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INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT

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Estimation and Comparison of Fish Growth Parameters from Pond Experiments: A Spreadsheet Solution

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Abstract

A method is presented to estimate and compare the growth of fish in pond experiments using a Gulland/Holt plot. The method is implemented as a LOTUS 1-2-3 "spreadsheet" allowing easy data editing and analysis. An example is provided along with a 5 1/4" diskette for use with IBM PC and/or compatibles.

Introduction

A common subject in experimental aquaculture is the selection of appropriate species and/or culture methods to optimize yield. One of the criteria to consider is overall growth performance. Comparing the growth performance of different species (or strains) under the same growing conditions, or a single species under different growing conditions is valuable tool in gathering the needed information for the selection procedure.

Growth of fish is commonly described by means of the von Bertalanffy Growth Formula (VBGF) (von Bertalanffy 1957), which has, for growth in length, the form

$$L_t = L_\infty [1 - e^{-K(t - t_0)}] \quad \text{... 1)}$$

where L_t is the length at age t, L_∞ the asymptotic length, K a growth constant and t_0 the theoretical age of the fish at $L_t = 0$.

Even though a multitude of methods is available to determine the growth parameters of the VBGF, the very nature of these parameters and the way they are computed usually does not allow a separate comparison of single parameters between different species and/or growing conditions (Moreau et al. 1986).

Various authors, however, have successfully demonstrated that - within a species - a close relationship exists between asymptotic size (expressed as length or weight) and the growth constant K. From this known interdependence a number of methods have been derived that combine both parameters into one single index of overall growth performance (see Moreau et al. (1986) for a review and an appraisal of these approaches).

One of these indices is the parameter ϕ' presented by Pauly (1980), Munro and Pauly (1983) and Pauly and Munro (1984), which has the form

$$\phi' = \log_{10} K + 2 \cdot \log_{10} L_\infty \qquad \text{... 2)}$$

In their comparison of growth indices, Moreau et al. (1986) tested all methods with a large set of growth parameters and found the index ϕ' usually displaying the lowest coefficient of variation. They concluded that this index can indeed be used as an index of growth performance.

The properties of ϕ' are such that, within a given species, a pair of computed L_∞- and K-values will most probably produce a ϕ' that falls within a rather narrow range of possible values. This range is characteristic for the given species (Munro and Pauly 1983). Thus, values of ϕ' at the lower or upper end of this range would indicate comparatively poor or good growth, respectively. On the other hand, a ϕ' value completely outside the usual range of values known for the given species under similar conditions could indicate that the computed parameters of the VBGF are probably erroneous, or at least doubtful, and should be verified.

Comparison of Growth Performance in Pond Experiments

Studying fish growth in pond experiments has some characteristics that clearly distinguish it from investigation of fish stocks in the wild. Some of the important differences are:

- The fish used for stocking the ponds for a series of experiments usually originate from a single batch of fingerlings produced in a nursery pond (or in the course of a previous experiment). Thus, the fish in different ponds can be considered as belonging to the same population (given, of course, that recruitment is controlled or recruits are not included in monthly length measurements!)

- If ponds are stocked as described above, the mean size of the fish at the onset of the experimental phase will be quite uniform.

- If all experiments are stopped at the same time, the growth period for all fishes has been identical.

- If all experiments are carried out at the same location, many of the environmental parameters can be assumed similar, while the experimental design allows controlled changes of single parameters known to influence growth (e.g., stocking density, nutrient input, culture period, etc.).

Under conditions as described above, differences in observed growth performance can be assumed to be related to differences in experimental conditions. The computed growth parameters - and especially the growth index ϕ' - that were obtained from different experiments can, therefore, be used to draw first conclusions regarding the influence of these experiments on the growth performance of the fish.[1] Such conclusions, of course, should always be verified using appropriate statistical procedures.

Estimation of Growth Parameters

There are many ways of computing the parameters of the VBGF from growth data. They all differ in data requirement and computational procedure. For the purpose of the spreadsheet presented in this paper a method is applied

- that can use time series of length data (as typically available from pond experiments);
- that needs no additional input, as e.g., preliminary estimates of one (or both) of the parameters to be computed;
- that does not require the time intervals between measurements to be of equal length.

