



## Growth II

© 2006 Pisces Conservation Ltd

# Growth II

---

*by Pisces Conservation Ltd*

*Growth II - a major upgrade to our 'Simply Growth' software.  
Fits and plots von Bertalanffy, Gompertz, Logistic and a wide  
range of other growth curves to length and/or weight at age  
data.*

*Pisces Conservation Ltd  
IRC House, The Square  
Pennington, Lymington,  
Hampshire, SO41 8GN  
UK.*

*Tel: +44 (0)1590 674000*

*Fax: +44(0)1590 675599*

*[pisces@irchouse.demon.co.uk](mailto:pisces@irchouse.demon.co.uk)*

*Website: [www.pisces-conservation.com](http://www.pisces-conservation.com)*

*Online shop: [www.piscesconservation.com/shop](http://www.piscesconservation.com/shop)*

## **Growth II**

**© 2006 Pisces Conservation Ltd**

All rights reserved. No parts of this work may be reproduced in any form or by any means - graphic, electronic, or mechanical, including photocopying, recording, taping, or information storage and retrieval systems - without the written permission of the publisher.

Products that are referred to in this document may be either trademarks and/or registered trademarks of the respective owners. The publisher and the author make no claim to these trademarks.

While every precaution has been taken in the preparation of this document, the publisher and the author assume no responsibility for errors or omissions, or for damages resulting from the use of information contained in this document or from the use of programs and source code that may accompany it. In no event shall the publisher and the author be liable for any loss of profit or any other commercial damage caused or alleged to have been caused directly or indirectly by this document.

Printed: November 2006

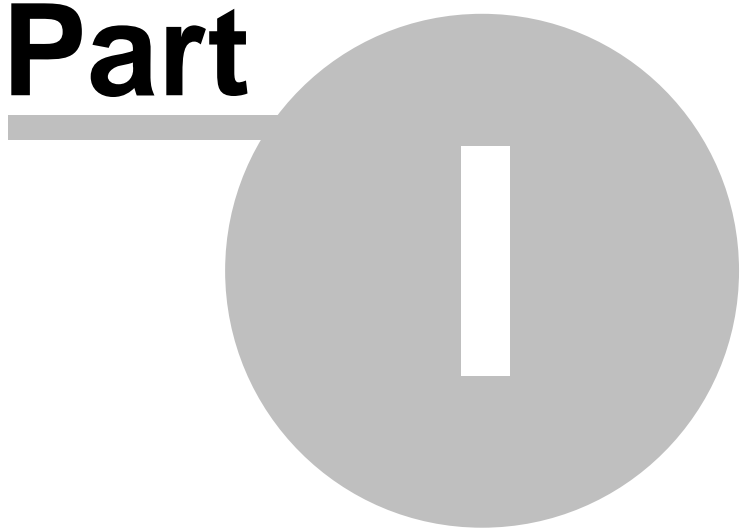
Peter Henderson, Richard Seaby & Robin Somes, Pisces Conservation Ltd.

# Table of Contents

Foreword	0
<b>Part I Introduction</b>	<b>7</b>
<b>Part II Installation</b>	<b>10</b>
<b>Part III System requirements</b>	<b>12</b>
<b>Part IV How to reference this program</b>	<b>14</b>
<b>Part V Using Growth II</b>	<b>16</b>
1 Main Window.....	16
Classed Data Tab .....	18
Calculations Tab .....	19
Length Results Tab .....	20
Highlighting Individual Parameters.....	22
L Gulland Tab .....	23
W Gulland Tab .....	24
L Ford-Walford Tab .....	25
W Ford-Walford Tab .....	26
Weight Results Tab .....	27
Incremental Data Tab .....	28
The drop-down menus .....	29
File .....	29
Saving a data set.....	29
Closing the program.....	30
Open an existing data file.....	30
Age/Size .....	30
Length Weight Relationship .....	31
Graphical von Bertalanffy.....	32
Seasonal Age/Size.....	33
Incremental.....	34
The von Bertalanffy model for incremental data.....	34
The Gompertz model for incremental data.....	34
The Logistic model for incremental data.....	35
The Richards model for incremental data.....	35
Help .....	36
Initial parameter dialog incremental data .....	36
Initial parameter dialog .....	36
Error dialog .....	37
2 Entering and editing data.....	38
Creating a new data set within Growth II .....	38
Age classed data .....	39
Incremental data.....	41
Creating a data file using a spread sheet .....	42
Editing data .....	44
3 Maximum size of the data set.....	45

4	Maximum size of a variable.....	45
5	Editing and changing graphs.....	45
	Graphical menu bar .....	45
	Enlarging part of a chart .....	47
	Editing directly from the chart .....	48
6	Printing and exporting your results.....	49
	Print Grid .....	49
	Print Chart .....	50
7	Copying .....	51
	Copy/Export Chart .....	51
	Copy Grid .....	53
<b>Part VI Tutorials and demonstration data sets</b>		<b>55</b>
1	Choosing a growth model.....	55
2	Fitting seasonal data.....	58
3	Fitting a model to incremental data.....	65
<b>Part VII Types of growth curve</b>		<b>71</b>
1	Gompertz growth curve.....	71
2	Logistic curve.....	74
3	Richards curve.....	76
4	Weibull .....	79
5	Janoschek .....	80
6	Exponential.....	81
7	Morgan-Mercer-Floden.....	82
8	The von Bertalanffy growth equation.....	84
9	Seasonally adjusted von Bertalanffy.....	85
<b>Part VIII Regression diagnostics</b>		<b>88</b>
1	Weighted Sum of squared residuals.....	88
2	Akaike Information Criterion.....	88
3	Schwarz Criterion.....	89
<b>Part IX References</b>		<b>91</b>
1	References .....	91
<b>Part X Contact Pisces</b>		<b>93</b>
1	Contact Pisces.....	93
<b>Index</b>		<b>94</b>

**Part**



# 1 Introduction

Growth II is designed to allow scientists and students, with no mathematical knowledge, to fit a variety of common growth curves to their data. The methods on offer range from the relatively simple and familiar to more complex models such as the general Richards curve and seasonally adjusted von Bertalanffy. The program also offers some graphical methods which have generally been superseded by numerical techniques, but which may still be useful when exploring your data.

*Growth II*, completed in October 2006, is an upgrade from *Simply Growth* and includes the following additions and enhancements:

- An improved user interface and graphics
- No maximum size for the data set - all arrays are dynamically sized
- Improved help system with tutorials
- Additional new models including a seasonal von Bertalanffy
- Appropriate model statistics to help with choice of method

## A full list of the New Features in Growth II

### New Models

- Exponential
- 4 Parameter Gompertz
- 4 Parameter logistic
- 3 Parameter Weibull
- 4 Parameter Weibull
- Morgan-Mercer-Flodin (MMF)
- Janoschek
- 4 Parameter Richards
- 5 Parameter Richards
- Non Linear Seasonally adjusted von Bertalanffy
- Linear Seasonally adjusted von Bertalanffy

### New Appropriate Model Statistics

- Akaike Information Criterion (AIC)
- Schwarz Criterion (SC)

### Improved Models

- Non Linear Von Bertalanffy
- 3 Parameter Gompertz
- 3 Parameter Logistic

### Improved Graphic

- Export Charts as BMP, WMF, EMF, JPEG, PCX, GIF and PDF
- Updated graphics
- New tools on each graph making publication quality charts easier
- Active clicking on graphs - takes you to the editor for each part of the graph
- Interactive results and Equation - click on a parameter and the corresponding part of the equation will be highlighted

**Improved data entry and editing**

- Redo/Undo on grids
- Paste in to grid
- Output to grids
- Opens Excel (\*.xls) files

**New Help**

- Completely rewritten Help
- Explanations of the models
- Tutorials and worked examples



# Part

---



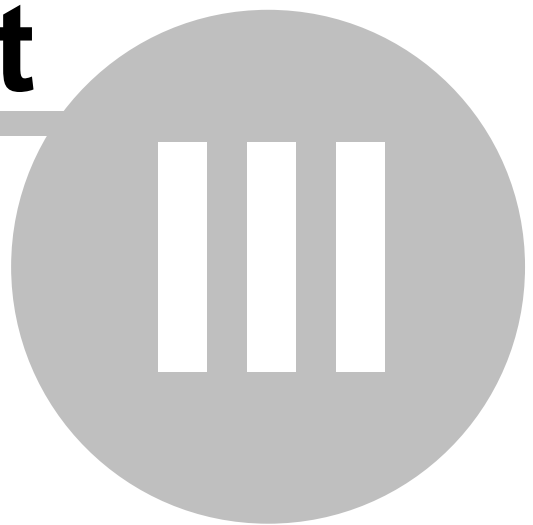
## 2 Installation

- Place the Growth II CD in the drive.
- The installation process should begin automatically; follow the on-screen instructions.
- If the CD does not auto-run, browse in Windows Explorer or My Computer, and double-click the file named **Setup.exe** in the root directory.

When installation is complete there will be a Growth II entry on your Start menu and a folder (directory) on your hard drive called *C:\Program Files\GrowthII* which holds the Growth II program files. An uninstall program will also be created, accessible from the Start menu should you wish to remove the program. If you wish to make a shortcut to the program on your desktop, go to the Growth II entry on the Start menu, right-click on it, and choose Send To: Desktop (create shortcut).

# Part

---



### 3 System requirements

- An IBM-compatible PC with CD-ROM drive.
- 10 MB of free hard disk space
- Windows 98/NT/2000/XP operating system.

We do not produce any software designed to run under the Mac OS or Linux, however, our programs should run satisfactorily using Windows emulation software. We recommend downloading one of our demo versions to test this, from the download page on our website. We regret that we are unable to provide any guarantee that our programs will work correctly under operating systems other than Windows.

**Part**

---

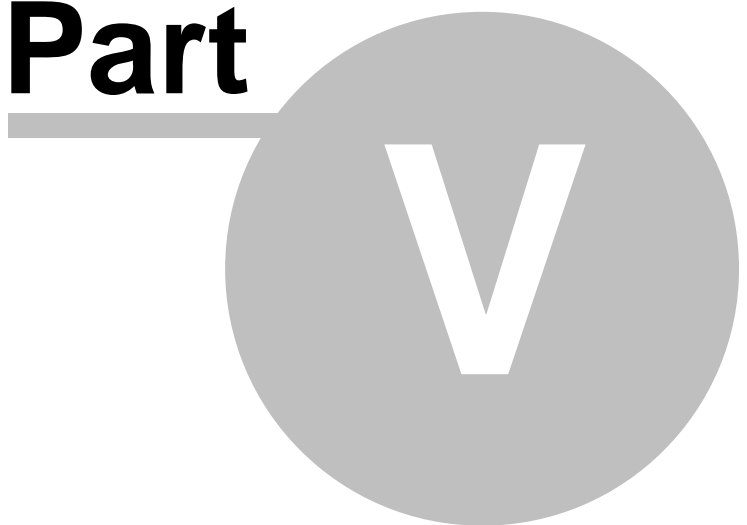
**IV**

## 4 How to reference this program

This program should be referenced as:

Henderson, P. A. & Seaby, R. M. (2006). *Growth II*. Pisces Conservation Ltd., Lymington, England.

**Part**

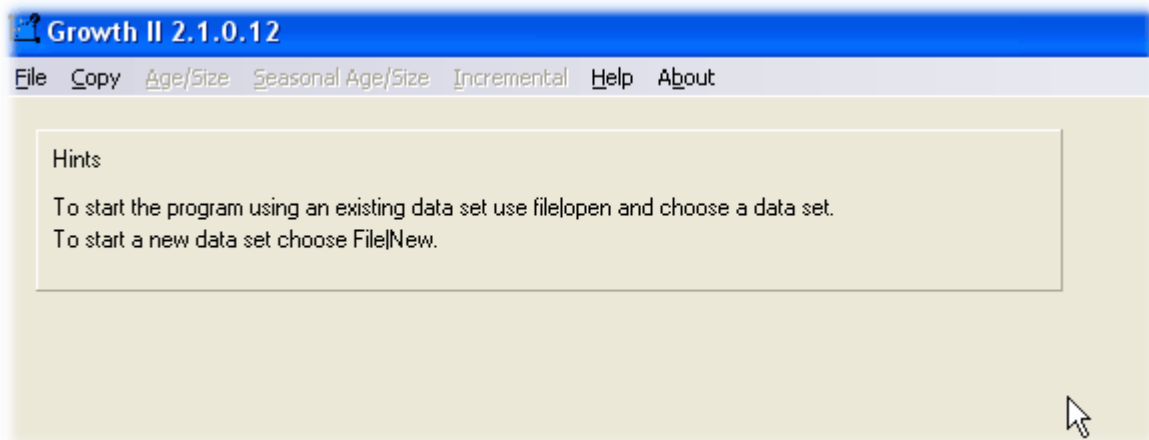


## 5 Using Growth II

Start *Growth II* in the normal Windows fashion either by clicking on the desktop icon or from the Start menu. The program appears with no open data set.

### 5.1 Main Window

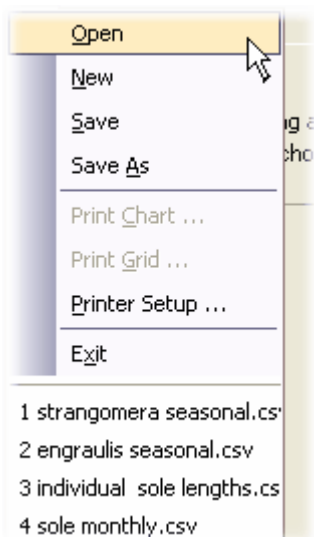
Start *Growth II* in the normal Windows fashion either by clicking on the desktop icon or from the Start menu. The program appears with no open data set, as shown below:



Most of the menus will not become active until a data set is opened or created.

**File:** To open and create data sets, save files and print results.

To open an existing data set click on **File|Open** as follows:



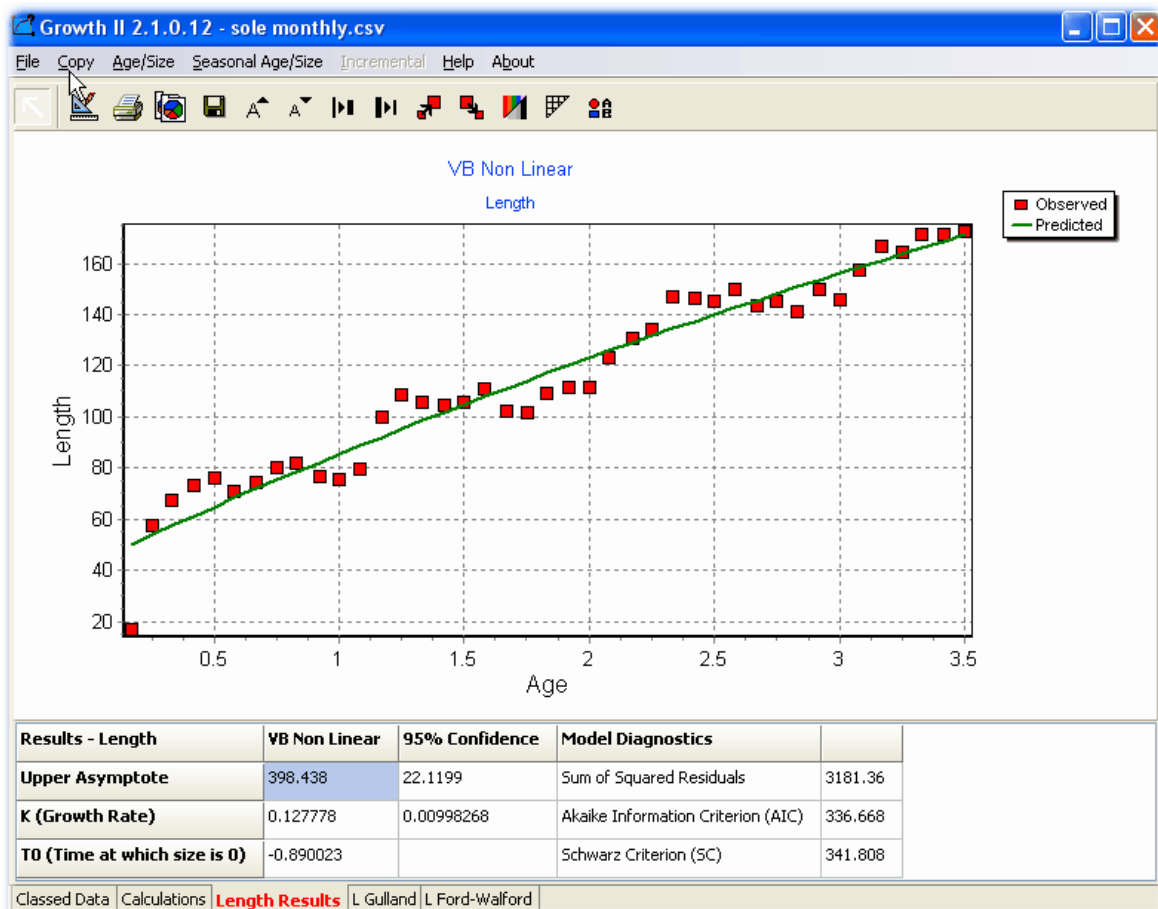
To get you started, Growth II comes with numerous demo data sets; see for example



fitting seasonal data.

For example use **File|Open** to find and open **sole monthly.csv** (saved by default during installation in the folder **C:\program files\GrowthII\GrowthDemoData**)

This will give a plot of the data in a tabbed output, and a number of the drop-down menus will be activated. Upon opening the data set Growth II has automatically fitted a von Bertalanffy growth equation using non-linear methods. Do not worry if you wish to fit another model - this is easily accomplished.



Along the top bar are a number of drop-down menus. These work in the same way as most standard Windows programs.

**File:** To open and create data sets, save files and print results.

**Copy:** To copy or export the graph or the data and predicted results.

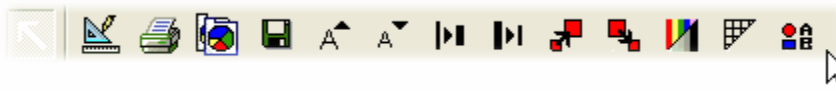
**Age/size:** To select a model to apply to age (time) size data.

**Seasonal Age/size:** To fit a seasonal growth model to age size data.

**Incremental:** To fit a growth model to incremental data.

**Help:** to enter the Help system. Context-specific help can also be obtained for each method by opening its window and then clicking on the right hand mouse button, or by pressing the F1 key on your keyboard.

Below these pull-down menus is a series of buttons, each displaying a standard symbol:



This is the graphics tool bar which will allow you to edit your plots.

Below the plot there is a table which gives the the parameter estimates for the model and model fitting diagnostics (see above).

At the bottom there are a series of tabs that you can click on to select various data and output displays.



The tabs displayed will depend on the data set entered. The full list of tabs is as follows:

**Classed Data:** This tab shows age and size data. For example, it will be displayed if you have entered or opened a data set that comprises age and length data for individual organisms.

**Calculations:** This tab presents the observed and predicted values.

**Length results:** This tab presented a plot of the observed and predicted fit plus model parameters and diagnostics for length data.

**Weight results:** This tab presented a plot of the observed and predicted fit plus model parameters and diagnostics for weight data.

**L Gulland:** This presents a Gulland plot (incremental change in length against length).

**L Ford-Walford:** This presents a Ford-Walford plot (length at age  $t+1$  against length at age  $t$ ).

**W Gulland:** This presents a Gulland plot (incremental change in weight against weight).

**W Ford-Walford:** This presents a Ford-Walford plot (weight at age  $t+1$  against weight at age  $t$ ).

### 5.1.1 Classed Data Tab

Click on this tab to show the data grid for age classed data.

Observations - Classed				
Age	Length			

Data can be edited, saved, copied or printed. To print, export or copy the grid see Print Grid and Copy Grid

### 5.1.2 Calculations Tab

This tab shows a grid giving both the observed (entered data) and the predicted values for the selected model. The model used is shown in the title. If the data set comprises both lengths and weights, then both will be displayed in the grid.

The grid below shows the output when size at age data are used. In this example both weight and length data were supplied, so the output includes both observed and predicted lengths and weights.

Result - Exponential				
	Observed L	Predicted length	Observed W	Predicted weight
2.00	240	242.62	180	70.72
3.00	300	289.42	250	247.55
4.00	340	331.79	400	417.34
5.00	360	370.14	500	580.39
6.00	400	404.87	650	736.94
7.00	450	436.31	850	887.27
8.00	470	464.77	1050	1031.61
9.00	500	490.54	1300	1170.21
10.00	530	513.87	1500	1303.30
11.00	550	535.00	1600	1431.10
12.00	560	554.12	1625	1553.80
13.00	565	571.43	1650	1671.63
14.00	568	587.11	1665	1784.77
15.00	568	601.30	1670	1893.41

The grid below shows the output when incremental data are analysed. The two columns on the left, labelled Time and Predicted Size, present the predicted growth curve. To the right the Observed column holds the observed sizes for individual organisms from your data set. The adjacent columns on the right give the model prediction and the difference between the observed and predicted.

Result - Logistic					
Time	Predicted Size		Observed	Predicted	Difference
0	0.7313		2.19	2.14	0.05
0.08	0.8013		4.80	5.59	-0.79
0.16	0.8776		11.00	12.62	-1.62
0.24	0.9608		16.00	16.50	-0.50
0.32	1.051		19.30	17.19	2.11
0.4	1.15		20.70	17.67	3.03
0.48	1.257		21.70	17.84	3.86
0.56	1.373		16.50	15.94	0.56
0.64	1.498		1.50	1.50	0.00
0.72	1.634		14.00	15.29	-1.29
0.8	1.781		18.20	16.55	1.65
0.96	2.11		20.00	17.43	2.57

To print, export or copy the grid see Print Grid and Copy Grid

### 5.1.3 Length Results Tab

Click on this tab to see a plot of your data, plus the fitted model and a grid of the parameter estimates and regression diagnostics. The screen is arranged into a number of panels.

The graphical menu bar at the top of the chart can be used to change many features of the plot.

The chart is active, and features of the chart can be edited directly by moving the cursor over them, holding down the Shift key and left clicking.

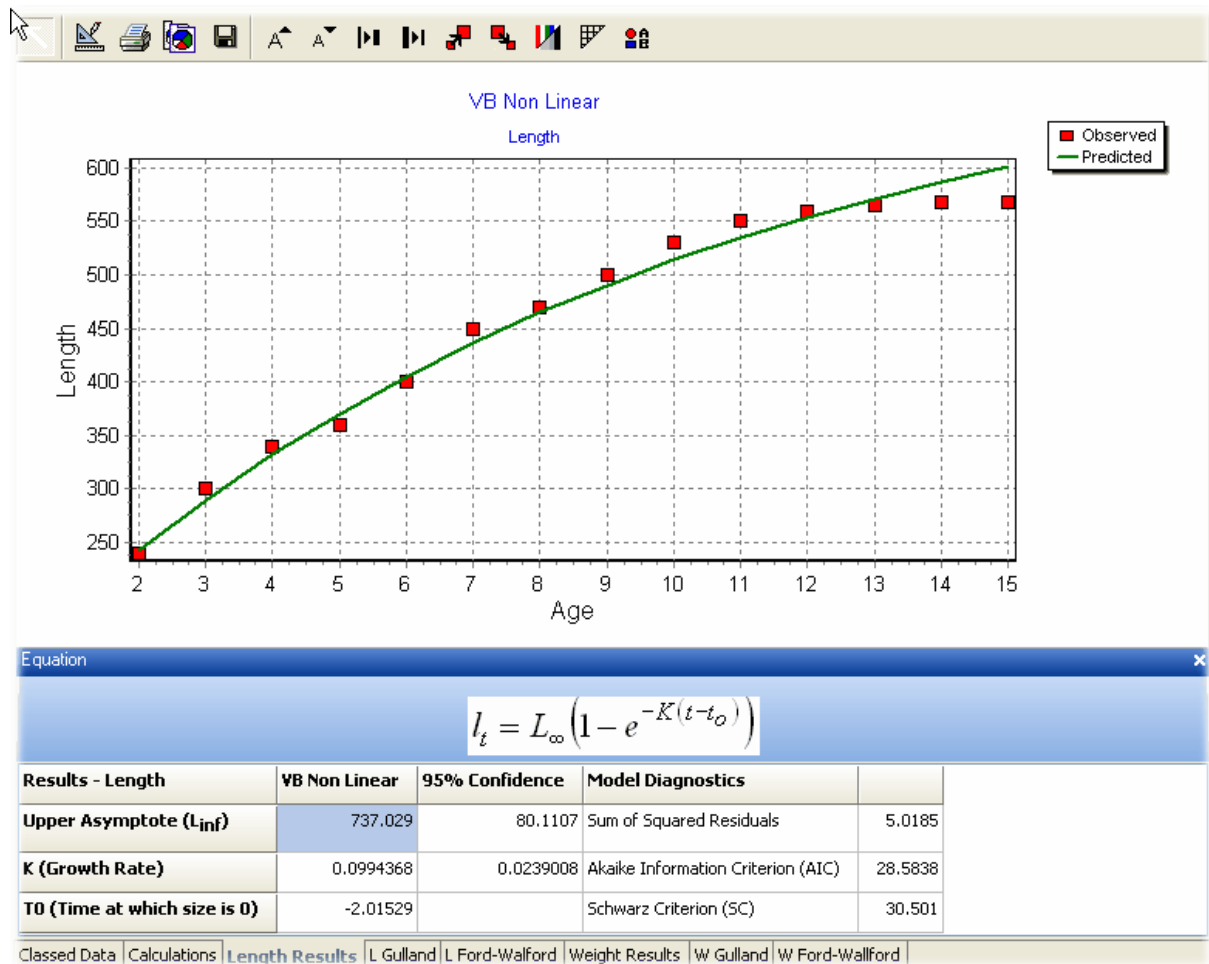
You can use the mouse to enlarge part of the chart.

