, without previously translating the

length scale into an age scale, as an alternative to the MPA approach described below.

ELEFAN I

ELEFAN I is a routine that can be used to identify the (seasonally oscillating) growth curve that "best" fits a set of length-frequency data, using the value of R_n as a criterion. FiSAT II provides three options to the user to identify that "best" growth curve: (1) curve fitting by eye (plotting of the histogram or restructured data may also be accessed from the Support Menu): (2) scan of K-values (Fig. 4.1), and (3) response surface analysis (Fig. 4.2). The plotting and curve fitting by eye is described in detail in the Support Menu below.

Note that in ELEFAN I, the parameter t_o is replaced by the coordinates of a point (any point actually) through which the curve must pass, and whose coordinates consist of SS (a starting sample) and of SL (a starting length).

Required file   Time series of length-frequency data with constant class size.

Input parameters **Option 1**: Scanning of K-values

               Fixed value of L_∞, C and WP and, as an option, a fixed starting point.

               Option 2: Response surface analysis

               Range of values for two parameters (e.g., L_∞ and K), fixed value for the two others (e.g., C and WP), and, as an option, a fixed starting point.

Functions   In ELEFAN I, data are reconstructed to generate "peaks" and "troughs", and the goodness of fit index (R_n) is defined by
$$R_n = 10^{ESP/ASP}/10$$

where the ASP ("Available Sum of Peaks") is computed by adding the 'best' values of the available 'peaks' and the ESP ("Explained Sum of Peaks") is computed by summing all the peaks and troughs "hit" by a growth curve of the form,

$$L_t = L_\infty (1 - EXP(-K(t - t_o) + S_{ts} + S_{to})$$

where

$S_{ts} = (CK/2\pi) \cdot \sin (2\pi(t-ts))$,
$S_{to} = (CK/2\pi) \cdot \sin (2\pi(t_o-ts))$, and
L_t is the length at time t.

Outputs
Option 1: Scanning of K-values

This plots R_n values for a range of K values (0.10 to 10) on a log-scale.

We recommend use of this plot for all growth analyses, if only to assess how reliable an estimate of K is.

Option 2: Response surface analysis

This outputs an 11 by 11 matrix showing R_n values and in which the 10 best values are highlighted, thus enabling selection of the "best" combination of growth parameters.

User interface
ELEFAN I contains three tabs. The first tab is only to identify the length frequency file to use. The tab, "K Scan" (Fig. 4.1), would allow the user to view

the behaviour of the scores given estimates of L_∞.

The starting point can be set to variable or fixed starting point (see red arrow in Fig. 4.1). If starting point is set to a fixed value, the starting sample and starting length can be selected from a drop-down list.
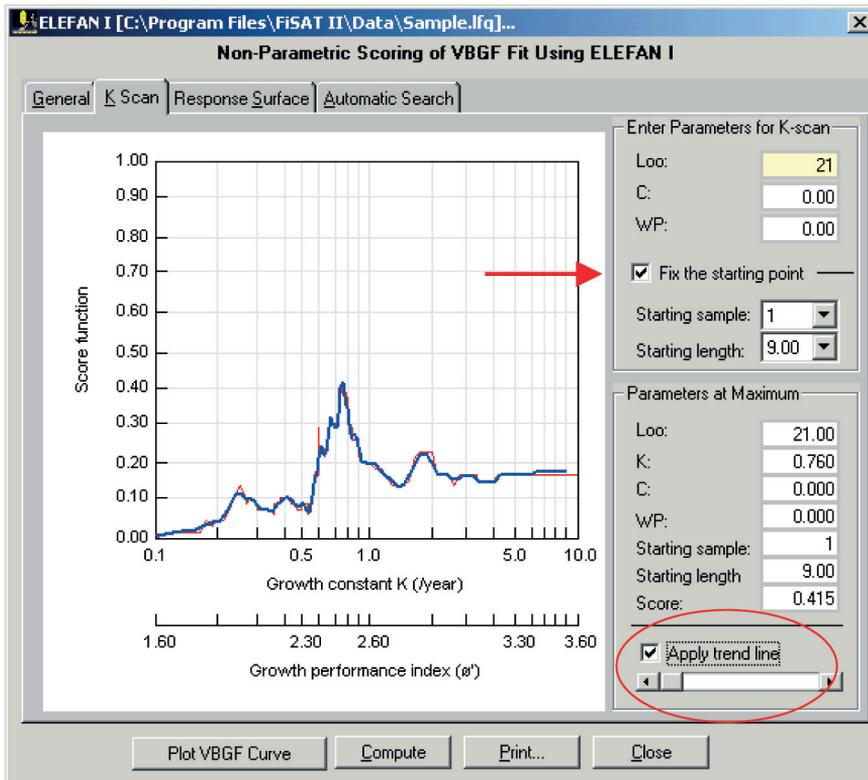
Fig. 4.1. User interface of ELEFAN I, K-scan routine. The red line in the plot is the actual score and the thick blue line is the overlaid trend line.

The behaviour of the scores may be so erratic that assessment of the possible solution is difficult. A trend line (see red circle in Fig. 4.1) may be applied.

The scroll bar is used to change the resolution of the trend line.The third tab is to execute a response surface analysis (Fig. 4.2). The starting point is a requirement of this subroutine. Note that the value of the L_∞ cannot be less than the starting length.
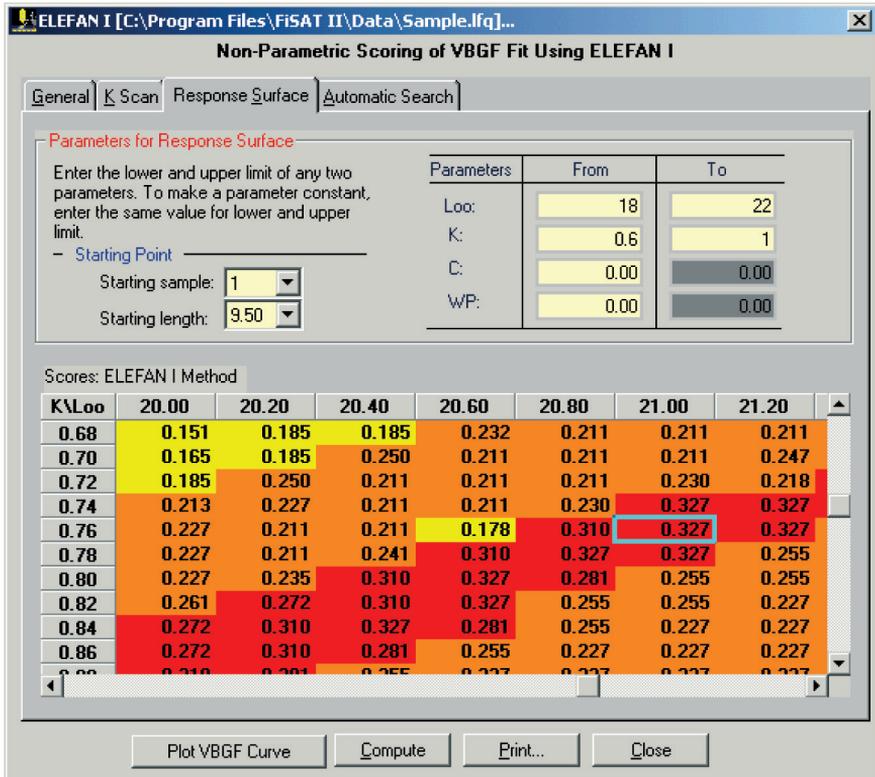
Fig. 4.2. User interface of ELEFAN I, Response surface analysis. Note the change of colour indicating improvement on the score.

| *Remarks* | It is imperative that users of ELEFAN I read detailed accounts of this method. |

Readings	Pauly (1982)
	Pauly and David (1981)
	Pauly and Morgan (1987)

Shepherd's method

Conceptually, this approach is similar to ELEFAN I in that it is designed to maximize a non-parametric scoring function. Two options for identifying optional values of L_∞ and K are available: (1) response surface analysis and (2) scan of K-values, both of which are very similar, in display and operations, to those of the ELEFAN I routine (see above).

Required file   Time series of length-frequency data with constant class size.

Input parameters   **Option 1**: Response surface analysis

Range of values for L_∞ and K.

Option 2: K-scanning

Fixed value of L_∞.

Functions   The score (S) for Shepherd's method is defined by:

$$S = (s_A{}^2 + s_B{}^2)^{1/2}$$

where s_A and s_B are the goodness-of-fit scores (s_{tz}) obtained with the origin of the VBGF in calendar time (t_z) set to 0 and 0.25, respectively. s_{tz} is defined by:

$$s_{tz} = \sum_i T_i \cdot \sqrt{N_i}$$

where

N_i = frequency for length group i,
T_i = D · cos 2π (t-t_i),
D = (sinπ (Δt)/π(Δt)),
t = Δt/2,
Δt = t_{max} - t_{min},
t_i = t_z - (1/K)·ln(1-(L_i/$L_∞$)), and
t_z = (1/2π) · $\tan^{-1}$(s_B/s_A).

Outputs   **Option 1**: This outputs an 11 by 11 matrix of S values (with S_{max} standardized to 1) and in which the 10 best scores are highlighted, thus enabling selection of the "best" combination of $L_∞$ and K;

Option 2: This generates a plot of S values (with S_{max} standardized to 1) for a range of K values (0.1 to 10 year^{-1}) on a log scale, thus enabling the identification of the best value of K for a given value of $L_∞$.

User interface   The user interface of this routine is very similar to that in ELEFAN I. It also contains three tabs where the first tab is used only to identify the file to be analysed. The second tab (Fig. 4.3) is to examine the S values given a fixed $L_∞$ and a fixed range of K values.
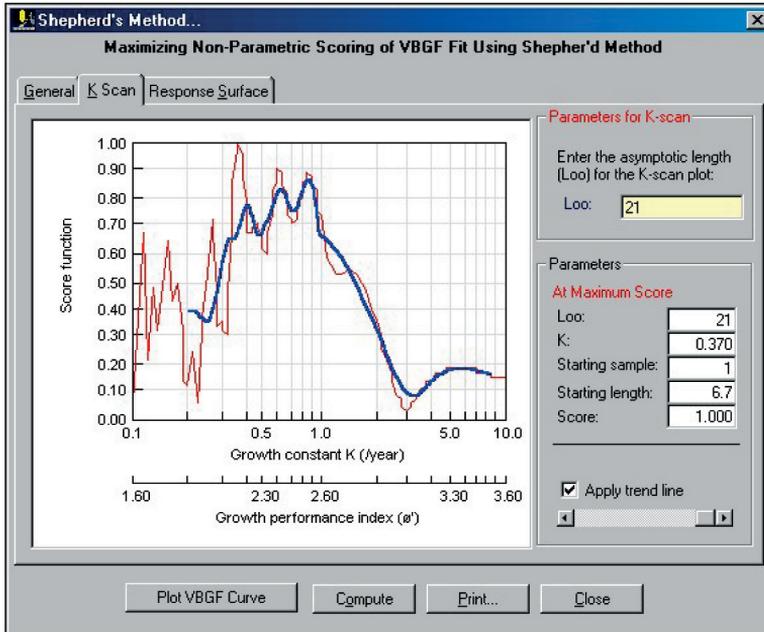
Fig. 4.3. User interface of Shepherd's method. The trend line indicates a K value in the same range as that generated by ELEFAN I in Fig. 4.1.

The third tab (Fig. 4.4) is the response surface analysis given a range of L_∞ and K values. The main difference with ELEFAN I is that, in this approach, the starting point and seasonality parameters (C and WP) are not identified.
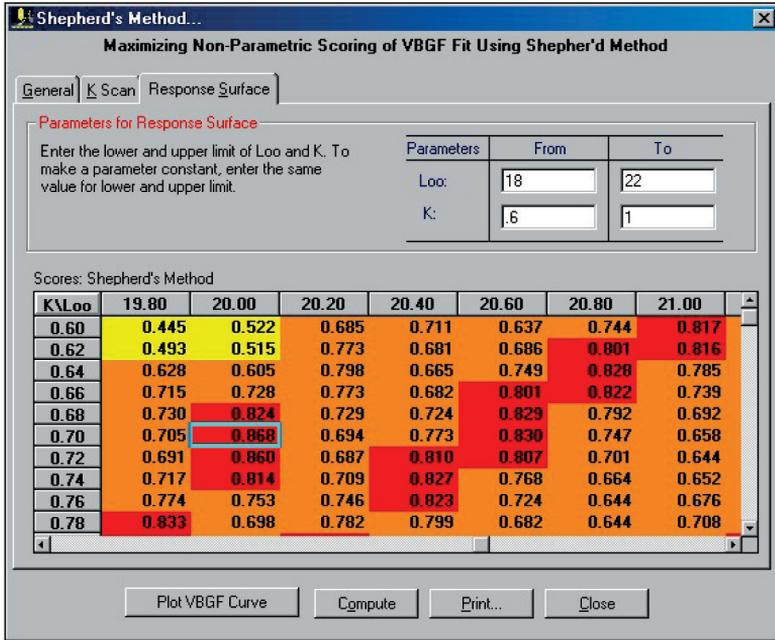
Fig. 4.4. Results of the response surface analysis where red (i.e. darker coloured cells) indicates improvement on the score.

Remarks   As for the ELEFAN I routine, this method is best applied when L_∞ has been estimated using another method (e.g., the Powell-Wetherall plot, see below). Note however, that this method differs from ELEFAN I in that it cannot deal with seasonal growth oscillations. Also, note that in this implementation, the score function is standardized to 1, i.e. S_{max} is made equal to unity. Further, the parameter "t_z" (which is *not* similar to t_o), is here replaced by a "starting point" (as for ELEFAN I, see above), and hence the ELEFAN I output routine can be used to display growth curves whose parameters have been estimated using Shepherd's method.

Readings   Shepherd (1987) and Isaac (1990)

Powell-Wetherall plot

This method allows estimation of L_∞ and Z/K from a sample representing a steady-state population, as can be approximated by pooling a time series of length-frequency data.

Required file   Length-frequency data file with constant class size

Input parameter   Graphical identification of smallest length fully recruited by the gear (L', or cut-off length):

Functions $(\overline{L}-L') = a + b \cdot L'$

where

$$\overline{L} = \left(\frac{L_\infty + L'}{1 + (Z/K)} \right)$$

from which

$L_\infty = -a/b,$
$Z/K = - (1+b)/b.$

Outputs L_∞ and Z/K estimates and regression parameters.

User interface   In this routine, as with other routines in FiSAT II, options are provided to select and deselect samples to be included in the analysis. To deselect a sample, uncheck the sample represented by the sampling date. Three options are provided to do a temporary data transformation (see Chapter 3 for details). Use the radio buttons (Fig. 4.5) to select the option. In addition to the

available temporary data transformation, temporal weighting may also be applied to the selected samples by checking the appropriate box (see Chapter 3 for details of this option).
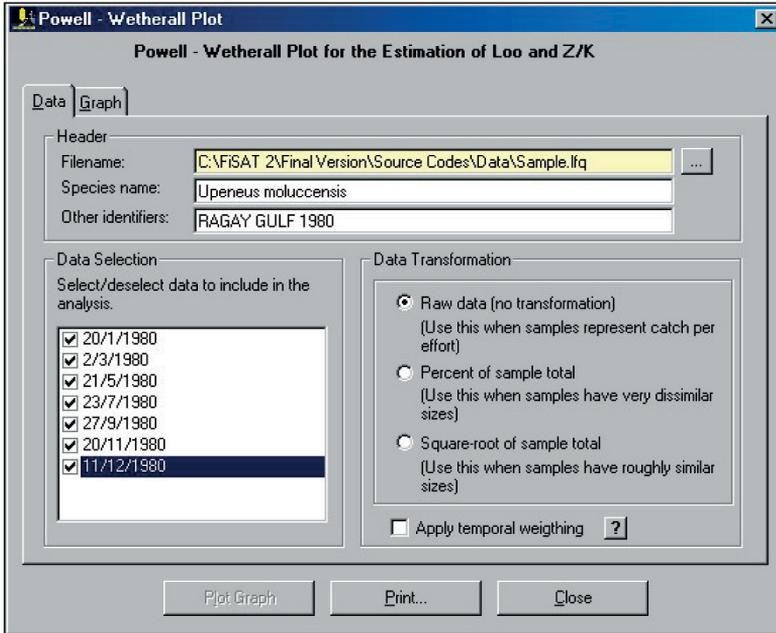
Fig. 4.5. File identification tab and options to temporarily transform data before data analysis. These options are available in other routines of FiSAT II that sums a time series of length frequencies to approximate a steady-state condition.

Once the initial inputs are satisfied, the data points may be plotted (Fig. 4.6). In FiSAT II, the identification of the cut-off length (L') is facilitated by an adjacent graph (pseudo-catch curve; Fig. 4.7), showing one's L/F data, and from which L' is often identifiable. The cut-off length may be identified using a mouse pointing device directly from the Powell-Wetherall plot or from the pseudo-catch curve to estimate L_∞ and Z/K or from the pseudo-catch curve.

A command button, "Open pseudo-catch curve" is available in Fig. 4.6, if the pseudo-catch curve (to help identify the cut-off length) was previously closed.
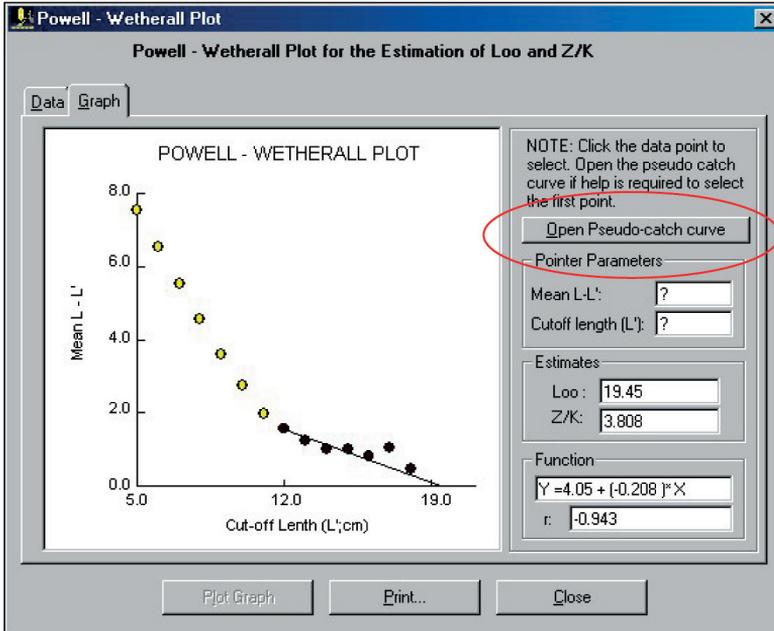
Fig. 4.6. The Powell-Wetherall's plot showing the regression line with the Y-intercept as the estimate of L_∞.
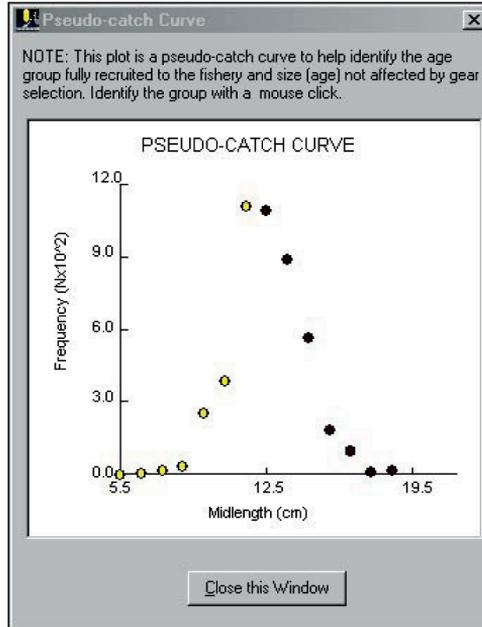
Fig. 4.7. Pseudo-catch curve to help identify cut-off length in Powell-Wetherall's plots. Selecting the cut-off length can also be done through this plot.

Remarks	This approach should be used only when sufficient samples are available.
Readings	Pauly (1986)
	Powell (1979)
	Wetherall (1986)

Analysis of length-at-age data

This routine allows non-linear estimation of growth parameters from length-at-age data.

Required file	Length-at-age data, consisting of at least four age-length data pairs.

Input parameters **Option 1: Non-seasonal growth**

The minimum and maximum constraints and starting values for the growth parameters L_∞, K, and t_o.