The method used here is commonly called the "Gulland and Holt Plot" (Gulland and Holt 1959). It basically consists of a plot of length increments per unit time against corresponding mean length. Mathematically, this relationship is expressed as follows:

$$\frac{(L_2 - L_1)}{(t_2 - t_1)} = a - K \cdot \bar{L} \qquad \ldots 3)$$

with: $\bar{L} = (L_1 + L_2) / 2$
and : L_1, L_2 = successive lengths measured at times t_1 and t_2

Equation (3) has the form of a linear regression: $Y = a + b \cdot X$; with its sign changed, the regression coefficient b (the slope of the regression line) is an estimate of K. Obviously, the asymptotic length is reached when the length increments per unit time become equal to zero, i.e., where the slope cuts the X-axis. Thus, solving Equation (3) for Y = 0, one obtains

$$X = a / K = L_\infty \qquad \ldots 4)$$

Inspecting visually the regression line of the Gulland and Holt plot allows to assess the reliability of the estimated parameters. Strong deviation of one or more data points from the regression line could indicate a sampling error (e.g., mean length is computed from too small a sample). If this explanation can be accepted and the number of

[1] In comparing the growth of different fish species, the use of ϕ' is limited, however, to species with similar shape (Pauly and Munro 1984).

"outlyers" stays small in relation to the total number of data points, one can overcome this problem by omitting the outlyers from the regression analysis.[2]

If, however, a large number of data points deviate markedly from the regression line (resulting, hence, in a low coefficient of determination, r^2), and sampling bias can be excluded, growth of the fish might have differed from the VBGF. This would lead to the rejection of the computed growth parameters produced by the Gulland and Holt plot. A comprehensive analysis of the experimental design should then help determine if a different growth model is applied (e.g., one that considers oscillation in growth) or if perhaps unaccounted external factors in the experiment are causing the observed deviations.

The Growth Curve

With the parameters L_∞ and K obtained from growth data one can construct a growth curve using a derivation of the VBGF which has the following form:

$$L_2 = [L_1 \cdot e^{-K \cdot (t_2 - t_1)}] + L_\infty [1 - e^{-K \cdot (t_2 - t_1)}] \qquad \ldots 5)$$

Starting with an L_1 equal to the mean length at the beginning of the experiment and a $t_1 = 0$ days, one can compute for every single day of the culture period the corresponding theoretical length. When plotting these lengths against culture period a growth curve results that ideally should combine most of the observed mean lengths. Again, the comparison of the computed growth curve and the observed data points can be used to detect "outlyers" or to completely reject the computed parameters because of strong derivations of most of the data points.

The Spreadsheet Solution

Spreadsheet programs like LOTUS 1-2-3 are very useful when data analysis is to be combined with a simple and quick translation of the data into graphics. In addition, the built-in mathematical functions and the powerful programming language allow programming of even relatively complex tasks of data analysis.

The spreadsheet developed for the model described above and presented with this paper has the following features:

- Data input is reduced to the minimum:
  - experiment identification
  - sampling dates
  - average length in sample

[2] Note that the method is quite sensitive regarding outlyers especially at the end of the observation period. Large deviations from the expected values can easily result in a complete reversion of the direction of the regression line, which leads to very small or even negative values of L_∞.

- Numeric results produced by the model are:
  - Asymptotic length L_∞, in cm
  - Growth constant K (converted to K per year, K/Y)
  - Index ϕ'
  - Coefficient of determination r^2 of the regression
  - F statistics (F_{emp} and DF, degrees of freedom)

- Graph options:
  - Plot of observed lengths against culture period
  - Gulland and Holt plot
  - Plot of the computed growth curve against culture period with the observed mean lengths superimposed

- Print options:
  - Spreadsheet with data in their original form and re-arranged for the Gulland and Holt plot
  - Saving of all three graphs in "print files" for printing with printing with the LOTUS Print Graph program

- No user input required for graph settings (data range, titles, legends, etc.)

- All options are selected from a LOTUS-style menu ("point and shoot")

- Only very basic knowledge of handling LOTUS 1-2-3 is required to use the spreadsheet successfully.

Details on and user's instructions for the spreadsheet are given in the Appendix.

An Example

To illustrate the use of the method presented in this paper, a data subset was extracted from data generated by the ICLARM-CLSU integrated animal-fish farming project (Hopkins and Cruz 1982).

Among many other things this project tested the effect of stocking density and length of culture period on the growth of Nile tilapia *(Oreochromis niloticus)*.