Use File|Print Chart to print the graph.

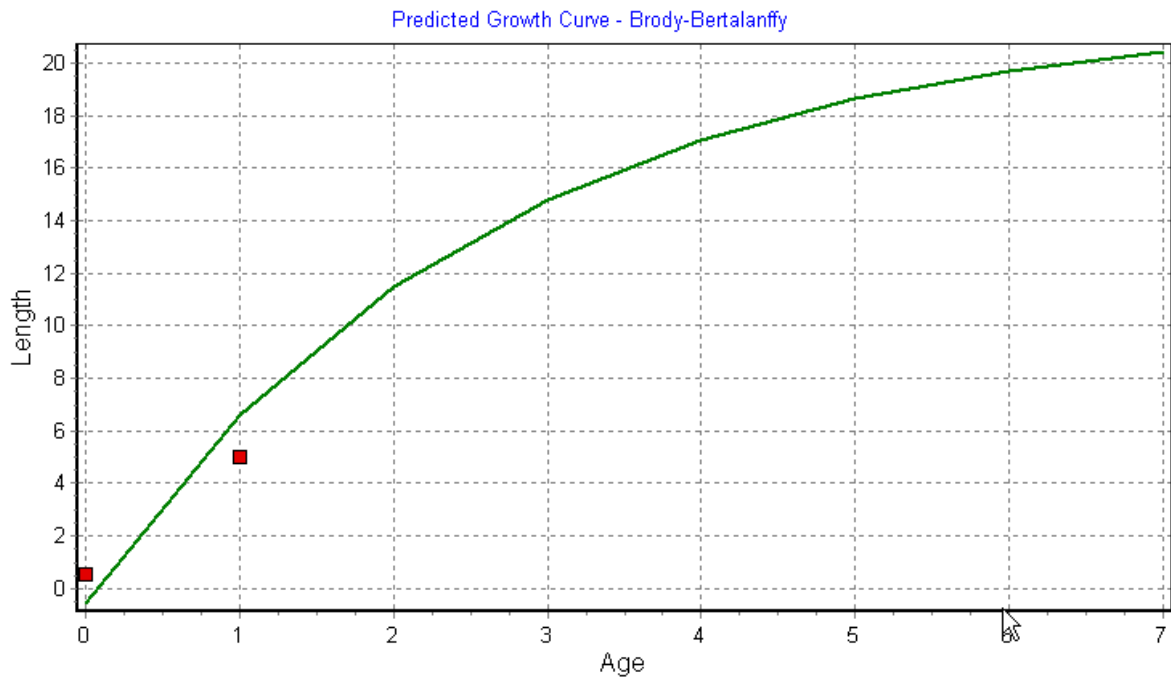
The fitted equation is displayed in the panel below the plot and the individual parameters can be highlighted.

Finally the results and regression diagnostics are shown in the bottom grid.

The data in this grid can be printed, copied and exported.



When incremental data have been analysed the output shows the predicted curve as a green line and the observed length at age observations as red squares.



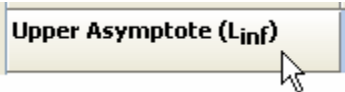
### 5.1.3.1 Highlighting Individual Parameters

When any model is run the results are presented together with the fitted equation as shown below.

Equation			
$l_t = L_{\infty} \left( 1 - e^{-K(t-t_0)} \right)$			
Results - Length	VB Non Linear	95% Confidence	Model Diagnostics
Upper Asymptote ( $L_{inf}$ )	737.029	80.1107	Sum of Squared Residuals
K (Growth Rate)	0.0994368	0.0239008	Akaike Information Criterion
T0 (Time at which size is 0)	-2.01529		Schwarz Criterion (SC)
Classed Data	Calculations	Length Results	L Gulland L Ford-Walford Weight Results W Gulland W

To help you understand which parameter the different estimates refer to, you can highlight each parameter in turn by left button clicking on the parameter name in column 1 of the grid or the result in column 2. This will result in the parameter name and symbol in the equation both being highlighted in red.

For example, using the **bass.csv** data set and running a von Bertalanffy growth curve, to highlight the upper asymptote in the equation, left-click on the Upper Asymptote in the grid:



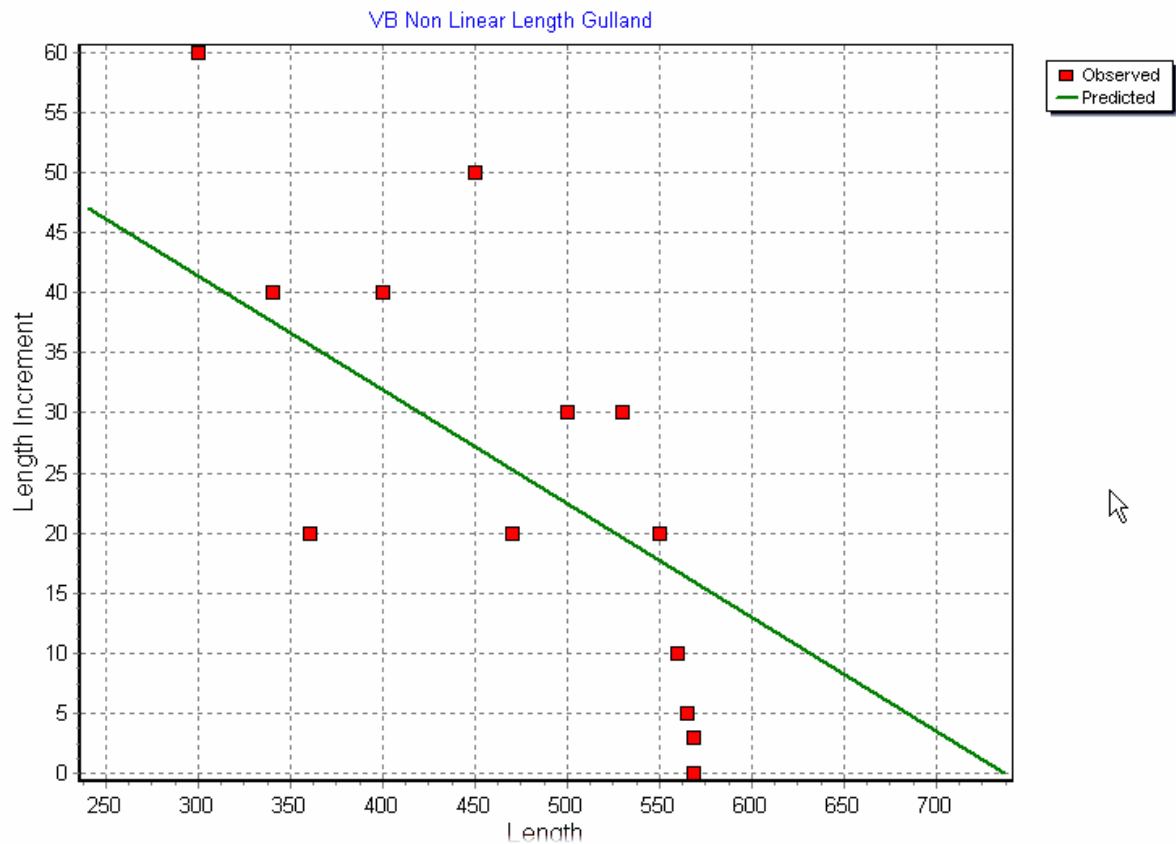
then the following is displayed:

Equation			
$l_t = L_{\infty} \left( 1 - e^{-K(t-t_0)} \right)$			
Results - Length	VB Non Linear	95% Confidence	Model Diagnostics
<b>Upper Asymptote (<math>L_{\infty}</math>)</b>	737.029	80.1107	Sum of Squared Residuals
<b>K (Growth Rate)</b>	0.0994368	0.0239008	Akaike Information Criterion
<b>T0 (Time at which size is 0)</b>	-2.01529		Schwarz Criterion (SC)

#### 5.1.4 L Gulland Tab

This tab presents the Gulland plot of your length data. It shows the incremental increase in length at each length. It is only shown if you run a von Bertalanffy growth model. This plot can be useful to help you estimate initial parameters for nonlinear regression. It is also useful to assess the goodness of fit of the chosen model, as the predicted line for the chosen model is marked on the plot.

The graph below shows a typical example using the **bass.csv** data. The green line is the model prediction.

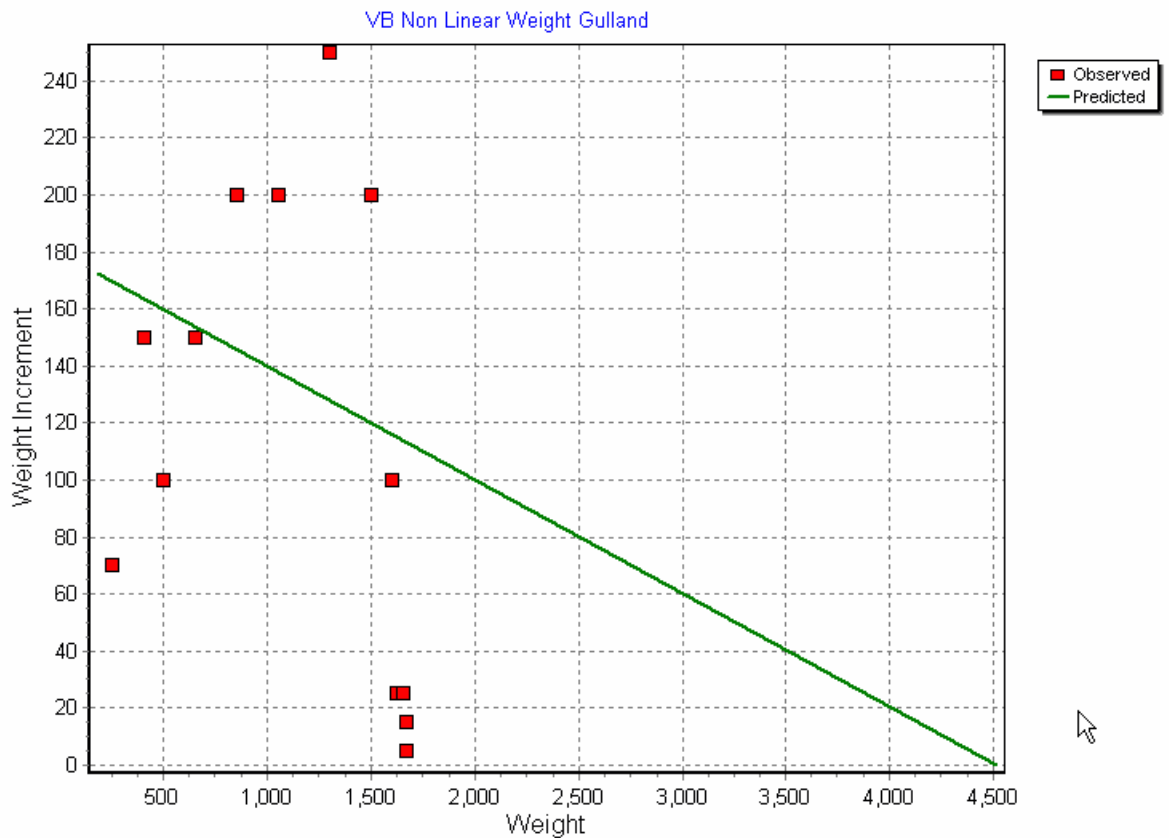


### 5.1.5 W Gulland Tab

This tab presents the Gulland plot of your weight data. It shows the incremental increase in weight at each weight. It is only shown if you run a von Bertalanffy growth model. This plot can be useful to help you estimate initial parameters for nonlinear regression. It is also useful to assess the goodness of fit of the chosen model as the predicted line for the chosen model is marked on the plot.

The graph below shows a typical example using the **bass.csv** data. The green line is the model prediction, and the graph suggests that the von Bertalanffy curve is poor model for the growth in bass weight.

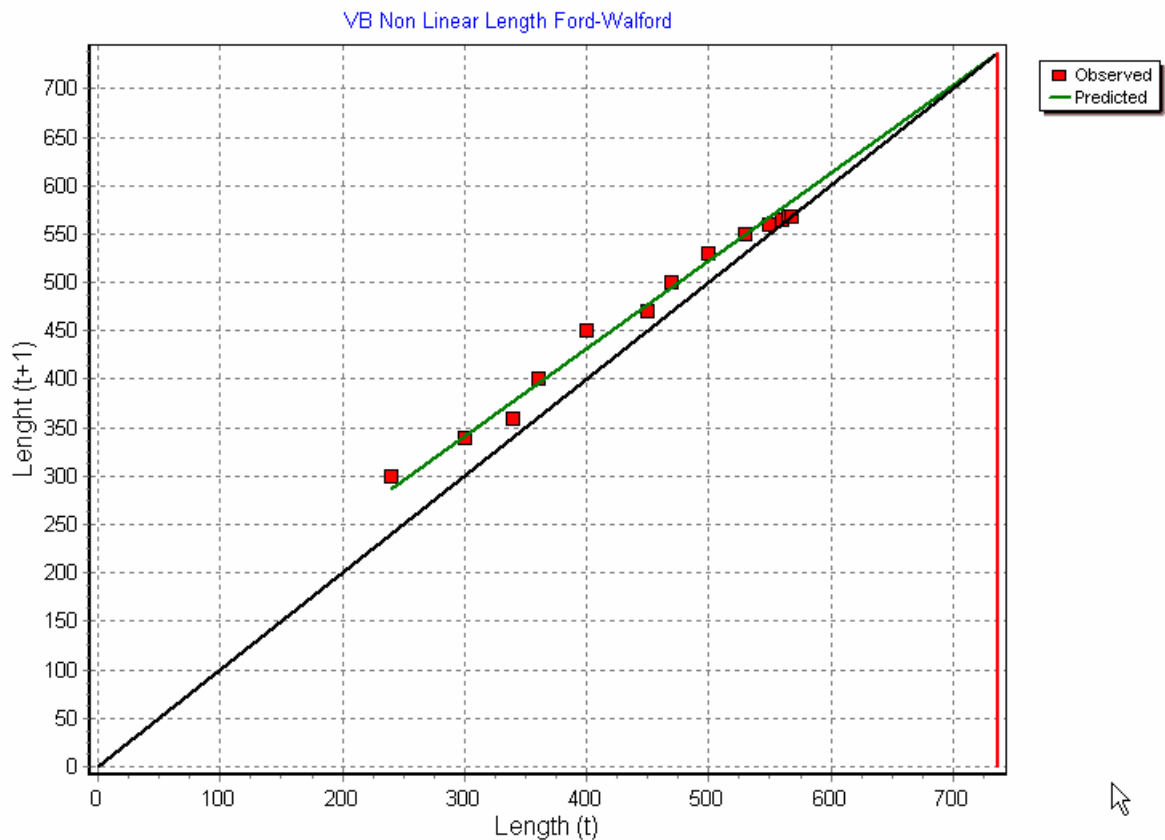




### 5.1.6 L Ford-Walford Tab

This tab presents the Ford-Walford plot of your length data. It shows a plot of length at  $t+1$  against length at  $t$  which was used as a graphical method to solve the von Bertalanffy growth equation. It is only shown if you run a von Bertalanffy growth model. This plot can be useful to help you estimate initial parameters for nonlinear regression. Marked on the plot is the 45 degree line and the best fit through the observed points as found by least squares. The point where these two lines intersect is an estimate of  $L_{\infty}$ .

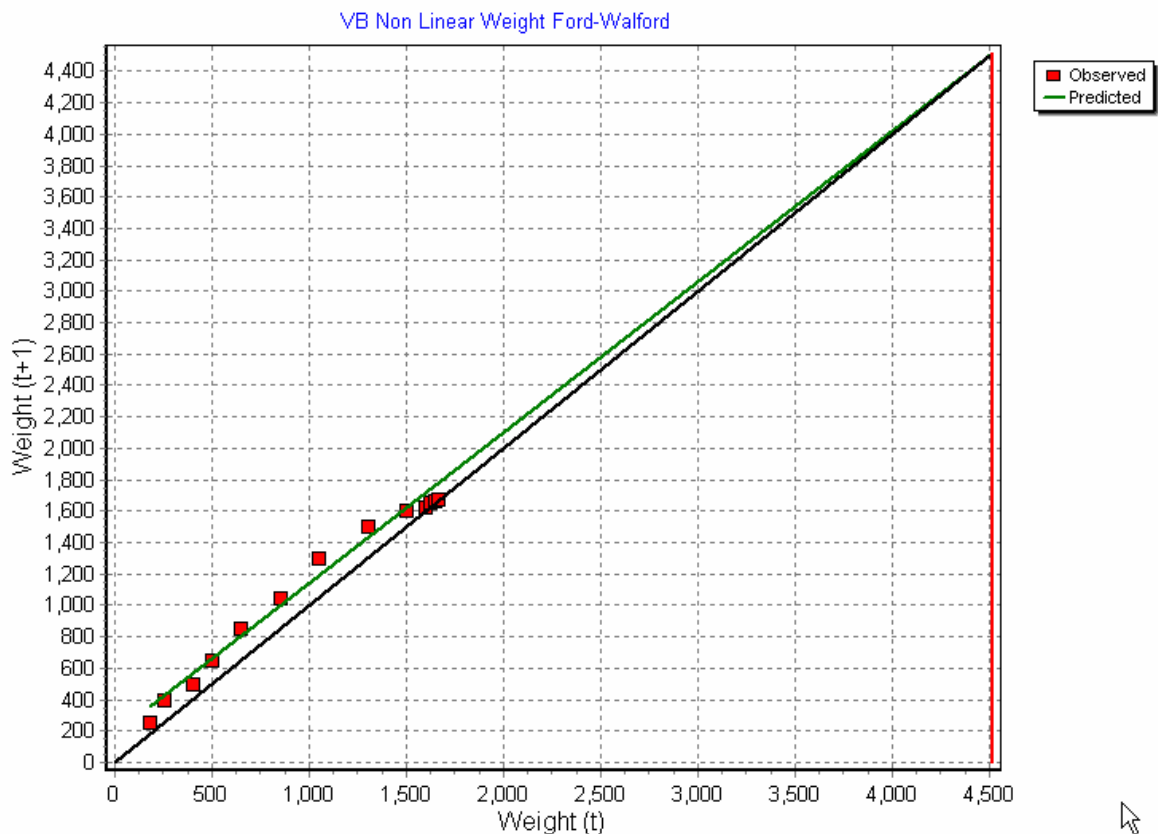
The graph below shows a typical example using the **bass.csv** data. The red line marks the estimate of  $L_{\infty}$  which is about 735 cm. for these data (the non-linear regression method estimated a value of 737 cm., showing that the graphical method can give quite good results). This method was the standard method to estimate  $L_{\infty}$  in fisheries science until the 1980s.



### 5.1.7 W Ford-Walford Tab

This tab presents the Ford-Walford plot of your weight data. It shows a plot of weight at  $t+1$  against weight at  $t$  which was used as a graphical method to solve the von Bertalanffy growth equation. It is only shown if you run a von Bertalanffy growth model. This plot can be useful to help you estimate initial parameters for nonlinear regression. Marked on the plot is the 45 degree line and the best fit through the observed points as found by least squares. The point where these two lines intersect is an estimate of  $W_{\infty}$  (asymptotic weight).

The graph below shows a typical example using the **bass.csv** data. The red line marks the estimate of  $W_{\infty}$ , which is about 4,500 g (4.5 kg) for these data (the non-linear regression method estimated a value of 4.415 kg showing that the graphical method can give similar results). However, this plot does indicate that this estimate should be viewed with caution as it is an extreme extrapolation. This method was the standard method to estimate  $L_{\infty}$  in fisheries science until the 1980s.



### 5.1.8 Weight Results Tab

Click on this tab to see a plot of your data, plus the fitted model and a grid of the parameter estimates and regression diagnostics.  
The screen is arranged into a number of panels.

The graphical menu bar at the top of the chart can be used to change many features of the plot.

The chart is active and features of the chart can be edited directly by moving the cursor over them, holding down the Shift key and left clicking.

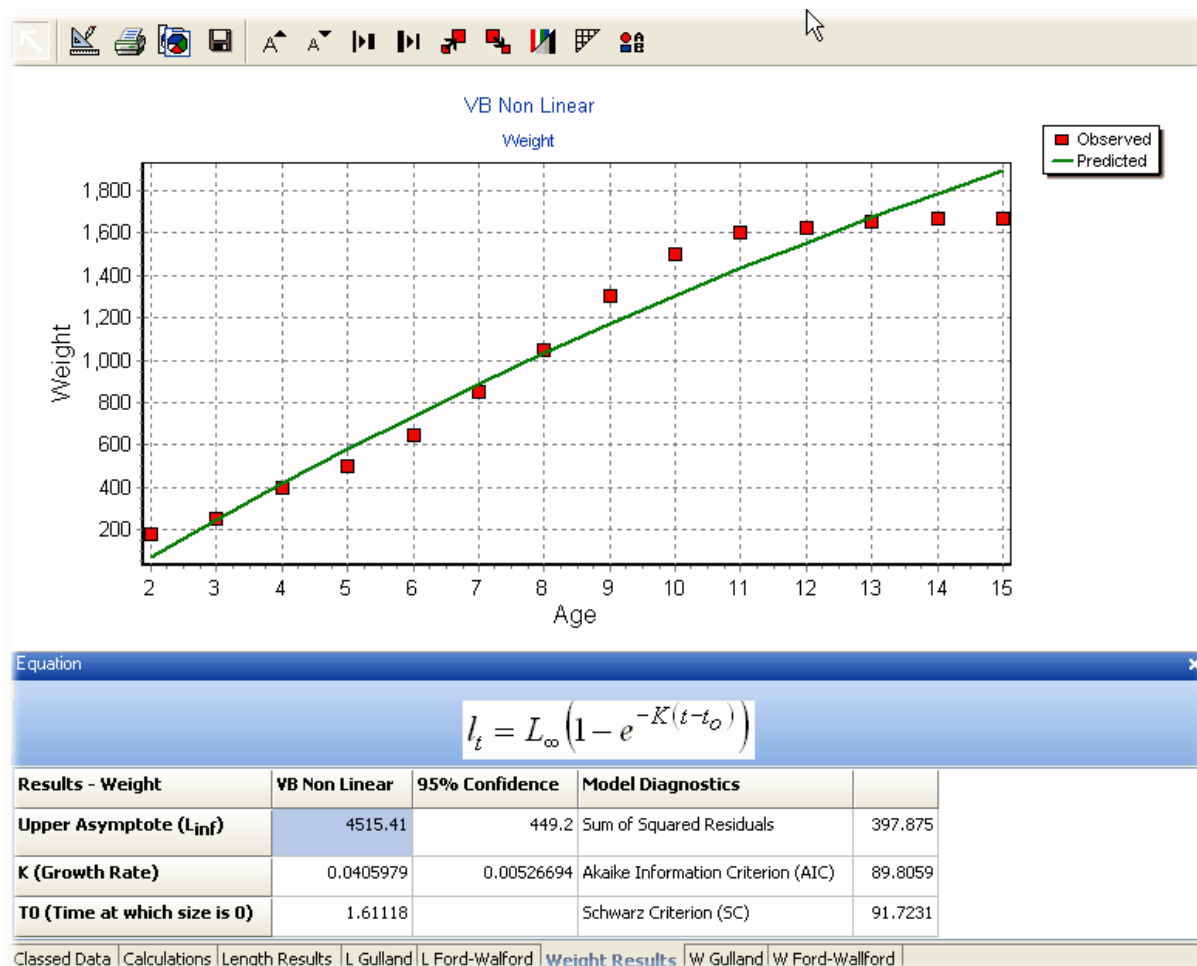
You can use the mouse to enlarge part of the chart.