Option 2: Seasonal growth

The minimum and maximum constraints, and starting values for the growth parameters L_∞, K, t_o, C and WP (where $WP = t_s + 0.5$).

Functions Find the global minimum of the following functions using Marquardt's algorithm:

Option 1

$$SSE = \sum_i \left\{ L_i - L_\infty \left[1 - EXP(-K(t_i - t_0)) \right] \right\}^2$$

Option 2

$$SSE = \sum_i \left\{ L_i - L_\infty \left[1 - EXP(-K(t_i - t_0) + S_{ts} + S_{t0}) \right] \right\}^2$$

where

$S_{ts} = (C \cdot K / 2\pi) \cdot \sin(2\pi(t - t_s))$,
$S_{to} = (C \cdot K / 2\pi) \cdot \sin(2\pi(t_0 - t_s))$.

Outputs L_∞, K, t_o, and their standard errors for **Option 1** and in addition, C and WP for **Option 2**. For either option, the coefficient of determination (r^2 and adjusted r^2), phi prime (ø'), and its standard error.

User interface   The user interface of this routine contains only two tabs (Fig. 4.8 and Fig. 4.9). The first tab (Fig. 4.8) provides the option to enter the range of values identified by the minimum and maximum constraints, and the starting estimates for each parameter. After the iteration process, the results are also displayed in this tab.

Fig. 4.8. The "Parameters" tab of the user interface when analysing length-at-age data. This tab identifies the file and range of values to search for the growth parameters. The results, including the statistics to measure the fit, are also displayed after iteration.

The second tab (Fig 4.9) is a plot of the results, i.e. the data points overlaid by the computed growth curve.
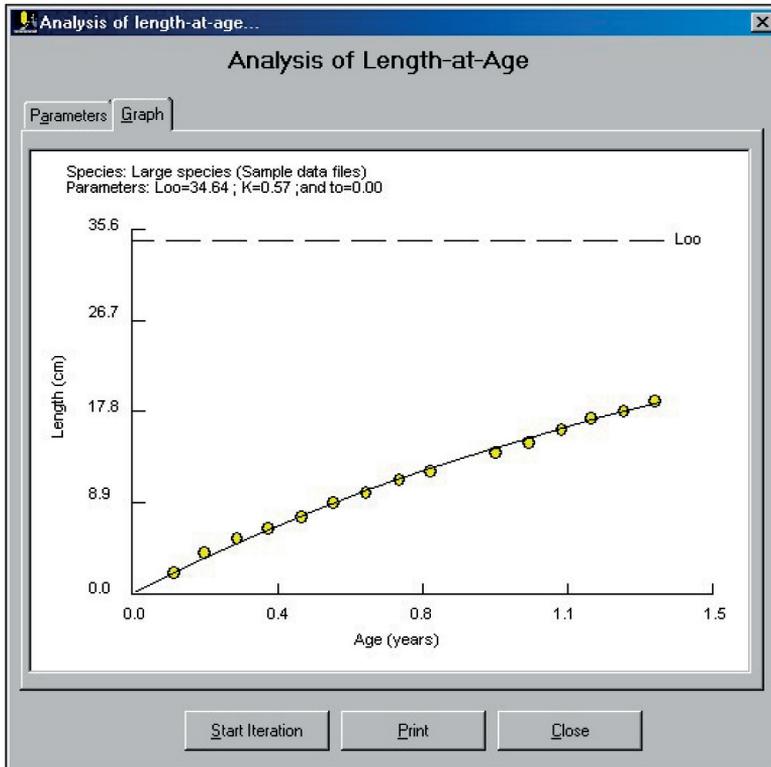
Fig. 4.9. Plot of the growth curve based on the computed growth parameters.

Remarks For rapid convergence, the routine should be initiated with a *wide* range of constraints. To fix inputs at certain set values, enter minimum constraint = maximum constraint.

Note that up to 200 iterations may be performed until the routine converges or stops.

The method for estimating the standard error of ø' stems from J. Hoenig (pers. comm.).

Readings   Kvalseth (1985)
                    Pauly *et al.* (1992)
                    Saila, Recksiek and Prager (1988)
                    Soriano and Jarre (1988)

Modal progression analysis

Modal progression analysis (MPA) refers to a methodology that infers growth from the apparent shift of the modes or means in a time series of length-frequency samples. MPA involves three stages: (i) decomposition of composite distributions into their components to identify means, (ii) subjective identification and "linking" of the means perceived to belong to the same cohorts and (iii) using the growth increments and size-at-age (relative) data resulting from the linking to estimate growth parameters.

In FiSAT II, two methods are provided to decompose composite length-frequency distributions:(i) Bhattacharya's method and (ii) NORMSEP.

Bhattacharya's method

Required file   Length or weight frequencies with constant class size.

Input parameters Visual identification of frequencies perceived to belong to one age group, using the graphs provided for this.

Functions $\ln (N_{i+1}) - \ln (N_i) = a_j + b_j \cdot L_i$

                    where

                    N_i and N_{i+1} are successive frequencies of the same component of a group of fish in a sample (i.e. representing age group j) and where L_i is the upper class limit of N_i.

From this, the mean of the normal distribution is

$$L_j = -a_j/b_j$$

while its standard deviation (σ) is

$$\sigma_j = (-\Delta\overline{L}/b_j)^{1/2}$$

where $\Delta\overline{L}$ is the constant class size.

Also, a separation index (SI) is computed.

$$SI = \Delta\overline{L}_j/\Delta\sigma_j$$

where $\Delta\overline{L}_j$ is the difference between two successive means, and $\Delta\sigma_j$ is the difference between their estimated standard deviations.

The separation of length-frequency samples into their components is an iterative process in that every identified component is subtracted from the remainder of the sample using the Gaussian function,

$$N_{2i+1} = N_{i+} - \left\{ \left(\frac{1}{\sigma_j \sqrt{2\pi}} \right) \cdot EXP \left(- \left(\frac{(L_i - L_j)^2}{2\sigma_i^2} \right) \right) \right\}$$

where N_{i+} refers to the previous set of frequencies and N_{2i+} is the new set of frequencies, less the component identified so far. Also, the user can backtrack and redo any step of the analysis without losing intermediate results.

Outputs   Mean lengths, population sizes (in numbers), standard deviations and separation index (SI) for the age groups identified.

These results are automatically saved to disk as a "mean and standard deviation" file, using the same filename as the input.

User interface   The module contains three tabs (Fig. 4.10). As with previous routines, the first tab is used only to identify the file to analyse. The "Plots" tab shows the log-plots of the slopes between successive frequencies and the resulting distributions.

The process starts with the selection of the sample to analyse (see red circle in Fig. 4.10) and identification of the first and last data points that identify a group using the mouse.
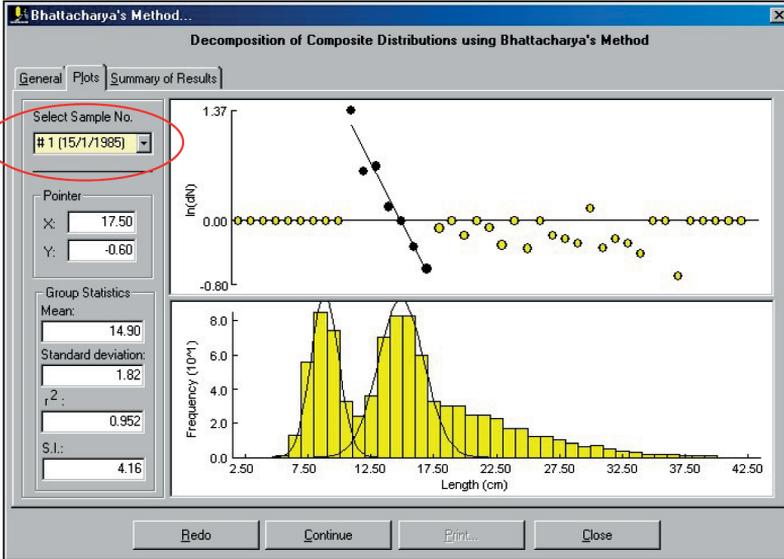
Fig. 4.10. User interface for Bhattacharya's method in FiSAT II.

Clicking the "Redo" command button will re-initialize the display and the user will be provided with the option to reselect data points. Clicking the "Continue" command button indicates acceptance of the results and the group will be eliminated from the composite distribution to emphasize the next possible group (if any). This process is continued until all groups are identified. The result can be saved (Fig. 4.11) by clicking the "Save MSD" command button that replaces the "Continue" command button after group identification. The results will be saved as a "mean and standard deviation file" that can later be linked to form growth increments or saved as length-at-age (relative) data.
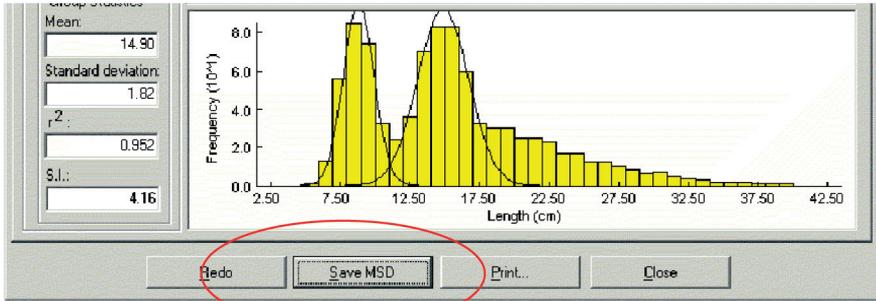
Fig. 4.11. "Save MSD" command button replaces the "Continue" command button in Fig. 4.10 every after successful identification of an age group.

A summary of the results, including the SI values, is presented in the third tab (Fig. 4.10).

Remarks Up to 10 age groups can be identified per sampling period, but separation is generally unreliable when the SI value is below 2. Also, note that the standard deviations usually increase with lengths.

Reading Bhattacharya (1967)

NORMSEP

This method applies the maximum likelihood concept to SEParation of the NORMally distributed components of size-frequency samples.

Required file Length or weight frequencies with constant class size.

Input parameters The expected number of age groups (maximum of ten) and their expected mean lengths. [The results from Bhattacharya's routine (see above) are used as initial inputs when available.]

Functions	(Refer to suggested readings for the maximum likelihood method)
Outputs	Mean lengths, population sizes (in numbers), standard deviations and separation index (SI) for the groups identified.
	These results may also be saved to disk as a "mean and standard deviation file" using the same filename, and overwriting results from previous analyses.
User interface	The user interface of this routine is very similar to Bhattacharya's routine. However, it contains only two tabs (see Fig. 4.12). The first tab identifies the file to analyse and the second tab is for group identification and a summary of the results.
	Users first select the sample to analyse then approximate the mean length of each group (normally, the results of Bhattacharya's routines are used as defaults). Clicking the "Compute" command button iterates for the best fit using the approximate means as a starting point. The computed mean lengths can be saved by clicking the "Save MSD" command button as in Bhattacharya's method.
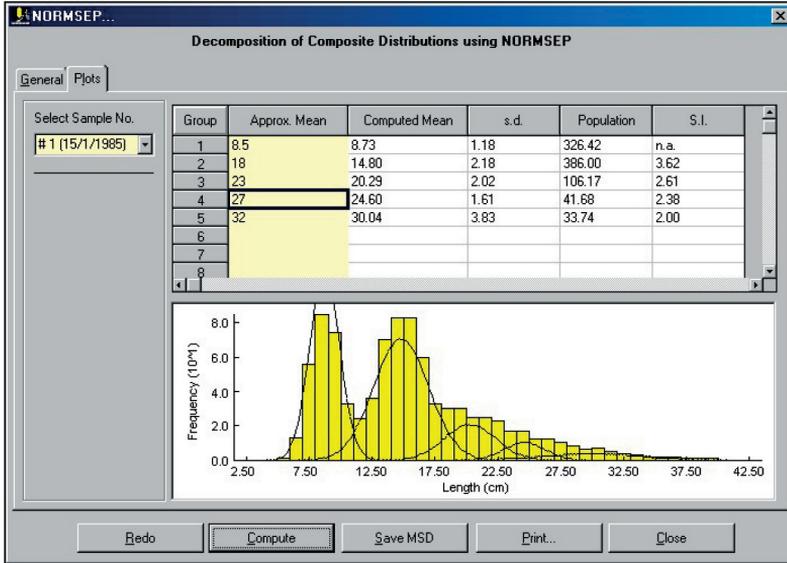
Fig. 4.12. NORMSEP user interface in decomposing composite distributions.

Remarks	It is advisable to use Bhattacharya's method to obtain initial guesses and to refine the results using NORMSEP.
	NORMSEP, once initiated, will run until it reaches an optimum, or 200 iterations.
Readings	Abrahamson (1971) Hasselblad (1966) Pauly and Caddy (1985)

Linking of means

| *Required file* | Mean lengths and standard deviations file. |
| *Input parameters* | Links between means thought to represent the same cohort. |

Function   None: linking of means results from user's subjective interpretation of a graph.

Outputs   Either (1) a number of links between means (i.e. growth increment data), for analysis with a Gulland and Holt plot, then refined using another method, or (2) series of linked means, stored as a length-at-age (relative), for analysis with the appropriate routine.

User interface   The module requires a mean and standard deviation file (*.MSD) that can be created from the results of Bhattacharya's analyses or from NORMSEP. The file can also be created manually (see Chapter 2). The points can be linked using the mouse (Fig. 4.13).
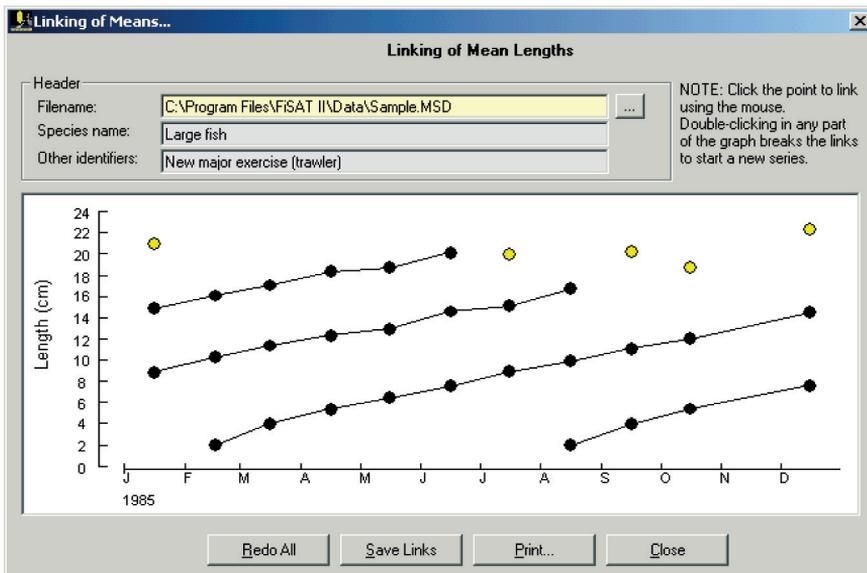
Fig. 4.13. Linking of mean lengths in FiSAT II.

Clicking the subsequent data points automatically links the points. To break the link, i.e. creating a new cohort, double-click in any part of the plot. Clicking on the "Save Links" command button will save the links as growth increments or as length-at-age (relative) data. To redo the links, click the "Redo" command button.

Remarks Linking of the mean lengths without any prior knowledge of the growth patterns of a given species is usually extremely difficult, and should not be attempted if the mean lengths do not display a clear progression through time.

The most likely of two alternative hypotheses concerning the distribution of lengths about age are:

(i) constant CV, or

(ii) CV changing with $\Delta L/\Delta t$ and hence with length.

However, for the second hypothesis to be likely the analysis should indicate a significant correlation; also, the CV of L_∞ must be positive.

Reading Sainsbury (1980)

Analysis of growth increment data

FiSAT II provides four options to estimate the growth parameters of the von Bertalanffy Growth function (VBGF) from growth increment data, which may originate from linking of mean lengths (see above), or from tagging/recapture experiments.

Gulland and Holt plot

This method allows *preliminary* estimation of growth parameters from growth increments, based on the fact that under the VBGF, growth rate declines linearly with length, reaching zero at L_∞. Also, the residuals of the plot are used for inferences on seasonality of growth.

Required file   Growth increment data file with at least 3 pairs of points.

Input parameters Data points to be included in the regression analysis; also independent estimate of L_∞ if such value is to be used (in a "forced" Gulland and Holt plot).

Functions $\Delta L / \Delta t = a + b \cdot \bar{L}$,

where

$$\Delta L = L_r - L_m,$$
$$\Delta t = t_r - t_m, \text{ and}$$
$$\bar{L} = (L_r + L_m)/2.$$

where L_m is the length at marking (initial reading), L_r is the length at recapture, and t_m and t_r the corresponding dates.

From these, growth parameters can be estimated using

$$L_\infty = -a / b \text{ and}$$
$$K = -b$$

Also, the plot of residuals, re-expressed in %, and plotted against the midrange

of the time at large are used for preliminary identification of growth oscillations, through an iterative routine which identifies the time of the year that maximizes the difference between the means of two sets of residuals, covering 6 months each. A t-test is used to identify significant differences, and a preliminary estimation of C is obtained from:

$$C \geq \Delta d \, (\pi/2)$$

where

Δd relates the difference of the means of the two sets of residuals to the amplitude of the sinusoid growth oscillations.

Outputs   Preliminary estimates of K and L_∞, or of K alone if a "forcing" value of L_∞ is used; a t-test is used to indicate whether the residuals of the plot can be separated into two significantly different groups pertaining to two periods of sixth months, and hence suggest seasonal oscillations. If the test is positive, preliminary estimates of C and WP are outputted.

User interface   The routine contains three tabs (Fig. 4.14). The parameters (L_∞ and K) are automatically computed once a file has been identified.
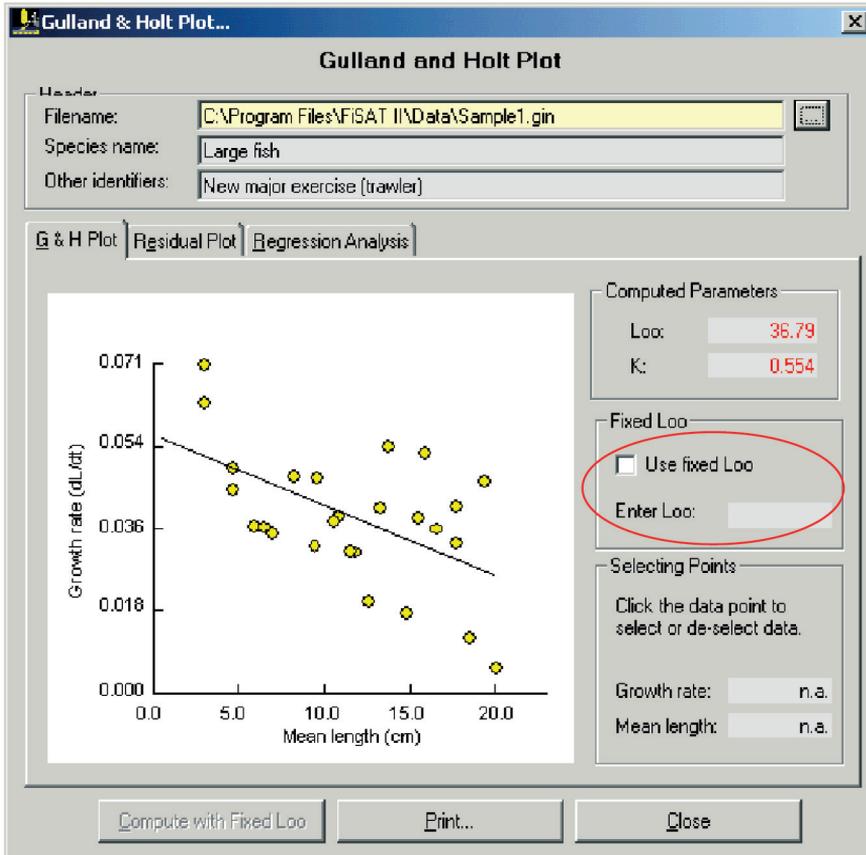
Fig. 4.14. User interface for the Gulland and Holt plot. A fixed value of L_∞ can be entered (red circle).