Table 1 presents a set of length measurements obtained in three experiments in which these two parameters vary. A third parameter, the number of pigs, was kept fairly constant. The design of the experiments was as follows:

- Experiment 3/11:	Culture period	:	102 days
	Stocking density	:	8,500 fish per ha
- Experiment 5/08:	Culture period	:	157 days
	Stocking density	:	8,500 fish per ha

- Experiment 5/11: Culture period : 157 days
  Stocking density : 17,000 fish per ha

In this context, mean length represents the arithmetic mean of all length measurements taken from subsamples of the respective pond.

Table 1. CLSU project: data on fish growth from pig-fish yield trials.

EXP. 3/11: 80 pigs/ha, 102 days, 8,500 fish/ha
EXP. 5/08: 100 pigs/ha, 157 days, 8,500 fish/ha
EXP. 5/11: 100 pigs/ha, 157 days, 17,000 fish/ha

SITE SPEC. CODE	CLSU Tilapia 3/11	SITE SPEC. CODE	CLSU Tilapia 5/08	SITE SPEC. CODE	CLSU Tilapia 5/11
SAMPLING DATE dd/mm/yy	AVG. LENGTH cm	SAMPLING DATE dd/mm/yy	AVG. LENGTH cm	SAMPLING DATE dd/mm/yy	AVG. LENGTH cm
25/06/79	5.2	24/02/80	5.7	24/02/80	5.4
11/07/79	9.7	11/03/80	11.2	12/03/80	10.1
25/07/79	12.4	25/03/80	12.0	26/03/80	12.2
08/08/79	13.2	09/04/80	13.5	09/04/80	14.5
21/08/79	13.9	23/04/80	15.2	23/04/80	15.1
05/09/79	15.3	08/05/80	16.6	07/05/80	15.9
18/09/79	16.5	21/05/80	17.4	21/05/80	17.0
05/10/79	17.9	04/06/80	18.2	04/06/80	18.5
		18/06/80	19.2	18/06/80	18.6
		02/07/80	19.5	02/07/80	19.5
		17/07/80	20.0	17/07/80	19.9
		30/07/80	20.7	30/07/80	20.5

Table 2 summarizes the growth parameters and statistics computed from these data by means of the LOTUS 1-2-3 spreadsheet program presented with this paper. It should be noted that the coefficient of determination, r^2, of the Gulland and Holt plot is significant at the 95 % level in all three cases.

The growth parameters L_∞ and K in experiment 3/11 and 5/08 display a marked difference. The higher value of L_∞ in experiment 5/08 has to be attributed, however, to the increase in culture period. It does not reflect any substantial change in overall growth performance as the values of ϕ' are very similar in both experiments. In pond

Table 2. Summary of computed growth parameters.

SITE : CLSU
SPEC. : *Oreochromis niloticus*

CODE		3/11	5/08	5/11
Cult. period	:	102	157	157
Stock. density	:	8,500	8,500	17,000
L_∞	:	19.0	21.2	21.1
K(/Y)	:	7.765	6.510	6.386
ϕ'	:	3.45	3.47	3.46
r^2	:	0.673	0.593	0.755
DF	:	5	9	9
F	:	10.29	13.12	27.72

management, such a result would help decide whether the length of culture period for a given species should be decided primarily on the basis of biological or economic considerations (e.g., optimum market size).

In the second example, the doubling of the stocking rate from 8,500 fish/ha to 17,000 fish/ha does not seem to affect the growth performance of the fish, as both the growth parameters and the index φ' are very similar. This would be an important finding when trying to determine the optimum carrying capacity of a pond system.

Fig. 1 shows the information displayed on the screen after a set of data (sampling date and average length) had been entered and processed. The headings comprise general information to identify the data set and a summary of the computed parameters (including their statistics).

Fig. 1. Example of the screen display after data processing.

GROWTH

SITE	:	CLSU	L_∞	:	21.1	r2	:	0.755
SPEC.	:	*Oreochromis niloticus*	K(/Y)	:	6.386	DF	:	9
CODE	:	5/11 (EXP/POND)	φ	:	3.46	F	:	27.72