Use File|Print Chart to print the graph.

The fitted equation is displayed in the panel below the plot, and the individual parameters can be highlighted.

Finally the results and regression diagnostics are shown in the bottom grid.

The data in this grid can be printed, copied and exported.



### 5.1.9 Incremental Data Tab

Click on this tab to show the data grid for incremental data.

Growth II 2.1.0.21 - inc.csv

File Copy Age/Size Seasonal Age/Size Incremental Help About

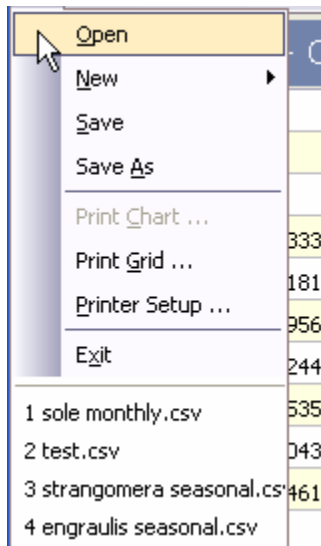
Observations - Incremental							
Sample	Size t0	Size t1	Time Gap		Known Age	Known Size	
Catch 1	19.22	19.65	0.225		0	0.5	
Catch 2	20.82	21.28	0.904		1	5	
Catch 3	17.7	17.84	0.126				
Catch 4	20.23	20.3	0.123				
Catch 5	17.9	18.98	0.937				
Catch 6	19.23	20.41	0.967				
Catch 7	20.3	20.48	0.973				

Data can be edited, saved, copied or printed. To print, export or copy the grid see Print Grid and Copy Grid

## 5.1.10 The drop-down menus

### 5.1.10.1 File

Use this drop-down menu to open and create data sets, save files, and print results.



Options are as follows:

Open

New

Save: saves the data file as a csv file.

Save As: allows you to select a name for the saved file.

Print Chart

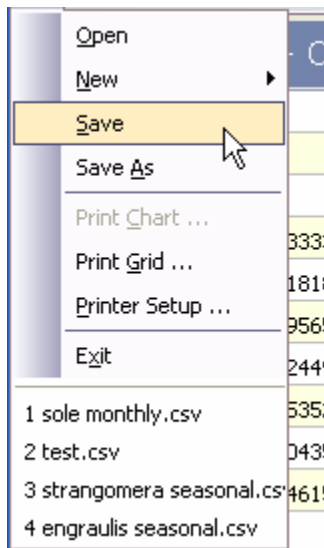
Print Grid

Printer Setup: allows you to select printer options

Exit

#### 5.1.10.1.1 Saving a data set

To save the current data set, use Save or Save As from the **File** menu.

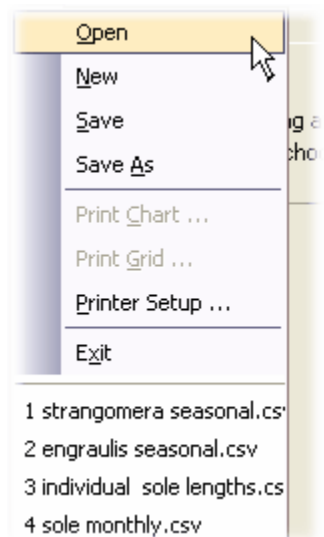


#### 5.1.10.1.2 Closing the program

Choosing the Exit button (last on the right on the lower toolbar), Exit from the File menu, or the cross symbol at the top right corner of the program window will close Growth II.

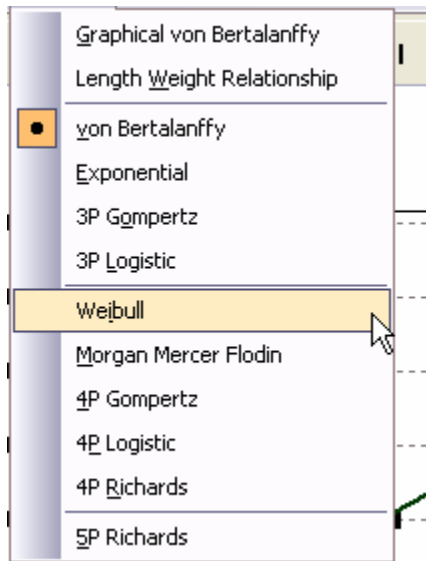
#### 5.1.10.1.3 Open an existing data file

Use **File|Open** to select a data file for analysis. To reopen a recently opened dataset, select from the recent file list at the bottom of the menu.



#### 5.1.10.2 Age/Size

This drop-down menu allows you to choose from a range of calculations and models applicable to data entered in the form of size at age or time. The orange square with a black dot indicates the method currently applied to the data.



When a nonlinear regression method is chosen an initial parameter dialog window opens

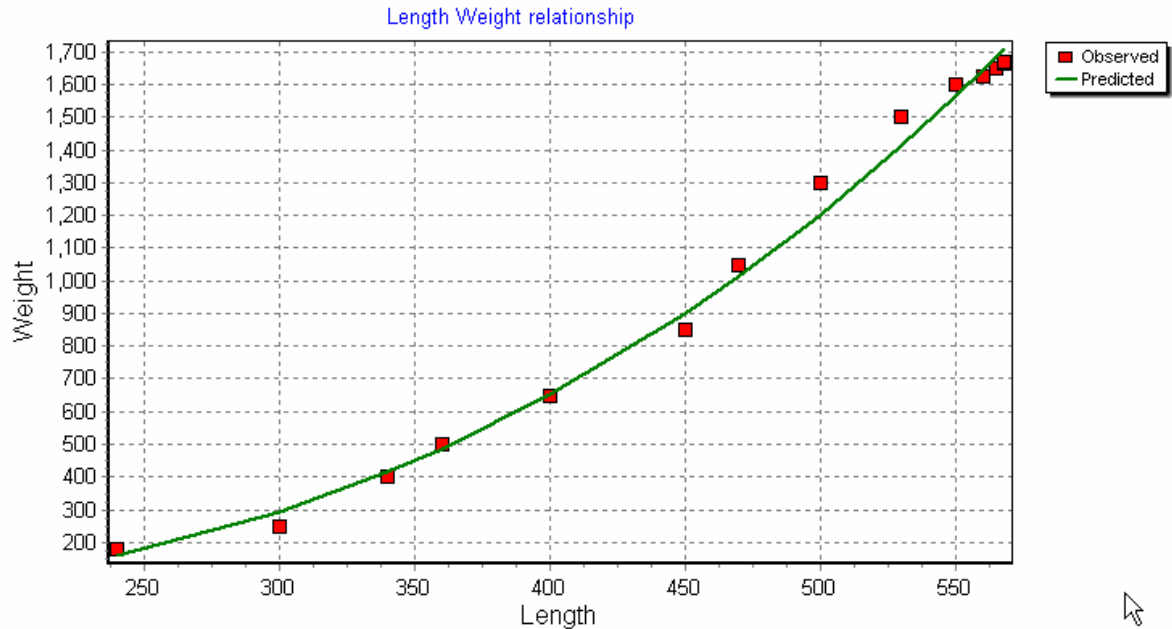
Graphical von Bertalanffy  
 Length Weight Relationship  
 von Bertalanffy growth equation  
 Exponential growth  
 3 parameter Gompertz growth equation  
 3 parameter logistic growth equation  
 Weibull growth curve  
 Janoschek growth curve  
 Morgan-Mercer-Flodin  
 4 parameter Gompertz growth equation  
 4 parameter logistic growth equation  
 4 parameter Richard's model  
 5 parameter Richard's model

#### 5.1.10.2.1 Length Weight Relationship

This option will only be available if the data set comprises both length and weight data. An example data set supplied with Growth II which comprises both weights and lengths is **bass.csv**.

Growth II plots the change in weight with the length and fits by regression a power curve of the form:

$$W = aL^b$$

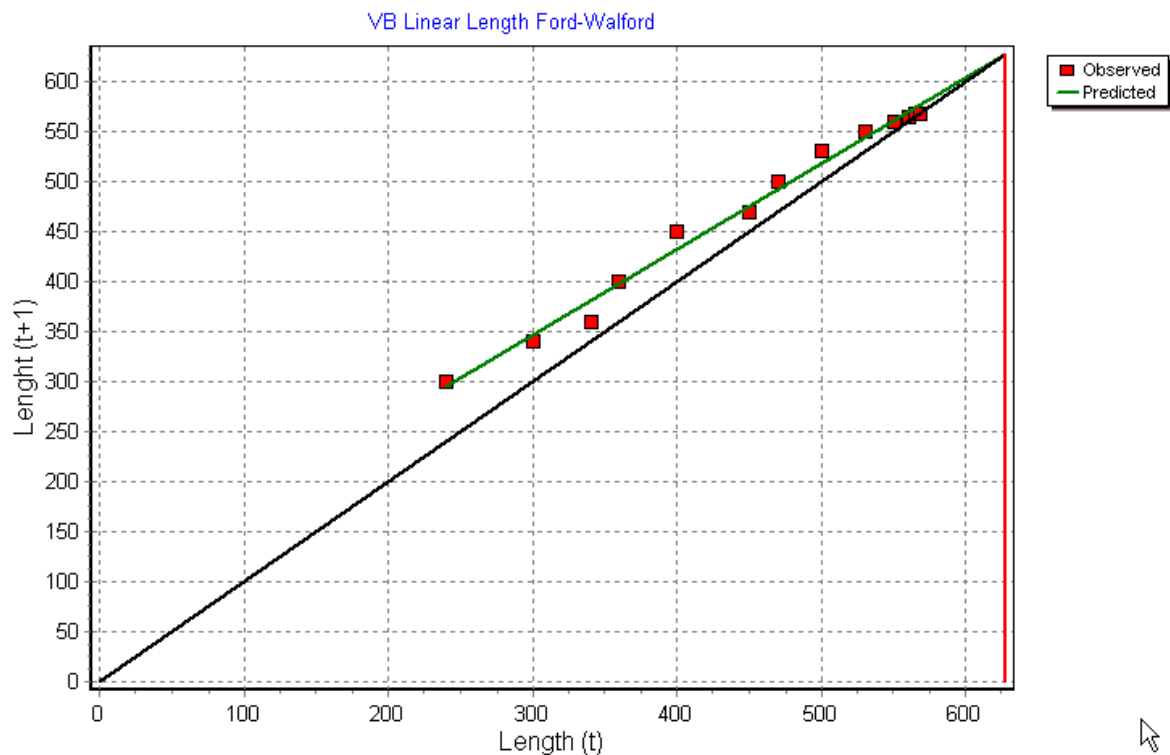


#### 5.1.10.2.2 Graphical von Bertalanffy

Each of the growth equations offered is solved using the Levenberg-Marquardt Method for non-linear regression. The one exception is the Graphical von Bertalanffy. This fits the von Bertalanffy growth curve using a graphical method which was much used before the development of computers.

To allow comparison with older methodologies that are still described in books on fisheries methods, a graphical method for fitting the von Bertalanffy is included. This is based on the Ford-Walford plot of length (or weight) in which the length (or weight) at time  $t+1$  is plotted against the length (or weight) at time  $t$ . If a straight line is fitted to the graph then the growth parameter,  $k$ , can be estimated from the slope and  $L_{\infty}$  is given by the intercept of this line with a 45 degree line from the origin. This method is not as accurate as nonlinear regression and should not be the method of choice.

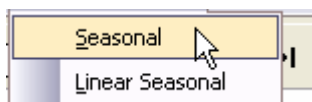




While the graphical method is included mainly for historical interest, but may be useful for diagnostic purposes should the Levenberg-Marquardt Method fail to reach a solution. Growth II estimates the initial guesses of the parameters for fitting the von Bertalanffy curve required by the Levenberg-Marquardt Method using this graphical approximation.

#### 5.1.10.3 Seasonal Age/Size

This drop-down menu allows you to choose from two methods to fit a seasonally adjusted von Bertalanffy growth model.

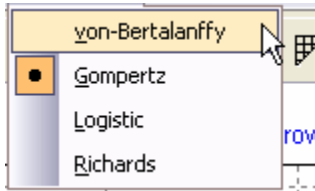


Choose **Seasonal** to fit the model using the Levenberg-Marquardt Method for non-linear regression. This is the preferred method as it will produce the most accurate estimates.

The **Linear Seasonal** method may be useful for diagnostic purposes should the Levenberg-Marquardt Method fail to reach a solution. Growth II estimates the initial guesses of the parameters for fitting the curve by the Levenberg-Marquardt Method using this linear approximation.

#### 5.1.10.4 Incremental

This drop-down menu allows you to choose from a range of models applicable to data entered in the form of incremental data. The orange square with a black dot indicates the method currently applied to the data.



#### Growth

Four growth models can be fitted to your data using Fabens (1965) method. These are:  
 von Bertalanffy used with incremental data  
 Gompertz used with incremental data  
 Logistic curve used with incremental data  
 Richard's model with incremental data

In the case of Richards model the method only estimates 3 of the 4 parameters and if this model is chosen you will be presented with a dialog window in which you will be asked to enter

##### 5.1.10.4.1 The von Bertalanffy model for incremental data

von Bertalanffy derived this equation in 1938 from simple physiological arguments. It is the most widely used growth curve and is especially important in fisheries studies. There are a number of different ways that this equation can be written (see von Bertalanffy growth equation). When using incremental data the version used is

$$l_t = L_{\infty} \left( 1 - be^{-Kt} \right)$$

where t is time,  
 l is length (or some other measure of size),  
 K is the growth rate  
 b a parameter determining the rate of growth at t = 0 and  
 $L_{\infty}$ , termed 'L infinity' in fisheries science, is the asymptotic length at which growth is zero.

In this version of the equation the parameter  $t_0$  is not included. However  $b = \exp(kt_0)$  so  $t_0$  can be easily calculated.

##### 5.1.10.4.2 The Gompertz model for incremental data

The Gompertz curve was originally derived to estimate human mortality by Benjamin Gompertz (Gompertz, B. "On the Nature of the Function Expressive of the Law of Human Mortality, and on a New Mode of Determining the Value of Life Contingencies." Phil. Trans. Roy. Soc. London **123**, 513-585, 1832). Charles Winsor (1932) presents an early

description of the use of this equation to describe growth processes. There are a number of different ways that this equation can be written (see 3 parameter Gompertz growth equation). When using incremental data the version used is

$$l_t = L_{\infty} e^{1 - be^{-kt}}$$

where t is age  
 where k is the growth rate  
 b a scaling parameter and  
 $L_{\infty}$ , termed 'L infinity', is the asymptotic length at which growth is zero.

#### 5.1.10.4.3 The Logistic model for incremental data

The logistic growth curve (sometimes called the Verhulst model as it was first proposed as a model of population growth Pierre Verhulst 1845, 1847) is one of the simplest of the S-shaped growth curves. A generalization of the logistic, which is no longer symmetrical about the point of inflection, was developed by Richards (1959) and is termed the Richards curve or generalized logistic.

There are a number of different ways that this equation can be written (see Logistic curve). When using incremental data the version used is

$$l_t = \frac{L_{\infty}}{1 - be^{-kt}}$$

where t is age  
 where k is the growth rate  
 b a scaling parameter and  
 $L_{\infty}$ , termed 'L infinity', is the asymptotic length at which growth is zero.

#### 5.1.10.4.4 The Richards model for incremental data

The Richards curve or generalized logistic is a widely used growth model that will fit a wide range of S-shaped growth curves. There are both 4 and 5 parameter versions in common use. The logistic curve is symmetrical about the point of inflection of the curve. To deal with situations where the growth curve is asymmetrical, Richards (1959) added an additional parameter.

There are a number of different ways that this equation can be written (see Logistic curve). When using incremental data the version used is

$$l_t = \frac{L_{\infty}}{(1 - be^{-kt})^{\delta}}$$

where  $t$  is age,  
 where  $k$  is the growth rate,  
 $b$  a scaling parameter,  
 $\delta$ , a parameter that in part determines the point of inflection on the  $y$  axis and  $L_{\infty}$ , termed 'L infinity', is the asymptotic length at which growth is zero.

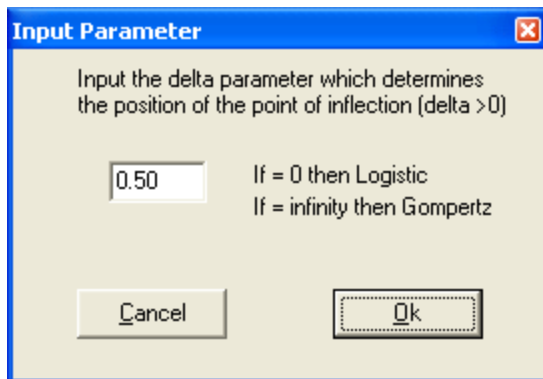
For incremental data Growth II will not estimate  $d$ , which must be supplied prior to fitting.

#### 5.1.10.5 Help

Select this drop-down to use the help system

#### 5.1.11 Initial parameter dialog incremental data

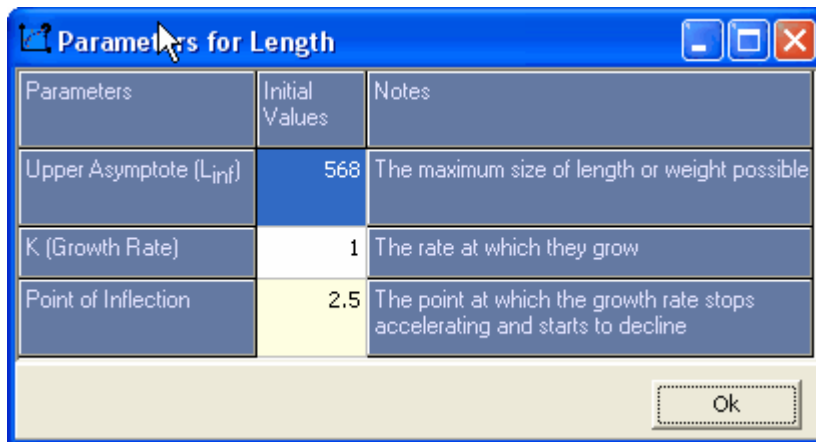
If you choose to fit a Richards curve to incremental data, Growth II will ask you to enter an appropriate value for the parameter that fixes the point of inflection.



If you do not want a value of 0.5 (the default) click on the number and type in the required number. This dialog gives you some guide values - for example, if a value of 1 is entered you will in fact be fitting the Gompertz. It is worthwhile examining the shape of your curve to decide if the shape is closer to a logistic von Bertalanffy or Gompertz in shape and then chose a shape parameter value close to that of the appropriately shaped curve.

#### 5.1.12 Initial parameter dialog

Estimation of nonlinear regression parameters using the Levenberg-Marquardt Method requires the user to supply initial guesses for each parameter. Growth II will attempt to identify useful initial guesses and these will be presented in the initial values column.

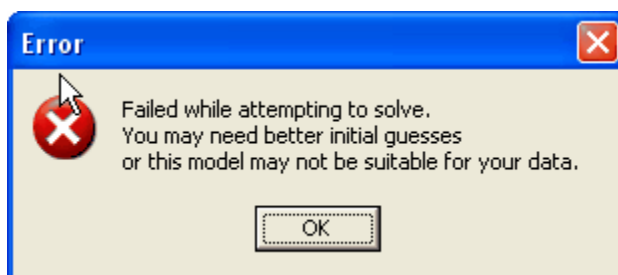


Generally you should initially see if these values lead to a solution by clicking OK. If a solution is not obtained, as can easily happen with the Richards curve, you will need to try some different guess for the initial values. These can be input by left-clicking on the existing value and typing in a new figure. One way to make some suitable guesses is to run some of the other models and look at the parameter estimates produced. For example, if the Richards curve fit fails, run a Gompertz or logistic and look at the value of the asymptotes and try these as initial guesses.

### 5.1.13 Error dialog

The Levenberg-Marquardt numerical method to solve for the nonlinear regression is the best method known, however, it can fail and may often do so when the Richards curve is fitted to data. Failure is normally caused by the choice of inappropriate guesses for the values of the parameters to be estimated.

This box is shown when Levenberg-Marquardt has failed to converge to a solution.



Click on OK and either try some other starting values until a solution is achieved or use a different model. One way you may be able to identify better starting values is to look at the output for models that were successful.

## 5.2 Entering and editing data

### Demonstration data sets

A number of example data sets are supplied with the program. These allow the user to test the program, and can be opened in a spreadsheet or word-processor program to examine the way the data are organized.

### Creating data sets

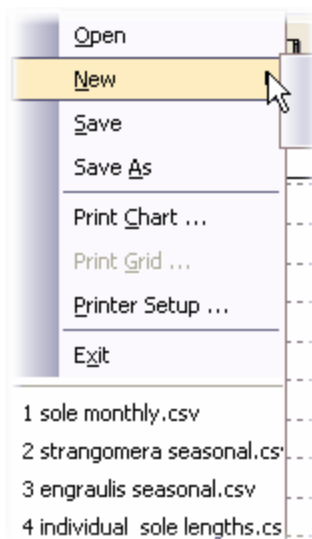
Data sets can be created within Growth II, or by using a spreadsheet such as Microsoft Excel, or many other spreadsheets, word processors, database programs etc. We recommend that you organize large data sets using a spreadsheet like Excel, as this will give access to a wide range of sorting and editing procedures to ease your task.

Creating a data file using a spreadsheet

Creating a new data set within Growth

### 5.2.1 Creating a new data set within Growth II

Data sets can also be created and edited within Growth II. To create a new data set, select New from the File drop-down menu. You will be presented with the a choice of Classed or Incremental.



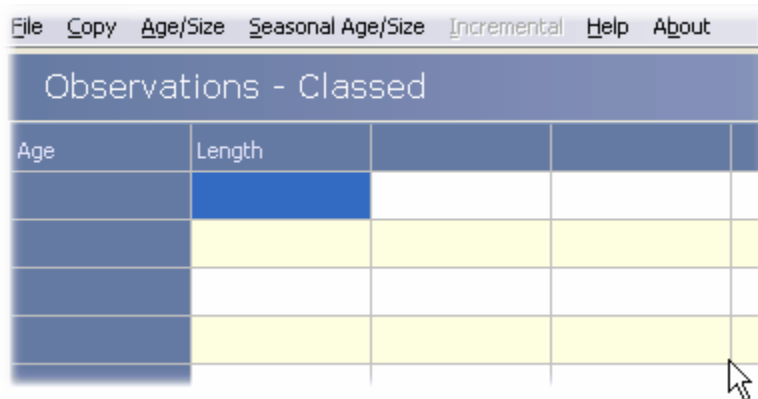
Choose classed if you wish to enter data where you have information on size at particular ages or points in time.

Choose incremental if you have observations on the change in size between different points in time.

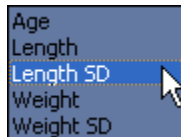
Remember that for larger data sets you are advised to use a spreadsheet to create your dataset, as it will give you superior editing and data search facilities. See Creating a data file using a spreadsheet.

#### 5.2.1.1 Age classed data

If **File|New|Classed** is selected, an empty grid will be formed with two titles, Age and Length, in place.



These titles can be changed and others added by clicking in the top cell of another column and selecting a suitable title from the drop-down list.



Alternatively, you can simply type in one of the following titles:

**Age** identifies the column as holding the ages (time since birth) of the animals. Ages can be input as integer or real numbers. Age can either be the age of an individual animal, or refer to an age class.

**Length** identifies the column as holding length at age data. These data can be either measurements for individual animals or the mean for an age class.

**Weight** identifies the column as holding weight at age data. These data can be either measurements for individual animals or the mean for an age class.

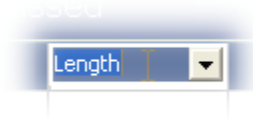
**Length SD** identifies the column as holding the standard deviations of length at age data. When age classed data are used this column gives a measure of the variation in length between the individuals in a single age class.

**Weight SD** identifies the column as holding the standard deviations of weight at age data. When age classed data are used this column gives a measure of the variation in weight between the individuals in a single age class.

Please note that the column title should be added exactly as given above.

You should avoid adding duplicate column titles; these are likely to cause the program to malfunction. If you add a duplicate title, the program will give a warning message to alert you. To delete a column title, click into the title cell, so that the text is highlighted,

(see below) and press the Delete key on your keyboard.



Once you have the correct titles for the columns you can type in values in the grid by clicking on a cell and entering a number.

The typical structure of age classed data in an Excel spreadsheet is as follows:

	A	B	C
1	Age	Length	
2	0.33	6.37	
3	0.41	7.43	
4	0.49	7.91	
5	0.49	8.49	
6	0.48	9.26	
7	0.48	9.36	
8	0.75	9.26	
9	0.75	7.04	
10	0.83	7.23	
11	0.82	7.71	
12	0.82	8.19	
13	0.82	8.87	

To insert a new row, use the Up / Down arrows to highlight any cell in the bottom row of the grid so that it turns blue - as shown below - then press the Down arrow key on your keyboard.