The user also has the option to encode a fixed value of L_∞. In which case, only the VBGF growth constant, K, will be computed. Growth seasonality will be inferred from the residual plot (Fig. 4.15) presented in the second tab based on the computed growth parameters. The third tab of the module summarizes the statistical results of the regression analysis to estimate the growth parameters from the Gulland and Holt plot.
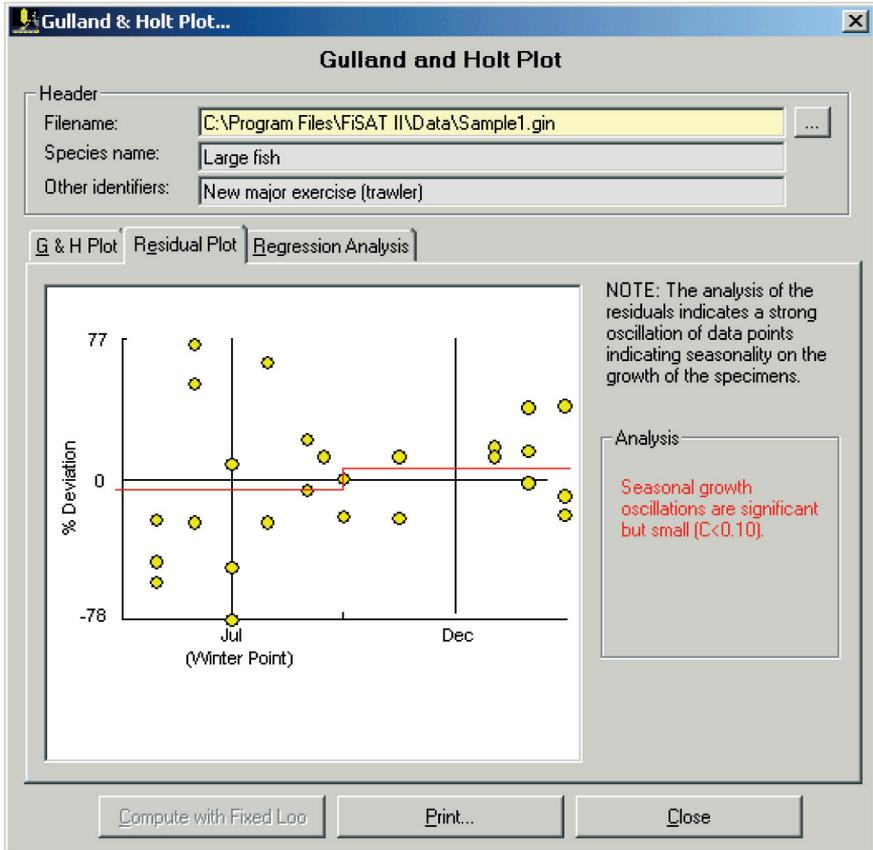
Fig. 4.15. Residual plot of the Gulland and Holt plot indicating seasonality of the growth.

Remarks	An option is provided to omit selected data points from the analysis, and/or to set the value of L_∞, leading to a "forced Gulland and Holt plot".
Readings	Gulland and Holt (1959) Pauly (1984a)

Munro's method

This method, based on Munro (1982), uses growth increment data to estimate L_∞ and K (**Option 1**), or K alone, given L_∞ (**Option 2**).

Required file	Growth increment data file

Input parameter Fixed value of L_∞ if fixed value option is selected

Function(s) Minimize the coefficient of variation of

$$\text{ratio} = [\ln(L_\infty - L_m) - \ln(L_\infty - L_r)]/(t_r - t_m)$$

where: L_m is the length at marking (initial reading), L_r is the length at recapture, and t_m and t_r the corresponding dates. Each growth increment leads to an estimate of K, given L_∞, and the variance of this estimate is computed; in **Option 1** the value of L_∞ is selected which minimizes that variance; under **Option 2** only the mean of the K estimate and its standard error are output, following input of L_∞.

Outputs **Option 1**: Estimate of K and L_∞
Option 2: Estimate of K, given L_∞

User interface The user interface of this routine contains three tabs (Fig. 4.16). The first tab presents the results of the analysis that follows immediately after a file has been identified for analysis. The user has the option to select or deselect data points for the analysis through the equivalent Gulland and Holt plot using the mouse. As points are selected or deselected, the results of Munro's plot are also re-computed and the graph re-plotted. The regression analysis of the Gulland and Holt plot is given on the

third tab, "Regression Results from Gulland & Holt Plot".
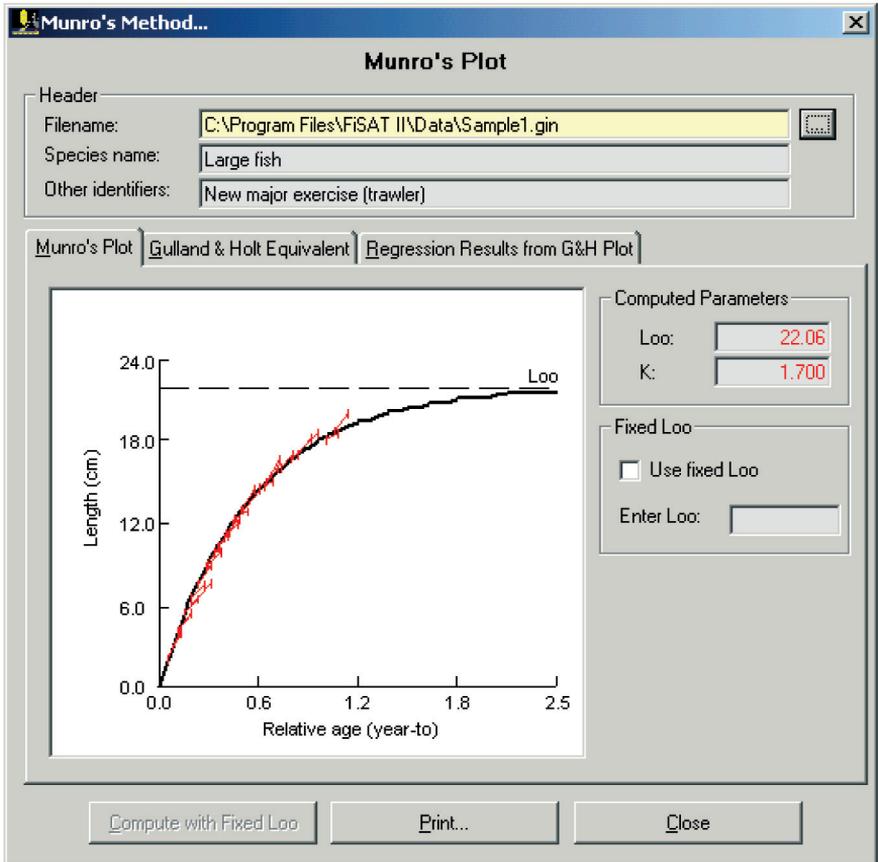
Fig. 4.16. User interface for the routine using Munro's method. This plot is recomputed automatically as data points are selected or deselected from the equivalent Gulland and Holt plot.

Remarks   The data pairs with lengths greater than L_∞ will be deselected automatically as these introduce negative values into the logarithmic expression of the function Note that this method does not account for seasonal growth oscillation.

Readings   Munro (1982)
Pauly (1984a)

<u>Fabens' method</u>

Fabens (1965) suggested a method for estimating L_∞ and K by predicting length at recapture (L_r') based on the current parameter selection and the length at marking (L_m). The growth parameters are estimated by minimizing the sum of squares of errors (SSE), i.e. the squared differences between the observed lengths at second reading (L_r) and the predicted lengths (L_r').

Required file	Growth increment data file
Input parameter	Fixed value L_∞ if fixed value option is selected
Functions	Minimize the following functions, using the Newton-Raphson iteration method:

$$\text{SSE} = \sum_i \left(L_{ri} - L_{ri}'\right)^2$$

where the predicted length at recapture (L_r') is given by

$$L_{ri}' = L_{mi} + (L_\infty - L_{mi})(1-\exp(-K\Delta t_i),$$
and
$$\Delta t_i = t_r - t_m$$

Outputs	Estimates of the L_∞ and K parameters of the VBGF, and their standard errors.
User interface	This module utilizes the same user interface as with the Munro's method. The plot (Fig. 4.17) is automatically computed after a file has been identified. Data points may be selected or deselected, using the mouse, from the equivalent plot using the Gulland

and Holt concept. As points are selected or deselected, the parameters are automatically re-computed and results re-plotted. The results of the regression analysis are given on the third tab.

Also, users have the option to enter a fixed value of L_∞.
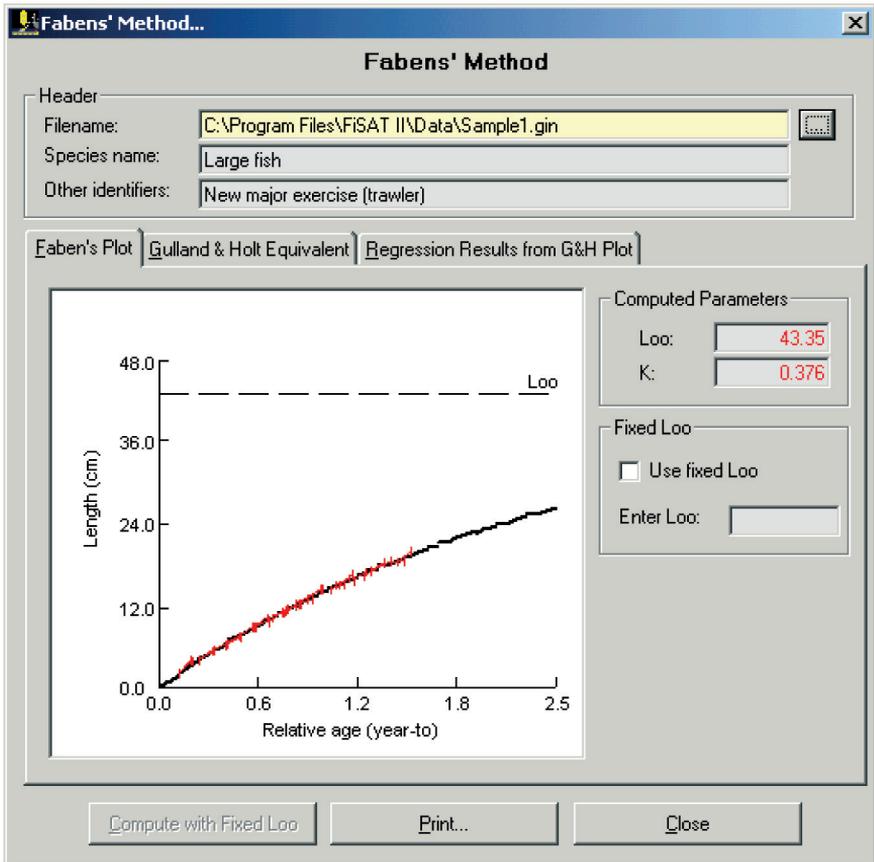
Fig. 4.17. User interface of Fabens' method in FISAT II. Data points may be selected or deselected from the equivalent representation in the Gulland and Holt plot.

Remarks   As with Munro's method (above), Fabens'method does not account for seasonal oscillation.

Reading   Fabens (1965)

Appeldoorn's method

This method, based on Appeldoorn (1987) and Soriano and Pauly (1989), allows the use of growth increment data to estimate the parameters of a seasonally oscillating version of the VBGF.

Required file Growth increment data file.

Input parameters The minimum and maximum constraints, and starting values for the growth parameters L_∞, K, C and WP.

Functions   Minimize the following function using Marquardt's algorithm for a non-linear fit:

$$SSE = \sum_1 \left\{ L_{i+\Delta t} - \left(L_\infty - \left(L_\infty - L_i\right) EXP\left(-\left(K\Delta t - S_t + S_{t+\Delta t}\right)\right)\right)\right\}^2$$

       where

       S_t $= (CK/2\pi) \cdot \sin(2\pi(t\text{-}ts))$,
       $S_{t+\Delta t}$ $= (CK/2\pi) \cdot \sin(2\pi((t+\Delta t)\text{-}ts))$,
       and,
       ts $= 0.5 + WP$.

Outputs   Estimates of L_∞, K, C, and WP and their standard errors.

User interface The user interface of this routine is similar to the user interface when analysing length-at-age data (Fig. 4.18). Users may enter a range of possible values and a starting estimate of the growth parameters. Default values are given based on the data.

The resulting growth curve of the analysis is plotted in the second tab (Fig. 4.19), "Growth Curve". A summary of the statistical parameters (partially presented in the second tab) is given in the third tab.

Fig. 4.18. User interface of Appeldorn's method in estimating growth parameters from growth increment data using a non-linear fit approach.

Remarks   For rapid convergence, the routine should be initiated with a *wide* range of constraints. To fix inputs at certain set values, enter minimum constraint = maximum constraint. Note that unlike

in the two previous routines, data points cannot be selected or deselected from this routine. Selection may be done by manually editing the source file.

Readings   Appeldoorn (1987)
Soriano and Pauly (1989)
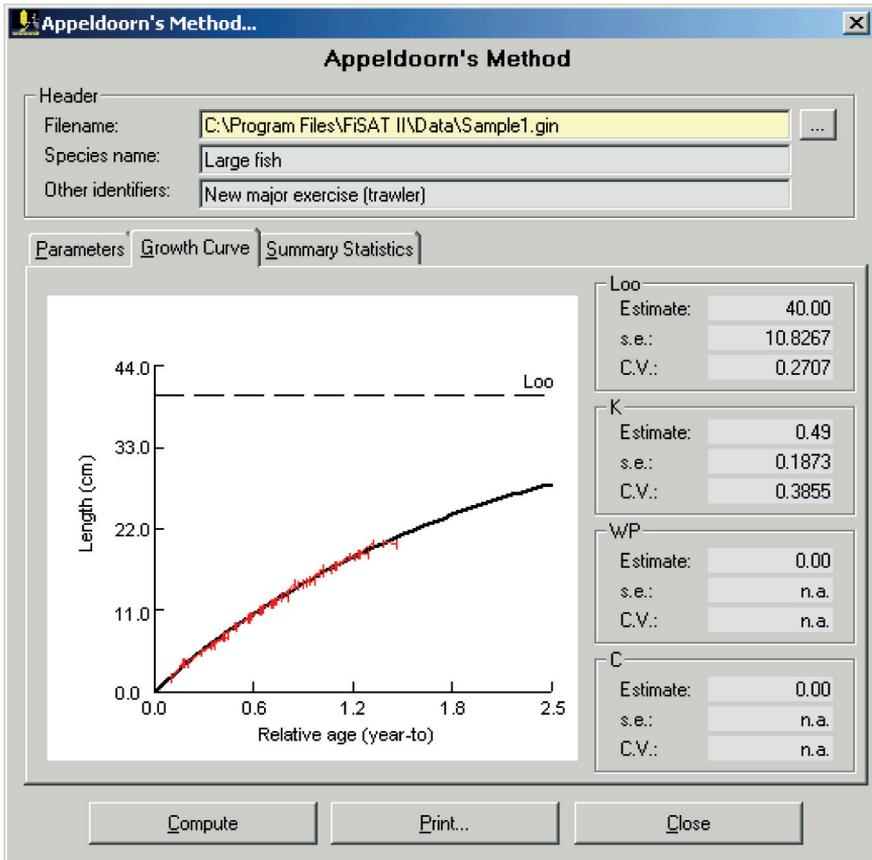
Fig. 4.19. The resulting growth curve computed using Appeldorn's model from growth increments.

Mortality estimation

Most of the routines to estimate mortality and related parameters incorporated in FiSAT II require estimates of growth parameters as obtained from the previous set of routines. They are grouped in FiSAT II as either (1) routines to estimate total mortality (Z) from steady-state sample or (2) routines to estimate mortality from natural causes (M), here assumed to be constant for all sizes.

Z from steady-state sample

The set of routines included here assumes that length-frequency samples are available which represent a steady-state population (as can be approximated by pooling a long series of samples).

Length-converted catch curves

FiSAT II provides two options for length-converted catch curve analysis: (1) length-converted catch curve for cases where growth does not exhibit annual oscillations, i.e. $C = 0$ and (2) length-converted catch curve for cases where growth exhibits annual oscillations, i.e. when $C > 0$.

Required file   Length-frequency data with constant class size

Input parameters L_∞, K, and t_o (t_o is a facultative entry, not required for estimation of Z) (and, for **Option 2**, C and WP) and identification of the smallest length class that is fully selected and recruited (L').

Option 1 provides an extension of the methodology, leading to the estimation of F, E ($= F/Z$) and probability of capture; here, an estimate of the mean

annual habitat temperature, (T, in °C) will be required, to estimate M from Pauly's empirical formula (see further below).

Functions

Option 1: Without seasonality

$$\ln(N_i/\Delta t_i) = a + b \cdot t_i$$

where

N is the number of fish in length class i, Δt is the time needed for the fish to grow through length class i, t is the age (or the relative age, computed with $t_o = 0$) corresponding to the mid-length of class i, and where b, with sign changed, is an estimate of Z.

Following estimation of Z, the routine can be used to estimate M using Pauly's M equation and F, from Z = M+F, as well as the exploitation ratio, E = F/Z.

Catch curve analysis can then be extended to an estimation of probabilities of capture by backward projection of the number that would be expected if no selectivity had taken place (N'), using

$$N'_{i-1} = N'_i \cdot EXP(Z\Delta t)$$

with Δt as defined above and

$$Z = (Z_i + Z_{i+1})/2,$$
$$Z_i = M + F_i,$$
$$F_{i-1} = F_i - X, \text{ and}$$
$$X = F / (\text{no. of classes below } P_1 + 1);$$

and where P_1 is the first length group with a probability of capture equal to 1.0, and whose lower limit is an estimate of L'. From this, probabilities of capture by length are computed from the ratios of N_i/N'_i.

Option 2: With seasonality

$$\ln(N) = a + b \cdot t'$$

where N is the number of fish in (pseudo) cohorts "sliced" by means of successive growth curves, t' the relative age of the fish in that pseudo-cohort, while b, with sign changed, provides an estimate of Z.

Outputs　　　**Option 1**
Estimates of Z, F, M, E, L', and probabilities of capture.

Option 2
Estimate of Z

User interface　　The first tab of the length-converted catch curve routine (Fig. 4.20) is similar to that presented for Powell-Wetherall's plot (Fig. 4.5) except that the growth parameters are required inputs. **Option 2** will be taken if parameters indicating seasonality in growth are given.
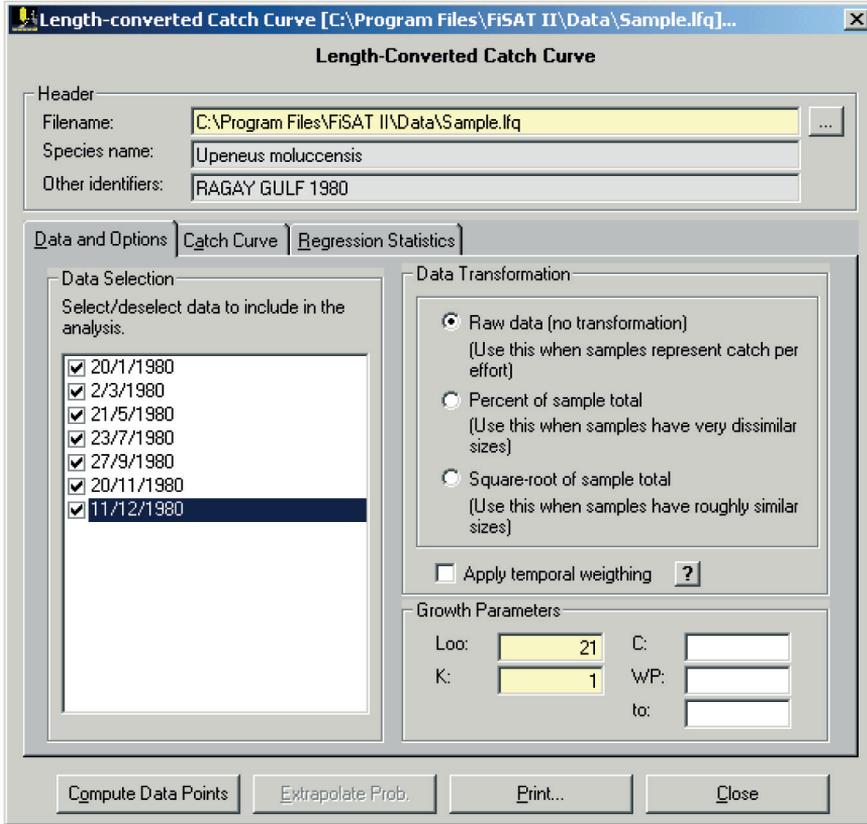
Fig. 4.20. The length-converted catch curve user interface in FiSAT II.

