

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.

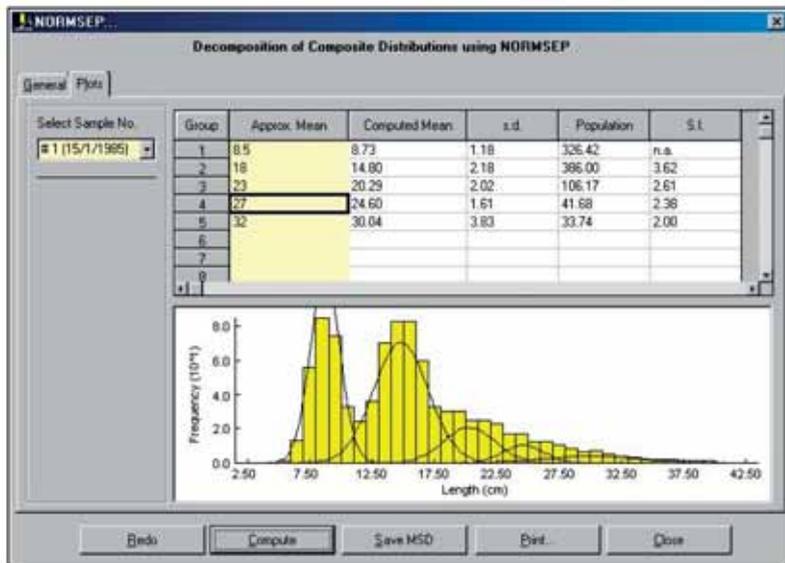


Fig. 4.12. NORMSEP user interface in decomposing composite distributions.

#### *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.

<i>Function</i>	None: linking of means results from user's subjective interpretation of a graph.
<i>Outputs</i>	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.
<i>User interface</i>	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).

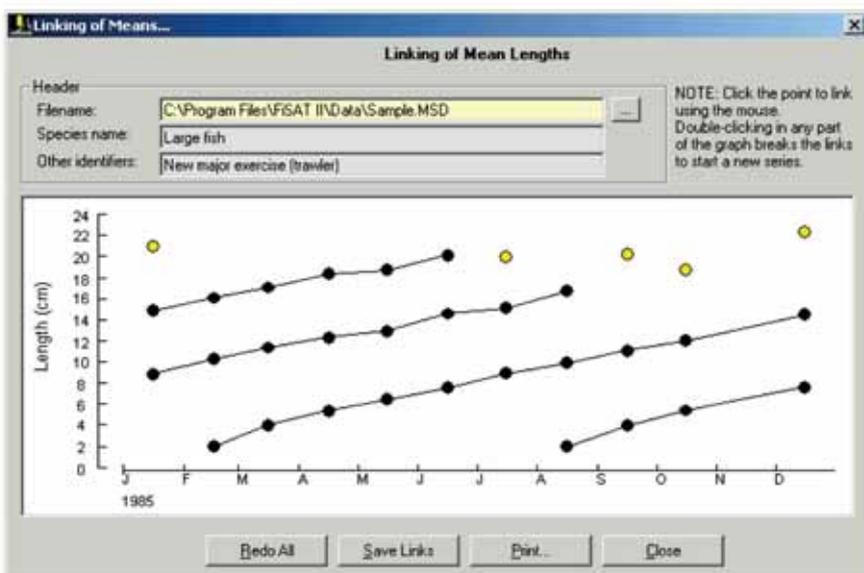


Fig. 4.13. Linking of mean lengths in FiSAT II.

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  $L_{\infty}$  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  $L_{\infty}$ . 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  $L_{\infty}$  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

$\Delta d$  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  $L_{\infty}$ , or of K alone if a "forcing" value of  $L_{\infty}$  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 ( $L_{\infty}$  and K) are automatically computed once a file has been identified.