Age	Length	
0.33	6.37	
0.41	7.43	
0.49	7.91	
0.49	8.49	
0.75	9.26	
0.83	9.36	

To delete a row, highlight any cell in that row, so that the cell itself is highlighted blue, rather than its contents, and press the Delete key on your keyboard. Please note that the Undo function does not apply to row deletion; once a row has been deleted, it cannot be



restored.

### 5.2.1.2 Incremental data

Incremental data comprises observations of the size of organisms at two points in time. To fit a growth curve to such data, you will also need to supply at least one observation of known size at a known age. If **File|New|Incremental** is selected, an empty grid will be formed with titles, Sample, Size T0, Size T1, Time Gap, Known Age and Known size in place.

File Copy Age/Size Seasonal Age/Size Incremental Help About						
Observations - Incremental						
Sample	Size t0	Size t1	Time Gap		Known Age	Known Size
1	12	14	2		20	
2	10	11	1			
3	2	20	12			
4	1	15	9			
5	4	9	6			
6	3	6	3			

**Sample** identifies the column as holding an identification number or name for the individual.

**Size T0** identifies the column as holding length or weight of the individual when first measured.

**Size T1** identifies the column as holding length or weight of the individual when measured on a second occasion.

**Time Gap** identifies the column as holding data on the time difference between the measurements at time T0 and T1.

**Known Age** for a growth curve to be fitted to incremental data it is necessary to know the size of at least one individual at a known age. Place in this column a known age, as either a real or integer value.

**Known Size** place in this column the size of individuals of known age.

To insert a new row, highlight any cell in the bottom row of the grid so that it turns blue - as shown below - then press the Down arrow key on your keyboard.

Catch 5	17.9	18.98	0.937
Catch 6	19.23	20.41	0.967
Catch 7	20.3	20.48	0.973

To delete a row, highlight any cell in that row, so that the cell itself is highlighted blue, rather than its contents, and press the Delete key on your keyboard. Please note that the Undo function will not apply to row deletion; once a row has been deleted, it cannot be restored.

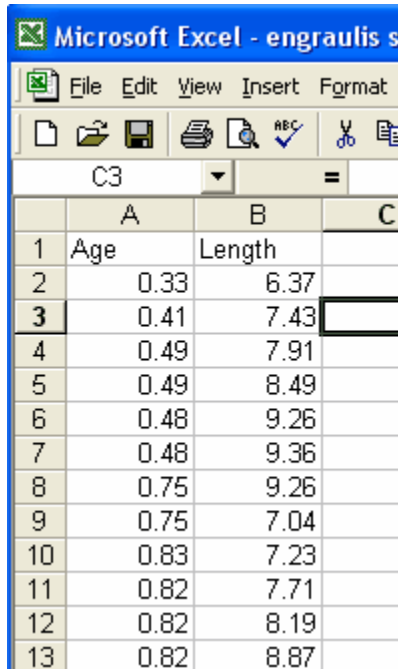
### 5.2.2 Creating a data file using a spread sheet

A data set is stored as a comma-delimited text file with the extension **.csv** or an Excel file (.xls). It is normal to initially organize your data in a spreadsheet such as Excel and then save the worksheet as a comma delimited (csv) file for use with Growth II.

There are different arrangements of data for the analysis of age classed and incremental data which will be described in turn below.

#### Age classed data

For simple size at age measurements, the data are organized as a simple 2-dimensional array as follows:



The screenshot shows a Microsoft Excel window titled 'Microsoft Excel - engraulis s'. The menu bar includes File, Edit, View, Insert, and Format. The toolbar contains icons for file operations and editing. The active cell is C3. The data table is as follows:

	A	B	C
1	Age	Length	
2	0.33	6.37	
3	0.41	7.43	
4	0.49	7.91	
5	0.49	8.49	
6	0.48	9.26	
7	0.48	9.36	
8	0.75	9.26	
9	0.75	7.04	
10	0.83	7.23	
11	0.82	7.71	
12	0.82	8.19	
13	0.82	8.87	

Your data for analysis should comprise observations of the age (time), length, standard deviation of length, weight and standard deviation of weight for organisms, which are organized into columns. The first row of each column holds the title that the program uses to know what type of data the column holds. You must use the following standard titles:

For age classed data:

**Age** identifies the column as holding the ages (time since birth) of the animals. Ages can be input as integer or real numbers. Age can either be the age of an individual animal or refer to an age class.

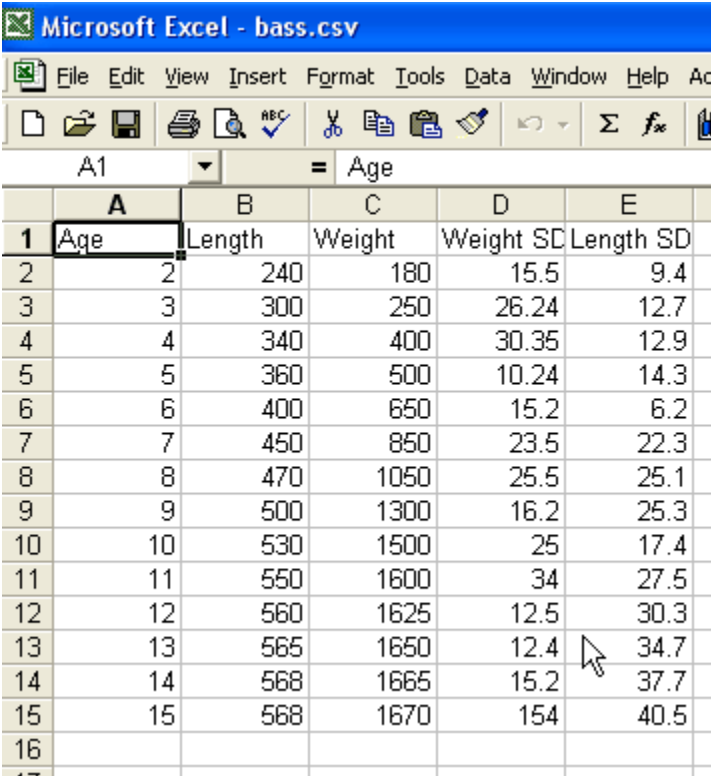
**Length** identifies the column as holding length at age data. These data can be either be measurements for individual animals or the mean for an age class.

**Weight** identifies the column as holding weight at age data. These data can be either be measurements for individual animals or the mean for an age class.

**Length SD** identifies the column as holding the standard deviations of length at age data. When age classed data are used this column gives a measure of the variation in length between the individuals in a single age class.

**Weight SD** identifies the column as holding the standard deviations of weight at age data. When age classed data are used this column gives a measure of the variation in weight between the individuals in a single age class.

The image below shows an example of data that includes lengths and weights and standard deviations. This data set, named **bass.csv**, is included with Growth II.



	A	B	C	D	E
1	Age	Length	Weight	Weight SD	Length SD
2	2	240	180	15.5	9.4
3	3	300	250	26.24	12.7
4	4	340	400	30.35	12.9
5	5	360	500	10.24	14.3
6	6	400	650	15.2	6.2
7	7	450	850	23.5	22.3
8	8	470	1050	25.5	25.1
9	9	500	1300	16.2	25.3
10	10	530	1500	25	17.4
11	11	550	1600	34	27.5
12	12	560	1625	12.5	30.3
13	13	565	1650	12.4	34.7
14	14	568	1665	15.2	37.7
15	15	568	1670	154	40.5
16					

### Incremental data

For incremental data the layout in a spreadsheet is as follows. This data set, named **incremental test Gompertz.csv**, is included with Growth II.

	A	B	C	D	E	F	G	H
1	Sample	Size t0	Size t1	Time Gap		Known Age	Known Size	
2	1	0.89	2.19	0.8		6	16.4	
3	2	2.2	4.8	1		8	19.4	
4	3	8	11	1		1	2.2	
5	4	5	16	4				
6	5	18.1	19.3	1				
7	6	20	20.7	1				
8	7	20.7	21.7	1				
9	8	14.2	16.5	1				
10	9	1.2	1.5	0.2				
11	10	8	14	2				
12	11	14.2	18.2	2				
13	12	19	20	1				
14								

**Sample** identifies the column as holding an identification number or name for the individual.

**Size T0** identifies the column as holding length or weight of the individual when first measured.

**Size T1** identifies the column as holding length or weight of the individual when measured on a second occasion.

**Time Gap** identifies the column as holding data on the time difference between the measurements at time T0 and T1.

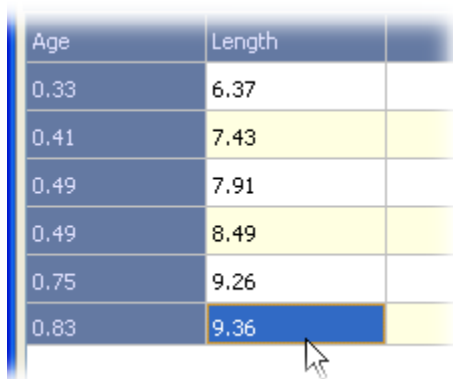
**Known Age** for a growth curve to be fitted to incremental data it is necessary to know the size of at least one individual at a known age. Place in this column a known age as either a real or integer value.

**Known Size** place in this column the size of individuals of known age.

### 5.2.3 Editing data

To edit an open data set click on the tab to display either the **Classed Data** or **Incremental Data** tab to display the data grid. Click on the cell you wish to edit and type in the new value.

To insert a new row, use the Up / Down arrows to highlight any cell in the bottom row of the grid so that it turns blue - as shown below - then press the Down arrow key on your keyboard.



Age	Length
0.33	6.37
0.41	7.43
0.49	7.91
0.49	8.49
0.75	9.26
0.83	9.36

To delete a row, highlight any cell in that row, so that the cell itself is highlighted blue, rather than its contents, and press the Delete key on your keyboard. Please note that the Undo function does not apply to row deletion; once a row has been deleted, it cannot be restored.

To make major changes it may be quicker to open the data set in a spreadsheet program.

### 5.3 Maximum size of the data set

Growth II has been written to handle any size of data set. However, there will still be a maximum upper limit to the size of data set it can handle that will be defined by the processing power and available memory of your computer.

Very large data sets may create problems for the non-linear regression to find suitable solutions. In practice, Growth II should be expected to always work with 10,000 age-length observations.

### 5.4 Maximum size of a variable

The maximum size of any number in Growth II is 2147483647. You are advised to rescale numbers to sensible sizes or you will experience problems with the Levenberg-Marquardt Method for non-linear regression. For example rather than expressing weights as 22,000 g it would be wise to input 22.0 kg.

### 5.5 Editing and changing graphs

Almost all aspects of the charts in Growth II can be edited.

Many useful changes can be quickly accomplished using the graphical menu bar buttons.

For instructions to zoom in and out of part of a graphing see enlarging part of a chart.

Many chart features can be edited directly from the chart by simply clicking on the chart.

#### 5.5.1 Graphical menu bar

The graphics bar situated above the charts in Growth II allows you to quickly edit many features of your graphs.



The functions of the individual buttons are as follows.



Opens the main graphics dialog window, which allows you to edit every feature of the chart.



Prints the chart - see Print Chart for more details.



Copies the chart to the clipboard. See Copy/Export Chart for information on file formats.



Saves the chart to a file. See Copy/Export Chart for information on file formats.



Increases the size of the text on the chart.



Decreases the size of the text on the chart.



Increases the thickness of the growth curve predicted by the model.



Decreases the thickness of the growth curve predicted by the model.



Increases the size of the observed data points on the chart.



Decreases the size of the observed data points on the chart.



Switches between black and white and colour graphics.



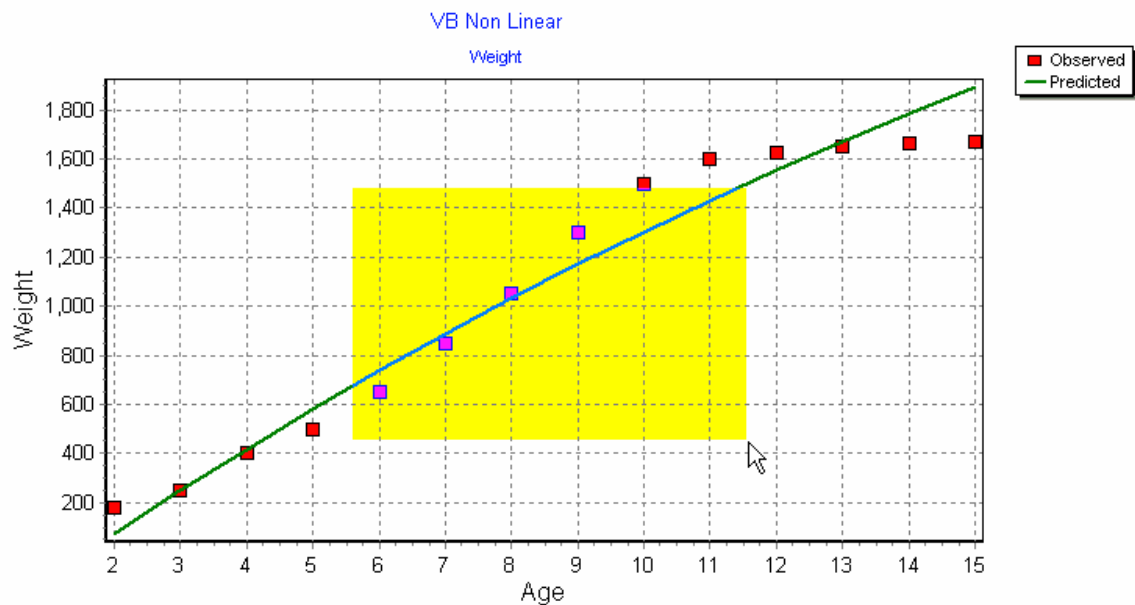
Switches grid on and off on the graph.



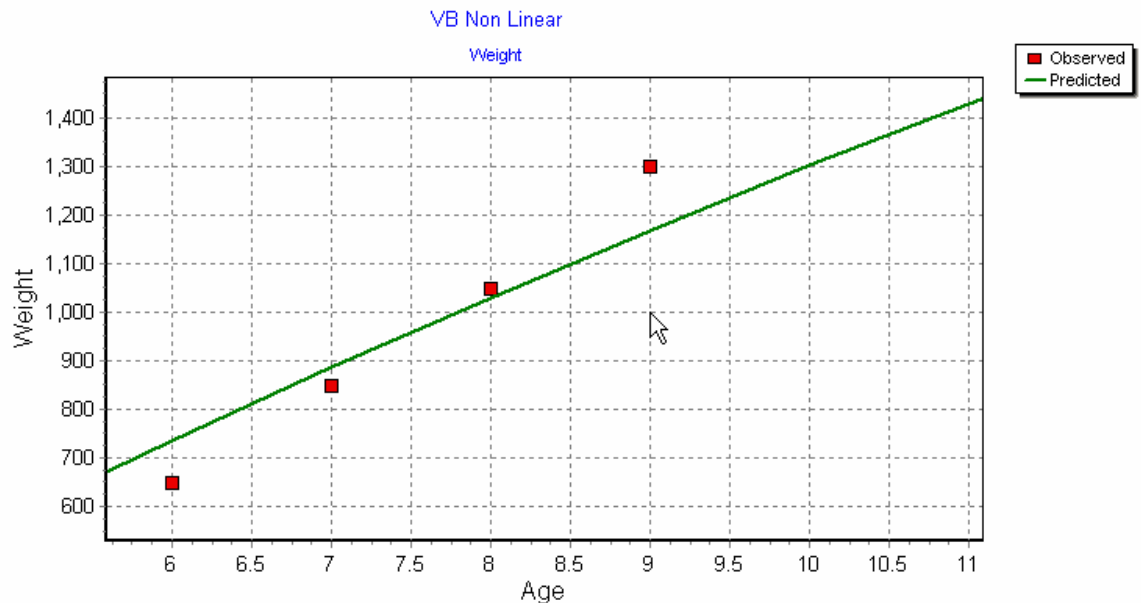
Switches the legend on and off.

### 5.5.2 Enlarging part of a chart

To expand part of the chart, move the cursor to the upper right hand corner of the area you wish to magnify, and hold down the left hand mouse button. Now without releasing the button, drag downwards and towards the left. A yellow box will appear (see below) showing the area that will be enlarged. Release the button and the yellow part of the plot will be enlarged. To return to the full plot simply reverse the process by left clicking and dragging the cursor up and to the left.

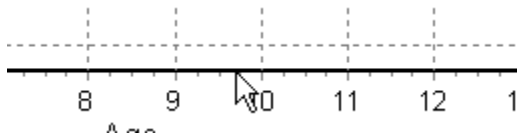


The result of releasing the button after forming the yellow rectangle above is shown below.



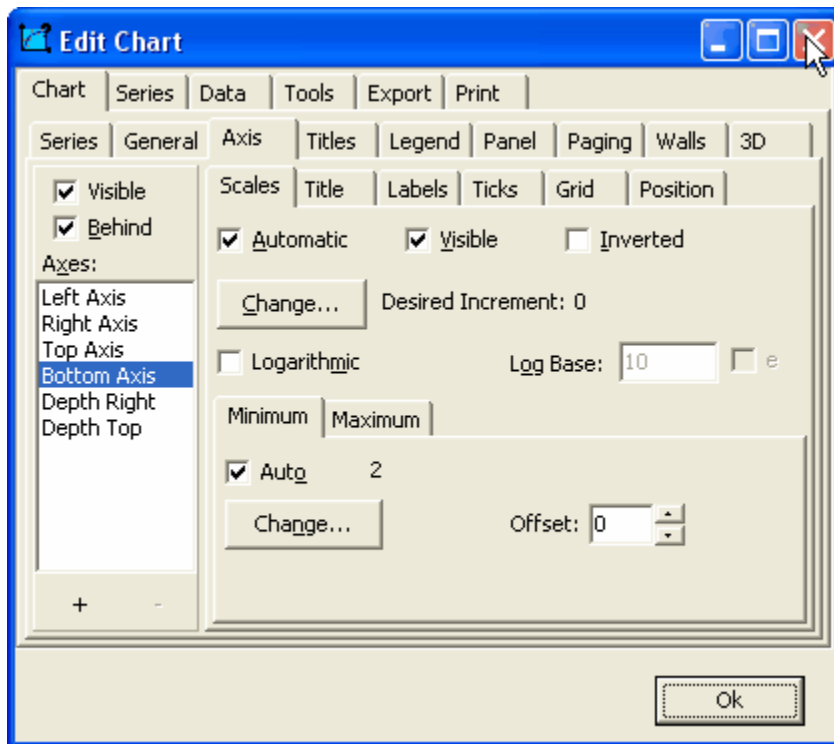
### 5.5.3 Editing directly from the chart

The chart is active, and features of the plot can be edited by moving the cursor over them and **shift left clicking**. For example, to edit the x-axis move the cursor over the axis like this:



and then hold down the Shift key (key on left with  $\Upsilon$  symbol that changes from lower to upper case) and left click on the mouse. The following dialogue window will pop up, allowing you to change the chart defaults.





## 5.6 Printing and exporting your results

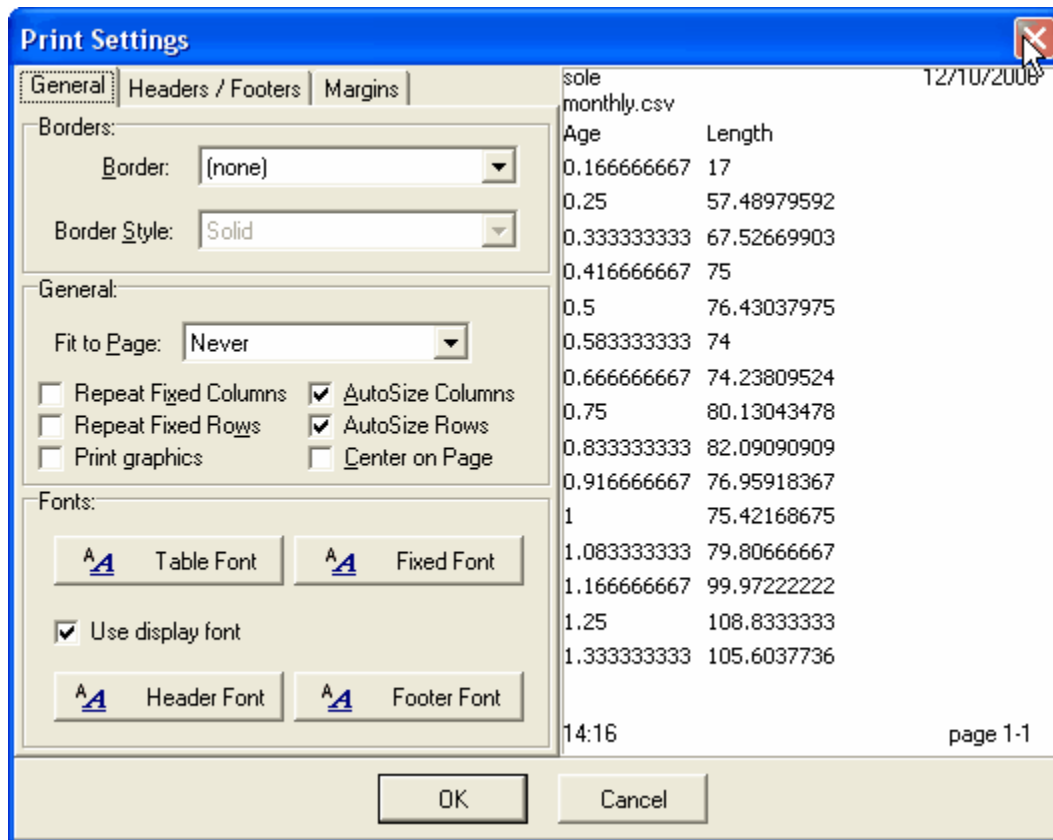
The data grids and graphs can be printed using the **Print** option from the **File** menu.

Different printing options are offered for graphs and grids.

Print Grid  
Print Chart

### 5.6.1 Print Grid

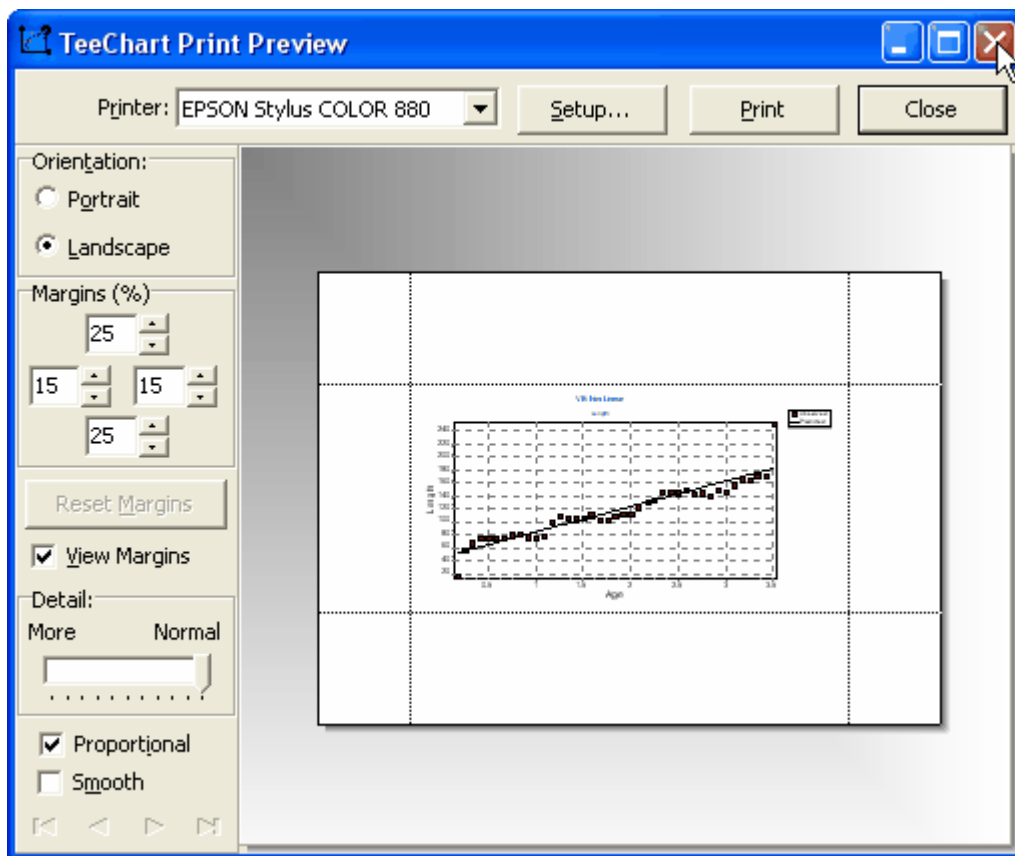
Selecting **File|Print Grid** opens the grid printing dialogue, which allows the font and page layout to be selected before printing.