The growth parameters are required to compute the data points presented in the second tab.

If the required inputs are encoded, clicking the "Compute Data Points" will plot the results presented in the second tab (Fig. 4.21).
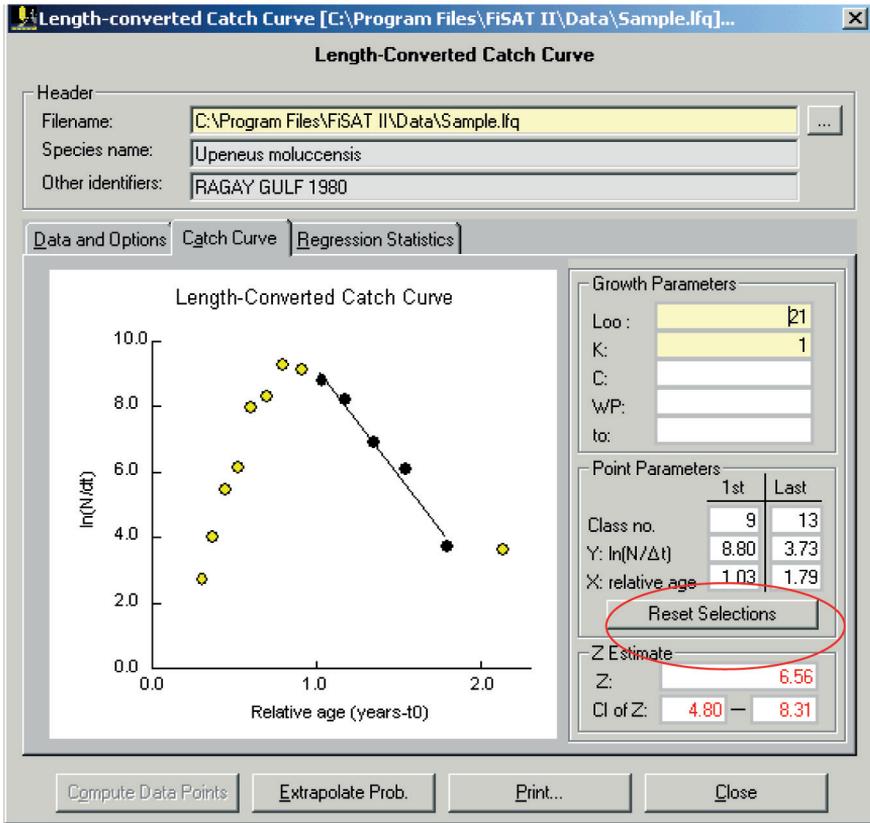
Fig. 4.21. Length-converted catch curve based on the growth parameters entered in the first tab of the user interface.

The first and last data points to be included in the regression analysis are computed automatically but users have the option to change the default points by clicking on the "Reset Selections" command button. The first and last data points may be selected or deselected using the mouse.

The statistical results of the regression analysis are presented in the third tab. When C is not given or set to zero, the regression line can be extrapolated to approximate the probability of capture given natural mortality. FiSAT II

provides the option to estimate this value using Pauly's empirical equation (Fig. 4.22).

Fig. 4.22. User interface to compute natural mortality (M) from Pauly's empirical equation. Users may encode the value of M directly that will be used in extrapolating points of the catch curve (Fig. 4.23)

The extrapolated points (Fig. 4.23) will be used to approximate the probability of capture. To estimate the selection parameters based on the extrapolated points, click the command button "Show Prob." that replaced the command button "Extrapolate Prob."

The probability of capture for each length group will be plotted and users have options to use either the logits plot or simply using the running average technique to estimate selection parameters (see below for detailed discussion on how to use the user interface in estimating the selection parameters).
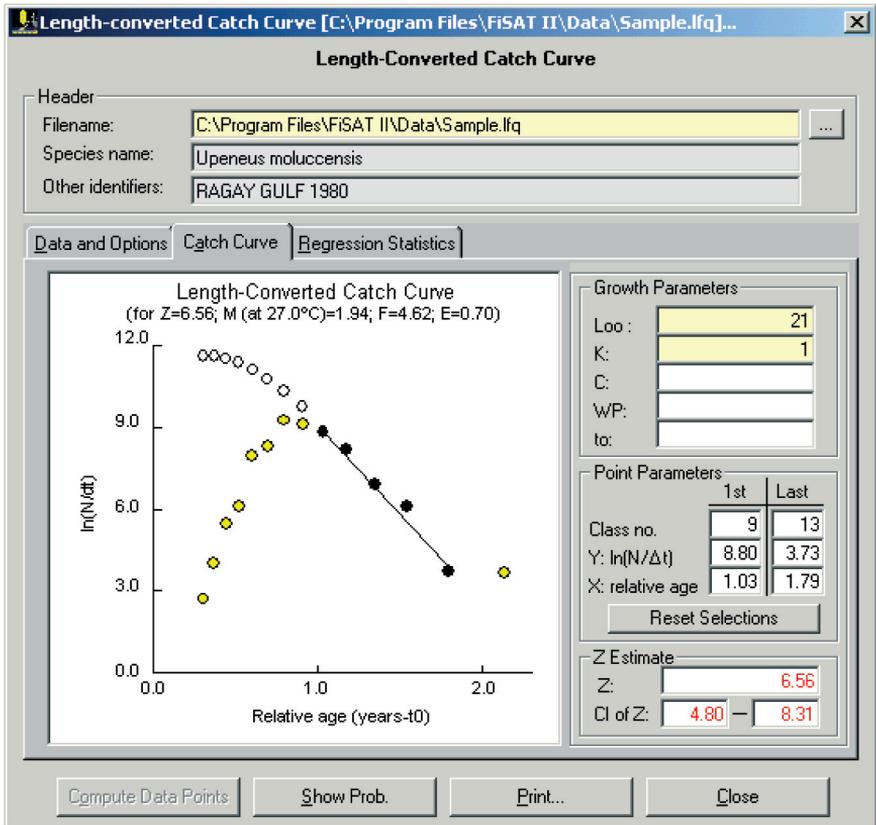
Fig. 4.23. Length-converted catch curve with extrapolated data points. Clicking "Show Prob." will open the dialog box to estimate the selection parameters (see further below for details).

Remarks   In both options, defaults for the points to be included in the regression analysis are proposed by FiSAT II; use these only if no better sequence of points can be identified by visual inspection of the catch curve.

Option 1 provides the facility to proceed to the estimation of L_{25}, L_{50} and L_{75}. This routine is discussed further below.

Readings   Pauly (1984a; 1984b; 1990)

Jones/van Zalinge plot

The cumulative plot of Jones and van Zalinge is an early form of length-converted catch curve and these two methods thus share many common assumptions.

Required file   Length-frequency data with constant class interval.

Input parameters L_∞ and K (or 1 if K is unknown), with graphical selection of the points to be used in the regression analysis.

Function $\ln(C_{Li,\infty}) = a + b \cdot \ln(L_\infty - L_i)$

where

$C_{Li,\infty}$ is the cumulative catch (computed from the highest length class with non-zero catch) corresponding to length class i,

and

L_i is the lower limit of length class i. The slope b, is an estimate of Z/K.

Outputs   Z or Z/K if 1 was entered instead of K.

User interface   The first tab of this user interface identifies the file and provides options (see Fig. 4.5) for temporary data transformation.

The data points will be plotted after encoding the growth parameters to be used in the analysis. Points to be included in the regression analysis are not automatically identified by FiSAT

II as in the case of the length-converted catch curve routine. The user will be required to identify the first and last points to be included using the mouse (Fig. 4.24).

The details of the regression analysis are given in the third tab.
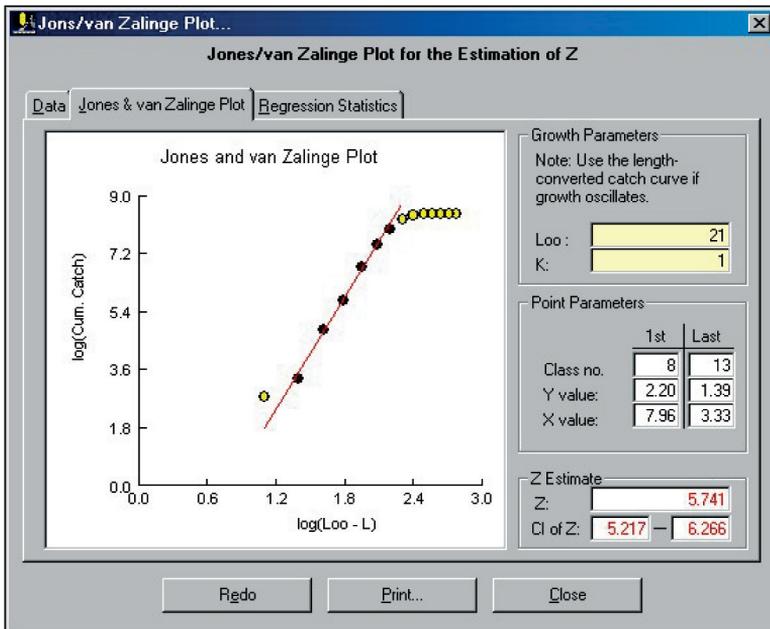
Fig. 4.24. User interface of the Jones and van Zalinge plot to estimate total mortality.

Remarks   This routine was included in FiSAT II mainly for comparison, as it lacks many of the advantages of length-converted catch curves (independence of the data points, ability to deal with seasonal growth oscillations, etc.), without offering any distinct advantage over catch curves.

Readings   Jones (1984)
Jones and van Zalinge (1981)

Z from mean length

Two routines are available in FiSAT II which derive estimates of Z from mean lengths:

Beverton and Holt model

This model, a classic developed by Beverton and Holt (1956), assumes that growth follows the VBGF, that mortality can be represented by negative exponential decay, and that L is estimated from a sample representing a steady-state population.

Required file   None

Input parameters   Growth parameters L_∞ and K, cut-off length (L') and mean length ($\overline{L}$) above L'.

Function $Z = K \cdot (L_\infty - \overline{L})/(L_\infty - L')$

Output   Estimate of Z

User interface   This routine will require only the inputs to the growth parameters (L and K), mean length and the cut-off length to estimate the total mortality. Note that if K is unknown and set to 1, the result should be read as Z/K.

If a value is altered, clicking the "Compute" command button will re-compute the Z estimate (Fig. 4.25).
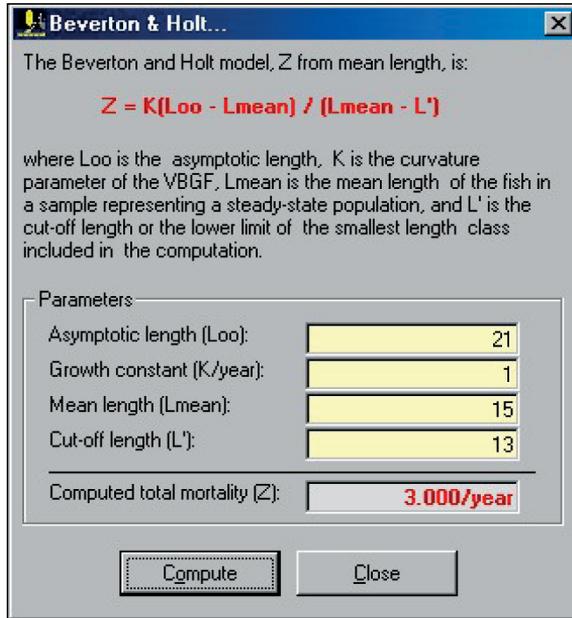
Fig. 4.25. User interface in estimating the total mortality using the Beverton and Holt model.

Remarks   This routine is presented along with the model of Ault and Ehrhardt (see below) because the inputs are similar. This model is best applied to long living and slow growing species.

Reading   Beverton and Holt (1956)

Ault and Ehrhardt method

Unlike the Beverton and Holt Z equation (above), this model does not assume an infinite life span for the fish of the stock being analysed and thus is applicable to short-lived tropical species.

Required file   None

Input parameters   Growth parameters L_∞ and K, the cut-off length (L'), the mean length ($\overline{L}$) and the maximum length (L_{max})

Functions
$$\left(\frac{L_\infty - L_{max}}{\overline{L} - L'}\right)^{Z/K} = \left(\frac{A(L')}{A(L_{max})}\right)$$

where
$A(L') = Z(L'-\overline{L})+K(L_\infty-\overline{L})$, and
$A(L_{max}) = Z(L_{max}-\overline{L})+K(L_\infty-\overline{L})$

Outputs   Estimate of Z

User interface   As with the previous routines, the total mortality will be estimated only after the required inputs are given (Fig.4.26).

Fig. 4.26. User interface to estimate the total mortality using the Ault and Ehrhardt model in FiSAT II.

Remarks   The function is solved iteratively. The value of L_{max} required here may be the largest specimen in a set of samples, or L'_{max} as estimated via the extreme value theorem (see Chapter 5). The required $\bar{L}$ and L' can be obtained as for the Beverton and Holt model (see above).

Readings   Ault and Ehrhardt (1991)
                     Ehrhardt and Ault (1992)

<u>Hoenig's model</u>

The method below relates t_{max} (i.e. the longevity of fish) and mortality.

Required file   None

Input parameters t_{max} (maximum age in years) observed in a given stock and as an option, t_c (mean age at first capture) and the sample size, N from which t_{max} was estimated.

Functions   When t_c and N are not available, Z is computed from the empirical model

$$\ln(Z) = 1.44 - 0.984 \cdot \ln(t_{max})$$

When t_c and N are available, total mortality is estimated from

$$Z = 1 /(c_1 \cdot (t_{max} - t_c))$$

and the standard error (s.e.) of the estimated Z is from the relationship:

$$\text{s.e.}(Z) = (c_2 \cdot Z^2)^{\frac{1}{2}}$$

where c_1 and c_2 are table values and a function of N (these table values are pre-programmed in FiSAT II).

Output   Estimate of Z

User interface   The user interface of this routine provides the user with options on what model to use as presented by the author of the model. Note that the text boxes for N and tc will be enabled only if the checkbox for Model 2 is checked using the mouse (Fig. 4.27).

Remarks   The estimates of Z obtained by these models (particularly the first) are rather approximate, and should be validated using other methods.
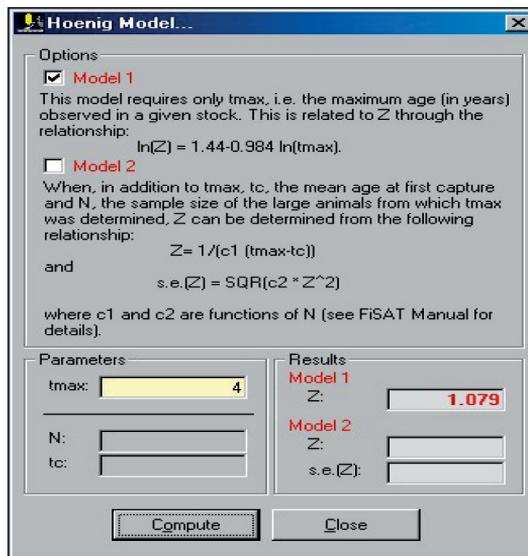
Fig. 4.27. User interface of Hoenig's model as implemented in FiSAT II. Note that the estimates using the two models can be calculated simultaneously.

Tabulated values of c_1 and c_2 may be found in Hoenig and Lawing (1982) and Pauly (1984a).

Readings Hoenig (1982)
Hoenig and Lawing (1982)
Pauly (1984a)

Natural mortality

In fish stock assessment, natural mortality is the most difficult parameter to estimate. The following models, two empirical and one analytical, may be useful to approximate M.

Rikhter and Efanov's method

A variant of the Beverton and Holt (1956) equation which relates longevity (t_{max}) with the L_{mass}/L_∞ ratio (where L_{mass} is the mean length at first maturity), this model relates natural mortality (M) to the age at which 50% of the stock reaches the age of "massive spawning" (t_{mass}).

Required file None

Input parameter t_{mass} ($\approx$ age at first maturity)

Function $M = ((1.52/t_{mass}) \cdot 0.72) - 0.16$

Output Estimate of M

User interface The dialog box for this routine will require only the input of the age at massive maturation to estimate the natural mortality (Fig. 4.28)**.**
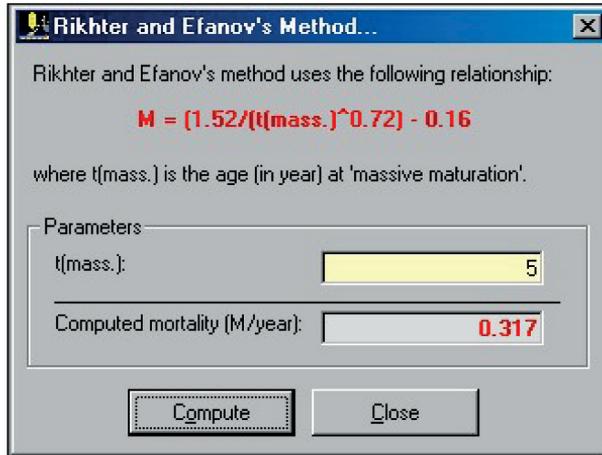
Fig. 4.28. User interface to estimate natural mortality using Rikhter and Efanov's empirical model.

Remarks   The derivation of the model was based largely on data from boreal/temperate stocks and should not be used for tropical stocks without prior comparison with the results of other models.

Reading   Rikhter and Efanov (1976)

Pauly's M equation

These equations were derived from 175 independent sets of estimates of M and predictor variables for most tropical species. Two options are provided; (1) for cases when L_∞ is available and (2) for cases when W_∞ is available.

Required file   None

Input parameters   Growth parameters L_∞, (in cm) or W_∞ (in g) and K (year^{-1}) and T [mean annual habitat temperature (in °C)]. The values of L_∞ to be used should refer to or approximate total length.

Functions   **Option 1**: L_∞ is given

$$\ln(M) = -0.0152 - 0.279 \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T),$$

and

Option 2: W_∞ is given

$$\ln(M) = -0.4851 - 0.0824 \ln(W_\infty) + 0.6757 \ln(K) + 0.4687 \ln(T)$$

Output   Estimate of M

User interface   The user interface of this routine provides the users with the two options to estimate natural mortality (M) based on Pauly's M empirical equations. Option 1 is the default model. Clicking on the second option (red circle in Fig. 4.29) will change the labels of the function and input fields.

Fig. 4.29. User interface to estimate the natural mortality using Pauly's M empirical equations.

Remarks	These equations provide reasonable estimates of M for fish, and perhaps shrimps and squids as well, but should not be applied to bivalves for which M≈K may provide a better approximation. The models assume L_∞ to be in cm, and W_∞ in g; FiSAT II automatically performs any required transformation. Also, values of T down to -2°C can be entered and are adjusted internally.
Readings	Pauly (1980, 1984a)

Recruitment patterns

This routine reconstructs the recruitment pulses from a time series of length-frequency data to determine the number of pulses per year and the relative strength of each pulse.

Required file	Length-frequency data with constant class size.
Input parameters	Growth parameters: L_∞, K, (C, WP), and t_o if available.
Functions	Backward projection, along a trajectory defined by the VBGF, of the frequencies onto the time axis of a time-series of samples (one single, but well-structured sample may also be used). Two options are provided; **Option 1,** use of the length-frequency data. **Option 2**, use of restructured data.

Output   Plot showing the seasonal pattern of
                  recruitment.