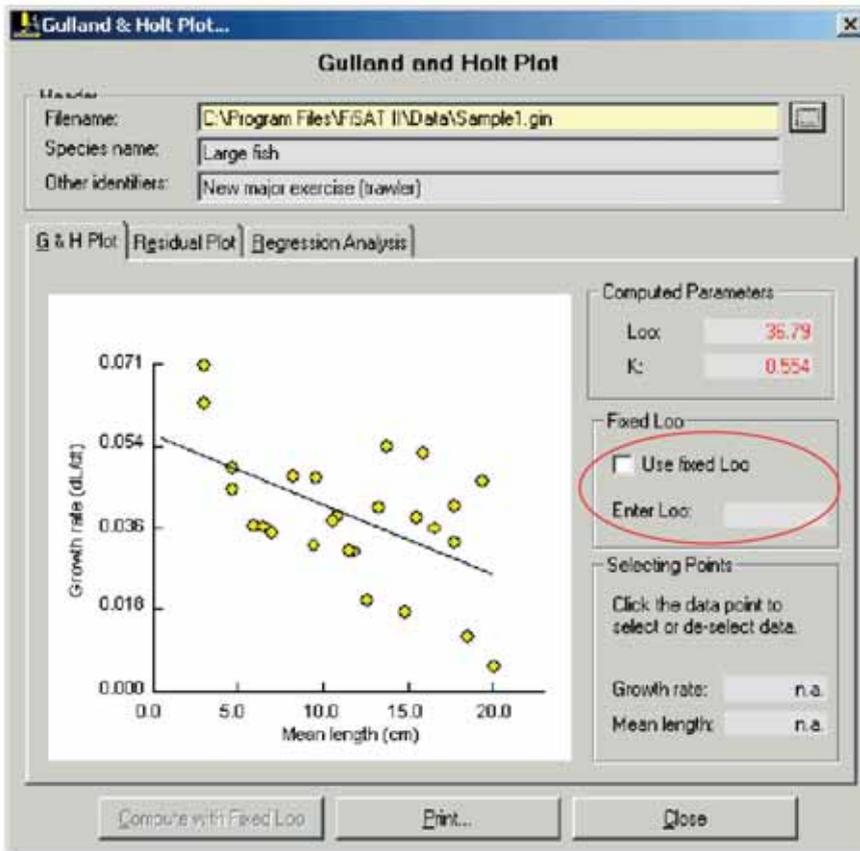


Fig. 4.14. User interface for the Gulland and Holt plot. A fixed value of  $L_{\infty}$  can be entered (red circle).

The user also has the option to encode a fixed value of  $L_{\infty}$ . 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.