### 5.6.2 Print Chart

Selecting **File|Print Chart** opens the grid printing dialogue which allows the chart and page layout to be selected before printing.

This window shows a representation of the graph on the paper. The print margins are displayed as dotted lines and can be dragged by moving the cursor over the margin, holding down the left hand mouse button and dragging.



## 5.7 Copying

The data grids and graphs can be copied to the clipboard, or exported in different formations using the **Copy** drop-down menu.

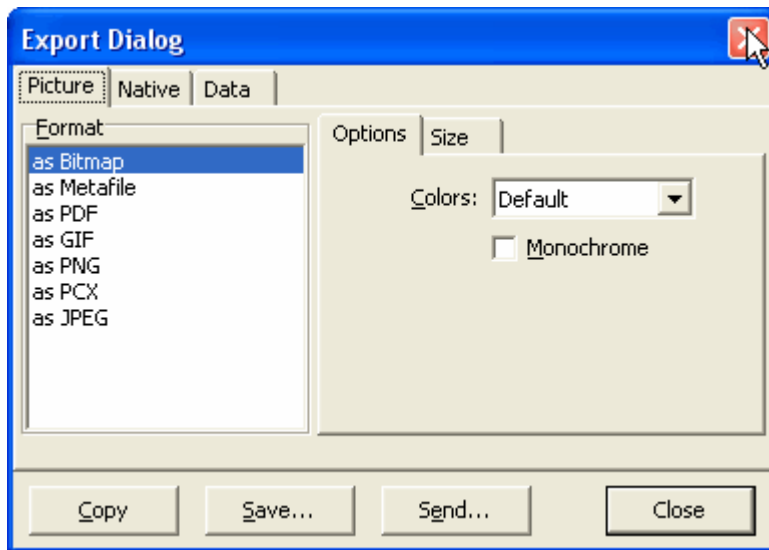
Different options are offered for graphs and grids.

Copying Charts

Copying tabulated data

### 5.7.1 Copy/Export Chart

Selecting **Copy|Copy/Export Chart** opens the Export dialog.



You can change the colour depth and size of the image if desired. The default file format for the file is a bitmap, select another file format by left clicking on the format of choice in the list.

You can also copy a chart using the copy button on the graphical menu bar.

### File formats

The chart can be saved in a number of different file formats: Bitmap (\*.bmp), Metafile (\*.emf), PDF (\*.pdf), GIF (\*.gif), PNG (\*.png), PCX, (\*.pcx) and JPEG (\*.jpg). Each file format has advantages and disadvantages.

- Bitmaps are a lossless method of saving; the stored file will not lose any of the original's detail. Because of this, bitmaps tend to be much larger than compressed files such as Enhanced Metafiles, GIFs or JPEGs.
- The advantage of Enhanced Metafile is that, if pasted into, for instance, a Word document, it can be resized by dragging, without losing resolution.
- PDF is an Adobe Acrobat file, which is a useful format to send to other people or for inclusion in a pdf document.
- GIFs offer advantages for web use as they compress the file.
- JPEGs are file formats which can be compressed to take up less space - useful if you wish to send one by email, put it on a website, or paste it in to a document. If they are compressed too heavily, they can lose resolution and detail, and spoil colours.
- PNG and PCX are graphics file formats in common use. PCX format is one of the most usable graphic formats. Originally it was designed by Zsoft for PC Paintbrush MS-DOS. PNG (Portable Network Graphics) is a bitmap image format that employs lossless data compression. PNG was created to both improve upon and replace the GIF format with an image file format that does not require a patent licence to use.

There are three buttons at the bottom of the screen. Select

**Copy** to copy to the clipboard

**Save** to open a save file dialogue window and

**Send** to activate your email system and send the file

### 5.7.2 Copy Grid

Select this option to copy the data grid on the active (visible) tabbed page to the Windows clipboard. The data can then be pasted into some other program using the **Paste** or **Ctrl+V**. Once the file is copied you will see a confirmation dialogue.



**Part**

---

**VI**

## 6 Tutorials and demonstration data sets

Upon installation of Growth II a number of demonstration data sets will also be placed on your hard disc. These data files are saved by default in the folder **My Documents/Growth 2 Data**. These data sets are used in the help tutorial system.

Click on the links below to see the different tutorials

Choosing a growth model - this demo uses the file **Male turkey weights.csv** packaged with Growth II.

Fitting seasonal data - this demo uses the files **sole monthly.csv** and **individual sole lengths.csv** which are packaged with Growth II.

Fitting a model to incremental data - this demo uses the file **incremental test Gompertz.csv** packaged with Growth II.

### 6.1 Choosing a growth model

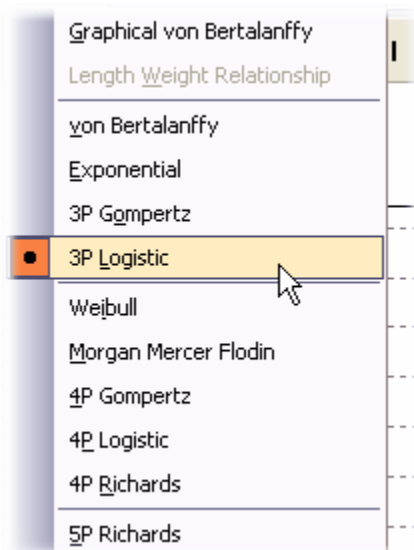
This demonstration data set was copied from the paper by Sengul & Kiraz (2005). The data set comprises the age in weeks and body weight in grams of male large white turkeys for the first 18 weeks of their life.

Use **File|Open** to find and open **Male turkey weights.csv** (saved by default during installation in the folder **C:\Program files\GrowthII\GrowthDemoData**)

Once the data set has been opened, Growth II will immediately fit a von Bertalanffy growth curve to the data and plot the result.

A brief glance at this graph and the Regression diagnostics in the grid below shows that the von Bertalanffy is a poor choice (note the size of the Akaike Information Criterion,  $AIC = 290.165$ ). We will now take you through an investigation of other possible more appropriate models.

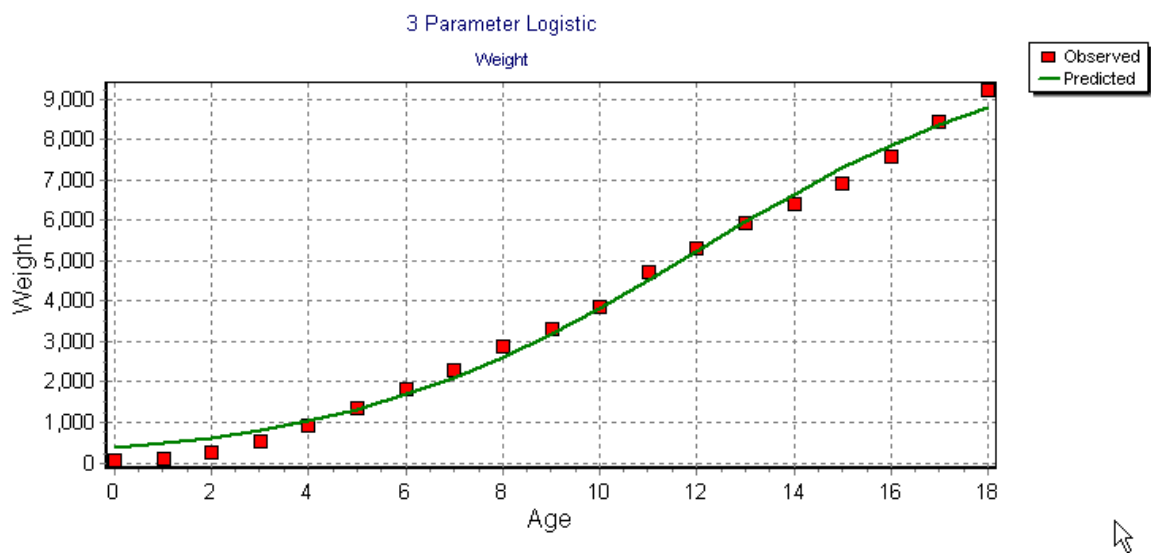
Now choose from the Age/Size drop-down menu 3P logistic (logistic growth curve with 3 fitted parameters):



Growth II immediately opens a dialogue box showing the initial guesses for the 3 parameters. The program needs initial guesses as it solves the non-linear regression using the Levenberg-Marquardt method. While the initial guesses can and sometimes have to be changed to get a solution, it is sensible to first try the defaults you are given.

Parameters	Initial Values	Notes
L Inf	9.2E003	The maximum size of Length or Weight possible
Growth Rate K	1	The rate at which they grow
Point Of Inflection I	2.5	The point at which the growth rate stops accelerating and starts to decline

Click OK and the fit is immediately presented:

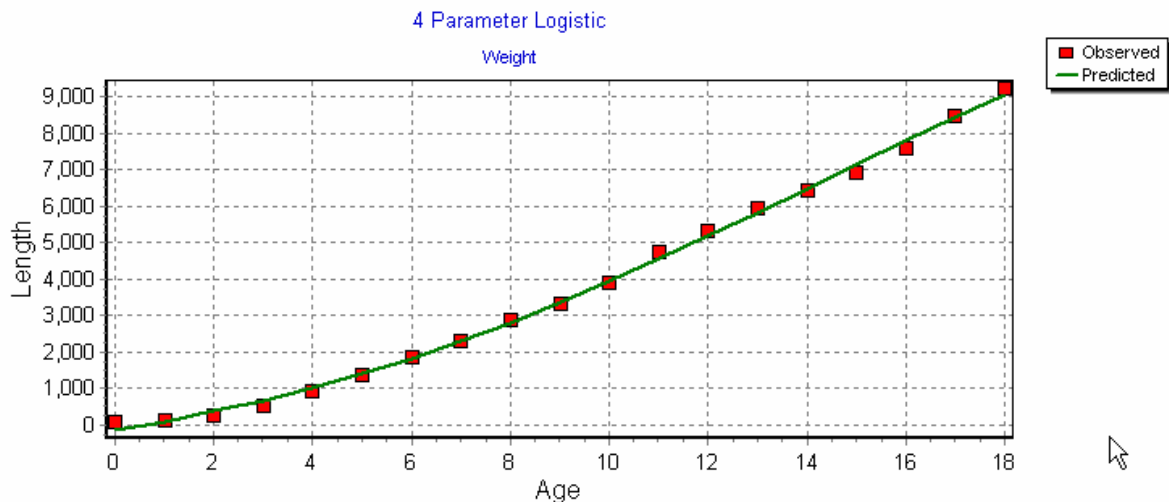


It is clearly a fair fit, but it seems poor for the youngest age groups. Note the size of the



Akaike Information Criterion (AIC = 270.94), this is smaller than that for the von Bertalanffy, suggesting that the logistic is the superior model.

Staying with the logistic we can now fit a 4 parameter logistic by choosing 4P logistic from the drop-down. This fit is clearly a superior fit with with the lowest AIC so far of 248.79:



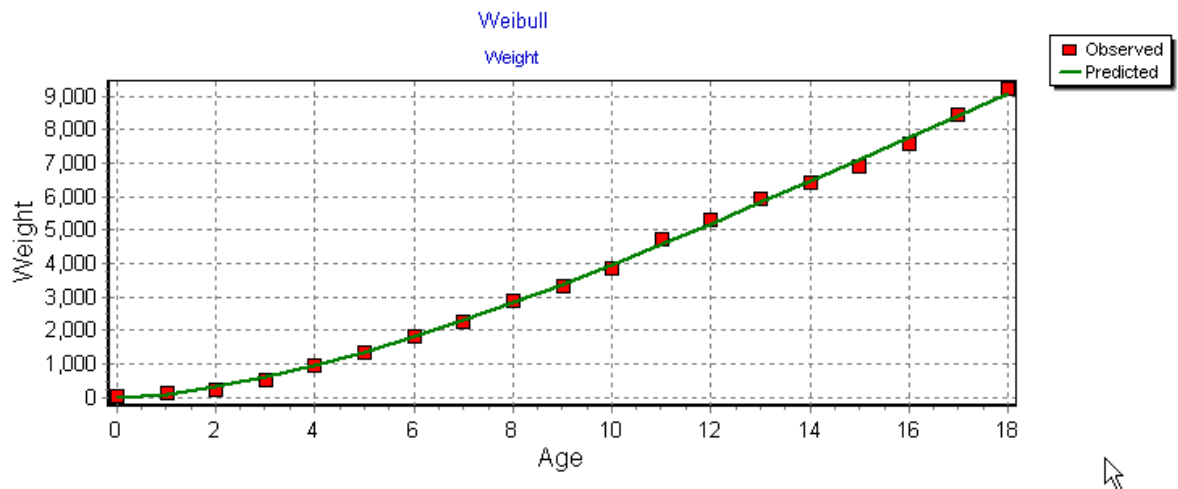
Trying other models will give the following values for the Akaike Information Criterion:

Exponential	-	290.166
3 parameter Gompertz	-	281.06
Weibull	-	239.748
Morgan-Mercer-Flodin	-	239.46
4 parameter Gompertz	-	244.668
Janoschek	-	239.747

The Richards curves could not be fitted successfully to these data. However, by rescaling the data by dividing by 1000, so that weight is in kilograms and not grams (see file **Male turkey weights kg.csv**) the 5 parameter Richards was successfully fitted to the data. Comparison with other models using the AIC suggested that this model was inferior to most other models)

The results indicate that the Weibull or closely related Janoschek curve is the best description of the turkey data. However, almost all the models were equally good.

Here is the plot of the Weibull to compare with the logistic above. It is clearly a good fit to the data. The authors of this paper actually used the coefficient of determination,  $R^2$ , as a measure of fit, and found very high  $R^2$  values with all models tested. The coefficient of determination should not be used to measure the goodness of fit of nonlinear regression. Interestingly, they did not fit the Weibull or Janoschek models, but certainly noted that most models gave good fits:



## 6.2 Fitting seasonal data

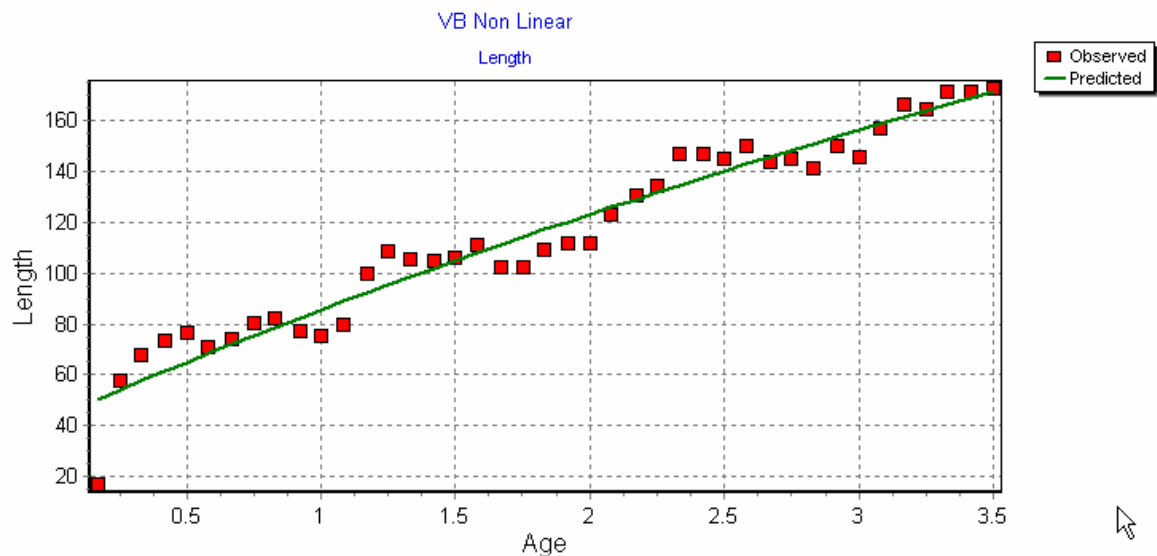
For this demonstration we use length data for the sole, *Solea solea*, a flatfish. The data set was collected over a 25 year period in the Bristol Channel, England. Two data sets have been prepared as follows.

**sole monthly.csv** is a file giving the mean age of sole from an age of 0.16667 years (2 months) to 3.5 years of age. Note that age is expressed in fractions of a year, this is required when fitting a seasonal model using Growth II.

**individual sole lengths.csv** is a file holding the individual lengths and ages of sole.

Use **File|Open** to find and open **sole monthly.csv** (saved by default during installation in the folder **C:\Program files\GrowthII\GrowthDemoData**)

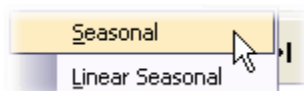
Once the data set has been opened, Growth II will immediately fit a von Bertalanffy growth curve to the data and plot the result:



A brief glance at this graph and the Regression diagnostics in the grid below shows that the von Bertalanffy gives a fit that does pass through the scatter of points, but there is a clear periodic oscillation that the model fails to fit (note the size of the Akaike Information Criterion, AIC = 336.8). This number will be useful later to compare the models:

Model Diagnostics	
Sum of Squared Residuals	3181.36
Akaike Information Criterion (AIC)	336.668
Schwarz Criterion (SC)	341.808

We will now get Growth II to fit a seasonally adjusted von Bertalanffy. From the **Seasonal Age/Size** drop-down select **Seasonal**

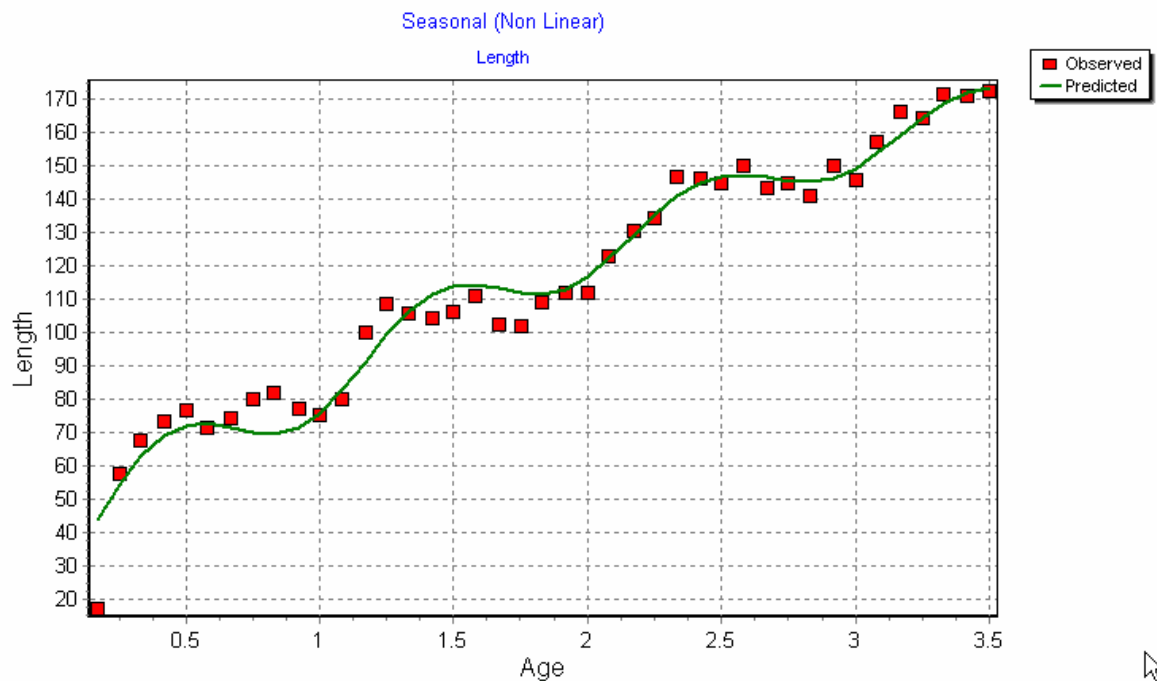


This will run a non-linear curve fitting routine to fit a seasonally adjusted von Bertalanffy model. Growth II immediately opens a dialogue box showing the initial guesses (shown below) for the 5 parameters needed for this model. The program needs initial guesses as it solves the non-linear regression using the Levenberg-Marquardt method. While the initial guesses can and sometimes have to be changed to get a solution, it is sensible to first try the defaults you are given.

Parameters for Length		
Parameters	Initial Values	Notes
L Inf	4E002	The maximum size of Length or Weight possible
Growth Rate K	0.13	The rate at which they grow
T0	-1	Size at time 0
Seasonal Magnitude	1.3	Magnitude of seasonal effect
Timing of cycle	-0.17	Offset of seasonal cycle (in fractions of a cycle)

Ok

Click on OK and the fit is immediately presented. The plot shows the observed data and the fitted curve.



Below the plot are presented the the parameter estimates, their 95% confidence intervals.

Results - Length	Seasonal (Non Linear)	95% Confidence	Model Diagnostics	
Upper Asymptote	279.772	7.28285	Sum of Squared Residuals	1819.38
K (Growth Rate)	0.223705	0.0100199	Akaike Information Criterion (AIC)	317.756
C (Seasonal Change in Growth)	-1.42913	0.079561	Schwarz Criterion (SC)	326.324
T0 (Time at which size is 0)	-0.732739	0.0095449		
TS (Seasonality Parameter)	-0.313511	0.00412841		

Classed Data Calculations **Length Results**

The fitted model has an upper asymptote (called L infinity in fisheries science) of 279.77 cms with 95% confidence intervals of  $279.77 - 7.28 = 272.49$  cms and  $279.77 + 7.28 = 287.05$ .

The growth rate K has units of Year<sup>-1</sup>.

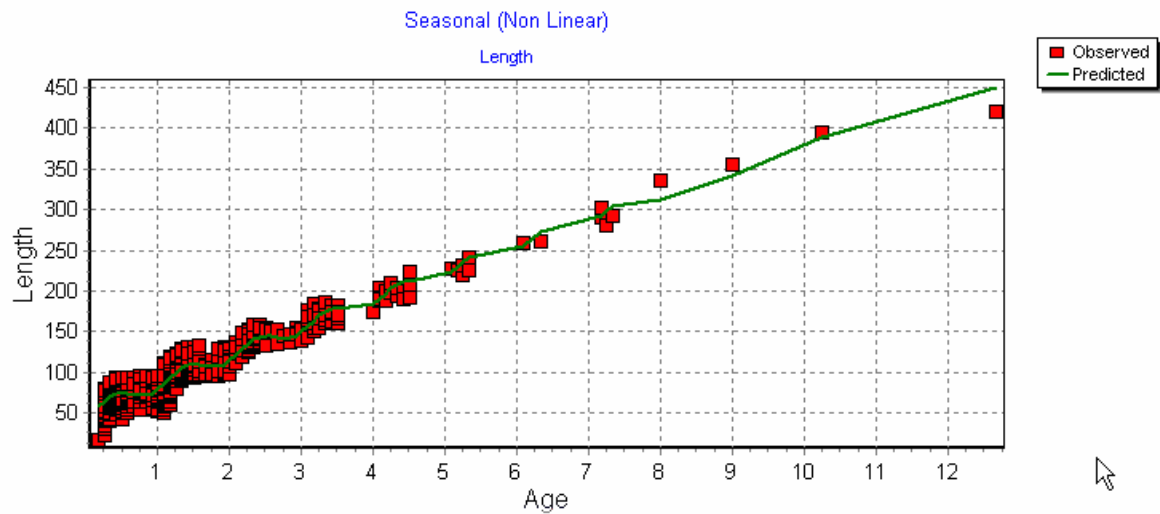
C, the seasonal parameter has an absolute magnitude greater than 1, this indicates that the model predicts that the sole shrink during the winter. While individual fish do not shrink, close examination of the data does indicate that the average size does decline during the winter, this is probably because the larger fish migrate offshore and are not included in the winter samples.

The Akaike Information Criterion, AIC = 326.324 which is lower than the AIC for the none seasonal von Bertalanffy (AIC = 336.8). This indicates that the seasonal model, which uses two additional parameters to fit the data, is the preferred model. The Schwarz criterion also indicates that the seasonal model is superior.

The above example was fitted to average length data, we can also fit a seasonally adjusted growth curve to individual measurements.