User interface The user interface for this routine
                  contains three tabs. The first tab is to
                  identify the file to analyse and options
                  for data transformation (Fig. 4.30).
                  Another option is provided to the user,
                  i.e. the use of the length frequency data
                  as it is and use of restructured data as is
                  done in ELEFAN I.
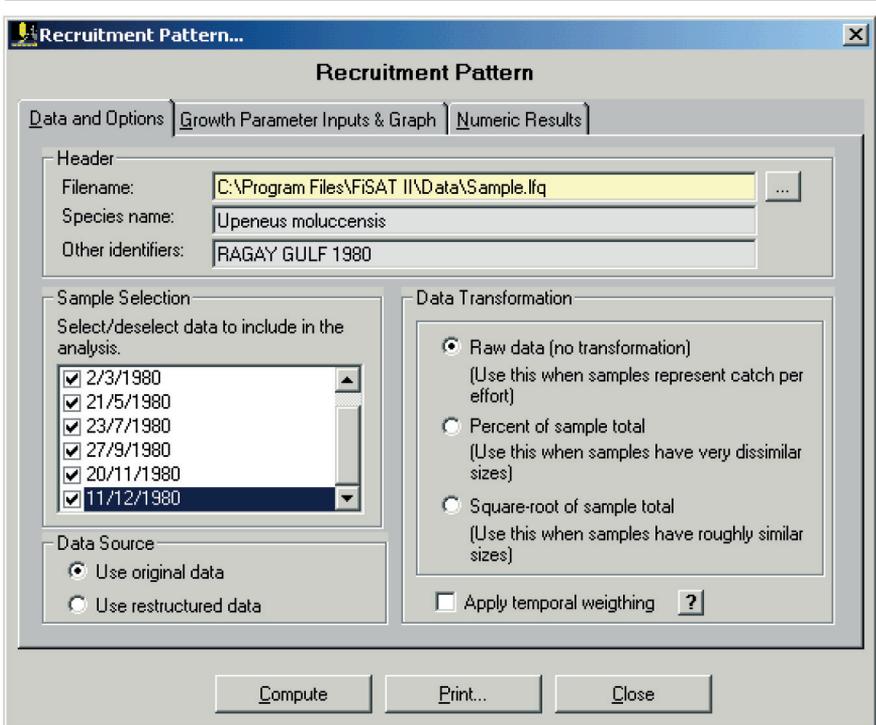
Fig. 4.30. File identification tab and options to temporarily transform data before data analysis.

The growth parameters are required
inputs and clicking the "Compute"
command button will compute the
recruitment pulse(s) (Fig. 4.31). In
cases where there are two recruitment

pulses, the composite data can be decomposed using the approach as implemented in NORMSEP (see above). In this case, starting estimates of the mean (in months) are required to compute the Gaussian distributions. The numeric results are given on the third tab.

When t_o is set equal to zero, the ordinate scale of the plot will be relative, not calendar time.
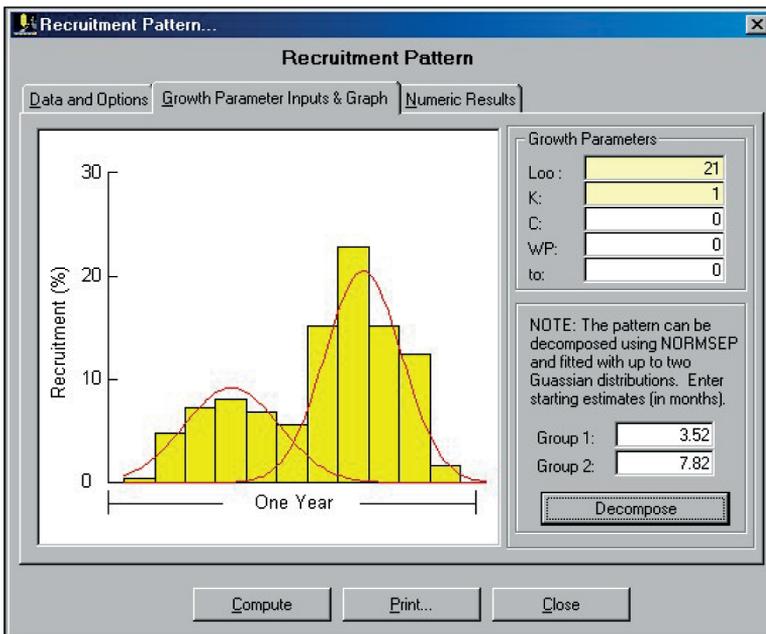
Fig. 4.31. User interface to estimate the recruitment pulses in FiSAT II.

Remarks   The results generated by this routine should be treated as approximations because, while allowing statements on the number of annual pulses and on their relative strength, this model is based on two assumptions that are rarely met in reality: (i) all fish in the

sample grow as described by a single set of growth parameters and (ii) one month out of twelve always has zero recruitment. When using restructured data, the temporal spread reduces and thus probably better reflects the actual seasonality of recruitment. As an additional option, FiSAT II also allows the user to analyse recruitment patterns using a maximum likelihood approach (see section on NORMSEP) to fit a Gaussian distribution.

Readings   Moreau and Cuende (1991)
Pauly (1983)

Probabilities of capture

"Probabilities of capture..." leads, in FiSAT II, to those routines that can be used to determine gear-specific selection curves.

Trawl-type selection

Trawl-type selection curves are characterized by left-hand selection, i.e. small fishes escape through the mesh and hence are not caught. In most cases, this type of data is obtained from trawl selection experiments, which usually consist of covering the cod-end whose selectivity is to be assessed with a fine-mesh cover. However, similar information may also be obtained from length-converted catch curves, by backward extrapolation of the catch curve, and comparison of the numbers actually caught with those that "ought" to have been caught.

To estimate selection parameters, (L_{25}, L_{50}, L_{75}), FiSAT II provides the user with the options of either: (1) using the logistic curve, which assumes selection to be symmetrical

or nearly so or (2) using moving averages over three classes and interpolating the selection parameters.

Required file   Probability data file

Input parameters   **Option 1:** Logistic curve

Visual selection of the points of a logits plot to be used for the regression analysis.

Option 2: Moving average

None

Functions   **Option 1:** Logistic curve

$$\ln((1/P_L)-1) = S1 - S2 \cdot L$$

where P_L is the probability of capture for length L, and

$$L_{25} = (\ln(3)-S1)/S2$$
$$L_{50} = S1/S2$$
$$L_{75} = (\ln(3)+S1)/S2$$

Option 2: Moving average

$$P_{L,i(new)} = (P_{L,i-1}+P_{L,i(old)}+P_{L,i+1})/3,$$

which provides a smoothed series of probabilities from which L_{25}, L_{50} and L_{75} are estimated through linear interpolation.

Outputs   Estimates of L_{25}, L_{50} and L_{75}

User interface   This routine (Fig. 4.32) requires a probability of capture file that can be created based on selection experiments

or from a length-converted catch curve routine (see above). This routine can also be accessed directly from a length-converted catch curve routine.

Two options are provided to the user to estimate the selection parameters. The use of the logistic transformation plot (also referred to as logits; Fig. 4.33) will require the user to identify at least three data points to be included in the analysis (default is all data points will be used). The use of the running average technique will not require additional user intervention to estimate the parameters.
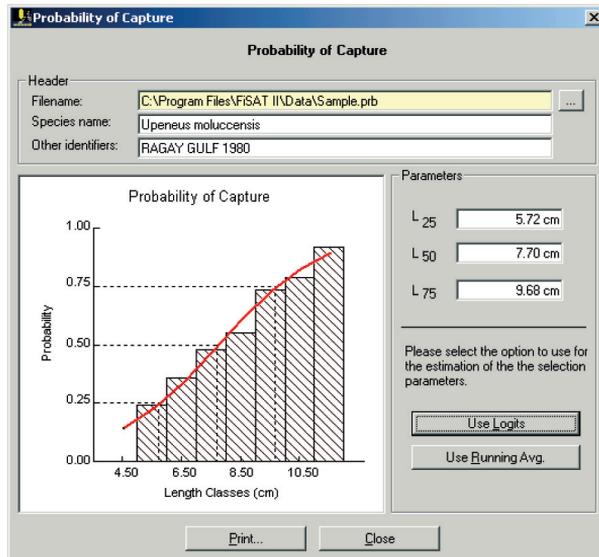
Fig. 4.32. The user interface for the estimation of the selection parameters using either logistic transformation or running average technique.
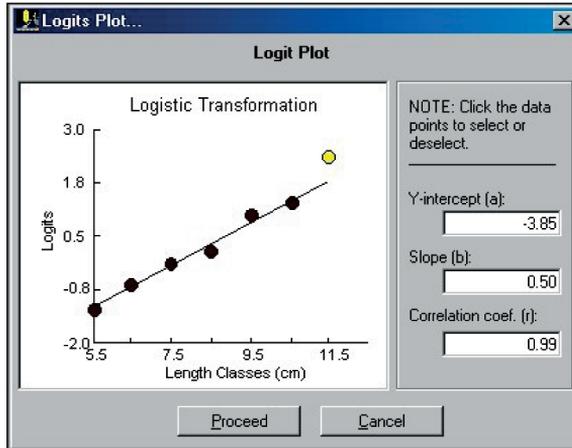
Fig. 4.33. Logistic transformation of the data points to identify points to be included in the analysis.

| *Remarks* | This routine may also be accessed directly from the length-converted catch curve analysis. The selection curve can be saved to a file for subsequent analysis of L/F data for the effects of gear selection and incomplete recruitment or as an input to yield per recruit analysis. |

| *Reading* | Pauly (1984a) |

Gillnet selection

The selection curves of gillnets (and some other gears such as hooks) are characterized by strong left-hand *and* right-hand selection. This selection type can be modelled using normal (**Option 1**) or log-normal (**Option 2**) selection curves.

| *Required file* | Length-frequency data file with constant class size with two samples representing the catches (in numbers) of two gillnets of different mesh sizes, with at least 3 overlapping non-zero length classes. |

Input parameters   Mesh sizes of the two selected samples (m_A and m_B), where one (m_A) should be smaller than the other.

Functions   The probability of capture for mesh size m_A and m_B at a given length L is,

$$P_{A,L} = \exp\left(-\left((L-L_A)^2/(2\cdot\sigma^2)\right)\right),$$
$$P_{B,L} = \exp\left(-\left((L-L_B)^2/(2\cdot\sigma^2)\right)\right),$$

where L_A and L_B (the optimum length for mesh sizes m_A and m_B respectively) are given by

$$L_A = SF \cdot m_A,$$
$$L_B = SF \cdot m_B,$$

and where SF is the selection factor computed from,

$$SF = (-2a)/(b\cdot(m_A+m_B)).$$

The coefficients a and b are estimated from the regression:

$$\ln(C_{i,B}/C_{i,A}) = a + b \cdot L_i$$

where the index i denotes length classes, and $C_{i,A}$ and $C_{i,B}$ are the observed catches (in numbers) for class i of gears A and B, respectively.

The standard deviation (σ), assumed equal for both mesh sizes, is then computed from

$$\sigma = \left((2\cdot a\cdot(m_A-m_B)/(b\cdot(m_A+m_B)))\right)^{1/2}$$

For **Option 2**, the logarithms of the variables referring to length (L_i, m_A, m_B) are first taken before the functions are applied.

Outputs Probabilities of capture by length for each mesh size and the joint standard deviation (σ).

User interface The user interface of this routine has two tabs. The first tab (Fig. 4.34) is to identify the length frequency file (with at least two samples). In addition, the two samples have to be identified and corresponding mesh sizes encoded.

Fig. 4.34. User interface to identify the length frequency file, the samples and corresponding mesh sizes used to generate the catches.

Once the required inputs have been entered, clicking on the "Compute" command button will plot the distribution (Fig. 4.35) and estimate the probability curve that can be saved as probability data for further analysis.
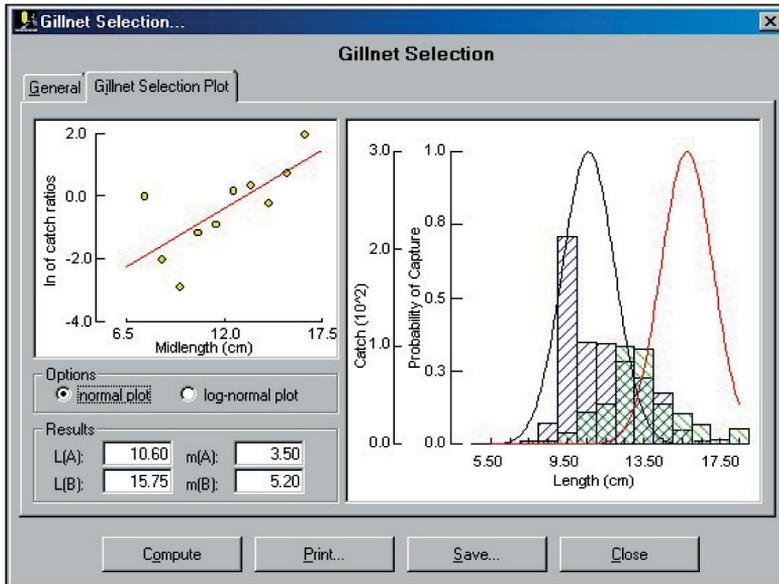
Fig. 4.35. Computed probability curve based on catch data from two gillnets of different sizes.

Remarks   The mesh sizes (m_A, m_B) will be read from the "Gear description" field in sample sub-headers (default values) if they are not entered at run time. Also, note that the normal and log-normal models are performed concurrently and that the user can toggle between the results from both models.

Readings   Pauly (1984a)
Pauly (1983)

Virtual population analysis

Virtual population analyses (VPA) are methods which allow the reconstruction of the population from total catch data by age or size.

Age-structured VPA

This is the version of VPA proposed by Gulland (1965).

Required file   Catch-at-age data file

Input parameters   Natural mortality (M), an initial guess of terminal fishing mortality (F_t), and the time interval between age groups (in years).

Functions   The reconstruction of the population starts by estimating the terminal population (N_t) given the inputs, from

$$N_t = C_t \cdot (M + F_t)/F_t$$

where C_t is the terminal catch (i.e. the catch taken from the oldest age group).

Then, starting from N_t, successive values of F in the previous age group are estimated, by iteratively solving

$$C_i = N_{i+1} \cdot (F_i/Z_i) \cdot (EXP(Z_i)-1)$$

with population sizes (N_i) computed from,

$$N_i = N_{i+1} \cdot EXP(Z_i)$$

The last two equations are used alternatively, until the population sizes

and fishing mortality for all age groups have been computed.

Outputs   Plot of the reconstructed population and fishing mortality for each age group.

User interface   The routine (Fig. 4.36) requires catch-at-age data and inputs of the required parameters (in years). The second tab (Fig. 4.37) presents the results of the analysis. The stacked histograms present the survivors, population lost to natural causes and the catches. Overlaid in the stacked histograms is the computed F-array. The numeric results are presented in the third tab.

Fig. 4.36. File identification and input of parameters when analysing catch-at-age data using the age-structure VPA in FiSAT II.
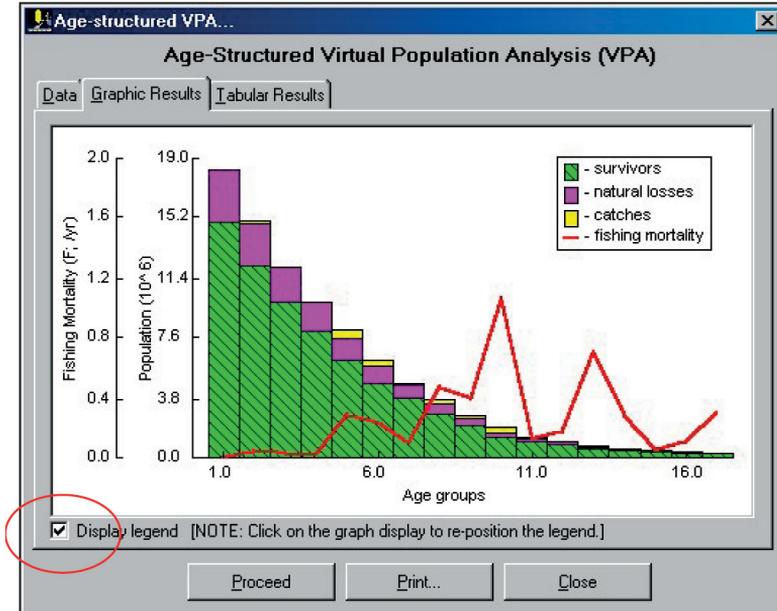
Fig. 4.37. VPA plot of the results. Note the option to display the legend and position it anywhere on the graph.

Readings	Gulland (1965)
	Mesnil (1985)
	Pauly (1984a)
	Pope (1972)

Length-structured VPA

This routine modified from Jones and van Zalinge (1981) utilizes basically the same approach as the previous routine (age-structured VPA), but is adapted to accommodate length frequencies.

Required file Length-frequency data file (representing mean annual catch at length, see below).

Input parameters L_∞ and K. Note that L_∞ must be at least 10% larger than the largest fish in the file. If you need to increase L_∞, use ø' to

reduce K accordingly. Alternatively a plus group may be created.

Functions

The initial step is to estimate the terminal population (N_t) given the inputs, from

$$N_t = C_t \cdot (M + F_t)/F_t$$

where C_t is the terminal catch (i.e. the catch taken from the largest length class).

Then, starting from N_t, successive values of F are estimated, by iteratively solving,

$$C_i = N_{i+\Delta t} \cdot (F_i/Z_i) \cdot (EXP (Z_i \cdot \Delta t_i)-1)$$

where

$$\Delta t_i = (t_{i+1} - t_i),$$

and

$$t_i = t_o - (1/K) \cdot \ln(1-(L_i/L_\infty))$$

where population sizes (N_i) are computed from

$$N_i = N_{i+\Delta t} \cdot EXP (Z_i)$$

The last two equations are used alternatively, until the population sizes and fishing mortality for all length groups have been computed.

Outputs

An F-array representing the fishing mortality for each length group, the

reconstructed population (in numbers), and the mean stock biomass by length class.

User interface   The user interface of this routine contains three tabs. The first tab (Fig. 4.38) is to identify the file to use and data transformations. Note that if data were raised by some value, this should be re-transformed to represent catches (in numbers; red circle in Fig. 4.38).
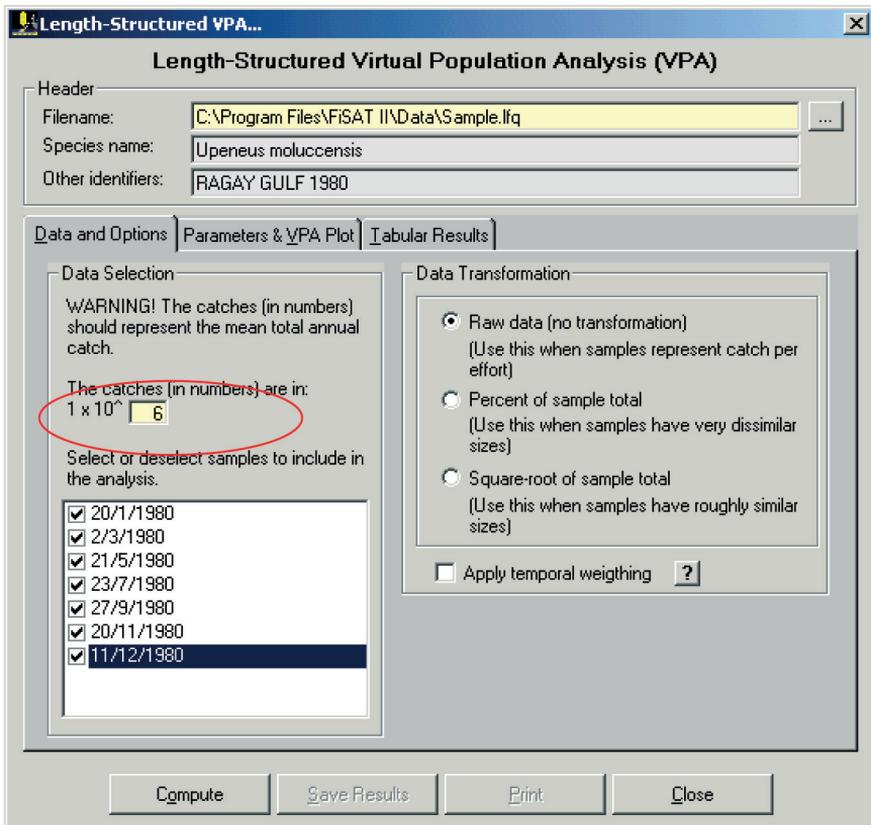
Fig. 4.38. Data identification tab of the length-structured VPA routine in FiSAT II.

The required parameters, including the initial estimate of the terminal fishing mortality (Ft) are given in the second tab (Fig. 4.39).

As in the age-structured VPA, the legend can be displayed and re-positioned on the graph.