Sampling Date dd/mm/yy	Avg. Length cm	Cult. Prd. days	D1	D2	L1 cm	L2 cm	Growth Rate cm/d	Mean Length cm
24/02/80	5.4							
12/03/80	10.1	17	24/02/80	12/03/80	5.4	10.1	0.276	7.8
26/03/80	12.2	31	12/03/80	26/03/80	10.1	12.2	0.150	11.2
09/04/80	14.5	45	26/03/80	09/04/80	12.2	14.5	0.164	13.4
23/04/80	15.1	59	09/04/80	23/04/80	14.5	15.1	0.043	14.8
07/05/80	15.9	73	23/04/80	07/05/80	15.1	15.9	0.057	15.5
21/05/80	17.0	87	07/05/80	21/05/80	15.9	17.0	0.079	16.5
04/06/80	18.5	101	21/05/80	04/06/80	17.0	18.5	0.107	17.8
18/06/80	18.6	115	04/06/80	18/06/80	18.5	18.6	0.007	18.6
02/07/80	19.5	129	18/06/80	02/07/80	18.6	19.5	0.064	19.1
17/07/80	19.9	144	02/07/80	17/07/80	19.5	19.9	0.027	19.7
30/07/80	20.5	157	17/07/80	30/07/80	19.9	20.5	0.046	20.2

There are nine columns in Fig. 1: the first two of these contain the original data set. The next column ("Culture Period") shows for every data point the number of days elapsed since the beginning of the experiment. The following four columns are simply a re-arrangement of dates and lengths to make it more clear how the last two columns are computed. Growth Rate is the length increase (L_2 - L_1) divided by the numbers of days between D_1 and D_2, expressed in cm per day. Mean Length is the arithmetic mean of the corresponding lengths L_1 and L_2 (which by themselves can already be means).

Figs. 2 to 4 represent typical graphs created with LOTUS 1-2-3, using the preprogrammed graph options. When saved to a print file (another menu option), a hard copy of these graphs can be produced on a standard printer or plotter.

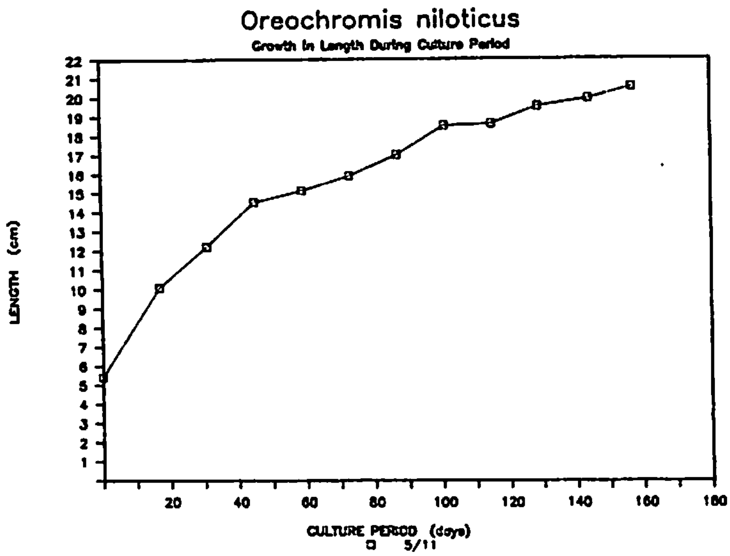

Fig. 2. "LENGTH" graph.

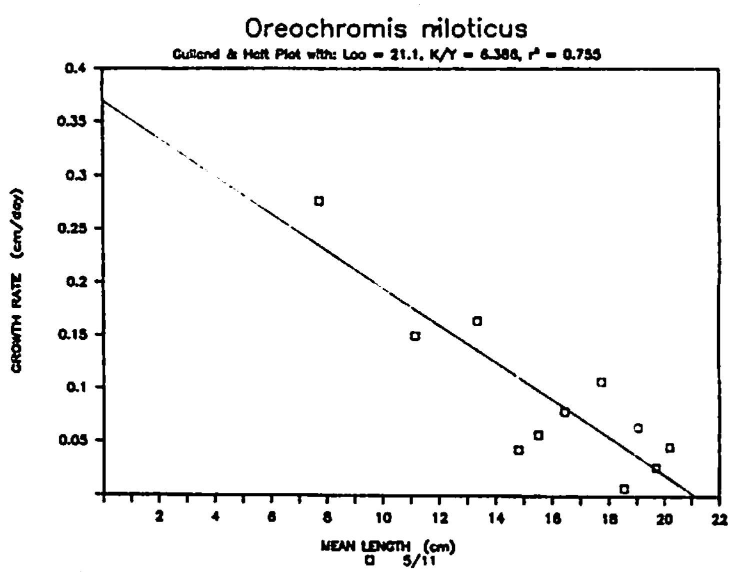

Fig. 3. "G&H PLOT" graph.