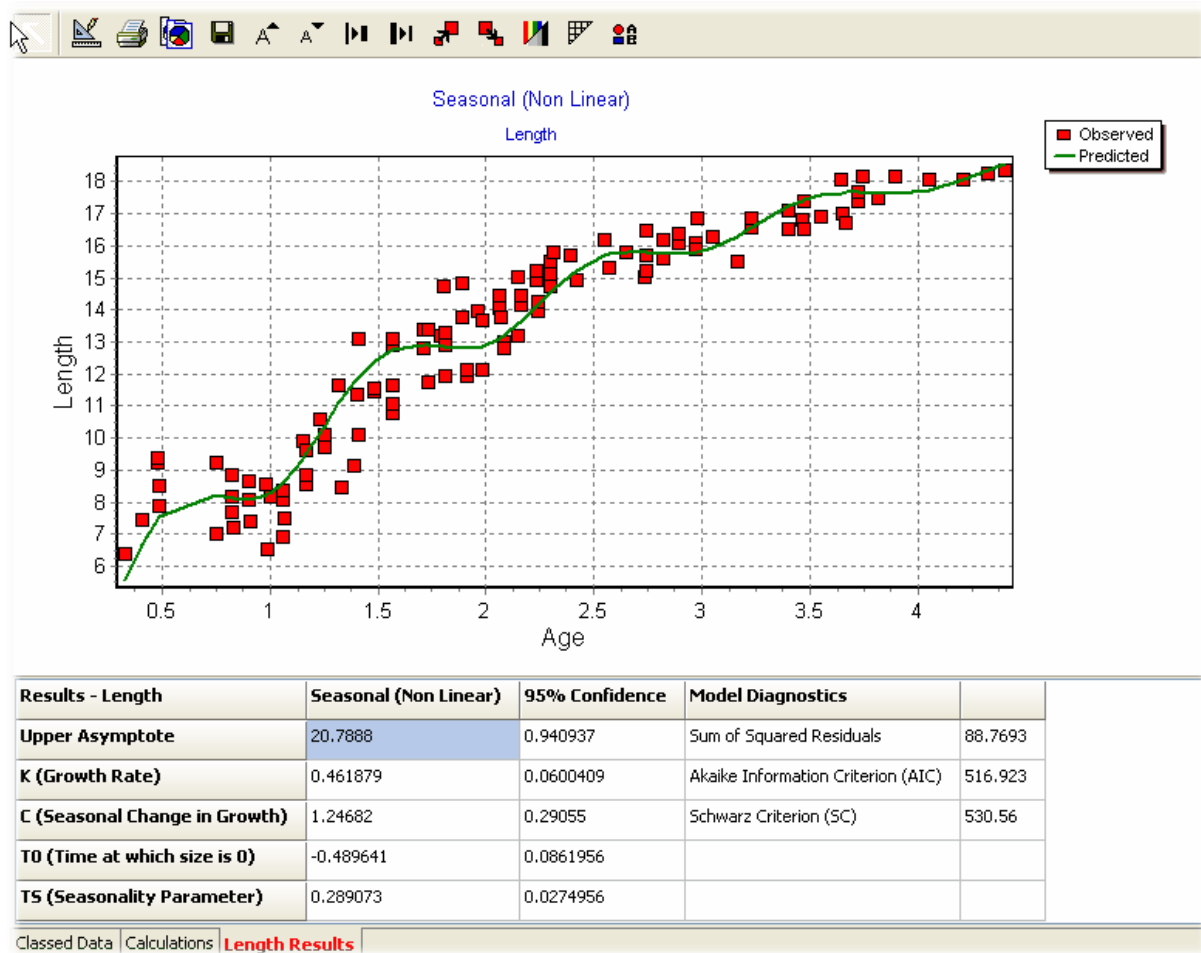
Use **File|Open** to find and open **individual sole lengths.csv** (saved by default during installation in the folder **C:\Program files\GrowthII\GrowthDemoData**).

From the **Seasonal Age/Size** drop-down select **Seasonal** which will fit a curve to the individual data points. Note that this fit is not very impressive because almost all the data are for the youngest ages and there is insufficient data for sole above 5 years of age to give a good fit.

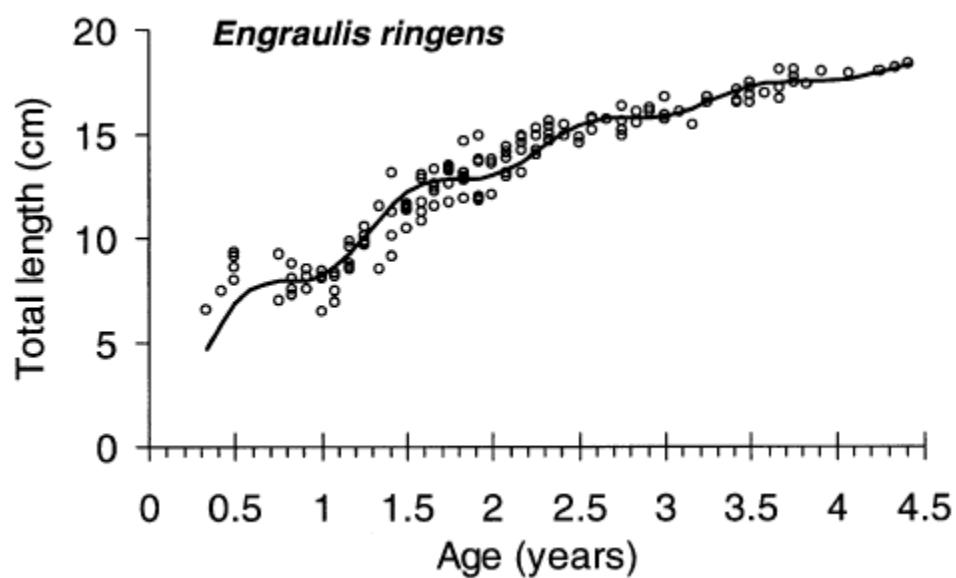


Our final examples use data from Cubillos et al (2001). Because the data points were read from the published graphs and could not be accurately acquired we will not get exactly the same fit as the authors, but we can demonstrate similar results and show the quality of fit to data sets that include data close to the asymptotic length, and do not show a winter decline in size.

Use **File|Open** to find and open **engraulis seasonal.csv** and run a seasonal model. You will obtain the following fit:



For comparison here is the published graph



The published parameters for *Engraulis ringens* are shown in the table below. The authors replace TS by the Winter Point (WP) = TS+0.5 and gives the winter point at which growth is slowest. Our results indicate that WP = 0.289+0.5 = 0.789 where as the published value is 0.312. The authors argued that the slowest growth rate occurred prior to the southern hemisphere winter in April-May. Our result (using less accurate data suggests lowest growth in occurred in late winter (September 9/12 = 0.75). It is easy to see the cause of this discrepancy as for an extended period the fish grow little and during their first winter appear to shrink. Thus TS is easily changed by small alterations in the data.

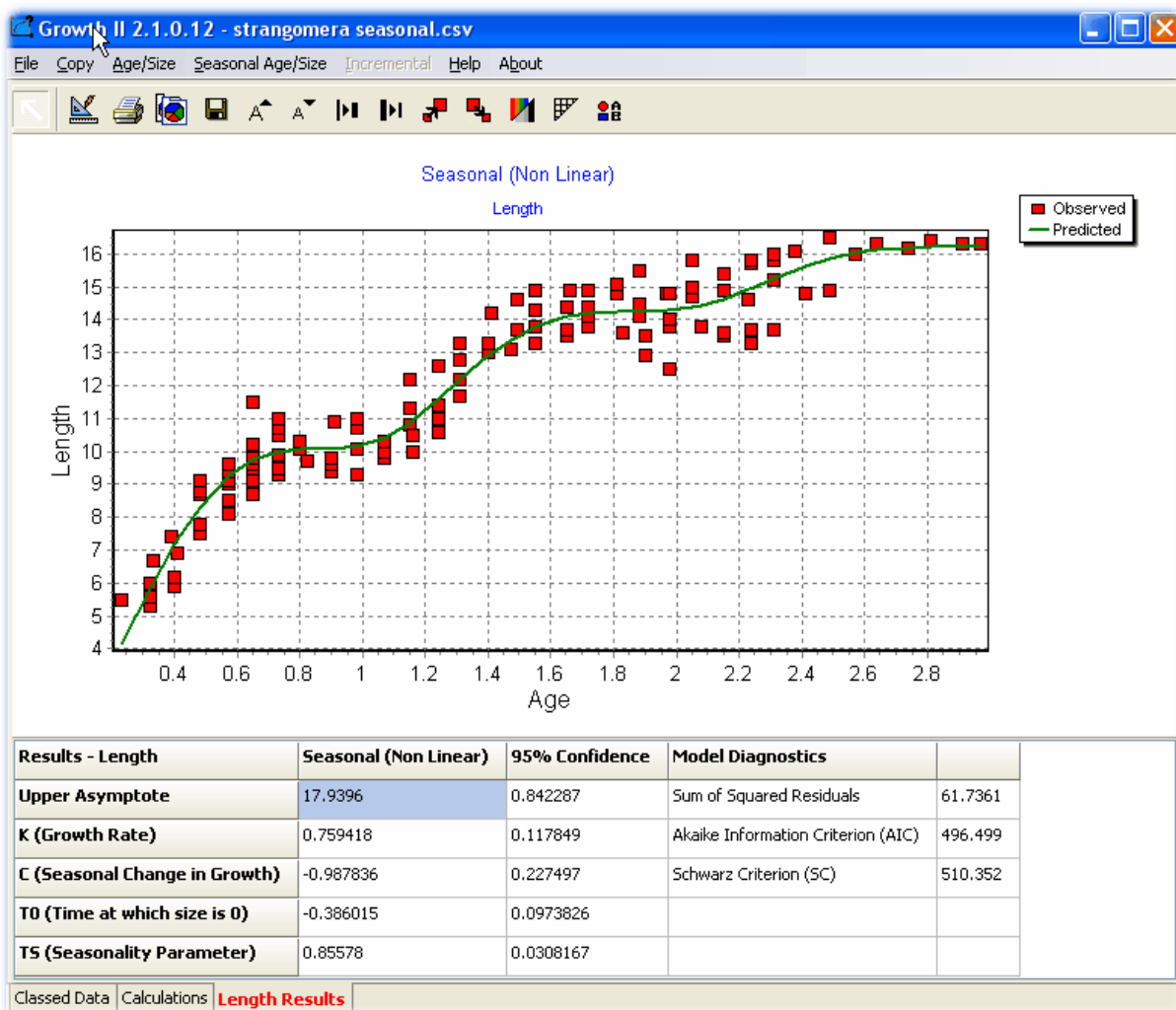
**Table II.** Growth parameters of *Strangomera bentincki* and *Engraulis ringens* describing the von Bertalanffy growth function modified to take into account seasonal growth oscillation.

Parameters	<i>S. bentincki</i>	<i>E. ringens</i>
$L_{\infty}$ (cm TL)	18.1 (0.6)	20.1 (0.6)
$K$ (year <sup>-1</sup> )	0.745 (0.07)	0.514 (0.05)
$t_0$ (year)	-0.330 (0.09)	-0.042 (0.19)
C	0.998 (0.10)	0.997 (0.16)
WP	0.363 (0.02)	0.312 (0.03)
$r^2$	0.948	0.929
SSQ	65.73	105.33
$n$	150	144

The standard deviation of parameter is shown in parentheses; C: amplitude of seasonal growth; WP: winter point or phase of seasonal growth; SSQ: sum of square,  $n$ : number of data.

As our final example use **File|Open** to find and open **strangomera seasonal.csv** and run a seasonal model. You will obtain the following fit:





The published parameters for these data, which are similar to those calculated by Growth II, are shown in the table above.

### 6.3 Fitting a model to incremental data

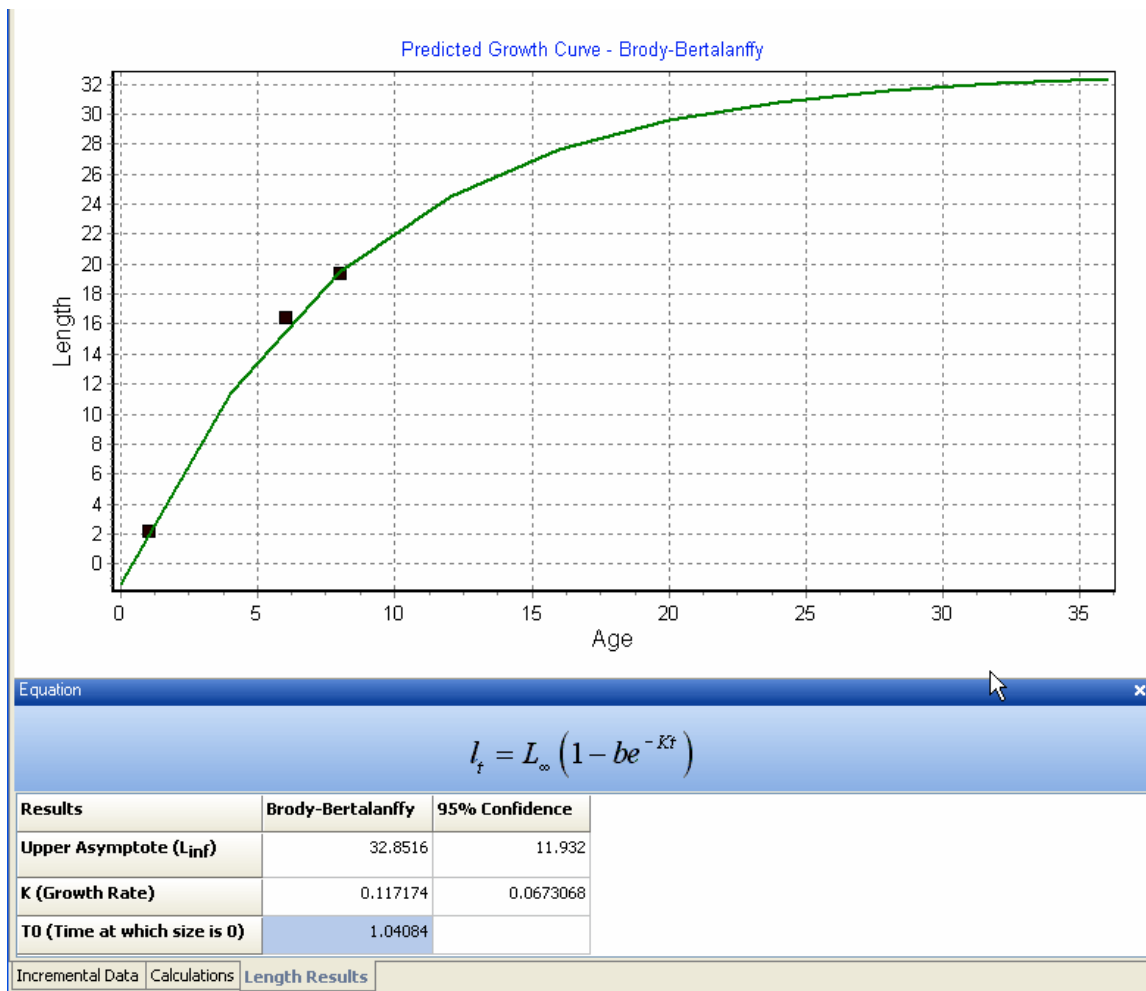
Use **File|Open** to find and open **incremental test Gompertz.csv** (saved by default during installation in the folder **C:\Program files\GrowthII\GrowthDemoData**)

This demonstration data set was generated for demonstration purposes using a Gompertz growth curve with an upper asymptote ( $L_{\infty}$ ) of 21.9, a growth rate of 0.417 and a point of inflection at  $t=3$ .

With the data file loaded you can click on the **Incremental Data** tab to examine the data set. The first column just gives an identifier for each individual measurement set (it might be a number or name). The **Size t0** column gives the initial size measurement for each individual, the **Size t1** column gives the size measurement at a later time and the **Time Gap** column gives the time jump between  $t_1$  and  $t_0$ . For Fabens' 1965 method to work we must also give at least one observation of known size at age and these observations are placed in the **Known Age** and **Known Size** columns. (see Entering and Editing Data for information on how to enter your own data)

Observations - Incremental						
Sample	Size t0	Size t1	Time Gap		Known Age	Known Size
1	0.89	2.19	0.8		6	16.4
2	2.2	4.8	1		8	19.4
3	8	11	1		1	2.2
4	5	16	4			
5	18.1	19.3	1			
6	20	20.7	1			
7	20.7	21.7	1			
8	14.2	16.5	1			
9	1.2	1.5	0.2			
10	8	14	2			
11	14.2	18.2	2			
12	19	20	1			

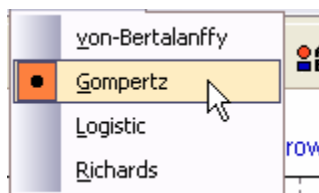
Once the data set has been opened, Growth II will immediately fit a von Bertalanffy growth curve to the data and plot the result.



A brief glance at the grid below shows that the von Bertalanffy upper asymptote estimate has an estimate of 32.85 with 95% confidence intervals of 11.92. This suggests a rather poor fit. This is conformed by clicking on the **Calculations** tab and examining the differences between the observed and predicted values.

Observed	Predicted	Difference
2.19	3.75	-1.56
4.80	5.59	-0.79
11.00	10.75	0.25
16.00	15.42	0.58
19.30	19.73	-0.43
20.70	21.42	-0.72
21.70	22.04	-0.34
16.50	16.26	0.24
1.50	1.93	-0.43
14.00	13.19	0.81
18.20	18.10	0.10
20.00	20.53	-0.53

From the **Incremental** drop-down now choose the Gompertz option



The results are immediately displayed and the plot looks like a better fit. More importantly the confidence intervals on the parameter estimates are far smaller. For the asymptote, the 95% confidence intervals are only 1.98 compared with 11.932 for the von Bertalanffy. The Gompertz is clearly the better model, as it should be as the data was generated from a Gompertz curve with an asymptote of 21.9.

$l_t = L_{\infty} e^{1 - be^{-kt}}$		
Results	Gompertz	95% Confidence
Upper Asymptote ( $L_{inf}$ )	21.8662	1.98798
K (Growth Rate)	0.407528	0.0136919
T0 (Time at which size is 0)	1.11785	
Incremental Data	Calculations	Length Results

The superiority of the Gompertz over the von Bertalanffy is also reflected in the differences between the observed and predicted on the **Calculations** tab.

You can also try a logistic fit which will give a poor fit to the data.

**Part**

**VII**

## 7 Types of growth curve

Growth II offers a wide range of growth curves these vary in their shape, flexibility and the number of parameters that need to be fitted to your data. Generally you should favour a growth model that gives the best fit while taking into account the number of parameters (see Akaike information criterion). Fitting a model with 4 or 5 parameters to data set that is noisy (high error levels in the measurements) and holds a small number of points < 10 is unlikely to be successful.

### 3 parameter models

Exponential growth  
3 parameter logistic growth equation  
3 parameter Gompertz growth equation  
von Bertalanffy growth equation

### 4 parameter models

Morgan-Mercer-Flodin  
Weibull growth curve  
4 parameter logistic growth equation  
4 parameter Gompertz growth equation  
4 parameter Richards model

### 5 parameter models

5 parameter Richard's model  
seasonally adjusted von Bertalanffy growth model

#### 7.1 Gompertz growth curve

The Gompertz curve was originally derived to estimate human mortality by Benjamin Gompertz (Gompertz, B. "On the Nature of the Function Expressive of the Law of Human Mortality, and on a New Mode of Determining the Value of Life Contingencies." Phil. Trans. Roy. Soc. London **123**, 513-585, 1832). Charles Winsor (1932) presents an early description of the use of this equation to describe growth processes.

Assume that the rate of growth of an organism declines with size so that the rate of change in length,  $l$ , (or any other measure of size or weight) may be described by:

$$d \log l / dt = K(\log L_{\infty} - \log l)$$

where  $K$  is the growth rate and  $L_{\infty}$ , termed 'L infinity', is the asymptotic length at which growth is zero. (This equation has the same form as the von Bertalanffy but with log length replacing length)

Integrating this becomes:

$$l_t = L_{\infty} e^{e^{-k(t-I)}}$$

where  $t$  is age and  $I$  is the age at the inflection point.

The equation above is the 3 parameter version of the Gompertz growth curve (see below for an example plot). Growth II can also fit the 4 parameter version:

$$l_t = A + B e^{e^{-k(t-I)}}$$

in which  $A$  is the lower asymptote (see below for an example plot) and  $B$  is the upper asymptote minus  $A$ .

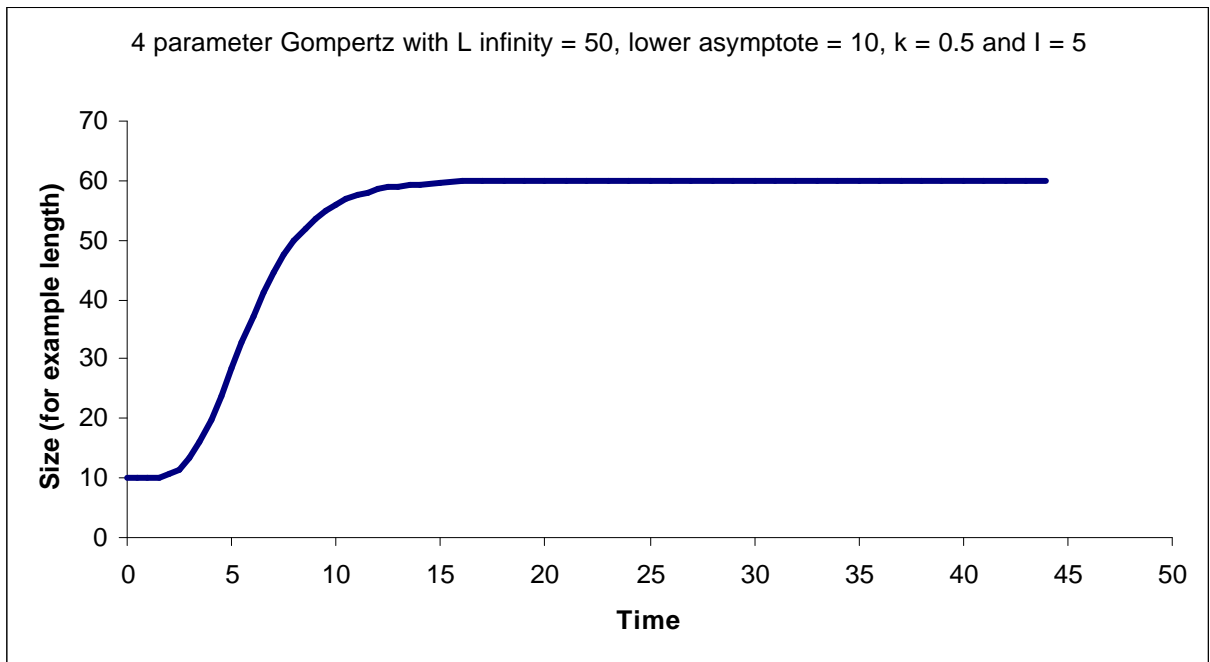
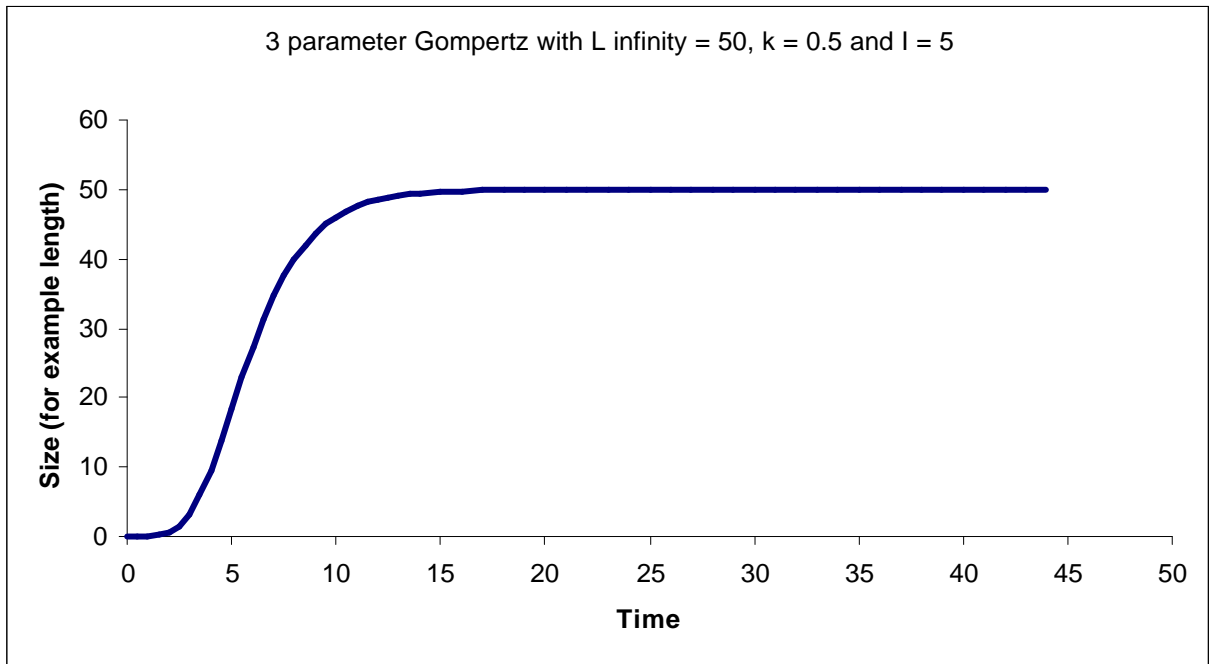
The point of inflection on the  $y$ -axis occurs at

$$I_y = B/e$$

This last formula states that the point of inflection is always at at about 36.8 % of the asymptotic size ( $L_{\infty}$ ). This does not hold true for all growth processes. You should consider using the Gompertz growth curve to model sigmoid growth processes in which the point of inflection is approximately 1/3 of the maximum possible size.