To alter the value of the terminal F graphically, check the "Modify terminal F from Graph" option and click on the graph to represent the position of the terminal F. If the mouse is pointing to a length group less than the largest recorded length, a +Group will be generated.
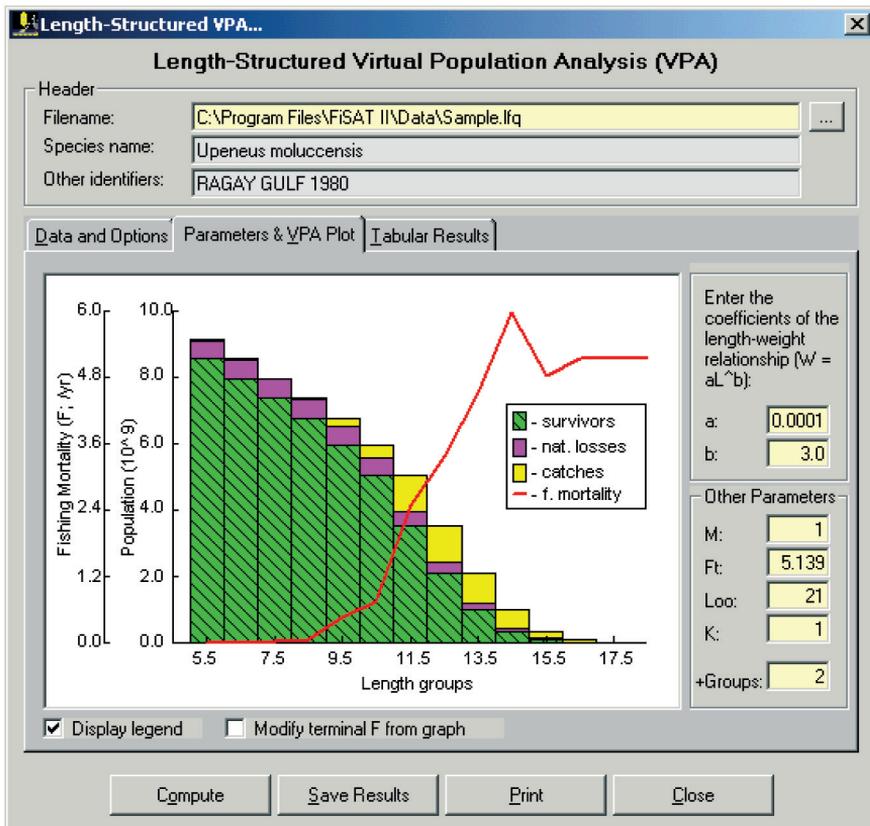
Fig. 4.39. Results of the length-structured Virtual Population Analysis (VPA). The terminal F may be modified directly from the graph.

The numeric equivalent of the graph is given in the third tab.

The resulting F-array can be saved as a Species Table that can be accessed directly when creating Scenario Files for the Thompson and Bell routine of FiSAT II.

Remarks   The "length-frequency" file used here must in fact consist of total annual catch-at-length data, in numbers. It may be the average total catch of several years.

Reading   Pauly (1984a)

Predictions

While the previous routines of ASSESS are used to estimate the value of certain parameters, the routines below, which *require* these inputs, are meant to be used for yield and stock predictions, and hence, to identify appropriate management regimes.

Relative Y/R and B/R analysis: Knife-edge selection

The relative yield-per-recruit model based on the Beverton and Holt model of 1966.

Required file   None

Input parameters L_c/L_∞ ratio (from 0.05 to 0.95) and M/K ratio (from 0.10 to 9.99)

Functions　　　　Relative yield-per-recruit (Y'/R) is computed from:

$$Y'/R = E \cdot U^{M/K}\left\{1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{U^3}{(1+3m)}\right\}$$

where

$U = 1-(L_c/L_\infty)$
$m = (1-E)/(M/K) = (K/Z)$
$E = F/Z$

Relative biomass-per-recruit (B'/R) is estimated from the relationship

$B'/R = (Y'/R)/F$, while

E_{max}, $E_{0.1}$ and $E_{0.5}$ are estimated by using the first derivative of this function.

Outputs　　　　Plots of Y'/R vs E (=F/Z) and of B'/R vs E, from which E_{max} (exploitation rate which produces maximum yield), $E_{0.1}$ (exploitation rate at which the marginal increase of relative yield-per-recruit is $1/10^{th}$ of its value at E=0) and $E_{0.5}$ (value of E under which the stock has been reduced to 50% of its unexploited biomass) are also estimated.

User interface　　FiSAT II automatically plots the Y'/R isopleths diagram with M/K set to 1.00. If the user changes the M/K value (red circle in Fig. 4.40), a new isopleths diagram will be plotted automatically.
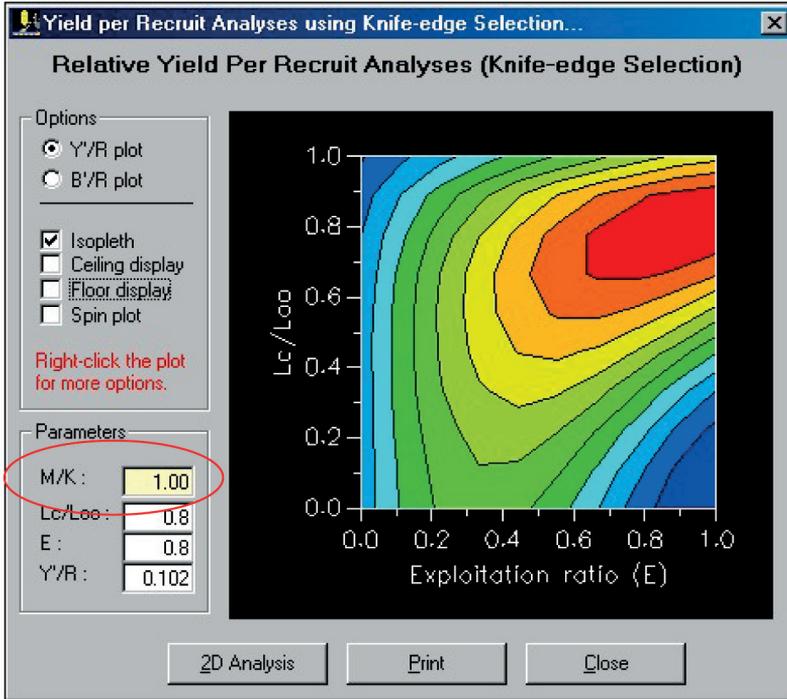
Fig. 4.40. Y'/R isopleths diagram with M/K value set to 1.0 (see figures 4.41 and 4.44 for facsimile presentations of other possible options in the presentation of the results).

The user interface also provides other options for viewing the results. Fig. 4.41 is an example of a 3D presentation of results for B'/R using the same M/K value. Note that the ceiling display, floor display and spin plot options are applicable only when the plot is presented in 3D.

To manually spin the plot in all axes, click both buttons of the mouse and drag the plot to the desired viewing angle.

Whether the results are presented as isopleths or in 3D, moving the mouse over the plot identifies the numeric values of the plot.

A 2D plot of the results (see a similar plot in Fig. 4.44) may also be plotted by clicking on the "2D Analysis" command button.
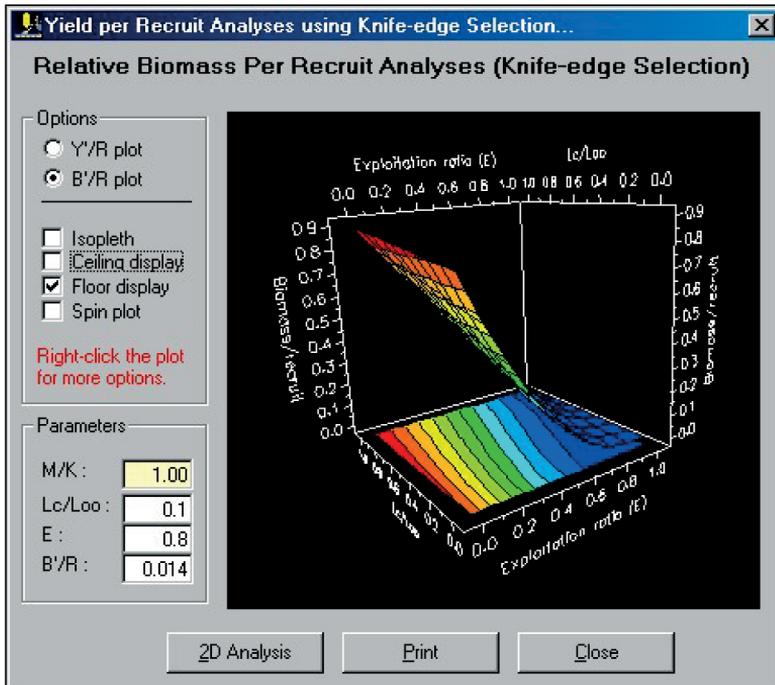
Fig. 4.41. 3D presentation of the B'/R plot with a floor display of the results.

Remarks   An example of the 2D graph is given in Fig. 4.44.

Readings   Beverton and Holt (1966)

Relative Y/R and B/R analysis: Using selection ogive

The relative yield-per-recruit model presented in the following is based on the Beverton and Holt model of 1966, modified by Pauly and Soriano (1986).

Required file   Probabilities of capture data

Input parameters L_∞, K and M

Functions   Relative yield-per-recruit (Y'/R) is computed from

$$Y'/R = \Sigma P_i((Y'/R)_i \cdot G_{i-1}) - ((Y'/R)_{i+1} \cdot G_i))$$

where

$(Y'/R)_i$ refers to the relative yield-per-recruit computed from the lower limit of class i using

$$(Y'/R)_i = E \cdot U^{M/K} \left\{ 1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{U^3}{(1+3m)} \right\}$$

where U and m are defined as above,

P_i is the probability of capture between L_i and L_{i+1}, while G_i is defined by

$$G_i = \Pi \, r_j$$

where

$r_j = (1-c_i)^{S_i}/(1-c_{i-1})^{S_i}$, and

$S_i = (M/K)(E/(1-E))P_i$.

Here, B'/R is estimated from

$$(B'/R)_i = (1-E) \cdot A/B$$

where

$$A = \left\{ 1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{U^3}{(1+3m)} \right\}$$

$$B = \left\{ 1 - \frac{3U}{(1+m')} + \frac{3U^2}{(1+2m')} - \frac{U^3}{(1+3m')} \right\}$$

and where $m' = 1/(M/K) = m/(1-E)$.

E_{max}, $E_{0.1}$ and $E_{0.5}$ are estimated by using the first derivative of the function.

Outputs

Plots of Y'/R vs E (=F/Z) and of B'/R vs E, from which the E_{max}, $E_{0.1}$ and $E_{0.5}$ (as defined above) are also estimated.

In addition to these two-dimensional outputs, the user has the option to plot yield-isopleths diagrams, which can be used to assess the impacts on yields of changes of E (corresponding to the level of exploitation) and of c (= L_{50}/L_{∞}, corresponding to a change of mesh size).

User interface

The user interface of this module is very similar to the presentation of the results using the knife-edge assumption. The display options are the same. However, a selection data (probability file) has to be loaded before any calculations are done by the routine (Fig. 4.42).
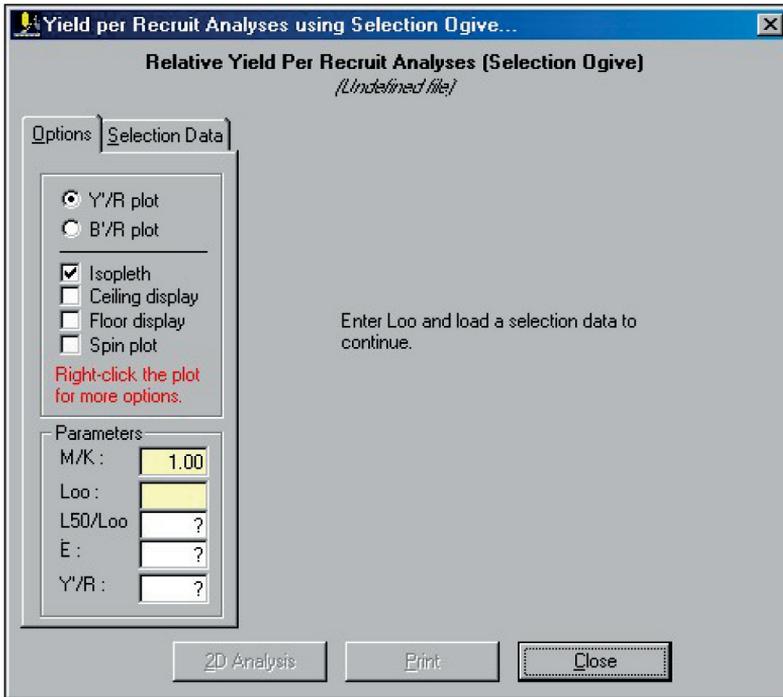
Fig. 4.42. Initial display of FiSAT II when the Beverton and Holt Y/R model using selection ogive routine is accessed. A probability of capture file is required by the routine.

The L_∞ used in previous calculations using the file or associated files are used as defaults. The user may change the value to compute new points of the plot.

As in the previous routine, the results may be plotted in three dimensions (Fig. 4.43) with options to also plot the ceiling and floor displays.

The 2D plot (Fig. 4.44) is the graphical representation of the results for a specific c (= L_{50}/L_∞) value. The user has the option to change the value or may slide the scroll bar to examine changes of the c value (simulating a change of the mesh size).
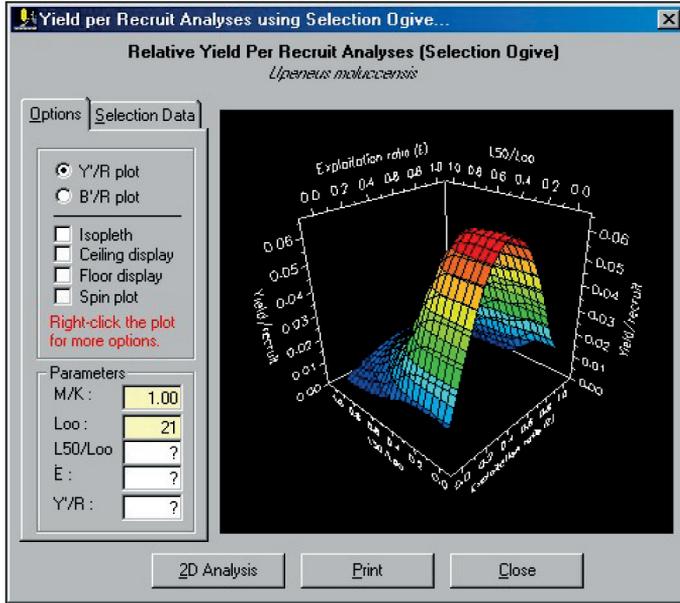
Fig. 4.43. A 3D presentation of the Y'/R plot using the selection data.
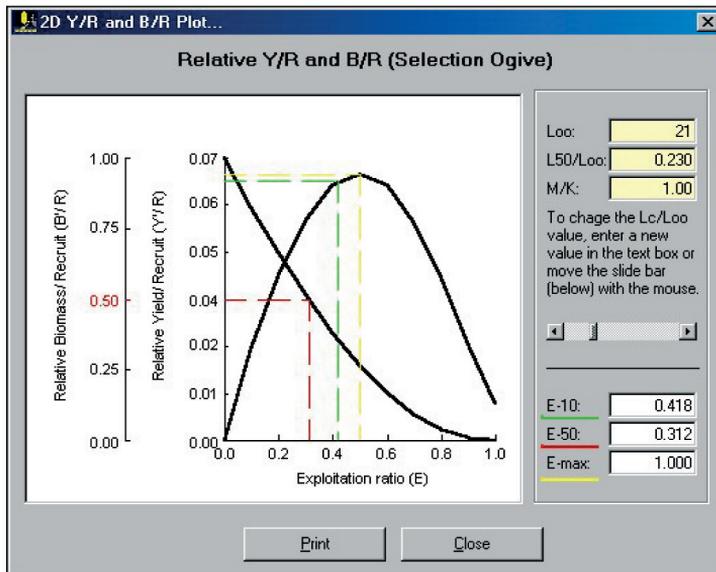
Fig. 4.44. 2D presentation of the results for specific L_{50}/L_∞ value. The scroll bar may be used to examine changes of the L_{50}/L_∞ values.

Remarks	Using probabilities of capture which abruptly change from zero to 1 at $L_{50}(=L_c)$ enables this model to simulate the behaviour of the same model assuming a knife–edge selection, and thus allows comparison between the two approaches.
Readings	Pauly (1984a) Pauly and Soriano (1986) Beverton and Holt (1966) Silvestre *et al.* (1991)

Thompson and Bell yield and stock prediction

This model combines features of Beverton and Holt's Y'/R model with those of VPA, which it inverts. The version presented here can be used to analyse either a single species, exploited by a single gear, or several species, exploited by several fleets. Naturally, the data requirements increase with the complexity of the analysis required. It is for this reason that this routine is presented through a series of "options".

Five options are provided: (1) Create, edit, save or print a Species Table, containing population parameters, value by length groups and the F-array associated with one species, (2) Create, edit, save or print a Fleet Table, containing a text description of the fleet, (3) Create, edit, save or print a Relations Table linking the Species and Fleet Tables, data on selection and catch indexes used, to split the F-array if the species is (are) exploited by several fleets, (4) Run a Predict routine, which executes the model and outputs the graphical and numeric results, (5) Help, which contains a short description of the procedure and data requirements.

Required file	Scenario File

Input parameters Species Table(s), Fleet Table(s), and relations between the species and the fleets.

Functions The sum of the yields $(Y = \Sigma Y_i)$ is computed from

$$Y_i = C_i \cdot \overline{w}_i$$

where the mean body weight

$$\overline{w}_i = \left(\frac{1}{L_{i+1} - L_i}\right) \cdot \left(\frac{a}{b+1}\right) \cdot \left(L_{i+1}^{\,b+1} \cdot L_i^{\,b+1}\right)$$

and where a and b are the coefficients of the length-weight relationship and L_i and L_{i+1} are the lower limit and upper limit of the length class, respectively; also we have

$$C_i = (N_i - N_{i+1})(F_i/(M+F_i))$$

where the predicted population (N_i) is given by

$$N_{i+1} = N_i \cdot EXP(-(M+F_i) \cdot \Delta t_i), \text{ and}$$

$$\Delta t_i = (1/K) \cdot \ln((L_\infty - L_i)/(L_\infty - L_{i+1}))$$

The biomass is computed from

$$B_i = ((N_i - N_{i+1})/(M+F_i)) \cdot \Delta t_i \cdot \overline{w}_i$$

and

the value (V_i) is computed by

$$V_i = Y_i \cdot v_i$$

where v_i is the unit value for class i.

In the multi-species/multi-fleet scenario, an F-array has to be generated (based on the ratio of catches of the different gears) before any yield predictions can be made. The yields, computed on a per species and per fleet basis, are then added.

Outputs   Plots of yields, values and biomass estimates for a range of f-factors for each species-fleet combination as well as the cumulative curve. An option is provided to examine the effect of changes of selection parameters.

User interface   The user interface of this routine has three tabs. The first tab (Fig. 4.45) opens the scenario file (*.SCE) that identifies the list of species and fleets included for analysis.
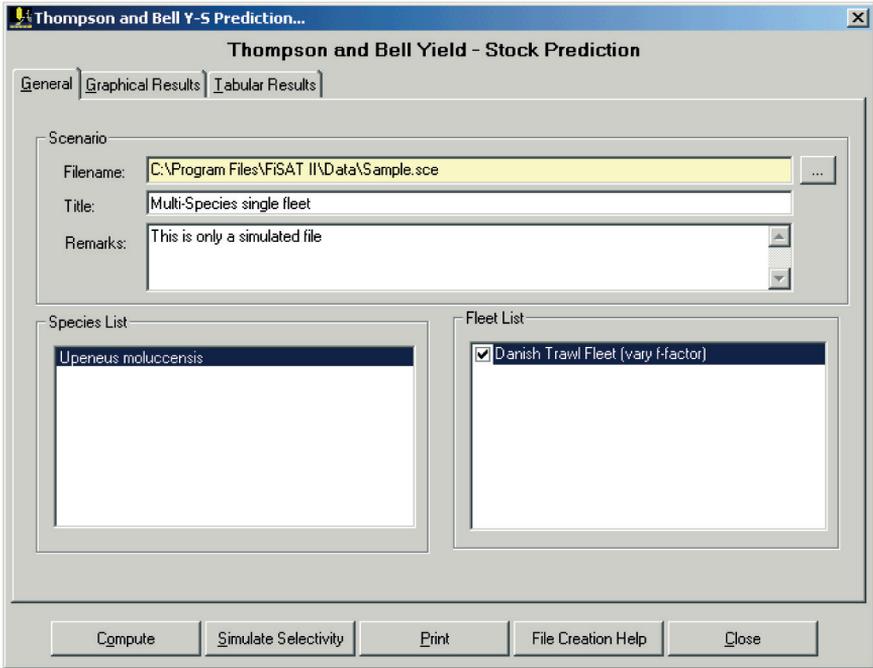
Fig. 4.45. User interface of the Thompson and Bell yield-stock prediction module that identifies the file and options to simulate changes in the f-factor for each fleet included in the scenario.