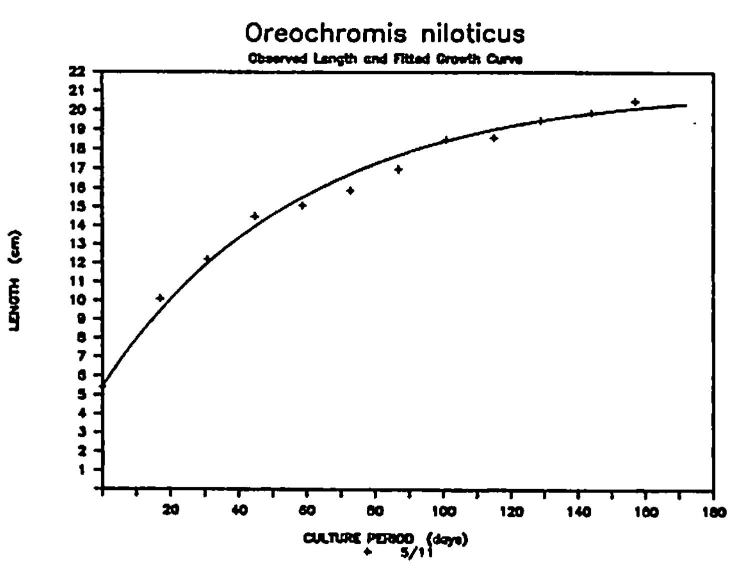

Fig. 4. "VBGF" graph.

Conclusions

Analyzing growth performance under different experimental conditions is a crucial task in present aquaculture research. The implications are far-reaching in view of the selection of species (strains) and/or growing conditions to optimize production. Given access to a microcomputer and appropriate software, the method presented here and adapted to a spreadsheet program offers to a researcher the possibility to obtain very quickly a first insight into the dynamics of growth experiments conducted in fishponds.

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Appendix: User Instructions

The preprogrammed spreadsheet is contained in a file called **GROWTH.WK1**, and stored on a diskette formatted under MS-DOS (360 KB). The spreadsheet can be used with LOTUS 1-2-3, Rel. 2 or higher (English version).

Before working with the spreadsheet, you should make a copy of the file and store the original diskette in a safe place. In case something happens to your spreadsheet you still can go back to the original one and make a fresh copy.

If you are using a computer with two floppy drives, copy the file onto another data diskette. If you are using a hard disk to store your data, copy the file into the directory where LOTUS 1-2-3 looks for its data files by default.

The original file has a size of approximately 19 KB. If, after a working session, you save the spreadsheet in a file together with an analyzed data set and all the graphics settings added, the new file will be much larger. The size depends, of course, on the number of data points. With, e.g., a set of 8 observations, the resulting file would have around 50 KB.

The user instructions assume that you are familiar with the following:

- how to start LOTUS 1-2-3
- how to retrieve a file from diskette or hard disk
- how to use the cursor keys to move the cell pointer
- how to select an option from the LOTUS menu
- how to enter numbers as "labels"
- how to use the PRINTGRAPH program of LOTUS 1-2-3 to produce a hard-copy of your graphics on a printer.

ACTION	COMMENT
Call LOTUS 1-2-3 Load the spreadsheet "GROWTH"	After the spreadsheet is loaded and has gone through various initialization routines, the MAIN MENU is presented to you.
Select INPUT	This option allows you to enter data into the appropriate cells of the spread-sheet. Type the value (number or label) and hit the key that moves the cursor to the right [-->]; this enters the value into the spreadsheet and moves you to the next entry cell.
Enter "SITE"	This can be anything that is needed to identify the site of the experiment.
Enter "SPECIES"	Enter the name of the species investigated. This name will later be used as the first line in the graph headings.
Enter "CODE" * (see footnote)	Enter a code that identifies the experiment, e.g., experiment number and pond number. This input will later be used as a legend in the graphs.
Enter "SAMPLING DATE" * (see footnote)	The sampling date must be entered exactly in the two-digit form shown in the table heading, i.e., dd/mm/yy (abbr. for "DAY/MONTH/YEAR").
Enter "AVG. LENGTH"	Enter the avg. length of the fish in the sample (length should be measured as total length, in cm)
Repeat the previous two steps for all data pairs (Maximum: 50 data pairs)	Note that a minimum of four observations is required for the model to work.
Check data input, than hit ENTER [<--'] without any previous input to return to the MAIN MENU	Cell entries can be corrected by moving the cell pointer to a cell and using the normal LOTUS edit functions.