The following graphs show example plots of the 3 and 4 parameter Gompertz.





## 7.2 Logistic curve

The logistic growth curve (sometimes called the Verhulst model as it was first proposed as a model of population growth Pierre Verhulst 1845, 1847) is one of the simplest of the S-shaped growth curves. A generalization of the logistic, which is no longer symmetrical about the point of inflection, was developed by Richard (1959) and is termed the Richards curve or generalized logistic.

Assume that the rate of growth of an organism declines with size so that the rate of change in size may be described by:

$$dl/dt = l(k - \delta)$$

where  $t$  is time,  $l$  is length (size),  $K$  is the growth rate and  $\delta$  a term which expresses the rate at which growth declines with size.

After integration and some rearrangement we arrive at the 3 parameter logistic growth curve:

$$l_t = \frac{L_{\infty}}{1 + e^{-k(t-I)}}$$

where  $I$  is the age at the inflection point and  $L_{\infty}$  is the upper asymptote (maximum size reach after infinite growing time).

The 3 parameter logistic has a lower asymptote of 0. The point of inflection on the y-axis occurs at

$$I_y = L_{\infty} / 2$$

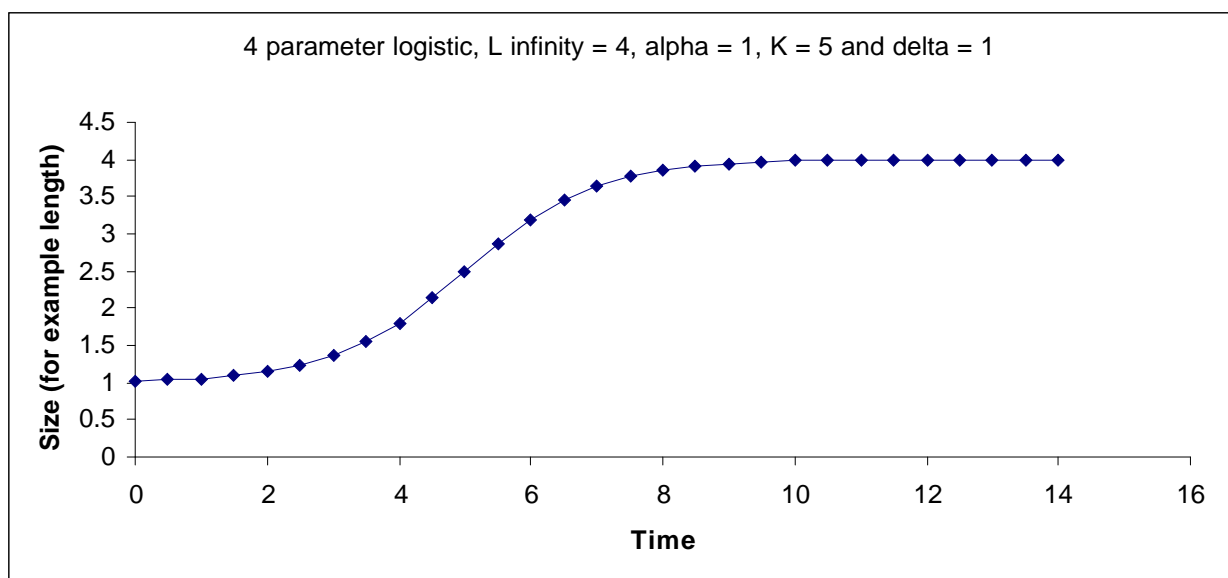
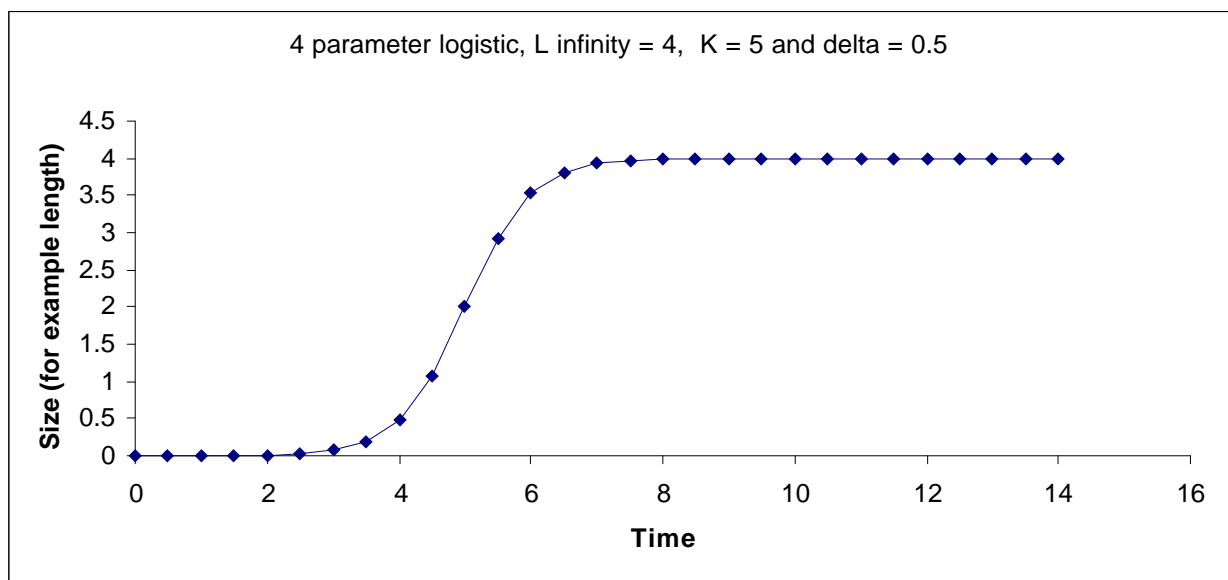
This last formula states that the point of inflection is always at at 50 % of the asymptotic size ( $L_{\infty}$ ). This does not hold true for all growth processes. You should consider using the Logistic growth curve to model sigmoid growth processes in which the point of inflection is approximately 1/2 of the maximum possible size.

If a non-zero asymptote is required then the 4 parameter version of the equation is required this is expressed by the equation:

$$l_t = \alpha + \frac{(L_{\infty} - \alpha)}{(1 + e^{-(k-t)/\delta})}$$

where  $\alpha$  is the lower asymptote and  $\delta$  is a shape parameter that determines the steepness of rising curve.

The following graphs show example plots of the 3 and 4 parameter Logistic growth curve.



### 7.3 Richards curve

The Richards curve or generalized logistic is a widely used growth model that will fit a wide range of S-shaped growth curves. There are both 4 and 5 parameter versions in common use. The logistic curve is symmetrical about the point of inflection of the curve. To deal with situations where the growth curve is asymmetrical, Richards (1959) added an additional parameter producing the equation:

$$l_t = L_{\infty} \left[ 1 + (\delta - 1)e^{-k(t-\gamma)} \right]^{1/(1-\delta)}$$

where  $l$  = length, (or weight, height, size),  $\delta \neq 1$  and  $t$  = time.

The four parameters are:

$L_{\infty}$ , the upper asymptote;

$k$ , the growth rate;

$\gamma$ , the point of inflection on the x axis

$\delta$ , a parameter that in part determines the point of inflection on the y axis;

The y-ordinate of the point of inflection is determined from

$$\frac{L_{\infty}}{\delta^{1/(1-\delta)}}$$

The average normalized growth rate is:

$$\frac{k}{2(\delta + 1)}$$

Richards curve requires one more parameter than the logistic curve to generate asymmetry; you can avoid this additional parameter by using the Gompertz curve which generates an asymmetrical growth curve with only 3 parameters.

The Richards curve can be difficult to solve because of numerical difficulties. This particularly the case with 5 parameter model, where the choice of initial parameters is critical. The Janoschek model has much of the flexibility of the Richards model and is far

easier to solve.

The 5 parameter version of the Richards curve is:

$$l = \beta + \frac{L_{\infty}}{\left(1 + Te^{-k(t-t_m)}\right)^{1/T}}$$

where

$\beta$ , is the lower asymptote;

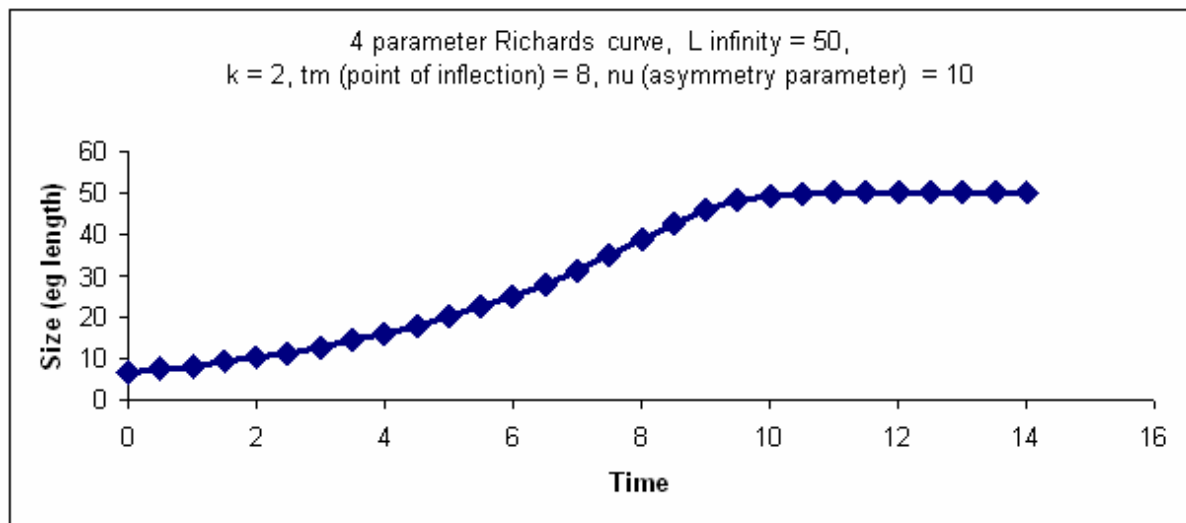
$L_{\infty}$ , is the upper asymptote;

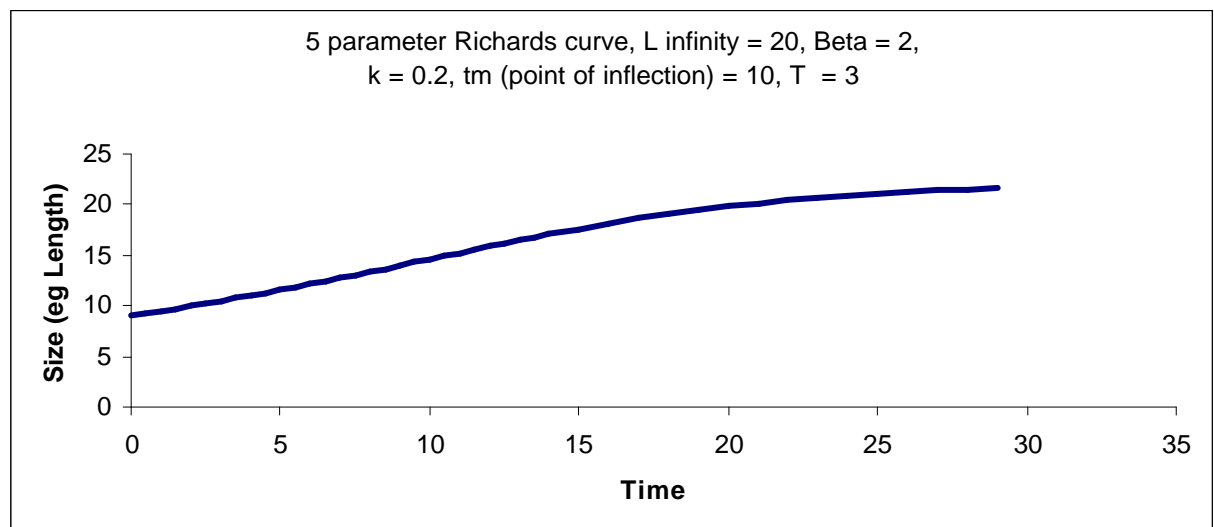
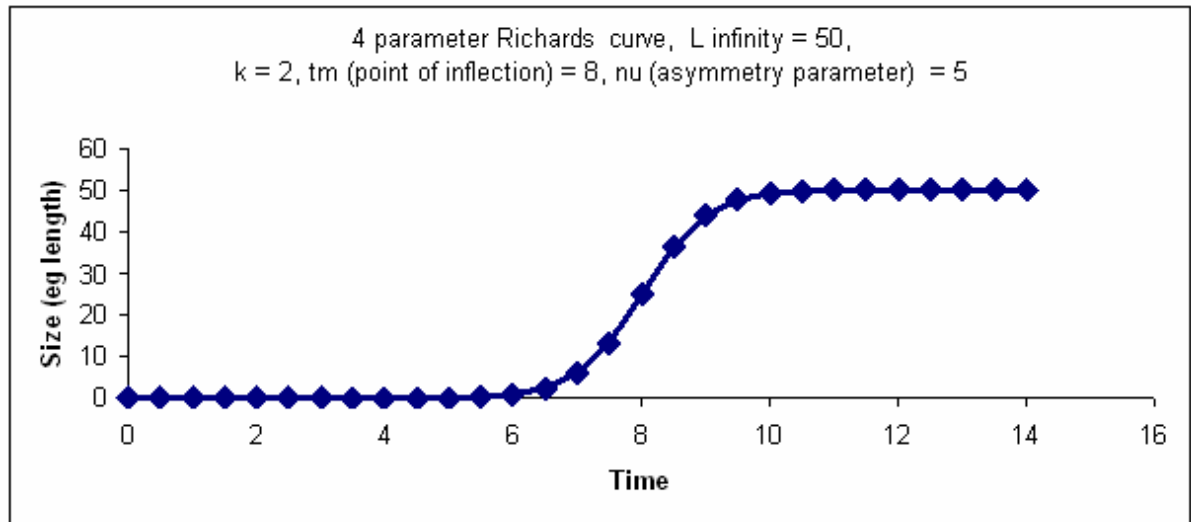
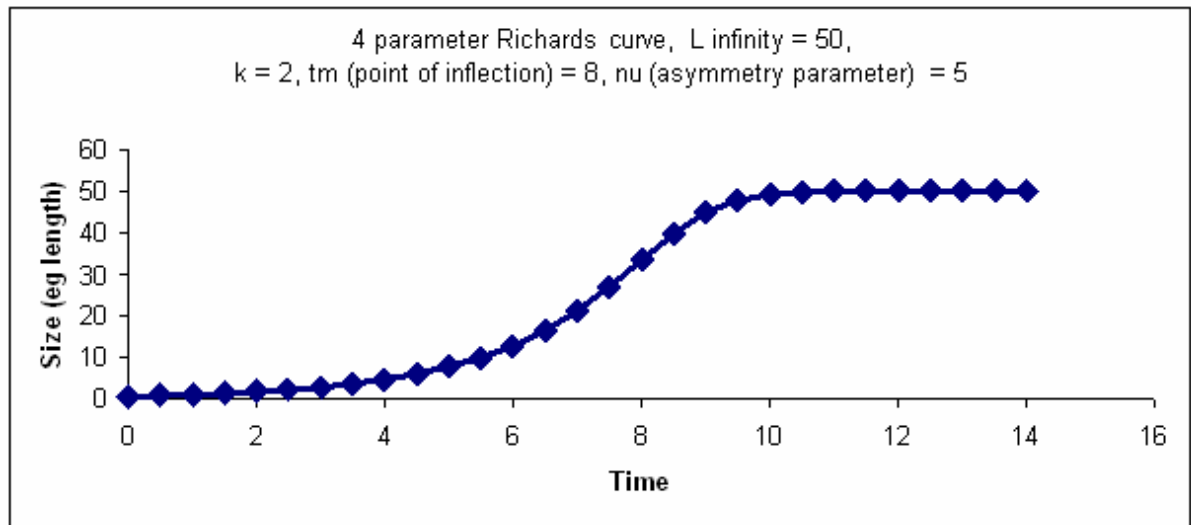
$t_m$ , is the time of maximum growth;

$k$ , is the growth rate and

$T$ , is a variable which fixes the point of inflection.

The following graphs show example plots of the 4 and 5 parameter Richards growth curve. The first 3 graphs show the effect of varying,  $\eta$  (nu), which is the parameter determining the degree of asymmetry. The final plot is the 5 parameter version with a lower asymptote greater than zero.





## 7.4 Weibull

The Weibull growth model is described by the equation:

$$l_t = L_{\infty} - (L_{\infty} - \beta)e^{-(kt)^{\delta}}$$

where  $l$  = length, (or weight, height, size) and  $t$  = time.

The four parameters are:

$\beta$ , is the lower asymptote;

$L_{\infty}$ , is the upper asymptote;

$k$ , is the growth rate and

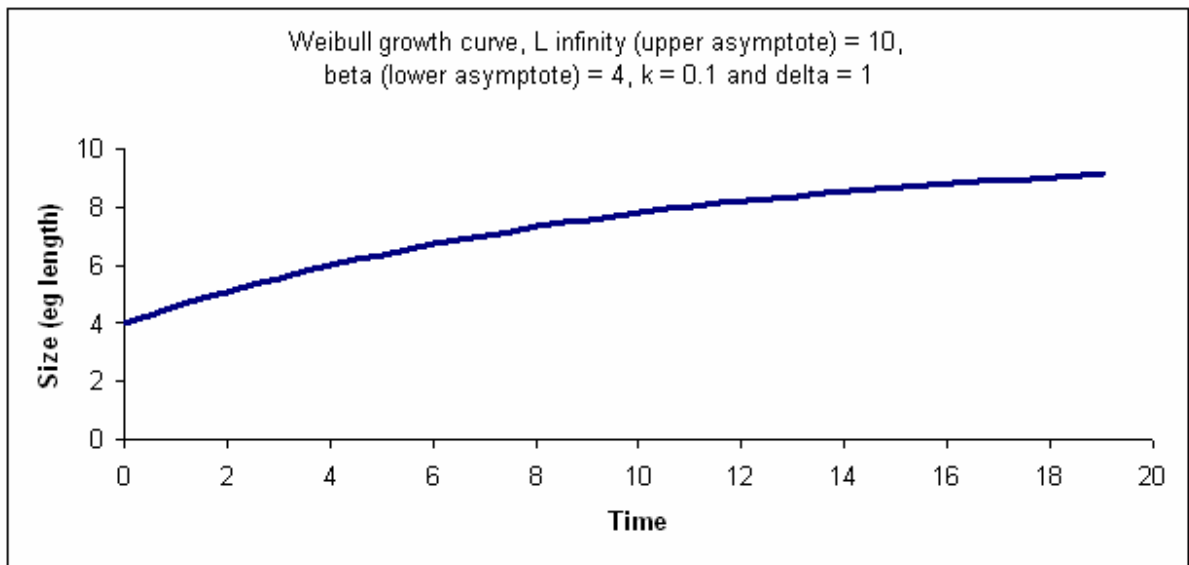
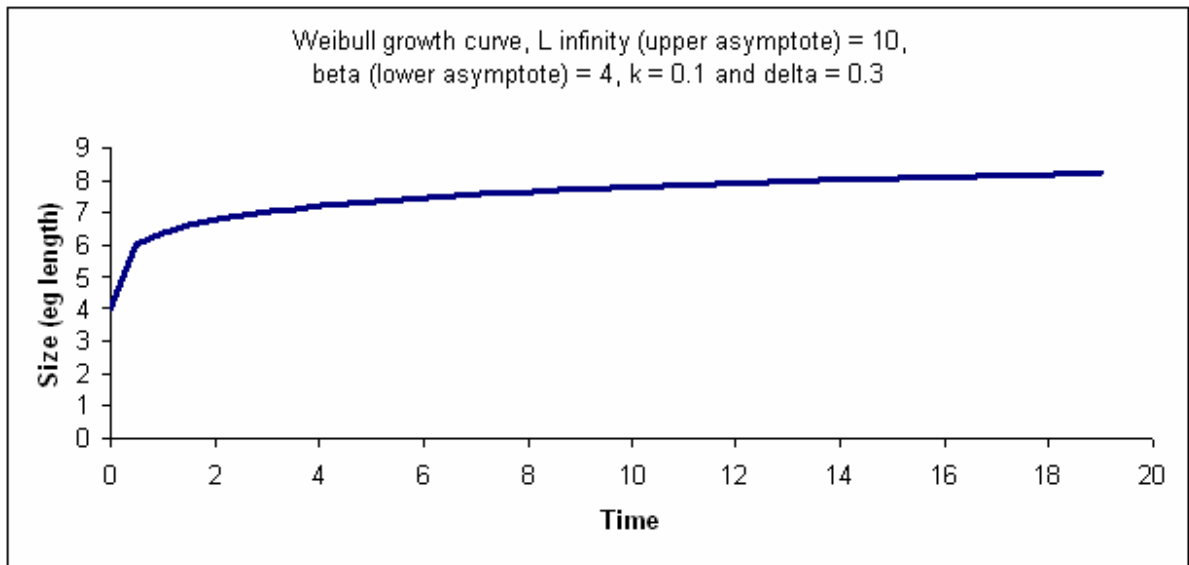
$\delta$ , is a parameter that controls the x-ordinate for the point of inflection.

The point of inflection on the x axis lies at:

$$\left(\frac{1}{k}\right)\left(\frac{\delta-1}{\delta}\right)^{1/\delta}$$

If  $\delta = 1$  the Weibull is a simple exponential growth curve.

The following graphs show example plots of the Weibull growth curve for different values of  $\delta$  (delta).



## 7.5 Janoschek

This growth curve was originally proposed by Janoschek, A. (1957). The form of the equation used by Growth II can have initial values greater than 0 and was originally described by Sager (1978). It has the equation:

$$l_t = L_{\infty} - (L_{\infty} - \beta)e^{-kt^{\delta}}$$

where  $l$  = length, (or weight, height, size) and  $t$  = time.

The four parameters are:



$\beta$ , is the lower asymptote;  
 $L_{\infty}$ , is the upper asymptote;  
 $k$ , is the growth rate and  
 $\delta$ , is a parameter that controls the x-ordinate for the point of inflection.

Note that this curve is extremely similar to the Weibull growth curve.

The Janoschek growth curve has the flexibility of the Richards curve, but is far easier to fit and manipulate. It rarely fails to converge during non-linear regression.