As an option, the user may also uncheck the box corresponding to the fleet label to simulate a fixed value for the f-factor. In which case, the user will be prompted on what value to use. If the box is checked, FiSAT II will present results with the f-factor of the fleet varying from 0 to 4.

When the "Compute" command button is clicked, the results will be plotted as shown in Fig. 4.46. The numeric equivalent of the result is given on the third tab.
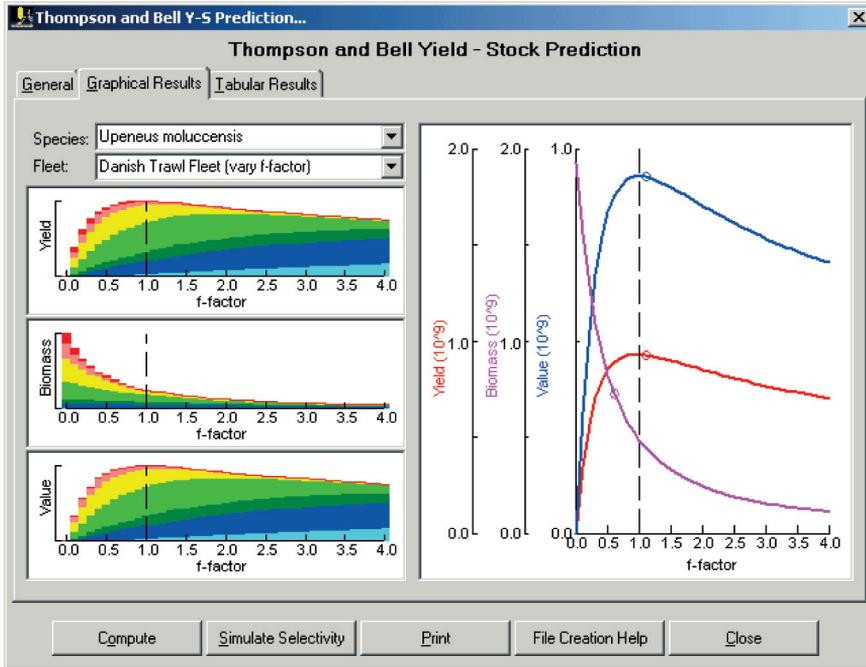
Fig. 4.46. The graphical result of the Thompson and Bell yield-stock prediction module of FiSAT II. The left panel with three graphs shows results specific to a fleet and a species while the right panel shows the cumulative results.

The three graphs in the left panel are the results of the simulation for a specific species as exploited by a fleet. Use the dropdown list in the upper left panel of the interface to view results of other combinations. The range of colours used (red to light blue; the blue band is not visible in Fig. 4.46) represents the age group distribution with red representing the oldest age group.

The right panel is the graphical representation of the cumulative results. The important points of the plotted lines are given by small circles. The small circle in the value and yield curves

represents the maximum point while that for the biomass curve, represents the point at which the biomass has reach 50% of the original biomass.

Remarks   When used here, the output of a length-structured VPA fulfils most of the data requirements (on a per-species basis). Thus, this form of VPA was programmed to automatically generate the appropriate file for transfer to this routine.

Readings   Sparre and Willmann (1993)
                   Thompson and Bell (1934)

Chapter 5. SUPPORT menu

What you will learn from this chapter

This chapter will introduce you to routines meant to supplement or support the data analyses presented in the previous chapter.

Simulation of length-frequency samples

This routine applies the Monte Carlo technique to simulate the dynamics of a fish stock and a random sampling procedure, taking into account the various stochastic elements of the biological system when generating length-frequency samples. The file(s) output by this simulation routine may be used in various ways such as for assessing the applicability of a model to data with known characteristics or estimating population parameters by changing them iteratively until the length frequencies that are generated come very close to those observed.

This routine includes options to generate length frequencies through random sampling in a "closed habitat" and length frequencies accounting for migrations.

Required file   None

Input parameters   Except for one element, the migration route for migratory stocks, the required inputs are the same for both options. These inputs are summarized in Tables 5.1 to 5.3.

Functions   The sequence of probability functions used are summarized in Table 5.4. These are used for simulating the life (growth, migration) of one individual

fish at a time, from one sampling period
to the next, until it dies due to M or F.

Table 5.1. Required single field inputs for simulating length-frequency data.

Field name	Type	Limits	Remarks
Number of areas	N	1 to 5	The number of hypothetical areas between which the stock will migrate (for migratory stocks only).
Sample type	Ch	-	Three sample types are available; (1) representing population, (2) representing catch, and (3) double sampling, representing both population and catch.
Number of fish sampled	N	1 to 10^6	Total number of specimens in a simulated sample.
Number of age groups	N	1 to 10	Number of age groups assumed to occur in the sample.
Number of length groups	N	2 to 100	Number of length groups in the simulated samples.
L_∞	N	1 to 10^5	Asymptotic length.
CV of L_∞	N	0 to 99	A measure of the assumed variability of L_∞, i.e. CV = $\sigma(L_\infty) \cdot 100 / L_\infty$.
K	N	0.1 to 20	Curvature parameter of the VBGF.
CV of K	N	0 to 99	A measure of the assumed variability of K, i.e. $\sigma(K) \cdot 100 / K$.
C	N	0 to 1	The amplitude of the seasonal oscillations of the growth curve. An input of zero will automatically set the Winter Point (WP) to zero.

Table 5.1 (cont). Required single field inputs for simulating length-frequency data.

Field name	Type	Limits	Remarks
CV of C	N	0 to 99	A measure of the assumed variability of C, i.e. $\sigma(C)\cdot100/C$
WP	N	0 to 1	Time of the year when growth is slowest.
CV of WP	N	0 to 99	A measure of the assumed variability of WP, i.e. $\sigma(WP)\cdot100/WP$.
L50*	N	0 to 10^6	50% retention length (left hand selection and/or recruitment).
L75*	N	0 to 10^6	75% retention length (left hand selection and/or recruitment).
R50*	N	0 to 10^6	50% retention length (right hand selection or de-recruitment).
R75*	N	0 to 10^6	75% retention length (right hand selection or de-recruitment).
F maximum*	N	0 to 99	The maximum fishing mortality over age group that will be applied to the stock.

*In migratory stock, these fields are area-specific, i.e. values are defined for each area the fish migrates to.

Table 5.2. Other required inputs when running a simulation routine (Options 1 and 2).

Field name	Type	Limits	Remarks
Seed value for randomization	N	0 to 100	Use the same seed value to obtain exactly the same values as in a previous run.
No. of samples	N	0 to 50	This refers to the number of sampling months to simulate. Note that as more simulations are required, computing time increases exponentially.
No. of months between samples	N	1 to 11	Number of months separating simulated samples.
Run time identifier	C	9 char.	This will be recorded, when stored to a FiSAT file in OTHER FILE IDENTIFIERS. Provide inputs to this field that will clearly identify the simulation run.
Recruitment strength	N	0 to 100	The inputs for this table are in relative terms, i.e. the strength of recruitment in a given month *vis-à-vis* other months. FiSAT will proportionally adjust all values such that the largest entry will be equal to 1.
Relative strength	N	0 to 100	Relative strength of each age group; as with the previous table entry, FiSAT will proportionally adjust all values such that the largest entry will be equal to 1.
Natural mortality	N	0.01 to 20	The natural mortality affecting each age group.

Table 5.3. Additional inputs for running a simulation routine incorporating migrations.

Field name	Type	Limits	Remarks
L50 when migration starts	N	0 to 10^6	50% retention length (left-hand selection) at the start of migration out of the nursery area (Area 1).
L75 when migration starts	N	0 to 10^6	75% retention length (left-hand selection) at the start of migration out of the nursery area (Area 1).
Where to go from Area 1	N	2 to 5	Destination (Area 1+i) at the start of migration out of Area 1.
Stay in Area 1+i	N	1 to 10^5	Duration of stay in Area 1+i (in months).

Following the above inputs, FiSAT will prompt the user to identify the subsequent areas of migration (2 to 5) and durations in the specified area (1 to 10^5).

Table 5.4. Summary and sequence of procedures which defines a Monte Carlo simulation to generate length-frequency samples.

Probability distribution	Input Parameters	Probability of occurrence	Output
Recruitment	no. of age groups (t_n) and year class strength (Cy_i); if year class strength is not specified, class strength is assumed equal for all year classes	$Cy_i/\Sigma Cy_i$	the age grps. where the fish should be placed
Month of birth	relative monthly recruitment (MR_i)	$MR_i/\Sigma MR_i$	day is assumed to be the 15th of the month and birthdate (tz) is defined

Table 5.4 (Cont.). Summary and sequence of procedures which defines a Monte Carlo simulation to generate length-frequency samples.

Probability distribution	Input Parameters	Probability of occurrence	Output
Growth parameters	growth parameters and their corresponding standard deviations $\sigma(x)$	$1/(x+2\cdot\sigma(x))$	defines the growth curve of a fish
Migration	the ages at which the fish is expected to stay in the fishing ground	(n.a.)	checks if the fish has left or arrived at the fishing ground
Mortality	Natural mortality (M_t) and selection data SEL_t at age t, and the maximum fishing mortality the sample is exposed to during its life (F_{max})	e^{-Z}, where $Z=\Sigma((F_{max}\cdot P_t)+M_t)$	checks if the fish survived to that age or died due to fishing or natural mortality
Gear selection	Probability of capture (i.e. selection and recruitment curve) by length or age groups (P_t)	P_t	checks if the fish was caught by the gear or not

Outputs Both options of this routine can generate time series of length frequencies that are saved automatically.

User interface The user interface of this routine contains a series of tabs (Fig. 5.1) to encode the parameters. Default values are provided by FiSAT II that can be modified. The resulting length

frequencies are automatically saved for use in various routines of FiSAT II.

Remarks The time required to run this simulation routine depends on the inputs provided, and may range from a few minutes to several days. However, it is possible to interrupt any simulation by pressing any key (warning: intermediate results are not saved, and the simulation must be restarted from scratch if interrupted).
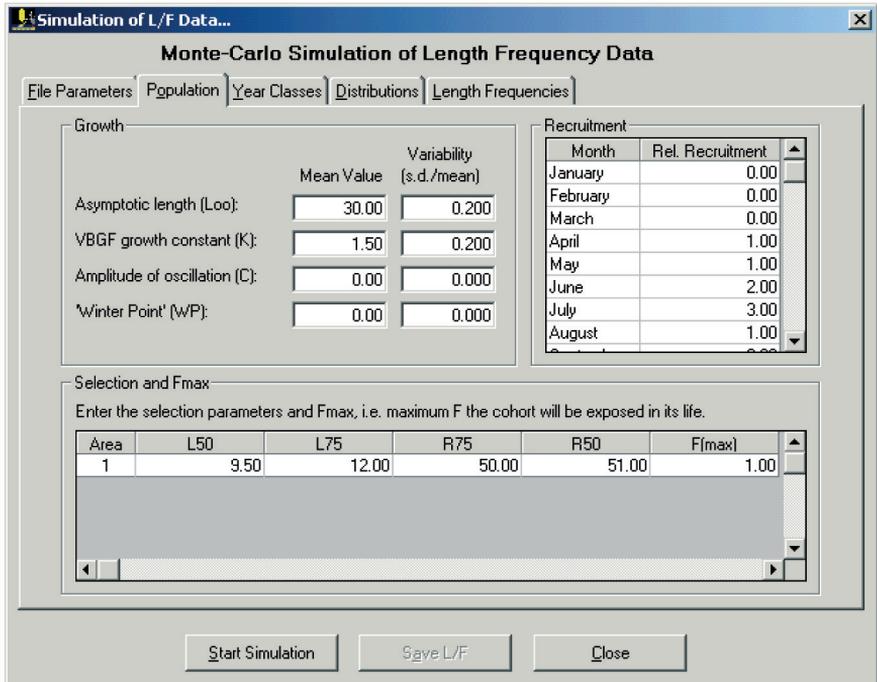
Fig. 5.1. User interface when executing the simulation routine to generate length frequencies.

Sample weight estimation

This routine allows users to estimate sample weights as required to estimate raising factors, or for other purposes.

Required file	Length frequencies with constant class size.
Input parameters	a and b coefficients of the length-weight relationship.
Functions	The mean weight of the sample $(\overline{W}s)$ is computed from

$$\overline{W}s = \sum_i \overline{w}_i \cdot N_i / \sum_i N_i$$

where

N_i is the frequency count, and $\overline{w}_i$ is the mean weight of the fish in class i computed from

$$\overline{w}_i = \left(\frac{1}{L_{i+1} - L_i} \right) \cdot \left(\frac{a}{b+1} \right) \cdot \left(L_{i+1}^{\ b+1} - L_i^{\ b+1} \right)$$

	where a and b are the coefficients of the length-weight relationship and L_i and L_{i+1} are the lower limit and upper limit of length class i, respectively;
Outputs	A table of computed weights for each length class and the weight of the sample.
User interface	The user interface contains two tabs (Fig. 5.2 and Fig. 5.3). The "General" tab (Fig. 5.2) identifies the file and provides the fields to enter the 'a' and 'b' coefficients of the length-weight relationship.

Fig. 5.2. User interface to encode inputs for sample weight estimation routine.

The second tab (Fig. 5.3) is the results of the analysis. Note the presence of the "Compute" command button. After file identification and encoding the required coefficients, clicking this button will commence the calculations.

Also, note the presence of the "Update Samples" command button. Clicking this command button will update the sub-header of the length frequency file, replacing whatever value is stored. This function should, therefore, be used with caution.
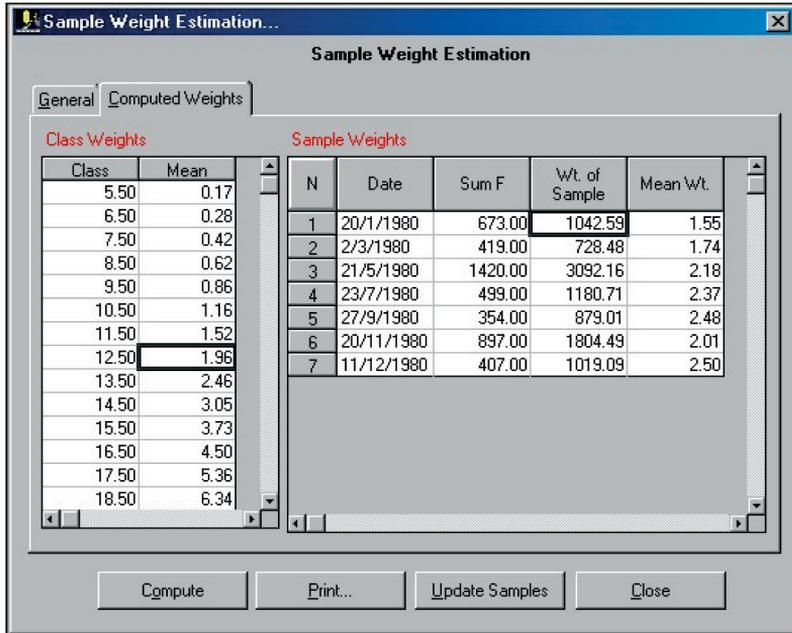
Fig. 5.3. Outputs of the sample weight estimation routine. Note that the sample sub-header can be automatically updated using the computed sample weights.

Remarks   The unit for the computed weights is determined by the coefficient a, provided as input to the routine.

[The above equation provides unbiased estimates of $\overline{w}$; estimating $\overline{w}$, as the weight corresponds to $\overline{L}$, leads to bias].

Reading   Beyer (1987)

VBGF and L/F plot

This routine provides the option to view length- or weight-frequency data as a 2-dimensional plot (Fig 5.4).

Required file   Length or weight frequencies with constant class size.

Input parameter   None

Function   None

Outputs   A plot of the histogram in two dimensions.

User interface   The user interface for this routine contains two tabs (as in the previous routine) (Fig. 5.4). The first tab identifies the length frequency file to plot and text boxes to encode the growth parameters to use in plotting the VBGF curve (if applicable).

There are several options that the user may invoke in plotting the length frequency histograms and the growth curve. An option is provided to plot the restructured data (see Chapter 4 on data restructuring as employed in ELEFAN I). However, the option to plot using "Solid Bar Graphs" will be disabled if restructured data are to be plotted.
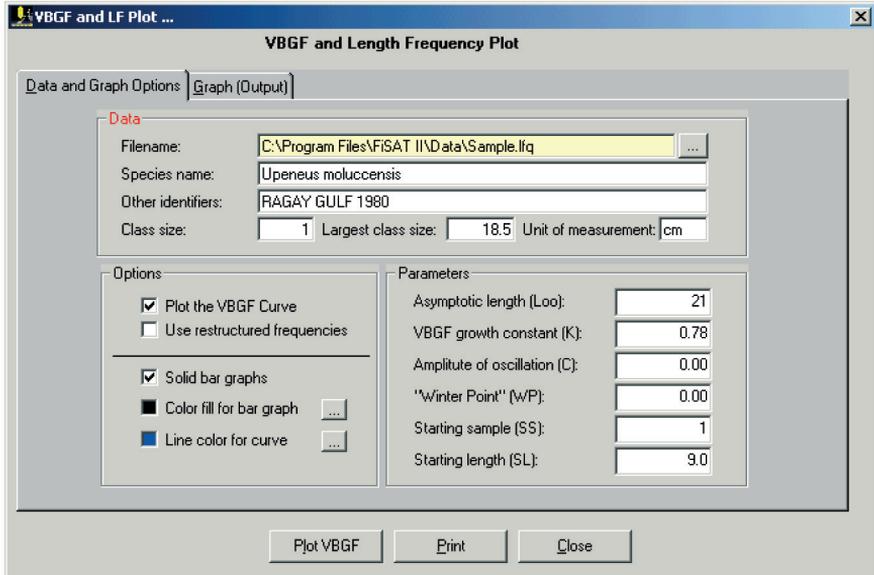
Fig. 5.4. User interface for encoding parameters for the VBGF plot and selecting plotting options.

The resulting graph (Fig. 5.5) may be printed or saved to file (from the Print command). The checkbox in the lower left corner of the graph, "Display all" is enabled only if more than one year of data has been detected. In this case, users may use the scroll bar to view other parts of the resulting plot or view the complete file in one screen by checking the "Display all" checkbox.
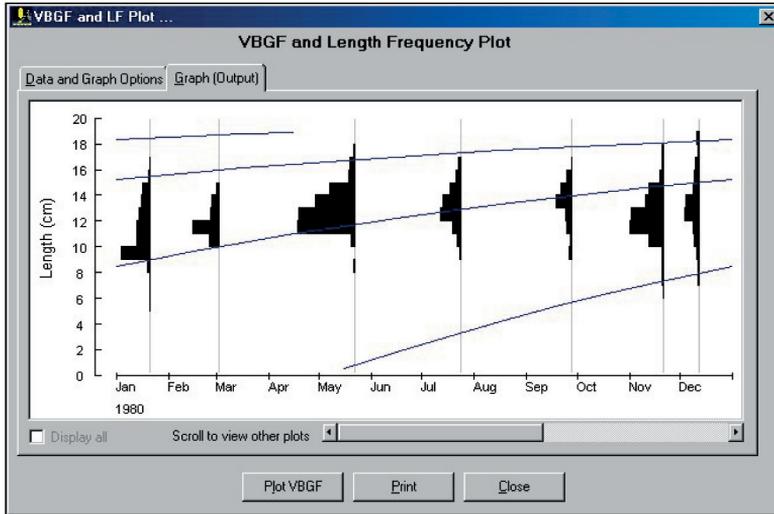
Fig. 5.5. Resulting VBGF plot overlaid by the length frequency histograms.

Remarks   Users should rely on this routine to assess visually the progression of modes in a series of samples before attempting to estimate growth parameters from such series.

Maximum length estimation

This routine estimates the (un-sampled) maximum length of fish (L_{max}) in a population, based on the assumption that the observed maximum length of a time series of samples does not refer to a fixed quantity but rather, represents a random variable which follows a probabilistic law.

Required file   Time series of length frequencies with constant class size (the routine only uses the extreme length of each sample).