* PLEASE NOTE: Numbers entered in this cell must be identified as LABELS. Therefore, a numeric entry has to be started with the "label indicator" provided by LOTUS, i.e., with a single quotation mark ('). (If the contents of a cell are different from what you entered, always check the label indicator!)

ACTION	COMMENT
Select CALC	Executes all necessary computations and initializes the graphs.
Select PRINT	Use this option if you wish to obtain a print-out of the spreadsheet produced. Make sure, the printer is on-line.
Select GRAPH	This option brings you to the GRAPH SUB-MENU. Note: graphs can be viewed only after the option CALC was executed.
GRAPH SUB-MENU	
Select LENGTH**	Displays graph of avg. length over culture period.
Select G&H PLOT**	Displays graph of the GULLAND and HOLT plot.
Select VBGF	Displays graph of the computed growth curve with superimposed observation points.
GRAPH SUB-MENU	
Select SAVE	This option brings you to the SAVE SUB-MENU that allows you to save any of the three graphs in a "picture file". Use the PRINTGRAPH program to produce hard copies of your graphs. Note: No duplication of file names allowed!
Select QUIT	Returns you to the MAIN MENU.
Select SAVE	Saves the present worksheet in a file. Note: No duplication of file names allowed!
Select NEW	Erases the present worksheet and retrieves a fresh copy of the original file from disk.
Select QUIT	Leaves the MAIN MENU to work in normal spread-sheet mode. Return to the MAIN MENU by pressing ALT M.
Select EXIT	Exits from LOTUS 1-2-3. (Enter "Y" when prompted!)

** When calling the graph for the first time the program still has to make some adjustments to the graph settings. Therefore, the graph is displayed with a preliminary scaling (LENGTH) or not at all (G&H PLOT). Simply press any key to obtain a better picture. (Thereafter, this step is not needed any more!)

It is recommended to check and - if necessary - to edit the data set before selecting the CALC option that starts the computational routines in the spreadsheet. Editing can be done while still in the INPUT routine, or by calling this routine again from the MAIN MENU.

However, changes to the data set are also possible after the CALC command has been executed. This option might be needed when doing various "what, if" simulations.

To change the primary data set, use the INPUT routine again. After you select INPUT, you will be shown first the VBGF graph. This step,though superfluous for the user, is needed in the LOTUS programming to have the new graph settings correctly adjusted. Simply ignore this graph and press any key to proceed with the data correction. After you have finished your corrections, you must select the CALC option again to have the spreadsheet recalculated! Thereafter, you can view the new graphs and save them in print files. (Remember to never use a file name that already exists on the disk when prompted for the file name!)

There are two cases where subsequent corrections are impossible: First, you can not add a new set of data points. Second, if any of the corrected lengths exceeds the previous maximum length in the sample, the scaling of the VBGF and LENGTH graph will be most probably inappropriate. In these two cases, it is recommended to start with a fresh spreadsheet.

Any user is, of course, free to change table headings, graph settings, or add new program routines. When doing so, keep in mind that the spreadsheet needs a number of preliminary settings for the regression analysis and the graphs. These settings are all stored with the original spreadsheet. You should, therefore, follow this procedure:

1. Always start with a fresh copy of the original spreadsheet
2. Select QUIT from the MAIN MENU to leave the menu
3. Make your changes
4. Save your updated spreadsheets (don't use the SAVE option from the MAIN MENU!)
5. Test your spreadsheet with a data set

It is important to save the spreadsheet before entering any data. A spreadsheet that already had been used for data analysis and is then saved (even with the data erased!) will not work properly.

Also note that if you change any of the graph settings, you have to make sure that the VBGF graph has been made current before you save the spreadsheet. If this is forgotten, the VBGF graph will be nonexistent!

OTHER TITLES IN THIS SERIES

- **User's manual for the fish population dynamics plug-in module for HP41CV calculators.** M.L. Palomares and D. Pauly. 1987. ICLARM Software 1, 5 p. Distributed with a custom-made plug-in module for HP41CV calculators for US$150 (airmail).

- **A draft guide to the Compleat ELEFAN.** F.C. Gayanilo, Jr., M. Soriano and D. Pauly. 1988. ICLARM Software 2, 65 p. Distributed with a 10-diskette (5-1/4") Compleat ELEFAN package for US$50 (airmail).

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