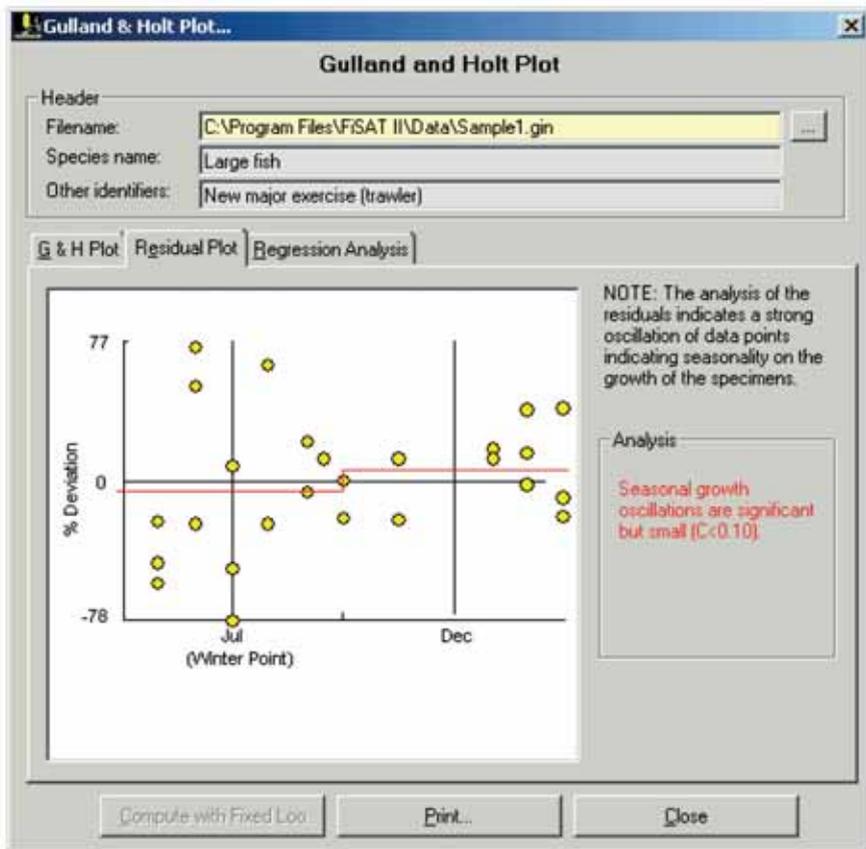


Fig. 4.15. Residual plot of the Gulland and Holt plot indicating seasonality of the growth.

*Remarks* An option is provided to omit selected data points from the analysis, and/or to set the value of  $L_{\infty}$ , 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  $L_{\infty}$  and  $K$  (**Option 1**), or  $K$  alone, given  $L_{\infty}$  (**Option 2**).

<i>Required file</i>	Growth increment data file
<i>Input parameter</i>	Fixed value of $L_{\infty}$ if fixed value option is selected
<i>Function(s)</i>	<p>Minimize the coefficient of variation of</p> $\text{ratio} = [\ln(L_{\infty}-L_m)-\ln(L_{\infty}-L_r)]/(t_r-t_m)$ <p>where: <math>L_m</math> is the length at marking (initial reading), <math>L_r</math> is the length at recapture, and <math>t_m</math> and <math>t_r</math> the corresponding dates. Each growth increment leads to an estimate of <math>K</math>, given <math>L_{\infty}</math>, and the variance of this estimate is computed; in <b>Option 1</b> the value of <math>L_{\infty}</math> is selected which minimizes that variance; under <b>Option 2</b> only the mean of the <math>K</math> estimate and its standard error are output, following input of <math>L_{\infty}</math>.</p>
<i>Outputs</i>	<p><b>Option 1:</b> Estimate of <math>K</math> and <math>L_{\infty}</math>  <b>Option 2:</b> Estimate of <math>K</math>, given <math>L_{\infty}</math></p>
<i>User interface</i>	<p>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</p>

third tab, “Regression Results from Gulland & Holt Plot”.