Input parameter   None

Functions L'_{max} is estimated from a set of n extreme values (L^*, the largest specimen in each sample of a file) using the (Type I) regression:

$$L^* = a + 1/\alpha \cdot P$$

where P is the probability associated with the occurrence of an extreme value, $1/\alpha$ a measure of dispersion, and L'_{max} is the intercept of the regression line with the probability associated with the nth observation (note that the scale used for P is non-linear, i.e. corresponds to that used for extreme value probability paper).

P is computed for any extreme value from $P = m/(n+1)$ (Gumbel 1954) where m is the position of the value, ranked in ascending order and n is the number of L^* values.

Output   Predicted L'_{max} for a given sample size n, and its confidence limits (here for 95% probability).

User interface   The user interface of this routine contains three tabs (Fig. 5.6 and Fig. 5.7). The first tab identifies the file to use in the analysis and summary of the results. The second tab displays the probability plot with the corresponding confidence region. The third tab summarizes the result in table format.

Remarks　　　　This routine may also be invoked to estimate L'_{max} for inputs to routines described earlier (e.g. Ault and Ehrhardt's model) or as an initial estimate of L_∞.

Readings　　　　Formacion *et al.* (1991)

Fig. 5.6. User interface used for the prediction of the maximum length from extreme values. This tab identifies the file and summarizes the results.
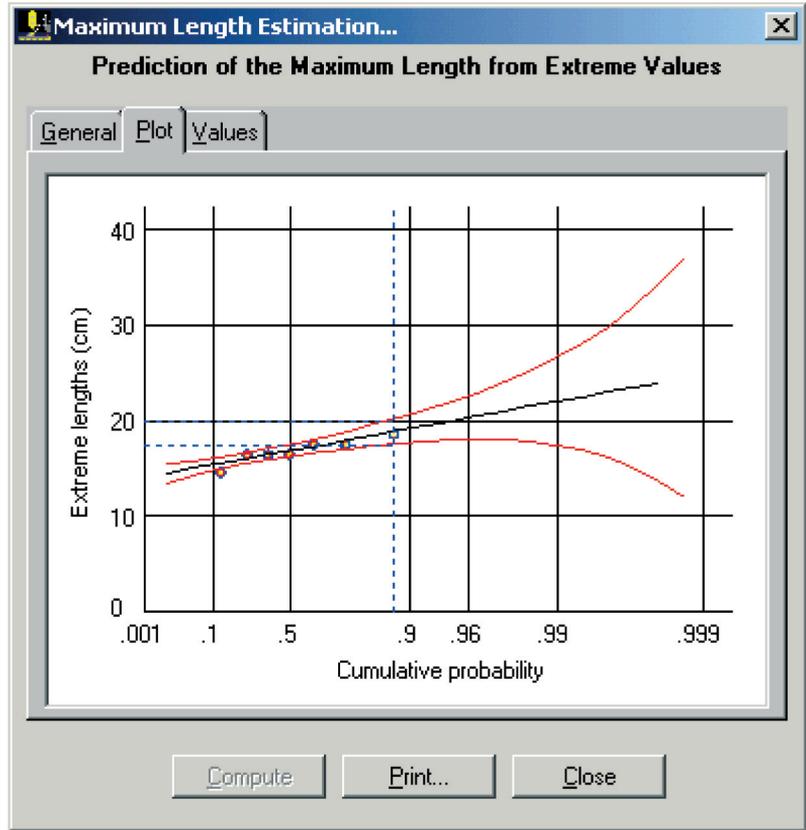
Fig. 5.7. Facsimile representation of the resulting analysis of extreme values.

Growth performance indices

This utility provides the facility to rapidly compute the growth performance index (1) ø (if asymptotic weight is given) or (2) ø' (if asymptotic length is given).

Required file   None

*Input parameter*s   **Option 1**: ø

Growth parameters W_∞ (asymptotic weight; g) and K (VBGF curvature parameter; year^{-1})

Option 2: ø'

Growth parameters L_∞ (asymptotic length in cm) and K (VBGF curvature parameter; year^{-1})

Functions	**Option 1**: ø

$$\text{ø} = \log_{10}(K) + 2/3 \cdot \log_{10}(W_\infty)$$

Option 2: ø'

$$\text{ø}' = \log_{10}(K) + 2 \cdot \log_{10}(L_\infty)$$

Outputs ø and/or ø' values.

User interface The user interface of this routine (Fig. 5.8) provides fields for the user to encode known parameters. Depending on what is available, the other parameters will be computed. For example, if L_∞ and the growth constant K are given, phi prime (ø') will be computed. If L_∞ and phi prime are given, the growth constant K will be computed. The same is true with regards to the relation of phi, K and W_∞.
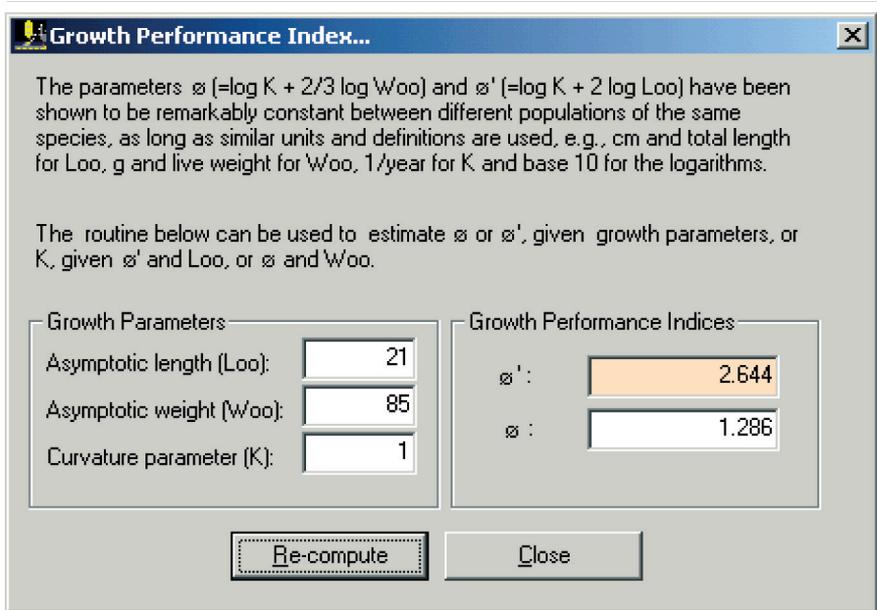
Fig. 5.8. User interface in the calculation of growth indices.

Remarks   None

Readings   Munro and Pauly (1983)
                   Pauly (1979)
                   Pauly (1981)
                   Pauly and Munro (1984)

Regression analysis

FiSAT II provides a routine to perform linear regression analyses as commonly used in fisheries stock assessment. Several options are provided;

(1) $Y = a + b \cdot X$ (Type I, or AM regression)
(2) $Y = a' + b' \cdot X$ (Type II, GM regression)
(3) $\log(Y) = a + b \cdot \log(X)$
(4) $\ln(Y) = a + b \cdot X$
(5) $Y = a + b \cdot \ln(X)$
(6) $Y/X = a + b \cdot X$
(7) $\ln((1-Y)/C) = a + b \cdot X$

(8) Y^C = a + b·X
(9) Y = a + b · X^C

Required file   Two-column regression file with at least three pairs of data.

Input parameter   **Options 1 to 6** : None

                        Options 7 to 9 : A constant C (>0 to 999).

Functions   As defined by the option labels, where a is the Y-intercept, b is the slope, and C is a constant.

Outputs   An XY-plot of the points, and the regression line (Fig. 5.9).
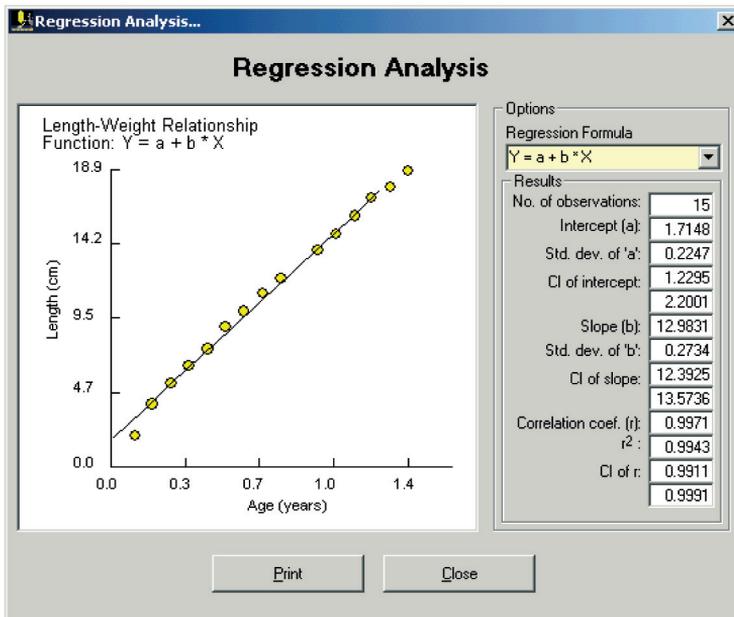
Fig. 5.9. User interface in regression analysis of a XY file.

User interface   This routine requires an active XY Regression file (*.xyf). The options presented above can be accessed from

the dropdown list. The results (standard regression statistics) are given on the right hand side of the interface.

Remarks   The options available in this routine may be applied to various scenarios. **Option 3**, for example, may be used to establish the length-weight relationship of fish; **Option 4** can be used for catch curve analysis, where ln(N) is plotted against absolute or relative age; **Option 6** is typically used for surplus production models whose parameters are often estimated through a plot of catch per unit effort (C/f) against effort (f); **Option 7** may be used to linearize complex functions, such as the VBGF in which case, $Y = L_t$, $C = L_\infty$ and $X = t$.

APPENDIX A. Terms and variables

ΔL	-	length increment; or
	-	width of length class in grouped data; or difference between two successive mean lengths
$\Delta L/\Delta t$	-	growth rate expressed as difference
Δt	-	time difference, e.g., the time needed by an average fish to grow from the lower to the upper limit of a length class
$\Delta \delta$	-	difference between two successive standard deviations
δ	-	standard deviation of variates, used as a measure of their dispersion
δ^2	-	variance; the square of δ
$\$$	-	US dollars, or any other monetary unit
Σ	-	summation sign
π	-	pi = 3.1415...
ø	-	phi, i.e. a weight-based index of growth performance ($\emptyset = \log_{10}(K) + 2/3 \log_{10}(W_\infty)$)
ø'	-	phi-prime, i.e. a length-based index of growth performance ($\emptyset' = \log_{10}(K) + 2\log_{10}(L_\infty)$)
a	-	Y-intercept in a Type I, or AM linear regression, or
	-	multiplicative term in a length/weight relationship
a'	-	Y-intercept in a Type II, or GM linear regression
AM	-	arithmetic mean; used to characterize "Type I" regressions
ASP	-	"Available Sum of Peaks"; the sum of available "points" in a file restructured for analysis with the ELEFAN I routine
B	-	biomass, or stock size in weight

b	-	exponent of a length-weight relationship, or
	-	slope of Type I (AM) linear regression
b'	-	slope of a Type II (GM) linear regression
B/R	-	biomass per recruit
B'/R	-	relative biomass per recruit
C	-	refers to fields that will accept alpha-numeric entries when used to describe the characteristics of a field, or
	-	catch in numbers, or
	-	parameter expressing the amplitude of seasonal growth oscillation in the VBGF, or
	-	a constant
c	-	the fraction L_c/L_∞
C.V.	-	coefficient of variation, i.e. C.V. = δ/X (also expressed in %, i.e. C.V. = $\delta \cdot 100/X$)
C/f	-	catch per unit of effort (also: CPUE)
c1, c2	-	multipliers for estimating Z and its standard error using one of Hoenig's methods
CGA	-	Colour Graphic Adapter
Ch	-	refers to limited choice fields (i.e. users have to choose from a list).
$C_{Li,\infty}$	-	cumulative catch in numbers from length i to L_∞
$C_{i,A}$	-	cumulative catch in numbers for mesh size m_A
$C_{i,B}$	-	cumulative catch in numbers for mesh size m_B
cm	-	centimetre
C_t	-	terminal catch, as used in VPA
D	-	Fraunhofer diffraction function in Shepherd's method, or
	-	dimension, as in "2D", "3D"
DD	-	two digit number denoting the day of a month, or
	-	degrees latitude
DDD	-	three digit number denoting the degrees longitude

d.f.	-	degrees of freedom, i.e. the "real" number of cases available for testing a statistical hypothesis
e	-	base of the natural (or Napierian) logarithms; $e = 2.71828...$
E	-	exploitation rate; $E = F/Z$
$E_{0.1}$	-	level of exploitation at which the marginal increase in yield per recruit reaches $1/10$ of the marginal increase computed at a very low value of E
$E_{0.5}$	-	exploitation level which will result in a reduction of the unexploited biomass by 50%
E_{max}	-	exploitation level which maximizes Y/R or Y'/R
EGA	-	Enhanced Graphic Adapter
EPSON	-	registered trademark of Seiko Epson Corp., Japan
ESP	-	"Explained Sum of Peaks"; the points "explained" (or hit) by a growth curve traced by the ELEFAN I routine
EXP	-	exponent
F	-	instantaneous rate of fishing mortality
f	-	fishing effort
f-factor	-	factor used as a multiplier to simulate a change in effort level, for a defined fishing regime
fl	-	index for fleet
F_t	-	terminal fishing mortality, as used in VPA and cohort analysis
g	-	gram
GM	-	geometric mean, used in Type II regression
HD disk	-	High-density disk with a capacity of 1.44MBytes for 3½" disk and of 1.2MBytes for 5¼" floppy disk.

HERCULES	-	Hercules graphic adapter for monochrome screens, with a resolution of 729 by 348 pixels.
HP	-	registered trademark of Hewlett-Packard Co., USA
i	-	symbol or subscript used for counting items (samples, means, etc.)
IBM	-	Registered trade mark of International Business Machines, Corp., USA
K	-	curvature parameter of the VBGF
k	-	the number of parameters estimated by a given procedure
L	-	"length" of a fish, shrimp, etc. (length itself is defined differently, depending on what is measured, see TL, SL, FL, etc.)
$\bar{L}$	-	mean length of fish, computed from L' upward, or
	-	mean of two or more lengths, e.g., mean of length at tagging and at recapture
L'	-	a length not smaller than the smallest length of fish fully represented in catch samples; used to compute L
L*	-	largest observed specimen in a sample
L/F	-	length-frequencies or length-frequency sample
L_{25}	-	length at which 25% of the fish will be vulnerable to the gear (left-hand selection)
L_{50}	-	length at which 50% of the fish will be vulnerable to the gear (left-hand selection)
L_{75}	-	length at which 75% of the fish will be vulnerable to the gear (left-hand selection)
LAN	-	Local Area Network
L_c	-	mean length of fish at first capture; equivalent to L_{50}
L_m	-	length at tagging or marking
L_{mass}	-	mean length at first maturity (or "massive maturation")

L_{max}	-	maximum length reached by the fish of a given stock; may also be predicted from the largest specimens of several samples using the extreme value theorem
L_{min}	-	smallest length represented in one or several samples
ln	-	$\log_e$, logarithm of base e
log	-	$\log_{10}$, logarithm of base 10
L_r	-	length at recapture, or
	-	mean length at first recruitment
L_r'	-	computed length at recapture given growth parameters (L_∞ and K) and length at marking
L_A	-	optimum length for mesh size m_A
L_B	-	optimum length for mesh size m_B
L_t	-	(mean) length at age t
L_∞	-	asymptotic length, i.e. the (mean) length the fish of a given stock would reach if they were to grow forever
M	-	instantaneous rate of natural mortality, i.e. due to all causes except fishing
m	-	mesh size, or
	-	metre
m_A	-	gillnet mesh size
m_B	-	another gillnet mesh size, with $m_B > m_A$
ML	-	"mid-length" or length class midpoint
MM	-	two digit number denoting the month of a year, or
	-	minutes in latitude and longitude
MPA	-	modal class progression analysis
MS DOS	-	disk operating system for IBM PCs or its compatibles, or
	-	registered trademark of Microsoft Corp., USA
n	-	number of items in a sample, number of cases investigated, etc.
N	-	number of fish in a given size class of a catch sample, or

	-	refers to numeric fields, i.e. indicates that only numbers can be entered;
N_t	-	number of fish in the oldest age group of a cohort or population ("terminal population")
P	-	probability of capture or occurrence on the fishing ground
P_L	-	probability of capture for length (or mid-length) L
P_1	-	first point of a length-converted catch curve included in the computation of Z; this point is by definition the first where the probability of capture is 1
PC	-	Personal Computer; also microcomputers
Prompt	-	a software message or signal inviting the user to enter data, or to perform an operation
r	-	product-moment correlation coefficient
r^2	-	coefficient of determination
R_{50}	-	length at which 50% of the fish will no longer be vulnerable to the gear (right-hand selection, or deselection)
R_{75}	-	length at which 75% of the fish will no longer be vulnerable to the gear (right-hand selection, or deselection)
RAM	-	Random Access Memory; a part of the memory of the computer where the program and the data are loaded.
R_n	-	"goodness-of-fit" index of the ELEFAN I routine (=$10^{ESP/ASP}/10$)
S	-	score function in Shepherd's method
SF	-	selection factor
SI	-	separation index
SL	-	starting length; one of the two coordinates used to locate a growth curve in the ELEFAN I routine
SS	-	starting sample; the other coordinate used to locate a growth curve in the ELEFAN I routine. Jointly, SL and SS define the

		location of a pre-selected point of a growth curve, or
	-	seconds in latitude and longitude
s.e.	-	standard error of a statistic
S_1, S_2, S_3, S_4	-	variables used for estimating the probability of capture under the logistic model
S_{max}	-	maximum score in Shepherd's method for a range of L_∞ and K parameters
SSE	-	sum of squared errors; a measure of dispersal from the mean
t		a given time or age (normally expressed in years) , or
	-	absolute age of a fish, e.g., as estimated from daily otolith rings, or
	-	age corresponding to L_t
T	-	mean annual habitat temperature, in °C
t'	-	relative age of a fish, defined as $t' = t - t_o$
t_c	-	mean age at first capture, corresponding to L_c
t_i	-	mean age at length i
t_m	-	age at marking, corresponding to L_m
t_{mass}	-	mean age at massive ($\approx$ first) maturity
t_{max}	-	longevity (in the wild)
t_o	-	the "age" fish would have had at length zero if they had always grown according to the VBGF; t_o generally has a negative value, but does not usually express "prenatal growth"
t_r	-	mean age at recruitment
t_s	-	parameter of the seasonally oscillating version of the VBGF (see WP)
t_z	-	in Shepherd's method: origin of the VBGF in calendar time, (expressed as fraction of a year); here replaced (without affecting other results) by a starting point, defined by SS and SL
v_i	-	total of estimated value at length i
VBGF	-	von Bertalanffy Growth Function, either in original or seasonally oscillating form
VGA	-	Virtual Graphic Array

VPA	-	Virtual Population Analysis
W	-	mean weight of fish in catch samples, computed from W' upward
w	-	mean weight of fish within a given length class
WF	-	weighting factor assigned to an observation
WP	-	"Winter Point"; in the seasonalized VBGF, the time of the year when growth rate is slowest; equivalent to $t_s + 0.5$ year
WC	-	total weight of the catch
WS	-	total weight of the sample
W_∞	-	asymptotic weight, i.e. the (mean) weight the fish of a given stock would reach if they were to grow forever
x	-	any variable (often used for the abscissa in 2-dimensional plots)
x^2	-	chi-square statistics
Y	-	yield, catch in weight
Y_i	-	yield at length i
y	-	any variable (often used for the ordinate in 2-dimensional plots)
YY	-	two-digit number denoting the year
Y/R	-	yield per recruit
Y'/R	-	relative yield per recruit
Y/R_{max}	-	maximum yield per recruit achievable under a given fishing regime
Z	-	instantaneous rate of total mortality

APPENDIX B. References

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FISAT II
FAO-ICLARM stock assessment tools II
Revised version

The revised version of FiSAT (FiSAT II) is a program package consisting of methodologies for use with computers, enabling users to formulate some management options for fisheries, especially in data-sparse, tropical contexts.

The FiSAT II was developed for computers running on Microsoft Windows® operating system. The new version utilizes the standard Windows graphic user interface.

FiSAT II was developed mainly for the analysis of length-frequency data, but also enables related analyses, of size-at-age, catch-at-age, selection and other data typically collected for tropical fish stock assessment.