## 7.6 Exponential

The exponential growth model is described by the equation:

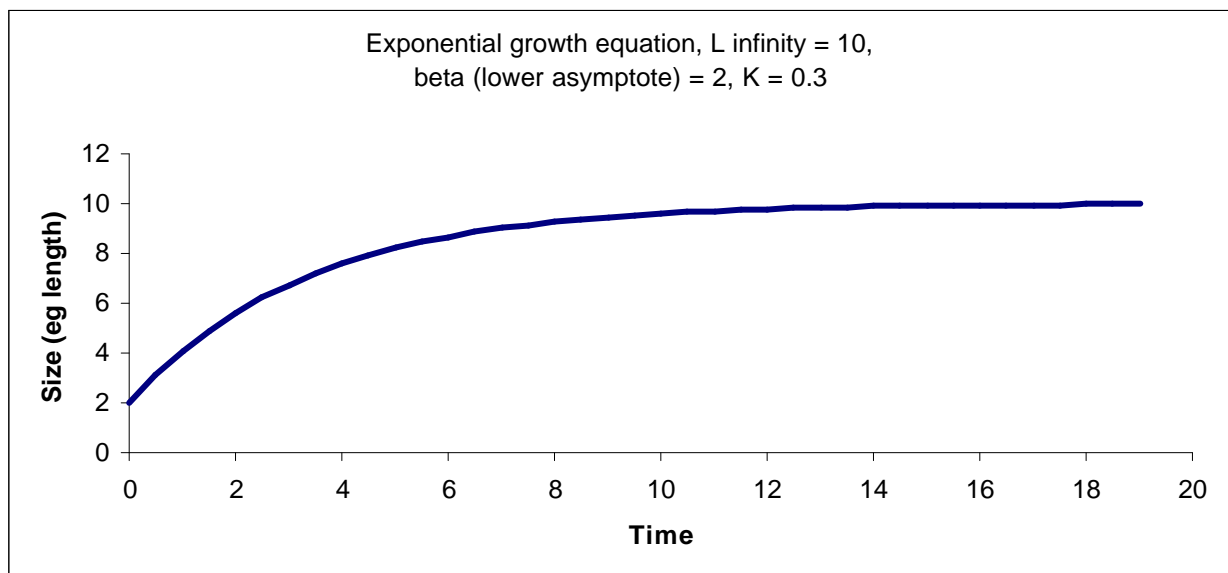
$$l_t = L_{\infty} - (L_{\infty} - \beta)e^{(-kt)}$$

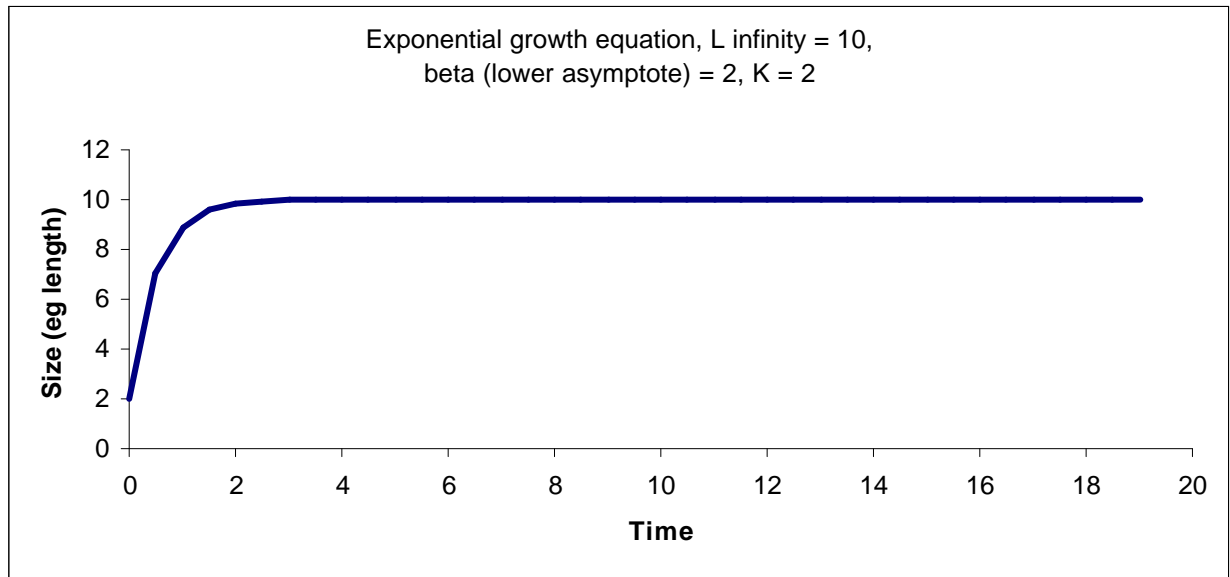
where  $l$  = length, (or weight, height, size) and  $t$  = time.

The three parameters are:

$\beta$ , is the lower asymptote;  
 $L_{\infty}$ , is the upper asymptote;  
 $k$ , is the growth rate.

The following graphs show example plots of the exponential growth curve for different values of  $k$ .





## 7.7 Morgan-Mercer-Floden

The Morgan-Mercer-Flodin (MMF) growth equation is described by the equation:

$$l_t = L_{\infty} - \frac{L_{\infty} - \beta}{(1 + (kt)^{\delta})}$$

where  $l$  = length, (or weight, height, size) and  $t$  = time.

The four parameters are:

$\beta$ , the size at  $t=0$ ;

$L_{\infty}$ , the upper asymptote;

$k$ , the growth rate and

$\delta$ , a parameter that controls the point of inflection.

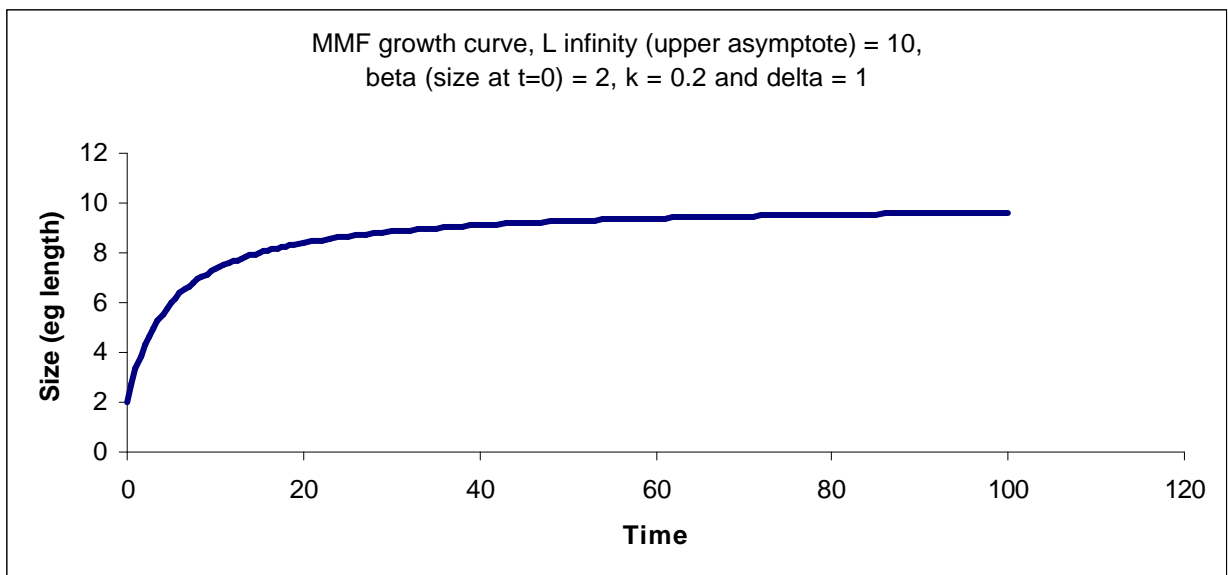
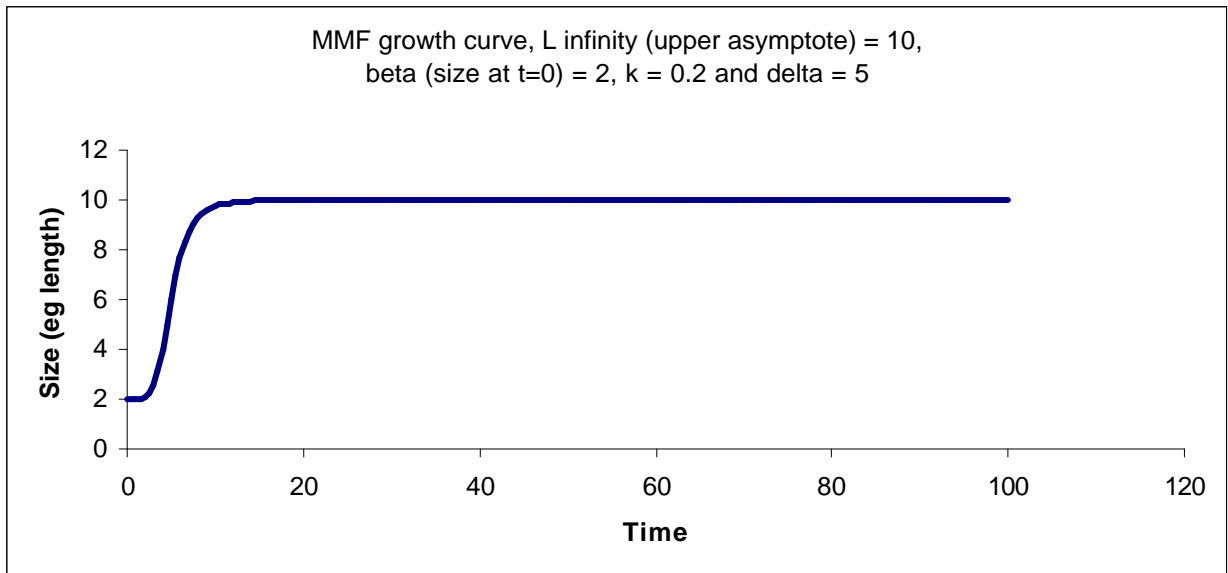
The point of inflection is located at:

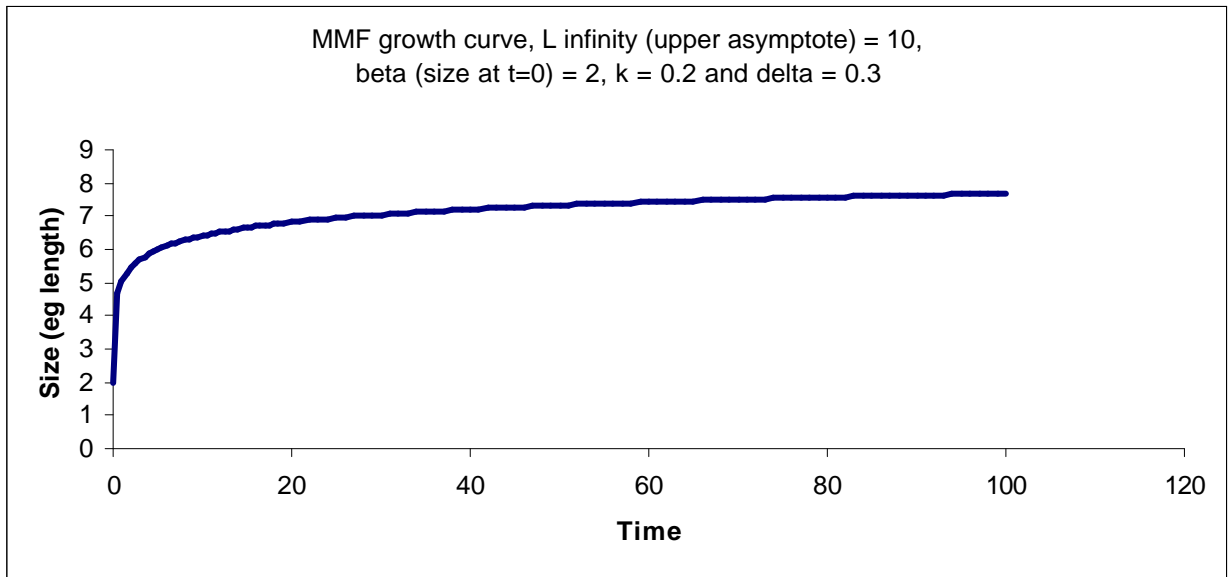
$$t = \left[ \frac{\delta - 1}{\delta + 1} \right]^{1/\delta}$$

and

$$l = \frac{\delta - 2}{2\delta}$$

The following graphs show example plots of the MMF growth curves for different values of  $\delta$  (delta).





## 7.8 The von Bertalanffy growth equation

von Bertalanffy derived this equation in 1938 from simple physiological arguments. It is the most widely used growth curve and is especially important in fisheries studies.

Assume that the rate of growth of an organism declines with size so that the rate of change in length,  $l$ , may be described by:

$$\frac{dl}{dt} = K(L_{\infty} - l)$$

where  $t$  is time,

$l$  is length (or some other measure of size),

$K$  is the growth rate and

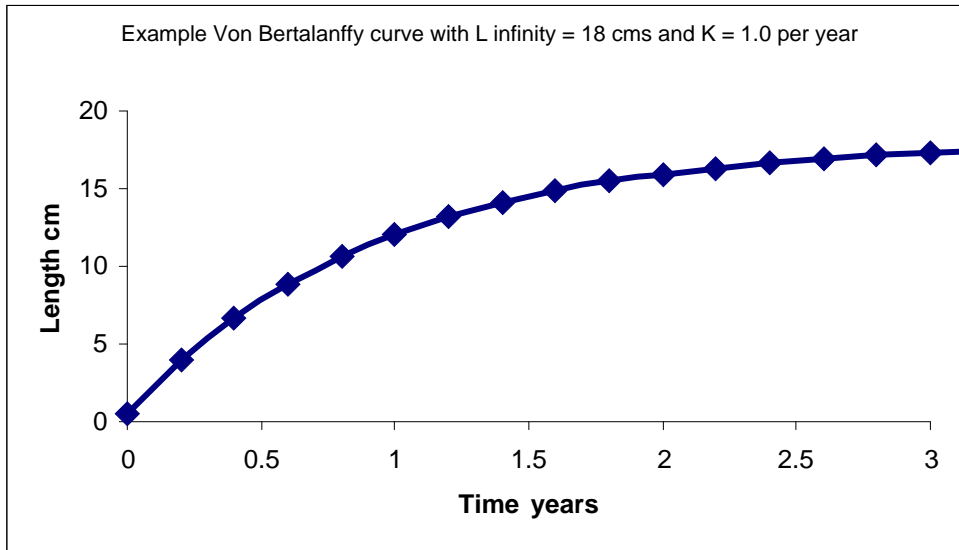
$L_{\infty}$ , termed 'L infinity' in fisheries science, is the asymptotic length at which growth is zero.

Integrating this becomes:

$$l_t = L_{\infty} \left( 1 - e^{-K(t-t_0)} \right)$$

The parameter  $t_0$  is included to adjust the equation for the initial size of the organism and is defined as age at which the organisms would have had zero size. Thus to fit this equation you need to fit 3 parameters ( $L_{\infty}$ ,  $K$  and  $t_0$ ) by nonlinear regression.

The following graph shows an example plot of this equation.



To fit this curve we must therefore estimate 3 parameters,  $L_{\infty}$ ,  $K$  and  $t_0$ . While this was once done graphically, it is now accomplished using the Levenberg-Marquardt Method for non-linear regression. Growth II offers both the graphical and the more accurate nonlinear numerical method.

## 7.9 Seasonally adjusted von Bertalanffy

Because organisms generally grow seasonally, a good description of the pattern of growth of an organism that lives for a number of years requires a seasonal adjustment to the growth rate. The seasonal growth equation used by Growth II is an extension of the von Bertalanffy growth equation derived by Somer (1988). This has the form:

$$l_t = L_{\infty} \left[ 1 - e^{-(k(t-t_0)+S(t)-S(t_0))} \right]$$

where  $K$  is the growth rate and  $L_{\infty}$  is the asymptotic length (or size) at which growth is zero and  $t_0$  is time at which the organism would have zero length (size) and

$$S(t) = \left( \frac{Ck}{2\pi} \right) \sin \pi(t - t_s)$$

$$S(t_0) = \left( \frac{Ck}{2\pi} \right) \sin \pi(t_o - t_s)$$

C is a parameter that measures the size of the seasonal variation in growth. When  $C = 0$ , the equation has no seasonal variation and is the same as the von Bertalanffy. When  $C = 1$  or  $(-1)$  growth becomes zero during the winter or other low growth season. If  $C > 1$  or  $< -1$  then the organism will shrink during the non-growth season. The parameter  $t_s$  is the time between  $t = 0$  and the start of a growth oscillation. For visualization, it helps to define  $t_s + 0.5 = WP$ , which expresses, as a fraction of the year, the period when growth is slowest. WP represents Winter Point.

This equation cannot describe long periods of zero growth, however, it often gives an adequate description of seasonal growth, and the parameter C can be used to compare the degree of seasonal growth shown by different species.

**It is important to note that Growth II expects age (time) to be expressed in years or fractions of years. Thus, age 3 months is 0.25 years.**

Tutorial and examples of seasonal growth fitting.

**Part**



## 8 Regression diagnostics

Growth II offers 3 measures of the suitability of a model as a fit for your data.

Weighted Sum of squared residuals  
Akaike Information Criterion (AIC)  
Schwarz Criterion (SC)

### 8.1 Weighted Sum of squared residuals

The sum of squared residuals gives a measure of the deviation of the observed size values from that predicted by the selected model; it is calculated using:

$$SS = \sum_{i=1}^{i=n} (Y_{obs,i} - Y_{calculated,i})^2$$

where n is the number of observations.

If standard deviations (SD) have been given for the mean size at age, then the weighted sum of residuals is calculated using:

$$WSS = \sum_{i=1}^{i=n} \frac{1}{SD_i^2} (Y_{obs,i} - Y_{calculated,i})^2$$

See also

Akaike Information Criterion (AIC)  
Schwarz Criterion (SC)

### 8.2 Akaike Information Criterion

The Akaike Information Criterion (AIC) (Akaike, 1974) is a measure to help in the selection between candidate models. Using this criterion, the best model is the one with the lowest AIC. This criterion takes into account both the closeness of fit of the points to the model and the number of parameters used by the model.

It is calculated as:

$$AIC = N \ln(WSS) + 2M$$

where N is the number of data points, WSS is the weighted sum of squares of residuals and M is the number of model parameters.



See also Schwarz Criterion.

### 8.3 Schwarz Criterion

The Schwarz Criterion (SC) is a measure to help in the selection between candidate models. Using this criterion, the best model is the one with the lowest SC. This criterion takes into account both the closeness of fit of the points to the model and the number of parameters used by the model.

It is calculated as:

$$SC = N \ln(WSS) + \ln(N)M$$

where N is the number of data points, WSS is the weighted sum of squares of residuals and M is the number of model parameters.

See also Akaike Information Criterion

**Part**

---

**IX**

## 9 References

### 9.1 References

- Akaike, H. 1974. A new look at the statistical model identification. IEEE Trans. Automat. Control, **19**, 716-723
- Janoschek, A. 1957. Das reaktionskinetische Grundgesetz und seine Beziehungen zum Wachstums- und Ertragsgesetz. Stat. Vjschr. **10**, 25-37.
- Sager, G. 1978 Zuwachsfunktionen vom Typ  $dw/dt = k \cdot t^p (E-W)^n$  und ihre Integrale. Anat. Anz. **144**, 366-374.
- Schwarz, G. 1978. Estimating the dimension of a model. Ann. Stat., **6**, 461-464.
- Sengul, T & Kiraz, S. 2005. Non-linear models for growth curves in large white turkeys. Turk J. Vet. Anim. Sci. 29, 331-337.
- Somer, I.F. 1988. On a seasonally oscillating growth function. Fishbyte **6**(1):8-11.
- Winsor, C. 1932. The Gompertz curve as a growth equation. Proc. Nat. Acad. Sciences, **18**, 1-8.

**Part**

---



## 10 Contact Pisces

### 10.1 Contact Pisces

For most active windows, context sensitive help can be obtained by pressing F1, clicking on the help button or selecting the help drop down menu. or clicking on the right-hand mouse button and choosing help from the pop-up menu.

If pressing F1, make sure that the window that you are seeking help for is the active one.

If you have problems using the program or entering data which you cannot solve then contact Pisces Conservation Ltd by e-mailing [pisces@irchouse.demon.co.uk](mailto:pisces@irchouse.demon.co.uk) or by phone to UK (0)1590 674000 during office hours (09.00 to 17.00).

PISCES Conservation Ltd,  
IRC House, The Square  
Pennington,  
Lymington  
Hants,  
SO41 8GN  
UK

Telephone            44 (0) 1590 674000  
                         or 44 (0) 1590 676622  
Fax                    44 (0) 1590 675599

For more information, details of our other software, and answers to a range of technical queries, visit our web site at <http://www.pisces-conservation.com>

For details about our consultancy and research work, visit  
<http://www.irchouse.demon.co.uk>

# Index

## - A -

add row 39, 41  
 add title 39, 41  
 age 39  
 age/size 30, 33  
 Akaike Information Criterion 88  
 altering 44  
 authors 91

## - B -

bibliography 91  
 Bitmap 49, 51  
 bmp 51  
 buttons 45

## - C -

calculation 19  
 Calculations 16  
 CD 10  
 change 44  
 chart 45, 47, 48  
 chart grid 45  
 chart print 50  
 choosing a growth model - demonstration 55  
 citation 14  
 cite 14  
 classed 18  
 classed data 16, 39  
 clipboard 45, 51, 53  
 close 30  
 colour 45  
 columns 45  
 contact 93  
 contact pisces 93  
 copy 45, 49, 51, 53  
 copy chart 51  
 copy data set 51, 53  
 copy graph 51  
 copy grid 51, 53  
 create classed data set 39, 42

create data file 42  
 create data set 38  
 create incremental data set 41, 42  
 curve 20, 27

## - D -

data 18, 38  
 data file 42  
 data sets 55  
 data type 42  
 dataset 45  
 delete 44  
 delete row 39, 41  
 delete title 39, 41  
 demo 38, 55  
 demo data sets 16  
 demonstration 16  
 demonstration data 38  
 demonstrations 55  
 disk space 12  
 drop-down menus 29

## - E -

edit 45, 48  
 editing 44  
 emf 51  
 end 30  
 enlarge 47  
 enter data set 38  
 equation 20, 22, 27  
 error 37  
 error message 37  
 examples 16  
 Excel 38, 39, 42, 53  
 exit 30  
 Exponential 30, 71  
 Exponential curve 81  
 export 29, 49, 51, 53

## - F -

features 7  
 file 29, 30  
 file menu 29  
 fit 88, 89

fit tests 88, 89  
fitting a model to incremental data - demonstration 65  
fitting model to incremental data - demonstration 55  
fitting seasonal data - demonstration 55, 58  
font size 45  
footers 49  
Ford-Walford 25, 26, 32

## - G -

general 16  
getting data 30  
gif 51  
Gompertz 30, 34, 71  
Gompertz growth curve 71  
Gompertz model 34  
goodness of fit 88, 89  
graph 20, 27, 45, 47, 48  
graph editing 45  
graph options 45  
graphical menu bar 45  
graphical von Bertalanffy 32  
graphs 49  
grid 38  
grid lines 45  
growth curve types 71  
growth model - demonstration 55  
Gulland 23, 24, 32

## - H -

headers 49  
help 93  
Help menu 36  
highlight equation 22  
highlight parameters 22  
how to 10, 16

## - I -

import 42  
increment 41  
incremental data 28, 34, 35  
incremental data - demonstration 55, 65  
individuals 45

initial parameter dialog - Levenberg-Marquardt 36  
initial parameter dialog - Richards curve 36  
Input 38  
insert 44  
insert row 41  
insert title 41  
install 10  
instructions 16  
intial setting 37  
intial settings 36  
introduction 7, 16

## - J -

Janoschek 30, 71, 80  
jpeg 51  
jpg 51

## - K -

known age 41

## - L -

L Ford-Walford 16  
L Gulland 16  
legend 45  
length 20, 39  
Length results 16  
Length Weight 30, 71  
length-weight relationship 31  
Levenberg-Marquardt 30, 34  
line thickness 45  
line weight 45  
line width 45  
linux 12  
Logistic 30, 34, 71  
Logistic growth curve 74  
Logistic model 35  
lotus 42

## - M -

mac 12  
main window 16  
maximum 45  
menus 29

menus toolbars 16  
Metafile 49, 51  
methods 7  
MMF 30, 71  
Morgan-Mercer-Flodin 30, 71  
Morgan-Mercer-Flodin curve 82

## - N -

new data set 38

## - O -

observation size 45  
open 29  
open data set 30  
opening 30  
operating system 12  
output 45, 49

## - P -

pages 16  
papers 91  
parameter 22, 36  
parameters 20, 27, 36  
paste 49  
pcx 51  
pdf 51  
pisces conservation 93  
plot grid 45  
png 51  
point size 45  
predicted 19  
print 29, 45, 49  
print chart 50  
print preview 50  
printer setup 29  
printing 49  
program files 10

## - R -

RAM 12  
reference 14  
references 91  
refs 91

regression diagnostics 88, 89  
requirements 12  
results 19, 20, 27  
Richard's 30, 34, 71  
Richards curve 36, 76  
Richards model 35  
row delete 44  
row insert 44  
rows 45

## - S -

sample data sets 16  
samples 45  
save 29, 45  
save as 29  
Schwarz Criterion 89  
seasonal 33  
seasonal data - demonstration 55, 58  
seasonally adjusted von Bertalanffy 85  
sheet 42  
shortcut 10  
size 41, 45  
spread 42  
spreadsheet 42  
start menu 10  
starting 30  
storage 12  
suitability of fit 88, 89  
sum of squared residuals 88  
support 93

## - T -

t0 41  
t1 41  
tabs 16  
tech support 93  
text size 45  
toolbar 45  
tutorial 16, 55  
types of growth curve 71

## - V -

versions 7  
von Bertalanffy 23, 24, 25, 26, 30, 33, 34, 71



---

von Bertalanffy growth equation 84  
von Bertalanffy model 34  
von Bertalanffy, seasonally adjusted 85

## - W -

W Ford-Walford 16  
W Gulland 16  
Weibul 30, 71  
Weibull curve 79  
weight 27, 39  
Weight results 16  
weighted sum of squared residuals 88  
what's new 7

## - Z -

zoom 47