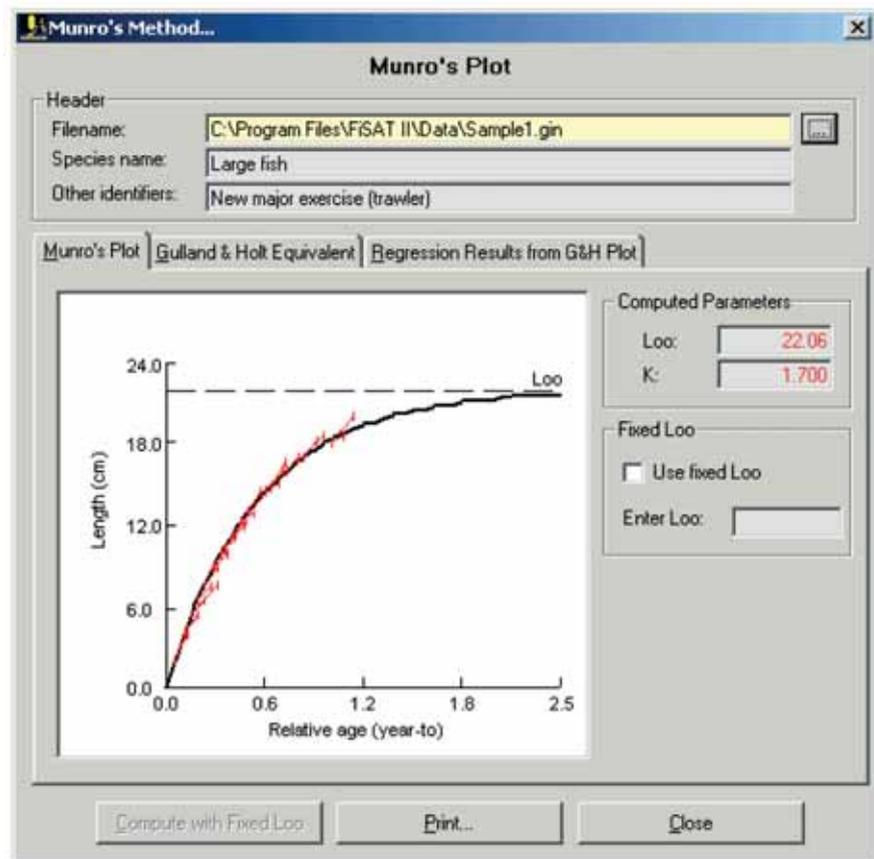


Fig. 4.16. User interface for the routine using Munro's method. This plot is recomputed automatically as data points are selected or deselected from the equivalent Gulland and Holt plot.

*Remarks*

The data pairs with lengths greater than  $L_{\infty}$  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)

### Fabens' method

Fabens (1965) suggested a method for estimating  $L_\infty$  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  $L_\infty$  if fixed value option is selected

*Functions*      Minimize the following functions, using the Newton-Raphson iteration method:

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

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  $L_\infty$  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  $L_{\infty}$ .

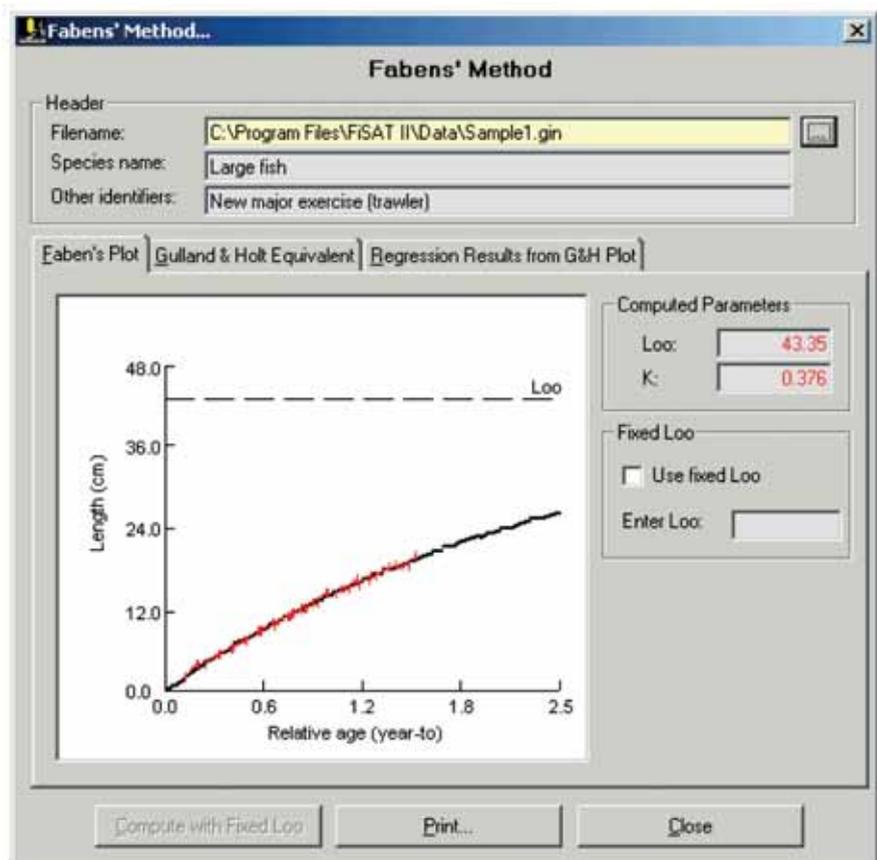


Fig. 4.17. User interface of Fabens' method in FISAT II. Data points may be selected or deselected from the equivalent representation in the Gulland and Holt plot.

#### 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  $L_\infty$ ,  $K$ ,  $C$  and  $WP$ .

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

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

where

$$S_t = (CK/2\pi) \cdot \sin(2\pi(t-ts)),$$

$$S_{t+\Delta t} = (CK/2\pi) \cdot \sin(2\pi((t+\Delta t)-ts)),$$

and,

$$ts = 0.5 + WP.$$

*Outputs* Estimates of  $L_\infty$ ,  $K$ ,  $C$ , 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.

**Appeldoorn's Method**

Header

Filename: C:\Program Files\FISAT II\Data\Sample1.gin

Species name: Large fish

Other identifiers: New major exercise (trawler)

Parameters | Growth Curve | Summary Statistics

Starting Parameter Matrix

	Minimum Constraint	Starting Estimate	Maximum Constraint
Loo (asymptotic length)	20.13	22.14	40.26
K (VBGF curvature parameter)	0.10	1.00	10.00
C (degree of oscillation)	0.00	0.00	0.00
WP (Winter Point)	0.00	0.00	0.00

NOTE: To fix a parameter, set the minimum and maximum constraints equal.

Compute Print... Close

Fig. 4.18. User interface of Appeldoorn'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)

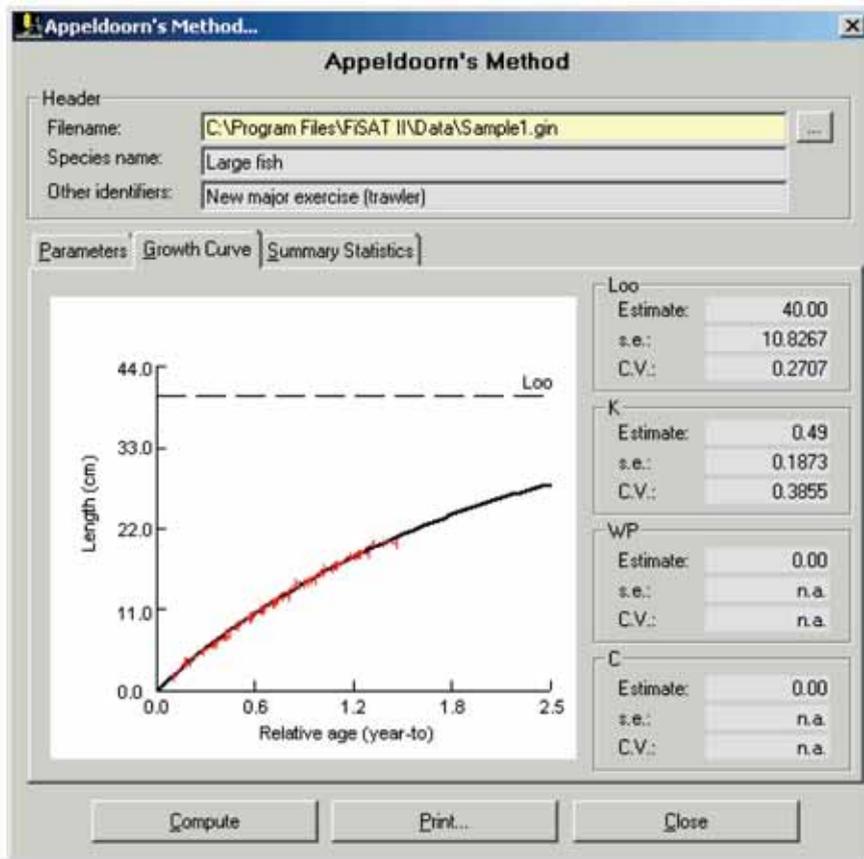


Fig. 4.19. The resulting growth curve computed using Appeldoorn's model from growth increments.

## 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*    $L_{\infty}$ , K, and  $t_0$  ( $t_0$  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,  $\Delta t$  is the time needed for the fish to grow through length class i, t is the age (or the relative age, computed with  $t_0 = 0$ ) 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

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

with  $\Delta t$  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.